Gresley

A

TREATISE

CONTAINING

The PRACTICAL PART

OF

FORTIFICATION.

In FOUR PARTS.

I. The Theory of Walls, Arches, and Timbers, with several Tables of their Dimensions.

II. The Knowledge of the Materials, their Properties, Qualities, and the Manner of using them.

III. The Manner of tracing a Fortress on the Ground, the making an Estimate, and executing the Works.

IV. The Method of building Aquatics, as Stone-bridges, Harbours, Quays, Wharfs, Sluices, and Aqueducts.

Illustrated with Twenty eight COPPER PLATES.

For the USE of

The ROYAL ACADEMY of ARTILLERY at *Woolwich*.

By JOHN MULLER,
Professor of ARTILLERY and FORTIFICATION.

The SECOND EDITION, with Improvements.

LONDON:
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MDCCLXIV.

TO

HIS ROYAL HIGHNESS

GEORGE,

PRINCE of WALES.

SIR,

THE generous encouragement conſtantly given by your Royal Progenitors to thoſe who have endeavoured to make any Improvements in the uſeful arts and ſciences, makes me flatter myſelf that Your Royal Highneſs, who give ſuch early hopes of inheriting all their virtues, will be graciouſly pleaſed to honour the following treatiſe with Your Patronage.

My aim in publiſhing it, is to ſhew how fortreſſes may be built in the beſt and cheapeſt manner. I may venture to ſay, that a work of this kind has been hitherto wanting in the *Engliſh* language: and I may add, that the ſubject is moſt certainly of importance; experience having too often ſhewn the fatal effects which the neglect of the art of Fortification may produce, as well as the advantages arising to our prudent neighbours from the great encouragements they give to this branch of Knowledge.

Your Royal Grandfather, ever attentive to the public security and welfare, most graciously instituted the Royal Academy of Artillery for the instruction of young gentlemen in the Art of War. As it is my duty, so it has ever been my care, to facilitate their studies: and if my labours should be thought to deserve Your Royal Highness's attention and approbation, it would be an inexpressible satisfaction to me, who think myself happy in every opportunity of shewing the profound respect with which I am,

SIR,

Your ROYAL HIGHNESS'S

most humble,

most dutiful,

and most obedient servant,

JOHN MULLER.

Woolwich,
Sept. 1755.

PREFACE.

WHEN a fortreſs is to be built, to chooſe ſuch a ſituation as will anſwer the intent in the beſt manner, to adapt the works porperly, and to uſe no more than are neceſſary, to make from their plans and profils an eſtimate of the quantity of maſonry requiſite, and of the earth to be removed, to trace the plan on the ground, to lay the foundation in any kind of ſoil, to compleat the walls, ramparts, and all the military buildings, ſuch as draw-bridges, town-gates, powder-magazines, barracks, ſtore-houſes, cazemats, and ſally-ports; theſe are the ſubjects of Practical Fortification, and what we propoſe to treat of in the following work, together with the manner of building ſtone-bridges over large rivers, piers for incloſing harbours, wharfs, quays, ſluices, and aqueducts.

As no Treatiſe of this kind has appeared yet in Engliſh, I thought it would not altogether be uſeleſs to the public, if I ſhould give, in a plain and eaſy manner, the conſtruction and executive part of the works belonging to a fortreſs, and add whatever might contribute to the improvement of this uſeful art, ſuch as the theories contained in this work, which it has been my endeavour to render as general, and as ſimple as the nature of the ſubject will admit of, that they might extend to all the different caſes which may occur, and at the ſame time be with eaſe adapted to common practice.

It being of importance to know the proper thickneſſes of the walls which ſupport earth, ſo that they may be ſtrong and durable, yet not more ſo than is neceſſary; therefore this work begins with a general theory of them; which being deduced from the leaſt exceptionable principles, is applicable in all kinds of ſoils and caſes: for the common ſuppoſition made by ſome gentlemen of the Academy of Sciences at *Paris*, and by Mr. *Belidor*, that the natural ſlope of earth not ſupported by a wall forms an angle with the horizon of 45 degrees, is true in one particular kind of ſoil only. This is plain to reaſon, from the different tenacities of different ſoils, and may be verified by an eaſy experiment; which will ſerve likewiſe as a practical method for finding the angle formed by the natural ſlope of any kind of earth.

Make a bank of newly removed earth about ten or twelve feet high, and cut it vertically on one ſide; this bank being left ſtanding during eight or ten months in the dampeſt ſeaſon, will form the angle required. It is true, the particles of earth being heterogeneous, they will not form an even ſurface, therefore that angle will vary in different places; but as in practice no geometrical exactneſs can be obtained, nor is required; if that angle comes within five degrees of the real one, it is ſufficient; for that quantity, more or leſs, makes little difference in the thickneſs of walls, as may be ſeen in the table of general rules. Since then sand causes a greater pressure, and clay a less one, than common earth; to make the walls in each case of an equal strength would endanger those which support sand of falling down, and there would be more work than need be in those which support clay: besides, as stone is specifically heavier than brick, it is evident, that stone walls do not require so great a thickness as those made of brick, yet the gentlemen mentioned before, have made no distinction between the one and the other in their theories.

As some of my readers may not understand algebra, which I have been obliged to use, in order to make the theory general; therefore, to render this work useful to every reader, I have added a table, containing general rules for finding the dimensions of stone and brick walls of any height, according to the different angles made by the natural slope of earth with a vertical section, from 80 to 30 degrees for every 5 degrees interval, and according to the different slopes given to walls on the outside. The natural slope of common earth making nearly an angle of 45 degrees, and being the case that most frequently happens in practice; I have computed four tables of dimensions upon this supposition, two for stone walls, and two for brick ones, from ten to fifty feet high, with or without parapets: these tables contain the thicknesses above and below in regard to the different slopes given to the walls on the outside, together with the dimensions of the counterforts; in order to save a builder the trouble of computing them himself, although it be very short and easy.

Since fortresses are mostly built at present with demi-revetements, that is, they are partly walled, and partly turfed on the outſide; I imagined that tables containing the dimenſions of this kind of walls would alſo be very uſeful, and ſo much the more acceptable to the reader, as no author has given any before; this was not owing to any belief that they were not uſeful, but rather to the difficulties in conſtructing them: for as the height of the walls and that of the earth above them, form an infinite number of caſes, to comprehend them all in a table would have been impoſſible: therefore the only thing that could have been expected was to give tables of their ratio's, as we have done.

That I might omit nothing uſeful in practice, I have given problems of all the different profils of walls which have hitherto been uſed upon various occaſions; and have compared the quantity of maſonry that each of them requires, in order to know which is preferable to the reſt; whereas the *French* authors, who are the only ones that have written upon this ſubject, have implicitly followed the profil of Mr. *Vauban*, as being univerſally uſed by all the engineers in *France*, without conſidering whether it might not be changed for another better adapted to the nature of the ſubject; whereby they have been reduced to the neceſſity of making their computations ſo very operoſe as they have done; on the contrary, I conſidered that as the ſections in the ſame kind of earth are always ſimilar, by making the profils likewiſe ſimilar, the operations would become very eaſy; ſince the thickneſſes of thoſe walls which have the ſame ſlope would then be to their heights in a conſtant ratio.

I proceed next to the theory of arches, which is eſteemed one of the moſt difficult problems in mechanics;

chanics; for tho' ſeveral eminent mathematicians have attempted to ſolve it, yet in my opinion, not one has entirely ſucceeded; for whoever reads their performances of this kind, will find, whenever their general equations are applied to any particular example, that nothing but abſurdities follow from ſome, and ſuch dimenſions from others, as by no means anſwer the purpoſe. Some of them have ſuppoſed that all the arch-ſtones were quite ſmooth and poliſhed, laid without any cement or mortar; and others, that the part of the arch between the key-ſtone and the hanches was as it were one continued ſtone, and the other part between the hanches and the ſpring of the arch, joined to the pier as if all together formed likewiſe one ſtone: but as both theſe ſuppoſitions are erroneous, and contrary to what happens in arches, it is evident, that the concluſions drawn therefrom cannot be juſt.

I have conſidered the preſſure of every arch-ſtone ſeparately, both in regard to its weight and the obliquity of its direction, and have ſuppoſed them to be laid in ſuch mortar, as is neither hard enough to make the arch like one continued ſtone, nor yet ſo ſoft as that they may ſlide with eaſe upon each other: from thence, and ſome known principles of mechanics, it is eaſily proved, that the ſum of the preſſures of all the arch-ſtones contained in half the arch is equal to the preſſure which the whole weight would make, were it placed in the center of gravity of half the arch; whereby the ſolution of the problem has been reduced to that of finding the centers of gravity in the ſeveral figures of which arches are compoſed, which centers are found in the moſt ſimple and eaſy manner that the nature of of the ſubject will admit of; and the ſolution of the problem, whereby the thickneſſes of the piers are found, is contained in a very ſimple quadratic equation.

It has hitherto been imagined, though without any foundation, that an elliptic arch is weaker, and preſſes the piers with a greater force than a circular one: the reaſon which authors pretend to give for this ſuppoſition is, that all the joints of a circular arch when produced meet in the ſame point; from thence they erroneouſly conclude, that it is the ſtrongeſt; without conſidering that all low arches require leſs maſonry than thoſe which are higher, and that the increaſe of force againſt the piers, ariſing from the obliquity of their directions, is diminiſhed more in proportion by the leſſer quantity of weight which they ſupport.

In the problems given of the ſeveral kinds of arches, it has been found, that the thickneſs of the piers are nearly the ſame in all arches of the ſame width; though thoſe of circular ones are rather greater than any others, but yet not ſo much as deſerves to be taken notice of. This appears alſo from the common principles of mechanics; ſince the higheſt arches, which are moſt loaded, have the directions of their preſſures leſs oblique; and on the contrary, the loweſt, which are leaſt loaded, have the directions of their preſſures more inclined.

This being demonſtrated, many difficulties, which often ariſe in the conſtruction of arches, are eaſily avoided: as for example, when a powder magazine built in the common manner would become ſo high as to be ſeen from without, it may be made with an elliptic arch: when cazemats, ſally-

ſally-ports, or any other ſubterraneous buildings are to be built under low ramparts, and there is not a ſufficient quantity of earth to cover them if the arches were made circular, they may be made elliptic, or with arcs of circles. It is true, that elliptic arches may appear not ſo ſtrong in powder magazines as circular ones, and of conſequence, leſs able to reſiſt the ſhock of the ſhells thrown upon them: but if it be conſidered, that they are more curvated at their hanches where they are thinneſt, and that the middle of the arch, which is its weakeſt part, is ſufficiently covered by maſonry to apprehend no danger there; it will be found that the elliptic arches are full as ſtrong as the circular ones.

But the greateſt uſe of elliptic arches appears to be in the building of bridges, and they ſeem indeed to be the only ones that are proper for ſuch works: for when the arches are of a great width, the circular form raiſes the middle of the bridge too high above the ends, whereby the draught of heavy carriages becomes very great, neither does it appear ſo well to the eye, and requires much more maſonry than is neceſſary; to which may be added, that this great weight requires larger foundations for the piers, and often cauſes them to ſink when the ſoil underneath is not very hard and ſolid, as experience has ſufficiently ſhewn.

I do not know what can excuſe an architect, who makes uſe of circular arches in bridges, when it is known that they require ſo much more maſonry than is neceſſary; ſince an elliptic arch is as eaſily deſcribed upon boards with a ſtring about two points as a circular arch about one, neither

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is there any greater difficulty to trace the joints in one than in the other, nor in the making patterns for cutting the arch-ſtones: therefore the pretended difficulties which ſome builders alledge, to be met with in the conſtruction of elliptic arches, are frivolous and trifling, in compariſon to the many advantages they have over all others.

If the arches of *Weſtminſter-bridge* had been made elliptical, and ſo as that their heights had been two thirds of what they are now; then the gaeat or middle arch, which is 76 feet wide, and 38 feet high, would have been reduced to the height of 25 feet 4 inches only, and the reſt in proportion; the quantity of maſonry contained in the arches would have been diminiſhed by one third, and the ſlope above, which is ſo conſiderably ſteep, and makes the bridge appear ſo diſagreeable to the eye, would have become quite eaſy.

In order to explain the ſeveral problems given for different arches, and to make their application plain and eaſy; I have given examples in numbers of every one, and for the ſake of ſaving trouble to the builders, I have computed a table of dimenſions for piers of powder magazines, from 6 to 24 feet high, wherein the ſhock of the ſhells that may be thrown upon them has been conſidered: as theſe dimenſions agree very nearly with thoſe which Mr. *Vauban* has uſed in the conſtruction of ſeveral magazines; and theſe magazines have never failed in any ſiege, though many thouſands of ſhells have fallen upon them, as has been related; the reader may depend upon the dimenſions we have given in our table.

The

The third ſection contains the theory of timber, a ſubject of no leſs importance to an engineer than any of the former; ſince thereby he is informed, how to place every piece in its beſt poſition, and what dimenſions they ought to have, ſo as the whole frame ſhall be equally ſtrong in every part, without uſing more timber than is neceſſary. After having determined the proportion between the ſtrength of ſcantlings of the ſame or different ſorts of timbers, placed any how, and which have different dimenſions; I give ſeveral tables of dimenſions for girders, joiſts, principal rafters, and other pieces uſed in buildings, made of oak or fir, adapted to large and ſmall buildings; and from thence it is ſhewn, that the dimenſions given by architects, bear no juſt proportion to each other.

As moſt of our architects make the oak ſcantlings of larger dimenſions than thoſe of fir, which are to ſupport the ſame weight; and as Mr. *Parent*, formerly of the Academy of Sciences at *Paris*, is ſaid to have made ſeveral experiments on the ſtrength of timber, and found that the ſtrength of fir ſcantlings is to the ſtrength of oak ſcantlings of the ſame dimenſions, as 6 to 5: I was induced to make ſome experiments myſelf, in order to confirm, or ſhew the falſity of a ſuppoſition ſo improbable. By theſe experiments I found, that the ſtrength of the weakeſt oak I tried, was to the ſtrength of the beſt fir I could get, as 8 to 7, and by comparing the beſt of each ſort, as 3 to 2; which differs greatly from the practice of our architects, and the experiments made by Mr. *Parent*.

In regard to the practice which I have treated of, in the ſecond and third parts of this work, ſuch

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as forming a ſcheme for building a fortreſs, the manner of tracing the works on the ground, the preparing and diſtinguiſhing the materials, the laying the foundations in any kind of ſoil, the building the walls and ramparts, together with all the military buildings which fall under the direction of an engineer; we ſhall refer the reader for theſe to the table of contents; and only obſerve here, that nothing has been omitted which I imagined to be of any uſe to the young and unexperienced engineer.

The fourth and laſt part treats of aquatic buildings, a ſubject more copious, and no leſs neceſſary to be underſtood by an engineer than any yet mentioned: for few fortreſſes are now-a-days built but what are ſituated near navigable rivers, lakes, or the ſea, for the benefit of trade and navigation; conſequently bridges, harbours, ſluices, and aqueducts are immediately connected with them, and are to be built by the ſame engineer who directs the works of the fortreſs; for which reaſon, I have endeavoured to aſſiſt him as much as the ſhortneſs of the work will admit of.

This part begins with the deſcription of ſtone-bridges, where, after having treated of their ſituations, and other previous precautions to be taken before the dimenſions are fixed upon; I give a problem for determining the thickneſs of piers of any height, when the width of the arch is given; and from thence I have conſtructed a table, containing the thickneſſes of piers from 6 to 24 feet high for arches from 20 to 100 feet wide, which no author has yet done: It is true, Mr. *Belidor* has given a rule for finding the thickneſs of piers which

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are six feet high: but as this rule serves in one case only, and is deduced from practice, and not grounded on theory, nor any substantial reasons; it is evident, that no great dependence can be had thereon. Then I describe various methods for laying the foundations, either with batardeaus, coffers, or other contrivances, in different depths of water, and in any kind of soil; and also the manner of carrying on the work from the beginning to the entire finishing the bridge, with all the security and necessary precautions we could think of.

After this I treat of harbours, a subject of great importance in a trading nation like this, to preserve not only the royal navy in stormy weather, but likewise afford an asylum for merchantmen in distress; though there have been several built in different parts of *Europe* in later times, yet we are very much in the dark in regard to a method whereby we may proceed in all kinds of situations. Very few directors of these works have thought proper to communicate their proceedings to the public. Mr. *Belidor* is the only author who has written particularly upon this subject; but as in most parts of *France* stones are in great plenty, whereas they are generally very scarce in the greatest part of this country; the method which the *French* chiefly follow can be but of very little use here: it is true, this author has given several others, that may be used in most situations, which I have taken care to insert in this work, and have added such others as I imagined might serve upon those occasions where his could not be applied.

I have endeavoured to be as particular as possible, in the preliminary enquiries to be made before a resolution is taken to fix upon the spot of ground

for

for making a harbour; as likewiſe in the choice of the materials to be uſed; in placing the entrance of the harbour, ſo as the ſhips may enter in ſtormy weather, and ſail out when fair; in the manner of laying the foundations in any kind of ſoil, in that of carrying on the work; and finally, in examining into the proper thickneſs which the piers ought to have, in order to reſiſt the waves, and at the ſame time be convenient for lading and unlading ſhips whenever it ſhould be found neceſſary.

To illuſtrate what has been ſaid, I have given the plan and ſection of a pier made of ſtone or brick, together with the plan and ſection of one of wood, both which have formerly been propoſed for incloſing a harbour to be built at that time. As it was ſaid that the funds allowed were not ſufficient to build the piers with ſtone, I propoſed to lay the foundation only with ſtone, and to finiſh the reſt with bricks, ſtrengthened at every eight feet high, with a courſe of ſtones crampt together; or, if this method was yet too dear, to build the piers with wooden frames, in the manner given here; but an objection was made that brick would ſoon be deſtroyed in ſalt-water; though it may be proved that when they are well burnt, ſuch as thoſe called clinkers, they are more laſting than *Portland* ſtone: For at *Portſmouth*, the foundations on the ſea ſide built with this ſtone, are made quite hollow, and worn away by the motion of the ſea-water; whereas the bricks uſed at *Woolwich* wharf, at *Chatham* dock, and at *Dover* harbour, beſides ſome others to be met with in *Holland*, are not the leaſt damaged, though they have been laid theſe many years.

What

What has been ſaid in reſpect to laying the foundation, and carrying on the work of piers for harbours, will equally ſerve for building wharfs, quays, and ſlips for docks; ſince the one and the other require a continued wall to be made in water; only wharfs and quays are built with leſs trouble, on account of being near the ſhore, where the motion of the water is not ſo dangerous; and are built but of a ſingle wall, which therefore is made ſtronger, and ſecured with land-ties, to prevent its being thruſt out by the heavy burthens generally laid upon them.

The work concludes with the manner of building ſluices and aqueducts, a ſubject too copious to be treated ſo fully as it ought to be in ſo ſmall a work as this; however, the manner of ſecuring the foundation with common and dove-tail piles has been fully explained, as well as that of making the wooden frames and floors which are laid upon them; and how the maſonry is to be carried on in the ſecureſt manner. That the reader may be enabled to procced upon all the various occaſions, which may happen in practice, I have given a general conſtruction of a large ſluice with a double pair of gates, in ſuch a manner as to be applicable to the moſt eſſential caſes, by changing a few particulars, which may vary in certain circumſtances; I have likewiſe ſhewn how to determine the moſt advantageous poſition of the gates, and given the dimenſions of the ſeveral pieces of which the gates of ſuch ſluices are compoſed, whoſe width are from 8 to 48 feet; as likewiſe the irons made uſe of to fix and ſecure them: in ſhort, nothing eſſential has been omitted, which might any ways contribute to the reader's ſatisfaction.

If it be considered, that canals for navigation are made from one end of a country to the other, over hills and valleys, by means of sluices and aqueducts; that harbours are formed and cleared from the sand and shingle driven in by the water; low and marshy lands dried and made arable, as likewise dry and barren lands supplied with a proper moisture to make them fruitful; countries are defended against a powerful enemy by forming inundations; towns supplied with water: and if to this we add, the excellent use of sluices in the attack and defence of places, so well described by Mr. *Belidor*, whereby a fortress may be made almost impregnable; whoever considers all these things, will find, that no works directed by an enigneer, require a more extensive knowledge, both in theory and practice.

I have endeavoured throughout the whole work to be as distinct as I could, in order to make the subject plain and easy; but as no improvements can be made in any branch of learning without the help of theory, I fear that many of my readers will not understand the most essential parts of this work, which it was not in my power to treat of otherwise; I would therefore advise the learner to begin to study my *Elements of Mathematics*, which were composed chiefly for military gentlemen, and to serve as an introduction to works of this kind.

As I am sensible, that, for want of being thoroughly acquainted with the *English* Language, many grammatical errors are to be found in this work, notwithstanding all the possible care that has been taken; I hope for the reader's indulgence in this respect.

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N.B. The Numbers as in the Book are conformable to the First Edition of Elem. Math. and those corrected to the New.

A TREATISE CONTAINING The PRACTICAL PART OF FORTIFICATION.

SECT. I.

The THEORY *of* WALLS.

IN order to have a clear idea of what follows in regard to the theory of walls, it is necessary to explain the suppositions, on which its veracity depends. Thus we suppose that if new-made earth, such as in ramparts, was not supported by a wall, the particles would loosen from each other by the dampness of the weather, and tumble down so as to make a slope nearly in a plane surface, which plane is called the natural slope of the earth; and is supposed to have always the same inclination in the same sort of soil.

The second is, that the wall is so well cemented, as if it were made of one single stone, as far as its foundation, so that, if a sufficient power was applied to any part of it, it would break off

off near the foundation, and would turn in the fame manner as if it was compofed of one ftone only.

The firft of thefe fuppofitions may be proved in this manner; fince whatever obliquity is required for one particle to tumble down, the fame will alfo be required for any other of the fame weight and tenacity, and therefore the fum of all the particles tumbled down, will form a plane furface nearly, which has always the fame inclination in the fame fort of foil, but will vary according as the foil has a greater or lefs tenacity. For example, fand will form a greater flope than common earth, and this a greater than loam or clay.

It may be faid, that all the particles of the fame fort of foil have not the fame magnitude, as may be feen diftinctly in fand, and therefore what we have faid is not abfolutely true: but though it is impoffible to determine this fubject according to a methamatical ftrictnefs, yet it is fufficiently exact for common practice, where fo great a nicety is not required, nor neceffary.

As to the fecond fuppofition, if we confider that the wall is always built a twelve month, or ought to be fo, before the earth is laid againft it, it has time to dry well, before any preffure is made againft it; befides fmall branches of wood are mixt with the earth to leffen its preffure: and though the wall is joined as firmly to its foundation as in any other part, yet this is advantageous to the refiftance of the wall; and the fuppofed equilibrium, between the momentums of earth and the wall, is not ftrictly true, nor ought it to be fo; or elfe the wall would foon tumble down, by the leaft accident that would happen.

PRO-

PROBLEM I.

To find the pressure of earth represented by the triangle CDT, *against the profil* ABCD, *of a wall, in a direction perpendicular to the vertical line* DC. Plate I. Fig. 1.

AS the profil ABCD, and the triangle DCT, represent the bases of solids which have the same altitude, the weights of these solids will be proportional to their bases; for which reason we shall consider the areas of the section ABCD, and of the triangle DCT, as so many weights, which are proportional to them. Since the sum of the momentums of all the parts is equal to the momentum of the whole weight re-united into its center of gravity by art. 422 of our Elem.

It is evident that the weight of the triangle DCT, may be considered as re-united into its center of gravity S, and the descent of that center, when the triangle slides along the inclined plane, will be that by which its force against the wall must be estimated. If therefore SR be drawn perpendicular to the side DC of the wall; the whole pressure may be considered as acting against that point R.

Now because the area of the triangle DCT, is equal to $\frac{1}{2}$ DC × CT; if we call T the action of the weight in the direction parallel to the inclined plane DT; and W the part acting in the direction SR perpendicular to DC: we have DT : DC : : $\frac{1}{2}$ DC × CT : T; by art. 499 of our Elements; and DT : CT : : T : W, by art. 501: and the compound of these proportions gives $\overline{DT}^2$: DC × CT : : $\frac{1}{2}$ DC × CT : W. Consequently the angle CDT being given, the pressure W will be given likewise.

COR. I.

Hence if the height DC of the wall be called a, DT unity, and CT$=s$: then will W$=\frac{1}{2}ssaa$, by the last proportion; and because the action along the inclined plane DT, is retarded by the cohesion of the parts, and it has been found by experiments that a body sliding along a smooth plane, requires one third of its weight to move it; therefore this expression ought to be diminished in the ratio of 3 to 2, in order to get the true pressure: Again, the specific gravity of stone is to that of earth as 3 to 2; so that if we will compare the weight of the triangle DCT of earth with the weight of stone; the expression must be reduced also in that ratio: that is, the value of W must be reduced in the ratio of 9 to 4, in order to get $\frac{2}{9}ssaa$ for the true pressure.

COR. II.

Because the line SR, is parallel to the base AD; DR will express the distance of the direction SR of the pressure against the wall from the base, or the point fix A, about which the wall must turn in order to be overset; and since DR is $\frac{2}{3}a$, by art. 427. the product of the weight $\frac{2}{9}ssaa$, multiplied by the distance $\frac{2}{3}a$, gives $\frac{4}{27}ssa^3$, for the momentum of the earth's pressure.

NB. It may be observed that DT is to CT, as the radius is to the sine of the angle CDT; and therefore, s expresses the sine of that angle, when the radius is unity.

PRO-

PROBLEM II.

To find the thickness BC *above of a stone wall* ABCD, *so as to resist the pressure of the earth* CDT.

Draw BE perpendicular to the base AD; and let the weights Q, P, be suspended in the centers of gravity of the triangle ABE, and the rectangle EC, and to be proportional to their areas respectively.

Now because the pressure of the earth endeavours to overset the wall in the direction SR or DA, whilst the weights Q, P, retain it in the direction perpendicular to AD: the sum of the momentums of the weights Q, P, must therefore be equal to the momentum of the earth's pressure, in case of equilibrio. Hence, if BC or ED $= x$, and AE $= na$; the letter n expressing an indetermined but constant quantity; then will $Q = \frac{1}{2} naa$, $P = ax$; and as the distances of the weights Q, P, directions from the point A, are $\frac{2}{3}$ AE, AE $+ \frac{1}{2}$ ED; that is, $\frac{2}{3}na$, $na + \frac{1}{2}x$; therefore $\frac{1}{3}nna^3$ will be the momentum of the weight Q, and $naax + \frac{1}{2}axx$, that of the weight P: the sum of these two momentums being made equal to $\frac{4}{27} ssa^3$ the momentum of the earth, and both sides divided by $\frac{1}{2}a$, gives $xx + 2nax + \frac{2}{3}nnaa = \frac{8}{27}ssaa$; by adding $\frac{1}{3}nnaa$ to both sides, the first will be a perfect square, whose root multiplied by 9, and the other side by 81, is $9x + 9na = a\sqrt{24ss + 27nn}$.

N. B. Mr. *Cotes*, in his Hydrostatic lectures, page 61, says that the specific gravity of stone is to that of bricks as 2.5 to 2; that is, as 5 to 4. If therefore we increase the first term $24ss$, under the radical sign in the ratio of 4 to 5, we shall have $9x + 9na = a\sqrt{30ss + 27nn}$, for the equation which determines the thickness above of brick walls.

For example, if the base of the wall's slope is one fifth of its height, and the slope of earth makes an angle of 45 degrees; then will $n = \frac{1}{5} = .2$, $nn = .04$, and $ss = .5$: whence multiplying 24 by .5 and 27 by .04 and extracting the square root of the sum 13,08, we get 3.6167, from which substracting 1.8, and the difference divided by 9, gives $x = .2018\,a$, or $x = \frac{1}{5}\,a$ nearly in stone walls. But if 30 be multipled by .5, and added to 1.08; the square root of 16.08, will be 4.009 nearly; from which substracting 1.8, and dividing the difference by 9, we get $x = .245\,a$ nearly in brick walls.

Of Counterforts.

IN building walls that are to support earth, buttresses are made behind them at certain distances from each other, which are not seen, as being covered with earth; they are made in view to strengthen the wall against the pressure of earth, and to save expences; for by this means there is no occasion to make the walls so thick as they otherwise must be. These buttresses, are called *Counterforts*, in fortification, and are made of various forms.

Plate I. Fig. 2. Suppose the trapezium ABCD to represent the section of a wall without parapet; then the rectangle DF represents the elevation of the Counterfort, which is generally as high or within a foot, as the wall, and the base DG the length; and if we consider the plane of the wall; where KLMN, represents the base of the Counterforts, and NP, their distance from each other, which may vary at pleasure.

Mr. *Vauban* made the base KLMN of the counterforts always broader at the root KN than at the tail LM, in the constant proportion of three to two; and the distance from the center of one to that of the next, 18 feet: On the other hand, Mr. *Belidor* would have them made the contrary way, that is, narrower at the root KN than at the tail LM in the same in verse proportion of two to three; because the center of gravity of the counterfort, being thereby farther from the wall, will support a greater weight, than those made

by

by Mr. *Vauban*; they are besides not so easily destroyed by cannon, when the wall is beat down, and so keep better up the earth. But as he imagined that the engineers would hardly change an old established practice, for any other ever so advantageous; he computed his tables according to Mr. *Vauban's* profil.

We, on the contrary, make the base of our counterforts rectangular, partly because our engineers make them so, and because they are very near as strong as those made by Mr. *Belidor*; they likewise bind better with the wall, and the workmanship is cheaper and easier; so that in the mean, they are better than those of any other form.

Instead of placing the counterforts at the same distance, whether the wall is high or low, as Mr. *Vauban* does, we make their thickness K N to their interval N P always in the constant ratio of unity to three, and their length K L or D G, one fourth of the height D C of the wall. From this disposition of the counterforts, the profils become similar, and their thickness B C above is in a constant ratio, with the height D C, when the slope A B remains the same; as will be seen hereafter; whereby the operations become extremely easy. And this rule is agreeable to the pressure of the earth, which we have shewn above to be similar in the same sort of soil.

In a wall of ten feet high, the counterforts, according to Mr. *Vauban's* general profil, are 3 feet thick and at 15 feet distant from each other; and in a wall of 80 feet, their thickness is 10 and distance but 8; and therefore his counterforts are too far distant in low walls and too near in high ones; whereas ours may be placed farther from or nearer to each other, according as it is convenient in practice, provided the proportions mentioned above are observed.

It may be observed, that the longer the counterforts are the greater force they have to resist the pressure of the earth; but when they are made to narrow, they do not bind so well with the wall; for which reason, I would make their thickness never less than half their length. For instance, in a wall of 40 feet high, the length of the counterforts will be 10 feet, according to the proportion mentioned before: their thickness ought, in my opinion, to be no less than 5 feet, and then their distances from each other will be 15 feet; but in a wall of ten feet high, their length will be two feet six inches; and their thickness ought to be two feet; then their interval will be six; whereas if they were made thinner, they would stand too close to one another.

PROBLEM III.

To find the thickness above, of stone walls which have counterforts, so as to resist the pressure of the earth. Fig. 2.

Because the length DG of the counterforts is a fourth part of the height DC; the area DF will be $\frac{1}{4}aa$, and AD $+ \frac{1}{2}$DG, that is, $x + na + \frac{1}{8}a$, will be the distance of its direction from the point A; therefore $\frac{1}{4}aax + \frac{1}{4}na^3 + \frac{1}{32}a^3$, will be the momentum of the counterfort: but as there is an interval between them, and therefore is too much by that interval, or as but one part in four is taken up by the countereforts, this momentum must be divided by 4 in order to have $\frac{1}{16}aax + \frac{1}{16}na^3 + \frac{1}{128}a^3$, for the true momentum; which being added to that of the wall found in the last problem, and their sum made equal to that of the earth, when divided by $\frac{1}{2}a$, gives, $xx + 2nax + \frac{1}{8}ax + \frac{2}{3}nnaa + \frac{1}{8}naa + \frac{1}{64}aa = \frac{8}{27}ssaa$: if we add $\frac{1}{3}nnaa - \frac{7.5}{64}aa$ to both sides, the first will be a perfect square, and the second reduced under the same denomination, whose common denominator is 81×64; then the first side multiplied by its root 72, gives $72x + 72na + 4.5a = a\sqrt{1536ss - 60.75 + 1728nn}$ for the general equation which determines the value of x in stone walls: But if we increase the

the first term 1536 ss under the radical sign, in the ratio of 4 to 5, as has been shewn in the last problem, we get $72x + 72na + 4.5a = a\sqrt{1920ss - 60.75 + 1728nn}$, for the general equation which determines the value of x, in brick walls.

Hence it is manifest, that when the sine s, and the value of n are known, the thickness above x of the wall, will be always expressed by parts of a, the height of the wall; and from thence, general rules may be found for all the different slopes that commonly are given to walls, and for any angle the slope of earth makes with the vertical line D C, as will appear by the following examples.

Let the base A E of the slope be one fifth of the height D C, and C D T an angle of 45 degrees: then will $n = \frac{1}{5} = .2$, and $ss = \frac{1}{2}$; these values being substituted into the first equation gives 776.37 for the quantity under the radical sign, whose square root is 27.863a; from which subtracting the sum 18.9 a, of the two known terms, and dividing the difference by 72, we get $x = .1245a$, or $x = \frac{1}{8}a$ nearly in stone walls.

But if we substitute the values of ss an n, into the second equation, we get 968.37 for the sum of the terms under the radical sign, whose square root is 31.118a, from which subtracting the sum 18.9a, of the two known terms, and dividing the difference by 72, we get $x = .169a$, in brick walls.

If the base A E of the slope is one sixth, and the angle C D T, 45 degrees: then will n equal $\frac{1}{6}$, $ss = \frac{1}{2}$; these values being substituted into the first equation gives 755.25 for the sum of the terms under the radical sign, whose square root is 27.481 a, from which subtracting the sum 16.5a of the two known terms, and dividing the difference by 72, we get $x = .153a$, in stone walls.

But if the same values of n and ss, are substituted into the second equation, we get 947.25, whose square root

root is 30.777a, from which subtracting the sum 16.5a of the two known terms, and dividing the difference by 72, gives $x = .198a$, in brick walls.

Again suppose the angle of the slope DT to be 30 degrees, then will $s = .5$; and $ss = .25$: these values being substituted into the first equation, give 384, for the first term under the radical sign, and by substituting that value in the second equation, we get 480 for that term.

Now if $n = .2$; we get 392.37 for the sum of the terms under the radical sign, whose square root is 19.808, and hence $x = .013a$, nearly in stone walls; and in brick walls, we get 488.37 for the quantity under the radical sign, whose square root is 22.099, and hence $x = .044\,a$ nearly.

Because the sum of the squares of the sine and cosine of any angle is equal to the square of the radius; if we subtract the square .25 of the sine of 30 degrees, from the square of the radius or unity, we shall have .75 for the square of the sine of an angle of 60 degrees.

Whence, substituting this value into the first equation, we shall have 1152 for the first term under the radical sign, and by substituting the same value into the second, we get 1440 for the first term under the radical sign.

Now if $n = .2$; then will 1160.37 be the sum of the terms under the sign, whose square root is 34.064, and hence $x = .211a$, in stone walls, and 1448.37, will be the sum of the terms under the sign, whose square root is 38.057: and therefore $x = .266a$, in brick walls. When the slope of earth DT makes any other angle, the operations become more tedious; and in that case the values of s, are to be taken out of the tables of natural sines; and it will be sufficient to take only the three first numbers.

But to save the trouble to practical engineers, we have computed the values of x, when the slope is $\frac{1}{5}$, $\frac{1}{6}$, $\frac{1}{7}$, $\frac{1}{8}$; for both stone and brick walls; and when the slope D T of earth makes an angle from 36 to 80 degrees for every 5 degrees, which we imagine to be sufficient, as may be seen in the following table, where the fractional numbers in the first horizontal line express the ratio of the base A E of the wall's slope to the height of the wall; the first vertical column shews the angles which the slope of earth makes with the vertical line DC: and the other numbers give the ratio of the thickness of the wall; or the values of x, to its height, which numbers are all decimals.

Example, If the base A E of the slope is one fifth of its height, and the angle C D T, 45 degrees; then the number opposite to 45 and under $\frac{1}{5}$, is 125, which being multiplied by the height of the wall, suppose 30 feet, gives 3.750, or 3 feet 9 inches: suppose the angle C D T, to be 60 degrees, and the base of the slope one fifth; then the number 211 opposite to 60 and under $\frac{1}{5}$, being multiplied by the height of the wall 30 feet, gives 6.330 or 6 feet 4 inches nearly.

N. B. It must be observed once for all, that we always take the nearest number in all our computations. Thus if the fourth decimal is either 5 or above we always increase the third by unity; the same thing is to be observed in regard to inches: for in the last example .33, multiplied by 12, gives 3.96 inches, which is 4 inches nearly.

GENE-

GENERAL RULES

For Stone walls. For Brick walls.

Ang.	$\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{7}$	$\frac{1}{8}$	$\frac{1}{5}$	$\frac{1}{6}$	$\frac{1}{7}$	$\frac{1}{8}$
80°	275	304	3 6	342	338	368	389	406
75	265	292	316	332	327	356	378	395
70	250	280	301	217	311	340	362	378
65	235	262	283	299	290	320	342	358
60	211	239	256	277	266	296	314	333
55	191	214	235	251	238	267	288	304
50	153	185	202	221	205	230	251	271
45	125	153	173	189	169	198	219	235
40	089	117	137	153	130	159	179	195
35	052	079	093	114	087	116	134	152
30	013	038	057	072	044	071	090	106

As the base of the slope is never less than one eighth nor greater than one fifth of the wall's height; we thought it needless to carry these general rules any farther, which however may be done by means of the two preceeding equations, whenever it is thought necessary.

To find the general rule for any intermediate angle say, As 5 degrees is to the difference between the given angle, and that next to it in the table, so is the difference between the numbers in the table opposite to the angles next below and above the given angle; the fourth term added to the nearest number if above it, or substracted if below, gives the number sought. Thus the angle being 53: substract it from 55, substract the number 153 of 50 from the number 191, which gives 38. Then say, 5 : 2 : : 38 : 15; and 15 substracted from the number opposite to 55, which is 191 gives 176 for the number sought.

The

The first and second tables have been computed from the general rules, when the slope of earth makes an angle of 45 degrees, which is most commonly the case in a middling soil, and is what Mr. *Belidor* and others have supposed; so that if any error should have been committed in these tables, they may be corrected by the last rules, and if the height of a wall, not expressed in these tables, should be given, whose thickness above being required, it may be found. Thus if the given height be 35 feet, and the slope one fifth; multiply that height by 125, which gives 4.375 feet or 4 feet and 4.5 inches for the thickness required in a stone wall.

The thickness near the foundation, is found by adding the base of the slope to the thickness above; thus when the base of the slope is one fifth, and the wall 30 feet heigh, then one fifth of 30 is 6, to which add the thickness above 3 feet 9 inches, and the sum 9 feet 9 inches will be the thickness required. It is to be observed that the length of the counterforts, in these tables, is always one forth of the wall's height as has been mentioned before, and their thickness is to their interval as unity is to 3.

PROBLEM IV.

To find the thickness of walls which have parapets, according to the third profil. Fig. 3.

In walls with parapets, the slope A B of the wall is always terminated by the cordon B, within four feet of the top F, and the upright wall BFHI, never exceeds three feet in thickness; and the part H I, is always terminated by the line DC produced, when BC does not exceed three feet.

If the upright part I F of the wall was sufficient to resist the pressure of the earth, above the line B K produced; there need be no other tables than those already given; but as this is not the case; the pressure of the earth above the line BK should be computed as well as the resistance of the wall IF, in order to have the true solution of the problem: But this would make the work more tedious, than is necessary in practice, and therefore we shall estimate this force in an easier manner, and which answers full as well.

Suppose the wall ABCD to be carried up quite to the top F, and so as to be sufficiently strong to resist the pressure of the earth, and from thence the thickness at BC is to be found; then I say, that the strength of the whole wall will be sufficient to resist the pressure of the earth.

For the earth above the line BC, extends not above 18 feet, that is very little farther than the parapet FN reaches; and therefore the part IF of the wall will nearly be sufficient to resist the pressure of that earth; and as BC is more than it should be, were the earth no higher than BC, it is plain that the wall thus determined will resist the pressure of the earth more than is sufficient: besides this agrees perfectly well with Mr. *Vauban's* profil of 30 feet high, that has been used in above 50 places without having ever failed.

Now because the height BE is to the base EA of the slope as the height BF, or 4 feet, is to the difference between the thickness at B and that at F; that is, as AE is $= na$, BE $= a$; we have $a : na :: 4 : 4n =$ to the difference required, which therefore being added to the thickness at F, found in the preceding tables, answering to the height EF, gives the thickness BC required.

GENERAL RULES.

If the base AE *is one fifth of the height* BE; *then* $4n$ *becomes* .8 *or* 9.6 *inches, which is to be added to the thickness in the second Column.*

If

If A E *is one fixth of* B E, *than will* 4 *n become* $\frac{4}{6}$ *or* 8 *inches, which is to be added to the thickness in the fourth column.*

If A E *is one seventh of* B E; *then will* 4 *n become* $\frac{4}{7}$ *or* 7 *inches nearly, which is to be added to the thickness in the sixth column.*

Lastly, If A E *is one eighth of* B E; *than* 4 *n becomes* $\frac{4}{8}$, *or* 6 *inches; which is to be added to the thickness in the eighth column.*

By these general rules the third and fourth tables have been constructed, the lengths of the counterforts in the tenth column, are the fourth part of the total height; though they are never carried higher than the cordon: But it must be observed, that the numbers in the first column, express the heights, from the foundations to the cordon B only; because the height B F, of the upright part is always 4 feet in all walls whatsoever, that have parapets.

To shew by a few examples how the preceding general rules are applied; we shall suppose the height E B of a stone wall to be 30 feet, and the base A E one fifth of that height: then adding 4 feet to 30 we get 34 feet for the total height E F; and the thickness found in the second column of the first table, answerting to 34 feet, being 4 feet 3 inches; to which adding 9.6 inches by the first rule, gives 5 feet and .6 of an inch, for the thickness required. Mr. *Vauban* makes this thickness 5 feet; so that ours does not exceed his but by half an inch nearly.

If a stone wall is 24 feet high, and the base of the slope on sixth; then 4 feet added to 24 gives 28 feet; and the thinkness answering to this height in the fourth column of the first table is 3 feet 6 inches; by adding 8 inches according to the second rule; then the sum 4 feet 2 inches will be the thickness at B C required.

Thus we have given tables not for stone walls only, but likewise when they are built with brick; and their con-

constructions are deduced from the most simple principles, and at the same time the most general that could have been thought of, and those general rules we have given for the different angles the slope of earth makes, are of excellent use in practice; for it is easily perceived, that when the soil is of a strong nature, such as loam or clay, a great deal of masonry may be saved, and when the soil is sandy, how to proceed with method and safety, which cannot be done without them, or by guess only.

PROBLEM V.

To find the thickness above, of a stone wall which supports a parapet of earth above it, according to the fourth profil. Fig. 4.

We shall for conveniency sake, suppose the slope C G of earth to be parallel to D H, that which the earth forms; though this is not always the case in practice, yet the difference arising from thence is inconsiderable.

Let the vertical line D C produced, meet the horizontal one G H in F; if $DC = a$, $DF = b$, and the rest as before; then if from the momentum of the triangle D F H, which has been found in Cor. 2. after the first problem to be $\frac{4}{27}ssb^3$, we subtract the momentum of the triangle C F G, we shall have the momentum of the earth.

Now as $CF = b - a$; the pressure of that triangle will be $\frac{2}{9} \times ss \times \overline{b-a}^2$, by Cor. 1. after the first problem; and since the distance of the line of direction drawn from the center of gravity of this triangle perpendicular to D F, from the point fix A, is $DC + \frac{2}{3}CF$, or $\frac{a + 2b}{3}$; and the product of this distance multiplied by the weight, gives $\frac{2}{27}ss \times \overline{2b^3 - 3abb + a^3}$ for the momentum of that triangle; which therefore being subtracted from $\frac{4}{27}ssb^3$, gives $\frac{2}{27}ss \times 3abb - a^3$.

Now

Ta… Wa…		
	When th…	
height	Thickn… above…	
Feet	F°	I…
10	1	3
12	1	6
14	1	9
16	2	[illegible]
18	2	3
20	2	6
22	2	[illegible]
24	3	[illegible]
26	3	[illegible]
28	3	[illegible]
30	3	[illegible]
32	4	[illegible]
34	4	3
36	4	6
38	4	9
40	5	[illegible]
42	5	3
44	5	6
46	5	[illegible]
48	6	[illegible]
50	6	[illegible]

nsions of Brick
to the Second Profil

...e is 1/7	When the Slope is 1/8				pag.	
...ckn.s ...low	Thickn.s above		Thickn.s below		Leng.th of y Countf.	
In.	F.t	In.	F.t	In.	F.t	In.
8	3	9	5	6	3	6
4	4	3	6	3	4	0
1	4	9	7	0	4	6
10	5	2	7	8	5	0
8	5	8	8	5	5	6
3	6	2	9	2	6	0
0	6	7	9	10	6	6
9	7	1	10	7	7	0
5	7	6	11	3	7	6
2	8	0	12	0	8	0
11	8	5	12	8	8	6
8	8	11	13	5	9	0
4	9	5	14	2	9	6
1	9	11	14	11	10	0
10	10	4	15	7	10	6
6	10	10	16	4	11	0
3	11	4	17	1	11	6
0	11	9	17	9	12	0
9	12	3	18	6	12	6
5	12	9	19	3	13	0
1	13	2	19	11	13	6

Now because the momentums of the wall and counterfort are the same here as in the third problem, if we divide the momentum of earth by $\frac{1}{2}a$, and multiply by 3×64, we get $768\, ss \times \overline{3bb - aa}$ which being substituted instead of the first term under the radical sign in the equation of that problem we get $72x + 72na + 4.5a = \sqrt{768\, ss \times \overline{3bb - aa} - 60.75aa + 1728nnaa}$, for the equation which determines the unknown quantity x in this case.

When F C becomes $= 0$, that is when there is no parapet of earth above the wall; then will $a = b$, and the last equation becomes the same as that in the third problem.

If the base A E of the slope is one fifth of the height E B; and the angle C D H 45 degrees; then will $n = .2$ and $ss = .5$: and the equation above becomes $72x + 18.9a = \sqrt{1152bb - 375.63aa}$, in this case; but if the base A E be one sixth of the height B E, and the angle C D H, the same as before, we get $72x + 16.5a = \sqrt{1152bb - 396.75aa}$.

By means of these two last equations, the fifth and sixth tables have been constructed, which contain the ratio's between the height of walls and their thickness above: they shall be explained by a few examples.

Let the height of a stone wall be to that of the earth above it as 3 to 2; then because $3 : 2 :: a : \frac{2}{3}a = $ C F, we get $a + \frac{2}{3}a = \frac{5}{3} = b$; whose square being multiplied by 1152 gives 3200; from which subtracting 375.63, and extracting the square root of the difference, we get 53.144, from which subtracting 18.9 and dividing by 72, gives $x = .476a$ nearly, in the first case.

But if we subtract 396.75 from 3200, and extract the square root of the difference, we shall have 52.945; from which 16.5 being subtracted, and the difference divided by 72, gives $x = .506a$ nearly, in the second case.

If the height of the wall is to that of the earth above it, as 4 to 3; then will $b = \frac{7}{4} a$; this value being substituted into $1152\,bb$, gives 3528, from which taking 375.64, and extracting the square root of the remainder, we get 56.145; if we take 18.9 from this and divide the remainder by 72, we shall have $x = .517\,a$ nearly, in the first case.

But if we subtract 396.75 from 3528 and extract the square root of the difference, we get 55.975; from this subtracting 16.5 and dividing by 72, we shall have $x = .548\,a$ nearly, in the second case.

If the walls are built of brick, then by what has been said at the end of the second problem, we have no more to do than to increase the first term under the radical sign, in the ratio of 4 to 5; then the general equation above, becomes that for brick walls. Whence, if the base AE of the slope is one fifth of the height BE, and the angle CDH, 45 degrees; then will $n = .2$, $ss = .5$; and $72x + 18.9a = \sqrt{1440\,bb - 471.63\,aa}$, will be the equation in this case: and if that base be one sixth of the height BE, and the angle CDH, the same as before, we have $n = \frac{1}{6}$, $ss = .5$: and therefore $72x + 16.5a = \sqrt{1440\,bb - 492.75\,aa}$ will be the equation.

Let the height of the wall be to that of the earth above it as 5 to 2; then will $b = \frac{7}{5} a$, whose square multiplied by 1440 gives 2822.4, from which subtracting 471.63, and the square root being extracted, gives 48.484, and taking 18.9 from this, the remainder divided by 72 gives $x = .411\,a$, nearly in the first case.

But if we subtract 492.75 from 2822.4 and extract the square root of the difference, we get 48.266 and 16.5 being taken from it; the difference divided by 72 gives $x = .441\,a$, nearly in the second case.

4

Explanation

Explanation of the following TABLES.

The fifth and ſixth, contain the ratio's between the heights of ſtone walls and their thickneſs above, when there is a parapet of earth above them; the baſe of the ſlope being one fifth and one ſixth of the height of the wall; and the ſlope of earth makes an angle of 45 degrees; the ratio's between the height of the wall to that of the earth above it, are marked in the firſt horizontal line and column: the length of the counterforts being one fourth of the walls height, and their thickneſs is to the interval between them, as unity to 3, that is the ſame as before: The ſeventh and eighth tables contain the ſame ratio's when the walls are of brick.

Their uſes are as follows: when the height of the wall is given, as well as that of the earth above it, reduce the ratio to its loweſt term; look in the firſt column for the antecedent, which is always ſuppoſed to expreſs the height of the wall, and for the conſequent in the firſt horizontal line, then the number oppoſite to the firſt, and under the ſecond, expreſſes the ratio between the height of the wall to its thickneſs above. This number being multiplied by the height of the wall, and the three laſt figures taken as decimals, gives the thickneſs required.

Example, Let the height of a ſtone wall, whoſe ſlope is one fifth, be 20 feet, and that of the earth above it 12: then becauſe 20 is to 12 as 5 is to 3; look in the firſt column of the fifth table for 5, and in the horizontal line for 3: then the number 442 oppoſite to the firſt, and under the ſecond, being multiplied by 20, the height of the wall, gives 8.84 or 8 feet 10 inches nearly for its thickneſs above.

If the height of a ſtone wall, whoſe ſlope is one fifth, be 13 feet, and that of the earth above it 6: then in the ſame table, the number 371 oppoſite to 13 and under 6, multiplied by 13, the height of the wall, gives 4.823 or 4 feet 9 inches nearly for the thickneſs above.

But if the ſlope is one ſixth, look into the ſixth table oppoſite to 13 and under 6, and you will find 403, which being multiplied by 13, gives 5.239 or 5 feet 3 inches nearly. We have not inſerted the thickneſs of the walls near the foundation; becauſe they may be found by adding the baſe of the ſlope to the thickneſs above.

N. B. Thoſe ſquares which are marked with a point only, are oppoſite to ſuch ratio's as have been determined before, and therefore it would have been needleſs to repeat them. Thus the ratio of 2 and 2, of 3 and 3, of 6 and 6, &c. is the ſame as that of unity to unity; and it is the ſame in reſpect to all other equal ratio's.

PROBLEM VI.

To find the thickneſs above BC *of a wall when the counterforts have a ſlope as* FG. Fig. 5.

Draw FL perpendicular to the baſe AG; then if, for conveniency ſake, we ſuppoſe CF to be one eighth, and the baſe DG three eighths of the height DC; the area of the rectangle DC, will be $\frac{1}{8}aa$, that of the triangle LGF, will alſo be one eighth of aa; and becauſe the diſtances of the lines drawn through the centers of gravity, of the rectangle DF, and of the triangle FLD, perpendicular to the baſe DG, from the point fix A, are AD $+ \frac{1}{2}$ DL, AL $+ \frac{1}{3}$ LG; that is, $x + na + \frac{1}{16}a$; $x + na + \frac{5}{24}a$; and therefore their ſum, multiplied by $\frac{1}{8}aa$, and the product reduced in the ratio of 4 to unity, as has been ſhewn in the third problem, gives $\frac{1}{16}aax + \frac{1}{16}na^3 + \frac{3.25}{3.84}a^3$, for the momentum of the counterforts, which being added to that of the wall found in the ſecond problem, and the ſum made equal to that of the earth; after having multiplied by $\frac{1}{2}a$, and the ſecond ſide reduced under the ſame denomination, and the root of the firſt multiplied by the root of the common denominator 81×64, we get

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Table V. Containing the Proportions between the Height of Stone Walls and that of the Earth above them the Base of the Slope being $\frac{1}{5}$ of y^e height

0	1	2	3	4	5	6	7	8	9	10
1	641	1125	1604	2079	2553	3026	3499	3971	4443	4915
2	391	.	885	.	1365	.	1842	.	2316	.
3	305	476	.	804	965	.	1285	1445	.	1762
4	261	.	517	.	763	.	1005	.	1246	.
5	235	340	442	542	.	739	836	933	1029	.
6	217	.	.	.	559	.	723	.	.	.
7	205	280	354	427	498	570	.	711	781	850
8	194	.	327	.	454	.	579	.	702	.
9	186	247	.	363	420	.	532	587	.	695
10	180	.	287	.	.	.	491	.	591	.
11	173	225	273	321	368	414	460	506	551	596
12	171	.	.	.	349	.	433	.	.	.
13	168	211	251	292	332	371	411	449	488	527
14	165	.	242	.	318	.	391	.	463	.
15	162	199	.	270	.	.	374	408	.	.
16	160	.	228	.	294	.	359	.	423	.
17	158	190	222	254	285	316	346	376	406	436
18	156	.	.	.	276	.	334	.	.	.
19	154	183	212	240	268	296	323	351	377	405
20	152		208	.	.	.	314	.	366	.

Table VI. Containing *the* Proportions *between the* Height *of Stone* Walls, *and that of the* Earth *above them, the Base of the Slope being* ⅙ *of the height*.

0	1	2	3	4	5	6	7	8	9	10
1	672	1157	1636	2112	2586	3060	3532	4004	4477	4949
2	422	.	917	.	1397	.	1874	.	2349	.
3	335	506	.	835	997	.	1317	1477	.	1796
4	291	.	548	.	796	.	1037	.	1277	.
5	264	370	472	574	.	770	868	965	1061	.
6	246	.	.	.	589	.	756	.	.	.
7	233	310	384	458	530	604	.	742	812	882
8	223	.	357	.	485	.	610	.	734	.
9	216	276	.	393	450	.	562	617	.	726
10	209	.	317	.	.	.	523	.	625	.
11	204	254	302	350	400	444	497	536	582	627
12	200	.	.	.	379	.	464	.	.	—
13	196	239	281	322	362	403	441	480	519	557
14	193	.	272	.	347	.	421	.	494	.
15	191	228	.	300	.	.	404	439	.	.
16	188	.	257	.	324	.	388	.	453	.
17	186	219	233	284	316	346	377	408	438	466
18	184	.	.	.	307	.	364	.	.	.
19	183	213	241	270	299	327	354	382	409	435
20	181	.	237	.	.	.	344	.	400	.

Table VII. Containing *the* Proportions *between the* Height *of Brick* Walls *and that of the* Earth *above them, the Base of the Slope being ⅕ of the height*

0	1	2	3	4	5	6	7	8	9	10
1	748	1289	1824	2355	2885	3414	3943	4471	4999	5527
2	468	.	1020	.	1557	.	2089	.	2620	.
3	372	562	.	929	1110	.	1468	1646	.	2001
4	323	.	609	.	884	.	1155	.	1424	.
5	293	411	523	637	.	857	966	1074	1182	.
6	273	.	.	.	655	.	838	.	.	.
7	259	344	427	509	589	668	.	826	904	974
8	248	.	396	.	539	.	678	.	816	.
9	239	306	.	436	500	.	624	686	.	808
10	232	.	352	.	.	.	581	.	692	.
11	227	282	336	390	442	494	545	596	647	697
12	222	.	.	.	420	.	516	.	.	.
13	218	266	312	357	402	446	490	533	576	619
14	215	.	302	.	386	.	468	.	549	.
15	212	253	.	333	.	.	449	487	.	.
16	209	.	286	.	360	.	432	.	504	.
17	207	243	279	314	349	383	418	452	485	518
18	205	.	.	.	340	.	404	.	.	.
19	203	236	268	300	331	362	392	423	453	843
20	201	.	263	.	.	.	382	.	440	.

Table VIII. Containing *the* Proportions *between the* Height *of Brick* Walls *and that of the* Earth *above them the Base of the Slope being* $\frac{1}{6}$ *of the height*

0	1	2	3	4	5	6	7	8	9	10
1	779	1322	1856	2388	2918	3447	3976	4504	5032	5559
2	499	.	1052	.	1589	.	2122	.	2653	.
3	402	593	.	961	1142	.	1500	1678	.	2034
4	354	.	640	.	916	.	1187	.	1456	.
5	323	441	556	668	.	888	997	1106	1214	.
6	320	.	.	.	687	.	870	.	.	.
7	288	374	459	539	620	700	.	858	935	1013
8	277	.	427	.	570	.	710	.	848	.
9	269	336	.	467	530	.	656	717	.	840
10	262	.	383	.	.	.	612	.	724	.
11	256	312	367	420	473	525	576	627	678	729
12	251	.	.	.	451	.	546	.	.	.
13	247	295	341	387	432	477	521	564	608	651
14	244	.	332	.	416	.	.	.	580	.
15	241	282	.	362	.	.	480	518	.	.
16	238	.	315	.	390	.	463	.	535	.
17	236	273	309	344	379	414	448	482	516	548
18	234	.	.	.	369	.	435	.	.	.
19	232	265	298	329	361	392	423	453	484	512
20	230	.	293	.	.	.	412	.	470	.

$72x + 72na + 4.5a = a\sqrt{1536ss - 67.5 + 1728nn}$, for the equation required, which differs from that found in the third problem, by the term 67.5, which there is 60.75.

Hence, if $n = .2$, and $ss = .5$; these values multiplied by their coefficients, gives 769.62, for the sum of the terms under the radical sign, whose square root is 27.742, from which subtracting the sum 18.9 of the two known terms, and the difference divided by 72; gives $x = .1228\,a$, which is less than that found in the third problem; but not so much as is worth taking notice of: since in a wall of 30 feet high, the difference is only .7 of an inch: consequently either of these counterforts may be used according to the builder's fancy.

Sometimes counterforts may be made with steps, which may be done by making them so as that the base and the area be the same, without changing its momentum.

Fig. 6. Sometimes the section of walls are made parallelograms without any counterforts, especially when they are low: such as ABCD: To find their thickness AD or BC; draw the diagonal AC, and through the middle L, and the point C, the lines LK, CE perpendicular to the base AD produced; and let $AD = x$, $DE = na$, and $CE = a$; then will ax express the area of the parallelogram DB; and since the point L is the center of gravity of the parallelogram, AK will be the distance of the line of direction from the point A; but because AL is half of AC, the distance AK, will be $\frac{1}{2}x + \frac{1}{2}na$, half the distance AE. Therefore the area ax multiplied by the distance AK, gives $\frac{1}{2}axx + \frac{1}{2}aanx$, for its momentum, and so equal to $\frac{4}{27}ssa^3$ that of the earth by the first problem; which being divided by $\frac{1}{2}a$, and $\frac{1}{4}nnaa$, added to both sides: the first will be a perfect square whose root is $18x + 9na = a\sqrt{96ss + 81nn}$, after having reduced the second side under the same denomination,

 and

and multiplied the root of the first by the root of the denominator 324, of the second.

If the first term $96\,ss$ under the radical sign be increased in the ratio of 4 to 5, we shall have $18\,x + 9\,na = a\sqrt{120\,ss + 81\,nn}$ in walls built with brick.

Hence if $n = .2$, and $ss = .5$; we shall get $x = .31a$ nearly in stone walls, and $x = .355\,a$, in brick walls.

Hence it may be easily known whether these kinds of walls require more masonry, than those in the first figure without counterforts: for we have found in the second problem, when n and ss expressed the same values as here, that $x = .2018\,a$, and therefore the area of that profil, will come out to be $.3018\,aa$; and the area of the parallelogram DB, is $.31\,aa$: therefore the difference $.0082\,aa$, shews that this last figure requires more than the former; tho' not much in low walls.

Before we conclude this section, we shall add one general problem more, in order to shew that it would have been easy to reduce almost every thing into a few problems, were it not necessary to menage the learners capacity, and to lead him gradually from the most simple and easy truths, to others more complex.

PROBLEM VII.

Let the profil of a stone wall be a parallelogram as DB, *and the counterforts a trapezium* DCFH, *whose outward slope* FH *being equal to* CD *that of the wall, to find the thickness of the wall when there is a parapet of earth above it.* Fig. 7.

If, for conveniency sake, CF be one tenth of the height CE; and the rest the same as before; then will $DH = 2\,na + \frac{1}{10}a$; which being added to CF, $\frac{1}{10}a$, and the sum multiplied by half the height CE, gives $naa + \frac{1}{10}aa$ for the area of the trapezium, which being multiplied by $AD + \frac{1}{2}DH$, that is $x +$

na

$na + \frac{1}{20}a$, and the product reduced in the ratio of 4 to unity, gives $\frac{1}{40}aax + \frac{1}{4}nna^3 + \frac{3}{80}na^3 + \frac{1}{800}a^3$ for its momentum; which being added to $\frac{1}{2}aax + \frac{1}{2}naax$ that of the wall found above, and the sum made equal to $\frac{2}{27}ss \times \overline{3abb - a^3}$ that of earth, found in the fifth problem; the whole being divided by $\frac{1}{2}a$, and $\frac{1}{16}nna - \frac{3}{80}naa - \frac{1.5}{800}aa$, added to both sides, the first will be a perfect square, and the second, being reduced under the same denomination, gives $36x + 27na + .9a = \sqrt{192ss \times \overline{3bb - aa} + 81nnaa - 48.6nna - 2.43aa}$, after having multiplied the first side by 36 the root of the common denominator 1296 of the second.

When the wall is made of brick, there need no more than to increase the coefficient 192, of the first term under the radical sign, in the ratio of 4 to 5, which gives 240 for that coefficient in this case; the other terms will remain the same as before.

When there is no parapet of earth above the wall, then will $b = a$; and the first term under the radical sign becomes $384ssaa$. and the rest will remain as before.

When $n = .2$, and $ss = .5$; then will $36x + 6.3a = \sqrt{288bb - 104.91aa}$, in stone walls: but if $n = \frac{1}{6}$, and $ss = .5$; then will $36x + 5.4a = \sqrt{288bb - 98.97aa}$.

And if $b = a$; that is, if there is no parapet of earth above the wall, we shall have $x = .202a$, in the first case, and $x = .232a$, in the second. But if the height of the wall is to that of the earth above it, as 4 to 3, then will $b = \frac{7}{4}a$; the square of which being substituted into the two equations, gives $882aa$, for the first term under the radical sign, and the square root being extracted, we shall find that $x = .6a$ nearly in the first case, and $x = .627a$, in the second.

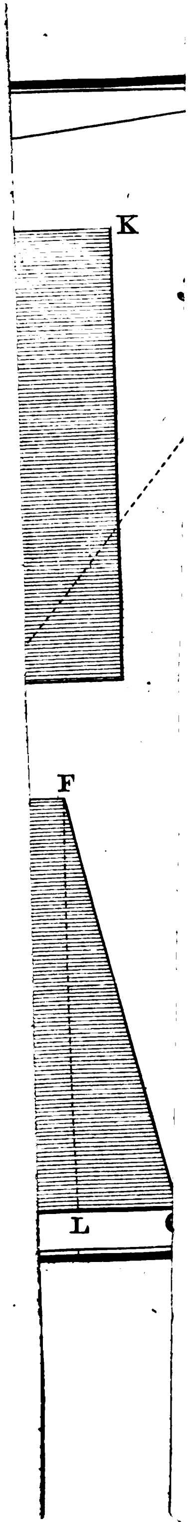
Hence it is very easy to compare the quantity of masonry, contained in walls, whose profil is a parallelogram as in this figure, and the counterforts a trapezium; and those whose profil is a trapezium, and the counterforts rectangles, as in the second profil: for the area of the profil in the second figure, with that of the counterfort reduced, is found to be .287 aa, when $n = \frac{1}{5}$, and 299 aa, when $n = \frac{1}{6}$.

And the aera of the profil and counterfort, according to the seventh figure, is found to be .277 aa when $n = \frac{1}{5}$; and .298 aa, when $n = \frac{1}{6}$.

Therefore the profil in the form of a parallelogram, requires less masonry than that whose figure is a trapezium; and the difference is greater when $n = \frac{1}{5}$, than when $n = \frac{1}{6}$; but when n is one seventh or eighth, the trapezium figure has the advantage, as will be found by computation.

Thus we have shewn how to find the thickness of walls, such as shall resist the pressure of the earth, of all the different profils, that may be used; and it will easily appear, that our method is both more general, and much easier than that given by other authors; the many general rules given here before, and their easy application to practice, are convincing proofs of it; besides no author has attempted before to give tables for ramparts with demi-revetements; though they are much more useful than any other, on account, that the most experienced engineers, scarcely build any others now-a-day, and that for very good reasons; because it saves great expences, besides they are not so easily destroyed by battering pieces, and, when a breach is made, are soon repaired.

It may perhaps be said, that we have reduced the counterforts to certain figures which are easily computed, and therefore our solutions are not so general as is pretended: But if the reader be pleased to consider that the length given here agrees very nearly with that given by Mr. *Vauban*, and the rectaugular form has been shewn to be more advantageous, than that of a trapezium, besides it is generally used here: As to those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those whose profil is a trapezium, such as in the fifth and sixth figures; regard has been had to such dimensions as are most useful in practice, and such as are of a due proportion in respect to the walls which they are to strengthen.

SECT. II.

The Theory of ARCHES.

IN fortresses it is absolutely necessary to build vaults and arches, such as over gate-ways, under-ground passages, from the body of the place to the ditch, powder-magazines, cazemats, and lodgings for the sick and wounded, and for those which are not on duty, to rest in with safety.

It is of no little importance, in the building of a fortress, to know exactly, and with certainty, what thickness piers that support arches of various magnitudes, require in different circumstances, so as to make the work durable, and to use no more materials than it requires. The making powder-magazines, so as to resist the shells thrown upon them in a siege, requires the utmost skill of an engineer, and has not hitherto been rightly determined by any body I know of. The engineers generally follow the dimensions of those constructed by Mr. *Vauban*, which indeed have so well succeeded, that it seems to be unnecessary to attempt any other rules to go by; were it not required, in many cases, to make arches of different width, figure, higher and lower; and therefore, it will be proper to lay down general rules, which shall answer all these various circumstances.

It is one of the most difficult problems in mechanics, to find the momentum or force with which different kinds of arches act against the piers that support them; and though many great mathematicians have endear-

voured

voured to solve it, especially the gentlemen of the royal Academy of Sciences at *Paris*, and Mr. *Belidor* in his book called *La science des Ingenieurs*; yet, if I am not mistaken, neither of them has succeeded; for whoever reads their performances will be more convinced of the difficulties that attend it, than of the truth of their solutions; and it is easily perceived that some of them are mistaken, and have perplexed themselves with tedious algebraic expressions, which when applied to easy practical cases are impossible, which shews that their computations are built upon erroneous principles.

It is true, Mr. *Belidor* has better succeeded in his principles than many others; yet his applications are not free from objections, as will appear hereafter, and which is the reason that the thickness of the piers he assigns are so much less than they should be.

It seems to be a difficult matter to determine this problem exactly, on account of the suppositions which are necessarily to be made in regard to the cement that is used in the joints, in order to keep the arch-stones together.

Those who go upon the refined supposition that the joints are quite smooth and polished, without any mortar, are greatly mistaken; for besides that no such thing subsists in practice, their solutions, when applied to practical examples, give nothing but impossibilities, as any one may be convinced who reads them with attention.

In the enusuing work, we shall suppose, with Mr. *Belidor*, that the arch-stones are laid in mortar, and so cemented together as to prevent their sliding upon one another; but not so hard as to compose as it were one solid stone, because this would be a plain contradiction, since it could not act upon the piers in an oblique manner; but the mortar being of such a consistence only, that if the piers were not sufficiently strong, the arch would break in the weakest part, and thereby overturn the piers. This supposition is the most natural that

that can be made, and has been found true in practice; for several arches have fallen down, for want of sufficient strength in the piers to resist their pressure; besides mortar requires some time to harden, which being once effected, no accidents happen afterwards.

PROBLEM I.

To find the pressure of an arch against the piers that support it. Plate II. Figure I.

Let AEFG be the section of half the arch, ABCD that of the pier which supports it; the point C taken near the foundation, may be considered as fixed, and about which the pier must turn to be overset; MN, one of the arch-stones; O the center where all the joints meet when produced; and lastly, let AS be the line which terminates the spring of the arch.

From the center of gravity X of the stone MN, draw the vertical XT, and the perpendicular XQ to the joint OM; and from any point *a* in XT, draw *ab* perpendicular to XQ and *bd* to XT: then the weight of the stone MN is to its effect in the direction *b*X as *a*X is to *b*X, and to that in the direction *ab*, as *a*X is to *ab*: as this last effect is destroyed by the friction of the stones together with the mortar, the first *b*X is only to be considered. But the force *b*X is equivalent to the forces *bd*, *d*X, the first perpendicular, and the second parallel to the direction CV in which the pier resists, by art 445 of our elem. and as this last is destroyed by the contrary action of the other half arch, the first *bd* is only to be considered.

If from the point fixed C, the line CQ be drawn perpendicular to the direction XQ, and XQ intersects CV in R; then as the angles CRQ, *b*X*d*, are equal, the right angled triangles CRQ, *b*X*d*, are

are similar; therefore $CR : CQ :: bX : bd$, or $CR \times bd = CQ \times bX$.

Since then the momentum (art. 422) $CQ \times bX$ of the force bX is equal to the product of the force bd, multiplied by the distance CR, and what has been proved of one arch-stone, is equally true of any other; by the property of the center of gravity (cart. 422) the momentum of half the arch against the pier, is equal to the product of its weight applied to its center of gravity, multiplied by the respective distance CR, from the point C to its direction XR.

If therefore, the point L be the center of gravity of AEFG half the arch, and LI, drawn perpendicular to OM, intersects OD in H and meets CV in I: the product of the sum of all the weights in the direction bd multiplied by the distance CI, will express the total momentum of the pressure of the arch against the pier.

COR. I.

Hence if LK be perpendicular to AO, and s denotes the sine of the angle LOK, r its cosine, the radius being unity; and if n expresses the weight of half the arch; the right angled similar triangles LKO, Xbd, give $1 : r :: aX : bX = rn$, and $1 : s :: bX : bd = rsn$: this value of bd, being wrote into $CR \times bd$, and CI for CR, gives $rsnx \times CI$ for the momentum of the pressure against the pier; and if W expresses the weight of the pier, we have $rsn \times CI = \frac{1}{2} BC \times W$, in a state of rest; by art. 427.

COR. II.

When the arch is semi-circular, then $r = s = \sqrt{\frac{1}{2}}$, and when it is elliptical or an arc of a circle, the height OE is seldom less than the two thirds of half the width AS; and in this case s is to r as 2 to 3, and the radius $\sqrt{4+9} = \sqrt{13}$; whence $rs = \frac{6}{13} =$

$\frac{1}{2}$ —

$\frac{1}{2} - \frac{1}{26}$; which differs so little from that in a semicircle; by supposing $r s = \frac{1}{2}$, the difference will scarcely be sensible inpractice: and if n expresses half the area A E F G; the equation in the last corollary, becomes $2 n \times CI = BC \times W$.

COR. III.

If the friction of the stones be considered, let q express the weight which would just move a stone lying upon another placed horizontally: then because that weight or force is to its effect in any other direction O M, as the radius is to the sine s of the angle L O K (art. 499,) that is, $s q$ will express that effect; and the radius is to the cosine r as the effect in the direction O M is to rsq the effect in the horizontal direction $b d$, which being subtracted from the force $r s n$ in that direction found above, gives $r s \times \overline{n - q} \times CI = \frac{1}{2} BC \times W$: or because it has been found by experiment, that a force equal to one third of the weight, will move a body in a horizontal direction upon a smooth plane: the force q will therefore at least be equal to one third of the weight n: hence $\frac{2}{3} r s n \times CI = \frac{1}{2} BC \times W$, or when $rs = \frac{1}{2}$, and n expresses one third of the area A E F G, we get $2 n \times CI = BC \times W$, as before.

REMARK I.

As the surfaces of the arch-stones are generally very rough, and besides the mortar renders them less liable to slide upon one another, than they would do without it; the momentum we have here given, is more than what arises barely from the weights of the arch stones; and even more than when the weight n is diminished by one third, on account of the friction as in the last corollary; but as arches under ground support a weight of earth, besides its own, and those above ground, ought

ought to resist the force of shells, we shall not diminish that momentum hereafter in our computation; leaving to the engineers to make it less whenever they shall think it necessary; which they may do, by supposing n to express any part of the area AEFG; in the following equations.

REMARK II.

As the angle AOL increases, so the perpendicular QC or the momentum of the arch increases, till that angle becomes a right one; then CQ becomes equal to the line CV, terminated by the horizontal line, passing through the middle of the upper joint EF; and therefore CV is the greatest distance CQ of all the CQ's; and when XQ passes through the point fix C; then CQ becomes nothing; and when the direction XQ passes between the points B, C, it becomes negative, and the greatest when equal to DG $+ \frac{1}{2}$ AG, and the part of the arch from the point where CQ $=$ o to the spring AD, instead of acting against the pier, add strength to it, but as the above property of the center of gravity is general, whether a part is negative or not; we have no occasion to consider the negative part separately.

PROBLEM II.

To find the thickness of the piers BC, *when the arch is terminated by two concentric circles described from center* O *placed in the line* AS, *which passes through the spring of the arch.*

Let the radius OA of the interior circle be a, that OG of the exterior b, the height of the pier AB $= c$, its thickness sought BC $= z$, and the perpendicular LK $= m$; then as the right angled triangles OHL, HDI, are isosceles, we have OH $= 2m$, DH or DI $= a + z - 2m$, and CI $= c - a - z + 2m$, or if $g = c + 2m - a$,

$-a$, $CI = g - z$; and as $W = cz$; these values wrote into $2n \times CI = BC \times W$. found in Cor. 2, give $2ng - 2nz = czz$ or $czz + 2nz = 2ng$, whose square root is $cz + n = \sqrt{2cng + nn}$.

By means of this equation the thickness of the pier may be found; but before it can be applied, the values of n and m must be determined. Let therefore unity be to r as the diameter to its circumference; then $\frac{1}{4}ra^2$, $\frac{1}{4}rb^2$, will express the areas of the quadrants by art. 175; and $4n = rbb - raa$. The semispheres described by these quadrants about the axis O A, are (art. 216) $\frac{2}{3}ra^3$, $\frac{2}{3}rb^3$ and their difference will be the solid described by the area of the arch about the same axis, which solid is also equal to the product of the generating plane n and the circumference $2rm$ described by the center of gravity L (art. 425). Hence $2rnm = \frac{2}{3}rb^3 - \frac{2}{3}ra^3$, or $3nm = b^3 - a^3$, when reduced; and this equation divided by $4n = rbb - raa$, gives $\frac{3}{4}rm = a + \frac{bb}{a+b}$.

EXAMPLE.

Let $a = 12$, $b = c = 15$; then because $r = 3.14159$, (art. 252) we get $n = \frac{1}{4}r \times \overline{bb - aa} = 63.6171$ or $\frac{1}{2}n = 31.808\frac{1}{2}$, $a + \frac{bb}{a+b} = 20\frac{1}{3}$, and hence $m = 8.629$, $g = c + 2m - a = 20.258$; which gives $2cg + n = 639.548$, this multiplied by $31.808\frac{1}{2}$, gives 20343.062558 for the sum of the terms under the radical sign, whose square root is 142.629; from which subtracting the known term 31.808 and dividing the difference by the coefficient (c) 15 gives $z = 7.388$, or B C equal to 7 feet and 4 inches.

If we take 21.2056, one third of the value n, on account of friction, then $2cg + n = 628.9456$, which multiplied by 21.2056, gives 13337.168815 for the sum of the terms under the radical sign, whose square root

root is 115.866; from which subtracting the known term 21.2056, and dividing the difference by the coefficient 15 gives $z = 6.285$, or B C equal to 6 feet 3 inches.

PROBLEM III.

To find the thickness B C *of the piers, when the outside* G F *is a right line perpendicular to the radius* O M *which bisects the quadrant* O A E. Fig. 2.

It is evident that the triangles O L D, H D I, are the same here as in the first figure, and therefore this problem differs from the former only in the values of n and m: whence if O M $= b$, and the rest as before; then because the right angled triangle G O F is isosceles, we have G F $= 2b$, and so bb expresses the area of that triangle, and as $\frac{1}{4} raa$ expresses the quadrant O A E, we have $n = bb - \frac{1}{4} raa$.

Because O F $= b\sqrt{2}$, the cone described by the triangle O F G, about the axis O F, will be expressed by $\frac{2}{3} rb^3 \sqrt{2}$, and the semi-sphere being $\frac{2}{3} ra^3$, by the last problem; and since unity is to $2r$, as the radius K L or O K (m) is to the circumference $2rm$ described by the center of gravity L in the rotation, we have $3nm = b^3\sqrt{2} - a^3$, by what has been said before, after multiplying by 3 and dividing by $2r$: consequently $g = c + 2m - a$, and $cz + n = \sqrt{2cgn + nn}$ as before.

EXAMPLE.

Let $a = 12{,}5$, $b = 15.5$, $c = 15$; then will $n = 117.5387$, $m = 9.3988$, $g = 21.2976$, and if we take 58.7694 half the value of n, we get $2cg + n = 697.6974$, which multiplied by 58.7694 gives 41003.257579, for the sum of the terms under the radical

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radical ſign, whoſe ſquare root is 202.492, from which taking the known term 58.769 and dividing the difference by the coefficient 15 gives $z = 9.58$, or B C equal to 9 feet 7 inches.

But if we take 39.1796, one third only, on account of the friction, we then get $2cg + n = 678.1076$; this multiplied by 39.1796, gives 26567.984525 for the ſum of the terms under the radical ſign, whoſe ſquare root is 162.996, from which taking the known term 39.179 and dividing the difference by the coefficient 15 gives $z = 8.254$, or B C equal to 8 feet 3 inches.

REMARK.

All arches require a certain thickneſs at the hanches M to ſupport their own weight, and in powder magazines, to reſiſt the ſhock of ſhells beſides, but how to determine it exactly is not eaſily done: It is true, that Mr. *Vauban*, makes it 3 feet in an arch of 25 feet wide, and as his powder magazines have been found ſtrong enough by all accounts; there is no reaſon to doubt, but that this thickneſs is ſufficient for arches of that width: And if we conſider that the force, which a timber ſcantling ſupports, is as the ſquare of its height divided by the leaver of the force applied; as will be ſhewn in the next ſection prob. I: Then as the height of the ſcantling, is repreſented here by the thickneſs of the arch and the leaver by the radius of the arch: the radius 15.5 feet is to any other radius as the ſquare 9 of the thickneſs 3, is to the ſquare of the thickneſs ſought. Hence this rule; *multiply the radius of any arch by 9, and divide the product by 12.5; then the ſquare root of the quotient will be the thickneſs of that arch.*

PROBLEM IV.

To find the thickness B C *of the piers when the inside is a right line parallel to the outside.*

The same thing being supposed as in the last, we shall have $n = bb - aa$, $3nm = \overline{b^3 - a^3} \times \sqrt{2}$ or $\frac{3m}{\sqrt{2}} = a + \frac{bb}{a+b}$, $g = c + 2m - a$, and $cz + n = \sqrt{2cgn + nn}$.

EXAMPLE.

Let $a = 12.5$, $b = 15$, $c = 15$; then, $n = 84$, $a + \frac{bb}{a+b} = 21.08$, or $m = 9.937$, $g = 22.374$, and $2cg + n = 713.22$, which multiplied by 42 half the value of n, gives 29955.24, for the sum of the terms under the radical sign, whose square root is 173.075, from which subtracting the known term 42, and dividing the difference by 15 gives $z = 8.738$, or B C = 8 feet 8.8 inches. This is less by about a foot than in the last example, the reason is that $n = 117$ is there, whereas it is but 84; therefore the pier has here less weight to support, than there.

PROBLEM V.

To find the thickness B C *of the piers when the arch is terminated by two circular arcs, described from the same center* O, *below the line* A S *which passes through the spring of the arch.* Fig. 3.

Let the chord A E be drawn; the radius A O produced so as to meet the arc G F in R, and the line O D

O D parallel to P A, meeting C I in D, and intersecting the direction L I in H; then if O A $= a$, O M $= b$, A P $= p$, P E $= d$, A E $= h$, and the arc A E $= v$.

This being supposed, we shall have $\frac{1}{2}av$ for the area of the sector O A E, and as the sectors O A E, O R F, are similar, they are as the squares of the radii; therefore $aa : bb :: \frac{1}{2}av : \frac{bbv}{2a} =$ to the sector O R E; and $2an = v \times \overline{bb - aa}$.

Now because the solids described by these sectors in the rotation of the figure about a line passing through the center O perpendicular to the radius O M, are the two thirds of the cylinders of the same bases, and whose altitudes are the chords of these arcs, by art. 217. of our Elem. Math. the bases being raa, rbb, and the altitudes, h, $\frac{bh}{a}$, these solids are $\frac{2}{3}raah$, $\frac{2r}{3a}bb^3$, and if O L $= m$, then will $3amn = h \times \overline{b^3 - a^3}$.

The right angled triangles O L H, H D I, are similar to the triangle A P E, and therefore P E (d) : A E (h) :: O L (m) : O H $= \frac{hm}{d}$, and so D H $= p + z - \frac{hm}{d}$; we have likewise A P (p) : P E (d) :: D H : D I $= d + \frac{dz}{p} - \frac{hm}{p}$; now because O P $= a - d$, by subtracting the sum of D I and O P $= a - d$, from the height of the pier c; we shall have C I $= c - a + \frac{hm}{p} - \frac{dz}{p}$; or if $g = c - a + \frac{hm}{p}$, it will be C I $= g - \frac{dz}{p}$, and consequently, $czz = 2ng - \frac{2ndz}{p}$, by cor. after prob. I. and if $dn = pq$; the square root of this equation will be $cz + q = \sqrt{2cng + qq}$.

Hence, if the height P E of the arch be the two thirds of A P; that is if $d = \frac{2}{3}p$; the right angled

 triangle

triangle A P E, gives $b = \frac{2}{3} p \sqrt{13}$, and the right angled triangle A P O, gives $12 a = 13 p$, because $PO = a - d$, $q = \frac{d}{p} n$, we get $PO = \frac{5}{13} a$, $q = \frac{2}{3} n$, and $g = c + \frac{1}{3} m \sqrt{13} - a$. But A O ($a$) is to P O ($\frac{5}{13} a$) as the radius 100000 is to 38461 the cosine of the angle A O P, and therefore this angle is 67 degrees and 23 minutes nearly or $67 \frac{23}{60}$ degrees. Now because ra expresses half the circumference of the radius a, we have 180 degrees is to $67 \frac{23}{60}$ degrees as ra is to $v = \frac{4043}{10800} ra$.

EXAMPLE.

Let $AP = p = 12$, $c = 15$, then will $a = 13$, $b = 16$; hence $b = 14.422$, $v = 15.2887$, $n = 51.1583$, $m = 13.727$, $q = 17.0527$, $g = 18.4975$; and $2 cng = 14194.5095$, $qq = 290.9753$: therefore 14485.4848 is the sum of the terms under the radical sign, whose square root is 120.355, from which subtracting the known term 17.053, and dividing the difference by the coefficient 15, gives $z = 6.886$ or B C equal to 6 feet 10 inches, which is less than $z = 7.388$ found in the second problem.

PROBLEM VI.

To find the thickness B C *of the piers when the outside* G F *is a right line parallel to the chord* A E, *and the rest being the same as before.* Fig. 4.

It is evident that this problem differs from the former, in the values of m and n only. Whence because of the right angled similar triangles A P E, O M F,

we

we have A P (p) : P E (d) : : O M (b) : M F $= \frac{bd}{p}$; and as M R is equal to M F, we have $\frac{bbd}{p}$ for the area of the triangle O R F, and since $\frac{1}{2}\, a\, v$ expresses the area of the sector O A E by the last problem, we have $2\, p\, n = 2\, d\, b\, b - a\, p\, v$.

Now because the solid described by the triangle O R F about an axis passing through the center O parallel to the chord A E, is the two thirds of the cylinder of the same base and altitude; the base being $r\, b\, b$, and the altitude R F, $\frac{2\, b\, d}{p}$, this solid will be $\frac{4\, r}{3\, p}\, d\, b^3$; and as the solid described by the sector O A E, in that rotation, is $\frac{2}{3}\, r\, a\, a\, b$; we get $3\, m\, n\, p = 2\, d b^3 - a\, a\, b\, p$; after having multiplied both sides by $3\, p$ and divided by $2\, r$.

Therefore $g = c - a + \frac{b\, m}{p}$ and $c\, z + q = \sqrt{2\, c\, n\, g + q\, q}$, by the last: supposing $d\, n = p\, q$. If the center O be supposed to coincide with the point P; then a, p, and d, are equal, and the equations in the two last problems, will then become the very same as those in problems the second and third, with this reserve, that O L is here called m, and L K in the first and second figure.

If P E be again the two thirds of A P; we shall find the same values as in the last; that is, $d = \frac{2}{3}\, p$, $q = \frac{2}{3}\, n$, $12\, a = 13\, p$, $b = \frac{1}{3}\, p \sqrt{13}$, $g = c + \frac{1}{3}\, m \sqrt{13} - a$, and $v = \frac{4043}{10500}\, r q$.

EXAMPLE.

Let $p = 12$, $c = 15$; then $a = 13$, $b = 16$, $v = 15.288$, $n = 71.289$, $m = 14.139$; and if we

 take

take half the value of n, we get $q = 23.763$, $2cng = 20312.0183$, $qq = 564.6802$, and 20876.6985, will be the sum of the terms under the radical sign; whose square root is 144.487, from which subtracting the known term 23.763, and dividing the difference by the coefficient 15, gives $z = 8.04$, which is less than $z = 8.254$, found in the third problem.

N. B. We have neglected the small space AGR, in the two last figures, as being but inconsiderable, and would have rendered the operations very tedious; besides in practice a geometrical exactness is impossible and not necessary; especially when the departing from it renders the operations more easy and simple, as it happens here in this case.

PROBLEM VII.

To find the thickness BC *of the piers, when the arch is terminated by two circular arcs described from the center* O, *placed in the line* AS, *which passes through the spring of the arch.* Fig. 5.

It is evident that the values of m and n are here the same as in the fifth problem, since we have the same sectors and triangles here as in the third figure; therefore $2na = vv \times \overline{bb - aa}$, and $\frac{3vm}{2b} = a + \frac{bb}{a+b}$.

Now because of the similar triangles PEA, OLH, we have PE (d) : AE (b) : : OL (m) : OH $= \frac{bm}{d}$, and so $a + z - \frac{bm}{d} =$ DH; and the similar trangles APE, DHI, give AP (p) : PE (d) : : DH : DI $= \frac{da}{p} + \frac{dz}{p} - \frac{bm}{p}$; whence CI $= c - \frac{da}{p} - \frac{dz}{p} +$

bm

$\frac{bm}{p}$, or if $g = c - \frac{da}{p} + \frac{bm}{p}$; then will $CI = g - \frac{dz}{p}$; consequently, $czz = 2ng - \frac{2dnz}{p}$; by corol. after the first problem; and if $dn = pq$; the square root of this equation will be $cz + q = \sqrt{2cng + qq}$.

If O P is one fourth of the radius O A; that is, if the radius is the two thirds of the span of the arch, then will $AP = p = \frac{3}{4}a$; and the right angled triangle O P E, gives $PE = d = \frac{1}{4}a\sqrt{15}$, and the right angled triangle A P E, gives $AE = b = \frac{1}{2}a\sqrt{6}$. But O E ($a$) is to P O ($\frac{1}{4}a$) as the radius 100000 is to the cosine 25000 of the A O E, which is found to be 75 degrees and 32 minutes, or $75.5\frac{1}{3}$ degrees.

And since unity is to 3.14159, as the radius a is to the semi-circumference $3.14159a$; and 180 degrees is to $75.5\frac{1}{3}$ as the semi-circumference $3.14159a$, is to the arc $v = 1.32a$ nearly.

EXAMPLE.

Let $AP = 12$, $c = 15$; then will $a = 16$, $b = 19$; hence $n = 69.3$, $m = 16.2645$, $g = 20.8985$; and if we take half the value of n, we get $q = 44.733$, $2cng = 21723.9907$, $qq = 2001.0413$, and the sum of the terms under the radical sign will be, 23725.032; whose square root is 154.028; from which subtracting the known term 44.733, and dividing the difference by the coefficient 15, gives $z = 7.2$, which is less than $z = 7.388$, found after prob. II.

PROBLEM VIII.

To find the thickness B C *of the piers, when the outside is a right line parallel to the chord* A E, *of the inside arc.* Fig. 6.

By the similarity of the triangles O M G, A P E, we have P E (d) : A P (p) : : O M (b) : G M $= \frac{bp}{d}$; and since G M and M R are equal, we get $\frac{bbp}{d}$ for the area of the triangle O G R, and as the area of the sector O A E is $\frac{1}{2} av$, we have $2nd = 2bbp - adv$: But the solid described by the triangle O G R, about an axis passing through the center O parallel to A E, is $\frac{4rp}{3d} b^3$; and that of the sector O A E described in that rotation $\frac{2}{3} raab$; therefore $3dmn = 2pb^3 - aadb$, by what has been said before. And because there are the same triangles here as in the last figure; we have $g = c - \frac{da}{p} + \frac{bm}{p}$, $dn = pq$, and $cz + q = \sqrt{2cng + qq}$ as before.

If we suppose again that O P is the three fourth of the radius O A; then will the values of p, d, b be the same as before.

EXAMPLE.

Let as in the last be $p = \frac{3}{4}a$, $a = 16$, $b = 19$, $c = 15$; then will $d = \frac{1}{4} a\sqrt{15}$, $b = \frac{1}{2} a\sqrt{6}$, and $n = 110.74$, $v = 1.32\,a$, $m = 16.895$, $g = 21.933$, and if we take half the value of n, we get $q = 71.796$, $qq = 5154.6656$, $2ncg = 36432.9063$: therefore the sum of the terms under the radical sign is 41587.5719; whose square root is 203.93; from which

which subtracting the known term 71.796 and dividing the difference by the coefficient 15 gives, $z = .8.8$.

N. B. We have neglected the space E R F, in the two last figures, which could not be considered without rendering the operations very tedious and perplexed, and as in practice a scrupulous nicety becomes more troublesome than useful, we aim more at simplicity than a too great mathematical strictness wherever practice is concerned.

LEMMA I.

The diameter O L, *which bisects the chord* A E, *joining the extremities of the two semi-axes* A Q, *and* O E, *of an ellipsis, bisects the area of the quadrant* A L E O. Plate III. Fig. 7.

For the diameter O L bisects all its ordinates which are parallel to that chord, as well as all the lines drawn in the triangle A O E parallel to the base A E; consequently, the diameter L O bisects the area A L E O of the quadrant.

COR. I.

Hence, because the tangent L H, is parallel to the ordinate A E of the diameter O L, by the nature of the ellipsis, and this diameter bisects A E in *m*, and since A O E is a right angle; A *m*, *m* O, *m* E, are equal; therefore the triangle O *m* A, is isosceles, and being similar to the triangle O L H, this triangle is likewise isosceles; consequently, O K = K H, and O L = L H.

COR.

COR II.

Hence the triangles A O E, O L K, are similar; for the triangles O K L, H K L, having all their sides equal, are equal in all respects: and since the triangle H K L is similar to the triangle AOE, its equal OKL will be so too.

COR. III.

Because O K : O A : : O A : O H, or 2 O K, by the last corollary; whence O A $= OK\sqrt{2}$; and by the similarity of the triangles A O E, O K L; we have O A : A E : : O K : O L, and since O A $= OK\sqrt{2}$; we have A E $= OL\sqrt{2}$ by equality of ratio's.

PROBLEM IX.

To find the thickness B C *of the piers, when* G F, A E, *are two similar elliptical quadrants, described from the same center* O, *and the joints are perpendicular to the tangent in that point.* Fig. 8.

If O A $= a$, O G $= b$, O E $= d$, and the rest as before; then will O F $= \frac{bd}{a}$, by supposition, whence since the circular quadrant described with the radius O G, b, will be $\frac{1}{4}rbb$, and is to the elliptical quadrant O G F, as O G (b) to O F ($\frac{bd}{a}$) and therefore this elliptic quadrant will be $\frac{rbbd}{a}$; and the quadrant OAE, will be $\frac{1}{4}rad$ by the same reason; therefore $4ax = rd \times \overline{bb - aa}$, after having multiplied by $4a$.

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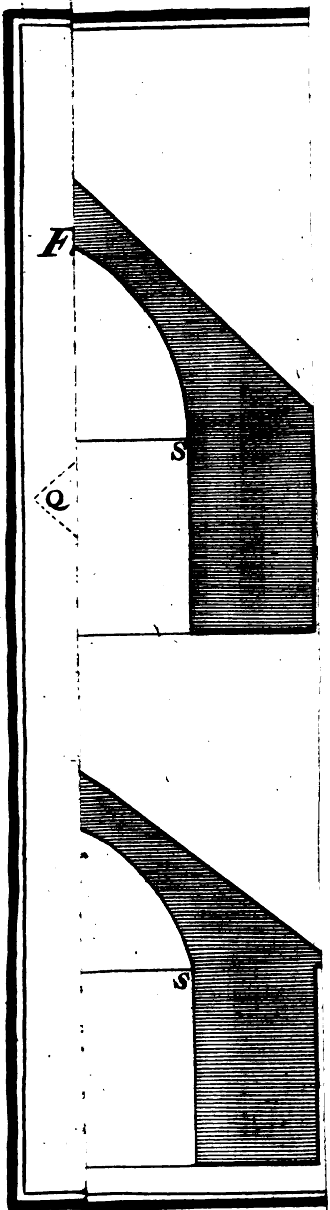
Now


F
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Now because raa, rbb, express the areas of circles described by the radii O A, O G, in the rotation of the figure about the axis O F, and since the solids described by the elliptical quadrants in this rotation are the two thirds of the cylinders of the same base and altitudes, these solids will be $\frac{2}{3}raad$, $\frac{2r}{3a}db^3$, and their difference equal to $2rm$ by art. 425. supposing OK $= m$; which gives $3amn = d \times \overline{b^3 - a^3}$, after having multiplied by $3a$. The first side of this equality being divided by $4an$, and the second by its equal, gives $\frac{3}{4}rm = a + \frac{bb}{a+b}$.

If we imagine a quadrant of an ellipsis to be described through the center of gravity L, similar to the former; then the direction L H, will be a tangent to the ellipsis, and therefore perpendicular to the joint passing through that point; and O K $=$ K H, by cor. I, or O H $= 2m$; hence D H $= a + z - 2m$; and by the similarity of the triangles A O E, H D I, we have A O (a) : O E (d) : : D H : D I $= d + \frac{dz}{a} - \frac{2md}{a}$, and so C I $= c - d + \frac{2md}{a} - \frac{dz}{a}$; or if $g = c - d + \frac{2dm}{a}$; we have $czz = 2ng - \frac{2ndz}{a}$, by cor. after prob. I. and if $aq = nd$, the square root of this equation is $cz + q = \sqrt{2cng + qq}$.

EXAMPLE.

Let $a = 12$, $b = c = 15$, $d = 9$; then as $r = 3.142$ nearly, we get $n = 47.72$, $m = 8.629$, $g = 18.943$, and taking the two thirds of the area 47.72 for the value of n, we shall have $q = 23.86$ and 18648.4988 for the sum of the terms under the radical sign, whose square root is 136.559, from which subtracting

subtracting the known term 23,86, and dividing the difference by 15, we shall have $x = 7,513$, or B C equal to 7 feet 6 inches.

PROBLEM X.

To find the thickness B C *of the piers, when the outside is a right line* G F, *parallel to the chord* A E *which subtends the elliptical quadrant,* Fig. 9.

If A O $= a$, O E $= d$, O M $= b$, O m or A $m = b$, and the rest as before; then by the parallel lines A E, G F; we have O m (b) : O E (d) : : O M (b) : O F $= \frac{bd}{b}$; and O m (b) : O A (a) : : O M (b) : O G $= \frac{ab}{b}$; whence $\frac{abbd}{2bb}$ will express the area of the triangle G O F, and since $\frac{1}{4} rad$ expresses the area of the elliptical quadrant, we have $4bbn = ad \times \overline{2bb - rbb}$ after having multiplied by $4bb$.

Now because raa, $\frac{raabb}{bb}$, express the circles described by the radii, O A, O G, in the rotation of the figure about the axis O F; we have $\frac{2}{3} raad$, $\frac{raadb^3}{3b^3}$ for the solids described by the quadrant OAE, and the triangle GOF, in that rotation; therefore their difference is equal to $2rmn$ by what has been said before which gives $6mnb^3 = aad \times \overline{b^3 - 2b^3}$.

As the rest of the figure is the same as before, we have $g = c - d + \frac{2md}{a}$, $aq = nd$, and $z + q = \sqrt{2cng + qq}$, as above.

EXAM-

EXAMPLE.

Let $a = 12$, $d = 9$, $c = 15$; then will $b = 7.5$ and the diameter On = AE $\sqrt{2}$ by cor. 3. will be 10.6, and if we allow 3 feet for the thickness Mn of the arch: we have $b = 13.6$, whence $n = 92,72$, $m = 9,23$, $g = 19.845$; and if we take 61.812 the two thirds of the area 92.72 for the value of n, we get $q = 46,36$, and 38949.0238 for the sum of the terms under the radical sign, whose square root is 197,355, from which subtracting the known term 46.36, and dividing the difference by 15, gives $z = 10.066$, nearly; which is 5 inches more than when the inside is circular, this arises from the difference between the weights of the arches; for we found 112 feet in problem 3, and here only 92.72, so that either of these arches may be used as occasion shall require.

But if $c = 9$, and the rest as before; then will $z = 9.57$, which is very little less than what has been found in the third problem.

When both sides of the arch are terminated by ellipsis, its piers require less masonry, than when it is terminated by circles; for we found in the second problem 7 feet 4 inches, and in the ninth 7 feet 6 inches, and therefore the difference is 2 inches: notwithstanding Mr. *Belidor* found the contrary, and from thence concludes that the elliptic arch has a greater pressure than the circular one: this would be true if the weights of the arches were equal; but we have found the area in the circular one to be 63.62 feet, and 47.72 feet in the ellipsis; and therefore the weight of the circular arch is to the weight of the elliptic arch, as 133 is to 100 nearly. So that the weight of the first is about one third more than in the second.

PRO-

PROBLEM XI.

To find the thickness B C *of the piers when there are counterforts* V D; *the inside of the arch being circular and the outside a right line.* Fig. 10.

Let C V = b, be the length of the counterforts, which have the same height as the piers, and the interval from the one to the other, is to their thickness as two to one.

It is plain that the point C is no more that about which the piers must turn in order to be overset, but it is the point V or extremity of the counterforts: so that the distance V I of the direction L I, must here be found on the line V R.

If we retain the same values as before, we get $n = bb - \frac{1}{4} raa$, $3nm = b^3\sqrt{2} - a^3$ and O H = $2m$, by the third problem: whence R H $= a + b + z - 2m$, and V I $= c - a - b + 2m - z$, or if $g = c - a - b + 2m$; then will V I $= g - z$; therefore $2ng - 2nz$ will be double the momentum of the arch.

And since cz expresses the area of the pier C A, and $b + \frac{1}{2}z$, the distance of its center of gravity from the line R V, we have $cbz + \frac{1}{2}czz$ for its momentum; and the area cb of the counterforts multiplied by $\frac{1}{2}b$, gives $\frac{1}{2}cbb$ for its momentum, which being reduced in the ratio of 3 to unity, gives $\frac{1}{6}cbb$; therefore twice the sum of these last momentums, must be equal to that above, by cor. after prob. 1, that is $czz + 2cbz + \frac{1}{3}cbb = 2ng - 2nz$; and if $q = n + cb$; the square root of this equation will be $cz + q = \sqrt{2cng - \frac{1}{3}ccbb + qq}$.

EX-

EXAMPLE.

Let $a = 12$, $b = 15$, $c = 9$, $h = 4$; then will $n = 112$, $m = 9.072$, $g = 11.144$, and $q = 148$; hence 43938.304 will be the sum of the terms under the radical sign, whose square root is 209.614; from which subtracting the known term 148, and dividing the difference by 9, gives $z = 6.846$ feet nearly, or B C equal to 6 feet 10 inches, which is 14 inches only less, than what Mr. *Vauban* has given to his piers, the counterforts being the same.

If we suppose $c = 15$, and $h = 5$; the rest being the same as before, we shall have $n = 112$, $m = 9.072$ as before, and $g = 16.144$, $q = 187$; whence the sum of the terms under the radical sign is 87337.84, whose square root is 295.529, from which subtracting the known term 187, and dividing the difference by 15, gives $z = 7.235$ nearly, or B C equal to 7 feet 3 inches nearly, whereas Mr. *Belidor* finds but 3 feet one inch for the same thickness; which methinks might have given him reason to suspect his theory, as differing so widely from Mr. *Vauban's* practice, although the latter did not deduce his rules from any theory, yet his great practice made him arrive generally pretty near the truth.

If we suppose the height of the piers c to be 9 feet, and the length h, 3 feet only, we shall find $z = 7.746$ or B C equal to 7 feet 9 inches nearly, which differs from the thickness given by Mr. *Vauban*, by 3 inches only; so that, according to this theory, he made the length of his counterforts one foot more than is required.

Having considered that most practitioners are unacquainted with algebra, and being willing to render this book useful to every person employed in these works, we imagined that a table containing the dimensions of the piers of different width of arches would be acceptable to many of my readers, for which reason we have inserted the following one.

A

A Table containing the thickneſs of the piers of Powder Magazines.

	10	12	14	16	18	20	22	24	26	28	30	32	34	36
9	3.686	4.239	4.750	5.224	5.606	6.082	6.472	6.844	6.969	7.545	7.855	8.165	8.465	8.754
10	3.768	4.347	4.885	5.386	5.855	6.297	6.740	7.106	7.483	7.841	8.180	8.510	8.821	9.164
11	3.838	4.440	5.00	5.533	6.021	6.486	6.935	7.343	7.741	8.120	8.184	8.834	9.171	9.494
12	3.899	4.529	5.105	5.649	6.168	6.657	7.118	7.554	7.974	8.375	8.757	9.125	9.479	9.822
13	3.950	4.592	5.179	5.763	6.298	6.809	7.292	7.747	8.185	8.604	9.006	9.392	9.765	10.123
14	3.990	4.653	5.267	5.861	6.415	6.939	7.445	7.922	8.371	8.814	9.230	9.638	10.027	10.402
15	4.039	4.711	5.348	5.949	6.521	7.053	7.585	8.079	8.553	9.006	9.456	9.861	10.270	10.661
16	4.076	4.761	5.411	6.031	6.616	7.180	7.715	8.223	8.714	9.185	9.636	10.073	10.493	10.894
17	4.109	4.806	5.469	6.106	6.703	7.278	7.832	8.349	8.869	9.348	9.816	10.268	10.712	11.125
18	4.138	4.847	5.522	6.167	6.783	7.373	7.948	8.479	8.998	9.499	9.982	10.443	10.868	11.333
19	4.172	4.884	5.563	6.227	6.859	7.457	8.038	8.590	9.125	9.637	10.136	10.612	11.080	11.528
20	4.257	4.917	5.614	6.282	6.921	7.537	8.129	8.694	9.242	9.769	10.279	10.772	11.218	11.710

The

The first line 10, 12, 14, &c. expresses the width of the arches in feet; the rest of the lines, the thicknesses of the piers in feet and decimals, answering to their heights marked in feet in the first column 9, 10, 11, 12, &c. respectively from 9 to 20 feet.

It may be observed that the length of the counterforts, have here been made one sixth part of the opening of the arch, or $3b$ is always equal to the radius a: which proportion we found to be most agreeable in regard to the thickness of the piers; for by making the counterforts longer, the piers of small arches would become so thin, and the materials would thereby not join so well, which ought to be avoided.

Those who are not versed in Algebra, may depend on the dimensions here given, and that the arches will be good and lasting, provided the work is well executed, and the materials good; it is however adviseable to leave the centers standing at least for six months, in order to give time to the masonry to settle and harden; which being done, the work will not fail afterwards.

PROBLEM XII.

To find the thickness of the piers, having counterforts when the inside is an ellipsis. Fig. 10.

Because we have $6mnb^3 = aad \times \overline{b^3 - 2b^3}$ and $4bbn = ad \times \overline{2bb - rbb}$ by problem X; and $RH = a + l + z - 2m$, by the last problem, supposing $CV = l$, and by the similarity of the triangles OAE, RHI, we have $AO\ (a) : OE\ (d) :: RH : RI = d + \frac{dl}{a} + \frac{dz}{a} - \frac{2dm}{a}$. Hence $VI = c - d - \frac{dl}{a} - \frac{dz}{a} + \frac{2dm}{a}$; or if $g = c - d - \frac{dl}{a} +$

E $\qquad$ $2dm$

$\frac{2dm}{a}$; we get $VI = g - \frac{dz}{a}$, and therefore $2gn - \frac{2ndz}{a}$, will be double the momentum of the arch, which therefore is equal to double the momentum of the pier and counterfort, found in the last problem; that is, $czz + 2clz + \frac{1}{3}cll = 2gn - \frac{2ndz}{a}$; and if $q = cl + \frac{nd}{a}$ the square root of this equation will be $cz + q = \sqrt{2cng - \frac{1}{3}cccl + qq}$.

EXAMPLE.

Let $a = 12$, $d = c = 9$, $l = 4$; then will $n = 92.72$, $m = 9.23$ by problem X. whence $g = 10.845$, and $q = 105.54$; these values being substituted into the equation above, gives 28806.5628 for the sum of the terms under the radical sign, whose square root is 169.72, from which subtracting the known term 105.54, and dividing the difference by 9, gives $z = 7.13$ feet.

This thickness of the piers exceeds that, when the arch is circular by 3 inches only; but as the quantity of masonry in the circular arch is to the quantity in the elliptic arch, as 112 to 92.72; or as 7 to 5.8 nearly; it is evident that the elliptic arch and piers together requires less masonry than the circular arch and its piers.

Since then the elliptic arch is rather stronger at its hanches than the circular one, and the middle or its weakest part, sufficiently covered by masonry; and as it is lower, and therefore better covered from the sight of an enemy, it cannot be so easily destroyed; it is evident, that it may be used as well, and often with greater advantage, than the circular one.

PRO-

PROBLEM XIII.

To find the thickness of the piers of a circular arch when there is a wall AEFG *above the piers as it happens over the gates of a fortress.* Fig. 11.

The same thing being supposed as in the second problem, and calling the thickness AE of the wall d, its height EF, b; then will $d b$ express the area of the wall, which being multiplied by $z - \frac{1}{2} d$, gives $d b z - \frac{1}{2} d d b$ for its momentum, and as that of the pier is $\frac{1}{2} c z z$, that of the arch $n g - n z$, by the second problem, and therefore $c z z + 2 d b z - d d b = 2 n g - 2 n z$; and if $q = n + d b$; we shall have $c z + q = \sqrt{2 c n g + c d d b + q q}$.

N. B. It must be observed that $4 n = r b b - r a a$, $\frac{3}{4} r m = a + \frac{b b}{a + b}$, and $g = c - a + 2 m$ by the second problem.

EXAMPLE.

Let $a = 5$, $b = 7$, $c = 10$, $d = 2$, $b = 20$; then will $n = 18.852$, $m = 3.854$, $g = 12.708$, $q = 58.852$; and performing the operations indicated by the equation we shall find z, or the thickness BC of the piers to be 3 feet 3 inches nearly.

PROBLEM XIV.

To find the thickness of the piers when the arch is elliptical, the rest being the same as before. Fig. 11.

If the height within of the arch be called s; then will $4 a n = r s \times \overline{b b - a a}$, $\frac{3}{4} r m = a + \frac{b b}{a + b}$, $g =$

$c - s + \frac{2ms}{a}$, by the ninth problem; and $2ng - 2nz$ will be double the momentum of the arch, which being made equal to double the sum of the momentums of the pier and the wall, found in the last problem, gives $czz + 2dbz - ddb = 2ng - 2nz$, or $cz + q = \sqrt{2cng + cdd + qq}$ by supposing $q = n + db$.

EXAMPLE.

Let $a = 5$, $b = 7$, $c = 10$, $d = 2$, $h = 20$, as before, and the height $s = 4$; then will $n = 15.08$, $m = 3.854$, $g = 12.166$, $q = 55.08$; and performing the operations indicated by the equation, we get $z = 3.154$, which being something less than the former, shews that either of these figures may be used, according as it is judged convenient.

PROBLEM. XV.

To find the thickness of the piers of a circular arch, when they have a given slope C D *on the outside.* Fig. 12.

From the point C draw C E, and D F parallel to A B, and let the direction L H meet C E in I; then if B F $= z$, F C $= b$, and the rest as before, the rectangle cz multiplied by $\frac{1}{2}z + b$, gives $\frac{1}{2}czz + cbz$ for the momentum of the part F A of the pier, and $\frac{1}{3}bbc$ will be the momentum of the part C F D, therefore $czz + 2cbz + \frac{2}{3}cbb = 2ng - 2nz$ by the second problem; and if $q = cb + n$, the square root of this equation will be $cz + q = \sqrt{2cng - \frac{2}{3}ccbb + qq}$.

The values of m and n are the same as in the fifteenth problem, and $g = c - a = b + 2m$.

EXAMPLE.

Let $a = 5$, $b = 7$, $c = 10$, $h = 2$; then will $n = 18.852$, $m = 3.854$ as before, and $g = 10.708$, $q = 38.852$ whence the sum of the terms under the radical sign is 5279.5719, whose square root is 72.66, from which subtracting the known term 38.852, and dividing the difference by 10, we get $z = 3.38$ nearly, and B C equal to 5.38 feet.

PROBLEM XVI.

The same thing being supposed to find the thickness of the piers, when the arch is elliptical.

The same denomination being supposed as in the fourteenth problem; then the values of m and n are the same here as there; and $g = c - s - \frac{sh}{a} + \frac{2sm}{a}$; therefore, if $q = \frac{sn}{a} + ch$, the rest will be the same as in the last problem, that is $cz + q = \sqrt{2cng - \frac{2}{3}cchh + qq}$.

EXAMPLE.

Let $a = 5$, $b = 7$, $c = 10$, $s = 4$, $h = 2$; then will $n = 15.08$, $m = 3.854$, $g = 10.566$, $q = 32.064$; and performing the operations indicated by the equation, we shall have $z = 2.86$; and therefore B C will be 4.86 feet.

PROBLEM XVII.

Suppose a wall KOLM *to be continued above the arch with a slope on the outside; to find the thickness* KP *or* LM, *the base* PO *of the slope being given.* Fig. 13.

Let $PO = d$, $PL = h$; $KP = z$; and the rest as before; then zh multiplied by $\frac{1}{2}z + d$, gives $\frac{1}{2}hzz + dhz$ for the momentum of the part PM of the pier, and $\frac{1}{2}dh$ multiplied by $\frac{2}{3}d$, gives $\frac{1}{3}ddh$ for the momentum of the other part OPL; the rest being the same as in the fifteenth problem, and therefore $hzz + 2dhz + \frac{2}{3}ddh = 2ng - 2nz$; and if $q = n + dh$ the square root of this equation will be $hz + q = \sqrt{2nhg - \frac{2}{3}ddhh + qq}$.

EXAMPLE.

Let $a = 6$, $b = 8$, $c = 10$; $h = 16$, $d = 3$; then will $n = 22$ nearly, $m = 4.486$, $g = c - a - d + 2m = 9.972$, $q = 70$; and finishing the rest of the operations indicated by the problem, we shall have $z = 2$ feet nearly; and therefore KO, is 4 feet.

Arches, as these are useful in building galleries behind the counterscarps of ditches, such as are made at *Bergen-op-zoom*, but when they are made pretty large, they become too high; for which reason I would choose to make them elliptical; and as we have all along found that their pressure is rather less than that of the circular ones, on account of their having less weight; the same computations we made in regard to circular arches, will equally hold good in the elliptical ones.

PRO-

PROBLEM XVIII.

To find the thickness BF *or* AD, *when there is a pressure of earth against the outside slope* CD. Fig. 12.

We have shewn in the first section of this work, that the pressure of earth when compared to brick walls, was equivalent to $\frac{2}{27}$ parts of the cube of its height; and as these walls are commonly made of bricks, we have no more to do, than to add $\frac{2}{27}c^3$, to the momentum of the pier found in the seventeenth problem, in order to have the equation $cz+q=\sqrt{2cng-\frac{2}{3}ccbb+qq-\frac{2}{27}c^4}$, for this case.

EXAMPLE.

Let $a=5$, $b=7$, $c=10$, $h=2$; then will $n=18.85$, $m=3.854$, $g=10.708$, as before in the fifteenth problem, and $q=38.85$; these values being substituted into the equation, and the operations performed as indicated by the equation, gives $z=2$ feet nearly, and therefore BC is 4 feet.

PROBLEM XIX.

To find the thickness of the piers with counterforts, when there are two circular arches below, and a small one above, Plate IV. Fig. 14.

The same denomination being supposed as in the eleventh problem, in regard to the lower arch, and let the same lines be drawn in the upper one; then if $oa=s$, OQ or $ro=f$, Qo or O$r=x$; u half the area of the small arch, $ob=2p$; then will $u=.777ss$ and $p=.756s$, by the eleventh problem: whence rb or $ri=f-2p$; Oi or OH $=x-f+2p$; RH *or*, $RI = a + b + z - x + f - 2p$; and $VI = c - a - b - z + x - f + 2p$; or if $y = c + x + 2p - a - b - f$; then will $VI = y - z$, which being multiplied by $2u$, gives $2uy - 2uz$ for double the momentum of the upper arch; this added to $2ng - 2nz$ double the momentum of the lower arch, and the sum made equal to double the momentum of the pier and counterfort found in the before-mentioned problem, gives $czz + 2cbz + \frac{1}{3}cbb = 2ng + 2uy - 2nz - 2uz$; whence if $q = cb + n + u$, the square root of this equation will be $cz + q = \sqrt{2cng + 2cuy - \frac{1}{3}ccbb + qq}$.

EXAMPLE.

Let $a = 12$, $c = s = 8$; then if $OQ = f = 14\frac{1}{3}$; that is the lower arch, being three layers of brick thick; and the height $Po = 5\frac{2}{3}$; then will $Qo = x = 20$; $u = 49.728$, $p = 6.048$, $y = 9.763$, and $n = 112$, $m = 9.072$, $g = 10.144$, by the eleventh problem; hence we get $q = 197.728$, and 64700.98 for the sum of the terms under the radical sign, whose square root is 254.363; from which substracting the known term 197.728, and dividing the difference by the coefficient, gives $z = 7.08$ nearly.

N. B. We have supposed the trilinear space S between the lower and upper arch to be empty; that is without masonry, besides a small space between the roof and the pier of the upper arch has been neglected; but as it hardly can make any sensible difference in the thickness of the piers, the reader may depend on that found here to be sufficiently exact for practice.

PRO-

PROBLEM XX.

To find the thickness of the piers with counterforts, when there are two small arches below, and a great one above. Fig. 15.

Let $ao = s$; the height Vr of the lower piers, x; $u = .777ss$; $p = .756s$; then will $ob = 2p$, by the eleventh problem; and as $or = s + b + z$, we get rb or $ri = s + b + z - 2p$, and $Vi = x - s - b - z + 2p$; or if $y = x + 2p - s - b$; then will $Vi = y - z$, therefore $2uy - 2uz$, will be twice the momentum of the lower arch.

Now if we suppose the same values as in the eleventh problem, for the upper arch; that is $n = .777aa$, $m = .756a$, $g = c + 2m - a - b$; then will $2ng - 2nz$ be twice the momentum of the great arch; and therefore $czz + 2cbz + \frac{1}{3}cbb = 2ng + 2uy - 2nz - 2uy$; whence if $q = cb + n + u$; the square root of this equation will be $cz + q = \sqrt{2cng + 2cuy - \frac{1}{3}ccbb + qq}$.

EXAMPLE.

Let $a = 15$, $c = 26$, $x = s = 9$, $b = 4$; then will $u = 27.972$, $p = 4.536$, $y = 5.072$, $n = 174.825$, $m = 11.34$; and $g = 29.38$, $q = 306.797$; now the operations indicated by the equation being performed, we shall have $z = 11.54$ feet.

Either of these two last problems may serve to construct large powder magazines in the inland part of the country, where no enemy can come near them; for in fortified places, engineers choose to make several small ones, so that if any one be destroyed by the enemy, the powder might not all be lost, which would prove the loss of the place at the same time.

If

If the arches were made elliptical instead of circular, they need not be so high, and a great deal of masonry might be saved, as has been shewn in the twelfth problem.

PROBLEM XXI.

Let either the exterior or interior curve of an arch be given to find the other such, that all the arch-stones shall be in equilibrio with each other. Fig. 16.

Suppose the interior curve A *b c d* B to be given, and let all the joints produced, meet in the same point C; from the centers of gravity *v*, *x*, *y*, of the arch-stones, let the lines *v r*, *x s*, *y t*, be drawn at right angles to the horizontal line D Q drawn at pleasure, and the latter intersecting the joints in E, F, G; then it is evident, that if D E, expresses the weight of the stone *v*, E F that of the stone *x*, and F G, that of the stone *y*; the line C D, will express the force with which the stone *v*, presses the vertical joint H A; C E, the force with which the stones *v*, *x*, press the joint I *b*, and C F, the force with which the stones *x*, *y*, press the joint K *e*: for three powers are in equilibrio with each other, when they are as the sides of a triangle which are perpendicular to their direction; and the side D E, is perpendicular to the direction *v r*, of the weight, and the sides C D, C E, perpendicular to the directions of the forces with which the stone *v*, presses against the joints C H, C I: Again, E F, is perpendicular to the direction *x s*, of the stone *x*, and C E, C F, perpendicular to the directions of the forces with which the stone *x* presses the joints C I, C K; the same thing is true in regard to any other joint.

Since therefore the same line C E expresses the forces with which the stones *x*, *y*, press each other in contrary directions, they destroy each other; again as the

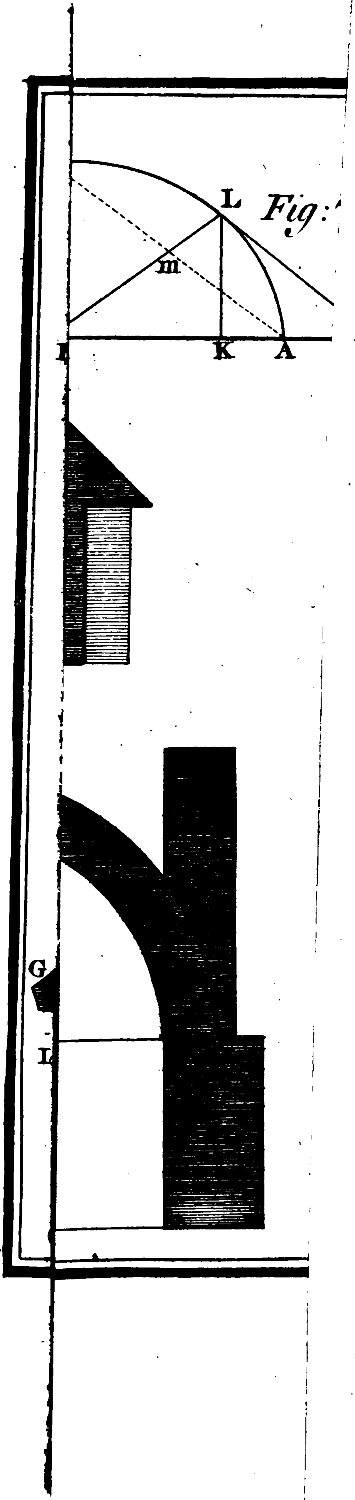


Fig:
L
m
K
A
G

the same line C F, expresses the forces with which the stones *x*, *y*, press each other in contrary directions, they likewise destroy each other; and this is true in regard to any other two adjacent stones. Consequently, if the weights of the stones are to each other as the lines D E, E F, F G, they will be in equilibrio with each other.

Whence, if the curve H I K L M be such that the space A H I *b*, be always equal to the corresponding triangle C D E, it will be that required, because the height C D, of that triangle is given, its area will be as the base D E.

Now because the circular sectors described by the radii C E, C *b*, C I, in the same time, are as the squares of these radii, and since those sectors are likewise as the fluxions of the spaces CDE, CA*b*, CHI; and the difference between the two last is equal to the first, by what has been proved; the difference between the squares of the radii C I, C *b*, will likewise be equal to the square of the radius C E.

Hence, when C E becomes C D, C I becomes C H and C *b* becomes C A: therefore the square of C D is equal to the difference between the squares of the height C A, and C H at the key-stone, which being given, the line D Q will be given in position, and from thence the curve may be described.

Though we have supposed the interior curve given, yet it is manifest, the solution holds equally good when the exterior curve is given.

When the interior curve A B, becomes a right line parallel to D Q; the exterior curve H M, will also be a right line parallel to D Q. For because C E will be to C *b* as C D to C A in this case; and therefore C E and C I will be in a constant ratio; *viz.* in the ratio of C D, to the root of the sum of the squares of C D and C A. Which shews that flat ceilings made of stones, so as all the joints meet in the same right line, or flat

arches,

arches, if we may call them so, will have all their stones in equilibrio.

PROBLEM XXII.

To construct the exterior curve HM, *when the interior* AB *is given.*

Case I. Let the interior curve AB be a quadrant of a circle, described from the center C with the radius CA or CB; and suppose the thickness AH or length of the key-stone to be given; then if BD be made equal to CH, and through the point D, the indefinite line DQ be drawn parallel to CB.

If after having drawn several radii CI, CK, CL, CM; intersecting DQ in E, F, G; you make one of the legs *ae* of a right angled triangle *acg*, equal to CA; and you take upon the other always *ce* = CE, *cf* = CF, *cg* = CG, and then CI = *ae*, CK = *af*, CL = *ag*; the curve passing through the points H, I, K, L, will be the required one.

For because CA, CB, are equal by supposition, and CH, BD, by construction, the square of CD will be equal to the difference between the squares of CH, or BD, and CA; and since, CA, *ca*; CE, *ce* and CI, *ac*, are equal, the square of CE or *ce*, will be equal to the difference between the squares of CI and C*b* or CA; consequently the curve HL is that required.

Fig. 17. Case II. Let the interior curve AB be a circular arc described from the center C, with the radius CB or CA, and let the part AH of the radius drawn through the vertex A, express the given thickness of the arch in that place; on CH as a diameter describe the semi-circumference of a circle HMC; take CM equal to CA, and in CA; CD equal to HM; and draw the indefinite right line DQ parallel to the horizontal line CB; then, after having taken upon

upon one of the legs *c a* equal to C A, of a right angled triangle *a c g*, and upon the other *c e*, *c f*; *c g*, respectively equal to the lines C E, C F, C G; you make C I, C K, C L, equal to the corresponding lines *a e*, *a f*, *a g*; the curve line H I K L passing through the points H, I, K, L, will be the required one.

For because C M, C A and C D, H M are equal by construction; the square of C D is equal to the difference between the squares of C H and C A; and since we have also C A, C E, C I, equal to *ca*, *ce*, *ci*, respectively, it follows that the square of C I is equal to the difference between the squares of C A, and C E; consequently the curve H K L, has been rightly constructed.

This problem has been given at the beginning of the fifth section, book the third of our mathematical treatise, not only for arches generated by a parallel, but likewise for such as are generated by a circular motion; to which the reader is referred, if he wants to know all the different cases.

We have endeavoured in this section to give all the different problems that possibly can happen in practice, relating to this subject; and to render it of more general use, we have given the table of the dimensions of piers for several openings of powder magazines; and though the arches are supposed to be circular, yet the same dimensions may serve for elliptic; or parts of circles. For in all the different kinds of arches, the thickness of the piers of the circular one has always been found the greatest, contrary to the erroneous notions of other authors; who have looked upon the circular one as the strongest and the best, without being able to give any other reason than because all the joints meet in the same point; not considering that the same thing is so in all arches, made of parts of circles; and as the finest bridges in *Europe* are built with elliptic arches, it is manifest, that they are able to support the weight with which they are loaded; besides we

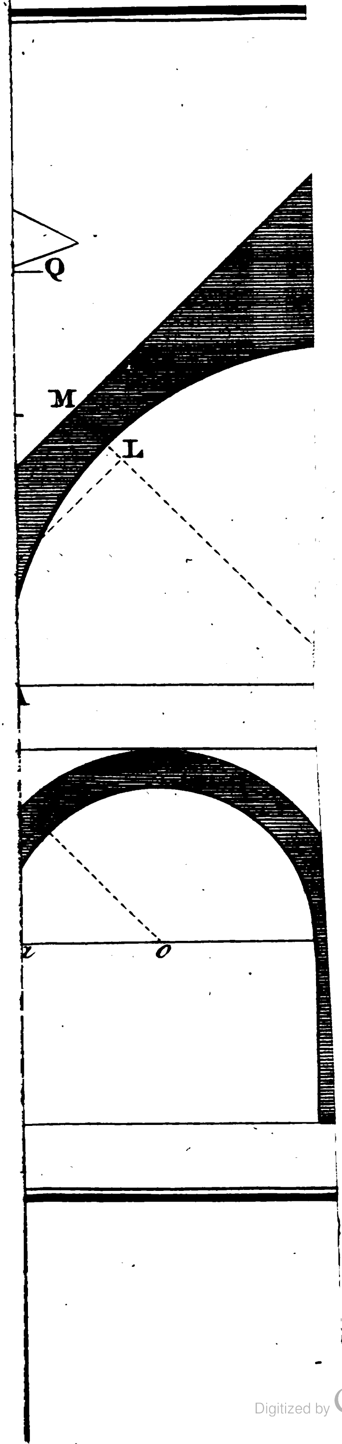
have

have shewn that they require about one third less masonry; it must therefore be allowed that they are preferable to the circular ones, especially when it is considered that they look more beautiful to the eye, and their slope is much less; which on the contrary is so very high in *Westminster-Bridge*, that it is with the utmost difficulty, that heavy loaded carriages can get over it; though in many other respects, one of the finest in *Europe*.

It is also easy to shew that powder-magazines, made with elliptic arches, have the advantage over circular ones in many cases. For in forts, or wherever the ramparts are low, it is impossible that circular powder-magazines can be built so low as not to be seen by the enemy from without, who therefore will endeavour to destroy it as soon as he can, knowing that the surrender of the place depends on it; and if they are built under ground, the powder can at least no longer be kept in it than during a short siege, otherwise it would soon grow damp, and lose its strength: whereas an elliptic arch may be made much lower. Nor will the shells have a greater effect upon these than on the others, because the weakest part is sufficiently covered with masonry, so as to be in no danger; and as to the hanches, they are more curvated than the circular ones, and of consequence are stronger in that place.

The two last problems are particularly useful in building of bridges, because the arch-stones being in equilibrio with each other, it is manifest, that the bridge will be stronger, than when they are made in any other form: it is true that the upper part of a bridge cannot be made in this form, unless it is of one arch only; since the passage must have a regular ascent and descent: yet nevertheless, the arch-stones being formed in this manner, and the rest of the side walls being finished in the usual way, the overplus of the weight is not so very considerable as to produce any very great alteration in respect to the force of the arch stone.

Besides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Besides when a bridge is built otherwise, that is, in the usual manner, the weakest part is loaded with a supernumerary weight, as well as the strongest, whereby it remains still the weakest, and and if that part is more loaded in proportion than the rest, the force to resist that weight must be weakened: on the contrary, the greatest part of the weight being in equilibrio, the remainder cannot cause so great a difference, as in the usual manner.

SECT. III.

Of the STRENGTH *and* QUALITY *of* TIMBER.

AS the strength and goodness of a building entirely depends on the well proportioning and uniting the whole together, in such a manner, as every part thereof may be equally strong; and as we have in the first section given tables of the thickness of walls which support earth, of any height, and according to any slope, that may be used, as likewise shewn how to find the proper thickness of piers of vaults and arches of any form or opening; it remains now to treat of the different kinds of timber, and of their quality, as well as of their strength, in respect to the different position in which they are made use of; especially of those most commonly employed in buildings; in order to render this work as useful as is possible, and thereby enable a young engineer to judge whether a building already excuted, is compleat in all its parts, or when a building is proposed, to make all its parts in due proportion, in such a manner as to be every where equally strong and good, and to avoid all needless expences; which is the point of greatest perfection that can be attained in the art of building.

Of

Of the NATURE *and* QUALITY *of* TIMBERS.

Of all the different kinds of timber known in *Europe* for building, oak is the best in all respects, because when it is well seasoned and dry, it is very tough and hard, it does not split so easy as other timber, and bears a much greater weight than any other whatsoever; when it is used under cover, it never perishes, no more than in water; on the contrary, the older it grows, the harder it becomes; and when it is exposed to the weather, it exceeds all other timber whatsoever for durableness.

Fir timber is the next in degree of goodness for building, especially in this country, where they build upon leases; for it lasts pretty long, when under cover; is very light, and is the cheapest timber that can be bought. It differs from oak in that it wants not so much seasoning, and therefore no great stock is required before hand: whereas oak must be kept at least a twelve month, and the longer it is kept the better it is; on the contrary, fir is much stronger while the resinous particles are not exhausted, than when it is very dry, as I have found by several experiments: Fir is used for flooring, above all other kind of wood, for wainscoting and the ornamental parts of building within doors; it lasts likewise a great while under water; some pretend, that it never perishes there, no more than oak.

Elm is the next wood in use, especially here and in *France*, where it is plenty; because it is very tough and pliable, it is easily worked, and does not easily split, it bears driving of bolts and nails into it better than any other wood: for which reason, it is chiefly used by wheelwrights, and coachmakers, for shafts, naves, fellows, and other such like things, and is almost the only kind of wood used in artillery.

Beach

Beach is alſo very uſeful upon many accounts; it is very tough and white when young, and of great ſtrength, but liable to warp very much when expoſed to the weather, and to be worm-eaten when uſed within doors; its greateſt uſe is to make planks, bedſteds, chairs, and other houſhold goods; and they uſe it likewiſe abroad, for axletrees, fellows, and in other wheel-wrights works.

Aſh is likewiſe a very good wood, but very ſcarce in moſt parts of *Europe*; it ſerves in buildings, or for any other uſes where it is ſkreened from the weather; hand-ſpikes and oars are chiefly made of it, and indeed it is the only wood that is fit for this and any other things which require to be tough and pliable.

Wild cheſnut timber is by many eſteemed to be as good as oak, and ſeems to have been much uſed in old buildings; but whether theſe trees are not ſo common at preſent as they have been, or have been found not to anſwer ſo well as was imagined, it is certain that this timber is quite out of uſe at preſent.

There are beſides many other kinds of woods, which are eſteemed uſeful upon ſundry occaſions, ſuch as *Engliſh* and *Virgina* walnut, mahogony, cedar-wood, roſe and box-wood, for turners and cabinet-makers works; but as we intend to confine ourſelves to thoſe woods only which are uſed in building; ſo the following obſervations, ſhall extend no farther than to thoſe mentioned above.

Oak may be diſtinguiſhed into three ſorts, *viz.* that which grows on high gravelly ground, in thick foreſts, and that which ſtands on the ſkirts of foreſts, in hedges, or any where elſe, in damp or low ground, where the air has a free circulation.

That which grows on high gravelly ground, is of a reddiſh colour, not much unlike that of red ſand; it is very brittle, cuts very ſoft, rots ſoon, and is neither good for building nor burning; for it never produces any flame no more than if it was rotten, for which reasons we shall say no more of it.

That which grows in thick forests, where the air has no free circulation, is very tall and strait, without knots, splits easily, and has a very fine whitish grain; it is therefore very good for building, and for any other carpenters work; it makes exceeding fine planks for all sorts of cabinet works, its natural colour and grain being so beautiful as no other wood can scarcely exceed; but as this wood is very tender and splits easily, it is not good for ship building, and therefore never to be used therein but when no other is to be had.

The third sort, which grows in soft ground, and where the air freely circulates, is very hard and tough; it is never so tall nor so strait and smooth as that in thick forests; but is the best that can be used for building of ships; especially if it stands in a wet soil; I have seen some that grew in a damp meadow ground which was so tough that the splinters would twist like ropes without breaking; If I mistake not, this is the reason that the *English* oak is so much better for building ships than any other in *Europe*; because the soil where it grows is generally damp, and low, and the forests are not so thick as they are elsewhere, by which the air circulates freely; whereas that which comes from *Norway* or other parts of *Germany* stands very thick and in great forests, for which reason it is so tender and so good for carpenters and joiners work.

Fir may likewise be distinguished into three different sorts; the red, or yellow and the white, and a sort between both. The red is by much the best and the most durable; because it is much more impregnated with rosin or turpentine, which fills it pores, and prevents the water or dampness from entering, and therefore is more able to withstand the weather than the other: I believe that this is the sort from which pitch and tar is extracted; this sort is always used in works that are

are exposed to the weather, and for stakes, to drive in the ground, but then it should be burnt in the fire and pitched over while warm, which will preserve it much longer; it has likewise been observed, that it does not decay under water; and it is the best for carpenters work.

The white sort is not so strong nor so durable, but is very good for the inside of a building; such as for flooring, doors, wainscoting, and other such like works; its colour and smoothness of grain makes it preferable for that use to the red sort; as to the third sort, it partakes of both qualities, is neither so strong and durable as the red, nor so beautiful as the white; but serves well enough for all sorts of timber in buildings where it is not exposed to the weather.

As to the elm or ash, I cannot find more than one sort of each; yet it is likely that the different soils in which it grows must make it either tougher, and stronger, or brittle; as likewise that which grows in the open air must be stronger than that which grows in thick forests. For all timber and plants in general grow strongest in a free air.

Beach, which grows in thick forests, is softer and more brittle than that which grows in the free air; and is very white and tough when young; therefore wheelwrights use no other than what is very young, and what is no bigger than the scantlings require; especially when used for axletrees, but for fellows they split it into two only; but that which is sawed into planks is much larger, and ought not to be too old, otherwise its grain is very coarse and the wood very brittle.

The goodness of timber not only depends on the soil and situation in which it stands, but likewise on the season in which it is felled; in which architects disagree very much; some will have it felled as soon as its fruit is ripe, others in the spring, and many in autumn or the fall of the leaves: and there are some who pretend that it should be felled in the increase or full of the moon, imagining that all things increase in the same manner; but we shall leave these moon-blind gentlemen to their own lunatic judgment, and give the most rational opinions concerning the properest season in which timber ought to be cut. Since sap, as well as any other moistness, is certainly the cause that timber perishes much sooner than it otherwise would do; which appears from timber exposed to the weather not lasting so long as that which is under cover, as likewise that dry timber, when used, is more durable than that which is fresh cut; this being the case, it is manifest that timber should be felled when there is the least sap in it; which is from the time that the leaves begin to fall to the time that the trees begin to bud; that is from the middle of *October* to the middle of *March*; the greatest number of architects agree with us, that this is the best season for felling timber.

The weather has likewise an influence over timber; for if it be felled in damp and rainy weather, it will not dry, and if it lies too long in this state, the sap will moulder and cause the timber in time to rot: but if the weather be dry and fair, it is plain that the air will draw out the sap and the timber will be more lasting.

When timber is cut, the bark should be taken off and let lie for some time exposed to the sun and weather, and afterwards cut into rough scantlings nearly of the size they are intended to be used, and then laid up in stakes under cover to secure them against wet weather and the heat of the sun; for the wet hinders it from drying, and the heat of the sun splits it. As oak seems to contain more sap than any other wood, and therefore requires a longer time to dry; the best way to make it soon fit for use, is, as soon as it is cut into scantlings, to throw it into water; this has been found by experience to draw out the sap much sooner than the weather; for the outside will in a short time grow as black as ink, which is a certain proof, that water

water draws out the ſap, in a ſhorter time than the air. As to the ſeaſoning of any other kind of timbers, I never heard of any other method, than to ſtake it up in piles, in ſuch a manner as that the air may freely paſs between; and to cover it from the rain and the heat of the ſun. The time required for drying timber before it is uſed is very uncertain, ſome ſorts require much more than others: oak muſt be kept a great while; for the dryer it is, the harder and ſtronger it grows: this we find by experience: for oak of an old building, or of a ſhip, is ſo hard ſometimes, that tools will ſcarcely cut it.

Beach requires likewiſe a great while drying; and if it is uſed before it is thoroughly ſeaſoned, it warps very much; and it may be obſerved in general, that the heavier the wood is the longer it requires to dry: it may be known whether any timber is dry and ſound by ſtriking with a hammer pretty hard at one end, and if it ſounds clear and diſtinct, you are certain that it is both ſound and dry.

Fir being a light wood requires leſs time to dry than any other ſort; fir ſcantling for roofing or for any other uſe within doors, ought to be half dry only; becauſe it is then ſtrongeſt, as we have found by ſome experiments, which ſhall be related hereafter; but as to the boards for flooring and wainſcoting they ought to be thoroughly dry, otherwiſe they ſhrink and ſpoil the work.

Timber ſhould likewiſe be cut when of a proper age; for when it is either too young or too old, it will not be ſo durable. It is ſaid that oak ſhould not be cut under ſixty years old, nor above two hundred; whether this is right or not, it is very certain that all timbers ſhould be cut in their prime and nearly when full grown, and before they begin to decay; that will be ſooner or later according to the dryneſs or moiſtneſs of the ſoil in which they grow: as alſo according to the bigneſs of the trees, and the kind of timber: there is therefore no certain rule to go by in felling of timber, but experience and judgment must direct here as well as in many more cases.

Method of computing the strength of Scantlings.

Mr. *Parent* is the first that we know, who has treated this subject in a scientific manner, and in order to enforce his demonstrations, he made several experiments, with various scantlings of oak and fir; by which he found that the strength of an oaken scantling is to the strength of a fir scantling of the same size as 5 is to 6: so that according to this experiment, fir wood is stronger than oak; Mr. *Belidor* has after him treated the same subject; and made likewise several experiments with oaken scantlings, but as to the experiment in respect to oak and fir, he took the foregoing proportion for granted. The same opinion, that fir is stronger than oak, has prevailed here; for, according to *Langley*, there was an act of parliament made, after the great fire in *London*, to settle the dimensions of scantlings; in which those of oak are always larger than those of fir: But as this appeared to me contrary to sense and reason, I resolved to try the experiment myself, and found exactly the contrary, as will be seen hereafter. As Mr. *Parent* was a man of veracity and character, we cannot imagine that he affirmed but what he really found; his oak must have been weaker and the fir stronger, than any I have met with; which led him into this error.

PROBLEM I.

To determine the strength of a scantling whose dimensions are given. Plate VI, Fig. 1.

We suppose that all the fibres of the wood are strait, and of the same strength in its weakest part, that is where it breaks; for it is no matter how they are elsewhere; and that the fibres are the ſame in the ſame ſort of wood; altho' this is not ſtrictly true, yet it is ſufficiently near in practice ſo as to cauſe no ſenſible error.

Suppoſe the ſcantling ABC to be ſupported in the middle D by the edge of a triangular block R, and two equal bodies, P, Q, to be ſuſpended at A and C, equally diſtant from the middle B; of ſuch a weight as juſt to break the ſcantling.

It is evident that the weights P and Q will cauſe the ſcantling to bend at firſt ſo as to make a kind of a curvilinear angle at B, and then to break in that place, in a ſection BD perpendicular to either of the ſides AC: now as the power or force of theſe weights is more or leſs, according as they are ſuſpended farther from or nearer to the point fix D; theſe forces will therefore be in proportion to the products of the weights each multiplied by its reſpective diſtance from the ſection BD; or becauſe the weights and diſtances are here ſuppoſed equal, twice the product of one of the weights P multiplied by its diſtance, from the ſection BD, will expreſs the force of theſe two weights.

Having determined the force of the weights, we are now to determine the reſiſtance or ſtrength of the wood; which is done in the following manner. Let *acb* repreſent the ſection of the ſcantling; it is evident that this area repreſents the ſum of all the fibres to be torn or broken, and as they are all equal and of the ſame ſtrength by ſuppoſition; this area will expreſs the ſum of the ſtrength of all the fibres: but as the point D, or the baſe *ab* of the ſection is fix; and the directions of the fibres perpendicular to the area *acb*: the force or reſiſtance of each fibre is equal to the product of its ſtrength multiplied by its diſtance from the baſe *ab*: and therefore the ſum of all the fibres placed in the ſame line *df*, parallel to the baſe *ab*, multiplied by their diſtance *ad*, from that baſe *ab*, will expreſs their momentum or reſiſtance: What has been proved in regard to all the fibres placed in the line *df*, is equally true of all those placed in any other line parallel to the base *a b*: and therefore the sum of all these products will express the total strength or resistance of the wood: But by a noted property of the center of gravity, the product of the area *acb*, multiplied by the distance of its center of gravity, from the base *a b*, will express the total strength or resistance of all the fibres; or that of the whole scantling. Consequently, having the strength of any scantling of the same wood determined by experiment, that of any other may be found.

Fig. 2. If the scantling A C be supported at both ends by the triangular blocks P, Q, and the weight W, hanging in the middle B: then if we suppose the weights P and Q in the last figure to represent the blocks P and Q in this; and as each block supports half the weight W; it is evident that the weight W, multiplied by the distance A B or B C, will express its momentum or force.

The same otherwise.

Since the weight W, is suspended in the middle between the point fix; it is evident that each block supports exactly half the weight; and as the power or force of this weight on the blocks P, Q, is as the product of half the weight multiplied by the distance A B or B C of its direction from the point fix: It follows that the whole force of this weight is as twice the product of half the weight W multiplied by A B or B C: or as the whole weight W, multiplied by the distance A B, or B C.

COR. I.

Hence, if the length A C of the scantling between the points fix A, C, be *c*; the area of the section *s*; the distance of its center of gravity, from the base *d*, and the weight W, *w*; then will $\frac{1}{2}cw$ express the force of the weight W, and *ds*, the strength of the scantling: there-

therefore the momentum of the weight is to the momentum of the scantling as $\frac{1}{2}cw$ is to ds; or as w is to $\frac{2ds}{c}$; or if this ratio be given $w = \frac{2ds}{c}$.

From whence we may draw several useful consequences, 1. The strengths of two scantlings of the same wood, and of different dimensions, or, which is the same, the weights they will bear, are to each other as the products of their sections multiplied by the distances of the centers of gravity, from the base, divided by their lengths.

2. The strengths of two scantlings of the same wood, which have the same length; are as the products of their sections multiplied by the distances of their centers of gravity from the base.

3. The strengths of two scantlings of the same wood, which have equal sections, are as the distances of their centers of gravity, divided by their lengths.

4. The strengths of scantlings of the same wood, whose distances of the centers of gravity of their sections from the base are equal, will be to each other as their sections divided by their lengths.

N. B. We have taken no notice of the parts of the scantlings at each end, which are beyond the points A, C, and which serve to support them on the blocks; for they cause no difference in respect to their strength: the same thing may be said in respect to the weights of the scantlings, which are so small in proportion to the weights they bear, that there is no occasion to consider them; because there is no geometrical exactness required, nor can be attained in practice. It may also be observed, that when the weight hangs between the point fix; the base to which the distance of the center of gravity is referred, is the upper surface A C; since it must open and break first at the lower D; whereas when the point fix is between the weight, as in the first figure, it is the lower surface.

COR.

COR. II.

Fig. 2. If the section of the scantling A C be a rectangle placed flat on one of its sides, which we call b, and its height or other side a; then will ab, express the area of the section; and the distance d of its center of gravity from the upper base, will be $\frac{1}{2}a$; therefore the equality found in the first corollary, $w = \frac{2ds}{c}$: becomes here $w = \frac{aab}{c}$. Which shews, that *the strength of a rectangular scantling laying flat on one of its sides; is as the product of the square of its height multiplied by its base, and divided by its length.*

Hence a deal board of an inch thick and ten inches broad, being placed on its flat side, and then on its narrow side; the force in the first case will be to the force in the second, as unity is to 10. For the force in the first case will be as 10 multiplied by the square of unity; and in the second as unity multipled by the square of 10; that is, as 10 is to 100; or as unity to 10. So that if it bears 50 pounds when it lies flat, it will bear 500 when it lies on the narrow side.

This is the reason that all timbers in buildings are always placed on the smallest side; because they will by this means bear a greater weight, than if they were placed otherwise; and therefore save a good deal of timber; and this in proportion as they are made higher.

EXAMPLE.

We may from hence likewise find, whether the proportions of scantlings commonly given by carpenters are right according to their length; for which we shall choose the dimensions of fir-girders as appointed by act of parliament, after the great fire of *London*; which are as follows.

Now

Length	Breadth	Height
10	8	10
12	8.5	10
14	9	10.5
16	9.5	10.5
18	10	11
20	11	12
22	11.5	13
24	12	14

If we suppose, that the dimensions of any one of these scantlings be right, as for example that of 10 feet long; then we may find those of any other, whose length is given, in this manner. Since these scantlings ought to bear the same weight or to be equally strong; the product of the square 100 of the height multiplied by the base 8, gives 800, which being divided by the length 10 feet or 120 inches, gives $\frac{20}{3}$ which expresses the strength of the given scantling, and therefore must be equal to the dimensions of any other; $\frac{aab}{c} = \frac{20}{3}$.

If we suppose the length c to be 12 feet or 144 inches, and the height a, 10 inches; then by substituting these values into the last equality, it becomes $\frac{20}{3} = \frac{100.b}{144}$; and if 20 be multiplied by 144, and 3 by 100; the former product divided by the latter gives 9.6 inches for the base b, of the scantling; which is 1.1 inches more than that above.

In the same manner may be found the dimensions of all the other scantlings, whose lengths and heights are the same, which gives the following table.

Length	Breadth	Height
10	8	10
12	9.6	10
14	10.1	10.5
16	11.6	105
18	11.9	11
20	11	12
22	9	13
24	9.8	14

The breadths of the same scantlings being compared, it appears, that those whose lengths are 12, 14, 16, 18, 20, are too little in the former table, and those of 22 and 24 feet long, too great: which shews that practice alone is not sufficient to determine the proper size of scantlings; and that without the application of mathematical principles, no great improvement can be expected in any mechanical

chanical art whatever; notwithſtanding what ignorant workmen inſinuate.

As to the dimenſions of oak ſcantlings given by workmen, we ſhall not compare them, till we have given the following experiments, we made with great accuracy, and upon which the reader may depend.

EXPERIMENT I.

The ſticks uſed in this experiment were 24.5 inches long from one end to the other, and half an inch ſquare; they were laid on two truſſes well ſquared, and ſtood 20 inches diſtant from each other; ſo that the length of the ſticks is to be conſidered as no more than 20 inches; the remaining part ſerving only to reſt upon; the weights were ſuſpended in the middle by a ſtring, ſuch as juſt to break the ſticks, and are as marked underneath.

Two dry oak ſticks	69 lb.
	50.
A dry fir ſtick	46.
A dry elm ſtick	31.

The firſt oak ſtick ſeems to have been thorougly dry; I had it from the dock, and likely was taken out of an old ſhip; the ſecond I had out of the warren as dry as could be had; the grain of the wood was ſtrait in both; but that of the firſt was finer than that of the ſecond, and of a deeper colour; which, if I am not miſtaken, denotes, that the tree was in its prime when felled.

The fir ſtick did not bend ſo much before it broke as the oak; it was of the reddiſh kind, and the ſtrongeſt that could be found: As to the elm it bent very much before it broke; and as this laſt is ſo weak, we did not think proper to try any more of it in the following experiments.

EX-

EXPERIMENT II.

Two oak ſticks cut out of an old axletree	55 lb. 54.
An oak ſtick cut out of a ſpoke of a wheel	56.5
Three fir ſticks out of the ſame piece	36.5 36 36
A fir ſtick of an equal ſection, whoſe baſe and height were as 2 to 3	42.5.

The oak ſticks in this experiment had a coarſer grain than thoſe in the former, and ſeem to have been of an older tree; as to the fir ſticks no difference could be perceived, either in the grain, colour, or any thing elſe, from the former.

By theſe experiments it plainly appears, that oak is ſtronger than fir, contrary to thoſe made by Mr. *Parent*, and common practice: for the weakeſt oak is ſtronger than the ſtrongeſt fir in the firſt experiment: in proportion as 25 to 23: But thoſe in the ſecond experiment, make a much greater difference, *viz.* as 54 to 36; or as 3 to 2: And if the ſtrongeſt oak ſtick in the firſt experiment be compared to the ſtrongeſt fir; the proportion will be as 69 to 46; or as 23 to $15\frac{1}{3}$; or as 3 to 2; that is the ſame as before; which is very conſiderable, and therefore deſerves to be taken notice of.

As the ſtrength of the ſame kind of wood varies very much, it is impoſſible ever to come to an exact knowledge of the juſt proportion between the ſtrength of oak and fir; but we are certain that oak is the ſtrongeſt of the two.

As the leaſt porportion we have found, viz. that of 25 to 23, is very nearly equal to that of 9 to 8; ſo by making the oak ſcantlings leſs in that proportion, there will be no danger of their being too ſmall, only it muſt be noted, that oak ought to have been cut a twelvemonth before it is uſed, as we have obſerved before, whereas

whereas fir does not require above six months seasoning.

As the last fir stick had the same length, and an equal section with the others, it is plain that its strength is to that of one of the others, as the height of the first is to the height of the second, by what has been proved before: and if x be the height of the last stick, then will $\frac{2x}{3}$, be its base, and $\frac{2xx}{3} = ab$, or because a and b are each $\frac{1}{2}$ or .5: we have $\frac{2xx}{3} = .25$; or $xx = .375$; whose square root gives $x = .611$, or 6 nearly; that is the strength of the last stick is to that of any of the former as 6 is to 5: Now if we say as 6 is to 5, so is the weight 42.5, this stick bore, to the weight 35.4 nearly, whereas it bore the weight of 36 pounds; this difference is inconsiderable, considering that the weight cannot be so nicely observed, to come within 2 or 3 ounces; and besides, the sticks were not so exactly of the given dimensions, as that no difference might arise from thence. So that this experiment, considering so small a difference, answered the theory pretty nearly.

Having determined the proportion between the strength of oak and fir scantlings, it remains now to determine the dimensions of oak girders, from those of fir; in which we suppose that a scantling of fir, being 10 feet in length, 8 inches in breadth, and 10 high, is sufficiently strong, and from thence all the succeeding ones both of fir and oak have been determined.

TABLE I.

TABLE I. Containing the dimensions of girders.

The lengths are expressed in feet, and the breadths and heights in inches.

FIR.

Length	Breadth	Height
10	8	10
12	8	11
14	9	11.1
16	9	11.9
18	10	12
20	10	12 6
22	11	12,6
24	11	13.2

OAK.

Length	Breadth	Height
10	7	10
12	7	11
14	8	11.1
16	8	11.9
18	9	11.9
20	9	12.5
22	10	12.5
24	10	13

For, according to the equality $w = \frac{aab}{c}$, above, if $c = 10$ feet or 120 inches, $a = 10$, $b = 8$; then will $w = \frac{20}{3}$; and $\frac{20}{3} = \frac{aab}{c}$; now if $c = 12$ feet or 144 inches, $b = 8$; then will $\frac{20}{3} = \frac{8aa}{144}$ or $aa = 120$, whose square root is 11 nearly, for the square of 11 is 121. In the same manner are found all the fir scantlings: And if we reduce $\frac{20}{3}$, in the proportion as 9 to 8; we shall have $\frac{160}{27}$ for the strength of oak scantlings: that is $\frac{160}{27} = \frac{aab}{c}$.

Hence if $c = 10$ feet, $b = 7$; then will $\frac{160}{27} = \frac{7aa}{120}$ or $aa = 101$, whose square root is 10 nearly; which is the same as in the table; the rest of the oak scantlings are found in the same manner.

TABLE

TABLE II. Containing the dimensions of fir joists common and trimming.

Common.

Length	Breadth	Height
6	2	8
8	2.5	8.2
9	3	8
10	3	8.4
11	3.5	8.1
12	4	8

Trimming.

Length	Breadth	Height
5	3	7
6	3	7.6
7	3.5	7.6
8	4	76
9	4.5	7.6
10	5	7.6

The dimensions of the first scantlings in each table, are supposed to be of a sufficient strength, and the rest are from thence determined. For if $c = 6$ feet or 72 inches, $b = 2$, and $a = 8$; then will $\frac{16}{9} = \frac{aab}{c}$; and if $c = 8$ feet, $b = 2.5$; then will $\frac{16}{3} = \frac{2.5\,aa}{96}$; or $aa = 68.26$, whose square root is 8.2; the same as above.

But if we suppose that $c = 5$ feet, $b = 3$, and $a = 7$; then will $\frac{49}{29} = \frac{aab}{c}$, by which the second table is constructed. For if $c = 6$ feet, $b = 3$; then will $\frac{49}{20} = \frac{3aa}{72}$, or $aa = 58.8$; whose square root is 7.6, nearly.

TABLE

TABLE III. Containing the dimensions of fir bridging joists.

In small Buildings.

Length	Breadth	Height
6	2.5	5
7	2.5	5.5
8	2.5	5.9
9	3	5.6
10	3	6
11	3	6.2
12	3	6.5

In large Buildings.

Length	Breadth	Height
6	3	5.4
7	3	5.8
8	3	6.2
9	3	6.6
10	3	6.7
11	3.5	6.8
12	3.5	7.1

If we suppose that $c = 6$ feet, $b = 2.5$, $a = 5$; then will $\frac{125}{144} = \frac{aab}{c}$, by which the second table is constructed, and if $c = 6$ feet, $b = 3$, $a = 5.4$, then will $\frac{7.29}{6} = \frac{aab}{c}$, by which the second table is constructed. It may be observed that carpenters alway allow larger scantlings in large buildings than in small ones, and they must be stronger, than barely to support the weight they are to sustain.

N. B. The reader will find the several names of the timbers mentioned in these tables explained in the latter part of this work, where we treat of timber frames and roofings.

TABLE

TABLE IV. Containing the dimensions of tie beams

Fir.

Lenght	Breadth	Height
12	6	8
16	7	8 5
20	7	9.5
24	7	10.4
28	8	10 5
22	8	11.3
36	8	12
40	9	12
44	9	12.3

Oak.

Lenght	Breadth	Height
12	5	8.2
16	6	8 7
20	6	9.7
24	6	10.6
28	7	10 6
32	7	11.3
36	7	12
40	8	12
44	8	12.6

By following the ſame method as before, we ſhall find $\frac{8}{3} = \frac{a\,a\,b}{c}$, for the equation by which the firſt table is conſtructed; and $\frac{7}{3} = \frac{a\,a\,b}{c}$ nearly, for that by which the ſecond is conſtructed.

TABLE V. Containing the dimenſions of the principal rafters.

Of Fir.

Lenght	Breadth	Height
18	4	5.5
20	4	6.1
22	4	6.4
24	5	6
26	5	6.2
28	5	6.4
30	5	6.7
32	5	6.9
34	5	7.1
36	5	7.3
38	5	7 5
40	5	7.7

Of Oak.

Length	Breadth	Height
18	3	5.3
20	4	5.7
22	4	6
24	4	6.3
26	4	6.5
28	4	6.8
30	4	7
32	5	6.5
34	5	6.7
36	5	6.9
38	5	7.1
40	5	7.3

Authors give various dimenſions to the principal rafters; Mr. *Smith* gives one ſort, Mr. *Price* another, and Mr. *Langley* will have them to to be ſtronger at the bottom than above; but, his is not followed by any workmen, as I am told; beſides Mr. *Price* ſays, that they ſhould be ſtronger in large buildings than in ſmall ones, although of the ſame length; I ſee no reaſon for any ſuch practice; their ſtrength ought rather to be in proportion to the weight of the covering, and to the diſtances they are from each other: as authors do not agree in regard to the ſtrength of rafters, we have choſe a medium between them, for the dimenſions of the firſt ſcantling of each table.

TABLE VI. Containing the dimenſions of ſmall rafters.

Of Fir.

Length	Breadth	Height
9	2.3	4.7
10	2.4	4.9
11	2.5	5
12	2.6	5.2
13	2.7	5.4
14	2.8	5.5
15	2.8	5.6
16	2.9	5.8
17	2.9	5.9
18	3	6
19	3	6.1
20	3.1	6.2

Of Oak.

Length	Breadth	Height
9	2.3	4.6
10	2.3	4.7
11	2.4	4.8
12	2.5	5
13	2.6	5.2
14	2.6	5.3
15	2.7	5.4
16	2.8	5.5
17	2.8	5.6
18	2.9	5.8
19	3	5.8
20	3	6

Theſe are the tables commonly given by carpenters and architects, concerning the dimenſions of ſcantlings; but as their exactneſs depend on the dimenſions taken out of other authors, of the firſt ſcantling of each ta-

 ble,

ble, ſo that if they are not right, all the reſt are likewiſe falſe; but as we always took the ſhorteſt, which are the likelieſt to have been uſed, and found to be of a ſufficient ſtrength, it is preſumed that the other ſcantlings given here are all ſtrong enough; and perhaps more ſo than they need to be.

EXAMPLE II.

Fig. 5. Let a rectangular ſcantling be placed edgeways, ſo that B D be the diagonal, and let the ſides ſtill be repreſented by a, and b; then will $d = \frac{1}{2}\sqrt{aa + bb}$; and therefore the equation $w = \frac{2ds}{c}$; becomes $w = \frac{2abd}{c}$ in this caſe; and ſince d or the diagonal B D is greater than any one of the ſides; the ſcantling will bear a greater weight in this poſition, than if it were placed flat on one of the ſides: But as wood will yield at the point B, by the force of the weight ſuſpended there; the ſtrength will be found ſomething leſs than is expreſſed by this equation.

EXAMPLE.

Let the ſection of the ſcantling be a circle, whoſe diameter is a, and area s; then will $w = \frac{as}{c}$ be the equation, which ſhews that the force of a cylindric ſcantling, is expreſſed by the area of its ſection multiplied by its diameter, and divided by its length; and therefore is to the force of a ſcantling whoſe ſection is the circumſcribed ſquare; as the area of the circle to that of the circumſcribed ſquare.

It is alſo manifeſt, that the ſtrength of a triangular ſcantling, when laid flat on the baſe, is double the ſtrength when the edge is undermoſt, ſo as the baſe be parallel to the horizon. For the diſtance of the center of of gravity from the base is half the distance of that center from the vertex.

PROBLEM II.

To find the weight a scantling A C *will bear, when it is suspended any where between the points* A *and* C. Fig. 3.

Since the block P, which is nearest to the point of suspension B, supports a greater part of the weight than the block Q, which is farthest from it; we are to find the parts of the weight which each bears, in order to solve the problem. By the known rules of mechanics, the whole length A C of the scantling is to any part A B or B C, as the whole weight W, is to the part supported by the block Q or P. If therefore we call A B, m, B C, n, and the rest as before; we have $c : n :: w : \frac{nw}{c}$ = to the part supported by the block P; and $c : m :: w : \frac{mw}{c}$ = to the part supported by the block Q: Whence these weights being multiplied by their respective distances A B, B C, give $\frac{nmw}{c}$, $\frac{nmw}{c}$, for their momentums, and the sum $\frac{2mnw}{c}$ must be equal to the strength ds of the wood by problem the first, which gives $\frac{2nmw}{c} = ds$, or $w = \frac{cds}{2nm}$ for the weight required.

If we suppose the weight to be suspended in the middle, then will $n = m = \frac{1}{2}c$; and the last equation becomes $w = \frac{2ds}{c}$; which is the same as in the first problem.

If

If the scantling A C is rectangular, and its base be b, altitude a; then will $ab = s$, and $d = \frac{1}{2} a$; these values being instituted into the equality above, gives $w = \frac{aabc}{4nm}$.

Since, when the weight is suspended in the middle, we have $w = \frac{aab}{c}$; it is evident, that the strength of the scantling when the weight is suspended in the middle, is to the strength of the same scantling, when the weight is suspended nearer to one end than the other, as $4nm$ is to cc: Consequently the weight any scantling will bear when suspended in the middle being known; the weight which that scantling would support at any distance from either end, may be found by the last proportion.

EXAMPLE.

Let A C be 20 inches, and the section half an inch square; suppose the scantling to be of fir, such as we used in the second experiment, which bore 36 pounds; and let A B be 5 inches; then will B C be 15; whence $4nm = 300$, and $cc = 400$; therefore $300 : 400 :: 36 : 48 =$ to the weight the same scantling would bear being suspended at the distance of 5 inches from either end.

This shews, that in buildings, it should be avoided as much as possible, to place the weight in the middle of a beam, such as king posts are in roofs; and therefore it is more advantageous to use prick-posts instead of king-posts; this is likewise what carpenters do in most buildings where there is no partition wall to support the beam in the middle.

Fig. 4. It may likewise be observed, that a scantling A C of the same strength with the former, will bear two weights W, W, each of 48 pounds, when their distances A E, F C from the ends are 5 inches: this

this appears plain from the foregoing example, becaufe thefe weights will caufe the fcantling to break in two places.

Mr. *Parent* is the firft we know, that has fhewn how to cut the ftrongeft fcantling poffible, out of a given tree: As this may be ufeful in practice, becaufe timber merchants are fenfible that the fquare is the greateft figure that can be infcribed in a given circle, and for which reafon they chufe to make all their timbers fquare, as being moft advantageous to them; we fhall infert the following.

PROBLEM III.

Let AFBE, *be the circumference of a tree out of which it is propofed to cut the ftrongeft rectangular fcantling that is poffible.* Fig. 8.

Draw the diameter DG, at right angles to the parallel fides AE, BF, interfecting AE in P; then becaufe the ftrength of the fcantling is expreffed by AE × AE × AF, as has been proved in the firft problem; but by the property of the circle, we have $AP^2 =$ DP × PG, and AF = 2 CP; therefore the ftrength of the fcantling will likewife be expreffed by 8 DP × PG × CP; now becaufe this expreffion is the greateft of all poffible, when the fquare of CP is one third of the fquare of CD, by article 247 of our *Elements of mathematics*; or which is the fame, when the fquare of the bafe AF is one half of the fquare of the altitude AE: For becaufe the fum of the fquares of CP and PA, is equal to the fquare of the radius CD, by the property of the circle: and therefore if the fquare of CP is one third; the fquare of PA will be the two thirds of that fquare, confequently, the fquare of AP muft be double the fquare of CP; or the fquare of AE double the fquare of AF.

 CON-

CONSTRUCTION.

Fig. 7. Divide the diameter A B of the tree into three equal parts at C and D; and from the points C and D of division, draw D E perpendicular above, and C F, below the diameter; then if the points of intersections E, F, of these lines and the circumference, are joined to the extremities A, B of the diameter; the rectangle A E B F, will be the greatest that can be inscribed in that circle.

For because A D is two thirds, and D B one third of the diameter A B by construction, the square of D E, will be two ninths, and the square of A D four ninths of the square of the diameter; therefore the square of A D is double the square of D E; and by the similarity of the triangles A D E, A E B; the square of A E is double the square of E B.

It has been observed a great while, that when the base of a scantling is to its height as 5 to 7; that it was nearly the strongest of all the scantlings whose sections are equal, and inscribed in a circle; and because the square of 5 is 25, and that of 7 is 49; the former being nearly half the latter, exceeding by an unit only; this observation perfectly agrees with what has been proved in the last problem.

PROBLEM IV.

If a scantling be supported at the ends by two blocks P, Q, *not placed in the same horizontal line, and the weight suspended in the middle, to find the strength of this scantling.* Fig. 9.

From the point C in the vertical line, passing through the edge of the highest block Q, draw C E parallel to the horizon, meeting the direction of the weight in L, and the vertical line drawn through the edge

edge of the lower block P in E; then becauſe it has been proved in the firſt problem, that the weight W multiplied by the diſtance of its direction from one of the points fix, expreſſes the momentum or force of that weight: that is $W \times CL$ expreſſes the momentum: but the force of the wood has likewiſe been proved to be as the product of the ſection multiplied by the diſtance of its center of gravity from the point B. Therefore if we call C E, n, and the reſt as before; we ſhall have $\frac{1}{2} n w = d s$, by what has been proved before, conſequently $w = \frac{2 d s}{n}$.

Hence, becauſe we have $w = \frac{2 d s}{c}$, when the ſcantling lies horizontally, and c expreſſes its length: the ſtrengths of the ſcantling in theſe different poſitions are to each other reciprocally as the diſtances of the directions of the weight from one of the points fix; that is the ſtrength of the ſcantling in this oblique poſition is to its ſtrength in a horizontal poſition, as C B is to C L; or as the radius is to the coſine of the inclination L C B.

For example, if the ſcantling A C bears a weight of 36 pounds, when placed horizontally; to find what weight it will bear when it makes an angle of 15 degrees; then becauſe the coſine 9659 of that angle is to the radius 10000, as the weight 36 is to a fourth term, which gives 37.2 pounds nearly.

But if the angle of inclination is 60 degrees; then becauſe the conſine of this angle is to the radius as 5 is to 10; the ſcantling will ſupport a weight 72 double the former. Whence it is plain, that as the angle of inclination increaſes, ſo the ſtrength of the ſcantling increaſes likewiſe: and when that angle becomes a right one, or the ſcantling becomes upright, its ſtrength is not to be expreſſed. But becauſe the fibres of wood are not always ſtrait, and give way when preſſed very hard,

hard, it is very possible to press an upright scantling so as to give way and break.

This problem is useful in finding the respective strengths of scantlings which are joined together, with different angles of inclinations; such as in the roofing of any building, and thereby save unnecessary expences.

Fig. 10. It is not sufficient that the strength of scantlings may be found, there are likewise some positions that are more advantageous than others, which ought likewise to be known. For instance, let ABC be the pitch of a roof, and a strut E F, is to be placed so as to support the rafter A B in the best manner: I say that when E F, is the base of an isosceles triangle AEF; or, which is the same, when it makes equal angles with the tie-beam AC, and the rafter A B, it is in its most advantageous position; for the strength of this piece is proportional to the distance of its direction from the point fix A; but the perpendicular drawn from the point A to the base E F is the greatest of all when the triangle is isosceles: Consequently, this is the best position that the piece can have.

But if the strength of the tie-beam AC, is to be considered, and there is no party wall to support it in the middle, the case is otherwise; for in that case the piece must be upright as G H; because the nearer the point G approaches the point fix C, the less strength is required to support the piece G H. Hence it is manifest, that a scantling may be most advantageously placed in respect to its own strength, but not in regard to other scantlings to which it is joined: And consequently, in the framing of timbers for a building, not only regard must be had to the strength of the scantlings themselves but likewise to those to which they are framed.

PRO-

PROBLEM V.

To find the strength of thbe principal rafters AB, BC, *so as to be proportional to that of the tie-beam* AC. Fig. 10.

Let the base of the rafters be x, and their height $2x$, that is double the base as they commonly are made: Let the base of the tie-beam AC be b, its altitude a, and half its length AD, n; then the strength of the rafter will be expressed by $\frac{4x^3}{n}$ by the last problem; and that of the tie-beam by $\frac{aab}{2n}$ by the first problem; therefore $\frac{4x^3}{n} = \frac{aab}{2n}$ by supposition, or $8x^3 = aab$; whence the cube root will be $2x = \sqrt[3]{aab}$.

Hence because the length AB of the rafters does not enter into the equation; it is evident, that whatever the pitch is, the cube root of the base of the tie-beam multiplied by the square of its height, will always give the height of the rafter. For example, a fir tie-beam of 12 feet long, is made 6 inches by 8, according to the tables given before; then because $a = 8$, $b = 6$; we get $aab = 384$, whose cube root is 7.2 inches nearly; for the height of the rafters, and hence we get 3.6 inches for the base.

If the beam AC be 24 feet long; then the base is 7 and height 10.4, according to the foregoing tables: whence $b = 7$, $a = 10.4$; and hence $aab = 757.12$, whose cube root gives 9.1 inches nearly, for the height, and 4.5 for the base of the rafters.

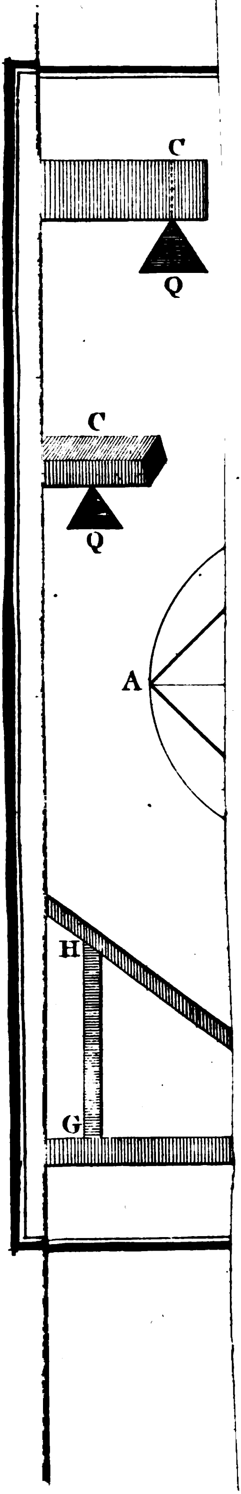
In the true pitch of a roof the principal rafters are the three fourths of the tie-beam, which being here supposed to be 24 feet long; and therefore the length of the principal rafters, will be 18; and according to the fifth table, their base is 4 and height 5.5; which dimensions

dimensions are therefore in no proportion to that of the tie-beams. But then it must be considered, that the rafters are always supported by struts or uprights, which, bearing a part of the roof, strengthens them and weakens the tie beam.

These are nearly all the different problems we could thinks of, that may be useful in framing of timber works; which the reader ought to be well acquainted with, if he designs to make any progress in the art of building; for what is found in most authors on architecture, relates chiefly to practice, which alone is not sufficient to make any improvements: and it is no wonder, that for so many ages as architecture has been cultivated, there has been so little progress made, since very few had any knowledge of those parts of the mathematics, which are necessary to be known, and therefore I advise the reader to make himself master of them; before he enters upon the practice.

The theory of timber given here is of very great use both in civil and military architecture, since we are taught thereby not only how to find the proper strength of scantlings in respect to their length, when placed in an horizontal position, but likewise when framed together, according to any angle of inclination, which practice alone could never have determined, to any degree of exactness: the entering into all the different applications that may happen in practice, would require more room than can be allowed in so small a tract as this; for which reason, we shall give as much of it hereafter, as will be sufficient to young engineers, for whom this work has been pubiished.

PART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PART II.

Containing the Knowledge of the Materials, their Properties, Qualities, and Manner of using them.

BEFORE we enter into the manner of building the several works of a fortress, it is necessary to be particularly acquainted with the several materials of which they are composed, in order to distinguish their good and bad qualities, how to prepare and use them, in the best manner, that the works may be durable and lasting; which ought in all such great undertakings be the principal view of an engineer, who is answerable for its success or miscarriage; this he is by no means able to perform without having a thorough knowledge of all the materials of which it is composed: But as these materials differ in their qualities in different parts of the country, where they are to be used; we shall explain first their general properties, and afterwards in what they differ in different places.

SECT. I.

Of the QUALITY *of* STONES *such as are used in* BUILDINGS.

STONES may be distinguished into two sorts, that is into hard and soft; the hard stone, is that which is exposed to the open air, such as rocks, and those which lie loose upon the surface of the earth, and in in ſeparate blocks: the ſoft ſtone is that which is found in quarries and under ground; it is undoubtedly true that the hardeſt ſtones make the moſt laſting works; but as there is ſeldom a ſufficient quantity of them, to build the whole fortification, the beſt ſerve in the facings of the works, in the foundations, and wherever, the works are bathed with water: for as the foundations ſupport a great weight, they muſt be made ſtrong accordingly, or elſe the works will ſoon be deſtroyed: therefore the outſide of rocks or the upper ſtones of quarries, being the hardeſt, are uſed for that purpoſe.

Altho the ſtones of ſome quarries are very ſoft and eaſily worked when they are freſh taken out, yet when expoſed for ſome time in the open air, become very hard and durable: therefore an engineer, who is employed in any particnlar place, may at all times know by the inhabitants, which of the quarries, if ſeveral, produces the beſt ſtones; he may likewiſe find by the buildings of ſome ſtanding, the quality of them; this will enable him to reſerve the beſt for ſuch works as require moſt ſtrength, and the ſofter ſort may be uſed in the inſide of the walls: but where there is but one quarry, he muſt examine whether ſome part is not better than others; in ſhort, a judicious choice of the materials, properly adapted, may render a building more laſting, than uſing them promiſcuouſly, as careleſs builders frequently do.

But if it happens that there is no quarry which has been opened long enough, ſo as to judge of the goodneſs of the ſtones, or where he is obliged to open new ones, he ought to expoſe the ſtones for a twelve month, at leaſt, to the weather, both to heat and cold, before he employs them; then if they do not ſplinter after a froſt, or do not moulder into dirt, when rubbed, he may be aſſured that the ſtone is good: and on the contrary, if they ſplinter or moulder, it is a certain proof of their bad quality.

5 Mr.

Mr. *Boyle* pretends, as he has been informed by workmen, that there is a sap in stones as well as in timber, by which the same sort of stone and taken out of the same quarry, if dug at one season, will moulder away in a very few winters; whereas if they are dug at another season, it will resist the weather for a great many years, not to say ages: but as he does not mention what season is best, nor gives any reason for what he advances; no rule can be gathered from what he says: we may say thus much, that they should always be dug in the spring, so as they may have time to dry before the cold weather comes in: for the heat of the sun will extract the greatest part of the moisture which otherwise expands in frosty weather, causes the stone to splinter, as it has been observed to do; altho' the stone is otherwise hard and good.

The same author says likewise, that some sort of stones will decay in a few years; and others will not attain their full hardness in thirty or forty years, nay even in a much longer time; and besides that there are quarries in some places of solid and useful stones, that, though being dug at a certain season of the year, prove good and lasting, yet when employed in a wrong time, moulder away, and perish in a few years. That there appears a seminal spirit, if I may call it so, in stone, is very probable; but what effect it has upon the stone when separated from its stock is very uncertain, and therefore cannot be known but by a strict inquiry of a long course of practice.

The manner of drawing the stones out of quarries, requires particular notice to be taken: for almost all stones lie in horizontal beds or stratas; that is, they cleave in that direction; and they have likewise a breaking one, which is perpendicular to the former, both which directions must be observed. The method of drawing stones out of quarries is thus: having uncoped it; that is, having removed the earth from the stone, it must be observed where it will cleave, and there drive in a good many wedges gradually together, till

it

it is loosened from the rock, which being done, you next proceed to break it, which is performed in this manner; you mark the breadth of the stone with a ruler, and then cut a small chanel in which a number of wedges are drove, from four to six inches distant from each other, slowly and all together, lest the stone should break across and not according to the mark; but it may be observed, that this method is not always to be used, because all the parts of a stone are not always of an equal hardness, but in some places it may be hard and in others soft, which is perceived in the cutting the chanel, and those wedges which are in the softer parts, are drove deeper than the other, in such a manner that all the wedges may press alike: this has been found by experience to be the best way of breaking stones.

Having thus broke them in length, which the stone-cutters can do, as they pretend, to any size within less than half an inch, which is sufficient for any rough stone; then you proceed to break them in breadth in the same manner as before in length. When these precautions are taken, the first expence is greater than if they were broke any how; but then there is little waste in the stones, the workmanship will be less, and saves expences in the carriage.

But when the stone is very hard they will not cleave so easily; for the workmen are then obliged to cut a pretty deep chanel, and so wide as to lay two iron bars in it, and to leave room besides for the wedges to be drove in between them, by which means the stones may be broken, which could not be done otherwise.

The workmen make at other times use of gunpowder to blow them up; which is performed in this manner: they make a small hole with a chisle, of an inch or a little more in diameter, sometimes vertically, and at others horizontally, as is most convenient, and as deep as they want to blow up stones; this hole being cleaned clear of all dust and rubbish, they put in some powder, then the rest of the cavity is filled with the same stone

beat

beat into duſt, and rammed in as ſtrongly as they can; in doing that they place a wire in the middle to preſerve a vent to ſet fire to the powder, and the rammer is hollow in the middle to receive this wire; this being done, and the powder fired, breaks off as much ſtone as they pleaſe; and the pieces are broken into ſuch blocks as are wanted. This way of breaking them is much cheaper than any other, but waſtes a great deal more ſtone, for which reaſon it is never uſed but where it is ſo plenty as that the ſmall pieces are no loſs, and which may ſerve as rubble to fill up the inſides of walls.

There are ſeveral kinds of ſtone; as marble, fire ſtone, purbeck ſtone, ray ſtone, alabaſter, free ſtone and common ſtone: of each we ſhall ſay ſomething in their order.

Marble is of various colours, as white, black, grey, green, ſome varied with ſpots and veins like the roots of trees; their nature and uſe are too well known to require any explanation; the marble found in *England* is moſtly black, and ſo very hard and difficult to poliſh, that very little uſe is made of it, except to burn and make lime; which is frequently done about *Plymouth*, where ſcarcely any other lime is uſed, as I am informed.

The fire ſtone comes from *Reygate*, and ſerves chiefly for chimneys, hearths, ovens, and ſtoves, being a dry porous gritty ſtone, which bears the heat without breaking, and it is, I ſuppoſe, on account of this quality that it has the name given of fire ſtone.

Purbeck ſtone is a hard greyiſh ſtone, and ſerves chiefly for paving, coping of walls, and for all ſuch uſes where ſtrength is required, as being the moſt hard and durable ſtone, after the *Plymouth* marble, we know of; it is found upon the [redacted] near the ſea ſide.

Rag ſtone is that which is commonly uſed in paving, and is of a blueiſh kind: but there is a ſtone called *Kentiſh* rags that are very uſeful in building; they ſplit very eafily and yet are very hard; a great quantity of this ftone has been ufed in *Weftminfter* bridge; they are brought down the river *Medway* from fome place near *Maidftone*.

Alabafter is a clear whitifh ftone not unlike marble; it is very plenty in fome parts of *Italy*, but there is none to be found in *England* excepting in fome parts of *Scotland*, where it is faid to be very plenty, and much ufed for making lime, which is exceeding good.

Free ftone is that which comes from *Portland*, an ifland near *Dorfetfhire*, and is commonly called *Portland* ftone: this ftone is chiefly ufed in and about *London*, in all great or fmall buildings; it is a fine whitifh ftone without any veins, but very dear; for it cofts about ninepence a cubic foot upon the fpot, and 16 cubic feet weigh a ton: this ftone is very foft when it comes out of the quarry, works very eafily and becomes very hard in time; the piers and arches at *Weftminfter* bridge are built with it. There is likewife a quarry of free ftone at *Bath*, of which moft houfes are built there: it has a fine whitifh colour, but I am informed that is not durable, and therefore is not fo fit for great heavy buildings as the *Portland* ftone.

When the ftones are drawn out of quarries and only roughly fquared, they are called afhler, but when they are fquared and finifhed, receive other names from the fituation they are placed. It may be obferved that when ftones are laid in the fame pofition as they are found in quarries, that is flat or horizontally, they will make better work than if they are laid any other ways: and they will cement ftronger together; this the workmen will not always obferve, unlefs care be taken to make them do fo.

SECT.

SECT II.

Of BRICKS.

BRICKS are made here of various kinds and colours; and have various names, as clinkers, samel or sandal, statute bricks, didoron, tetradoron, pentadoron, compass, concave, featheredge, triangular, cogging, place and stock bricks.

The compass bricks are of a circular form, their use is for steening of walls; the concave or hollow bricks are like common bricks on one side, but on the other they have a cavity, semi-cilindrical, about three quarters of an inch deep, and half an inch broad, so that if two of these bricks are placed with their hollow together, they are like a pipe of an inch and a half bore; they are usually a foot long, 4 $\frac{1}{2}$ inches broad, and 2 $\frac{1}{4}$ thick, they are generally laid in clay, and serve instead of leaden or wooden pipes to conduct water, as being much cheaper than any other materials.

Cogging bricks, are mostly used in *Sussex*, to make their work toothing or indented work under the copeing of walls built of great bricks: they are about ten inches long, 4 broad, and 2 $\frac{1}{4}$ thick. Copeing bricks are about 12 inches square, and 4 thick, flat underneath, and one third above is semi-circular, and the two ends flat.

Clinkers are nothing else than those common bricks that lie in the middle of the kiln or clamps, where they are so much burnt, that they are as if they were glazed all over; these bricks are always dearer than the rest of the same make, and are chiefly used in foundations, and facing the walls, especially where any water comes near the wall, as being the most durable.

Didoron were a ſort of bricks uſed by the antients of a foot and a half long, and a foot broad, but nearly as thin as common tiles. Great bricks are 12 inches long, 6 broad, and three thick; they are generally uſed in fence walls, made with pilaſters or buttreſſes, and in copeing. This manner of building walls ſaves great expences, and they will ſtand as long as if they were every where of the ſame thickneſs.

Paving bricks are made of various ſizes and forms, from 6, 8, 10, and 12 inches ſquare, and an inch and a quarter more or leſs thick; thoſe in the form of an hexagon look beſt; they ought to be of good earth and thoroughly well burnt, otherwiſe they will moulder away in a ſhort time.

Place bricks differ not in form, but in the manner of making them, being of the common dimenſions, *viz.* 9 inches long, 4 $\frac{1}{2}$ broad, and 2 $\frac{1}{4}$ thick, as the ſtatute brick; they weigh nearly five pounds each, though ſome will weigh 5 $\frac{1}{2}$; this depends on the quality of the earth they are made of, and on their being well burnt: A cubic yard contains about 460 bricks nearly; which at five pounds, makes two tons and 300 weight *per* cubic yard.

There are two ways of burning bricks, in kilns and in clamps; a kiln is a large hole in the form of a reverſed fruſtum of a cone, that is with the leſſer baſe below, built with brick, and a ſufficient quantity of earth about it, to keep the heat in as long as is poſſible; the bricks are not laid cloſe together, but leaving ſmall diſtances between them, that the heat may paſs between; and the fire is made underneath, where an opening is left for that purpoſe: This way of burning bricks is eſteemed the beſt, becauſe the figure of the kiln, and the wall about it, are ſuch that all the bricks within are nearly burnt of the ſame hardneſs; but where there is a great quantity required, it takes up much time to burn them, for which reaſon they uſe clamps in this caſe; which is nothing elſe than

than a great square or oblong pile of bricks laid so as to leave a small interval between them, for the heat to pass to the external parts; about this pile earth and bricks, which are not sufficiently burnt, are laid to keep the heat in. About *London*, where they have plenty of cinders, they throw some between each row, which helps to burn them much sooner, and with less fire than is otherwise required.

An ingenious brickmaker told me, that he could burn bricks as well in clamps as in kilns, provided he did it with wood; but the best way of burning bricks for a fortress, is to use both kilns and clamps at the same time, in order to have a sufficient stock of well-burnt bricks for the facings and foundations of the walls and other buildings.

A bricklayer with his labourer will lay 1000 bricks with ease in a day, when the wall is but brick and a half or two bricks thick, and therefore he may lay more in thick walls; and since a cubic yard contains 460 bricks, he will lay above two cubic yards in a day; and from hence it may be computed how many bricklayers are required to finish a certain piece of work in any given time.

An ingenious man, used much in brickwork, proposed a larger kind of bricks for walls to be built in water, or in a fortification; their size were to be 18 inches long, 9 broad, and 4.5 thick, and he affirmed to have made such bricks in *Scotland*. But a *London* brickmaker objected against them; that they could not be managed before they are burnt, as being too heavy, and it would be a difficult matter to burn them quite through: whether this objection is well grounded or not, I shall leave to those who are well versed in this business.

It is certain, that if such bricks could be made, they would be very useful in great works, both upon dry ground and in water, for in the latter case, they would not require so much terrass to lay them in as the

the ſmall ones, which, being very dear, would ſave great expences. The *Greeks* and *Romans* uſed bricks of 3 feet long and a foot broad, in their public buildings, but then they were very thin, that is, about an inch and a half thick, as may be ſeen in ſome old buildings, ſuch as the old caſtle at *Canterbury*; but at preſent brickmakers diſapprove all other ſizes but thoſe they are uſed to, not caring to go out of their own road.

An engineer told me, that he joined ſeveral bricks together with ſtrong mortar to compoſe as it were large ſtones, with which he formed the angles of the fortreſs: this muſt certainly make the walls ſtronger than by laying the bricks ſingly one after another in the uſual way.

It is my opinion, that bricks might be made of the ſize of four common ones joined together, that is 18 inches long, 9 broad, and 2 $\frac{1}{4}$ thick: For as they are no thicker than the uſual ones, they would require very little more burning, and ſeveral of theſe being cemented together, might ſerve inſtead of ſtone to ſtrengthen the wall in thoſe places where it is moſtly wanted; I propoſe this only in ſuch places where no ſtone is to be had, becauſe it is very certain that, wherever that can be had, it is much better than bricks.

It has been objected, that bricks will not laſt in ſalt water; but by conſulting Mr. *Bratte*, the maſter bricklayer of the ordnance, a man of great practice, he told me, that if the bricks were well burnt, ſuch as clinkers, and made of the ſame clay without any mixture, they would laſt as long in ſalt water as any ſtone whatſoever; as a proof of which he had built the wharfs at *Woolwich* and *Chatham*, and beſides, in ſome other places they were uſed, and without the leaſt appearance of any decay, though a good many years ago.

A friend

A friend of mine told me, that he had seen piers of an harbour at *Arles* in the southern parts of *France*, entirely built of bricks, and of such an age, that the sea has quite left the harbour which is now upon dry land.

There is a kind of bricks called grey stock, which make a very beautiful appearance in buildings, and are chiefly used in and about *London*, in all front walls, which are exposed to view: The Duke of *Norfolk's* house in St. *James's* square is built of a particular sort, the most beautiful that ever were seen, but they are very dear; these bricks are made in the country, and of a composition which I could not learn, it being a kind of mystery known but by a few workmen. Mr. *Bratte*, our master bricklayer, shewed me some bricks of a pale whitish colour, the finest sort I ever saw; they appeared to me, as if they were made of red clay mixed with chalk, are very hard and sound like a hard stone; the insides of the pieces are very smooth, without any cavities: If these bricks were better known, I think they would be preferred to any other sort that I have yet seen.

The best way of making bricks, is to dig the earth before winter, and to let it be exposed to the weather during the winter, which mellows the earth very much, and saves a great deal of labour in preparing it, and the bricks should be made in *April*, *May*, *June*, or *July*; for after that season the weather grows damp, and then they will not burn so well; and it is pretended by able bricklayers, that bricks should be two years old before they are laid, in order to make good work, and no brick-work should be made after the month of *August*; because the mortar has not time to harden before the damp weather comes in; by which it peals off, and the works require new pointing the very next summer, as I have been myself an eye-witness to such works.

As bricks are nothing else than artificial stones to supply the want of real ones, there is no doubt but their durableness depends on the goodness of the materials, well mixt, prepared, and well burnt; and therefore, an engineer that propoſes to make good works, muſt be very careful in his choice; but the beſt way to prevent any impoſition, is to have the bricks made near the place where the fortreſs is to be built, by ſkilful workmen, where the engineer, or thoſe under him, may obſerve the workmen, ſo as to perform their work in a proper manner; and the government will have them much cheaper than to buy them by contract, as is the cuſtom.

SECT. III.

Of LIME.

LIME is made of all kind of ſtones, that will calcine; that which is made of the hardeſt ſtones is the beſt, and the worſt of all is that made of chalk; the way of knowing whether a ſtone is calcinous, is to take a ſmall piece, the ſize of a walnut, and burn it in a common fire, and after it is red hot, to let it cool, and then fling ſome water on it, and if it ſmoaks and diſſolves, it is a ſign that it calcines; but the eaſieſt way of knowing upon the ſpot whether a ſtone will calcine, is to carry a ſmall viol of *aqua fortis* with you; by letting fall a few drops on the ſtone, it will boil and diſſolve a part of it, if the ſtone will calcine; but if it lies upon the ſtone like oil, and does not ferment, you may be certain that it will not calcine.

I have tried a great many ſorts of ſtone, firſt with *aqua fortis*, and then in the fire, and have found the experiment to anſwer: I was told that free-ſtone, ſuch as comes from *Portland*, would not calcine, but I found the contrary by both experiments; others pretend that flint and a kind of gritty pebble ſtone make the ſtrongeſt lime; but all the trials I could make

would

would not calcine them; for which reaſon, I am of opinion, that they make no lime, and thoſe who pretend they do, have it only from hearſay, without any other proof.

It is my opinion, that all ſtones that have any metallic particles in them, and thoſe that will vitrify, will never calcine, at leaſt, I always found it ſo; but leſt I ſhould be miſtaken, I leave it to the chemiſts, and thoſe that have an opportunity of making more experiments than I, to decide it.

Different counties in *England* produce different kinds of lime-ſtones; in *Kent*, where there are a great many chalk-pits, they make their lime of chalk, and the greateſt part of the lime uſed in and about *London* comes from thence, chiefly becauſe of the conveniency to bring it by water, which makes it much cheaper than any other that is brought by land: But this ſort is the very worſt that can be made; it is true, it may ſerve very well for whitewaſhing, and other things in the inſide of a building; but as moſt buildings are upon leaſes, people are not ſo nice about the ſtrength and goodneſs of the work; provided it laſts as long as they want it, it is ſufficient.

I have been informed that about eight miles from *Portſmouth*, is a chalky rock, pretty hard, that makes very good lime, and has been much uſed in building the fortification of that place: although the *Purbeck* ſtone which is not a great way of, and the fragments of *Portland* ſtone, make exceeding good lime: I ſuppoſe the former lime is uſed, not becauſe it is better, but cheaper than the other, which is a very bad reaſon, ſince all public works, which are of great importance, ought to be made as ſtrong and durable as is poſſible; for what is ſaved by cheapneſs of the materials, is loſt by the ſhort ſtanding of the works.

The beſt lime in any part of *England*, is that which is made of the marble, found near about *Plymouth*, and is very much uſed in all the country thereabout; the

Romans

Romans and *Italians* made uſe of no other lime than that of marble, in all their great and public buildings, it being the very beſt that can be made, and of conſequence, makes the buildings more laſting than any other.

Moſt builders in this country do not ſtand ſo much upon a good reputation, as to make moſt money of their works; and few gentlemen enter into the knowledge of building; ſo that the works are generally badly executed; provided the outſide of walls appears well, it is no matter how the reſt is. What ſpoils the method of making ſtrong and good walls is, that moſt houſes in and about *London* are built upon leaſes, ſo that if they but ſtand the number of years propoſed, the proprietors are ſatisfied, and give themſelves no further trouble; this cauſes the workmen to make their work in a ſlight and expeditious manner.

I am informed, that in moſt parts of *Scotland* there are exceeding good lime ſtones, and in great quantity, in ſuch a manner as to uſe the ſame ſtone for lime as they build with; in ſome parts they have alabaſter, which makes as good lime as marble. In *Ireland*, eſpecially about *Dublin*, lime-ſtones are likewiſe ſo plenty as to build with, which makes the beſt work; becauſe the mortar unites better with the ſtone, than if the parts were diſſimilar.

An engineer employed in any part of the country, ought to examine all the different ſtones to be had thereabouts, in order to find that which makes the beſt lime, and ought not to chuſe any becauſe it is the cheapeſt, which can ſcarcely be excuſed in private buildings, but ſuch as will make the beſt work; and ſince lime is the very ſoul of good manſonry, it cannot be too good; but if it ſhould ſo happen that all the lime in the country is very bad, he ſhould get as much from other parts that is good as to ſerve for the facings of the wall, for fourteen or fifteen inches deep; the reſt may be done with the cheapeſt ſort.

Lime

Lime is burnt in kilns much like thoſe of bricks; and the ſtones muſt be broke into pieces the bigneſs of a fiſt, and more eſpecially ſo when the ſtone is very hard; but when they are ſoft, ſuch as chalk, it requires not ſo much precaution: Care muſt be taken to burn it every where alike, and thoroughly; otherwiſe, thoſe parts which are not well burnt, will not ſlaken with the reſt, and when the mortar is employed, will diſſolve, and diſunite the wall wherever there is any of them.

There is likewiſe lime made of all ſorts of ſhells of ſea fiſh, which is eſteemed to be exceeding good, becauſe it dries and hardens in a ſhort time, for which reaſon it is mixt with *Dutch* terraſs, and uſed in all aquatic works; and, as it is much cheaper than terraſs, it ſaves great expences.

It muſt be obſerved, that thoſe ſtones taken out of quarries which are damp, make better lime than thoſe found above ground and are dry; it has likewiſe been found, that the dryeſt part of rock, and which is expoſed to the ſun, will make a different lime from that made of the inner part, which is damp and not expoſed to the ſun: Therefore an able engineer ſhould not only try the outward parts of a rock, or a quarry, but likewiſe thoſe parts which are not expoſed to the ſun and weather; otherwiſe he may poſſibly reject the beſt part as uſeleſs.

SECT. IV.

Of SAND, TERRASS *and* POZOLAN.

ALTHOUGH there appears very little difference in ſand, yet there is ſome which being mixt with lime makes much better mortar than others: In common buildings, they always uſe that which is neareſt at hand, and in *London* they beat the rubbiſh of of demoliſhed buildings, and uſe it as ſand; but in works of conſequence, ſuch as thoſe of a fortreſs, ſuch a practice ought to be rejected; the beſt materials ſhould be uſed in order to make durable work, for which reaſon greater precautions muſt be taken; and it is for the ſake of thoſe works we intend the following obſervations.

The beſt ſand for good mortar is that whoſe grain is not too ſmall, which is clear and free from earthy particles; for the ſmall-grained ſand has been found not ſo good, as being too fine to form a ſolid body when mixt with lime.

The manner of knowing whether ſand is free from earthy particles, is to take ſome and rub it in your hands, and if it makes them dirty, it is a ſure ſign that it is not pure, but if it be gritty and leaves no dirt behind it is very good. If it ſhould happen that no good ſand is to be found near the place where it is wanted, the beſt way will be to waſh as much as is required to make ſtrong mortar, for facing, and pointing arches, and other ſuch like works; that is, you put a good quantity into a tub, and fill it with water, then ſtir it well with a ſtick, and let the water run off; pour clean water in again, ſtir it and let it run out; this being continued till the water is pretty clear, your ſand will be clean.

Sand found in rivers is eſtemed the beſt, becauſe it is of a pretty coarſe grain, and moſtly free from mud; others will have it that ſand out of the ſea or ſalt water is likewiſe very good; but as for my part, I would not chuſe to uſe it, where good work is to be made, becauſe ſalt, if I am not miſtaken, is a bad ingredient for mortar; this will be explained hereafter.

It has been found by experience, that ſand ſhould be uſed freſh, and before it has been too much expoſed to the air; for it is ſaid, that dry ſand never makes good mortar, although mixt with a ſufficient quantity of good lime; and therefore when a large quantity is brought

brought to the place where it is wanted, it ſhould be covered ſo as the ſun may not ſhine upon it.

Inſtead of ſand mixt with lime to make mortar, ſeveral other things are uſed, ſuch as cinders, tiles, ſcalings of iron out of forges; but theſe ingredients muſt be well beat, ſo as to make a fine powder of them. I made ſeveral experiments with theſe materials, and found when they were well mixt with lime they made excellent mortar; ſome of which being put into joints of walls in the month of *December*, the weather being very damp, and others kept in a warm room, made up in ſmall balls, that which was expoſed to the air dried as ſoon, and grew as hard, as the other: Neither could I perceive any difference between the mortars made of theſe different ingredients, for they grew all equally hard nearly at the ſame time, although ſome pretend, that the ſcalings of iron make the ſtrongeſt mortar.

I have been told by a gentleman, that he has ſeen mortar compoſed of ſcalings of iron, and common lime, to be uſed in ciſterns, and that it grew ſo hard that the water could never penetrate it; but it muſt be obſerved, that mortar of this kind is worked with very little water, in ſuch a manner as to become like a ſtrong clay.

There are ſeveral other kinds of powder uſed in mortar inſtead of ſand, eſpecially for ciſterns and aquatic works; there is a ſort which is called pozolana, from the name of the place it comes from, which is in the kingdom of *Naples*; this powder is of a reddiſh colour, and when mixt with lime grows preſently hard and remains ſo although in water.

Another ſort made of a ſoft rock ſtone, found near *Collen* upon the lower part of the *Rhine*; it is burnt like lime, and afterwards reduced to powder by means of mills; from thence it is brought to *Holland* in great quantities, where it has acquired the name of *Dutch* terraſs; it is of a greyiſh colour when it is not mixt, which is very ſeldom the caſe; becauſe it is very dear, and

and abſolutely neceſſary in all aquatic works, and ſo they make as much of it as they can.

We have forgot to mention before, that lime ſhould be burnt with coals and never with wood; the reaſon given for it is, the coals being ſtrongly impregnated with ſulphureous particles, which mixing with the lime makes it more glutinous; and it has been found that the mixture of the cinders and the ſmall particles of lime, found in the lime kiln, being reduced to a powder and uſed inſtead of ſand, compoſe a mortar as ſtrong for aquatic works as *Dutch* terraſs. The reaſon of this appears to be owing to the particles of lime being mixt with the cinders and unſlakened; when they are mixt with lime they ſlaken and dry up the watery parts of the lime, and leave no more moiſture in it than what is ſufficient to lay hold on the bricks or ſtones, and compoſe as it were one ſolid body.

I have been informed, that in ſome parts of *England*, which is *Dorſetſhire*, if I am not miſtaken, is found a ſoft ſtone, much like that of *Dutch* terraſs, and that it might ſerve full as well in aquatic works; if this be true, I am ſurprized that it is not better known, ſince it would enable us to make theſe kind of works of our own materials, and much cheaper, than to buy them from the *Dutch*, who often mix it with other things, to get the more by it. As for my part, I do not doubt, that, if there was a proper enquiry made by ſuch as have it in their power, they might not only find ſuch ſort of lime ſtone as that which the terraſs is made of, but likewiſe the ſort which makes plaſter of *Paris*.

N. B. There is at preſent ſuch terraſs made here, and ſold for eighteen pence a buſhel, whereas the *Dutch* coſts two ſhillings, and is not better.

SECT.

SECT. V.

How to prepare and make MORTAR.

THE manner of making mortar is quite different in different countries, and even in the ſame country by different builders; the common way in and about *London*, is, to lay the lime ſtones upon a heap, and cover it with as much ſand as is thought requiſite for making the mortar; then they fling ſome water on it, ſo as the lime may ſlaken gradually and mix it at the ſame time, which they continue till the lime is ſlakened; when this is done, they paſs it through a ſcreen the next day, in order to ſeparate it from the ſmall ſtones, which have not been ſufficiently burnt to ſlaken ſo ſoon; after this they mix it and beat it well; and uſe it immediately without any further ceremony.

But our engineers uſe greater precautions; for they mix and beat it every 24 hours for a week together, and then let it lie for a week more, and when they uſe it, beat and mix it again; by this means it will make good mortar although the lime is but indifferent, provided, there is not too much ſand put into it.

The proportion moſt commonly uſed in the mixing of lime and ſand is, to a buſhel of lime a buſhel and a half of ſand; that is two of lime and three of ſand; this however is no general rule, for ſome lime is fatter or more glutinous than others, and therefore will bear a greater quantity of ſand. The common mortar in and about *London* has more ſand in it than according to the proportion above: for provided there is juſt lime enough to keep the ſand together, the workmen are ſatisfied: and they make large joints, becauſe this kind of mortar being cheaper than bricks, they get ſo much more by their work, than if they made the joints ſmaller; but if they are obliged to make good mortar, they make ſmaller joints, becauſe the mortar coſts them more than bricks.

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The *French* make their mortar in a quite different manner; for they dig a ſquare hole in the ground, a foot or 18 inches deep, and large in proportion to the quantity of lime they intend to ſlaken; they floor the bottom with boards; then they throw in lime firſt 6 or 8 inches deep, and pour in as much water as will juſt cover the lime; which they ſtir till the lime ſtones are diſſolved; when this is done they make their mortar in a few days after: this is the common practice, but in works of conſequence, they cover it with one third of ſand and let it lie for a twelve-month. It is pretended that the ancients ſlakened their lime many years before they uſed it; and there are ſome who ſay that freſh mortar is better than old: but in my opinion the nature of the lime ſhould be conſulted; for when lime is very ſtrong, by letting it lie too long it will grow hard and unfit for uſe, as it happend at *Metz*, as Mr. *Belidor* ſays, where they let it lie a twelve month, in which time it became as hard as ſtone: but when lime is bad, I take it, the longer it lies the better it becomes.

Two things are to be obſerved, in order to make good mortar, which are, that no unſlackened particles of lime remain, and not putting too much water in it when it is prepared: therefore if lime is kept till every part is ſlakened it will be ſufficient. It muſt likewiſe be obſerved, that burnt lime ſhould not be kept too long before it is ſlakened, becauſe it evaporates and the air makes it loſe its property; but when lime is once ſlakened and well covered with ſand, as likewiſe under ſhelter from the ſun and rain, it will keep as long as you pleaſe, provided it does not grow too hard.

The water that is uſed in the ſlaking of lime, requires likewiſe to be conſidered; for if it be dirty and full of mud, ſuch as is gathered in the ſtreets, as they do at *London*, it will ſpoil the mortar; it is imagined that all kind of clear freſh water is good; but I believe the ſofter the water is, the better: ſome pretend, that ſalt water out of the ſea may be uſed; but for my part I think it muſt diminiſh the goodneſs of the mortar very much: For it is well known that ſalt gives way and becomes fluid in damp weather, and therefore in winter, the mortar which is impregnated with ſalt muſt neceſſarily become ſoft, whereby it loſes the property of binding bodies together in bad weather, when it ſhould have moſt.

Mortar that is to be uſed directly, which ought never to be done but in caſes of great neceſſity, ſhould be ſlakened by covering it with ſand on a platform, and the water thrown over it little by little, ſo as to diſſolve it gradually, and then paſſing it through the ſcreen to free it from the ſmall ſtones not diſſolved; this being done, it ſhould be well beat and worked once a day for a week, and let it lie for another, and when it is uſed, to work is well again; and no water ſhould be uſed but the firſt time: but when mortar can be made betimes, it may be made in the manner mentioned above, and let it lie for about ſix months, which will be ſufficient to diſſolve all the parts of the lime that is burnt, and the reſt which are not burnt will not affect the work; although thoſe that are found may be thrown away.

The mortar made for ceilings is different from that we have been ſpeaking of; it is made of ox or cows hair well mixt and tempered with lime and water, without any ſand. The common method of making this mortar is, one buſhel of hair to ſix buſhels of lime; the hairs ſerve to keep the lime or mortar from cracking, and to bind and hold it faſt together.

Mortar made of terraſs, pozolana, tile duſt, or cinders, is mixt and prepared in the ſame manner as common mortar; only theſe ingredients are mixt with lime inſtead of ſand in a due proportion, which is about half and half. As this mortar is deſigned for aquatic buildings, the reader may eaſily imagine that the lime uſed in it ought to be the very beſt that can be had: for which reaſon, lime made of ſhells or of marble is what ſhould be had if poſſible, but in ſuch works which are ſometimes dry and at others wet, inſtead of terraſs, which is very dear, tile duſt or cinder duſt may be uſed, and is eſteemed to be the beſt mortar for ſuch work; for it has been found that terraſs mortar is not ſo good where the work is expoſed to the air.

In fortifications, docks, or piers of harbours, I would lay all the parts of the works under water with terraſs mortar, and the reſt of the facings, both within and without, with cinder or tile duſt mortar, for about two feet deep; for if this was done, the walls would not require to be pointed and repaired as they commonly do: cellars, and all kinds of arches or vaults, under and above ground ſhould likewiſe be done with this mortar: and the cinders out of lime kilns mixt with the particles of lime ſtone, is, in my opinion, ſtill preferable, for the reaſons given in ſection III. As to ciſterns, they require terraſs mortar as well as all the works which are conſtantly under water.

The ſtrength or goodneſs of mortar does not only depend on that of the materials of which it is made, but likewiſe on the manner of preparing it: for the workmen put generally much water in it to make it liquid, in order to ſave labour in mixing it; if this be done, the mortar will never be good for any thing: but if little or no water is uſed after it is ſlakened, and well beat, and mixt till it becomes ſoft, and this be repeated ſeveral times till it becomes glutinous, you may depend upon it, that the mortar is good.

A very able perſon, who has been employed a great while in the works of fortification, told me, that he wets his mortar very ſparingly, but beats it well every day for a week, and then lets it lie for a week or a fortnight before he uſes it, and has it well beat over again: this method is undoubtedly very good, and ought to be uſed in all the works of fortifications, ſince they are a great charge to the nation, and therefore whoever has the direction of them ought in a manner to be anſwerable for their goodneſs.

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A contrary practice is followed by some others, who have the direction of works; for I have seen, after works have been done, the mortar crumble off like sand, and when examined, found the lime in lumps, and not half mixt with sand; what can be expected from such work, I leave the reader to judge. Others pique themselves upon making the work look regular; and will have every course of bricks to be three inches high: and as the bricks are but two inches and a quarter thick, the joints must be three quarters, from whence the goodness of the work may be judged: instead of making the joints so large, I would oblige the bricklayers to make them only a quarter of an inch thick, which is sufficient.

Joints of Brickwork

Another observation is to be made, which is, that in all walls that have a slope, the courses of brick ought to be perpendicular to the slope, and not on the same level as is customary; and this for two reasons; first, all stones being cut square cause least waste, and are easier to the workmen; and when bricks are used, the joints are equally thick throughout; whereas, when the courses are on the same level, they raise the bricks on the outside, so as to make the slope, which makes them wider there than within; and when the mortar is not very good, the walls require pointing very often. Another inconvenience arises, that the outside of the course is perpendicular to the slope a brick length, and the rest lie horizontally, by which they make an angle or bending, so that the bricks of the same course can never bind together, and the outside of the wall is no more than a shell the depth of a brick, separated from the rest of the work.

SECT. VI.

Of PLASTER.

PLASTER is different from common lime, in that it composes a solid body by itself, without mixing either sand or any other ingredient, as is done in lime.

It is made of a bluish soft stone, taken out of quarries, which generally are at the side of a hill, much like the stone of which *Dutch* terrass is made. This stone is burnt in the same manner as lime, and when cold, beat into a fine powder, or dust; and when it is to be used, about a bushel is put into a tub and water poured in, till it becomes liquid; then it is well stirred with a stick, and used immediately; for in less than a quarter of an hour it becomes hard, and good for nothing; another of its properties is, that it will not bear mixing a second time, as lime will do.

Although plaster is to be found in most countries, yet nobody I know, has given a method to distinguish it from lime stone: I am apt to think, that it may possibly be the same sort of stone as that found near *Collen*, of which the *Dutch* terrass is made; and if it is not the same sort, it comes very near to it; for it dries very quick, and makes a very hard body: it is said not to remain hard in water, but I never heard that it was tried with mixing it with lime; for which reason, I will not affirm it to be the same as terrass.

That which is found in a hill near *Paris*, is esteemed the finest, and brought to *England* chiefly to make busto's, and to take off medals, as well as all kind of statuary works; but there it is used in flooring, and to line the inside of stone walls, instead of common mortar. But the plaster found in this country, being of a coarser sort, is chiefly used to make floors for gentlemens houses, and for granaries to keep corn in.

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The only way to know the ſtone, is to burn it in a fire, and reduce it to a fine powder; then if it grows hard immediately after it has been mixt with water, you are certain that it is plaſter; although the ſtone is of a blue greyiſh colour at firſt, yet it becomes very white by burning, and when mixed with water, it does not ferment or grow hot like lime.

Having thus given the quality and manner of preparing the chief materials uſed in works of a fortification, in the preceding ſections, as far as we poſſibly could from our own obſervations, and what we could gather from other authors; to which, if the young engineer will join his own obſervations with thoſe of his ſuperiors, under whom he is employed, eſpecially to thoſe of able workmen, I do not queſtion, but he will be able, not only to judge whether works are well executed, either in the whole or in parts, but likewiſe know how to proceed whenever he ſhall be employed as the chief director over ſuch works, for which reaſon, we ſhall proceed to what remains to be ſaid of this ſubject.

PART III.

Containing the manner of tracing a Fortreſs on the Ground, to make an Eſtimate, and to execute the Works.

SECT I.

Shewing the USEFULNESS *and* NECESSITY *of building* FORTRESSES.

THE neceſſity of building fortreſſes in all ſtates whatſoever, appears from this innate principle of ſelf preſervation; for a powerful nation has always powerful enemies; ſo that by the loſs of a battle, the whole country is in danger, if the remainder of the routed army has no place of ſafety to retire into, where they may rally and receive ſuccours, either from their allies, or new-raiſed troops from that part of the country, which the enemy is not yet maſter of.

It has often happened, that after an army has been defeated, it has received ſuch ſuccours in a place of ſafety, as not only to have been able to ſuccour their own country, but likewiſe drive the victorious army out of the field with loſs. There are many ſuch examples to be found, both in antient and modern hiſtories: Whereas, if an enemy gets once the victory in a country that has no fortreſſes, he is at that inſtant maſter of the whole ſtate.

An example of this kind has happened here in *England*; for had there been ſome good fortified places, when *William* the conqueror entered the country, it would not have been loſt by gaining of one battle; and had the town of *Genoa* been fortified in the laſt war, the *Auſtrians* could not have taken it at once, and been maſters of the whole ſtate, as they did; in ſhort, were it not for the many fortified places in *Flanders* the *Auſtrian* dominions in that country would have been long ago loſt.

In ſmall ſtates and republics, they are no leſs neceſſary than in great kingdoms, in order to reſiſt a powerful enemy, till ſuch time that their allies can come to their aſſiſtance. To this it may be objected, that fortified places in a free ſtate, may be a means to enſlave it by ſome ambitious and powerful man, aſſiſted by a neighbouring prince; but as no ſuch examples are recorded in hiſtory, as far as I know, and the contrary is evident, by the ſtates of *Holland*, who have many fortified places, and yet have preſerved their liberty, ſince their firſt ſeparation from the *Spaniards*, it is evident, that this objection has no foundation.

Maritime powers, and thoſe who inhabit iſlands, ſuch as *England*, *Sardinia*, *Sicily*, *&c.* require no leſs fortified places; for as an enemy may invade them by a ſurprize, and though his naval force be leſs, yet, when he once gets a footing, he may either conquer or deſtroy the country. Beſides, their trade, on which iſlanders chiefly depend, would become very precarious, without having ſome ſtrong place or other to ſecure their effects in, which otherwiſe might be ſurprized and carried off, before an army can arrive to defend them. Many other arguments might be alledged to prove the uſefulneſs of fortified places, were it not that all the world is convinced of it at preſent, and therefore it would be needleſs to ſay any more about it.

SECT. II.

Of their SITUATIONS.

THE situation of a fortress depends chiefly on the reason for which they are built; for if they are to promote or protect trade, they must be placed near the sea, lakes, navigable rivers, or channels; if they are designed to guard a pass or inlet into a country, they are placed on hills or high ground, that from thence they may infilade and defend that pass, and so as not to be commanded by any other adjacent hill; or near the passage of a large river; and if they are to secure a country from an invasion, they must be situated in such a manner, that the enemy must attack them before he can advance any farther; and in case he should pass by and leave them behind, they may cut off his communication with his own country, whereby his convoys may become precarious and difficult; and therefore must either advance farther or else besiege them.

In islands, the best situations are upon the coasts, and in such places, where an enemy may easily land, and where the garrison has a safe communication with some inland town, to receive succours and subsistance in case of an attack; or if there are any great rivers, that run into the sea, and where ships may come up into the country, there should always be one or more fortresses built near them, in such places, as may prevent the ships from passing by, without suffering greatly from the cannon placed there, and where the approach is very dangerous.

In an island of no very great extent, whose coast is of an easy access, in most parts, and where it is impossible to fortify every one; the best situation for a fortress is the middle of the island upon a rising ground; because

because troops may best be sent from thence to any part, to oppose the landing of an enemy; but this fortress should be pretty large, that, in time of need, the inhabitants of the country may retire into it with their cattle, and other most valuable effects, and help to defend the place, till the enemy is obliged to retire, either for want of provision, or having no hopes to get masters of the place.

But if the island is considerable, it is not sufficient to build fortresses near the most convenient landing places, but there should likewise some be built in the passes, to prevent an enemy from entering farther into the country, in case he should land, notwithstanding the forts on the coast; or at least to stop and protract time, so as the country may rise and come to oppose him.

In small states, that lie in an open country, which cannot afford the expences of building many fortresses, and are not able to provide them when built with sufficient garrisons and other necessaries for their defence, or those whose chief dependance consists in the protection of their allies; the best way is to fortify their capital, which, being made spacious, may serve as a retreat to the inhabitants in time of danger, with their wealth and cattle, till the succours of their allies arrive.

If a fortress is built near a river, lake, or sea, it must be considered whether it should stand quite close to the water side, or at some distance, so as the works may not be battered by the ships; whether an enemy may easily land thereabouts, and attack it by land; whether the ships may come close, or the water is shallow; when the water is so deep that ships can come up close to the walls, the parapets must be made high, and those that can be seen from the main top, should be covered above with canvase, planks, or with any thing else in time of siege, to cover the troops behind them.

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When a fort lies ſo near the water, that it may be battered from the ſhips, it is in danger of being ſoon deſtroyed by the ſuperiority of their fire; on the contrary, when the water is ſo ſhallow, that the ſhips cannot come near enough to batter in breach; care muſt be taken that the enemy may not land in their boats, and ſtorm it by land; to obſtruct which, redoubts or batteries muſt be built, to reſiſt both in front and in flank; and if they can land any where beyond the reach of cannon, theſe redoubts or batteries muſt be fortified all round with a wall and good ditch, that they may not be ſuprized in the rear; as we did at *Cape Breton*, where the large battery fronting the entrance of the harbour, was ſurprized, and the guns turned againſt the town, by which it was obliged to ſurrender; this would not have happened, if the precaution mentioned above had been uſed.

In a place where there is a harbour, ſome parts or other of the fortreſs ſhould command it, if poſſible; for though redoubts and batteries are made to defend its enterance, yet if the enemy finds means to deſtroy ſome, and paſſes by others, the harbour lies open for the ſhips to come in, without any farther obſtacle: and as theſe defences are at ſome diſtance from the fortreſs, they are always taken either by ſtratagem or main force; as being ſeparate from the garriſon, and are not eaſily relieved. But if part of the fortreſs commands the harbour, the ſhips are never ſecure in it till the place is taken, which is all that can be expected.

It is true, that the entrance ſhould not be neglected; for wherever there is a point of land that commands the approach of an enemy, it ſhould be carefully ſecured by ſome work or other; and as it often happens that ſmall rocky iſlands lie in the entrance, which, when properly fortified, are very advantageous in the defence of it: Nothing conduces ſo much to the ſafety of a place, ſituated near the ſea, or navigable river,

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as those works which keep the enemy's fleet at a distance; since thereby their main strength is of no use to them; and though they should make a descent in some part or other with a few small pieces, yet these may be easily repulsed by the garrison. As these kinds of situations are the most useful to a trading nation, we have so much the longer dwelt upon the method of securing them in the best manner possible.

When an old fortress is to be rebuilt, the engineer ought not to rely too much on the capacity of him who had made it first; he should consider whether there is no other situation thereabouts, that might be better than the former; whether the old works were properly adapted to the nature of the ground; how much expence will be saved by building upon the old foundations; whether it is too big or too little; whether by following partly the old plan, and building the rest in a different manner, it would not be better than to follow it in all its parts; or whether by chusing another situation, it would not be too expensive in respect to the advantage gained thereby; in short, he should leisurely, and well consider every minute circumstance, in order to form a true idea of the situation, the figure of the works, and the consequences resulting therefrom, before he determines his choice.

An engineer, who is truly conscious of the trust reposed in him, ought to be extremely cautious in all his undertakings, and well consider, that he is, or ought to be, answerable for all extraordinary and useless expences, which he causes to the nation, either for want of skill, or inapplication; and if a nation was rightly sensible of the trust they put upon them, I am persuaded that they should be very careful, and well examine those who are desirous to enter into such employments, before they admit them.

An engineer requires much greater skill in arts and sciences, than is generally imagined; for it is not sufficient to know how to draw plans, profiles, and land-

skips,

ſkips; to underſtand a few propoſitions in geometry, or to know how to build a wall or a houſe; on the contrary, he ought to be well grounded in all the moſt uſeful branches of the mathematics, and how to apply them to practice, natural philoſophy, and architecture; have a good notion of all kind of handicraft works; and above all things, to be well verſed in mechanics.

As the variety of nature is infinite, ſo it is impoſſible to deſcribe all the different ſituations, where fortreſſes ſhould be built; it requires the greateſt ſkill and knowledge to fix upon ſuch as may anſwer beſt all the different expectations; and as the building and maintaining them is attended with very great expences, when they do not anſwer the intent for which they are built, they are heavy burthens to a nation, without any conſiderable advantage: for which reaſon an engineer ought ſeriouſly to conſider what he is to do before he begins ſuch an undertaking: It is my humble opinion, that the choice of the ſituation, and the making a ſcheme of a fortreſs ſhould not be intruſted to any ſingle perſon; on the contrary, the expence of ſending five or ſix upon the ſpot, and in concert making a proper choice of the place and works, would be more than ſaved in the execution.

SECT. III.

OBSERVATIONS *relating to the* SITUATIONS *of* PLACES.

IN the former ſection we have treated of ſituations in general, it remains now to obſerve the particulars which are neceſſarily to be known, before the ſcheme or project of a fortreſs is fixed upon. The firſt thing to be conſidered, is to know whether the air is wholeſome; for it would not be for the intereſt of a ſtate, to build a place of that kind without the inhabitants being in a way of increaſing, in order that there may be be no occasion of sending often a supply of people; besides, a garrison in such a place, would continually weaken to such a degree, as would make the taking it very easy.

This may be known by the colour and strength of those who live there, or near the place; and if it is not inhabited, it may easily be known by the situation; because if it be surrounded by low and marshy ground, the place is certainly unwholesome; on the contrary, if the place is a dry soil, and produces plenty of wood and grass, and there are a great number of birds, or wild animals, it is no less certain, that the situation is wholesome and fruitful.

The next thing to be considered, is to know whether there is a plenty of fresh and wholesome water, sufficient for men and beasts, for without that, no place ought to be fortified, unless it may be supplied by some spring not far off, and which an enemy cannot cut off in time of a siege; otherwise, it would be impossible to defend it for any time. It may be observed, that all sweet waters are not equally wholesome; for it has been found by experience, that very clear and well-tasted water, has occasioned particular distempers to those that drank it constantly. Besides, as some waters will cure distempers, why should there be none of contrary qualities? The air of some places is esteemed unwholesome, when it is rather the water that occasions the distempers. It has been pretended, that the lightest waters are the best to drink: but Mr. *Cotes*, in his Hydrostatic lectures, has compared the weights of all the different waters that he could get, even some of the river *Ganges*, which is esteemed the best in the world, but could not find any sensible difference in their specific gravity; if this be the case, its goodness cannot depend on its lightness, but rather, on some quality imbibed from the soil, through which it runs, which cannot be distinguished by the taste: Others say, with some justice, that if water be boiled a good a good while, and let ſtand for a time, till it is quite cold, and when no ſettlement is found at the bottom of the veſſel, it will be wholeſome; this may be better known, by uſing the ſame veſſel for ſome time, and then obſerving whether any ſediments are found; for there may be ſo little at firſt, as not to be perceived, yet in length of time may gather ſo much as to make it appear quite plain.

I have been told by a gentleman of veracity, that very clear and well-taſted water, ſpringing out of a rock in *Ireland*, petrifies every thing on which it falls, in a very ſhort time: Therefore water of that quality can never be wholeſome, either for man or cattle.

Water ſeems to receive its chief quality from the nature of the ſoil, through which it runs, as we have obſerved before; as for inſtance, when it comes out of a rock, or of a gravelly ſoil, it is clear and cold; that which comes out of chalk, is ſoft and milky; and that of a marſhy ſoil, brackiſh; this latter ſort is the worſt of all.

If the inhabitants, or thoſe who live near the place, are ſubject to any particular diſtempers, more than thoſe in others, either the water or the air is unwholeſome; it may eaſily be known, whether the air is good or bad; for if there is any ſtagnated marſhy water adjacent to the place, the heat of the ſun draws up the corrupted particles, which fall in the cool of the night, and infect the air; but if there be no ſuch places near about, the air will be good. It is ſaid, that in bad air, the livers of birds and animals are full of ſpots; but wheth r this is ſo or not, I cannot ſay.

Next to the water, fuel to make fire is to be conſidered; it muſt therefore be enquired, whether there is wood, coals, or turf to be had near at hand, or may be brought to the place at an eaſy rate, either by land or water: this article is very neceſſary, eſpecially in northern climates; beſides its uſe in preparing victuals, wood ſerves for moſt ſorts of handicraft works; in ſhort, every thing that is necessary for the subsistence and conveniency of a garrison must be considered, before the construction of a fortress is undertaken, because the expences which attended such works, are always very great; and consequently, every individual circumstance ought to be examined and carefully considered beforehand.

In the next place, it must be observed, whether there are materials to be found for the building of the place, either upon the spot, or near at hand, so as to be transported at an easy rate; such as timber, stone, or brick, lime and sand, or whether they may be partly had on the spot, and partly brought by water; for if the greatest part is to be transported by land from some distance, the expence will be so excessive, that the utmost importance of the place only can excuse the building it.

If it be a place near the sea, or a navigable river, where a harbour is to be made, it must be carefully considered, on which side the fortress is to be placed, both in respect to the landing of the goods, and to the defence of the harbour, as likewise, where the ships may come as close to the quay as possible.

In a fortress built to promote and protect trade, it must likewise be considered, what kind of goods are to be found in or near the place, what might be brought by ships from foreign parts, and what might be exported, in exchange for those manufactured there, and where to be carried to market.

It may happen, that in some places, such as islands and some other places, where there are very few things to be had for exportation, yet if the harbour is convenient for ships to come in, when distressed by weather, or the place may serve as a magazine to bring and deposite *European* commodities, to be from thence transported by vessels, to some other market; or else, fresh water is to be found for ships, when no other place

place is near at hand, as is St. *Helena*; ſuch ſituations may be fortified, and become very uſeful.

There are many ſituations in inland countries, which we have not taken notice of here, and yet may be advantageous for building large fortified places, becauſe their uſefulneſs depends on too many circumſtances to be enumerated; therefore we ſhall obſerve in general, never to build a large fortification, excepting near navigable rivers, which may ſerve for conveniency of trade, and to be a ſtrong barrier to a ſtate; or to ſtop a paſs, through which an enemy might enter into the country; for where there is no river, he may paſs by and leave the place behind him; hills that command any of the works, or hollow roads, through which an enemy may approach, ſhould be avoided; and in general, the ground ſhould be level and free from trees, or any other thing, which may favour an approach under cover, for a mile all round.

SECT. IV.

How to make the PLAN *of a* FORTRESS.

WHEN a ſtate has reſolved to build a fortreſs, an engineer is to ſurvey the ſpot of ground, upon which it is to be, very exactly, and to draw the plan of it very diſtinctly, on a large ſcale, which muſt extend at leaſt as far as cannon ſhot beyond any of the outworks, together with ſeveral ſections or profiles, ſo as to expreſs the heights of the moſt material inequalities of the ground; if there be any river or ſtanding waters near it, their breadth and length muſt not only be taken and expreſſed in the plan, but likewiſe all the ſoundings, in order to know whether any ſhips or ſmall craft can come there.

If there be any hills or high grounds, or hollow roads near hand, they muſt be carefully expreſſed, both

both in the plan and sections; after which the engineer must compose a memorial, containing an exact and distinct account of the nature and situation of the ground; if rocky, hilly, marshy, or even; if there is a river, whether it is navigable or not; or if there be a lake, whether it may be useful for navigation, or to strengthen the works; if there is a good foundation to build upon; whether there are springs or river water to be had for the use of the garrison; and wood, coals, or turf, for fuel.

If the materials of which it is to be built, are to be had upon the spot, or, if at any distance, how they are to be brought by land or water; the nature and quality of the materials; their prices, and that of the workmanship; and above all, whether the works are to be built with stone or bricks, where to be had, whether any quarries are near hand, or proper clay to make bricks, and fuel for burning them; where to get the lime and sand, whether the materials are good, or but indifferent; in short, it must contain every thing required for the building of the place, and for its maintenance.

This memorial, together with the plan and profils of the situation, being laid before the council, which has the direction of such works; who ought to send three or more of the most able engineers to the place, in order to examine every particular, and to observe, whether the plan and memorial are both conformable to the situation; if not in all particulars, to correct them; and when they are sufficiently acquainted with every thing, to make a plan of the fortess, in conjunction, conformable to their instructions, and the consequence of the place.

For it is my humble opinion, that such an undertaking should never be trusted to the judgment of one single person, ever so well qualified, as it is too often the custom; and when they all agree in their opinions, a fair plan is to be made on a scale of 30 fathoms to an

 inch

inch at leaſt, with proper profils, in order to lay them before the council, with a new memorial, expreſſing their reaſons for making ſuch works preferable to any other, with references to the plan, and why the fortreſs is made of that extent.

But in caſe the engineers ſhould not agree in all the particulars; ſeparate plans muſt be made by each, and the reaſons given in writing, in order to be decided by the council, which of them is to be made uſe of; all this ſhould be done with the utmoſt candour, and without any views of intereſt, or preference in reſpect to capacity, or any thing elſe whatſoever, contrary to the true intereſt of the nation.

In making the plan of a fortreſs, particular regard muſt be had to the three following conſiderations:

1. *The expence neceſſary for the building of it.* For as it is generally very great in ſuch undertakings; by increaſing it without neceſſity, or the importance of the place requiring, it inſtead of being an advantage, it becomes a burthen to the nation.

2. *The number of troops required to guard and defend it, together with the quantity of artillery and ammunition for a ſiege.* For if this expence ſhould be equal to, or exceed the revenue or advantage ariſing from it; it is plain, that, inſtead of being an advantage, it would be a diſadvantage.

3. *The extent or capacity of the place, with reſpect to the ſpace taken up by the works of fortification.* For if it ſhould happen, as we are not without examples, that the town could not contain a ſufficient number of troops to defend it, beſides the inhabitants, it is evident, that it may be taken with leſs expence than another of fewer works, provided with the ſame number of troops; as each work would be capable to make a proper defence; and conſequently, a great expence would be thrown away on ſuperfluous works to no manner of purpoſe.

There

4

There are many other considerations to be had; as that the works should flank or defend each other in the most direct manner possible: that the communication from the body to the outworks, may be easy and secure, as well as those from one work to another: that the works are properly adapted to the nature of the situation; if the ground is low, tenaillous, lunets, or second ditch and covert way ought to be made; if level, ravelins and covert way only; if there are any hollow roads leading to it, some works that flank it in a direct manner; if there are any hills or rising grounds that command some of the works, little forts or redoubts should be made there, with a secure communication to the fortress; or else traverses are to be made in the works themselves, especially, if they are seen in the rear: If the place is large and of great consequence, horn or crown works are useful to secure the gateways, or a spot of ground which might be advantageous to an enemy: In short, engineers should be sparing in their works, to make no more than what are barely necessary, and whereby visible advantages are gained, both on account of saving expences in the building, and in the maintenance of a garrison to defend it, and in every thing else necessary for its defence.

When an old place is to be fortified, that has some works standing, the director ought to endeavour to find the reasons which engaged the builder to make these works; which being known, he must consider whether they answer the intent, and if not, how to change, either partly or the whole, so as to answer better, to make use of part of the old works, if not the whole; and never demolish old works to build new ones, without absolute necessity, in order to diminish the expences. I have seen projects for demolishing old works and to build new ones in their stead, which were not so good by much. This will always happen, when an engineer is entrusted with works, that does not understand his business; and those very people, are generally the most ambitious to shew their own performances, whether right or wrong.

Situations which are partly fortified by nature, such as when there are any precipices, rocks, or which are partly surrounded with water, are very convenient; for the other part may be fortified at an easy rate, besides the place requires but a small garrison to defend it. When the situation is rocky, care must be taken to make use of the rock for the facings of the works, as much as will agree with the plan, which will save expences; blowing up the highest parts to raise the lower ones; but it must be taken notice, that each work is to be of the same level, or nearly so, every where, and that the inner ones rise gradually above those before them.

When the plan of a fortress is fixed upon, the profils must be determined, and it must be considered, whether the works are to be wholly faced with walls or partly, how much the height of the body is to exceed that of the out-works. Engineers vary very much in their opinions, in respect to the heights of the works; Mr. *Vauban* made the body of the place 6 or 8 feet higher than the ravelins, and these higher by 6 feet than the glacis: Mr. *Coehorn* did the same nearly, but made his capital ditch narrow and deep, whereas the former made it wide and shallow; the latter covers the wall of the body very much, so that it cannot be battered for above three feet below the horizon, brings the works closer to each other, and makes their defence shorter; the broad ditch, on the contrary, discovers the wall to the very foundation; but when the ditch is dry, works may be raised in it so as to make a good defence; the passage through it to the breach may be obstructed and disputed for a long while. As for my part, I think a middling width is preferable to a large one; that is, I would never make the capital ditch above 16 fathoms at the salient angle of the bastion, when the exterior side of the polygon is 180 fathoms,

thoms, and so in proportion to the length of the sides.

The reasons given for making high ramparts, are, that they cover the houses and other buildings better than low ones, and that the enemy may be fired at from all the works in the same front, without incommoding those in the outworks. To this it is objected, that when the works rise gradually one above the other, the enemy may ruin the defences all at once, from the first batteries he makes, and then may advance without having any thing else to fear than the fire of small arms; besides the rampart of the place becomes very high, and, of consequence, increases the expences considerably.

On the contrary, if the works were made nearly all of the same height, the guns placed in the inner works cannot be dismounted till the outer works are taken, excepting by shells; but the chance of dismounting them is so very little, that it may be looked upon as inconsiderable.

Another material advantage arising from this method is, that the height of the body of the place is much less than the former, and therefore the expence of building it considerably diminished: As to not being able to fire at the enemy from all the works at once, it is of no consequence; because the outward works will hold as many guns as are required to keep the enemy at a distance, and, as he approaches, these guns may be brought into some others, when it is not safe to keep them longer there.

For my part, I would make the heights of the works so as to terminate in a right line drawn from the parapet of the body to the extremity of the glacis, because by this means great expences would be saved; the enemy must batter the works one after another, and therefore raise as many batteries as there are works; besides you may at any time fire *en barbet* from any of the works you please, or is found most convenient.

Mr. *Vauban* used to raise his revetements as high as the parapets, excepting at *New Brisac*, where they are not above 3 or 4 feet above the level of the fields: and to build very strong counterforts behind them; whereas Mr. *Coehorn*, who was more saving, made them only even with the level of *Bergen-op-zoom*.

This method is very good, because it saves great expences in the building, and when the place is besieged, the enemy can batter but a very little part of the wall; it requires more time to make a breach, and less expences to be repaired; whereas when the wall reaches quite up to the top, by battering it as low as can be, the upper part tumbling down all at once, makes a breach in a short time; and the expence of repairing them is very great.

Some will have the walls to begin from the bottom of the ditch, without making very deep foundations. It is certain, that the burying so much masonry under ground is of no other advantage than to support the walls above them: And when a foundation can be made firm with piles or other ways, it would save great expences. This may be done in wet ditches, because the wood being always under water will never perish; but it is not so in dry ones, unless the bottom is very good, the piling cannot be depended on; besides the foundations in the faces, where the breaches are made, should be as deep as can be, because the enemy's miners will otherwise carry galleries under the wall and blow it up, in less time than the breach can be made by cannon: But in the gorges or counterscarps where no breach can be made, nor any danger apprehended for making mines, it would be extravagant to lay the foundations any deeper than is just necessary to support the walls above them.

SECT.

SECT. V.

To make the estimate of a FORTRESS.

WHEN the plan of a fortress is drawn with proper profils and elevations, and every thing expressed on paper that can be done, or is necessary; all the angles and lines not given by the construction, must be found by trigonometry, according to the manner of the specimen given in our *Elements of mathematics*, page [redacted] 159: The quantity of masonry must be computed in the manner taught, in page [redacted] 200, as well as the excavation and transportation of the earth, and the expences of making the ramparts, parapets and glacis: then if the prices of the several materials are known in the country where the fortress is to be built; it will be easy to make a proper estimate of the expences that a state will be at, in order to have the work executed.

As it is impossible to determine the prices of the materials, which change in every place, according as they are near or upon the spot, and as the labour is dear or cheap; we shall content ourselves here, to give only the quantity of work of all the material parts; which together with the experience an engineer must have before he is employed in so great an undertaking, and the knowledge of the form used in the country, to represent it to the directors of these kind of works in a proper manner, will be sufficient for our reader to understand what is necessary upon such an occasion.

To compute the QUANTITY *of* MASONRY.

Plate VI. Fig. 1. We shall suppose, that the fortress is a regular pentagon, with ravelins, covertway and glacis; that the exterior side AB is 180 fathoms, the faces AH, BE, to be 50; the perpendicular CD, 30, according to Mr. *Vauban's* first method. Now because we have found in our *Elements*, page ~~211~~ 160, the flanks to be 27.27 fathoms, and as there are 10; the sum of their lenghts will be 272.7 fathoms, or because, we shall express all the contents by cubic yards, which is the usual method here in *England*, and each fathom is two yards, the sum of the lengths of all the flanks will be 545.4 yards We have likewise found in the same page, that the length of the curtain FG, is 76.39 fathoms; and as there are five, the sum of their lengths will be 381.95 fathoms, or 763.9 yards: And since the faces AH or BE, are 50 fathoms by construction, the sum of 10 faces will be 500 fathoms, or 1000 yards.

It may be observed, that it is the same thing to multiply each length by the number of square yards contained in the profil, or to multiply the sum of all the lengths, by the square yards contained in the profil; whence by adding the sums of the lengths of the faces 1000, the flanks 545.4, and that of the curtains, 763.9, we shall have 2309.3 yards, for the sum or total of all the lengths of the body of the place.

Fig. 2. Now if the height of the profil ABCD, be 30 feet, or 10 yards, from the foundation AD to the cordon BC; the rest of the parapet is supposed to be of earth only; then if the wall is of stone, according to our tables, the thickness BC above will be 5 feet, and that AD near the foundation 11. In order to find the area ABCD, we must add the two parallel sides AD and BC, which gives 16 feet, and multiply half the sum 8 by the height AB, 30, which gives 240 square feet; and since 9 square feet make a square yard, if we divide 240 by 9, we shall get $26\frac{2}{3}$ square yards for the content of the profil; exclusive of the foundation ADIH, and the counterforts; therefore

if

if we multiply the total length 2309.3, found above by 26 $\frac{2}{3}$, we shall get 61581.3 cubic yards for the content of masonry contained in the body of the place, exclusive of the foundation and the counterforts.

If we suppose the foundation A H to be 6 feet deep, and 12 broad, as they are rectangular we need but multiply the base, 12 by the height 6, which gives 72 square feet or 8 square yards for the area of the foundation: and therefore this content multiplied by the total length 2309.3, gives 18474.4 cubic yards for the foundation. In order to find the content of the counterforts, we must consider that their whole heighth H B is 36 feet; the length of the base H K, 8.6 feet according to our tables: and if the distances from the center of the one to that of the next be 16 feet, their breadth will be 4 feet by what has been said in the first section: whence multiplying 8.6 by 4, we get 34.4 feet for the area of the base or 3.8 $\frac{2}{9}$ square yards; and this multiplied by the number of yards, 12, contained in the height gives 45.8 $\frac{2}{3}$ for the content of one of the counterforts: The number of counterforts is found by dividing the total length of works, by the distance between the center of one counterfort to that of the next: and since the total length has been found to be 2309.3 yards, and the distance 5 $\frac{1}{3}$; we shall have 433, for the number of counterforts; and as the content of all the counterforts is equal to the product of the content of one multiplied by their number; it follows that 433 multipled by 45.84, gives 19860.2 yards for the sum or total content of all the counterforts. Whence we get for the quantity of masonry of the body of the place

The content of the	wall	61581.3.
	foundation	18474.4.
	counterforts	19860.2.
	Total content	99915.9.

Having

Having found the quantity of maſonry contained in the body of the place, the next thing is, to find that contained in the faces of the ravelins, which we ſhall ſuppoſe 24 feet high, and whoſe profil is repreſented by the third figure, the thickneſs above B C near the cordon is 4 feet 4 inches, and near the foundation 9 feet 11 inches, the ſum of the two parallel ſides will be 14 feet, 3 inches, half of which multiplied by the height 24, A B, gives 171 feet, or 19 yards exactly, for the content of the area A B C D of the profil, excluſive of the counterforts and foundation.

Now becauſe the faces of the ravelins, are 51.75 fathoms, according to our *Elements*, page 215; and ten of them will be 517.5 fathoms, or 1035 yards; this length being multiplied by the area 19 of the profil, gives 19665 cubic yards for the content of maſonry of the five ravelins, excluſive of the foundation and counterforts.

Suppoſe the foundation to be ſix feet deep, and 11 broad, then the product of 11 multiplied by 6, gives 66 feet for the ſection of the foundation, or $7\frac{1}{3}$ ſquare yards; now if this content be multiplied by the total length 1035, we ſhall have 7590 cubic yards, for the content of the foundation.

The length L A of the counterforts is 7 feet, and the height H B 30, including the foundation; therefore the area of the counterfort K B, will be 210 feet, or $23\frac{1}{3}$ ſquare yards; and if the diſtance of the center of one counterfort to that of the next be 16 feet, the thickneſs will be 4 feet, or $1\frac{1}{3}$ yard; whence multiplying $23\frac{1}{3}$, by $1\frac{1}{3}$, we ſhall get 31 cubic yards nearly, for the ſolid content of one counterfort. If we divide the total length 1035, by the diſtance $\frac{16}{3}$, we ſhall get 194 for the number of counterforts contained in the ravelins; and therefore this number 194, multiplied by the content 31 of one, gives 6014 cubic yards, for the total content. Conſequently, the quan-

tity

tity of masonry contained in the faces of the ravelins will be

The content of the	wall	19665
	foundations	7590
	counterforts	6014
		33269

It remains now to find the quantity of masonry contained in the counterscarp; suppose the fourth figure to be the profil, which is 16 feet high, from the foundation, 2 feet above, and 5 feet 2 inches near the foundation, according to our tables; the two parallel sides being added, gives 7 feet 2 inches, half that sum multiplied by the height 16 feet, gives 57 $\frac{1}{3}$ square feet, for the area, or 6.4 yards nearly.

The length of the counterscap is not found without a good deal of calculation, which we have explained in our *Elements*, pages 214, 215, and 216; to which we refer our reader, and content ourselves by giving the amount as found there, for the length before one front, which is 290 fathoms, or 580 yards; and as there are five fronts, five times this number, gives 2900 yards for the total length; this length being multiplied by the content 6.4 of the profil, gives 18560 cubic yards for the content of the wall, exclusive of the foundation and conterforts.

If the foundation is 5 feet deep, and 6.5 wide; then the product of 5 by 6.5 gives 32.5 square feet, or 3.6 square yards nearly, for the section of the foundation; and this number multiplied by the total length 2900, gives 10440 cubic yards for the total quantity of masonry in the foundation.

Now because the height of the counterforts is 21 feet, and their length 4; the product of 21 by 4, gives 84 square feet, or 9 $\frac{1}{3}$ square yards for the area of the counterforts; and if we suppose as before, the distance from the center of one to that of the next, to be 12 feet, their thickness will be 3 feet or one yard;

yard; therefore the content of one counterfort will be $9\frac{1}{3}$ cubic yards.

If the total length 2900 yards be divided by 4 yards, their diſtance, we ſhall get 725 for the number of counterforts, which being multiplied by the content $9\frac{1}{3}$ of one, gives 6766.6 cubic yards, for the total content of maſonry in the counterforts. Hence the total content of the maſonry contained in the counterſcarp will be

Content of the	wall	18560
	foundation	10440
	counterforts	6766
	Total	35766

Having thus found the quantity of maſonry contained in the ſeveral parts, according to the plan and profils here given, by adding them together, we ſhall have the content of the whole, excluſive of bridges, gates, and under-ground works.

Content of the	body	99916
	ravelins	33329
	counterſcarp	35766
	Total content	168951

Theſe computations may alſo be performed as follows; add the areas of the profil and foundations to that of one counterfort divided by 4, and the ſum multiplied by the total length, gives the whole content at once. Thus in the counterſcarp, the area of the profil is 6.4 yards, that of the foundation 3.6, and that of the counterfort $9\frac{1}{3}$, this laſt divided by 4, gives $2.3\frac{1}{3}$. Now the ſum $12.3\frac{1}{3}$ of theſe three areas multiplied by the total length 2900, gives 35766 cubic yards, for the whole content of the counterſcap; which is the ſame as before: The ſame thing will be true in regard to the reſt of the computations.

Although

Although this is not the exact content of the masonry contained in this fortress, because there are solids in every angle, such as are represented in the fourteenth plate of our *Elements*, which must be considered when the works are measured, as well as the coping stones; yet this mensuration is sufficient for an estimate. There are many engineers that are not so exact in their computation; for how could it be, since few of them have scarcely the least notion of geometry, without which, it is impossible to compute to an exactness any thing of this kind.

To compute the EXCAVATION *of the* DITCHES.

The method of computing the quantity of earth contained in the ditches of the body of the place, and ravelins, is reduced to the finding their area's, and then to multiply the sum by the depth of the ditch, that is, by 16 feet, or $5\frac{1}{3}$ yards. But by reason of the irregular figures, they must be divided into parts, in the following manner. From the point B draw B L perpendicular to the counterscarp; from the angle F of the flank F draw F T, perpendicular to the line of defence G E, and from the point D, D V perpendicular to the counterscarp I L produced; then if B K be the capital of the bastion produced, we must find the space I L B D, the triangles G E F, D G H, and the circular sector L B K, in order to get the area of the great ditch before one of the fronts.

The length I L of the counterscarp has been found in our *Elements*, page 214, to be 87.85 fathoms, or 175.7 yards, B L is 40 yards by construction; and in the right angled triangle D V I, we have D I, 25.93 fathoms, or 51.86 yards, by page 215; and the angle D I V, 74 degrees and 35 minutes; by which we find the perpendicular D V to be 50 yards, and the base I V 13.78, by adding I V to I L, we shall have V L, 189.48; and if we add the two parallel sides B L, D V, D V, we get 90, and half their ſum 45, multiplied by V L, 189.48. gives 8526.6 ſquare yards, for the ſpace D V L B, from which we muſt ſubtract the triangle D V I, in order to get the ſpace D I L B; but the ſide I V, is 13.78, and the perpendicular D V, 50; half the product of theſe numbers, gives 344.5 for the area of the triangle D V I, which being ſubtracted from the content of the area V L B D, leaves 8182 ſquare yards for the content of the ſpace D I L B.

The next thing to be found is the area of the triangle G F E, in which the ſide F G is 76.39 fathoms, or 152.78 yards, the ſide E F, 54.54 yards, and the ſide E G, 170, 28 yards; having the three ſides of a triangle, the ſegment E T is found by ſaying the ſum 207.32 of the ſides G E, F E, is to their difference 98.24, as the baſe G E, 170.28 is to the difference 80.6; between the ſegments G T, and T E, which being ſubtracted from the baſe G E, 170.28, gives 89.68, half of which 44.84, will be the leſſer ſegment E T; therefore the difference between the ſquares of E F, 54.54, and E T, 44.84, will be equal to the ſquare of the perpendicular F T; which will be found to be 31 yards. Now becauſe the two triangles G F E, D G H, have the ſame altitude, the ſum of their baſes G E, 170.28, D H, 89.74 being multiplied by the perpendicular F T, 31, half the product, gives 4030 yards for the content of the ſpace E F G H D.

It remains now to find the circular ſector L B K; the angle L B K in a pentagon, is 108 degrees, and 52 minutes, and the radius B L, 40 yards by conſtruction; whence if we ſay 7 is to 22, ſo is the radius B L, 40, to the ſemi-circumference 125.7 nearly; and again, 108 degrees is to 108 degrees 52 minutes, or 108.86 degrees nearly, as 125.7, is to the arc L K, which is 76 yards; then half the product of this arc, and the radius gives 1520 ſquare yards for the content of the ſector L B K.

Now

Now if we add twice the sum of the space D I L B, 8182, and the sector L B K, which is 19404, to the space H G F E D, which has been found to be 4030, we shall have 23434 square yards for the great ditch, before one of the fronts.

Lastly, The area of the ravelins ditch is to be found; if from the extremities of the face N Q, we draw N *b*, Q *n*, perpendicular to the opposite counterscarp, *a n*: Then because the width of the ditch is 24 yards by construction; and the face N Q, has been found in our *Elements*, page 214, to be 103.5; the breadth being multiplied by the length N Q, gives 2484 square yards, for the content of the area N Q *n b*.

In the right angled triangle N *b a*, the perpendicular N *b* is 24 yards, and the base *a b* has been found in our *Elements*, to be 8.72 yards; and half the product of these two sides, gives 104.64 for the content of this triangle.

The angle N Q R has been found to be 73 degrees, and 30 minutes; whence, if we say, as 7 is to 22, so is the radius 24 to the semi-circumference 75.4; and 180 degrees is to 106. degrees, 30 minutes, or 106.5 degrees, the measure of the angle *n* Q *m*, so is 75.4 to to the arc *n m*, 44.6 yards; and half the product of this arc and the radius, gives 535.2 square yards for the content of the sector *n* Q *m*.

Now if we add the content of the triangle N *b a*, 104.64 to that of the rectangle N *n*, 2484, their sum will be 2588.64; and twice that sum added to that of the sector *n* Q *m*, gives 5712.48 square yards for the content of the ditch before the ravelin.

Therefore if we add the contents of the great ditch 23434 to that of the ravelin, we shall get 29146.48 square yards for the sum, and five times this sum gives 145732.4 square yards for the content of the ditches round the whole fortress.

If

If this content be multiplied by the depth of the ditch 16 feet, or 5 $\frac{1}{3}$ yards, we ſhall get 777239.4 cubic yards for the total content of the ditches.

This is not the content of all the excavations to be made; that of the walls, counterforts, and their foundations muſt likewiſe be conſidered; as there muſt likewiſe be room for the workmen to work, which cannot be leſs than two feet, beſides the thickneſs of the wall, the length and breadth of the counterforts; but the ſlopes of the walls are not to be taken in here, becauſe we have ſuppoſed the ditch to be dug perpendicular.

Fig. 2. Therefore if R T be the line terminating the height of the ditch from the foundation, we muſt find the thickneſs of the wall at T; which is done by adding one fifth of the height R M 14 feet, to the thickneſs B C above 5 feet, which gives 8 feet nearly, to which adding two feet more, according to what has been ſaid above, gives 10 feet, and this multiplied by the height K R 16 feet, gives 160 feet, or 17.7 ſquare yards. Now the foundation D H being 6 feet deep, and 12 broad, to which adding two feet on each ſide, gives 16, and this multiply by 6, gives 96 feet, or 10.7 yards nearly; this added to 17.7, gives 28.4 ſquare yards to the area of the profil; therefore 28.4 multiplied by the total length 2309.3 of the body of the place found before, gives 65584 cubic yards, for the quantity of earth to be removed on account of the wall.

The height of the counterforts K R is 22 feet, including the foundation, the length K H is 8.6 feet to which adding two feet more, gives 10.6; this multiplied by 22, gives 233.2 feet, or 26 yards nearly. Now becauſe the thickneſs of the counterforts has been made 4 feet, by adding two more on each ſide, gives 8 feet, or 2 $\frac{2}{3}$ yards, which multiplied by 26, gives 69.3 for the quantity of earth removed on account of one counterfort; and as there are 433 of them, we ſhall have 30007 cubic yards for the total quantity of earth.

earth. This quantity, added to that above, gives 955.91 cubic yards for the total quantity to be removed on account of the wall of the body of the place.

Fig. 3. To find the quantity removed in the ravelin, where the height R M is 8, and the thickness B C 4.4 feet; one fifth of 8 is 1.6, which added to 4.4, gives 6, to which adding two feet more, gives 8; this multiplied by 16, gives 128 feet or 14.2 square yards for the section of the excavation.

The foundation has been supposed 6 feet deep, and 11 broad, by adding 4 to 11, gives 15, and this multiplied by 6, gives 10 yards for the foundation; the sum of 14.2 and 10, gives 24.2 square yards, which being multiplied by the total length 1035, gives 25047, for the content of the excavation of the faces.

The height of the counterforts K R is 22 feet, and their length K H, 7, to which adding two more, gives 9, and the product of 22 multiplied by 9, gives 198 feet, or 22 yards; and since the thickness of the counterforts is 4 feet, by adding 4 more, gives 8 feet, or $2\frac{2}{3}$ yards, which multiplied by 22, gives 58.6, for the excavation made for one counterfort; and as there are 194 in all, this number multiplied by the content 58.6 of one, gives 11368 for the total excavation made for the counterforts in the ravelin. This added to the former, gives 36415 cubic yards for the total excavation.

Fig. 4. Lastly, It remains to find the excavation made for the counterscarp: The thickness above is 2 feet, to which adding 2 more, gives 4, this multiplied by the height 16, gives 64 feet, or 7 yards nearly. The foundation is 5 feet deep, and 6.5 broad, to which adding 4 more, gives 10.5, and this multiplied by 5, gives 52.5 feet, or 5.8 yards nearly; and the sum of the foundation and the wall is 12.8 yards: and because the total length is 2900 yards, the product of this number multiplied by 12.8, gives 37120 cubic yards, for the content of the excavation.

L The

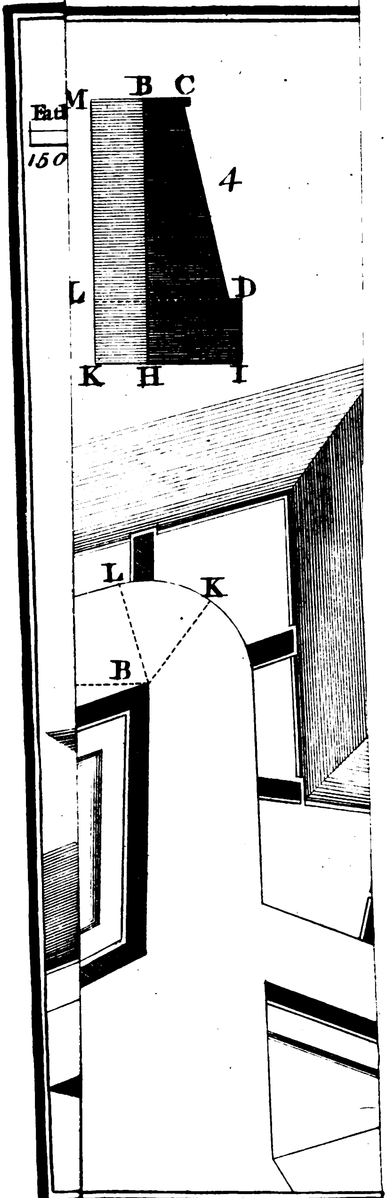
The height of the counterforts is 21 feet, and their length 4, to which adding 2 more, gives 6, the product gives 14 yards for the content; and as they are a yard thick, by adding a yard more, gives 2, and 14 by 2, gives 28 cubic yards for the content of one counterfort; and ſince there are 725, the total content of all the counterforts will be 20300. And this added to that of the wall 25047, gives 45347 cubic yards.

Whence the content of the ditches	777239
of the town-wall	95591
of the walls of the ravelin	36415
of the counterſcarp	45347
Total content of the excavation of earth	954592

If it is known how many men are required to remove the earth, either from the glacis or the ramparts of the body and ravelin, and how much they remove in a day, the expence for removing the earth may be pretty exactly computed; for there is no ſuch thing as to form an exact account, too many accidents happening during the time of the works of this nature, to come to any exactneſs; for example, if every cubic yard coſts ſixpence to remove, and make the works compleat, without any other expence either for tools, bridges, and roads; the expence of removing the whole quantity would amount to 23864 pounds, 16 ſhillings.

The computation of the quantity of earth has been made upon the ſuppoſition that the ground is level; but as this is ſcarcely ever the caſe in real practice, marks are left every where to ſhew the different depths that have been dug, and a proper reduction is made, in order to get the true quantity of earth removed; for which reaſon the reader muſt conſider what has been here done as the method by which he is to proceed when a fortification is to be executed; and that this is ſufficiently exact to make an eſtimate.

As



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As to the masonry, it may at all times be known what the stones cost in the quarries, and for the bringing them on the spot; as likewise the expence of cutting them, and to make the walls, when the situation of the fortress is once fixed upon: the same thing will hold good if the place is to be built either entirely or partly with bricks.

But there are many lesser articles, such as the gateways, bridges, cazemats, powder-magazines, storehouses, guard-houses, barracks, &c. which cannot be estimated without a great deal of experience in these kind of works: therefore an engineer must be well acquainted with it before he is able to undertake such a work.

SECT. VI.

To trace the plan of a FORTRESS *on the* GROUND.

IF the ground is uneven, filled with bushes, hedges, ditches, or any other obstacles, which hinder the stations from being seen, it is necessary to trace the exterior sides in a rough manner, in order to clear the ground, and then trace the works over again more exactly. If the fortress lies near a river, the side next to it must be traced first, so as to agree with the proposed plan; or if there are any buildings which are to be inclosed, you begin with that side first, which brings them in their proper situation: The greatest difficulties happen when the fortress is to be built on a descent of a rock or hill, where the works lie not all on the same level; in such a case, great care must be taken to make proper allowances for raising and falling the works, in order to place them in such a manner that the exterior works be always commanded by the interior ones; it is here where an engineer requires great ſkill and knowledge to make the different parts anſwer their true intent.

There are two different inſtruments commonly uſed in tracing the works on the ground; which are, the plain table and the theodolite.

The plain table is the moſt ſimple, but it is not ſo exact; for which reaſon, I would never uſe it, but in ſmall forts, or works of no great conſequence.

When a plain table is uſed, the plan muſt be drawn on a large ſcale, at leaſt of 30 fathoms to an inch, which is faſtened with ſealing wax to the table, ſo as to lay quite ſmooth and even; then, by means of a ruler with ſights, the angles are laid down on the ground, and the lengths of the lines meaſured by a chain and rod: But when the theodolite is uſed, the lines and angles muſt be found by trigonometry, in the manner given in our *Elements of mathematics*.

This being done, the angles muſt be traced on the ground with the inſtrument, and the lines laid down as before. But to explain the manner of uſing both theſe inſtruments, we ſhall begin with the plain table, and ſhew how the body of the place is to be traced, and then how this is to be done with the theodolite.

To trace the PLAN *of a* FORTRESS *with a* PLAIN-TABLE.

Plate VII. Having faſtened the plan on the table, in the manner mentioned before; which we ſhall ſuppoſe to be a regular pentagon, of the ſame dimenſions as in the laſt plate: Suppoſe the point O to be the center of the place: place the table exactly over the point O, ſo as the center on the paper is exactly over the center on the ground, lay the edge of the ruler along the radius or capital O A, and turn the table round, till the point A is ſeen through the ſights; place

place a piquet or stake in that direction; keep the table steddy, and turn the ruler about the center O, till it is in the direction O B on the paper, and place a piquet at any distance in that direction; keeping the table in the same direction, lay the ruler on the capital O C, and place a piquet in that direction; and proceed in the same manner with the capitals O D and O E; this being done, set off these capitals with a chain in the most exact manner you can, which gives the five points A, B, C, D, E; now to be certain, that these points were rightly determined, the exterior sides A B, A E, &c. must be measured with the chain, and if they are the same length as they should be, you are certain that these points are right: but if the exterior sides are either too short or too long, the capitals must be measured again, till such time that every line on the ground is exactly of the same length as those on the paper.

Having determined the exterior sides, the table is placed at A, and by the help of the ruler turned so as the two exterior sides A B, A E, on the paper coincide with those on the ground; then keeping the table in that position, and laying the ruler along the face A F of the bastion, and a piquet being placed in that direction; then the face A F is measured by the chain, which gives the point F; the table is placed over this point so as the line A F on the paper agrees exactly with the same line on the ground; by keeping the table in that position, and directing the ruler along the flank F G; then a piquet is planted, and the length of the flank measured, which gives the point G.

After this the table is carried to the point B, and turned so as the exterior sides B C, B A, on the paper agree with the same lines on the ground; keeping the table in that position, the ruler is directed along the face B L, and a piquet planted in this direction; then by setting off 50 fathoms for the length of the face, from B to L; the point L is given; to which the table being carried and turned ſo as that the face B L upon the paper, agrees with that line, on the ground: then directing the ruler along the flank L H, and planting a piquet in that direction: by ſetting of 27.27 fathoms for the length of the flank from L to H, which determines the flank and curtain.

Now to be certain, that this front has been rightly traced, the diſtance from H to G muſt be meaſured, to ſee whether it is 76.39 fathoms as it ſhould be, and from the points A and B, it muſt be obſerved, whether the points B, L, G, and A, F, H, are in a right line; if this is ſo, the front is rightly traced, and if not, it muſt be traced over again, till every thing comes out right.

The ſame operations muſt be performed at every ſide of the place, by which the body will be finiſhed for the preſent, becauſe the rampart and parapet, as well as the thickneſs of the wall, are determined afterwards.

If the fortreſs is either irregular, or there are any buildings in the way, in ſuch a manner, that the points A, B, C, D, E, cannot be ſeen from the center O: The exterior ſides A B, B C, C D, D E, muſt be traced; that is, the table is placed at A, in ſuch a manner, as the exterior ſide A E on the paper be in the ſame direction with A E on the ground; then, by keeping the table in that poſition, and directing the ruler along the ſide A B, in which a piquet is planted, and the lengths of the two ſides A E, A B, meaſured, which gives the points E, A, B; this done, the table is carried to the point B, and placed ſo as the ſide B A, on the paper agrees with that line on the ground; then the ruler being directed along the ſide B C, and its length being ſet off in that direction, gives the point C; in the ſame manner is found the ſide C D; and if the diſtance D E is found to be of its proper length, and the angle A E D agrees with that on the paper, the exterior ſides have been

been rightly determined: after this, the rest is performed in the same manner as before.

If the position of any other line is determined either by buildings or a river, you are to begin with that line and find by its means the exterior side next to it, and from thence you proceed as before: Thus if the direction of the line C D is given, on account of a river, so as to bring the greatest part of it into the great ditch; the table is placed at C, and directed so as the line C D on the paper agrees with that line on the ground; then keeping the table in that position, and directing the ruler along the exterior sides C D and C B; the rest is finished as before.

When an old place is to be fortified, it often happens, that the situation of one of the curtains is determined, suppose G H; then the table is placed at G, and H, in order to find the flanks G F, H L; and then at L and F to find the faces L B, F A, which gives the exterior side A B; this being done, the rest of the work is performed as before.

To trace the PLAN *of a* FORTRESS *on the* GROUND *with a* THEODOLITE.

When the fortress is regular, the theodolite is placed in the center O, and levelled by means of the cross levels and skrews; fix the index to 360 degrees on the limb; turn the whole instrument round till the north end of the needle hangs over the flower de luce, or 360 degrees in the box; there fix the limb of the instrument by means of a screw underneath, then discharge the index, and turn it about till the vertical hair in the telescope cuts the station A placed any where in the direction O A; then adding the degrees on the limb, which we suppose to be a certain number of degrees exactly, without any fraction, to the number of degrees of the angle A O B, and turn the index so as to cut exactly the same number of degrees on the limb; this done, place a ſtation in the direction O B; adding again, the number of degrees of the angle B O C, to thoſe on the limb, and turn the index round, till it cuts the ſaid number, by placing a ſtation in the direction O C, and proceed in the ſame manner all round, till the whole is finiſhed.

We prefer this practice to any other, becauſe the needle cuts always the ſame number of degrees nearly, as the index does on the limb; but it may be done thus, after having levelled the inſtrument, and fixed the index to 360 degrees, you turn the inſtrument round till the vertical hair cuts any ſtation placed in the direction O A; then the limb is made faſt by means of a ſkrew, and the index diſcharged, and turned about till it cuts the ſame number of degrees as the angle A O B at the center, which is here 72 degrees, then placing a ſtation any where in the direction O B, and turning the index about till it cuts as many degrees, as are contained in the angle A O C, which is here 144; by placing a ſtation in the direction O C, the index is turned round till it cuts the angle A O D, 216 degrees on the limb, and ſo on to the reſt; this done and a ſtation placed in O D; then, the index being turned round till the vertical hair in the teleſcope cuts the firſt ſtation A; if the index cuts exactly 360 degrees on the limb the angles are rightly laid down, and this it will always do, if the inſtrument has not been moved.

The angles at the center being laid down very accurately, the capitals O A, O B, *&c.* muſt be meaſured with the ſame care; and to prove the work, the exterior ſides A B, B C, *&c.* muſt alſo be meaſured, and if they anſwer their dimenſions, every thing is right. But if the fortification is irregular, or the points A, B, C, D, E, cannot be ſeen from the center O; the theodolite muſt be placed at any one angle as A, which we ſuppoſe to be determined by the ſituation; after the inſtrument is levelled, and the index placed on 360 degrees,

degrees, the whole inſtrument is turned round till the north end of the needle points likewiſe at 360 degrees; the limb is faſtened, with the ſkrew and the index diſcharged, which being turned, ſo as the teleſcope cuts the ſtation in the direction A E, which is ſuppoſed to be given; then obſerving the number of degrees which the angle made by A E, with due ſouth and north, ſuppoſe 5 degrees, which being ſubtracting from the angle E A B, of the polygon 180 degrees, then turning the index round till it cuts 103 degrees on the limb, which is the difference between 5 and 108; then placing a ſtation in the direction A B, and ſetting off from A to B, 180 fathoms for the length of the exterior ſide A B: Now the theodolite being placed at B, and the index fixed to the limb, the whole inſtrument is turned, ſo as the ſtation at A may be ſeen through the teleſcope; then the limb is faſtened, and the index diſcharged, after having obſerved the number of degrees it points at, to which adding the number of degrees contained in the angle A B C, and if the ſum exceeds 360 degrees, ſubtract 360 from it, and turn the index round, till it points at the given number of degrees, and looking through the teleſcope, the ſtation C is placed in that direction: the exterior ſide B C being ſet off on the ground, gives the point C; from whence proceed in the ſame manner as before, till you come to the point E; and when the inſtrument is brought to the firſt ſtation A, and the angle E A B is found the ſame as before, the operation is right.

It may be obſerved, that by laying thus down the angles from the meridian, paſſing through the point A, the needle will always point at the ſame number of degrees nearly in the box as the index on the limb, which being carefully obſerved at every ſtation, will ſhew whether any error has been committed, either by accident or miſtake; and if there be any found you muſt return to the former ſtation to correct it, before

you

you proceed farther; by which you ſave the trouble of going over the work again, for a miſtake made perhaps at the beginning. Moſt engineers content themſelves, by laying down ſimply, the angles of the polygon without any meridian.

As all the angles and lines of a plan muſt be found by trigonometry, when it is to be traced on the ground with a theodolite, you place the inſtrument at A, and ſet off the angle B A F, and the length of the face A F, and then at F, to make the angle A F G of the ſhoulder, and when the length of the flank F G is meaſured, the inſtrument is placed at the point B, and proceed in the ſame manner, to find the points L and H: then if the points B, L, G, are in the ſame right line as well as the points A, F, H, and the length of the curtain G H comes out right, you are certain, that no miſtake has been made: The ſame operations are performed with regard to any other front, by which the body of the place is traced on the ground.

The next thing in hand, is to trace the counterſcarp of the great ditch; which is done in this manner; make the angle M D N, equal to 74 degrees, 35 minutes, according to what is ſaid in our *Elements*, page 214; and ſet off from D to N twenty fathoms, for the width of the ditch, trace a line in the direction N R, perform the ſame operation before the face E R, and you will have the ſtrait part of the counterſcarp; the round parts before the baſtions are determined by placing piquets at certain diſtances from each other, ſo as to be 20 fathoms diſtant from the ſaliant angles of the baſtions; or if the ditch is not ſo wide, and that the chain may reach croſs, faſten one end of it to the piquet at D, and at the other end a looſe piquet, ſo as to reach the point N; then by turning the chain round the piquet at D, ſo as to keep it always ſtrait, with the point of the other piquet you may trace the round part on the ground.

To trace the raveling, through the middle of the exterior side D E, mark a line S T, at right angles to it, in which set off 50 fathoms, for the length of the capital of the ravelin, from the reentring angle S of the counterscarp to the point T; from the point T, trace two lines to the counterscarp, which when produced, shall meet the opposite faces of the bastion in a point X, within three fathoms, from the shoulder M. As to the counterscarp of the ravelins ditch, it is found by erecting perpendiculars at the extremities of the faces, each of 12 fathoms, for the width of the ditch: The round part is found as before.

To trace the COVERT WAY *and* GLACIS *on the* GROUND.

From the reentring angle *a* of the counterscarp, set off 20 fathoms for the semi-gorges *a b*, *a c*, of the place of arms; fasten two chains or chords to two piquets placed at *b* and *c*, each of them of 25 fathoms long; which being stretched, and so as to meet at *d*, place a piquet there, and trace the faces *b d*, *c d*. If two points are marked with piquets along each side of the counterscarp, and at 6 fathoms from it, then the lines traced in these directions will determine the covert-way: and setting off two perpendiculars to the sides of the covert-way, and at 20 fathoms from them, the lines traced through their extremities will determine the breadth of the glacis. The traverses are easily traced on the ground, from their construction on the paper.

This is the most accurate way of tracing the plan of a fortress on the ground; and it may be observed in general, that all works of what kind soever of this nature, are always to be traced, by the help of the lines and angles, either given by construction, or found by trigonometry.

For

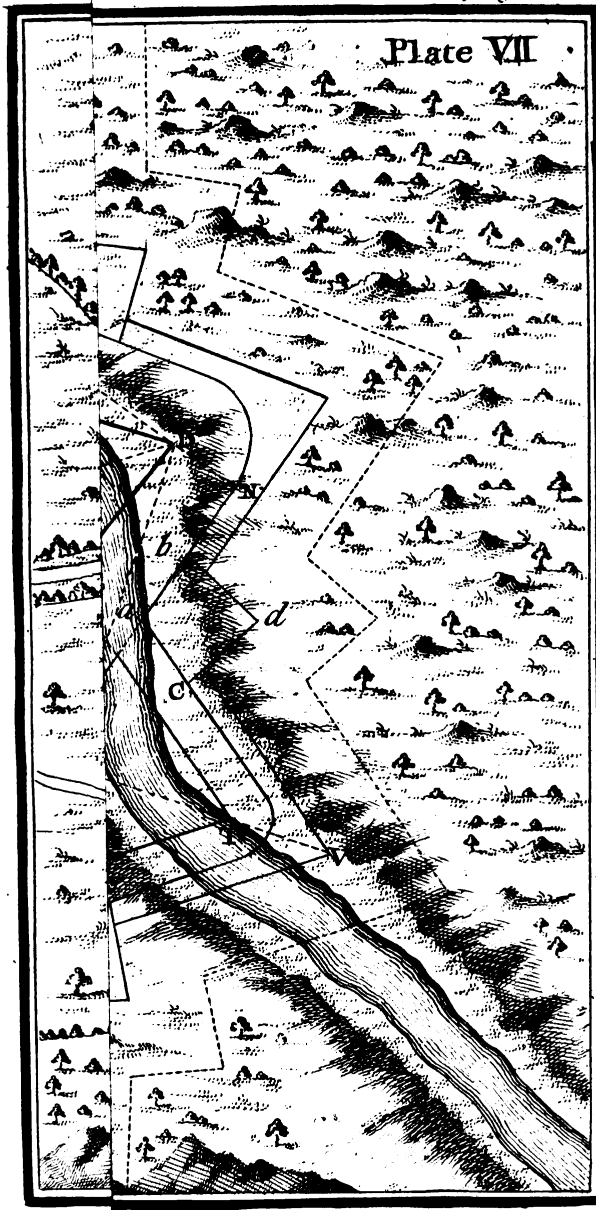
For inſtance, to trace a horn or crown-work, on the ground; the angle which their branches make, either with the counterſcarp or the faces of the baſtion, muſt be found as well as the length of the branches; theſe being once known and traced, the reſt may be performed in the ſame manner as in the body of the place.

The manner of tracing lunets, tenaillons, countergards, and all ſuch works, differs ſo little from what has been ſaid before, that it requires no farther explanation.

SECT. VII.

The METHOD *of building a* FORTRESS.

AFTER having traced the principal or magiſtral line of the works, the ground muſt be levelled round the body of the place, in order to chooſe a mean between the different raiſings and fallings of the ground for the level of the place, which ought to be ſuch that the earth of the higher parts may nearly fill up the cavities of the lower, and the center of the place muſt be marked, and is generally about ſix feet higher than the above mentioned level, in order to get a proper deſcent for the running of the water into the ditch; this being done, a trench is dug all round for the foundation of the body-wall; but care muſt be taken, to throw as much earth out of the trench and ditch, towards the center of the place, as will make the rampart and parapet; this may be done nearly by computing that part of the profil above the level ground, and cutting a trench of an equal ſection; it muſt likewiſe be conſidered, how much earth will nearly be dug within the place, for cellars, conducts, ſaly-ports and cazemats. For the removing the earth out of ditches and underground-works, in ſuch a manner, as juſt to make



J. Cowse Sculp.

make the rampart and parapet, and the rest for the glacis, is one of the most difficult tasks that can happen; since it requires great skill to do it so as not to have more than is wanted to compleat the work, and to prevent the moving of it over again from one place where it was thought necessary, to another, which, in my opinion, is hardly possible, and therefore the least removes will be the best.

That part of the trench made for the foundation of any work towards the rampart, ought to be cut into steps, as may be seen in the eighth profil, Plate VIII. and as near the wall as can be, without any inconveniency; because, when the rampart is compleated, there will be only the earth which has been dug, that will press against the wall; whereby its resistance becomes so much the stronger. In my opinion, the rampart should not be made till such time the masonry is settled and dry, which requires at least a twelve month, unless there is an absolute necessity for it; for when the damp earth is rammed against a wet wall, it will require a great while before it dries, and perhaps this will not happen at all, unless the mortar be very good; for which reason, I would mix cinders instead of sand with the lime, and lay this mortar about a foot and a half deep on the side of the wall next to the rampart; this will sooner dry, and prevent the moistness of the earth from penetrating into the masonry.

To prevent the pressure of the earth against the wall as much as is possible, branches of all kind of wood are stuck into the earth, by horizontal layers, with the sharp end as deep into the unmoved earth, and as firm as can be, and a bed of earth well rammed, of half a foot deep, in the manner represented in the eighth profil; when this is done, the wall has time to settle well, and becomes quite hard before it suffers any pressure.

Of the Foundations *and the manner of laying them.*

Plate VIII. As the foundations of all buildings in general, are of the greateſt importance, in reſpect to the ſtrength and duration of the work; we ſhall enter into all the moſt material particulars, which may happen in different ſoils, in order to execute works with all the ſecurity poſſible; becauſe many great buildings have been rent into pieces, and ſome fallen down, for want of having taken proper care in laying the foundation; and for a futher explanation we ſhall join here plans and profils, adapted to the moſt material ſituations that can be found.

Firſt, It is neceſſary to examine very carefully the nature of the ſoil, upon which the foundations are to be built; for doing this, proper augures are uſed to bore holes in ſeveral places 10, 12 to 15 feet deep, in order to diſcover the nature of the ſoil, and its hardneſs; or, if it is made of ſeveral layers or ſtratas, which is commonly the caſe, the difference of their nature and goodneſs; this is known by their colour or the difficulty of piercing through them.

If the ſoil be of a good conſiſtence, for a certain depth, without any water or ſoft ground, and this holds ſo all round the foundation, there need no other precaution be taken, than to lay the foundation four, five, or ſix feet deep; only obſerving to enlarge its breadth, in proportion to the heigth of the walls to be built upon them: Since the higher the wall is the more weight the foundation muſt ſupport: Although this is ſelf-evident, yet engineers do not ſeem to mind it, becauſe they make commonly the baſe of the wall in proportion to the depth of the foundation, and not to the height of the wall.

If the ſoil be a hard gravel for about 10 or 12 feet deep, the foundation may be built upon it, without any danger of its ſinking; or if the ſoil be a ſtiff clay,

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it will likewise be good; the first and second figures represent the profil and plan of such a foundation; where there are two or three courses of large stones to be put at the bottom; and the foundation projects by two or three feet before, divided into as many retreats, but not above a foot behind; because there is no danger of the wall falling backwards: this is the custom, but as for my part, I think there is no occasion for any projection at all backwards; since the counterforts are sufficient to support the wall, and this projection might be of greater advantage before, if added to those already mentioned.

If the soil be not very firm or hard to a sufficient depth, or when some parts are softer than others; it will be necessary to lay a grate of timber first cross-ways, and then long-ways; or some lay them first long-ways, and then cross-ways, which seems to be best, and well bolted together with wooden trunnels, as is represented in the third and fourth figures: Sometimes, these grates are boarded over with three inch planks, as is marked in the profil; at others large stones are laid between the timbers of the grate, and laid even with them, upon which the foundation is afterwards raised.

Some engineers choose to raise the fore part of the grate of about a twenty fourth part of its breadth, in order to prevent the wall from being overset by the pressure of the earth, as it has sometimes happened: this precaution seems to me to be very necessary, especially when the rampart is pretty high; and the courses of stone in the foundation should have the same inclination, excepting the last, or the base of the wall ought to be level, if those of the wall are so. I am sensible, that some engineers ridicule this practice, and say, that all beds of stone or brick should be exactly in a level; but Mr. *Coehorn*, who knew more of this matter than most, if not all of our modern engineers, has not only laid his foundations in this manner, but likewise

wiſe the walls quite up to the top. This is confirmed by *L'Abbé Dedier*, in his *Perfect French Engineer*, where he ſays, that in repairing the works at *Manheim*, which were built under the direction of Mr. *Coehorn*, they found that the courſes of maſonry were perpendicular to the outward ſlope, whoſe baſe is one ſixth part of the height, and the walls were only about three feet thick above, without any counterforts. This being the caſe, and the walls being ſtrong enough to reſiſt the preſſure of the earth, this manner of laying bricks or ſtones has greatly the advantage over that commonly uſed.

If the ſoil be ſand, and of no hard conſiſtence, the grating the foundation is abſolutely neceſſary; or if the ſoil be a ſoft loom or common earth, it is alſo neceſſary to take this precaution; and in general, when the ſoil is doubtful, though not abſolutely bad, a grating ſuch as this cannot but be very uſeful in preventing the walls from ſinking: and I muſt repeat it again, when the wall or rampart is very high, particular care ſhould be taken to ſecure the foundation in the beſt manner poſſible; for it is better to do this, though ſomewhat more expenſive, than to run the chance of making bad work at an eaſier rate, which might prove more burthenſome at the end.

It is neceſſary to obſerve, that when there is any timber under the foundation, the firſt courſe of ſtones ſhould be made without mortar, becauſe its corroſiveneſs deſtroys the wood; and in general, where any beams or timbers are laid into the maſonry, inſtead of mortar, ſtiff clay is uſed round it; and ſome carpenters make thin caſes of wood round the parts which enter into the wall.

When the foundations are ſo very bad, that the grate of timber mentioned before is not ſufficient, but is hard after a certain depth; upon ſuch an occaſion, it is proper to drive piles, and then lay a grate over them, ſuch as is repreſented by the fifth and ſixth figure; theſe

these piles are to be placed exactly under the crossings of the timbers, to which they are fastened with trunnels, and are to be drove into the ground as far as they will go.

As this method of laying foundations happens most frequently in the works of a fortress, and is very expensive, care must be taken not to make any more than what is necessary. In order to find the proper length of the piles, one or two are drove as deep as they will go, and then cut a certain number of the same length, and when these are drove, and the depth of the foundation remains the same, more are cut of the same length; but if the foundation changes, the rest must be made accordingly. By this method a good deal of timber may be saved; whereas, if the piles are all cut at once, some will happen to be too long, and perhaps some too short, which wastes a great deal of timber to no manner of purpose.

Some engineers drive piles into every corner of the squares formed by the timbers, and none under the frame, as is represented here; but this method must appear to every judicious reader, not so good as the former, because the frame is supported by nothing but the earth, which, being but soft, must give way to the great weight of the wall pressing upon the frame.

Others drive not only piles under the grate, as we have said above, but likewise two in every square, that is, in the opposite angles; but it seems to me, not worth while to make such expensive work without an absolute necessity, and when no other method is practicable.

Besides the piles under the grating, others are to be drove at the outside next to the ditch, as is represented in the plan by the letter *a*; their number is uncertain, and ought to be regulated by the goodness or badness of the foundation. In both foundations, represented by the third and fifth profils, the outside timber next to the ditch ought to be cut in such a manner that the wall may rest upon part of it, and the other part prevent it from sliding into the ditch, or else a smaller timber should be fastened with bolts upon the larger. Mr. *Belidor* gives an example of a wall sliding in the ditch, at *Bergue St. Vinoc*, in *Flanders*, which was the face of a ravelin; the same thing happened some years ago, at our wharf here, at *Woolwich*, for the middle part of it, slid five or six feet into the *Thames*, because the foundation was only clay rammed even with the bed of the river, and which would have been sufficient, had the precaution above-mentioned been taken.

We have mentioned before that sometimes planks are used to cover the grating, and sometimes not; where there is plenty of stones, these planks may be saved; but in walls made of brick they are absolutely necessary; for they being but of a small size, those which rest upon the timber will not be able to sustain those which are between them.

If the foundation is either all rock, or only partly so; the bed of the wall is to be sunk about 6 inches or something more into it, in the manner represented by the seventh figure, to prevent the wall from sliding, which otherwise might happen, because masonry seldom binds so well with the rock as to make it firm and durable. When the bed is made, care must be taken to sweep it very clean, in order that no rubbish or dust remain in it, and after this, it must be wet as the wall is made; by doing so, the mortar will enter better into the pores and small cavities, the masonry will likewise bind with the rock in a more easy manner, and form in time but one continued solid stone.

Although rock is the strongest foundation that can be built upon, nevertheless, engineers look upon it as one of the most difficult pieces of work to be met with; their reason for thinking so is, that they are seldom level, but raise and fall continually, by which the work changes its profil at every small distance, and to raiſe the foundation to a proper level, and bind the maſonry to the rock in a ſtrong and firm manner, meets with the greateſt difficulty.

The ſecureſt manner of proceeding in ſuch a caſe, is, to clear the rock, as well as can be, from all duſt and rubbiſh, in the manner obſerved before, and to ſink from four to ſix inches into it; then raiſe the lower parts with good maſonry made of very thin but ſtrong mortar, ſo as to be in the ſame level with the higher ones. This work muſt be left ſome time to dry and ſettle, otherwiſe, that part of the wall which ſtands upon the made foundation will ſink and break off from the parts which ſtand upon the rock.

Sometimes the rock will riſe at one end nearly as high as the wall itſelf; in this caſe, the work muſt be raiſed to a level, of about ſix feet from the bottom, and then left to dry and ſettle for ſome time; after that, it may be raiſed to the ſame height again till ſuch time as the whole wall is finiſhed; and to prevent the workmen from ſtanding ſtill, ſeveral parts may be undertaken at the ſame time and carried on alternately.

Sometimes it happens, that the rock riſes gradually behind, nearly as high as the wall, or, which is the ſame, that a wall is to be built againſt the rock; in this caſe, the rock muſt be well cleared from all dirt and rubbiſh, and if it is too ſmooth, it muſt be pickt, or ſmall cavities made in it, that the mortar may lay hold of, and bind it with the maſonry; and the work muſt be carried on gradually and ſlowly, otherwiſe the maſonry will naturally ſink and tear off from the rock.

Mr. *Belidor* propoſes a method for building walls in this caſe, which, he ſays, has often been practiſed by ſome *French* engineers with good ſucceſs; that is, inſtead of uſing common mortar and ſtone in the uſual manner, they prepare what is called ſtone-mortar; which is made of thin but ſtrong mortar, mixt with ſtones, about the ſize of a wallnut, a little more or leſs;

then they ſet a kind of coffer without a bottom, cut underneath, ſo as to agree nearly with the unevenneſs of the rock; then this coffer is filled with mortar, and let ſtand till it is dry and pretty hard; then they take the coffer away, in order to place it elſewhere. The reader may eaſily perceive, that the ſurface of this mortar is laid ſmooth and level, and that, when it is well ſettled, it will ſtick much better to the rock than any other kind of work whatſoever; theſe kinds of walls become in time as hard as ſtone itſelf, as appears by the remains of ſuch as have been found here, in *France*, and in *Germany*.

In ſome parts of *Scotland*, in *Ireland*, at *Gibraltar*, and *Mahon*, the rocks are generally of lime ſtone; in ſuch a caſe, no better work can be made, than to mix the ſtones of the ſame rock with the lime; this will, by the likeneſs of the parts, form a work that will join to the rock, and in time become as one continued ſtone.

It happens ſometimes that under a bed of gravel, clay, or any other hard conſiſtence, there is a ſoft watry ſoil or ſand, to a great depth; where it would be dangerous to drive piles, on account of the ſources or ſprings, which are generally under theſe places, which, when they get once a vent or opening, fill the trench made for the foundation in a ſhort time full of water, in ſuch a manner, as there is no poſſibility to build there. When this happens, a gutter muſt be made to lead the water out of the trench into ſome well made for that purpoſe, if none is found near enough, and engines ſet to work to draw the water out of it into ſome lower place or ditch.

It may happen, that the water comes ſo faſt into the trench, as not to be drawn off; in both caſes, a ſtrong grate of timber muſt be made, and planked over, which being laid over the foundation, and faſtened in ſuch a manner, as not to ſhift its place, then the maſonry is built upon it, by which it will ſink gradually,

dually, till it comes to the ground, and when the foundation is raised above the water, it is left dry and settle before the wall is continued.

I have been assured by people of veracity, and judges of these works, that many such instances happen in *Russia*, as well as in *Flanders*, and yet when the walls are finished, they stand nevertheless as firm as if they were built upon a strong foundation; it is certain, that these walls will sink, but then the business is to make the whole together without clinks or breakings; which can no otherwise be done, than with very good materials, and great care and industry.

Notwithstanding that no water appears above ground, and that there is only a hard crust of five or six feet deep over a swampy soil, yet it is necessary to lay a strong large grate under the foundation; by taking care to sink the trench as little as can be done, for the safety of the work; and the foundation must be carried all round alike by horizontal courses, and no new one begun before the last be quite finished, so that if the ground underneath gives way, it may be pressed alike every where, and sink together.

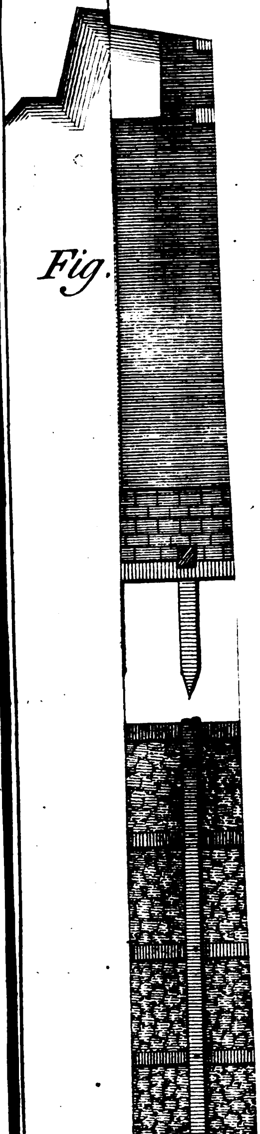
This method of carrying on the foundation alike all round the work, should be observed every where, excepting on rocks, or such a hard substance as cannot give way, where it may be done by parts one after another; only observing to join them well together, and by steps, that no two joints may be over one another.

There are some situations, which, besides being swampy, the trench dug for the foundation fills in a short time with water; the method used upon these occasions, is, to open only as much of it as can be made in a day, and the stones are laid, without any other precaution, on the ground, and the work is carried on as fast as possible, till the wall is above the height to which the water rises; but this foundation must be made very broad and by retreats; and the stones laid in terrafs mortar, that it may foon grow hard; when this is done all round, and the work fettled, the reft is built in the ufual manner.

Thefe kind of foundations are very common in *Flanders*, and Mr. *Vauban* was very much puzzled at firft how to proceed, till fome workmen of the country, who had been ufed to them, put him in a method of it: I have feen the fame at *Douay*, where they dug a trench of about 40 yards, and three feet deep; and as faft as it was opened the mafons worked at the foundation, which was raifed fix feet high; though the next day half of it was under water, yet the work ftood as well as if it had been built upon a folid foundation.

As the different fituations and foils require different precautions, it is impoffible to give particular methods for every one; the moft fecure and probable, by which an engineer may fucceed, is, to confult the workmen, who either live upon the fpot, or near it, and who have been employed in fuch foundations; for they generally know beft, what method will moft likely fucceed; by confulting feveral upon the fame fubject, if they differ in their opinion, which is often the cafe; it is the engineers bufinefs to judge what is beft to be done, and from his own experience, joined to that of the workmen, deduce the method, by which he is to carry on his work: But, notwithftanding all human precautions that can be taken, yet accidents will happen, which are to be repaired as foon as poffible, and whereby the engineer will learn how to avoid them afterwards, in the remainder of his works.

We have endeavoured to give here moft of the feveral cafes, which commonly happen, in all foundations made upon the land; and which, if ftudied with care, I do not doubt, but an engineer with a moderate fhare of practice and knowledge will be enabled to perform fuch works: But the manner of laying the foundations in water for bridges, fluices, moles, and piers for harbours, Fig.



bours, will be treated of separately in the latter part of this work.

How to carry on the Works *of a* FORTRESS.

The first thing to be done, is to know what part of a fortification is to be built first: Some engineers begin with the covert-way, and secure it with pallisades, in order, they say, to prevent the enemy from disturbing them in carrying on the works: This reason may do in time of war, and in a place where the enemy can come at; but in a time of peace, it is entirely groundless, because it is a difficult matter to know exactly how much earth is required to make the rampart of the body of the place, and those of the outworks; and therefore by leaving either too much, or too little, the carrying it afterwards to their proper places causes a great deal of superfluous expences, entirely owing to the want of skill in the engineer.

Others chuse to begin with the flanks, and then go on with the faces of the bastions, that in case an enemy should endeavour to disturb them, they might keep him off by means of the guns placed therein: This may do very well when the foundation is good, but would by no means be proper, where they are bad, for the reasons given before; because if one part should be built before the whole foundation is laid, it would be settled before the next is finished, by which the last would break off from the former by its settling: This will even happen, when the foundations are good; it is certain, that when the foundations are once laid all round, of about six feet high, and well settled; then the rest of the wall of the bastions may be finished first; and forasmuch, that when they are full, require a great quantity of earth, which is easily carried through the curtains; whereas the earth for the ramparts of the curtains cannot so well be carried through a passage in the bastion; but, however, every engineer may have his particular reasons, for beginning the works sooner one way than another.

When the foundations of the body of the place are laid, the first thing to be done is, the openings for the common sewers in proper places, to carry off the filth and rain water of the streets; and it must be particularly observed to give them a proper descent, from the center of the place towards the ditch, that the water may carry off the mud, otherwise they will soon choak up, and require continual cleaning; and they should always be carried either under or near the places where the bog-houses are to be made, that the water may carry off the filth, and prevent their stinking in warm weather, and their being nauseous to the inhabitants.

If there are any powder-magazines to be made in the bastions, or any other building, such as an hospital for the sick and wounded in time of a siege, or store-houses to lodge ammunitions in, they must be built at the same time as the bastions; in order that there may be no useless removings or diggings of earth, which would create superfluous expences. If there are galleries for mines to be made in any of the works, they should be begun at the same time: In general, all under-ground works should be first considered, and begun as soon as the foundation of the walls are laid: For which reason, not only the plan and profils of a fortress should be made at first, but likewise, drawings of the most minute parts of all the necessary buildings, which depend on the fortress, with their dimensions marked upon them, and expressed in the estimate.

SECT.

SECT. VIII.

METHOD *to be observed in making* MASONRY.

HAving entered into all the most necessary particulars of the materials used in the building of a fortress, we shall now shew how they are to be applied in the best manner; and as stone masonry is by much the greatest part, we shall begin with that first, and then proceed with the rest, each in their order.

As masonry made of hewn stones is certainly the best, but at the same time so expensive, that few works are hardly ever wholly built with them; for which reason, engineers content themselves to make the lower part of the wall of them, for about 8, 10 or 12 feet high, as likewise the salient angles quite up to the top: and the hardest sort are chiefly used at the angles, and in those places where a strong current, or the sea can beat against them: For if the stones are not very hard, the water striking with a great velocity, in an oblique direction, wears them presently out; as may be seen at *Portsmouth*.

Masons distinguish their hewn stones by two names, *viz.* stretchers and headers; that is, suppose a stone to be twice as long as it is broad, then if it be laid so as the length goes into the wall, it is called a stretcher, but if the length appears on the surface of the wall, it is called a header. These stones are laid alternately, a header, then a stretcher, through the whole length of the wall; and at the angles, that which is a header one way is a stretcher another.

The engineer or his overseers, ought to be very diligent, to see that these stones are well squared, and when they lay them, that they bed well, that is, that they

they lay quite flat on each other; for the masons often are very careless in their work, either for the sake of speed, or out of meer idleness; and when the stones are laid, and bed not well, they put wooden wedges under the corners, to save the trouble of removing and squaring them a-new; which should be prevented as much as possible; otherwise a wall can never be strong, and firm, and therefore has not a proper strength to resist the pressure of earth which is against it.

The ancients were so very nice in all their public buildings, that no joint scarcely ever appeared; which they did by rubbing the joining surfaces against each other, and laying the stones without mortar, leaving the outward surface rough, till the stones were all laid, and then making it smooth: But this precaution is never taken now-a-days, for which reason, no modern building comes up to those built by the ancients, either for beauty or strength: For you may see in the finest buildings in *England*, the joints in columns or pilaster, half an inch wide, filled with very bad mortar, which by the weather has been worn out in a short time, to the great shame of the modern architects.

The best stones being used in the facing, the rest is made with small stones, called rubble; but care must be taken, that this rubble work is well performed, in making the workmen choose those which lay close to each other, and that they fill up every part as well as they can, and not by a quantity of bad mortar, as they certainly will, if not prevented.

If the walls are to be built in water, the stones must be laid with terrass mortar, those parts which are sometimes dry and sometimes wet may only be laid in tile or cinder mortar: when we say that stones are to be laid in terrass mortar, it is meant only round the facings, and the rest is filled up with good common mortar; because terrass is very dear, as little is used as can be; I would advise the engineer, to lay all the facings with cinder or tile mortar, if he intends to make stong work.

work. For the mortar commonly used in facing the works, is generally so bad, that it requires to be new done in very few years; which is not only expensive but likewise troublesome.

The bricklayers and masons content themselves with making the facing look well; for which reason, when they build by contract they make use of mortar, with very little lime in it, that is, no more than to keep the sand together; and when the wall is run up, they scrape a little out of the joints, which they point with a better sort; so that the wall looks as well as if it had been built in the best manner. The only reason I can find, for their making worse work here than any where else, is, that most people in and about *London* build upon leases, so that they contract with the bricklayer to do the work, never troubling themselves whether it is well made or not; thinking if it but lasts their time it is sufficient.

This is what the workmen are so used to, that when they are employed, by the public, or government, it requires the greatest care and constant looking after them, to make them do better work.

The back part of walls, in ramparts and counterscarps, should be laid, for the depth of about two feet, in strong mortar, so as to dry soon; and the earth should not be laid against them before a twelvemonth; for if the wall is not well dried beforehand, the continual dampness of the earth will prevent it from drying afterwards; and this is often the case, that walls cannot resist the pressure of earth against them, which they otherwise in all probability would have done, had the work been set before the earth was laid against them.

The manner of building arches, and other works under-ground, requires some particular precautions, besides those mentioned already, which we shall mention, when we come to treat of these kind of works.

Mr.

Mr. *Belidor* says, that hard ſtones ſhould be laid in ſtiff mortar, and ſoft ones in ſoft mortar; which ſeems to me quite contrary to the nature of the thing: becauſe the pores of hard ſtones being very ſmall and cloſe, the mortar cannot enter into them without being very ſoft and thin; on the contrary, ſoft ſtones have larger pores, and are very ſpongy, and therefore require a greater ſubſtance to unite them; whereas thin mortar will ſoon be ſucked into the ſtones, without being able to unite them. This rule is obſerved by joiners, for when the wood is hard, they make uſe of thin glue, and on the contrary, in deal or other ſoft wood they uſe that which is thick and ſtrong.

The manner of building with bricks is much the ſame as that of building with ſtone; but it muſt be obſerved, that as bricks cannot be cut to the ſlope of the wall, and are always made ſquare; the bricklayers make the joints at the ſlope ſide bigger than within, in order to follow the propoſed profil, which is a very bad practice; for the weather beats the mortar out of theſe wide joints, by which the wall requires to be new pointed every two or three years; we have inſtances enough of this kind, not proper to be mentioned here.

Another defect ariſes from this practice, which is that the courſes of the bricks length being at right angles to the ſlope, and the reſt lie in a level, by which they make an angle, whereby the bricks can never bind ſo ſtrongly together, as if they were all laid in the ſame plan; whereas, if the outward ſlope be made one ſixth part of its height, and the courſes perpendicular to that ſlope, and to lie in the ſame plan, the bricks will bind much better together, and make a ſtronger work; as likewiſe reſiſt more the preſſure of the earth, as we have obſerved before.

I know that ſome engineers, and moſt workmen, ſay, that the courſes of ſtone or brick ſhould always be in a level, ſo as to bed well, otherwiſe, the wall will not ſupport itſelf upright; but this is no more than a conceit

conceit of the workmen, who will never go out of the old beaten road; for they do not consider that the pressure of earth endeavours to throw them forwards; and therefore, by opposing a greater force to this pressure, the walls must last the longer; what they say may do very well in civil architecture, but by no means in the military way.

An engineer should always consider, what method answers best the proposed design, and never follow the advice of others, unless it is agreeable to sense and reason; for he that follows blindly the practice of those that went before him, will never become a good engineer: This may chiefly be the cause of making so few improvements in fortification; for whoever reads authors that wrote upon the subject some hundred years ago, will be surprised, to see what few alterations have since been made, and these are, the most part, for the worse.

Another great defect in brick-work, is the large joints made with bad mortar; they are commonly three quarters of an inch, whereas, half that thickness is more than sufficient: A certain engineer piqued himself, to have all the courses exactly three inches; and as the bricks are two inches and a quarter thick, the joints were three quarters; but this ought not to surprize any body, considering the humours of the person, which are altogether extraordinary, as well as most of his actions.

Sometimes bricks and stones are used together, especially, in places where stone is scarce: This may be done to good purposes; for if the wall begins with stone to about six feet above ground, and then carried on as high with bricks, and over this, a bed of large stones is laid, then bricks, as before, and another bed of stones; it will make better work than bricks alone; because, stone being heavier than bricks, they keep the work better together by their own weight.

When

When large ſtones are ſcarce, the facings of walls are made of bricks, and the reſt with rubble ſtones; but as it is hard to bind ſtones and bricks together, the work becomes very bad, unleſs great care is taken, to intermix them in a proper manner. The *French* engineers make the bricks go off from the facing towards the back part of the wall, in an edge, or like an inclined plan, and fill the reſt with ſtones; this may be done another way, by carrying here and there a courſe of bricks quite croſs the wall, of three feet broad, and two high, at proper diſtances from each other, which will bind the wall pretty well together. In ſhort, the engineer ought to judge from the materials, and his own experience, what is beſt to be done upon all occaſions.

SECT. IX.

Of CASEMATS *and all ſorts of under-ground* WORKS.

THE method of building the walls of underground works requires much more precaution, than thoſe that are above, not only becauſe they are to be bomb-proof, but likewiſe to keep out the damp or wet, that whatever may be depoſited in them, as men, ammunition, and proviſion in time of a ſiege, may keep dry, and be preſerved without any damage.

In ſmall fortreſſes, there cannot be too many underground lodgements, becauſe nothing can be ſecure otherwiſe; ſince the ſhots and ſhells can reach every part of the place, and deſtroy it: Therefore there ſhould not only be a ſufficient number of magazines that are neceſſary to lodge ſtores and ammunition, but likewiſe hoſpitals for the ſick and wounded, and places to reſt the fatigued ſoldiers, in a ſecure manner. Whereas in in large places, there is always some part or other which are secure from shells or shot, which may serve to lodge every thing that is not immediately wanted.

But before we enter into the particulars of their constructions and situations; it is necessary to explain the manner of building them.

As we have but few works of this kind here, and most of them were built by such engineers as were not skilled in them; we shall insert the method pursued by the *French*, given by Mr. *Belidor* in his *Science des Ingeniures*; as knowing that he had it from the most knowing and experienced engineers of *France*.

We suppose, says he, that the masonry has been built with all possible precautions, that is, the stone or bricks to have been laid in mortar made of the best lime to be had, mixt with tile or cinder dust, and left to dry a sufficient space of time before it is covered with a particular kind of cement, made according to the following manner.

This cement is generally made of tourneys cinders, which is nothing else but the cinders, that are found in lime kilns, where they use coals, mixt with the small particles of lime stone: this is beat and prepared every four or five days, for the space of six weeks; observing to put only a small quantity of water to it the first time, and none afterwards; or this cement is made with mixing one third of unslaked lime, the best that can be had, with two thirds of terrass, or instead of terrass two thirds of pozolano, or else old tiles well burnt, reduced into dust, and passed through a sieve: but whether the one or the other of these cements be used, the parts must be well reduced into dust separately, with a hand mill, and afterwards the two materials well beat and mixed together, and to repeat this several times without any water, excepting at first.

Before the cement is applied to the vaults, it is necessary that the masonry be well finished, and had a sufficient

ſufficient time to dry, which is reckoned to be about ſix months; then the joints muſt be well cleaned with a ſmall iron hook, after that the duſt and dirt being ſwept off very clean, ſome water is ſprinkled over it with a water-pot; then the cement is laid over it, being well worked immediately before, of about an inch and a half thick every where, and as even as can be; which is beat all manner of ways with a wooden battle, of two inches broad only, in order to preſs the cement better into the joints; after that, it is made quite ſmooth with a flat iron, ſuch as are uſed for ironing linen, till it begins to be hard; and for ſome time it muſt be rubbed over with a mop dipt into cement made very thin, once every day, and then paſſed immediately over it with the aforeſaid iron, to make it ſmooth; and when this is done, it is covered with ſtraw, to prevent the heat from cracking it; this work is continued till ſuch time that no cracks appear in it: after that it is waſhed over for five or ſix days as before, without poliſhing or coverings.

In applying the cement, care muſt be taken, above all things, to make it ſmooth and even, and to terminate the upper part in an angle like a roof; and ſo as no ſtone appears through the cement. This being done, the cement is covered with a bed of gravel or coarſe ſand of four or five inches thick, laid every where very ſmooth and even; and upon this bed of gravel is laid another of earth of about a foot and a half thick, well beat and rammed down; and then more earth is put upon it, and beat down; this is continued quite up to the ſurface of the ground: Mr. *Belidor* ſays, that the vaults in the tower-baſtions of *New Briſac* were built in this manner.

I ſhould think, that if a bed of well-prepared clay of about ſix inches deep, was laid over that of the gravel, and over that one of earth, it would much better prevent the water penetrating to the cement, than earth only; as to the gravel, its uſe is to ſuck in the dampneſs

dampness of the ground above it, and to keep the moisture from the cement.

Mr. *Belidor* proposes another method, which, he says, has been used in the building of a famous orangery at *Versailles*, with great success, and which is as follows.

As soon the vault was made, it was well cleaned, and a bed of rubble stone laid over it, of 18 inches thick, without any mortar, only dust of lime thrown between the joints; upon which was laid a bed of the same dust four inches thick; and then a bed of pebble stone, and then another of flat stone of a foot deep; which was covered with another bed of lime dust of four inches thick: this, he says, was continued to the very top, and even with the level of the terrass above it: This vault has stood hitherto the weather, without the least change or alteration.

The same author says, that sometimes a bed of clay a foot thick has been laid over the first bed of stone, and one of mortar three or four inches thick over the last, and then the earth. To secure the piers of underground vaults against the water filtering through the earth, a wall of dry stone is made against them on the outside, of two feet thick, without mortar, the joints being filled with gravel or coarse sand; and the wall is continued to within two feet of the roof of the vault; the rest being finished with good masonry, and covered with the bed of cement, which lays on the vault, and is extended over the wall: this precaution will secure the piers from all dampness; but it ought to be observed, that this dry wall should be two feet lower than the foundation of the vault, in order to make a gutter for carrying the water into the ditch.

SECT. X.

Of SALLY-PORTS.

Plate IX. SAlly-ports, or poftern-gates as they are fometimes called, are thofe under-ground paffages, which lead from the inner works to the outward ones; fuch as from the higher flank to the lower, or to the tenaills, or the communication from the middle of the curtain to the ravelin. When they are made for men to go through only, they are made with fteps at the entrance and going out, as may be feen in the firft and fecond figures; it may be obferved, that when the rampart is not of a fufficient height, as it happens here, it being but 15 feet high, the entrance has been funk 5 feet below the level, in order to fecure the arch againft fhells; and the outfide of the arch is circular as well as the infide, and not in the form of a roof, as Mr. *Belidor* would have it; becaufe it is not poffible to make them fo, unlefs the rampart is very high; neither can the infide of the paffage be above 6 feet wide, and the height but 8 and a half, otherwife it will not be covered with a fufficient quantity of earth to fecure it againft accidents.

There is always a gutter or fhore made under the fally-ports which are in the middle of the curtains, for the water which runs down the ftreets to pafs into the ditch, as we have marked in the firft profil; but this can only be done when there are wet ditches, becaufe the water would fettle in dry ones before the fally-port, and make it difficult to go out and in; befides, the fmell of this dirty water would become very offenfive in warm weather.

Thefe under-ground paffages are fecured by two ftrong doors, the one at the entrance and the other at the going out; the outfide of the paffage is generally walled

walled up in time of peace, leaving only an opening like a window to let the air in, that it might not be too damp, and rot the doors. The side-walls, or piers, as well as the arches, are two feet thick above, and two and a half near the foundation; there being no occasion for counterforts, as Mr. *Belidor* has them; the wall being of a sufficient strength to resist the pressure of the earth, as we have found by computation. The white space above the arch in the first figure, terminated by two parallel lines, represents the crust of cement laid over it, and the dotted space above this, the bed of dry stone, spoken of before: the front wall at the entrance is raised three feet above the rampart, to prevent people from falling down in the dark.

At the sides of these passages, powder-magazines are often built, which are very necessary, for having stores and powder nigh at hand to transport them into the outworks in the time of a siege; they are made in proportion to the quantity of stores wanted. Those marked in the second figure are 15 feet by 18; but it must be observed, that their width depends also on the height of the rampart; because there must at least be 3 feet of earth above them, in order to make them bomb-proof. The walls as well as the arch are but 3 feet thick, sloping at the outside, so as to be but four near the foundation, without any counterforts.

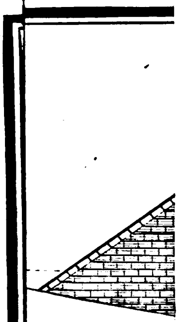
When sally-ports serve to carry guns through them for the outworks, instead of making them with steps as is represented in the first and second figures, they must be made with a gradual slope, as is represented in the third and fourth figures; and they must then be 8 feet wide: If the rampart is but low, the arch may be made elliptical; in short, in the building these passages, regard must be had to the profil of the rampart, and to the use they are intended for, whereby the proper dimensions may be determined.

When they are made with a gradual slope, the bricks of the piers or side-walls must be made by horizontal courſes, as high as the ſpring of the arch; and the arch itſelf perpendicular to the ſlope, in the manner repreſented by the third figure: there are two folding doors, one at the entrance, and the other at the going out, that they may leave a free paſſage for guns and other warlike engines, and ſometimes ſeveral of theſe doors are made, in order to defend the paſſage; for which purpoſe, wickets and loop-holes are made in them, to retire through and defend them one after another.

The walls are about two feet and a half near the foundation, with a ſlope on the outſide, ſo as to be two feet only near the ſpring of the arch, and the arch itſelf is but two feet without any counterforts; becauſe the weight of the arch is ſufficient to counterbalance the preſſure of the earth. The magazines on both ſides of this paſſage are 14 feet ſquare, and the walls are half a foot ſtronger than the others. The top of the arches of both the paſſage and the magazines are covered with a cruſt of cement, and above this with dry ſtones, as well as the ſide-walls, in the ſame manner as has been mentioned before.

In fortreſſes where a river paſſes through the ditch, ſuch a paſſage as the laſt is made to water the horſes; which are ſometimes walled up in time of peace, and at others left open, with a ſtrong gate to lock them up at night; but as they are the ſame as the former, we ſhall ſay no more about them. As to the foundations and many other particulars relating to theſe paſſages, we ſhall leave them to the judgment of the engineer, who is to conſider well beforehand all the conveniencies, and every minute circumſtance, before he begins the work.

It is cuſtomary to build hoſpitals for the ſick and wounded, under the level ground of the baſtions, as likewiſe powder-magazines, ſtore-houſes, and ovens to bake the bread; theſe buildings conſiſt of a long paſſage from the center of the gorge towards the ſalient



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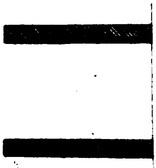

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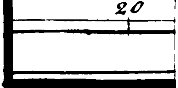


ent angle, with as many rooms on both sides as are thought necessary; some of them have chimnies, and others air-holes coming out within the bastion; these buildings are especially made when there is a cavalier in the bastion; because they need not then be sunk under the level, there being always a sufficient quantity of earth above them, to resist the force of the shells. These works are built in the same manner, and with the same precautions, as the former.

SECT. XI.

Of Casemats *in the* Ravelin.

As we esteem the ravelins to be the most essential of all the outworks of a fortress, so we think that nothing contributes so much to a long and stout defence, as the making them capable of all the resistance that is possible: For a town defended as it ought to be, can never be taken, till such time the enemy is master of the ravelin in the front attacked. *Coehorn* and some others have made their ravelins with casemated flanks, but for what reason is unknown to me; though several pretended engineers look upon them as considerable works: It is therefore worth our while to examine their use and perfection, in order that young engineers may not be misled by the erroneous opinions of their superiors.

As these flanks cannot defend the ravelin, in which they are, their intent must necessarily be to defend some other work: which can only be the breach in the faces of the bastions opposite to them; the passage of the great ditch, or the covert way: But as the ravelin in the front attacked, is either taken, or its defence destroyed by shells, and the ricochet batteries, before these works are or ought to be attacked, it is evident, that these flanks in the front attacked can be of no use at all. Neither can thoſe of the ravelins in the fronts, adjacent to that attacked, be of any uſe, ſince but a few of the guns placed there will bear upon the attack; and the beſiegers have always ricochet batteries to deſtroy the defences of theſe works, which ſee the attack, as may be ſeen in the ſixth plate of our attack; beſides, the ſame batteries which batter the breach in the baſtions, will ſee obliquely theſe flanks; or the moſt trouble theſe flanks can cauſe, is to oblige the beſiegers to raiſe two batteries of four guns each, in order to deſtroy them. I leave it therefore to the judgment of the reader, whether it is worth while to make theſe expenſive works, for ſo little a purpoſe, or whether ſome others might not be made of a much better defence, and of no more expence than theſe.

Notwithſtanding that the ravelin in the front attacked at *Bergen-op-zoom*, had caſemated flanks, yet the *French* took both baſtions and ravelin at the ſame time, without given the beſieged time to fire a gun from them: this was not ſo much owing to the bad conſtruction of the works, as to the unſkilfulneſs of the defenders, or to ſomething elſe not proper to be made public.

Plate X. The beſt way to ſecure the ravelins, when the ditches are dry, in my opinion, is to make redoubts in them, with a parapet of about 12 or 15 feet thick only, and about two feet lower than that of the ravelin; that thickneſs is ſufficient, ſince it can only be ſeen from the rampart of the ravelin: and if the counterſcarp be caſemated in the manner marked with dotted lines in the plan, Fig. 1; and as the plan of the works ſhews in the ſecond figure; it appears to me a difficult matter for an enemy to get poſſeſſion of it.

That there may be a ſecure communication from the works in the redoubt to thoſe in the ravelin, and from thence to the covert-way; traverſes are made in the ditches, marked L, L, in figure 1. or *l*, *l*, in the ſection, fig. 3: Theſe caſemats have two entrances, marked

marked E, E, in fig. 2, from the ditch or the caponier usually made from the opposite curtain to the gorge of the ravelin; as well as two stair-cases, marked D, D, in the same figure, to mount into the redoubt, as likewise two more in the level ground of the ravelin, not marked here; so that if the enemy gets possession of one side of the ravelin, the garrison may sally out through the other; or when the redoubt is lost as well as the under-ground work on one side, they may retire through the other.

As the besiegers can no other ways get possession of these works, than by mines; openings must be left in the great gallery A, A, at proper distances, for countermines to be carried on all the way under the ramparts, and behind the parapets, to resist the enemies miners; as likewise to oppose every attempt they can make, both above and under-ground, in such a manner, as to make it equally hazardous wherever they may choose to assail the work.

The openings of these galleries into the ditches of the ravelin and redoubt must be well secured with strong doors, full of iron, and behind these others with wickets and loop-holes, to retire behind, and to defend the entrance that way, in case the enemy should attempt it; as probably he would if they were not well secured.

The walls of these under-ground works need only be about two feet thick near the foundation, with a slope on the outside, so as to become a foot and a half near the spring of the arches; this will be sufficient, because the arches will secure them against the pressure of the earth. The piers which separate the lodgments B, are not so much made to strengthen the wall, as to prevent the arches from being too high, which may be elliptical or parts of circles. These lodgments are 10 feet wide, that is, as much as the great gallery is broad, in order that the arches may join well; and the base of the piers are 8 feet long; so that the whole breadth of the great gallery and the lodgment together is 18 feet.

The bottom of this gallery must be about 18 inches above the bottom of the ditch, in order to secure it from dampness, and the piers are 7 feet high, with loop-holes between them, which look into the ditch, to give air to the lodgments: as to the rest, the plans and section sufficiently shew our meaning, without being necessary to enter into any farther explaination: The only thing to be farther observed, is, that the arches at the entrance E, and over the stair-cases D, must be made conical; as to the others, the reader may easily perceive how they ought to join.

Mr. *Coehorn* made such galleries all round his counterscarp at *Bergen-op-zoom*, with loop-holes to fire into the ditch, and at the re-entring angles of the places of arms, lodgments nearly such as are marked here, which he called *Tambours:* and to secure the entrance above ground, he made a traverse on each side of the stairs, as likewise placed a row of palisades. As these lodgements made the best defence of all his works, in the last siege; it is plain that they are very advantageous in a fortress; but as to the gallery round the counterscarp, it was of no other use than to lodge the troops securely from danger, and to carry from thence galleries for mines under the covert-way and glacis. For which reason, I would either choose to make none or one of about 6 or 8 feet wide, which would sufficiently answer the intent proposed; and besides, would cost very little more than a single wall with counterforts: there might be some wooden doors placed at proper distances, with loop-holes, so that if one part was taken by the enemy, the defenders may retire securely into the others.

As to the casemats under the places of arms, they ought by no means to be neglected; and to secure their entrance above, there should small redoubts be made of 12 or 15 feet parapet, and a dry ditch before them; by this means the places of arms may keep off an enemy a long while, and make them pay dear if they take it; as it happened to the *French* at *Bergen-op-zoom.*

It may be observed in general, that a fortress without under-ground works can make but a small defence now-a-day, against the great quantity of artillery with which armies are furnished at present; for the defences above ground are soon destroyed thereby: therefore an engineer, who undertakes to fortify a place, must make use of all his skill and knowledge, to construct such under-ground works, as are best adapted to the nature of the situation; and to be as saving as possible, because these kind of works are naturally very expensive.

SECT. XII.

Of CASEMATED FLANKS.

Plate XI. MESS. *Coehorn* and *Vauban* were very fond of casemated flanks, the former made some in the ravelins at *Bergen-op-zoom*, and the latter in his tower bastions at *New Brisack*; they have been in great esteem formerly by most engineers, and a fortress without them was not thought to be of any strength; but now-a-days they are generally rejected, because experience has shewn, that the smoak becomes soon so troublesome as nobody can bear it, notwithstanding all the chimnies and air-holes that can be made to prevent it.

As the only objection against these casemated flanks, is their smoaking, engineers have endeavoured to find some remedy or other for it: but that proposed by Mr. *Belidor* seems, in my opinion, to be the best, and is what has been practised in several places, as I am told, and have seen myself at *Portsmouth*, near the sea; which

which is, to leave them open behind, in the form of piazzas; ſo that each gun has an arch over it, as the plan, elevation, and ſection, in the eleventh plate ſhews by the letter B; and the embraſures are marked by the letter C, which are Mr. *Belidor's* own draughts; he ſuppoſes the thickneſs of the front wall to be 18 feet, and to be of ſolid maſonry; but as this would be very expenſive, and ſeems to be uſeleſs, I would only make a common wall, and line the embraſures with brick, the reſt being filled up with earth in the ſame manner as other parapets, as we repreſented by one half of the plan: I ſaid, that the embraſures ſhould be lined with bricks, becauſe they, being ſofter than ſtone, do not ſplinter ſo much, and the ſhots make only holes, without breaking them ſo ſoon as if they were made of ſtone. Above theſe caſemats Mr. *Belidor* propoſes to make another battery, as may be ſeen in the ſection at A, annexed to the outſide elevation: but in low ramparts, ſuch as we propoſe, it will hardly be poſſible, and therefore this upper battery may be left out.

This method of making batteries may be of great uſe near the ſea or great rivers where large ſhips can approach pretty near; for they generally place men on the top maſt round, which, being higher than the parapets of low batteries, gaul the gunners in ſuch a manner with ſmall ſhot, that they cannot ſtand to their duty; this is, as I take it, the reaſon, that ſhips always get the better of land batteries, and not the ſuperiority of guns, as the mariners imagine; whereas, if the batteries were arched in the manner propoſed here, it would be quite otherwiſe.

Another obſervation is to be made, in regard to theſe caſemated batteries, which is, that if the piers were broader near the parapet, than at the other end, and the arches conical, ſo as to open more behind, the ſmoak would evaporate in a freer manner, than if they were cylindrical; it is true, that the conſtruction of conical arches is more difficult, and not very common, but an engineer

engineer ſhould never conſult the eaſineſs of the performance, but rather the perfection and uſefulneſs of the work.

If this manner of building batteries near the ſea, or navigable rivers, ſhould be thought too expenſive upon ſome occaſions, it will be ſufficient to make ſheds over them with planks or even with canvaſs, to prevent the gunners from being ſeen, when they are upon the battery; for as they are in no danger of ſhells, any thing that covers and hides them will anſwer the purpoſe; but the caſe is different in flanks, becauſe what the ſhot cannot effect, the ſhells will do, if no precautions are taken againſt them.

As we are treating of flanks, it will be proper to conſider the conſtruction of the embraſures; whoſe common form is, to make them narrow within and wide without; ſo as to enable the guns to fire not only directly, but likewiſe obliquely: this method has been objected againſt by a late author, ſaying, that the embraſures are ſooner deſtroyed this way than if they were narrow without and wide within. But as this author has very little knowledge in gunnery, notwithſtanding his boaſted experience, he did not know that it was impracticable to move the guns ſide-ways, from one ſide of the embraſure to the other, as the nature of theſe embraſures require: whereas the field carriages, having only two wheels, are eaſily directed to the right or left, as occaſion requires, when the embraſures are narrow within and wide without: This gentleman, ſeeing loopholes made in this manner at *Bergen-op-zoom*, imagined, I ſuppoſe, that cannon were as eaſily managed as muſkets, with which he is beſt acquainted.

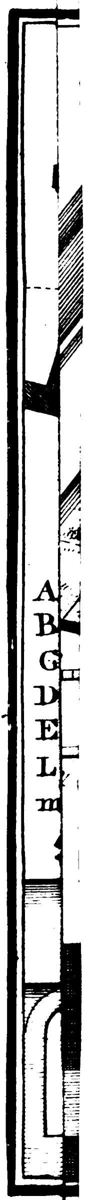
SECT-

SECT. XIII.

Of Caponiers.

A CAPONIER is nothing elſe but a paſſage made in a dry ditch from one work to another; when they are made from the curtain of the body of the place to the oppoſite ravelin, or from the front of a horn or crown-work, they have a parapet on each ſide of ſeven feet high, ſloping in a glacis on the outſide to the bottom of the ditch; the width within is from 15 to 18 feet, with a banket on each ſide: there is a brick wall to ſupport the earth within, of a brick and half above, with a ſlope of a fifth part of the height; this wall reaches only within a foot and a half to the top; to prevent graſing ſhot, from driving the ſplinters amongſt the defenders. Theſe caponiers with two parapets may properly be called double; for there are ſome made with one parapet only, in dry ditches of the ravelin, and in that of its redoubt, towards the ſalient angles, and open towards the body of the place; it is true, that theſe ſingle ones are alſo called traverſes, but differ from the traverſes in the covert-way, by their tops ſloping in a glacis to the bottom of the ditch, whereas the others are made in the form of all other parapets.

Caponiers made from the body of the place to the outworks, are ſometimes arched over, with loop-holes to fire into the ditch; they have likewiſe doors on both ſides for a communication from them into the ditch; becauſe the beſiegers never fail to deſtroy them by ſhot and ſhells, to render the paſſage more dangerous. The ſingle ones in the ditch of the ravelin and redoubt are likewiſe made with arches open towards the place, ſuch as we have ſpoken of here before; by making them in this manner, the guns which defend the ditch before


A
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before them can no other ways be dismounted than by mines, and when they are so low as that no mines can be made under them, the enemies passage over these ditches becomes very dangerous.

To make the passages or communications from one work to another, so as not be interrupted in time of a siege, or destroyed, is the most difficult part of fortification; for when the retreat out of a work is cut off or made dangerous, the troops in them neither will nor can defend them with so much courage and bravery as they would do otherwise; and this is the reason that an enemy always endeavours to destroy them; and should likewise engage engineers to prevent it.

SECT. XIV.

Of Town-gates *and* Guard-houses.

THESE gates are made various ways, sometimes there is only an open passage cut in the rampart, shut up by a strong wooden gate, or with a draw-bridge; and at others, this passage is arched all over, with a guard-house within, and a draw-bridge and a gate on the outside; the outside front is generally ornamented with pilasters and a pediment; the decoration chiefly depends on the taste the engineer has in architecture.

As we have no author that has wrote on military architecture, nor any of our fortresses, that I have seen, has any works of this kind worth mentioning; I was obliged to have recourse to Mr. *Belidor's Science des Ingenieurs*, which is the only work that treats of these things, in the modern taste; for what is to be found in *Dilichius*, *Spekel*, and other old *German* authors, is of so grotesque a taste, as scarcely would be followed now-a-days. But as the *French* are so magnificent in their military buildings, and the designs of this author are

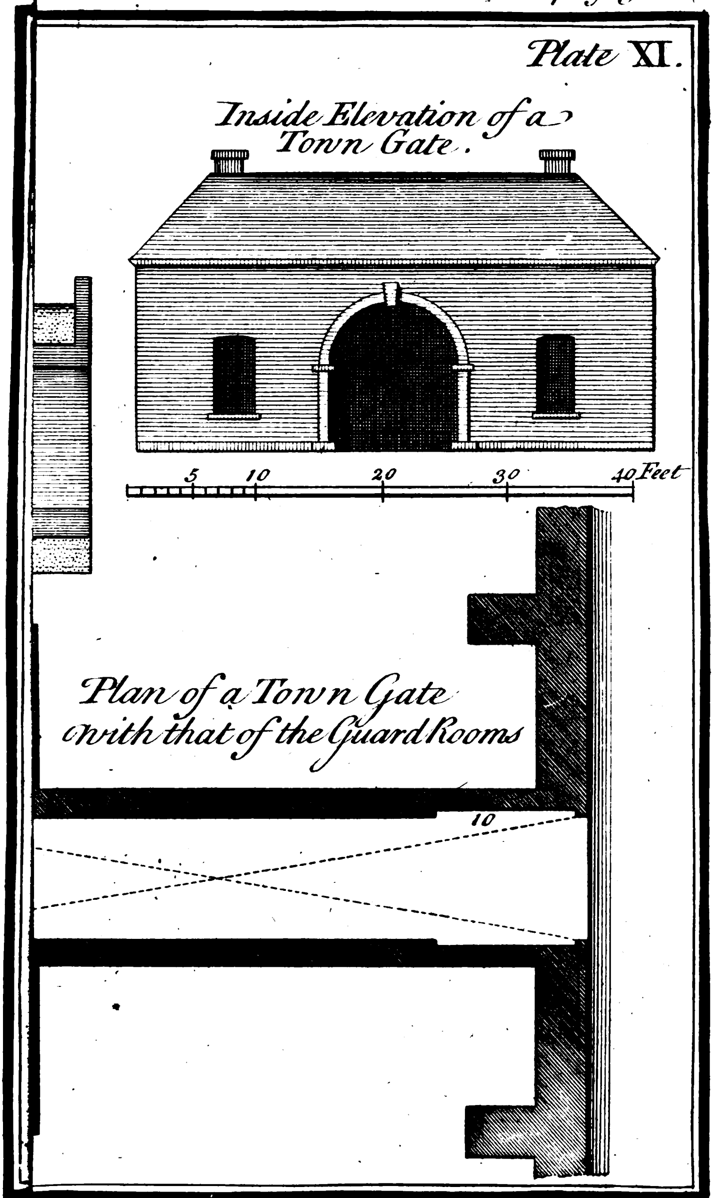
are chiefly adapted to large fortreſſes, which are not in uſe, nor neceſſary in this country; we have endeavoured to make ours in ſuch a manner as will moſt probably be of uſe to our engineers.

Plate XI. Our firſt deſign in this plate is quite plain; the width of the paſſage is ten feet, and arched above; at the entrance within is a guard-room for the ſoldiers on one ſide, and one for the officers on the other; each of theſe rooms is twelve feet ſquare, having a window in the front, two feet and a half from the ground, three feet wide, and ſix high; for it is a general cuſtom in all buildings to make the windows on the ground floor twice as high as they are broad; the chiminies are four feet wide, and a foot deep, half of which is taken out of the thickneſs of the wall and the other projects into the room, and is ſupported by piers of a foot thick: the doors are three feet wide and ſeven high.

The walls of the paſſage which ſupport the arch, are eight feet high, three feet thick near the foundation with a ſlope on the outſide, ſo as to be two feet and a half at the ſpring of the arch, which is alſo the thickneſs of the arch itſelf; the walls of the guard room are two feet thick only, and the height of the elevation from the bottom to the roof is fifteen feet.

I have made no counterforts to theſe walls, becauſe the preſſure of the earth, together with the ſtrength of the wall, will be ſufficient to reſiſt the preſſure of the arch. This arch, as well as all thoſe mentioned hereafter, muſt be covered with a bed of cement and dry ſtones over them, as has been mentioned before, where we have treated of this ſubject.

The outſide of this paſſage, that is next to the ditch, is ſhut by a ſtrong wooden gate covered with iron bars and rails, ſo as not to be cut open by any tools; and if it be thought neceſſary, a draw-bridge may be made; but as this gate is deſigned for a ſmall fort only, there is no occaſion of making any ornaments that require much



J. Couse Sculp

much expences; for which reason, a plain wall with a pediment will be sufficient.

Plate XII. As the outsides of gates are made various ways, and those in ravelins, horn or crown works, are different from those of the body of the place, because the passages are not arched, but always left open above; we have given here three different sorts; the first is quite plain, and may serve for any outwork: it is composed of two piers of 24 feet high and 7 broad, with a base of two feet high, having a cornish and round balls above; the opening in this and the two following ones, is 10 feet: The first figure represents the elevation, and the second the ground plan, with the slopes and projections; there is a draw-bridge to this gate, the section of which is represented in the elevation.

The third figure represents likewise the elevation of a gate in an outwork, made in a more expensive manner than the former: For the two piers are of hewn stones, ten feet broad, and 27 high; each of them is ornamented with two pilasters, made according to the *Tuscan* order; that is, the height is six times their breadth, the plinth or base is half the breadth high; as is likewise the torus or moulding next to it, with the fillet: And if we suppose the breadth of the pilaster to be divided into 24 equal parts; the astragal and fillet is one and a half of these parts, the gorge 4, the next fillet one, the quart de rond 3, the abacus 3; and the last fillet one; the entablement is 30 of these parts: The fourth figure represents the ground plan, with the slopes and projections.

The third gate, represented by the fifth figure, is designed for the body of the place, when the passage is arched; the width of the gate is 10 feet, the height from the bottom to the spring of the arch is 8, but may be from 8 to 10 or 12; the distance from one wall to the other 14, and their height including the cornish 30, and 12 broad; as to the pilasters, pedi-

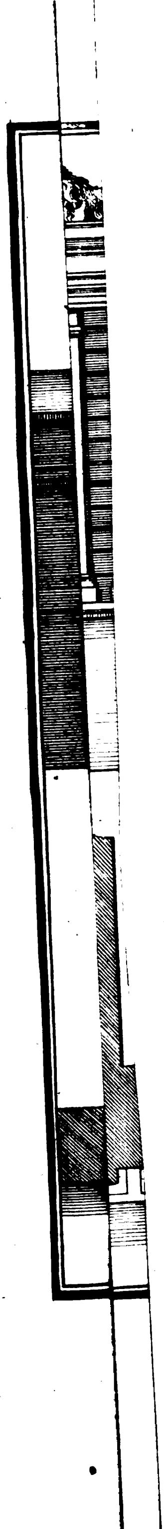
2 ment

ment and mouldings, they are the ſame as before, and the pediment is from one third to two ninth parts of its baſe high: The pediment ought to be ornamented either with the king's arms, or with military enſigns, and above the gate under the arch, which joins the piers, the arms of the city, or elſe of ſome particular perſon of note, who has moſtly contributed to the building of the place.

Theſe are only a few ſpecimens of gates, to give the young practitioners an idea of theſe kinds of work; the proportion of the parts may vary as well as the ornaments; but when there are pilaſters or columns, they muſt be conſtructed according to the dimenſions of the order, they are made of: We have made uſe of the *Tuſcan* order as being the moſt ſimple; but a young engineer ought not to content himſelf with what has here been given, but apply himſelf to that part of architecture, which is moſt uſeful; and if he wants gates of a finer taſte, he may conſult Mr. *Belidor's Science des Ingenieurs*, where he will find a great variety and well-choſen examples.

Gates of large fortreſſes require more attention, than thoſe of ſmall ones; they muſt not only be ſecured with draw-bridges, but with port-culiſſes, harrows, or organs. A port-culiſs is a wooden gate well covered with iron, with ſharp points, drawn up in a day-time by pullies, and let down at night: A harrow is a gate made of timber, whoſe dimenſions are commonly 6 by 4 inches; and 6 inches diſtant from each other, well faſtened to three or four croſs bars, and ſecured with iron: And an organ is a wooden frame, with double bars, through which the timbers ſlide and fall down: the organ differs from the harrow in that the timbers are not faſtened together, and is often preferred to the harrow on that account; becauſe it is ſaid, that if an enemy cuts one timber to pieces another may immediately be let down, which cannot be done in the harrow.

The



The port-culifs, harrow, and organ, ferve all for the fame purpofe; that is, to ftop an enemy in cafe he has found means to let down the draw-bridge; either the one or the other may be ufed as the engineers think proper, and fometimes two of them, that if one has been cut or burnt, the other may ferve to ftop the enemy.

But to leave nothing which may give a clear idea to beginners, we fhall give fome defigns of thefe gates when we come to treat of draw-bridges, barriers and other things of that kind.

Plate XIII. As we have given one example only of a town-gate, which is very plain and fimple, we fhall prefent the reader with another, that may ferve for the body of the place, which, though plain, yet is, in my opinion, fufficiently ornamented; it is compofed of an arched paffage and two piazzas at the entrance, for the conveniency of foot paffengers, to get by carriages that enter or go out; at the left fide of the entrance is the guard-room for the foldiers, and at the right the room for the officers, and as this laft need not be fo large as the former, a prifon is made, fo as to make both fides of the paffage alike: above thefe rooms, and over the gate, are lodging-rooms, for the town major, and fome other officers.

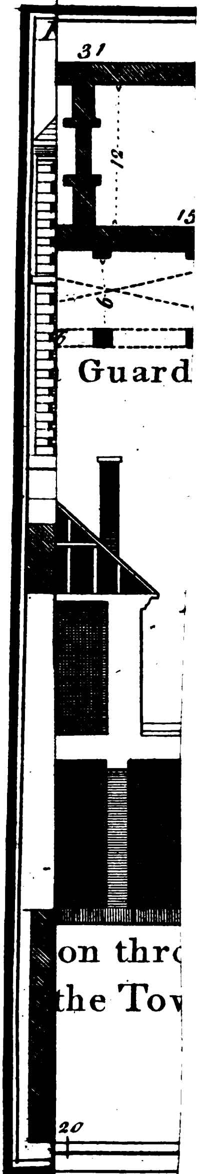
The paffage is ten feet wide, and the projections to form the cavity for the port-culifs, as well as thofe on both ends, are fix inches; the thicknefs of the walls or piers which fupport the arch is four feet near the foundation reduced to three above near the fpring of the arch, and are 8 feet 6 inches high, and the arch is three feet thick. The length of this paffage, and that of the former depends on the thicknefs of the rampart, for which reafon, they are not determined; the piazzas at the entrance are 9 feet wide, and 12 deep; the piers which fupport the arches 5 feet each way; the guard-room for the foldiers is 20 feet long, and 14 deep, with two windows of 2 and a half or 3 feet wide, and as high again; the chimney 4 or 5, and the door 3 by 7: The officers room is 10 ½ feet long, and 14 deep, and the priſon 8 by 14; the walls of theſe rooms are 27 inches or three bricks thick; the wall between the officers room and the priſon is a brick and a half only, and the chimneys 4 feet wide; as to the windows and doors they are the ſame as the others.

As this building is too large to make it but one ſtory high, it was for this reaſon we contrived the abovementioned lodging rooms above it: the elevation here is that of the inſide or entrance, in which we could not repreſent the chimneys for want of room in the plate: The fifth figure of the laſt plate is the elevation of the outſide next to the ditch; to this front is annexed another building, the lower part of which ſerves for the baſcul of the draw-bridge, and the upper, to receive the port-culiſs: The ſection through the length of the paſſage ſhews partly the nature of the building, whoſe breadth is equal to that of the paſſage and walls.

As the inſide and outſide buildings do not join above, there is a paſſage left between them for a free communication upon the rampart, from one ſide to the other; that part of the arch is covered with a bed of cement, and dry ſtones over it, with three feet of earth beſides. In this ſection is alſo ſeen the ſide of the wooden frame *a b*, called *baſcul* by the *French*, which is fixed to the draw-bridge, by one end *b*, with a chain at each ſide, each paſſing over two pullies or rollers, turning upon an axis at the other end *a*, and is a kind of counterpoiſe to the draw-bridge, to raiſe and let it down by; the particulars of which ſhall be explained hereafter, where we treat of draw-bridges.

There are ſtone ſteps made at the ſides of the inſide building to mount upon the rampart, which are not marked here in the plan, but are neceſſary, becauſe there is always a ſentry placed there at night; beſides, when there is an alarm, that the guard may mount quickly, and without any obſtruction.

At-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At the entrance of a fortress, and in the works that cover the gate, such as ravelins, horn or crown-works, are guard-rooms built, for the party without the inner gate, and which are shut out at night by the draw-bridge in the curtain of the body of the place: These buildings consist of two rooms, one for the officer, and the other for private men, as the plan and elevation in this plate shews.

The officers room is 12 by 12 feet, and that of the private men 12 by 15; and there is a piazza of four arches before it, of 6 feet broad, and as long as the building, for the sentry to walk under in hot and rainy weather; the arches are supported by five piers or pillars of about 15 inches square, and at 6 feet distant from each other: the wall is two feet thick, the windows 3 wide, and as high again; the chimneys 4 feet wide, and the doors 3 by 7; the elevation is about 16 feet high, including the parapet wall of the roof: The piazza may be made arched or flat roofed, according as it is thought proper by the engineer.

SECT. XV.

Of BRIDGES.

Plate XIV. THE next works in order are the bridges of different kinds, such as draw-bridges, turning-bridges, stone or wooden immoveable bridges; as the draw-bridges are immediately joined, and make a part of the town-gates, we shall enter first into their construction.

They are generally ten feet wide, and twelve long; and are composed of the trunion-beam *a*, head-beam *b*, and six joists C, covered with two inch planks, *d*: The trunion-beam is 12 inches broad, and 10 thick; the head-beam 10 broad, and 8 thick, and the joists are five by six, tenanted into the trunion and head-beam; as these planks would soon wear out by the carriages that continually pass over them, they are covered with iron bars of seven feet long, and about three inches broad, one over each joint, and one upon the middle of the plank; their number is generally 32; each of these bars is fastened with four cramps, which are not represented here; the joists are likewise fastened underneath to the trunion and head-beams with iron plates each about 3 feet long: the trunions are about six inches long, three in diameter; fastened to the trunion-beam with two plates, one above and the other below, bolted and rivetted together; the rings or handles of the chains are joined to the head-beam much in the same manner as the trunions.

Draw-bridges are drawn up and let down, by various contrivances; the most common way is, by a wooden frame, such as is joined to the draw-bridge in the third figure; it may be observed, that the side beams GK, HN, go tapering from the trunions E, F, towards the ends K, N, in order to make the frame EGHF, nearly of the same weight as the draw-bridge: It turns round the trunions E, F, upon iron plates, and the frame HG, moves in a cellar under the gate-way, built for that purpose; there are two holes, one on each side, to thrust two long poles, through upon the ends H, G, to press them down, and raise the draw-bridge, as likewise two chains are fixed to these ends, passing through the same holes, with a large ring at the end of each, whereby the bascul is drawn up, and the draw-bridge let down. This method can only be used when the ditch is dry; for when it is wet, the cellar is apt to fill with water, notwithstanding all the care that can be taken in the building of it; whereby the wood will rot in a short time, and the draw-bridge is in danger of not being drawn up when it is required; besides, the making this cellar in a proper manner, so as to be water-tight, will be very expensive.

Ano-

Another method of drawing up draw-bridges, and which is often practised, is to make the bascul separate, and not joined to the bridge; such as is represented by the second figure: This frame is fixed by the trunions at L, P, over the gate-way, and two chains, fixed on the other ends M, Q, go each over two pullies or rather rollers, and are fastened with the other ends to the head B, D, of the draw-bridge B C, figure 1; so that when the part M Q, is drawn down by chains fastened to them for that purpose, the draw-bridge raises. This method has the advantage, that in case the enemy should find means to break the chains which fasten the draw-bridge to the frame, and thereby make it fall down, the frame M P, will also fall down and stop the passage, and it will not be in his power to raise it: But in case any thing should happen to the chains, an opening W is left in the middle of the frame, to pass through it, and this opening may be shut up by a wicket, that is to be lockt upon occasion. We have supposed this method to be used in the gate-way, represented in the thirteenth plate, where the side view of the beam P Q is seen in the third figure, as well as one of the chains with its rollers.

It must be observed, that the head M Q of the frame must be well loaded with timber, in order to bring the frame nearly in equilibrio with the draw-bridge; which is not so easily done as one might imagine; and experience has shewn, that many engineers have miscarried in their design; and when this does not happen, the draw-bridge cannot be let down nor drawn up, without very great difficulty.

The only way of doing this, is to have timbers, or any other weights, fixed near the piece M Q, so as to slip off and on, and when both the bride and frame are fixed, to try how much weight w go.

Plate XV. Another way of fixing draw-bridges, is, a bascul with wings, such as is represented by the fourth figure, which is fixed over the gate-way, upon the two trunions E, F, and the chains are fastened to the ends of the wings; and two lesser ones to the ends A, C, of about eight feet long, with rings of 8 or 10 inches diameter, in order to draw down the hind part of the bascul, and thereby raise the bridge; and the bridge is let down, by raising up the hind part A C to the height of 5 or 6 feet, and then with poles they push it up higher, whilst others get upon the bridge to bring it down by their own weight.

When the bridge is down, two bolts fixed to it are pushed into two staples, drove into the fixed bridge; and to guard the sides of the bridge, that nothing may fall over, there are two strong chains fastened with one end to the wall, and the other to the post of the immoveable bridge, about four feet above the draw-bridge.

It is easily perceived, tnat the bascul E C, must be of such a weight as that the bridge may be drawn up with a small force; for which reason, the frame is loaded with timber towards the hind part A C, in the manner represented here, in this figure; and it happens sometimes, that they are abliged to fasten shells or any other heavy weight at the ends A, C, to bring the weight of the bascul nearly equal to that of the draw-bridge.

This method of fixing draw-bridges has been in use a long while, and has been practised more than any other; but when it is used in the draw-bridge of the body of the place, the cavities cut into the front of the building, to receive the wings, disfigure the ornaments of that front very much; and another inconveniency it has, is, that every time the bridge is raised, it requires a great force at first to move it; this motion accelerates afterwards more and more, till at last it becomes so great, that it shakes the building very much.

But when draw-bridges are made to the outworks, or sometimes on the middle of a fixed bridge, this method is always used; then the bascul A D is supported ed by a wooden frame, of about 12 feet high, upon which the trunions E, F, turn: It is true, that when the bridge is drawn up, the wings are upright, and exceed the height of the bridge, by about 12 feet, which the besiegers endeavour to break by firing at them, and if they accomplish their design, the draw-bridge falls down, whereby the passage is left open: But as no other method has yet been found, that answers the purpose better, this has been used to this day.

Mr. *Belidor* has proposed a new method of moving draw-bridges, in his *Science des Ingenieurs*, that seems to be preferable to any other hitherto known: which is, instead of a bascul, he fixes two cylindrical weights to the chains, which move in a curve on each side of the passage, in such a manner, that the motion of the bridge is always uniform, provided these weights are properly adapted; so that without spoiling the front of the building, or shaking it, two men may move it up and down with the greatest ease.

Those young engineers, who are desirous of knowing how this curve is constructed, and the weights are applied, may consult that author.

Of fixed or immoveable Bridges.

Fixed or common bridges are either built with wood or stone, or sometimes with both; they are of various lengths, according as the ditch or river is less or more broad; they differ likewise in their breadth; for those built over the ditches of a fortress are seldom above 14 feet broad, which is sufficient for two carriages to pass in breast, though they never allow above one at a time: but bridges built over large rivers, are from 20 to 36 feet broad: That at *Fulham* is 22 feet broad, and *Westminster* bridge 44, including the foot passages, and parapet walls.

When the bridge is to be built with stone, and the ditch is dry, the manner of laying the foundations of the piers, is the ſame as that of walls; it muſt only be obſerved, that as the piers ſupport a great weight, the baſe of the foundation muſt be made large in proportion; and they are always piled, and have a wooden grate over them, unleſs the bottom be rocky, or otherwiſe very hard: But when the ditch is wet, two rows of dove-tail piles or planks, are drove round the foundation, at about 6 feet diſtance from it, and 4, 5, or 6 feet from each other; and the interval between theſe two rows of piles is rammed full of clay, ſo as to keep the water out; or elſe, two rows of common piles are drove as before, of 3, 4, or 5, feet diſtant from each other, and to theſe piles are nailed boards at the inſide, and then the interval is filled with rammed clay as before.

This being done, the water is pumped out, and the foundation ſunk, as before: This method will ſerve in moſt caſes, excepting in deep water, where the current is very great: As to the proportions of the piers, in regard to the width of the arches, and the length of the arch-ſtones, they will be given in the latter end of this work.

If the bridge is made of wood, after the ditch has been ſunk to its proper depth, rows of piles are drove a-croſs the length of the bridge, at 10 or 12 feet diſtant from one another; the length of theſe rows is equal to the breadth of the bridge; and 4, 5, or 6, piles in each of them; when they are drove in as far as they will go, the upper part is made level, and bearing beams laid over them, into which they are tenanted; over theſe the tie-beams are laid, and then the planks. The firſt figure repreſents the elevation of ſuch a bridge, the ſecond the plan, and the third the ſection.

Plate XV.

The piles A, are a foot ſquare, and the bearing beams B, 14 inches broad, and 15 or 16 high, and the tie-beams C, 8 inches broad, and 12 high; as to the binding joiſts D, they are about 8 inches high, and

and 6 broad; the planks are 4 inches thick; the posts E about 4 by 6 inches, the top-rails *d*, about the same dimensions; the middle rails *e*, and struts *f*, are somewhat less than the former.

The bearing-beams B, are ten feet from each other, and supported by five piles each, and often with more, that is, when the bridge is very high: These piles should open below, as is represented in the section, figure 3; but it is easier to drive them vertically, as they are generally in that position; but since Mr. *Vaulvois's* new invented machine, they are as easily drove obliquely as upright; we choose this position, as making the bridge stronger and firm: If the foundation is hard and stony, the piles are shod with iron: The abuttments of all bridges are always made of stone, because the firmness and strength of the bridge depend very much thereon.

When a bridge is made over a navigable river, the middle opening between the piles is made wider than the rest, in order that the boats and small craft may pass through; and to prevent them from running foul on the piles, two or three planks are nailed on them, a little above the surface of the water. When the current is pretty rapid, it is necessary to add breakers; that is, two rows of piles are drove within five or six feet of each other, and two piles in the center line between them, at about six or eight feet distance from the bridge, so as to present a point on each side; these piles are braced to the others with timbers of about 4 by 5 inches, in two or three places; there are also boards nailed to them, in the same manner as we have mentioned before. This is the way that *Fulham* bridge was built; but those over the ditches of a fortress require no such precautions.

As the piles of wooden bridges are liable to rot very soon, in ditches which are sometimes wet, and at others dry; the best way to make the work durable, is to lay a foundation of masonry under them, as high as the

the higheſt water, upon which ſtrong beams are laid, into which the piles are fixed with tenants; this will make the bridge laſt much longer, and thereby the often repairing is avoided, which is not only expenſive, but likewiſe very inconvenient in ſtopping the paſſage out and in of the place.

To prevent the carriages from deſtroying the planks, ſand and gravel is laid over them, of about a foot or more deep; and very often they are paved, eſpecially thoſe of fortified places; the gravel or pavement is made higher in the middle than at the ends, that the rain water may run off freely, and not rot the wood: This may be ſeen in the third figure, as likewiſe in the ſecond; where one part repreſents the gravel or pavement, and the others, the planks and the binding joiſts.

Some engineers drive the thickeſt part of the piles foremoſt, and, on the contrary, others the ſmalleſt; the reaſon the former give for their practice, is, they ſay, that timber ſhould be uſed in the poſition they grow, whereby they will laſt longer; becauſe the fibres or grain of the wood are as it were adapted by nature to that poſition; whereas the latter affirm, on the contrary, and I think, with good reaſon, that being placed ſo, the wet will enter more eaſily in thoſe parts, where the branches have been cut off, and of conſequence, the wood will ſooner decay: but if they are in a contrary poſition, the water will run off, without being able to enter through the pores of the wood.

As our deſign is not to give a compleat treatiſe on bridges, but only ſo much as is neceſſary for a young engineer to know, and what moſt commonly happens in practice; we ſhall enter no farther into the manner of making all ſorts of wood bridges, either with a ſingle arch, or with a great many; neither ſhall we ſay any thing of turning or flying bridges, as being uncommon in this country; we ſhall add only ſomething relating to bridges of communication from one work to another;

another; as relating more immediately to an engineer's business.

As the besiegers endeavour always to destroy these bridges if possible, either with fire, shells, or shot; in order to hinder the troops in the outworks from being relieved or succoured by the garrison, and to obstruct their retiring, when hard pressed: To prevent this, these bridges are made as low as is possible, that is, they are made even with the surface of the water, and sometimes a foot under it; and, to save expences, piles are drove in the manner mentioned above, opposite to each other, and covered with a tie-beam; this is repeated at every ten or twelve feet distance, quite cross the ditch, like so many trusses; over which planks are laid, when there is occasion to pass over, and not before; at all other times these planks are kept in storehouses.

When there is a sufficient depth of water, a good number of boats are also kept to pass from the curtain to the ravelin, in case the bridges should fail: those that go from the ravelins to a counterguard, lunet, tenaillon, or into the covert-way, are always placed near the extremity of the faces, where a part of the parapet it cut off, to pass by, or else a passage is made through it for that purpose.

SECT. XVI.

Of BARRIERS, GATES, *and* PORTCULISSES.

Plate XV. THE fifth figure in this plate represents a barrier-gate, such as are made in the covert-way, at the entrance of a town, or in the passages cut in the places of arms, through the glacis; which is about 14 or 15 feet wide, and 10 feet high: the two side-posts are from 10 to 12 inches square, the part which is sunk into the ground is left rough, and about

about ſix feet long; the ſutle is as broad as the poſts are thick, and about ſix inches high: the frames of the gates are from 5 or 6 inches ſquare, and the planks 6 inches thick. Theſe gates are locked by an iron bar, turning about a bolt, ſo as that when one end raiſes, the other turns down, and one end is catched by an iron hook, whilſt the other is faſtened with a padlock.

The fourth figure in plate XIV. repreſents a gate made under the covered gate way; each ſide turns upon a ſtrong iron pivot, ſtanding on an iron ſocket, and are faſtened above to the wall, with hooks and hinges, much in the uſual manner of common doors; the outſide is covered with iron bars, in the manner repreſented here, for about eight feet high, and the parts between the bars are drove full of diamond headed nails, to prevent their being cut open: In one of theſe gates, is made a wicket, in order to paſs through, when there is any danger of ſurprize, and in the morning before the party of men, that is ſent out to reconnoitre and ſee whether any enemy appears, is returned; the upper part of the gate is left plain, without any iron, becauſe there is no danger of cutting it there.

The fifth figure of this plate repreſents a harrow or port-culiſs, which is drawn up by means of two-chains fixed to the upper ends A and B, and the other ends are faſtened to a wooden roller, with a handle on each ſide, which, when turned round, the chains roll upon it, and lift up the gate, and are faſtened above, by two ſtrong bolts: the lower croſs bar is covered with an iron flat bar from one end to the other, as likewiſe the rails or uprights as high as a man can reach, to prevent its being cut open.

Theſe portculiſſes are, in my opinion, better than thoſe called organs, becauſe if an enemy ſhould come ſo near as to cut it open, it will not be ſo eaſily done, if they are well covered with iron; and the men behind them may fire through it with very little danger; whereas,

whereas, the enemy must be very much exposed to their fire: besides, there might be an opening left above, to throw stones and blocks of wood upon those that dare approach them.

SECT. XVII.

Of Sentry-Boxes *and* Necessary-Houses.

FORMERLY sentry-boxes were made of hewn stones, and placed on the salient angles of the bastions, ravelins, and other outworks, and fixed to the walls; as they may be seen in most fortified towns in *France*, with a flower de luce at the top of them: but it has been found by experience that they serve as marks for the besiegers to direct their approaches by, for which reason, they build no more in this manner: the present method is to make them of wood, and so as to be moved from one place to another; and they are mostly placed at present upon the middle of the parapets of the faces; and wooden steps are made to get up, or slopes are sometimes cut into the parapet for that purpose; by which the enemy has it not in his power to make any advantage of their sight; these wooden ones are, besides, less expensive, and answer the intent full as well, which ought always to be considered in every kind of work whatsoever.

Plate XV. The figure given to sentry-boxes is either pentagonal or square; we make it a pentagon, as may be seen in the plan, figure 6, and the elevation, figure 7, as being more convenient; for by turning the point outwards, the adjacent parts are better discovered from the sides next to that angle: the sides are about four feet long, and six feet high; the timbers of the base ought to project about a foot each way, so as to have a good base to stand upon, to prevent the wind

wind from blowing it down; and if this baſe is not ſufficient, it may be pinned down by ſtakes: In each ſide is a hole to look out, of 4 inches broad, and 8 high: as the plan and elevation of this ſentry-box is ſo plain, there requires no further explanation.

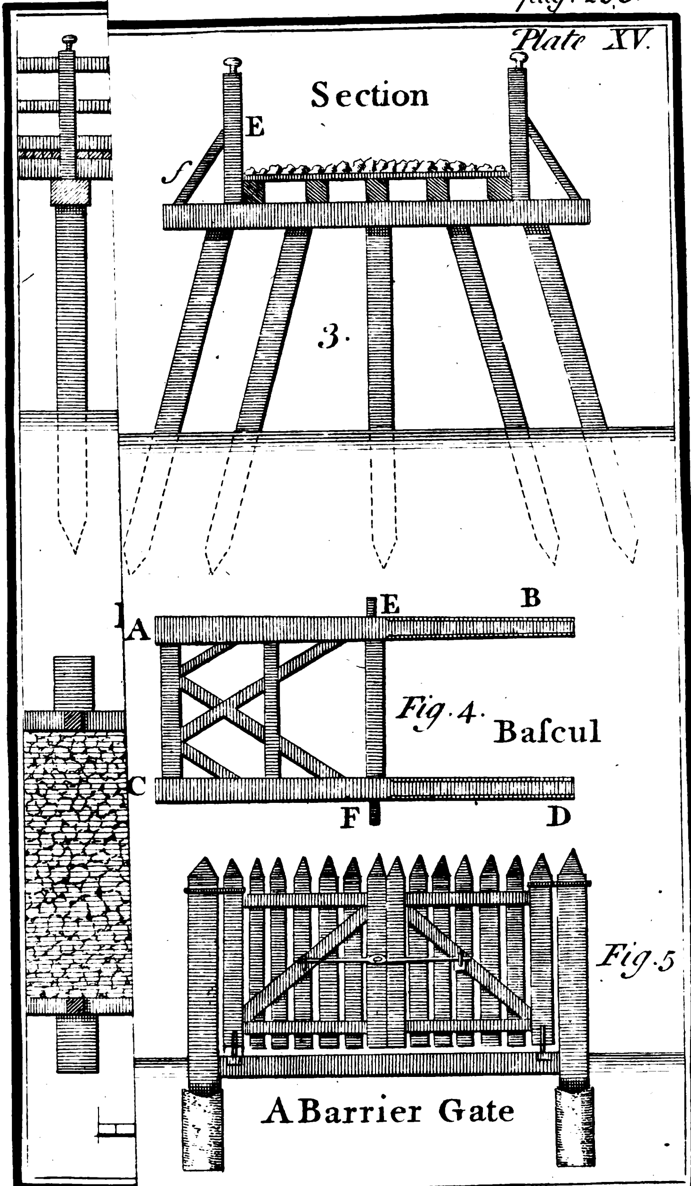
The ſentry-boxes placed near the governor's houſe, powder-magazine, houſes, &c. are made of a ſquare form, becauſe the ſentry has but one or two places to obſerve: each ſide of the baſe is four feet, and the box ſix high, beſides the covert: and they are made ſo light as to be eaſily turned about, or carried from one place to another.

Public boghouſes fall likewiſe under the care of the engineer: They ought to be placed over rivers, or ſtanding water, if it can be done, to prevent, if poſſible, the ſtench from becoming nauſeous; but where this cannot be done, they are placed on the curtain, where a paſſage is cut through the parapet, and ſupported with braces againſt the wall, ſo as to hang over the ditch; but care muſt be taken, not to place them too near the ſally-ports, otherwiſe, they will make the paſſage diſagreeable. But, in my opinion, if they were placed at the ſlope of the rampart, over the common-ſewers, it would be much better, becauſe the rain and other waters of the ſtreets would carry off all the naſtineſs, which makes them ſo diſagreeable.

SECT. XVIII.

Diſtribution of HOUSES *and* STREETS.

TOWNS were formerly built any how, according to the builder's fancy, without the leaſt regard to regularity or beauty; but now-a-day, when a place is fortified, which is not occupied by any houſes or other buildings, great care is taken, to make every part



J Conſe Sculp.

part within as regular as is possible; for which reason, care is taken to make the ground level, at equal distances from the center of the place, and descending gradually from that point in an easy slope towards the ramparts; that the waters in the street may run into the ditch.

Some *German* engineers will have the streets to part from the center of the place, and directed to the middle of the bastions and curtains, pretending that thereby, the troops assembled upon the parade, may render themselves in a shorter time to any part of the rampart, where their presence is required; this might be well for the defence; but then all the houses, and other buildings are made with a bevil, which is so great an inconveniency, that I believe, this, method will never be put in practice.

It is not only the regularity of the streets, which is sufficient, but likewise the rightly placing all the military buildings, such as the governor's house, guard-houses, store-houses, and magazines of different kinds: The governor's house is aptly placed in the middle of the side of the great square, opposite to the great church, so that he may see the troops, parade, and the garrison under arms, from his windows, or gallery; there should likewise be a guard-room in that square, from which the sentries placed at the governor's door, and near the magazine are taken. The other guard-rooms are placed near the gates, and sometimes one near the barracks: The store houses and magazines are best near the ramparts, where they are at hand in case of siege: As to the powder-magazines, they are always placed in the gorges of the bastions. In places near the sea, or navigable rivers, the naval store-houses must be as near the harbour, where the ships lie, as possible; on the contrary, those for land service on the opposite, or land side; as we have mentioned in the first book of fortification, where we have given the construction of those places.

When

When a town is very large, and therefore much room to build upon, it is neceſſary, for the publick uſe, to make ſeveral ſquares; but on the contrary, if the place is but little, and no room to ſpare, there muſt at leaſt be one, in the center of the place, whoſe bigneſs ought to be in proportion to the extent of the fortification, and conſequently, to the number of troops required to defend it: For this ſquare not only ſerves as a market place, but likewiſe, to draw up the troops and parade on it. Mr. *Belidor* thinks, that a fortreſs of ſix baſtions, whoſe exterior ſide is 180 fathoms, ſhould have a ſquare, whoſe ſide is from 40 to 45 fathoms, a place of ſeven baſtions, one whoſe ſide is from 55 to 60; that of 8 baſtions, from 70 to 75; that of 9 or 10 baſtions, from 80 to 85; and laſtly, that of 11 or 12 baſtions, from 90 to 95 fathoms; however, he ſays, that the engineer employed in theſe works will be able to judge of the proper bigneſs which theſe ſquares ought to have.

There is commonly an open ſpace left at the entrance or every gate of the town, in order that the guard-houſe, which is made there, may have room before it, to draw up the guard, and, in caſe of danger, to defend the gate and adjacent places: beſides, theſe openings have a good appearance, and ſerve alſo for the carriages to get out of the way, when any others are coming in.

In regard to the ſtreets, the principal ones ſhould go from the great or principal ſquare in the center, directly to the town-gates; to the ramparts, and to the citadel or harbour, if there is any; in order to be enfiladed by the guns and troops, placed in that ſquare in caſe of any danger or ſurprize: It muſt be obſerved, that the croſs ſtreets are all parallel to one another, and perpendicular to the former; ſo that all the buildings be at right angles to each other.

The principal ſtreets are generally 36 feet wide, in order that three carriages may paſs a-breaſt at a time,

time, or if two of them should stop, another may pass by, as likewise room for the foot passengers; but in regard to the other streets, they need not be so large; if they are from 18 to 24 feet wide, it will be sufficient, because there pass seldom above one or two carriages at a time.

The distance between one street to that which is parallel to it, is various; Mr. *Vauban* made them only the breadth of three houses, at *New Brisac*; that is, but one between the two corner houses; which, in my opinion, is not sufficient, because there is scarcely any room left behind to build warehouses, or shops for workmen, which are absolutely necessary; neither is there any room for gardens or openings for the light and air to pass freely, both useful for the preservation of the inhabitants.

We suppose that each house takes up 36 feet in the front, and the interval between the parallel streets is equal to the breadth of four houses, or 144 feet; so that if the houses are 36 feet deep, each of them will have an opening behind of the same extent, excepting the corner houses; either for a garden, or to build shops or store-houses: we suppose that the shops to work in are all behind, and in the front only those to expose and sell the goods.

Plate XVI. We made but one square in this design, whose sides are 75 fathoms, but if it should be thought necessary to make more, one of the spots occupied by houses terminated by four streets, in the most convenient place, may be used for that purpose; and it is there where the market for dry goods may be kept, and a town house should be built.

The governor's house is supposed to be in the great square, marked by the letter B, and the great church opposite to it, marked C: the governor's house takes up as much room as three others, and his garden as much as two: so that the house is 108 feet in front, and 36 in depth, and the garden 36 feet broad, and

72 long: and if this is not thought ſufficient, the whole opening behind may be taken into his garden.

It is alſo common to build a fountain in the very center of the place, or great ſquare, decorated in a neat manner, with four ſpouts facing the four principal ſtreets: For ſince water is the moſt neceſſary thing wanting in a garriſon, both for men and cattle; there cannot be too much care taken to ſupply the place with it: for which reaſon, water is brought from ſprings, or rivers near hand, by means of pipes, and engines if neceſſary, at the ſame time that the town is built; there ought beſides this, in the center of the place, to be ſeveral others contrived, in the corner of the ſtreets, if the place is large, to ſupply every part of the town plentifully.

When an old place is fortified where there are houſes, the ſtreets are left as they were; the principal ones are only widened and made ſtrait if poſſible, either by demoliſhing the old houſes, and building new ones, or elſe waiting till the old ones decay, and then obliging the inhabitants to build them on a ſtrait line: this is often practiſed by the *French*, when they fortify old towns, as I have ſeen at *Douay*, and other places: it is true, that this is againſt the laws of *England*; but any thing that tends to the benefit of the public in general, ought to be preferred before the obſtinacy of private people who loſe nothing by it.

In new places built abroad, in plantations where there is ſufficient room, and where the fortification often conſiſts of the town-wall and ditch only; I would make the intervals between the ſtreets greater than what we have repreſented here in this plan, as likewiſe all the bye ſtreets about 30 feet wide: For nothing contributes more to the wholeſomneſs of the place, as well as agreeableneſs, than fine large ſtreets, and great openings behind the houſes, planted with trees, eſpecially in warm climates; beſides, all the ſhops to work in ſhould be built there, and no others ought to be permitted

mitted in the front of the ſtreets, than thoſe for ſelling goods, as we have obſerved before.

The engineer employed in the building of *Halifax*, in *Nova Scotia*, has, in my opinion, committed a great miſtake, in building the ſtreets ſo near to each other as he did; for each houſe is 36 feet in front, and 72 in depth, and no opening is left behind, as I have been informed, by an officer that was there, and employed in the works. This miſtake can ariſe from no other reaſon, than the manner of building fortified places in *Europe*: but the caſe is quite different, becauſe theſe places have a great number of outworks, beſides the body of the place; for which reaſon, we are obliged to crowd the buildings as much as we can, that there may be room for the inhabitants, beſides a large garriſon: whereas abroad, where the fortification is conſiderable, the place ſhould be made as pleaſant and convenient as poſſible.

It was ſaid, the few people that went there, were not ſufficient to clear a larger ſpot of ground; but in anſwer to this, I ſay, they need not clear more ground at firſt than to build upon; and leave the openings behind for another opportunity, when they have more time; by doing this, the wood left may ſerve for timber to build out-houſes, and the branches for fewel to burn, when perhaps they muſt go far for it, and are expoſed to the inſults of the *Indians* at the ſame time.

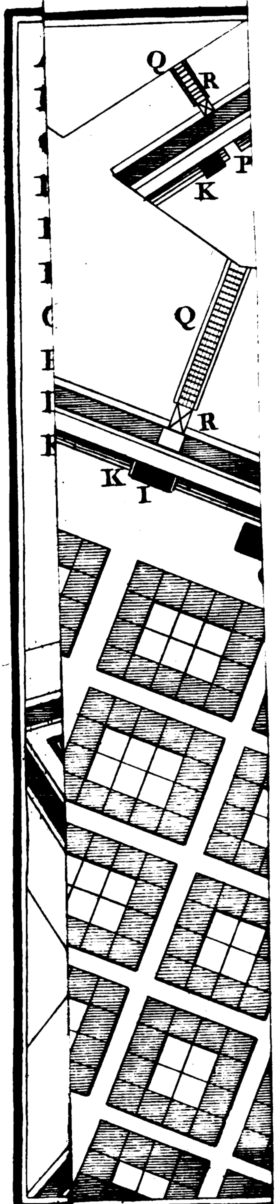
The ſtore houſes for amunition and artillery being military edifices, and requiring much room, it is not eaſy to determine their ſituations, becauſe they depend on many circumſtances, which cannot ſo well be known as upon the ſpot; it is neceſſary to obſerve, that they ſhould be ſeparate from one another, as well as from other buildings, to prevent accidents as much as is poſſible, which may happen by ſetting the adjacent buildings on fire, either by chance, or by the contrivance of an enemy: When there is a brook or river that paſſes through the town, it is requiſite, for the good of the ſervice, that the ſtore-houſes ſhould be near it; to bring timber and other materials, as well as ſtores, by means of water carriages.

We placed the ſtore-houſes and magazines here, near the curtains, which have no town gates; ſuch as are marked D; becauſe they are not near at hand, to tranſport them upon the rampart, where they are wanted in caſe of a ſiege: and the triangular openings formed by the ſtreets may ſerve them as yards, which ſhould be walled in; they are likewiſe near the barracks, which is another conveniency; for as ſoldiers are commonly employed in ranging and moving them, they are near at hand upon all occaſions.

The barracks are generally placed near the rampart of the curtains, as marked here by the letter G; with pavillions H at the ends, which are deſigned for the officers lodgments; this is undoubtedly the propereſt place for them; becauſe an open ſpace may be left before them to draw up and exerciſe the troops; the detachments in time of war may be more privately made for any enterprize that might be thought neceſſary, which could not ſo well be done in any other place; and the troops are quite ſeparated from the inhabitants, with whom they do not always agree.

As the tap-houſes and bake-houſes, for ammunition-bread, are neceſſary for the ſubſiſtance of the garriſon, they ought to be built near the barracks, and ſo as to have a guard-room not far from them, in order to prevent any riotous proceedings, that might happen; and as to the hoſpital, it is almoſt needleſs to mention, that it ſhould be placed in ſome bye place or other, ſo as to be ſeparate from the inhabitants, and noiſe of the workmen; eſpecially near a brook or river, in caſe there is any that paſſes through the town.

This is nearly all that can be ſaid in regard to this ſubject, when the place is large; but in ſmall forts there requires not ſo many ſtore-houſes, which however are always placed near the rampart. In ſuch places, where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where there are harbours or citadels, regard must be had to them in the placing these buildings; but the subject being so plain and easy, it requires no farther explanation; since a little practice and common sense will suggest the necessity of placing these buildings in the most convenient manner: but the execution of these, and all other military buildings, requires much more capacity and knowledge, in order to make them solid, and at the same time convenient; which we shall discuss more particularly, by treating of them each separately.

We have omitted several other things too trifling to be mentioned, which the reader will partly see in the sixteenth plate, which besides will serve as a further illustration to what has been mentioned; and what remains to be done, we must leave the sagacious reader to find out himself, the subject being too copious to treat particularly of all the minute parts.

SECT. XIX.

Of Powder-magazines.

FORMERLY powder-magazines were made in a quite different manner from those at present; they placed the powder in towers that had been built in the town-walls, by which they became liable to many accidents; for when the powder happened to be set on fire, either by chance or by some concerted scheme of the enemy with the inhabitants, it opened the town, and made a breach for the enemy to enter, as it happened at *Aire*, according to Mr. *Belidor*, when that place belonged to the *Spaniards*: The *French*, who then besieged it, having got intelligence from some inhabitant, found means to set the powder on fire, that was placed in one of the bastions; which had so great an effect, as to make a large breach, and as soon as the besiegers had prepared for an aſſault, the garriſon ſurrendered, whereas, without this accident, they might have defended themſelves much longer.

Finding by experience, that the building magazines in the rampart was of dangerous conſequence, they are now placed in different parts of the town, and made of various figures; but it was a great while before the right one was found: the moſt common had ſeveral pillars in the middle to ſupport the arches; but to bring theſe double arches under the ſame roof, the top muſt be loaded with ſo great a quantity of maſonry as almoſt burſt the arches: finding this method inconvenient, it was agreed to make them of one ſingle arch, as being much better than the former: the form of this arch was of the *Gothic* kind; and in order to get more room for lodging the powder, a floor was made at the ſpring of it.

Plate XVII. But Mr. *Vauban* having obſerved, in ſeveral ſieges, that theſe kind of arches were too weak, and that the floor loaded the piers very much to no purpoſe, ſince prudence requires not to lodge ſo much powder in the ſame place; and being better to divide it into ſeveral parts, he abſolutely rejected all the different methods till then followed, and propoſed a new one, much more perfect; and which is that repreſented by the firſt and ſecond figures, and is the only one hitherto executed with ſucceſs; though ſomething may be changed for the better, as we ſhall ſhew hereafter.

If we may believe what has been ſaid on that ſubject, we are told, that there were thrown upwards of 80 ſhells upon a magazine of this ſort, at *Landaw*, with out doing the leaſt damage to the vault: the ſame thing is reported to have happened at *Ath*, and in ſeveral other places. Mr. *Demus*, director of fortification, and a perſon of good reputation, aſſures, that in the ſiege of *Tournay*, by the duke of *Malborough*, where he ſerved, there were thrown upwards of 45000 ſhells into

into the citadel, and the greatest part of them fell upon two powder-magazines of this fort, and yet neither of them was damaged; whereas there were some built with *Gothic* arches, that were destroyed by three or four shells that fell upon them, notwithstanding that they had been covered with five or six feet of earth, some time berore the siege began.

The dimensions of Mr. *Vauban's* magazines are as follow; the plan is 60 feet long, clear within, and 25 broad; the foundations are 9 or 10 feet thick under the long sides which support the arch; and these sides he made 8 or 9 feet thick, according as the masonry was good or indifferent, and 8 feet high from the foundation to the spring of the arch; so that, making the floor about two feet from the ground to keep it free from all dampness, there remained 6 feet for the height of the story.

The thinnest part or hanches of the arch is three feet thick, and the arch made of four lesser ones, one over the other, and the outside of the whole terminated in a slope to form the roof; from the highest part of the arch to the ridges is 8 feet, which makes the angle somewhat greater than 90 degrees; the two wings, or gable ends, are four feet thick, raised somewhat higher than the roof, as is customary in other buildings; as to their foundations they are 5 feet thick, and as deep as the nature of the ground reqnired.

The piers or long sides are supported by four counterforts, each of six feet broad, and 4 feet long, and their interval 12 feet; between the intervals of the counterforts, are air holes, in order to keep the magazine dry and free from dampness; the dices of these air-holes are commonly a foot and a half every way, and the vacant space round them are three inches, made so as the in and outsides be in the same direction, as may be seen by the plan; the dices serve to prevent an enemy from throwing fire in, to burn the magazine, and for a further precaution, it is necessary to stop these air-holes with several iron plates, that have small holes in them like a skimmer, otherwise fire might be tied to the tail of a small animal, and so drive it in that way; this would be no hard matter to do, since where this precaution has been neglected, egg-shells have been found within, that have been carried there by weasles.

To keep the floor from dampness, beams are laid long-ways, and to prevent these beams from being soon rotten, large stones are laid under them; these beams are 8 or 9 inches square, or rather 10 high and 8 broad, which is better, and 18 inches distant from each other; their interval is filled with dry sea coals, or chips of dry stones; then over these beams are others laid cross-ways, of 4 inches broad, and 5 high, which are covered with two inch planks.

To give light to the magazine, a window is made in each wing, which are shut up by two shutters of 2 or 3 inches thick, one within and the other without; that which is on the outside is covered with an iron plate, and is fastened with bolts, as well as that on the inside. These windows are made very high, for fear of accidents, and are opened by means of a ladder, to give air to the magazine in fine dry weather.

There is likewise a double door made of strong planks, the one opens on the outside, and the other within; the outside one is also covered with an iron plate, and both are locked by a strong double lock; the store-keeper has the key of the outside, and the governor that of the inside: the door ought to face the south nearly if possible; in order to render the magazine as light as can be, and that the wind blowing in may be dry and warm. Sometimes a wall of 10 feet high is built round the magazine about 12 distant from it, to prevent any thing from approaching it without being seen.

Here we take not so much precautions, for I never did see any with double doors, or shutters, and they are built in so slight a manner, that it would be an easy matter to destroy them. I have seen a project for mending a powder-magazine at *Minorca*; there were to be no less than four doors, and as many windows as are commonly made in a dwelling house: there was to be likewise a brick floor, and to render the work compleat, cross-walls were to be built within, at every twelve feet distant: and yet this project was contrived by a person of the greatest repute for his skill in engineering; and would, in all probability, have been executed, had I not prevailed with the surveyor general at that time to lay it aside.

Such a magazine as this will hold about 200,000 pounds of powder, when the barrels are six above one another, which however is not done, but in case of necessity, because when they lie so much on each other, it is very troublesome to remove them, and change their position, which ought to be done once a year at least; otherwise the salt petre, being the heaviest ingredient, will descend into the lower part of the barrel, and the powder above will lose much of its goodness; but to prevent the barrels from rolling, when some are taken off, two wooden posts are erected, of about 4 or 5 inches square, between every 10 or 12 barrels, by this means they may be piled up as high as you please, or taken off without any danger.

Mr. *Belidor* would have brick walls made under the floor, instead of beams, and a double floor laid on the cross-beams; which does not appear to me to be so well as the manner proposed here; the reader is, however, at liberty to chuse that method he likes best.

Instead of making the side walls 8 feet thick, as Mr. *Vauban* does, we have made ours here but seven, and turned the counterforts contrary to his position; that is, instead of being 6 feet broad, and 4 long, ours are 6 feet long, and 4 broad, which strengthen the walls very much; as his were only 12 feet distant from each other, ours become 14 feet asunder, supposing the extreme

extreme ones to be within a foot from the inside of the wings produced.

It is likewise to be observed, that instead of making four arches one over another, each of them the length of a brick thick, in the manner of Mr. *Vauban*, we make but one continued arch three feet thick, which makes it much stronger, as it easily might be proved by what has been demonstrated in the second section. The reason of making our side walls seven feet thick only, instead of eight, according to Mr. *Vauban*, is because we found, by the rules of mechanics, and the strictest computation, but 7 feet and two inches, when they are four feet long, and six broad: but by making them six feet long, and four broad, the walls are capable of a greater resistance than his, and they being found strong enough by a long course of experience, there cannot be the least doubt, but that ours will be sufficiently strong.

In the theory of arches we made no allowance for friction, but consider the stones only according to their weight, whereas, in that of the walls which support earth, we made an allowance of one third of the weight, for the friction, and yet our walls are as strong as those built by Mr. *Vauban*; it may seem contradictory to make no allowance here; but if it be considered, that the stones never close and bed so together as to make one continued solid, as the theory supposes; but on the contrary, lay often hollow, and the void spaces are filled up with bad mortar, it is a great while before these piers or walls are dry, and become capable of as much resistance as is required: besides, an allowance must be made to resist the force of the shells thrown upon them, as has been observed in the second section.

In order to succeed in these kind of buildings, it is highly requisite that the engineer should watch the workmen continually, in order to make the wall as solid and compact as possible, that the stones or bricks bed

bed well, and no holes big enough to hold a ſtone or brick to be filled with mortar: And laſtly, to make uſe of the beſt materials to be had thereabouts; and when the arch is built, the centers ſhould be left to ſupport them, at leaſt for ſix months, that is, till the work is ſettled and dry, otherwiſe the arch is in danger of tumbling down, or elſe the walls muſt be made ſtronger than they need to be.

The third and fourth figures repreſent the plan and ſection of a large magazine, for ſtowing a great quantity in the ſame place: the piers or ſide-walls, which ſupport the arch, are here 10 feet thick, 72 feet long, and 25 high, from the foundation to the ſpring of the arch; the middle wall, which ſupports the two ſmall arches of the ground floor, is 8 feet high, and 18 inches thick, as are likewiſe the arches; the thickneſs of the great arch is 3 feet 6 inches, and the counterforts, as well as the air-holes, are the ſame as in the former.

Such large magazines as this, are by no means to be built in fortified towns, becauſe if any accident ſhould happen, all the powder would be loſt at once, whereby the place would be obliged to capitulate; but in ſome inland part of the country near the capital, where no enemy is expected, they might be uſed, as for a general magazine, and that from thence the powder might be diſtributed to the ſeveral places where it may be wanted: yet, in my opinion, it would be better to make two ſmall ones, and place them at a proper diſtance, that if one ſhould be blown up by accident, the other might be ſafe.

The ridge of the roof makes a right angle in both theſe magazines, and it is neceſſary to obſerve, that as the foundations grow deeper, ſo they ought to increaſe in width; this is obvious from the common practice of making walls thicker as they increaſe in height; but no certain rule has hitherto been given, to know how much that increaſe is to be; ſuppoſing the foundation to project inwards, by ſix inches only, which

which ſeems to be ſufficient, ſince the walls never fall that way: then I would allow ſix inches for every foot and a half depth on the outſide, ſo that if the foundation be ſix feet deep, its breadth muſt be increaſed by two feet divided into four ſteps; by this means you may know at all times how broad a foundation muſt be, when its depth is known. Although this rule is not founded upon a demonſtration, yet, by the obſervations of common practice, it appears to be ſufficiently accurate upon all occaſions.

SECT. XX.

Of BARRACKS, HOSPITALS, *and* STORE-HOUSES.

Plate XVIII. BARRACKS are built now-a-day in all fortified places, to keep up the diſcipline, and good order in the garriſon: they have been found ſo uſeful, that no place is built without them; and experience ſhews, that thoſe garriſons which have them, are much more quiet, on account of the conveniency which non-commiſſioned officers have to viſit the quarters every evening, and to ſee the ſoldiers ſhut up their quarters, which cannot be done when they are lodged amongſt the inhabitants, where they have the liberty of going out and in whenever they pleaſe; beſides, when the governor has a mind to make a detachment, or ſend out a party, he cannot do it, without the knowledge of the whole town: If any alarm happens, the garriſon cannot be aſſembled without great trouble and loſs of time; whereas, when there are barracks, every thing neceſſary for the good of the ſervice may be done with eaſe.

Barracks are built different ways, according to their different ſituations. When there is ſufficient room to make a large ſquare, ſurrounded with buildings, they are

Fig. 3.

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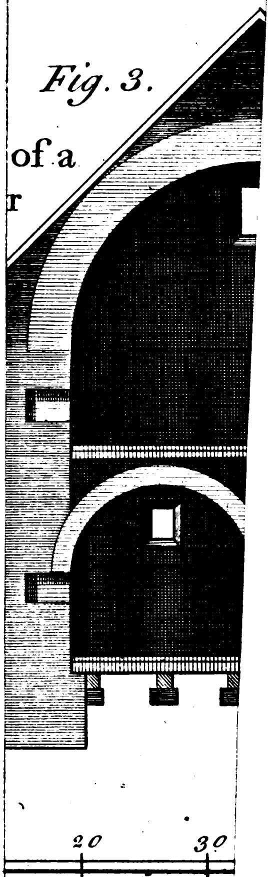


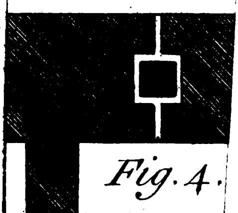


Fig. 4.

are very convenient, because the soldiers are easily confined to their quarters, and the rooms being contiguous, any order may be executed with privacy and expedition, and the soldiers have not the least connexion with the inhabitants of the place, which prevents quarrels and riots.

This disposition of the barracks is especially convenient for the horse and dragoons, because they want a convenient place for the daily mounting their horses; and in this case, the lodging-rooms are built over the stables, with a gallery serving for a communication from one room to another, quite round the building, with stair-cases in the corners, and sometimes another in the middle of each front; but care must be taken, to make the first row of lodging rooms pretty high, or else they will be darkened by the gallery above them.

When the barracks are built near the ramparts of the curtains, as Mr. *Vauban* has done in almost every place he fortified, they are composed of a large pile of building in a strait line, for lodging the soldiers, with pavillions at the extremities for the officers: these barracks are generally two or three stories high, besides the ground floor.

Between every two rooms in the front, is an entry of 8 feet wide, with doors to the four contiguous rooms, and a stair-case leading to the upper stories; as to the bigness of the rooms, Mr. *Vauban* made them 22 feet long, and 18 broad, in order to hold four beds each; I have seen some large enough to hold six beds, and with two chimneys in them; there were three men to each bed, which is the custom in all the *French* garrisons, because it is supposed, that one of the three is always upon duty, so that there is never but two in one bed at a time.

Our barracks here, at *Woolwich*, are but 16 feet each way, with three beds in each room, to hold six soldiers only, which is not sufficient, because it requires too large a building to quarter a whole regiment in them.

them. The plan and elevation in the eighth plate is much in the ſame manner, only we ſuppoſe four beds in a room, which they may hold; the rooms are 16 feet each way, though I think that if they were 20 feet long, and 18 broad, it would be much better; the ground ſtory is 11 feet high, the next to it 10, and the laſt but 8.

The outſide wall is two feet thick, and the partition or croſs wall a brick and a half; for if theſe latter are thinner, every thing that is done, and ſaid, will be heard by thoſe in the adjoining rooms: the outward doors are 3 feet and a half wide, and 7 high, the inner ones 3 feet wide, and 6 and a half high; the windows are 3 feet wide, and 6 high in the ground floor, the upper ones have the ſame breadth, but their height diminiſhes in proportion to the height of the ſtory; that is, the ſecond row is 5 feet high, and the laſt but 4: the chimneys are 4 feet wide, and 18 inches deep, going partly into the wall, and projecting partly in the rooms.

The corner houſes, being deſigned for officers lodgings, have each an entry of 6 feet wide, with a ſtair-caſe and a cloſet of 5 by 6 feet at the further end: under the ſtair-caſe is another going down into the kitcken and cellars, which we ſuppoſe are built under the officers houſes; but in regard to the ſoldiers barracks, there is no occaſion to make either kitchen or cellar, as they have done at *Woolwich*.

The third figure in this plate repreſents the ſection of the elevation, where it may be ſeen that the ſtair-caſe goes ſtrait up from one floor to the other; but if this is found inconvenient, it may turn at half-way, with a landing-place: the roof is divided into two ridges, becauſe it is both cuſtomary, and more convenient, than if it was continued, which would make it too high, and, requiring longer timbers, makes it more expenſive.

Sometimes

Sometimes there are piazzas built before the barracks, as those at *Dublin*, if I am rightly informed, which are very convenient; for when the troops are drawn up, and a shower of rain comes, they may shelter themselves under it, to keep their arms dry, and when the companies are to be examined, in regard to their cloathes or arms, it may be done there at any time or season.

In all garrisons it is necessary to build hospitals for the sick and wounded; its bigness ought to be regulated according to the number of troops required to defend it in time of a siege, and it has been found by experience, that out of 25 men, there is generally one sick; yet it ought to be observed, that in fortresses built in low and marshy ground, there are more people sick, than in places standing on a high ground in good air.

Knowing nearly the number of sick people, the number of beds wanted will also be known, and consequently, the bigness of the building, which consists of a long room to hold four rows of beds, and another above it; these rooms the *French* make 42 feet wide, and therefore if but two rows of beds be required, 20 or 21 feet will do; each bed ought to be 4 feet wide, and 6.5 feet long, and the distance from one bed to the next can be no less than 4 feet, so that as many 8 feet as there are beds, will be the length of the room which is to hold but two rows of beds; or half that length, if it is to hold four rows.

Besides these rooms, there must likewise be lodging rooms for a doctor, surgeon, their mates and attendants, for the nurses and servants; a kitchen and laundry, as well as a yard to dry their linen: In short, the building is to contain every thing necessary, both for lodging and conveniency of the hospital.

In regard to their situation, we have spoke of it already, but I must add, that if it is not possible to place it near a river, a canal might be cut to it, because water

water is abſolutely neceſſary, for cleaning the apparel of the ſick and wounded; for neatneſs in general is abſolutely neceſſary in ſuch places, where the ſmell of ſo many ſores, wounds, and other ſickneſs, muſt otherwiſe be very offenſive.

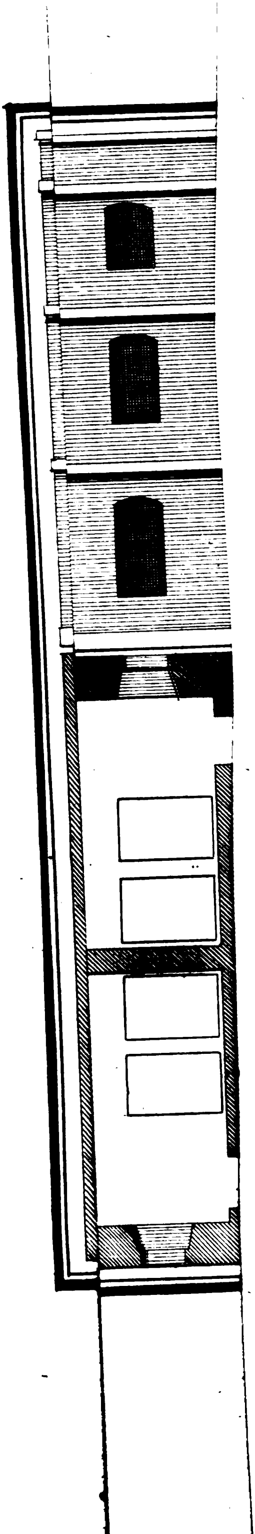
We have not given any plans of hoſpitals, becauſe they may be conſtructed various ways, according to their ſituations and bigneſs, which an engineer upon the ſpot will be acquainted with, and from thence regulate his draughts accordingly, and it would not be amiſs to conſult the doctor and ſurgeon about the ſeveral conveniencies to be made; this, and his own knowledge in building, will be ſufficient to perform ſuch a work in the beſt manner.

I had forgot that there is often a chapel built at one end of the great room, to perform divine ſervice, and when there are two rooms above one another, the upper one has a gallery looking into it, for the ſick to ſit in without being obliged to come down ſtairs.

The laſt public buildings we have to treat of, are the ſtore-houſes for all kinds of ammunitions, great and ſmall guns, and, if the place is ſituated near the ſea or a navigable river, for cables, anchors, timber, and other neceſſaries, to repair and furniſh ſhips.

In a ſmall fortreſs, ſuch as a citadel or fort, a ſtore-houſe of a moderate ſize will be ſufficient to hold the ammunition, and other neceſſaries for the defence of the place; whereas in a large town lying near the border of a ſtate, it is neceſſary to have a ſpacious one for the artillery, in ſuch a manner as to contain every thing wanted in a field train.

A ſtore-houſe of this ſort ought to be built near a river that may carry ſmall craft at leaſt, if poſſible; in this caſe a baſon ought to be made, to load or unload ſeveral boats at a time; ſuch a ſituation is of great importance, in regard to the ſaving expences; for it requires a great deal to tranſport a train of artillery with all



all its appurtenances by land to any considerable distance. And as there is seldom any fortress built but near a great river or the sea, it will always be in the power of the engineer to find a proper place for building the store-house; and what nature wants may be supplied by art.

The ground floor of a store-house ought to consist in a shed to place guns and their carriages, tumbrels, ammunition, waggons, mortars, and their beds; in short, all the other necessaries which are too heavy to be carried and deposited above: there must likewise be forges for smiths, places for carpenters to work in, to hold iron and wood, and wheelwrights shops, and every thing of this sort.

The first floor ought to contain an armoury, places to hold all kinds of small irons, others for cordage, pontoons, and every thing necessary, that is light and easily transported. An engineer, who is not perfectly acquainted with every part belonging to the artillery, will not be able to form a right notion of a store-house: there is such a connextion between the business of an engineer and that of an artillery officer, that neither the one nor the other can be master of his business, without being tolerably well acquainted with that of the other: I am sensible, that this will be ridiculed by many practitioners, but I leave the unbiassed intelligent reader to judge, whether this notion is right or not: As my intent in writing this work is to instruct young engineers, it is no matter what those say, who think experience is sufficient to shelter their ignorance.

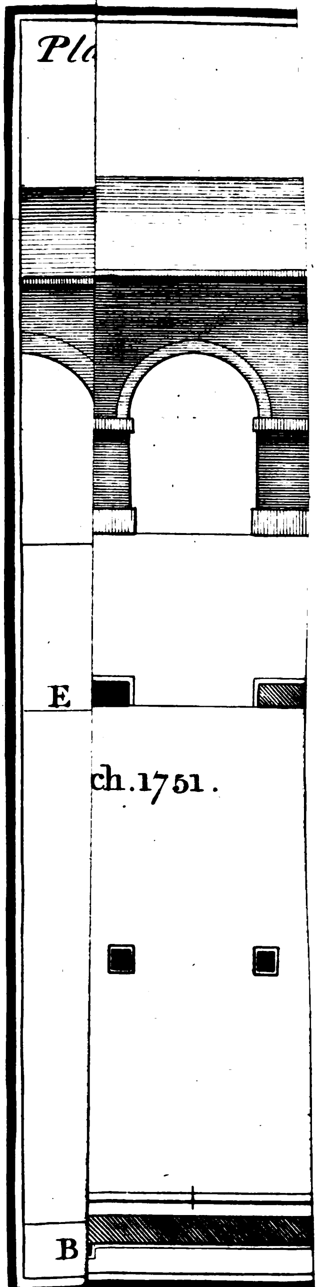
Plate XIX. To give an idea of these kind of works, we have represented the plan of the fourth part of a rectangular shed, in this plate, with the elevation of one of the insides, executed at *Woolwich*; the width within is 33 feet, the length 282 one way, and 156 the other; the wall is 18 inches thick, having pilasters 15 feet distance from each other, they are two feet broad, and project the wall by 9 inches; the elevation is 16 feet high at a medium, for the building ſtands on a ſmall deſcent: the gate-ways, which are three in each front, and one in the other ſides, are 10 feet wide; the arches of the inſide walls are 8, as well as the height of the piers from the bottom to the ſpring.

Plate XX. Here are repreſented the elevations of the front and outſide, together with a ſection through the middle of the longeſt ſide, wherein the ſection of the roof is repreſented: As theſe figures are drawn on the ſame ſcale as thoſe in the former plate, and there is nothing material in them, but what the reader may underſtand, we ſhall not enlarge any further on ſo eaſy a ſubject.

The uſe of this building is to put under cover the carriages of guns, both for land and ſea ſervice, mortar-beds, pontoon-carriages, bread-waggons, ammunition-carts; in ſhort, all kind of carriages, that are uſed in artillery: and as wood laſts much longer in a place where there paſſes a free air, than if confined, it was for this reaſon, that the inſide walls have been built with arches, in the manner repreſented in the preceding figures.

Beſides the great ſtore-houſes in large fortreſſes, ſeveral ſmall ones are built in different places, not far from the ramparts, in order to lodge ammunition and other things neceſſary in a ſiege, ſo as to be near at hand; they are ſupplied from the great ones, when there is any occaſion for it: but as their conſtruction does not differ eſſentially from the former, excepting in their bigneſs, it would be needleſs to take any further notice of them.

The ſtore-houſes built in a maritime town, are not only to have room for artillery and ammunition, but likewiſe for cables, ropes, maſts, anchors, and every thing elſe, neceſſary in the fitting or repairing of ſhips; and this in proportion to the bigneſs of the harbour or number of ſhips that generally reſort there; theſe places ſhould have two ſtories, the lower for heavy things, and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nd the upper for those goods that are light and manageable; their situation ought always to be near the harbour or quay, that the ships may come near them, whereby a great deal of labour may be saved, in the fetching and carrying things from them to the ships.

SECT. XXI.

Of framing Timbers *for* Partitions, Floors *and* Roofs.

As an engineer ought not to be ignorant of any thing relating to common architecture, we think it will not altogether be unnecessary, to shew here the different manners of framing timbers on most occasions, this being a branch of his business, especially as the carpenters follow no other rules than those they learn from practice, which are often defective, as will appear hereafter.

Plate XXI. Here are five examples of different partition-frames; the first, second, and fourth, are given by Mr. *Smith*; the third, and fifth, by Mr. *Price*; these are the only authors that wrote particularly upon this subject. The first example is in the common way, wherein it has been observed by an artist, that there are more mortises and tenons than need to be; for if the braces were let into the principal posts, so as to butt against shoulders of about half an inch deep, and nailed in, they would do the same office in a better manner than being tenoned in, as here represented, and would be done in less than half the time: and as the quarters are only to sustain the laths and plaster, because the weight of the roof is supported by the posts and plates, they have no need of being framed into the upper and under plates, which only take up much time, and will not last longer than when they are cut and nailed in only, and which is done in a very little time with little expence.

The example in the second figure represents the partition of a warehouse, or of any other large building, where the grinders, or some other weights are to rest on the king or principal post, E; but it may be observed, that if this wall was to support great weights in two places, it should be inverted, so as the weights may rest upon the posts A, A: for in the first case, the two struts adjoining to the post E, will increase its strength very much, and in the latter, the struts adjoining to the posts A, A, will, by the same reason, increase their strength; but where the weight bears equally on the upper plate, this manner of strutting is needless. The author is also justly blamed for making the joggles in the king-posts A, E, A, as being expensive in the workmanship, and in the waste of timber; it requires likewise much time in the framing of it; and after all, serves to no other purpose than the first example, which is full as strong, and much cheaper.

The example represented by the fourth figure is proposed to raise the height of two stories, the lower of 13 feet, and the upper of 12, or otherwise in one height only, as the side of an outhouse, hall, or saloon; now it is to be observed, that as joists are supposed to lie on the middle plate in the first case, which is framed into the king-posts E E, and the outward principal posts; the weight at each end must depend on the strength of the tenons, excepting such help as is given to it by the under quarters; the braces are therefore placed exactly the wrong way, because now they support the parts near the middle posts which do not want it, whereas if their ends were turned the contrary way, they would assist the ends, as they should do, as being the weakest part, and the whole would be equally strong every where, and they would at the same time perform

perform their office of bracing the frame in a proper manner.

As to the joggles at E, E, in the king-poſt, they are juſtly condemned by workmen here as well as in the firſt example, for the waſte of timber, and the loſs of time in framing; and it is thought, that if thoſe poſts were made a ſmall matter more in breadth, and their ſtruts let into them with a ſmall ſhoulder, commonly called by workmen, *bird's mouth*, they would be as ſtrong and ſecure as they can be done this way.

The next example in hand, is that repreſented by the third figure given by Mr. *Price*, which he ſuppoſes to be a partition between two rooms, wherein doors, A, A, are required next to the ends, and therefore has placed a king-poſt in the middle, and prick-poſts between it and the doors; it is here to be obſerved, that the middle plate, alſo called *intertie*, is halved, not only in the prick-poſts, but even into the king-poſt alſo, which is a great weakening to it, and therefore abſurd; nor indeed is there any occaſion for an intertie at all, if the height is intended for one ſtory only; but ſuppoſe there was one required, would not its being ſlighly tenoned into the king poſt have been a leſs weakening to it, and have given it a ſtrong bearing, by turning the lower ſtruts the contrary way, to that they are here? It is true, that it is a common practice to halve timbers together, but it ſhould never be done but with very great judgment, and always avoided in braces and ſtruts.

The fifth figure is another example given by Mr. *Price*, for a partition, wherein three doors are required, one at each end, and one in the middle; the two king-poſts and the intertie are again halved into each other; and therefore the ſame fault may be found here as in the former: the joggles in the king-poſts and prick-poſt are likewiſe needleſs; beſides, the braces ſeem to have no other meaning here than to ſhorten the quarters which croſs them, and ſo are only nailed upon them here as well as in all the preceding examples, without tenons or mortises.

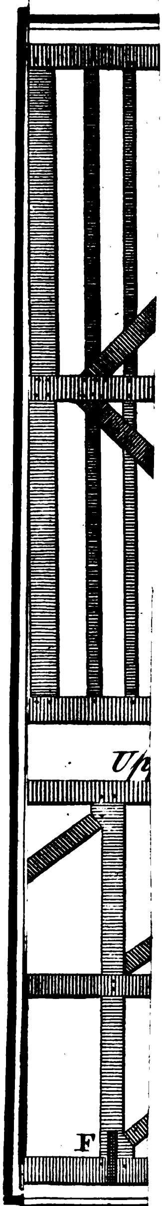
In all Mr. *Price's* examples of partition-walls, he ties the lower end of the king-posts to the lower plate with an iron band, but for what reason, is not easy to be known, since, as far as I can judge, they seem to be entirely useless, and therefore should never be used.

Many examples of partition-walls are given by authors, of different constructions, and for different uses; but the whole art of framing this sort of work consists in disposing the different parts in such a manner as to make the whole work equally strong; in using no more timber than is necessary, and to join them so as that the work may be done in the shortest time possible, and yet be strong and durable, which cannot be done without a competent knowledge of the rules deduced from mechanical principles, and a good deal of practice, which seldom both meet together; and for that reason, the art of building has received so little improvement in latter times.

SECT. XXII.

Of FLOORING.

Plate XXII. BEFORE a flooring is begun, there must be made an accurate plan of the building, whereby a judgment may be formed where to place the girders in the most substantial manner; and indeed, this should be done before the brick-work is raised high enough to receive them, that not only the lintels may be well placed over the doors and windows; which ought never be less than 5 by 7 inches; but in those places where the ends of the girders are to rest, if the lintels or bearing pieces are made equal in length to the distance that is contained between girder and girder, they will communicate the weight equally on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on the whole wall, and which is much better than when the bearing is on the part juſt underneath them only, which is the caſe when the lintels are made ſhorter; beſides, when lintels are ſo laid, and are 5, 6, or 7 inches in thickneſs, in proportion to that of the wall, they are a very great ſtrengthening, and tie thoſe parts very firmly together: wherefore they are alſo called *bond timbers*; but to prevent miſtakes, it muſt be obſerved, that bond timbers are properly thoſe laid in walls where no girders are, as in end and croſs-walls, and which are laid throughout at every 6 or 7 feet in height, and being dovetailed or cogged together at every outward angle of the building, as marked in figure 2, and at every party-wall, as in figure 3, or 4, will moſt firmly bind the whole together, ſo that, if even the foundation be bad, they oblige the whole building to ſettle together, prevent cracks and fractures, which unavoidably would happen, if they were neglected: It may be obſerved, that theſe three different ways of joining timbers are uſed, but the ſingle dovetail, as is marked in the fourth figure, is preferable to the other two, as being more ſimple, and yet tie the timbers full as well as the others.

The proper places for girders having been determined, it muſt be obſerved, to lay them ſo as the boards lay all one way throughout the middle of the building, ſo that the whole may be ſeen one way; for if the joints of the floor of one room are not parallel to thoſe of another, it would produce a very ill effect.

The ſituation of the girders being determined in the plan, we are thereby enabled to find their length, their number, and their diſtance, which ſhould never exceed 12 feet in any building whatſoever; nor ſhould joiſts exceed that length: It is alſo obſerved in placing of girders, always to lay them the ſhorteſt way, and that their ends have at leaſt 14 inches bearing in the wall, excepting thoſe in very ſmall buildings, where the walls are of thin dimenſions, then their bearing may be reduced to 10 inches.

Nothing being a greater enemy to timber than lime, it is a very good method to lay the ends of girders, lintels, and other bond-timbers in loam; and fir is beſt preſerved by anointing it over with melted pitch and greaſe, of which the laſt muſt be one fifth part, and the other four fifths: If this precaution is neglected, which is commonly the caſe, the building will never laſt ſo long as it would otherwiſe do.

As the proper ſcantlings of girders and other timbers have been treated of in the third ſection, where we have given tables of their dimenſions in reſpect to their length, we ſhall no farther enlarge upon it here; and having ſufficiently explained the ſituation and manner of laying girders, we ſhall now proceed to the joiſts, which are of various kinds, as common-joiſts, triming-joiſts, binding-joiſts, bridging-joiſts, and cieling-joiſts.

Common-joiſts are thoſe which are framed fluſh with the upper ſurface of the girders, and which ſometimes are all of equal depth, but leſs than that of the girders, whereby the girders become lower than the cieling; but the moſt genteel way is to have every third or fourth joiſt equal in depth with the girder, whilſt the other intermediate joiſts are of leſs depth, and between thoſe deep joiſts, fix ſmall ones to carry the cieling, whereby the under ſurface of the girders will be concealed, which otherwiſe have an ill effect.

Triming-joiſts are ſuch as are framed into two other joiſts, for other joiſts to be framed into them, which are againſt a chimney, or to make the opening for a ſtair-caſe, ſuch as are marked by the letter *a*: as theſe joiſts are weakened by receiving many mortiſes, and having to ſupport the weights of ſeveral joiſts which bear upon them; they are therefore to be made of larger ſcantlings than the common-joiſts.

Binding joiſts are thoſe on which bridging joiſts are laid, and in which the cieling joiſts are framed; theſe joiſts

joists are framed flush with the under surface of the girders, and about 3 or 4 inches lower than the upper surface; that the cieling-joists may be flush underneath with them as well as with the girders: their distance is from 3 to 10 feet, and their thickness in proportion to the length of their bearing, as has been shewn in the third section.

The figures 8, 9, and 10, represent the manner in which their tenons and mortises are made by Mr. *Price*; and which is esteemed by workmen in general much better than any other: but those who are conversant with the principles of mechanics, will easily perceive that neither the one nor the other is good for any thing.

In order to determine the best manner of making the tenons, it is necessary to consider, that when a great weight bears upon the middle of these joists, or upon any other timber supported at each end by tenons; it is evident, that it will bend a little, and the under part *x*, as in figure 8, will be the point fix; and therefore when the tenon is placed in the middle as here, the distance of the line of direction of the force which endeavours to break the joist, from the point fix *x*, is equal to half the height *x v*; but on the contrary, if the tenon is placed higher, that distance becomes greater; and of consequence, the resistance becomes greater, which shews that the nearer the tenon is to the upper part *v*, the greater the resistance will be: But as the mortise must not be too close to the upper edge, otherwise the tenon would break it; I think the best way is to divide the height *x v* into four equal parts, one of which is to be the thickness of the tenon, and placed two from the lower end *x*, and one from the upper *v*: as to the tenons marked in figures 9, and 10, they ought to be rejected as being contrary to the principles of mechanics. It is to be observed, that all binding-joists ought to be half as thick again as common joists; because, they being weakened by mortises and

and having a greater weight to ſupport, it is neceſſary that they ſhould be ſtronger in proportion.

Bridgings or bridging-joiſts are repreſented by the letter *f*, in the firſt figure, lying on the binding-joiſts *d* and which are alſo repreſented in figure 6, where *n*, *n*, repreſent the ſections of two binding-joiſts, and *d*, *d*, a part of the length of a bridging-joiſt, and *f f*, that of a cieling-joiſt, with the manner of their reception by the binding-joiſts; the fifth figure is a ſection which ſhews the manner of fixing cieling-joiſts *c* between the deep joiſts *b*, *b*, where ſhallow ones, as *a*, *a*, *a*, are framed in between them, as has been obſerved to be the moſt genteel way of framing common joiſts.

The diſtance of bridgings is generally about 12 to 14 inches, and their ſcantlings about 3 by 4 inches, or elſe 3.5 by 5, and their bearing is never more than the intervals of binding-joiſts, which is from 3 to 10 feet, as we have obſerved before, and which are laid even or fluſh with the girders to receive the boarding.

Cieling-joiſts, the moſt ſlender of all other kinds of joiſts, as having the leaſt weight to ſupport, are made about 2 by 3, or 3 by 4 inches, according to the ſtrength of the building; theſe are repreſented in the firſt figure by the letter *g*, whoſe diſtances are generally 12 or 14 inches: theſe joiſts are tenoned into the binding-joiſts, as is repreſented in figure 7, where *n* repreſents a ſingle mortiſe made on the one ſide of the binding-joiſts, and *r*, *s*, two double ones called *pulley-mortiſes*, in the ſide of a parallel binding-joiſt to receive the other end of the ceiling-joiſt. Theſe cieling and bridging-joiſts are ſeldom fixed till the building is covered in; when the laſt are pinned down to the binding-joiſts. Theſe kind of floors are called bridging-floors, and are the beſt ſort of carcaſe flooring.

Having ſhewn the manner of laying the ſeveral timbers for flooring, it remains now to ſhew how the floors themſelves are to be laid; their beauty depends on the colour and ſmoothneſs of the boards, without knots,

knots, and the closeness of the joints; for which reason, the carpenters plane the boards, and straiten the edges sometime before they are laid, in order that they may be sufficiently dry, and not shrink afterwards.

As it is not an easy thing to find a sufficient number of boards free from knots, the best are generally picked out for the floors of the principal apartments, and the rest are used in other places less conspicuous. It has been found by experience, that if the boards are ever so dry, and the edges are anew dressed, they will shrink again; for which reason, they never touch them after the first time: and the best way of making close joints is not to nail down the boards, till a twelve-month after they have been laid; this the workmen will not do unless they are obliged to it by agreement, under pretence that it is more work than they can afford to do.

The best wood for flooring in this country is the fine clear yellow deal well seasoned, which when well laid keeps its colour a great while; whereas the white sort becomes black by often washing, and looks very bad. In buildings of consequence the sappy part is cut off, and nothing but the heart is used, but then these floors are very expensive. But in common buildings, which are made by contract, they seldom make even use of dry stuff, unless it is particularly mentioned in the agreement.

The joints of the boards are commonly made plain, so as to touch each other only; but when the stuff is not quite dry, and the boards shrink, the water runs through them when the floor is washed, and spoils the cieling underneath; for which reason, they often make feather edges in better buildings, so as to cover each other of about half an inch; and sometimes they are made with groves and tenants; this last method, when well executed, appears to me preferable to any other whatsoever.

I am informed, that in the best buildings, the joints are made with dove tails; then the lower edge is nailed down,

down, and the next drove into it, by which the nails are concealed, which certainly makes the floor look much handſomer than when the nails are ſeen: for when they are waſhed the nails grows ruſty, and appear like ſo many black ſpots upon the floor, which has an ill effect.

The manner of meaſuring floors is by ſquares of 10 feet each ſide; ſo that taking the length and breadth in feet, and multiplying them together; then by ſtriking off the two laſt figures as decimals, the remainder will be the content expreſſed by theſe ſquares. Thus a floor of 18 feet by 16, gives 288 ſquare feet, or 2 ſquares and 88 decimal parts; ſo that if the price of a ſquare of flooring is known, that of the whole will be eaſily found by proportion.

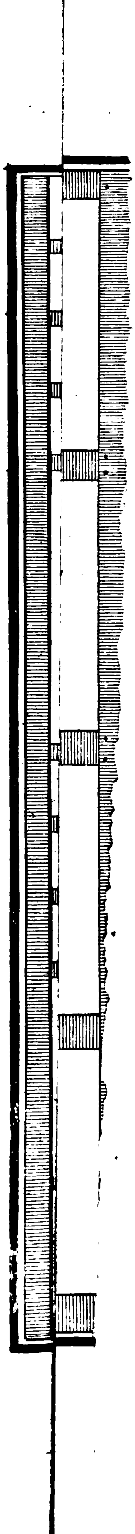
Formerly oaken boards were uſed for flooring, but at preſent they are neglected, excepting upon ſome particular occaſions, as in cloſets and other private rooms: theſe boards are framed together with pannels, like doors, and poliſhed with wax, which makes them look very beautiful, and are agreeable to thoſe who diſlike a wet room; but as they are ſlippery, and very expenſive, they are much out of faſhion.

SECT. XXIII.

Of ROOFINGS.

Plate XXIII. WE are now come to the formation of roofs, of which the former wall plates are a part, as being the baſe on which the ſmall rafters ſtand. We muſt, after having formed it, according to the plan of the building, and ſecured its angles, in the manner repreſented in the ſecond figure, plate XXII. conſider the proper diſtances

and



and places to lay the beams on; where it muſt be obſerved, 1. To avoid the joints of the plate: 2. That their diſtances be not too great, leſt you are obliged to have large cieling-joiſts, and large purlins, which are but a load to a building, and therefore ſhould not exceed ten feet: 3. That they lay over, or nearly over, the heads of the principal poſts, in timber buildings, and on the middle of the piers, when they are of brick or ſtone.

The ſituation and length of the tie-beams being determined, their under ſurface at each end being equal to the breadth of the wall-plate, is dovetailed an inch and a half or two in depth, according to their ſtrength, and which are let into both theſe plates, in the manner repreſented by the third and fourth figures, plate XXII; but, as it has been ſhewn already, with a ſingle dovetail; as in figure 4. If the breadth be divided into three equal parts, make the narrow part of the dovetail one, which to the end opens to the whole breadth of the beam. When the tie-beams are thus dove-tailed into the plates, they are then ſaid by the workmen to be cogged down, and ready to receive the cieling-joiſts and principal rafters.

But before the principal rafters can be framed, the height of the pitch, and their length muſt be determined; the pitch of every roof ought to be made according to its covering; which is of lead, pantiles, plaintiles, or ſlates; theſe are all the different coverings uſed in *England*. The uſual pitches are the pediment-pitch, common pitch, generally called true pitch, and the gothic pitch.

Pediment pitch is that whoſe perpendicular height is equal to two ninths of the breadth of the building; becauſe the height of a pediment is likewiſe two ninths of its baſe; this pitch is uſed when the covering is lead. Common pitch is that whoſe rafters are the three fourths in length of the breadth of the building; when it ſpans the building all at once; but is oftner divided

into

into two equal pitches; and it is used when the covering is of plaintiles.

Gothic pitch, is that when the length of the principal rafters is equal to the breadth of the building, and therefore is equilateral; this pitch is used when the covering is of pantiles; some workmen would have the breadth of the building divided into seven equal parts, the perpendicular height to have two of them, and the length of the rafters to be four; and that this pitch may serve for coverings of lead or pantiles: on the contrary, others will have the perpendicular height to be one fourth of the breadth, when the covering is lead, which is something less than what has been assigned above for that covering.

That the perpendicular height should be the three eighths of the breadth in pantiles covering, which is widely different from the former; or that the perpendicular height may be found by describing an arc from the extremity with a radius of two thirds of the breadth of the building. Lastly, the perpendicular height to be equal to half the breadth for plain-tiles covering, which makes the rafters somewhat shorter than in the pitch given before for that covering; and the length of the rafters to be five seventh parts of the breadth of the building for slate coverings, which is therefore nearly the same pitch as that for plain-tiles covering.

These are the various pitches commonly used for the different coverings, and seem to depend chiefly on the builder's fancy. We have proved in our *Elements* (art. 566.) *of Mathematics*, that if the height is 6 seventeenth parts of the breadth, or, which is nearly the same, if the height is one third of the breadth, the roof will be stronger than any other of the same scantlings; and therefore, if the scantlings are strong in proportion to the weight of the coverings, this pitch may serve upon all occasions.

Although

Although the principal rafters are commonly made equally ſtrong every where, yet ſome think that if they were at their feet nearly as thick as the breadth of the tie-beams, and to grow leſs towards the upper end, by one ſixth part, they would be better; which is certainly true, becauſe their centers of gravity become nearer to the point of ſupport; they require leſs timber; and as the rafters may as well be ſawed in this manner as in the uſual way, I ſee no reaſon why this method ſhould not be uſed.

The king-poſts ſhould be as thick as the tops of the principal rafters, otherwiſe they will not be able to receive them; and their breadth of ſufficient ſtrength to receive the ſtruts that are deſigned to be framed into them. Some will have it that the ſtruts ſhould diminiſh upwards as well as the rafters; but this would be carrying niceties further than is neceſſary; when the lower ends of the rafters are ſtrongeſt, the purlins, collar-beams, and ſtruts, ſhould be placed ſomething higher than the middle of the rafters, that the bearings may be proportional to the ſtrength, and not in equal parts, as is uſual.

Purlins muſt have the ſame thickneſs as that part of the principal rafters to which they are framed, and their breadth is generally made to their thickneſs, as 4 to 3; therefore the breadth being 8, the thickneſs muſt be 6: tho' this is the rule carpenters go by, yet their dimenſions ought to be determined by the rules given in the third ſection, part I.

Purlins are generally framed into the principal rafters; but, in my opinion, they ſhould rather be laid in the collar-beams, becauſe the rafters are not ſo much weakened by mortiſes, and the ſtrength of the purlins will then not depend on the tenons: when they are framed into the principal rafters, their length cannot be more than the diſtance between two contiguous rafters, which is from 10 to 12 feet only; but when they

they are laid in the collar-beams, they may then be twice or thrice that length, according as the ſtrength of the ſtuff will allow.

Small rafters may be in their ſcantlings 4 inches by 2.5, or 4.5 by 3.5, or elſe 5 by 3.5, according to the nature and ſtrength of the principals, and their length in a purlined roof ſhould not exceed ſeven feet: it is beſt to frame two rows of purlins, when the principal rafters are very long, in the manner repreſented in the firſt figure, plate XXIII. by the letters A, A; which figure repreſents the roof, as a plain ſurface; but the method of framing the purlins in a right line, as here repreſented, is not to be recommended; becauſe when the mortiſes in the principal rafters are againſt one another, they are not only weakened very greatly in thoſe parts, but you loſe the pinning alſo, and therefore they ſhould be framed, as repreſented by the letter B in the ſame figure.

The uſe of this figure is, to determine the number and ſituation of the principal ſmall and jack rafters; the principal rafters are thoſe marked by the letter D, and lie through the body of the plan, with tenons repreſented in the middle; the ſmall rafters are thoſe marked *f*, between the principals and the jack-rafters thoſe ſhort ones, whoſe tops bear againſt the hip-rafters C, and are marked by the letter E; the purlins are marked by the letters A and B; as to the other parts of a roof, which cannot be ſeen in this figure, they are repreſented in the following ſection.

Fig. 2. This figure repreſents the ſection of a large roof, having a king-poſt and two ſtruts to ſupport the principal rafters, the tie-beam is ſuppoſed to reſt in the middle upon ſome party or partition-wall, otherwiſe that beam would not be able to ſupport the roof; becauſe the greateſt weight, which is under the king-poſt, would reſt upon the weakeſt part, as has been ſhewn in the third ſection, part I.

Fig. 3. This figure is the section of a roof to be covered with pantiles; the length of the rafters is the two thirds of the breadth of the building, and the height one half; there is a lodging-room made in the middle; this roof is very strong, and may serve almost in any building, especially if the tie-beam is supported in the middle by a party-wall.

Fig. 4. This figure represents a roof, whose perpendicular height is three eighths, and the length of the rafters five eighths of the breadth; this roof is also very strong, but I think that in small buildings the king-post with its two struts might be left out without any inconveniency; because the two prick-posts together with their struts are sufficient to support the rafters.

Fig. 5. This figure is a section of a roof of pediment-pitch, with a valley in the middle to take off the barn roof aspect, which it otherwise would have, if the rafters were continued up to an angle; in this roof are made two lodging-rooms, as being framed with a collar-beam and middle-post, which last must be supported by a party-wall, otherwise the tie-beam will scarcely be able to support the weight upon it, without its being of very large dimensions.

It may be observed, that the posts in fig. 2, 3 and 4, have all joggles, which are by many workmen not approved of, on account of the waste of timber, and the length of time to frame them; in order to satisfy those that are for plain-work, and yet make it strong and durable, it will be sufficient to cut the tenons of the struts which enter into these joggles, as well as the mortises, in the same manner as they are represented here by the joggles, which will do very near as well; for all tenons cut at right angles will bear the pressure of the posts in the strongest manner that can be. It must likewise be observed, that all the iron bands represented in these roofs, are thought by the workmen to be very useful in strengthening the work, though needless in my opinion.

As workmen differ very much in their manner of framing roofs; it is impossible to give such rules as will satisfy every body; but what has here been said, together with the principles given in the third section, part I. of the strength of different scantlings, will be sufficient to the intelligent reader, to frame all sorts of plain roofs, upon any occasion, in the best manner, which is all we propose in this work: As to those called mansard, or broken roofs, and those for domes or cupolas, which are the most difficult of all carpenters work, their construction rather belongs to a compleat architect than to an engineer.

But before we conclude this section, it will not be unnecessary to shew how the length and position of the hip rafters C, C, figure 1, are to be found; the distance P Q of the last principal rafter D from the end P of the roof is always equal to half the breadth P S of the building; and having the length Q R of the principal rafter D, that of the hip-rafter P R is likewise given, as being the hypothenuse of a right angled triangle P Q R.

And because the perpendicular height of the roof is given as well as the diagonal drawn from the point P to the foot of the perpendicular dropt from the point R to the plan of the building; the inclination of the hip-rafter C, may be found by a ruler and compasses; or, by trigonometry, thns; The length of the hip-rafter P R is to the perpendicular height of the roof, as the radius is to the tangent of the angle made by this rafter and the plan of the building.

Of CEILING.

Although the manner of ceiling is very common, yet it is necessary, that the young engineer should know how it is performed: In buildings of no great consequence, the laths are nailed on the joists, so as a part of the girder appears below the ceiling; this is done in view to get 5 or 6 inches in the height of the room; and the part of girders that appear are covered with deal boards, with a little cornice round it, and painted with the same colour as the wainscot. The plaister for ceiling is made of lime and hair, to make it stick the better, and laid on very smooth; when it is dry and has any cracks in it, as commonly happens, it is passed over with a trowel dipt in thin plaister, this is continued till it is quite smooth, and without any cracks; after this it is white-washed two or three times over, with lime-water and size, till it appears of a fine white.

But in buildings of any consequence, ceiling-joists are framed into the girders, so as to be even with the under surface, as has been observed before: As these joists are put in after the frame of the floor is made, and just before the ceiling is finished; one of the mortises is made about a foot long, sloping so as that when the tenant at one end is fixt into the mortise, the other may slide through the other till it becomes perpendicular to the girder where it is pinned down.

As to ceilings made with various work, or that are painted, the curious reader may consult books of architecture, which treat of them; we shall only add that ceilings are measured by the yard of 9 feet square.

Of WAINSCOTING.

Formerly wainscoting was made with oak, and it is from thence it has derived its name, but at present white deal is used only; the rooms were commonly wainscoted quite up to the cieling, and terminated by a cornice; but the later custom is to carry it only up chair high, that is from two to three feet; the rest of the wall is covered with flowered paper, which is very cheap and beautiful, or else it is finished with stucco covered with hangings; to prevent the paper from being ſpoiled by the dampneſs of the wall, it is paſted on thin cloth, and fixed in frames.

Walls ſhould never be wainſcoted before a twelvemonth ſtanding at leaſt, two or three years would be better; otherwiſe the pannels will unglue, do what you will, and ſhrink in dry weather, whereby it will be ſo ſpoiled that all the repairs that can be made will never look well, ſo that all the trouble and expences will entirely be loſt.

Though the wall is dry, if the ſtuff is not ſo, it will produce ſtill the ſame effect; and as dry and well-ſeaſoned ſtuff is much dearer than that which is green, and not many workmen have it in their power to keep always a ſtock of dry ſtuff before-hand; it is a very difficult matter to have this work performed as it ought to be: I have ſeen a houſe that was repaired three times in five years, and now is good for nothing; becauſe the walls were not dry, and the ſtuff not ſufficiently ſeaſoned; and if government work, which is always well paid for, is ſo badly executed, what muſt a private perſon expect, if he is not very careful in his bargain, and does not underſtand the work himſelf.

Wainſcoting is meaſured by the ſquare yard of 9 feet, and all the turnings of the mouldings are meaſured by a thread, and looked upon as plain, excepting the cornice, which is meaſured and paid by the foot in length.

Of HOUSE-PAINTING.

As the various colours for priming and painting are now-a-days made up ready for uſe, and ſold in ſhops, I ſhall ſay nothing about them; but only obſerve that all painting in and about the houſe ſhould be well primed, and paſſed over twice with the ſame colour the rooms are to be of, and great care muſt be taken to ſee that the colour is laid full, even, and ſmooth, according to the grain of the wood; for when the bruſh is drawn

croſs

croſs the grain it never looks well; this is to be underſtood to be done from the beginning to the entire finiſhing of it; or elſe it will be to no purpoſe.

In all out-door painting, the colours ſhould be mixed up with linſeed oil, *Spaniſh* white, *Spaniſh* brown, and red lead in the priming, and finiſhed with white lead; this done, it will reſiſt the weather, and laſt a great while.

Painting is meaſured by the ſquare yard, in the ſame manner as wainſcoting, that is, all the mouldings are meaſured with a thread; the ſaſhes of windows are paid by the piece; if the doors and their frames are painted in mahogony colour, the price is ſomewhat more than that of common painting; this ſome workmen perform ſo well, as to appear at a diſtance as well as that wood itſelf. When chimnies are lined with *Portland* ſtone, they are often painted like marble, and when it is well done, look very neat for three or four years.

Of TYLING-ROOFS.

There are various ſorts, ſuch as plain-tiles, pan-tiles, ridge, hip, gutter, paving, and *Dutch*-tiles: plain-tiles are the common ſort which are uſed in covering of houſes; they are about 10.5 inches long, ſix and a quarter broad, and half an inch and half a quarter thick; but in the country they vary ſomething from theſe dimenſions; they weigh about 2.5 pounds, that is 100 weigh nearly 2500 pounds. Tyling is meaſured by a ſquare of 100 ſquare feet, and the number of tiles required for ſuch a ſquare depends on the diſtance of the laths; which when 6 inches, requires 800; when 6.5 inches, 740; when 7 inches, 690; when 7.5 inches, 640, and when it is 8 inches, but 600 tiles.

Pan-tiles are of a quadrangular figure, when flat of about 13 inches long, 6 or 7 inches broad; they are bent croſs-ways in the form of an S, only one of the arches is about three times as big as the other; ſo that when they are laid on a roof, one of the edges which is leaſt bent is covered by the edge of the other that is moſt bent, ſo that the roof looks like furrows, one high and the other low; theſe tiles ſerve moſtly for low roofs, ſuch as ſtables, ſheds, and outhouſes; about 600 will cover 100 feet ſquare.

Ridge-tiles are uſed to cover the ridges of houſes, and are made in the form of a ſemi-cylindric ſurface, of about 13 inches in length, and of the ſame thickneſs as plain tiles; their breadth at the outſide meaſures about 16 inches or leſs.

Hip, or corner tiles, are at firſt made flat like plain-tiles of a quadrangular figure, whoſe two ſides are right lines, and the ends arcs of circles; the upper end concave, and the lower convex, the latter being about ſeven times as broad as the other; they are about 10.5 long, but before they are burnt are bent upon a mould in the form of a ridge-tile, and have a hole at the narrow end to nail them on the hip-corner of the roof.

Gutter-tiles are made like corner-tiles, only the edges at the larger ends are turned up for about four inches: theſe tiles are ſeldom uſed where lead is to be had, as being better for this purpoſe.

Dutch-tiles are commonly uſed in chimnies; they are made of a whitiſh earth, glazed and painted with various figures, ſuch as birds, flowers, or landſkips, in blue or purple colour; and are about 6.5 inches each way, and three quarters of an inch thick: when theſe tiles are properly ſet with good mortar, they look very beautiful, and caſt a greater heat than ſtone; for being very ſmooth, and glazed, the rays of heat ſtriking upon them are all reflected backward into the room, eſpecially when the ſides of the chimnies are oblique or in the form of circular arcs.

Pan-tiles are laid in mortar, becauſe the roof being very flat, and many tiles being warpt in the burning, they

they will not cover the roof ſo well as that no water can paſs between them. Sometimes theſe tiles are varniſhed with a dark brown colour; which makes them laſt a great while, and look better than the others, but are dearer in proportion.

Plain-tiles are not laid in mortar, but pointed only in the inſide; as to the ridge and corner-tiles they are all laid in mortar, becauſe they lie ſeldom ſo cloſe, as not to admit any water to paſs between them. There are alſo uſed tiles in paving, that are either ſquare or hexagonal, which when well burnt and laid in good mortar, look very neat, and laſt long; but as paving in general is ſo well known, it would be needleſs to ſay any more about it.

PART IV.

Of AQUATIC BUILDINGS.

AS these kind of works contain a greater variety than those constructed on dry land, and require much more skill and knowledge both of the theory and practice; no lesser work than Mr. *Belidor's* Architecture Hydraulic, is necessary to give a true knowled : of their construction and execution, according to the different situations and circumstances; As this author had the assistance of the greatest engineers in *France*, who have more experience, and knowledge both in theory and practice, than any others in *Europe*; so no man had a better opportunity to give every thing necessary relating to this subject. Since therefore his works are, or ought to be, in the hands of every engineer, we shall content ourselves, to give here some general principles, together with particular observations of the most material parts of these buildings, for the sake of those, who have no opportunity to peruse so extensive a work as his.

SECT. I.

Of STONE-BRIDGES.

THE situations of bridges are easily known, and need no explanation; the only thing to be observed is, to make them cross the stream at right angles, for the sake of the boats that pass through the arches, with the current of the river; and to prevent the continual striking of the stream against the piers, which

which may endanger them in a long courſe to be damaged and deſtroyed in the end.

Bridges built for a communication of high roads, ought to be ſo ſtrong and ſubſtantial as to be proof againſt all accidents that may happen, to have a free entrance for carriages, afford an eaſy paſſage to the waters, and be properly adapted for navigation, if the river admits of it; therefore the bridge ought to be at leaſt as long as the river is wide in the time of its greateſt flood; becauſe the ſloping of the water above may cauſe too great a fall, which would prove dangerous to the veſſels, and occaſion the under graveling the foundation of the piers, and abuttments.

To this may be added, by reducing the paſſage of the water too much, in time of a great flood, it might break through the banks of the river, and overflow the adjacent country, which would cauſe very great damages; or, if this ſhould not happen, the water might riſe above the arches, and endanger the bridge to be overſet, as it has happened in many places.

When the length of the bridge is equal to the breadth of the river, which is commonly the caſe, the current is leſſened by the ſpace taken up by the piers, for which reaſon, this thickneſs ſhould be no more than is neceſſary to ſupport the arches; and it depends, as well as that of the abuttments, on the width of the arches, their thickneſs, and the height of the piers.

The form of the arch is commonly ſemi-circular; but when they are of any great width they are made elliptical, becauſe they would otherwiſe become too high; as has been done at the *Pont Royal*, at *Paris*, where the middle arch is 75 feet, and its height would have been 37.5 feet, inſtead of which, it is only 24 by being made elliptical.

Another advantage of much more importance ariſes from the oval figure, which is, the quantity of maſonry of the arches is reduced in the ſame proportion as the radius of the arch is to its height. That is, if the

the radius is 36 feet, and the height of the arch 24, that is, three fourths of the radius, the quantity of masonry of the arches is likewise reduced to three fourths; which must lessen the expence of the bridge considerably.

When the height of the piers is about six feet, and the arches are circular, experience has shewn, says Mr. *Belidor*, it is sufficient to make the thickness of the piers the sixth part of the width of the arch, and two feet more; that is, the thickness of the piers of an arch of 36 feet ought to be 8 feet; those of an arch of 48 feet to be 10.

When the arches become of a great width, the thickness of the piers may be reduced to the sixth part of that width; but the depression of the two feet is not done at once; that is, in an arch of above 48 feet, 3 inches are taken off for every six feet of increase of the width of the arch. For instance, the thickness of the piers supporting an arch of 72 feet wide, should be 14 feet, according to the preceding rule; but by taking off 3 inches for every 6 feet, above an arch of 48 feet wide, the thickness of the piers is reduced to 13 feet: Consequently, by following the same rule, the thickness of the piers supporting an ach of 16 fathoms wide, will be 16 feet; all the others above that width are the sixth part of the width.

After this Mr. *Belidor* gives a rule for finding the thickness of the piers which support elliptic arches, and makes them stronger than the former: The abuttments he makes one sixth part more than the piers of the largest arch.

It is plain, that these rules are merely guess-work, determined from some works that have been executed. But tho' examples are necessary to confirm the truth of the theory, yet they are not sufficient to form, from one or two bridges that have been built, a general rule for others of different forms or dimensions, without either making some stronger or weaker than they ought

to

to be; besides, granting this rule to be true, yet when the piers are of any other height, we are quite left in the dark; and therefore, it is necessary to have recourse to theory, in order to find how much the piers are to vary in their thickness, according to their height, and the width of the arches: But, previous to this theory, it is necessary to know, the proper thickness of the arches at their key-stones, because that of the piers depends partly on it.

The thickness of the arch-stones, I must confess, is not to be determined by theory, at least that I know of; nor do those authors who have written on the subject agree amongst themselves; Mr. *Gautier*, an experienced engineer, in his works, makes the length of the arch stones, of an arch 24 feet wide, two feet; of an arch 45, 60, 75, 90 wide, to be 3, 4, 5, 6 feet long respectively, when they are hard and durable; and something longer when they are of a soft nature; on the contrary, Mr. *Belidor* says they ought to be always one twenty fourth part of the width of the arch, whether the stone be hard or soft; because, if they are soft, they weigh not so much.

But that the length of the arch-stones should be but a foot in an arch of 24 feet wide, 2, 3, 4, in arches of 48, 72, 96, feet, it appears to me impossible; because the great weight of the arches would, as I imagine, crush them to pieces, by the pressure against one another; and therefore Mr. *Gautier's* rule seems to be much preferable: As he made the length of the arch-stones to increase in a slower proportion, from 10 to 45 feet wide, than in those above that width; we imagine, that the latter will be sufficient for all widths, whether they are great or little: Therefore in the following computation, we shall suppose the length of the arch-stones of 30 feet in width to be two feet, and to increase one foot in fifteen, that is, 3 feet in an arch of 45 feet, 4, 5, 6, in an arch of 60, 75, and 90 feet;

and

and ſo the reſt in the ſame proportion; this being premiſed, we ſhall proceed to ſhew how the thickneſs of the piers is to be found.

PROBLEM.

Plate XXIV. Fig. 4. *To find the thickneſs* B C *of the piers, when the arch is terminated by two concentric ſemi-circles, and there is a wall* R N *above the middle of the piers whoſe height is equal to that of the arch, and its baſe to the difference between the breadth* A D *of the pier, and twice the thickneſs* A G *of the arch.*

Let the radius O M paſs through the center of gravity L of half the arch G E, L K, and L I, perpendicular to O A and O L; then if the radius O A of the interior circle be called a, the radius O G of the exterior one b; their difference A G, d; O K or K L $= m$, n the area G E of half the arch; the height A B of the piers c, their thickneſs B C $= z$; laſtly, let unity be to r, as the radius is to the ſemi-circumference; or, which is the ſame, let $r = 3.142$ nearly; then by what has been ſaid in the ſecond problem, ſection II. of the firſt part; we have $4n = rbb - raa$, $\frac{3r}{4}m = a + \frac{bb}{a+b}$, $g = c + 2m - a$, and $2ng - 2nz$ for double the momentum of the arch's preſſure againſt the pier.

Now becauſe the baſe R G of the wall above the pier is equal to A D — 2 A G, or $z - 2d$, and its height R N $= b$, $bz - 2bd$ will expreſs the area of that wall, and as the line which paſſes through its center of gravity perpendicular to B C biſects that line; $\frac{1}{2}z$ will be its diſtance from the point fix C; we have $\frac{1}{2}bzz - bdz$ for its momentum; and as the momentum of the pier C A, has been found in the above-cited problem to be $\frac{1}{2}czz$; double the ſum of theſe two

two last momentums being made equal to $2ng - 2nz$, gives $bzz + czz - 2bdz = 2ng - 2nz$; or if we suppose $b + c = s$, and $n - bd = sq$; this equation becomes $szz + 2sqz = 2ng$; whose square root is $z + q = \sqrt{\frac{2}{s}ng + qq}$.

REMARK.

We have shewn in the second section of the first part, after problem the second, that on account of the cement and roughness of the stones, the weight of the arch, or, which is the same, the area n of G E, should be diminished by one third or more, in order to have the true momentum of the arch; and as in bridges, the parts between the arches are filled up with loose stones, their weight will be greater in this case, than it would be otherwise; The question is therefore to find what value ought to be assigned for n, in order to find the thickness of the piers able to support the pressure of the arch, when it is loaded with this additional weight. For since the spaces above the arches are always similar when the upper part of the bridge is horizontal, and consequently proportional to the similar parts A G F E, and this is nearly so in bridges; it is manifest, that if the whole area A G F E, is taken for the value of n, and the piers are sufficiently strong in one case, it will be so in all others.

As the value of n cannot be estimated so truly as from some bridge that has been executed, and is looked upon by the masters of this art as a model to go by; so we shall make it appear, that if n expresses the whole area A G F E; the thickness of the piers will come out nearly the same as those of the *Pont Royal* at *Paris*, which support the greatest arch.

According to Mr. *Belidor*, in an arch of 75 feet wide, the thickness of the piers whose height is about 6 feet, should be 13.5, when the arch is circular; and 15 feet when

when it is elliptical, as that of the above-mentioned bridges; But we have ſhewn in the ſecond ſection, that the preſſure of an elliptic arch is no greater than that of a circular form, on account of the weight being leſs in the former than in the latter; and ſince, according to the problem above, the thickneſs of the piers of ſuch an arch is found to be 14 feet, when they are 6 feet high, as in thoſe of the *Pont Royal*; it is evident, that the value of *n* aſſumed here, agrees with the above rule as nearly as can be expected.

Now as Mr. *Belidor* ſays, that his rules are agreeable to the practice of the greateſt maſters in that branch of engineering, we may preſume, that the thickneſſes of the piers, we have found, will be ſufficient in all the different caſes that can happen, with this precaution however, that the piers are made of ſtrong ſolid ſtones, laid in the beſt and moſt ſubſtantial manner.

It is to be obſerved, that the thickneſs of the piers here found, are ſuch as if there were but one ſingle arch; but when there are arches on each ſide, the preſſure of the one deſtroys that of the other; but as all the arches cannot be built together, it is of abſolute neceſſity, that the piers ſhould be able to reſiſt the preſſure of each arch, independent of the adjacent ones; for which reaſon, it is neceſſary to build the wall G N above the pier before the arches are formed, as Mr. *Labely* has moſt judiciouſly done at *Weſtminſter-bridge*; for by this means, the arch will be in no danger to fall and cauſe needleſs expences. As to the parts between the arches, and the wall G N, they ought not to be filled up till ſuch time as the arches on each ſide are finiſhed.

TABLE containing the thickness of the piers of BRIDGES.

	6	9	12	15	18	21	24
20	4.574	4.918	5.165	5.350	5.492	5.610	5.698
25	5.490	5.913	6.216	6.455	6.645	6.801	7.930
30	6.386	6.816	7.225	7.513	7.746	7.939	8.102
35	7.258	7.786	8.200	8.532	8.807	9.037	9.233
40	8.404	8.691	9.148	9.523	9.835	10.101	10.328
45	8.965	9.579	10.077	10.489	10.837	11.136	11.394
50	9.805	10.454	10.987	11.435	11.817	12.146	12.434
55	10.640	11.245	11.882	12.364	13.019	13.149	13.218
60	11.400	12.110	12.718	13.281	13.723	14.109	14.314
65	12.265	13.025	13.648	14.185	14.654	15.082	15.433
70	13.114	13.869	14.517	14.049	15.573	16.011	16.400
75	14.000	14.705	15.336	15.965	16.480	16.940	17.354
80	14.747	15.542	16.234	16.842	17.381	17.864	18.298
85	15.513	16.328	17.041	17.674	18.237	18.742	19.198
90	16.373	17.201	17.929	18.578	19.157	19.679	20.152
95	17.184	17.826	18.772	19.438	20.036	20.577	21.068
100	17.991	18.848	19.610	20.293	20.908	21.466	21.976

The first horizontal line expresses the height of the piers in feet, from 6 to 24 feet, each increasing by 3: the first vertical column, the width of arches from 20 to 100 feet for every 5 feet.

The other columns express the thickness of piers in feet and decimals, according to the respective height at the head of the column, and the width of the arch against it in the first column.

Thus for example, let the width of the arch be 60 feet, and the height of the piers 12; then the number 12.718, under 12, and against 60, expresses the thickness of the piers, that is 12 feet, and 8.6 inches; we must observe again, that the length of the key-stone is is 2 feet in an arch of 30 feet wide; 3, 4, 5, 6, in an arch of 45, 60, 75, 90; that of 20 feet width one foot 4 inches; and the length of any other width is found by adding 4 inches for every 5 feet in width.

As this table contains the thickneſſes of piers in reſpect to arches that are commonly uſed in practice, we imagined, that to carry it farther would be needleſs; beſides, if any other arch of a greater width was propoſed, the ſtrength of its piers may be found by the foregoing problem, as well as that of any intermediate one not inſerted here; or becauſe the difference between the thickneſs of the piers of any two contiguous arches is but ſmall; thoſe between any two marked here, may be made equal to half the ſum of the next below and above it: thus the thickneſs of the piers of an arch 52 or 53 feet wide is nearly equal to 10.222, half the ſum of the thickneſſes 9.805 and 10.64 of the arches 50 and 55 feet wide, when the height of the piers is 6 feet.

Rectangular piers are ſeldom uſed but in bridges over ſmall rivers; in all others, they project the bridge by a triangular priſm, which preſents an edge to the ſtream, in order to divide the water more eaſily, and to prevent the ice from ſheltering there, as well as veſſels from running foul againſt them; that edge is terminated by the adjacent ſurfaces at right angles to each other at *Weſtminſter* bridge, and make an acute angle at the *Pont Royal*, of about 60 degrees; but latterly the *French* terminate this angle by two cylindric ſurfaces, whoſe baſes are arcs of 60 degrees, in all their new bridges.

When the banks of the rivers are pretty high, the bridge is made quite level above, and all the arches of an equal width; but where they are low, or for the ſake of navigation a large arch is made in the middle of the ſtream, then the bridge is made higher in the middle than at the ends; in this caſe, the ſlope muſt be made eaſy and gradual on both ſides, ſo as to form above

one

one continued curve line, otherwise it appears disagreeable to the eye. Mr. *Belidor* will have the descent of that slope to be one twenty fourth part of the length; and Mr. *Labely* says he made it one twentieth part only, which he thinks to be scarce preceptible; but as *Westminster* bridge is 1220 feet according to his own account; if half this breadth be divided by 20, we shall find 30.5 for the difference between the height of the middle arch and the end of the abutments: now if this can be called scarcely perceptible, I should be glad to know how far this descent may be carried, since it is plain, that the slope of *Westminster* bridge is too much by a good deal, according to the best judges; for the beauty of any bridge consists, in that one may see from one end to the other, like a street, if it is possible; or, if the nature of the situation does not permit it, the least rising is the best; for which reason, I should think that one fiftieth part of the length is quite sufficient for the descent; whence, according to this rule, the middle arch of the above mentioned bridge would be about 11 feet higher than the ends of the abutment, which, in my opinion, would have looked very well.

It may be said, that the circumstances would not allow so easy an ascent, because the arches are circular; but if the middle arch, which is 38 feet high, had been made elliptical, then that height would have been reduced to 28.5 feet, that is, to three fourths of the present height; this would have diminished the height of the bridge by 9.5; and besides, one fourth of the masonry contained in the arches would thereby have been saved, which methinks would have been a sufficient inducement to recompence the little more trouble required to make an elliptic arch instead of a circular one.

The width commonly allowed to small bridges is 30 feet; but in large ones near great towns, these 30 feet are allowed clear for horses and carriages, besides a banquet at each ſide for foot paſſengers of 6 to 9 feet each, raiſed about a foot above the common road; the parapet-walls on each ſide are about 18 inches thick, and four feet high; the generally project the bridge with a cornish underneath; ſometimes balluſtrades of ſtone or iron are placed upon the parapet as at *Weſtminſter*; but this is only practiſed where a bridge of a great length is made near the capital of a country.

The ends of bridges open from the middle of the two laſt arches with two wings making an angle of 45 degrees with the reſt, in order to make their entrance more free and eaſy; theſe wings are ſupported by the ſame arches of the bridge next to them being continued in the ſame manner of an arch, of which one pier is much longer than the other.

We have before determined the length of the key-ſtone, but ſaid nothing of the others towards the ſpring of the arch; which were formerly made all of the ſame length, and the reſt of the front-walls finiſhed with horizontal courſes up to the cordon, and the ſpandrels or interval between the arches filled with rubble-ſtones without mortar; but now the joints of the arch-ſtones are continued quite up to the cordon, and the looſe ſtones between the arches on the inſide are laid in the direction of the ſame joints: this way of finiſhing the courſes of the ſtones, both without and within, is certainly preferable to the former: but the beſt and only true method is, to form the outſide courſes, in the manner juſt now mentioned, and in the inſide, the arch-ſtones continued ſo as to form the curve, whoſe conſtruction has been given in the laſt problem of the ſecond ſection, part the firſt; this being done, and the ſtones ſo far laid in mortar, they will be in equilibrio with each other, as has been ſhewn in that ſection; the reſt may be filled up with looſe ſtones having proper bonds as uſual.

As the conſtruction of this exterior curve is ſo eaſy its execution can admit of no difficulty; but becauſe we

we have not given that when the interior curve is an ellipsis, and we have proved that curve to be the best and only one to be used in bridges, we must beg leave to refer the reader to the fifth section of the third book of our mathematical treatise, where it is given; it was through oversight omitted in this work.

When the upper part of the bridge is finished with stones in the manner mentioned above, so as to form one continued curvilinear surface, a bed of sand and gravel is laid all over it, of about 6 feet deep, and then finished with paving the middle passage, or with coarse gravel, and the banquets are covered with flat stones for the foot passengers.

The spring of the arches should begin at low-water mark, that is, that of the middle or greatest, the rest are raised somewhat higher, so as to make the upper part of the bridge of the proposed descent; but in a situation where the water swells very high in some particular season of the year, regard must be had to that, and the arches must be raised accordingly.

The first figure of plate XXIV. is the elevation of a bridge with elliptic arches, the second is the plan, and the third a section through the middle of the arch next to the abutment; the arches are 75 feet wide, the piers 12 high, and 15 broad; the angles at the extremities are right ones, and reach from the bed of the river quite up to the top of the parapet, where they form recesses for passengers to retire into upon occasion; but the foundation up to the bed of the river is rectangular, for reasons mentioned hereafter. The section shews the wings of the bridge in front, and how the arch turns in that place.

We have thus given all the dimensions of the several parts of stone bridges (for the most part deduced from a well-asserted theory, and therefore may be depended upon with more security than those given by other authors) and which are to be necessarily known before the building of a bridge is undertaken; we shall now ſhew how to proceed in the execution from the beginning of laying the foundation to the entirely finiſhing of the work.

How the work is to be carried on.

As the laying the foundation of the piers is the moſt difficult part of the whole work, it is neceſſary we ſhould begin with an eaſy caſe, that is, when the depth of the water does not exceed 6 or 8 feet; and then proceed to thoſe which may happen in a greater depth of water.

One of the abutments with the adjacent piers is incloſed by a dyke called *batardeau* by the *French*, of a ſufficient width for the work, and room for the workmen; this batardeau is made by driving a double row of piles, whoſe diſtance is equal to the depth of water, and the piles in each row are 3 feet from each other; they are faſtened together on the outſide by bonds of 6 by 4 inches; this being done, frames of about 9 feet wide are placed on the inſide to receive the boards, which are to form the incloſure, the two uprights of theſe frames are two boards of an inch and half thick, ſharpened below to be driven into the ground and faſtened together by double bonds, one below, and the other above, each ſeparated by the thickneſs of the uprights; theſe bonds ſerve to ſlide the boards between; after theſe frames have been driven into the ground as hard as can be, then the boards themſelves are likewiſe driven in till they reach the firm ground underneath.

Between every two piles tie beams are faſtened to the bonds of the piles to faſten the inſide wall to the outſide one; theſe tie-beams are let into the bonds and bolted to the adjacent piles: This being done, the bottom is cleared from the looſe ſand and gravel, by a machine like thoſe uſed by ballaſt-heavers; and then well-prepared clay is rammed into this coffer very tight and firm, to prevent the water from oozing through.

Sometimes

Sometimes these inclosures are made with piles only driven close to each other, at others the piles are notched or dove tailed one into the other: but the most usual method is to drive piles with grooves in them, 5 or 6 feet distant from each other, and boards are let down between them.

This being done, pumps and other engines are used to draw the water out of the inclosure, so as to be quite dry; then the foundation is dug, and the stones are laid in the same manner, and with the same precautions as have been mentioned in respect to those of a fortress: observing to keep some of the engines always standing, in order to draw out the water that may ooze through the batardeau.

The foundation being cleared, and every thing ready to begin the work; a course of stones is laid, the outside all round with the largest stretchers and headers that can be had, and the inside filled with ashlers well jointed, the whole laid in terrass mortar: the facings are crampt together, and set in lead; and some cramps are also used to fasten the facings with the inside. The same manner is to be observed throughout all the courses to the height of low-water mark; after which the facings alone are laid in terrass mortar, and the inside with the best of the common sort.

The extent of the base of the foundation does not so much depend on the bigness of the piers as on the whole weight of the superstructure, which methinks has not always been so mnch considered as should have been done; for it is said, that every course should project about a foot beyond that which is next above it from the height of low water mark, whether the bridge be high or low, the arches circular or elliptic: but as every pier supports two half arches together with the weight of the stones laid between the hanches; the base ought to be regulated accordingly, as likewise in proportion to the height of the pier. When the foundation is carried to the height of low-water mark, or to the

the height where the arches begin, which ought to be either thereabout or at moſt two feet above it when the arches are elliptical; then the ſhaft or middle wall is to be carried up nearly to the height of the arches, and there left ſtanding till all the piers are finiſhed, in order that the maſonry may be ſufficiently dry and ſettled before the arches are begun.

As the piers end generally with an angle at each end, it is cuſtomary to lay the foundation in the ſame manner, which is not ſo well as to continue the baſe rectangular quite to the ends of the piers, and as high as low-water mark; both becauſe the foundation becomes then ſo much broader, and alſo becauſe the water will not be able to get under it: for when the current ſets againſt a flat ſurface, it drives the ſand and mud againſt it, ſo as to cover it entirely; whereas if a ſharp edge be preſented to the ſtream, it carries every thing away, and expoſes the foundation to the continual action of the water, which in courſe of time muſt deſtroy it.

The piers being all finiſhed, and the maſonry well ſettled; the next thing to be done is to frame and fix the centers, which ought to be ſo ſolid and ſtrong as to be able to ſupport the great weight of the arches; as their conſtruction is commonly known by workmen, and as thoſe made uſe of at *Weſtminſter-bridge* will be explained by Mr. *Labely* himſelf, we ſhall ſay no more of them than to obſerve, that they are fixed at the ends upon the projection of the foundation; and when the arches are very large they are ſupported in the middle by piles, and they muſt be raiſed by means of iron wedges about 3 inches higher than the arches are intended to be, in order to allow for the ſettling of the maſonry, theſe wedges by being looſened gradually ſerve to eaſe the center, ſo that it may only juſt touch the arch, and ſo facilitate the taking it quite away when the maſonry is ſufficiently ſettled.

The *French* engineers fix thin boards on each ſide with the directions of the joints marked upon them, for the conveniency of working with more ſpeed; this appears to be very uſeful, eſpecially when the arches are elliptical; they have patterns beſides for every joint, in order to cut the ſtones in a proper manner.

Theſe preparations being made, the ſtones of the firſt courſe are crampt together, as alſo all thoſe of every fifth courſe quite up to the key-ſtones. All the ſtones are to be laid in good ſtrong mortar, not very thick, ſo that they may lay as cloſe as poſſible, and cauſe but little ſettling: the arch being compleated, the center is eaſed by means of the wedges, but left ſtanding till the next arch is finiſhed; then it is taken away and made fit to ſerve for ſome other arch; ſo that there are not above three centers required to compleat the bridge.

After the intervals between the arches are filled up with ſtones laid in a regular manner without mortar, and the gravel is laid over them; two drains or gutters are made length-ways over the bridge one on each ſide next to the foot path, of about 6 feet wide, and a foot deep; which, being filled with ſmall pebble ſtones, ſerve to carry off the rain-water that falls on the bridge and to prevent its filtering through the joints of the arches, as often happens.

If the ſame precautions were uſed here, as have been above recommended to prevent water from penetrating through arches conſtructed under ground, I ſhould imagine that this would be much better than the method commonly practiſed: for when the water paſſes through the joints of the arch-ſtones, as it does at *Weſtminſter* bridge, it has an ill effect to the eye, becauſe thoſe ſtones that are wet look of a black colour, different from the reſt.

How to build in water with Coffers.

The former method of laying the foundation by means of batardeaus is very expenſive and often meets with great difficulties: for when the depth of water is 8 feet or more, it is ſcarcely poſſible to make the batardeaus ſo tight as to prevent the water from oozing through them; and in that caſe, the number of engines required, as well as the hands to work them, become very expenſive; and if part of the batardeau ſhould break by ſome extraordinary wind or tide, the workmen would be expoſed to very great danger.

Therefore the next and beſt method is to build with coffers, when it is practicable, ſuch as were uſed at *Weſtminſter bridge.* Since Mr. *Labely* promiſes to give a particular account of their conſtruction, and the manner in which they were uſed, we ſhall here mention ſome few things only, referring the reader for a fuller deſcription of them to this gentleman's work, a part of which has been publiſhed ſince the bridge was finiſhed.

The height of water was 6 feet at a medium when loweſt, and the tide roſe about 10 feet at a medium alſo; ſo that the greateſt depth of water was about 16 feet; at the place where one of the piers of the middle or great arch was to be, the workmen began to drive piles of about 13 or 14 inches ſquare, and 34 feet long, ſhod with iron, ſo as to enter into the gravel with more eaſe, and hooped above to prevent their ſplitting in driving them; theſe piles were driven as deep as could be done, which was 13 or 14 feet below the ſurface of the bed of the river, and 7 feet diſtant from each other, parallel to the ſhort ends of the pier, and at about 30 feet diſtant from them; the number of theſe piles was 34, and their intent to prevent any veſſels or barges from approaching the work; and in order to hinder boats from paſſing between them, booms were placed ſo as to raiſe and fall with the water.

This

This being done, the ballaſt-men began to dig the foundation under the water, of about 6 feet deep, and 5 wider all round than the intended coffer was to be, with an eaſy ſlope to prevent the ground from falling in; in order to prevent the current from waſhing the ſand into the pit, ſhort grooved piles were driven before the two ends and part of the ſides, not above 4 feet higher than low-water mark, and about 15 feet diſtant from the coffer: between theſe piles, rows of boards were let into the grooves down to the bed of the river and fixed there.

The bottom of the coffer was made of a ſtrong grate, conſiſting of two rows of large timbers, the one long-ways and the other croſs-ways, bolted together with wooden trunnels, ten feet wider than the intended foundation. The ſides of the coffer were made of fir timbers laid horizontally cloſe one over another, pinned with oaken trunnels, and framed together at the corners, excepting at the two ſalient angles, where they were ſecured with proper irons, ſo that the one half might be looſened from the other if it ſhould be thought neceſſary; theſe ſides were lined on the inſide as well as on the outſide with three inch planks placed vertically; the thickneſs of thoſe ſides was 18 inches at the bottom, reduced to 15 above, and they were 16 feet high; beſides, knee-timbers were bolted at the angles, in order to ſecure them in the ſtrongeſt manner. The ſides were faſtened to the bottom by 28 pieces of timber on the outſide, and 18 within, called ſtraps, about 8 inches broad, and 3 or 4 inches thick, reaching and lapping over the ends of the ſides; the lower part of theſe ſtraps had one ſide cut dove-tail faſhion, in order to fit the mortiſes made near the edge of the bottom to receive them, and were kept in their places by iron wedges; which being drawn out when the ſides were to be taken away, gave liberty to clear the ſtraps from the mortiſes.

Before

Before the coffer was launched, the foundation was examined, in order to know whether it was level; for which purpoſe ſeveral gauges were made, each of which conſiſted of a ſtone of about 15 inches ſquare, and 3 thick, with a wooden pole in the middle of about 18 feet long. The foundation being levelled and the coffer fixed directly over the place with cables faſtened to the adjacent piles; the maſons laid the firſt courſe of the ſtones for the foundation within it, which being finiſhed, a ſluice made in the ſide was opened near the time of low-water; on which the coffer ſunk to the bottom; and if it did not ſet level, the ſluice was ſhut, and the water pumpt out, ſo as to make it float till ſuch time as the foundation was levelled; then the maſons crampt the ſtones of the firſt courſe and laid a ſecond, which being likewiſe crampt, a third courſe was laid: than the ſluice being opened again, proper care was taken that the coffer ſhould ſettle in its due place. The ſtone-work being thus raiſed to within two feet of the common low-water mark, about two hours before low water the ſluice was ſhut, and the water pumpt out ſo far as that the maſons could lay the next courſe of ſtone, which they continued to do till the water was riſen ſo high as to make it unſafe to proceed any farther; then they left off the work, and opened the ſluice to let in the water; thus they continued to work night and day at low-water, till they had carried their work ſome feet higher than the low-water mark; after this the ſides of the coffer were looſened from the bottom, which made tham float, and then were carried aſhore to be fixed to another bottom, in order to ſerve for the next pier.

It muſt be obſerved, that the coffer being no higher than 16 feet, which is equal to the greateſt depth of water, and the foundation being 6 feet under the bed of the river; the coffer was therefore 6 feet under water when the tide was in; but being loaded with three courſes of ſtones, and well ſecured with ropes faſtened

to

to the piles, it could not move from its place. By making it no higher much labour and expence were saved, yet it answered the intent full as well as if it had been high enough to reach above the highest flood.

The pier being thus carried on above low-water mark, the masons finished the rest of it during the intervals of the tides in the usual way; and after all the piers and abutments were finished in a like manner, the arches were begun and compleated as mentioned before: the whole bridge was built in about seven years, without any accidents happening, either in the work or to the workmen, which is seldom the case in works of this nature.

It may be observed, that all the piers were built with solid *Portland* stone, some of them weighed four tons, the arch-stones were likewise of the same sort, but the rest of the masonry was finished with *Kentish rag-stones*; and the paths for foot passengers were paved with *Purbec*, which is the hardest stone to be had in this country, excepting *Plymouth* marble.

This method of building bridges is certainly the easiest and chapest that can be thought of, but cannot be used in many cases: when the foundation is so bad as not to be depended upon without being piled, or the depth of water is very great, with a strong current and no tide, I do not see how it can then be practised. For if piles are to be used, it will be next to impossible to cut them off in the same level five or six feet below the bed of the river, notwithstanding that saws have been invented for that purpose; because, if they are cut off separately it will be a hard matter to do it so nicely that the one shall not exceed the other in height, and if this is not done, the grating or bottom of the coffer will not be equally supported, whereby the foundation becomes precarious: neither can they be cut off all together; for piles are to be driven as far as the bottom of the coffer extends, which at *Westminster* bridge was 27 feet; the saw must have three feet play, which makes the total length

length of the ſaw 30 feet; now if either the water is deeper than it is there, or the arches are wider, the ſaw muſt ſtill be longer; ſo that I leave the reader to judge whether this method be practicable or not, in any ſuch like caſes.

In a great depth of water that has a ſtrong current and no tide, the coffers muſt reach above the water, which makes them very expenſive, and unweildy to manage, as well as very difficult to be ſecured in their places, and kept ſteddy: ſo that there is no probability of uſing them in ſuch a caſe.

In ſome caſes when there is a great depth of water, and the bed of the river is tolerably level, or can be made ſo by any contrivance, a very ſtronge frame of timber about four times as large as the baſe of the piers may be let down with ſtones upon it round the edges to make it ſink: after fixing it level, piles muſt be driven about it to keep it in its place; and then the foundation may be laid in coffers as before, which are to be kept ſteddy by means of ropes tied to the piles.

This method has frequently been uſed in *Ruſſia*, as I have been aſſured by a gentleman who has ſeen it. Though the bed of the river is not very ſolid, yet ſuch a grate, when once well ſettled with the weight of the pier upon it, will be as firm as if piles had been driven under the foundation; but to prevent the water from gulling under the foundation and to ſecure it againſt all accidents, a row of dove-tail piles muſt be driven quite round the grating; this precaution being taken, the foundation will be as ſecure as any that can be made.

The *French* engineers make uſe of another method in raiſing the foundations of maſonry under water; which is, to drive a row of piles round the intended place, nearer to, or farther from each other, according as the water is more deep or ſhallow; theſe piles, being ſtrongly bound together in ſeveral placed with horizontal tie-beams, ſerve to ſupport a row of dove-tail piles driven

driven within them; when this is done, and all well secured according to the nature of the situation and circumstances, they dig the foundation by means of a machine with scoops, invented for that purpose, until they come to a solid bed of gravel or clay; or if the bed of the river is of a soft consistence to a great depth, it is dug only to about 6 feet, and a grate of timber is laid upon it, which is well secured with piles driven into the opposite corners of each square, not minding whether they exceed the upper surface of the grate much or little.

When the foundation is thus prepared, they make a kind of mortar called *beton*, which consists of twelve parts of pozolano or *dutch* terrass, six of good sand, nine of unslaked lime the best that can be had, thirteen of stone splinters not exceeding the bigness of an egg, and three parts of tile-dust, or cinders, or else scales of iron out of a forge: this being well worked together must be left standing for about 24 hours, or till it becomes so hard as not be separated without a pick-ax.

This mortar being thus prepared, they throw into the coffer a bed of rubble stone not very large, and spread them all over the bottom as nearly level as they can; then they sink a box full of this hard mortar, broken into pieces, till it comes within a little of the bottom; the box is so contrived as to be overset or turned upside down at any depth; which being done, the pieces of mortar soften and so fill up the vacant spaces between the stones; by these means they sink as much of it as will form a bed of about twelve inches deep all over: then they throw in another bed of stone, and continue alternately to throw one of mortar and one of stone till the work approaches near the surface of the water, where it is levelled, and then the rest is finished with stones in the usual manner.

Mr. *Belidor* says, in the second part of his hydraulics, vol. ii. pag. 188, that Mr. *Melet de Montville* having filled

filled a coffer containing 27 cubic feet, with masonry made of this mortar, and sunk it into the sea, it was there left standing for two months, and when it was taken out again, it was harder then stone itself. Where such mortar can be made, this method has certainly the advantage over all the others, not only in building the piers of bridges over deep rivers, but likewise in making piers for harbours, and in all other aquatic works; but before it is made use of, I would advise the engineer to make first a trial of his mortar; since works of this nature are of too great consequence to be carried on without an absolute certainty of success.

We have hitherto mentioned such situations only where the ground is of a soft nature; but where it is rocky and uneven all the former methods prove ineffectual; nor indeed has there yet been any one proposed that I know of, which might be used upon such an occasion, especially in a great depth of water; but as an engineer ought to know how to proceed upon all occasions, we shall therefore mention some few observations under this head. When the water is not so deep but that the unevenness of the rock can be perceived by the eye, piles strongly shod with iron may be raised and let fall down by means of a machine, upon the higher parts, so as to break them off piece by piece, till the foundation is tolerably even, especially when the rock is not very hard; which being done either this or any other way that can be thought of, a coffer is made without any bottom, which is let down and well secured, so as not to move from its place; to make it sink, heavy stones should be fixed on the outside; then strong mortar and stones must be thrown into it; and if the foundation is once brought to a level, large hewn stones may be let down so as to lie flat and even; by these means the work may be carried on quite up to the surface of the water.

But when the water is so deep, or the rock so hard as not to be levelled, the foundation must be founded,

so

so as to get nearly the risings and fallings; then the lower part of the coffer must be cut nearly in the same manner, and the rest finished as before. It must however be observed, that we suppose a possibility of sinking a coffer, but where this cannot be done, no method that I know of will answer; and therefore I leave it to the judgment and knowledge of the engineer employed upon such an occasion, in what manner he is to proceed.

Among the aquatic buildings of the ancients none appear to have been more magnificent than *Trajan's* bridge. *Dion Cassius* gives the following account of it: "*Trajan* built a bridge over the *Danube*, which in "truth one cannot sufficiently admire; for though all "the works of *Trajan* are very magnificent, yet this "far exceeds all the others: The piers were 20 in "number, of square stone; each of them 150 feet high "above the foundation, 60 feet in breadth, and distant "from one another 170 feet. Though the expence of "this work must have been exceeding great, yet it be- "comes more extraordinary by the river's being very "rapid, and its bottom of a soft nature: where the "bridge was built, was the narrowest part of the river "thereabout, for in most others it is double or treble "this breadth; and although on this account it became "so much the deeper and the more rapid, yet no other "place was so suitable for this undertaking. The "arches were afterwards broken down by *Adrian*; but "the piers are still remaining, which seem as it were "to testify, that there is nothing which human inge- "nuity is not able to effect." The whole length then of this bridge was 1590 yards; some authors add, that it was built in one summer, and that *Apollodorus* of *Damascus* was the architect, who left behind him a description of this great work. It is a great loss to the world that his description has not come down to us, since it would have shewn both how these works were carried on formerly

formerly and how far modern builders are inferior to the antients.

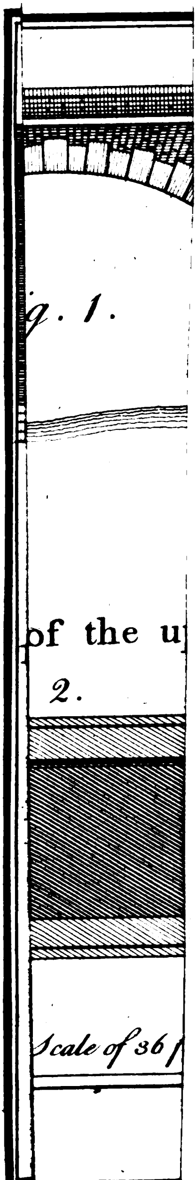
SECT. II.

Of Harbours.

THE making and inclofing harbours with piers, fo as to refift the wind and waves for the prefervation of fhips in ftormy weather, is one of the moft ufeful and neceffary works that can be made in a trading nation, fince the fecurity of their wealth and power depends greatly upon it; for many fhips have been caft away, and the lives of many people loft, for want of a fecure harbour, which might have been faved for a moderate fum of money, had it been properly applied.

Though engineers are not generally employed here in *England* in fuch kind of works, yet it is properly their bufinefs; this may perhaps rather be owing to their want of fkill in them to any thing elfe: but fince fortreffes are generally built near the fea or navigable rivers for the fecurity of trade, and this cannot be fecured without building fafe harbours; therefore it ought to be the particular ftudy of every young engineer, who is defirous of being ufeful to his country, or of diftinguifhing himfelf, to make himfelf mafter of this branch of bufinefs.

As it feldom happens that fuch works are carried on at home, he fhould attentively examine thofe harbours already executed, both at home and abroad, and take notice of their figure, fituation, entrance, wind and tide, whether the fhips can go in with fafety in foul weather, and out when favourable; whether it would have been better if the entrance had been made elfewhere; whether the piers are ftrong and folid, or want often to be repaired, and in general whether the harbour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harbour anſwers in every reſpect the intention for which it was built.

He ought to get information from the inhabitants, workmen, or the builder himſelf, if he is alive; to know the reaſons for making it of that figure, why the entrance is placed in that ſituation, how the foundations were laid, what accidents happened, how long it was in building, what number of hands were employed, and what the expences have been.

Having thus examined as many harbours as he could conveniently ſee, and having made himſelf acquainted with the manner of their building, he will be able to judge, when a new one is propoſed, whether the ſituation is proper or not, and how it may be executed in the beſt and ſecureſt manner, together with what the expences would nearly come to.

But before a young engineer enters upon practice, he ſhould have a proper knowledge of the mathematics, eſpecially of that part which treats of the mechanical powers and hydraulics, in order to know in what manner engines are conſtructed and applied to the ſeveral uſes they are intended for; this he may obtain by conſulting thoſe authors who have written upon them, and by examining the engines themſelves, to ſee if they anſwer the intention, or whether they might not be improved; or elſe, if others could not be invented of a different form, which would be more ſimple, and more expeditious.

In order to aſſiſt beginners, we ſhall ſet down here the principal enquiries to be made before a harbour is executed, the manner of laying the foundation, and how the works are to be carried on moſt ſecurely, in the plaineſt and eaſieſt manner that we could think of, and which has been approved of by moſt authors who have treated of this ſubject.

The firſt thing to be conſidered is the ſituation, which may be ſome large creek or baſon of water, in or near the place were the harbour is intended to be made, or at the entrance of a large river, or near the sea; for a harbour ſhould never be dug entirely out of dry land, unleſs upon ſome extraordinary occaſions, where it is impoſſible to do otherwiſe, and yet a harbour is abſolutely neceſſary; when a proper place is found, before it is fixed upon, it muſt be conſidered whether ſhips can lie there ſafe in ſtormy weather, eſpecially when thoſe winds blow which are moſt dangerous upon that coaſt; whether there be any hills, riſing ground, or high buildings that will cover it; in theſe caſes the ſituation is very proper; but if there be nothing already that will cover the ſhips, it muſt be obſerved whether any covering can be made at a moderate expence, otherwiſe it would be uſeleſs to build a harbour there.

The next thing to be conſidered is, whether there be a ſufficient depth of water for large ſhips to enter with ſafety, and lie there without touching the ground, and if not, whether the entrance and inſide might not be made deeper at a moderate expence; or in caſe a ſufficient depth of water is not to be had for large ſhips, whether the harbour would not be uſeful for ſmall merchantmen; for ſuch a one is often of great advantage when ſituated upon a coaſt much frequented by ſmall coaſting veſſels.

The place where the entrance is to be made ought to be well conſidered; it ought to be ſuch that the ſhips may enter in foul weather and go out when fair: for though ſhips may enter when in diſtreſs, yet if they cannot go out when the wind is fair to purſue their voyage and not to loſe their market; ſuch a harbour would not anſwer the end for which it was deſigned.

It is therefore neceſſary to conſider well the current, tide, and winds, as alſo the banks of ſand near about it; and to conſult the maſters of ſhips as well as the pilots who live thereabout, or freqnent the coaſts: they are better judges where the entrance ſhould be than any body elſe; but if it ſhould happen that they are divided in in their opinions, as it often is the caſe; it will be prudent not to determine the ſituation of the entrance till part of the piers are built, and ſufficient obſervations made, where it will be moſt convenient.

When a ſituation has been found that has all or moſt of theſe requiſite advantages, an enquiry is to be made concerning the materials to be uſed in building the piers, where they are to be had; if upon the ſpot, near at hand; or when at a diſtance, whether they are to be brought by land or water carriage, or partly one way and partly the other; their prime coſt muſt be known, the expence for bringing them to the ſpot, the time required, and the expence of the workmanſhip to make them ready for uſe.

All theſe preparative enquiries being made, the form or figure of the harbour muſt be determined in ſuch a manner that the ſhips which come in when it is ſtormy weather may lay ſafe, and ſo as there may be ſufficient room for as many as paſs that way: the depths of water where the piers are to be built, muſt be taken at every ten, fifteen, or twenty feet diſtance, and marked upon piles driven here and there, in order that the workmen may be directed in laying the foundation.

This being done, it muſt be conſidered what kind of materials are to be uſed, whether ſtone, brick, or wood: when ſtones are to be had at any moderate price, they ought to be preferred, becauſe the work will be much ſtronger, more laſting, and need fewer repairs than if made with any other materials: but when ſtones are ſcarce, and the expence becomes greater than what is allowed for building the harbour, the foundation may be made of ſtone as high as low-water mark, and the reſt finiſhed with brick. If this manner of building ſhould ſtill be too expenſive, wood muſt be uſed; that is, piles are driven as cloſe as is thought neceſſary, which being faſtened together by croſs-bars, and covered with ſtrong oaken planks, form a kind of coffer, which is filled with all kinds of ſtones, chalk, and ſhingles, as will be explained more at large hereafter.

The materials being fixed upon, an eſtimate is made of the expences; the number of hands to be employed at a time is determined, ſo as they may conveniently work without interfering with one another; and from thence it may be nearly computed what time will be required for compleating the whole work.

The manner of laying the foundation in different depths of water, and in various ſoils, requires particular methods to be followed: when the water is very deep, the *French* throw in a great quantity of ſtones at random, ſo as to form a much larger baſe than would be required upon dry land; this they continue to within 3 or 4 feet of the ſurface of the water, where they lay the ſtones in a regular manner, till the foundation is raiſed above the water; they then lay a great weight of ſtones upon it, and let it ſtand during the winter to ſettle, as likewiſe to ſee whether it is firm, and reſiſts the force of the waves and winds; after that they finiſh the ſuper-ſtructure with large ſtones in the uſual manner.

As this method requires a great quantity of ſtones, it can be practiſed but in a few places, where ſtones are in plenty; and therefore the following one is much preferable. A coffer is made with dove-tail piles of about 30 yards long, and as wide as the thickneſs of the foundation is to be; then the ground is dug and levelled in the manner deſcribed in the laſt ſection; and the wall is built with Beton mortar, as has been deſcribed in the ſame ſection.

As ſoon as the mortar is tolerably dry, thoſe piles at the end of the wall are drawn out, the ſide rows are continued to about 30 yards farther, and the end incloſed; then the foundation is cleared, and the ſtones laid as before. But it muſt be obſerved, that the end of the foundation finiſhed is left rough, in order that the part next to it may incorporate with it in a proper manner; but if it is not very dry it will incline that way

way of itſelf, and bind with the mortar that is thrown in next to it; this method is continued till the whole pier is entirely finiſhed.

It muſt likewiſe be obſerved, that the piers are not made of one contiued ſolid wall; becauſe in deep water it would be too expenſive; for which reaſon, two walls are built parallel to each other, and the interval between them is filled up with ſhingle, chalk, and ſtone: As theſe walls are in danger of being thruſt out or overſet, by the corps in the middle, together with the great weight laid at times on the pier, they are tied or bound together by croſs-walls at every 30 or 40 yards diſtance, by which they will ſupport each other in a firm and ſtrong manner. For want of theſe croſs-walls it has happened, not many years ago, that the walls of a work were overſet for the ſpace of ſome hundred yards.

If ſuch mortar can be made as what the *French* call Beton, there can ſcarcely be found a better method than that above for laying foundations in deep water, and it may be uſed upon all occaſions; but as ſuch mortar is not every where to be had without great expences, I imagine that common terraſs mortar, mixt with ſmall ſtones, and ſome cinders if to be had, will anſwer the purpoſe as well; but the engineer, who is to carry on the work, ought to make trial of it before he uſes it.

If the foundation be bad to a great depth, I would ſink it only about 4 feet below the bed of the river; and lay a ſtrong grate of timber, as in thoſe of the piers of a bridge; but if it ſhould be rocky, a coffer muſt be made without a bottom, and the under part cut nearly with the ſame riſings and fallings, according to the manner mentioned in the laſt ſection.

In a country where there is a great plenty of ſtones, piles may be driven in as deep as they will go, at about two or three feet diſtance, and when the foundation is ſunk and levelled, large ſtones may be let down, which will bed themſelves; but care muſt be taken to lay them cloſe, and ſo as to have no two joints over each other; and when the wall is come within reach, the ſtones muſt be crampt together.

Another method practiſed, is to build in coffers much after the ſame manner as has been done in building the piers of *Weſtminſter-bridge*; but as in this caſe the ends of the coffers are left in the wall, and prevent their joining ſo well as to be water-tight, the water that penetrates through and enters into the corps, may occaſion the wall to burſt and to tumble down. Another inconveniency ariſing from this manner of building is, that as there are but few places without worms, which will deſtroy wood wherever they can find it, by their means the water is let into the pier, and conſequently makes the work liable to the ſame accident as has been mentioned above.

To prevent the incoveniencies of this method, I would take the wood away, and joggle the ends of the walls together with large ſtones, and pour terraſs mortar into the joints; when this is done, the water between the two walls may be pumpt out, and the void ſpace filled up with ſtone and ſhingle as uſual: or if theſe joggles cannot be made water-tight, ſome dovetail piles muſt be driven at each end as cloſe to the wall as can be done, and a ſtrong ſail-cloth put on the outſide of them, which, when the water is pumpt out, will ſtick ſo cloſe to the piles and wall, that no water can come in. This method is commonly uſed in *Ruſſia*, as I have been informed.

Plate XXV. In order to underſtand clearly the method of building piers, we have given the plan and ſection of one of the walls, in the firſt figure, ſuch as had been propoſed for incloſing a harbour, upon a chalky foundation: the water is but 6 feet high when loweſt, and riſes to 24 when the tide is in. The manner propoſed for building the piers, was to dig the foundation about two feet deep, which is ſufficient for ſuch a ground, a ground, and to ſink large blocks of ſtone of about 3 feet high, which could have eaſily been crampt together at 3 or 4 feet under water; then to lay another courſe of large ſtones over the firſt, and to cramp them as before; the ſame thing was to be done, till the wall was carried about two feet above low-water mark: or if this method of laying the foundation was not approved of, to lay it in coffers in the manner mentioned above.

It was ſaid, that the funds allowed for building the harbour were not ſufficient to make the piers entirely of ſtone; for which reaſon, the reſt was to have been continued with hard bricks, ſuch as are called clinkers, to about 8 feet high; then a courſe of ſtones was to be laid of a foot high and crampt together; after this bricks were to be laid again to the ſame height as before, and then another courſe of ſtone; this was to have been continued quite up to the entire completion of the pier.

The ſtone foundation being 8 feet high, that is, from two feet under the bed of the water to low-water mark; and from thence to the top being 23 feet; therefore the inſide wall is five feet higher than high-water mark; and as the outſide wall has a parapet of 5 feet high, and 3 or 4 thick; this wall is ten feet higher than the water when the tide is in; which height was thought neceſſary, in order to cover the people ſtanding there, from the water, becauſe the waves riſe very high in that place, at certain times of the year.

The walls were to be 28 feet diſtant from each other, five feet thick above, and the baſe of the ſlope one fifth of the height; which would have made the thickneſs of the piers 34 feet above, beſides the parapet, which takes up 4, and 50 near the bottom of the water. At every 30 feet diſtance was to be made a croſs or tie-wall, of three feet thick, to bind the two walls together; this diſtance may be greater near the ſhore, where the waves have not ſo great a force as farther from it; and to ſave trouble as well as expences, theſe croſs-walls were to be built with low arches upon piers of four feet long, beginning at low-water mark, as may be ſeen in the plan and ſection.

The thickneſs of a pier depends on two conſiderations; it ought to be both ſuch as may be able to reſiſt the ſhock of the waves in ſtormy weather, and alſo to be of a ſufficient breadth above, that ſhips may be laden or unladen whenever it is thought neceſſary. Now becauſe the ſpecific gravity of ſea-water is about one half that of brick, and as 2 to 5 in compariſon of ſtone, and ſince the preſſure of ſtagnated water againſt any ſurface is equal to the weight of a priſm of water whoſe altitude is the length of that ſurface, and whoſe baſe is a right angled iſoſceles triangle, each of the equal ſides being equal to the depth of the water, therefore a pier built with bricks, whoſe thickneſs is equal to the depth of the water, will weigh about four times as much as the preſſure of water againſt it: and one of ſtone of the ſame breadth about 6 times and a quarter as much. Now this is not the force to be conſidered, ſince this preſſure is the ſame within as without the pier; but it is that force with which the waves ſtrike againſt the piers, and that depends on the weight and velocity of the waves, which can hardly be determined; becauſe they vary according to the different depths of water, the diſtance from the ſhore, and according to the tides, winds, and other cauſes. Conſequently the proper thickneſs of the piers cannot be determined by any other means than by experience.

Practitioners ſuppoſe, that if the thickneſs of a pier is equal to the depth of the water, it is ſufficient; but for a greater ſecurity they allow 2, 3, or 4 feet more; this might probably do, if piers were built with ſolid ſtones crampt together; but as this is hardly ever the caſe, and on the contrary, as the inſide is filled up with ſhingle, chalk, or other looſe materials, their rule is not to be depended upon: beſides it makes the ſpace

ſpace above too narrow, for lading and unlading the ſhips, unleſs in a great depth of water; ſo that it does not appear that their method can be followed excepting in a very few caſes where the water has but very little motion.

The reader will eaſily perceive, that the plan and ſection repreſented in this plate, may ſerve for a pier built either of all ſtone or brick, or elſe with both mixt together; by obſerving only to make the walls ſomething ſtronger when they are made with bricks, than when of ſtone. When ſtone can be had, no other materials ſhould be uſed, becauſe they being of a larger bulk than brick, will reſiſt better the waves by their own weight, till ſuch time as the mortar is grown hard; for after this is effected, brick will reſiſt better againſt the action of ſea-water than ſoft ſtones.

The wall muſt be built with terraſs mortar from the bottom to the height of low-water mark, and the reſt finiſhed with cinder or tile-duſt mortar, which has been found ſufficiently good in thoſe places where the wall is wet and dry alternately. The upper part of the pier ſhould be paved with flat hewn ſtones laid in ſtrong mortar, in order to prevent any water from penetrating into the pier: iron rings ought alſo to be fixed here and there at proper diſtances, to faſten the ſhips, and prevent them from ſtriking againſt the pier when agitated by the waves.

At the mouth of the harbour the piers ſhould be terminated with plat-forms, or forts, to place guns there, in order to defend the entrance, in caſe of neceſſity. Sometimes piers are built ſo large as to place ſtore-houſes upon them, eſpecially in ſea-port towns, where fleets are fitted out: this has been done at *Toulon*, about the harbour of the royal navy, whereby the ſhips are covered from the wind, as well as from being ſeen from without; ſo that a fleet may be fitted out in a private manner.

Wooden

Wooden fenders or piles ſhould be driven at the inſide cloſe to the wall, and crampt to it with iron, to prevent the ſhips from touching them, and from being worn by their continual motion. Where the ſea breaks againſt the piers with great violence, breakers ſhould be made at proper diſtances; that is, two rows of piles are driven nearly at right angles to the piers for the length of about 12 or 15 feet, and at about 8 or 10 feet diſtant from each other; and then another to join the two former; theſe piles being covered with planks, and the inſide being filled with ſhingle and rubble-ſtones, then the top is paved with ſtones of about a foot in length, ſet long-ways to prevent the waves from tearing them up. This precaution is abſolutely neceſſary where the water ruſhes in very ſtrongly.

The ſection repreſented here, contains 1035.6 cubic feet of maſonry, for every foot in length, and 834 cubic feet of rubbiſh or ſhingle to fill up the inſide; ſo that knowing the length of the piers, and the price of the materials and workmanſhip, the whole expence for building the piers will be eaſily known; barring accidents, which unavoidably will happen in all works of this kind, and for which the *French* generally allow one ſixth part of the expences computed.

When it happens that ſtones are not to be had, without great expence, or the importance of the harbour is not much; then piers are built with timber, ſuch as that at *Dover*, and in many other places. The plan and ſection repreſented by the ſecond figure may in ſuch a caſe be aptly applied; the breadth above of the ſection is 30 feet, the baſe of the ſlope of the outward piles one ſixth part of the height, which is here the ſame as in the former ſection, that is, 29 or 30 feet: the piles are about 14 inches ſquare, the croſs-beams *a* from 10 to 12, and the tie-beams *b*, 8 by 10. Theſe frames are from 12 to 15 feet diſtant from each other, and three piles are to be driven between them, as may be ſeen by the plan; there are beſides two rows of ſhort piles on each

each side of the pier, five feet distant from the long ones; and which reach no higher than low-water mark.

The reason for driving these short piles is, that being always under water they will not decay, and nothing will hurt them, excepting worms; so that when the long ones, which are exposed to wet and dry, are decayed, the foundation remains sound and firm; by which means it will be easy to repair that part of the pier above low-water mark, whenever there is any occasion for it. And to secure the foundation still better, dove-tail piles of about 6 inches thick, are to be driven all round, and strongly fastened together with timbers, one above to receive the heads, and others on the outside.

The sides of the piers are to be covered with good oaken planks of about 4 or 5 inches thick, fastened to the tie-beams *b*, with wooden trunnels; or else, these planks may be placed on the inside of the tie-beams *b*, which, in my opinion, is better, because the pressure of the shingle and rubble-stones with which the inside of the pier is filled, will not be able to loosen the planks, as it might do, when they are fastened on the outside.

It is said, that when the planks are fastened on the inside, they cannot be easily repaired when there is occasion for it; but this objection is inconsiderable, in respect to the advantage arising from this position; for the rotten plank being taken away, a new one may easily be slipped into it's place, between the tie-beams *b*, and the shingle: and if they cannot be fastened with wooden trunnels, it may be done with iron nails. The planks must reach about 4 feet above the upper surface of the pier, and be secured with proper timbers, so as to form a kind of parapet on each side, in order to prevent the people, standing there, from being wetted by the waves in stormy weather.

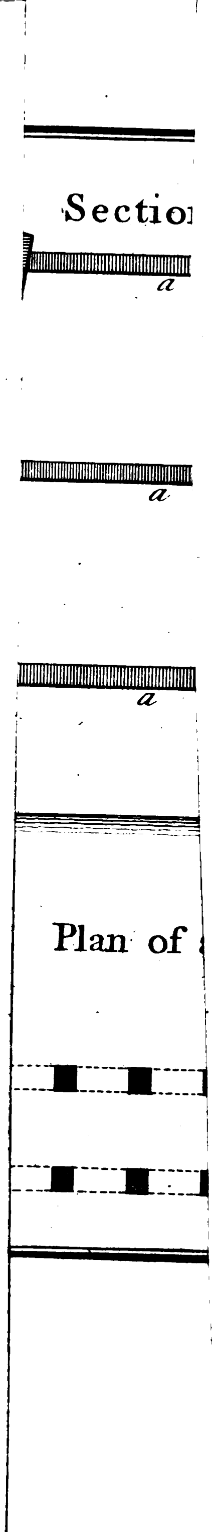
This frame is the most simple, and the most natural that we could think of; and yet as strong, in my opinion, as can be desired to resist the action of the waves let them be ever so great: it is true, that most of the workmen

workmen will think it insufficient, as having no braces, of which they are so fond, that they think no work well secured without them; but as I do not esteem them necessary, I have omitted them here.

In those wooden piers I have seen, there was no base made with short piles, such as are represented in the second figure; for the long piles reached from top to the bottom, and no dovetail piles were driven to secure the foundation, as far as I could find; but since such works ought to be made in the most secure manner, and so as not to want continual repairing; I would advise the directors of them, to consider well the nature of the situation, as well as the importance of the harbour, before they form a scheme for building the piers.

What has been said here in regard to the building of piers for harbours will equally serve for that of quays, and all other works made in water; it must only be observed, that as quays are often loaded with very great weights, the wall must be made much stronger than those of ramparts, which support the pressure of earth only. But to give some rule whereby the reader may be directed, I imagine that, if the thickness be treble that of the wall of a rampart of the same height, it will be sufficient: thus if the height of the quay be 10 feet, and the base of the slope one sixth of the height; by trebling the height 1.5 feet, found in table the first for the thickness above of a wall of the same height, we get 4.5 feet for the thickness above of the said wall. To secure these walls yet better, piles are driven on the inside about 20 feet distant from the wall, and about 15 feet from each other; the heads of which are tenoned into a beam, and others laid across are let into this beam at one end, and at the other going through the wall are fixed to the fenders on the outside with iron straps bolted into these beams.

SECT.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SECT. III.

Of SLUICES *and* AQUEDUCTS.

SLUICES are made for various purposes; such as to make rivers navigable; to join one river to another, which is higher or lower, by means of a canal; to rise inundations upon particular occasions, or to drain spots of ground that are overflown by high tides: they are also made in fortresses, to keep up the water in one part of the ditches whilst the other is dry; and to raise an inundation about the place when there is any apprehension of being attacked.

Sluices are made different ways, according to the uses they are intended for; when they serve for navigation, they are shut with two gates presenting an angle towards the stream: when they are made near the sea two pair of gates are made, the one to keep the water out and the other in, according as occasion requires; in this case, the gates towards the sea present an angle that way, and the others the contrary way; the space inclosed by these gates is called *Chamber*.

When sluices are made in the ditches of a fortress to keep up the water in some parts, instead of gates, shutters are made, so as to slide up and down in grooves; and when they are made to raise an inundation, they are then shut by means of square timbers let down into *cullises*, so as to lie close and firm.

Particular care must be taken in the building of a sluice, to lay the foundation in the securest manner that is possible; to lay the timber grates and floors in such a manner that the weather cannot penetrate through any part, otherwise it will undermine the work, and blow it up, as it has sometimes happened: Lastly, to make the gates of a proper strength, in order to support

port the preſſure of the water, and yet to uſe no more timber than what is neceſſary.

As a general conſtruction is much preferable to particular ones, we ſhall follow the example of Mr. *Belidor*, who is the firſt that gave one for ſluices; but before this can be done, it is neceſſary to know its width, and the depth of water it is to contain, and from thence the dimenſions of the ſeveral parts are determined, as will be ſhewn hereafter.

When ſluices are made in a canal, or navigable river, their width will be known from the ſize of the veſſels that are to paſs through them, as well as the depth of water they require; when they are made in a fortreſs to pen up the water in one part, and to keep the other dry, their width is determined by the quantity of water that is to paſs through them in a certain time: When they are near the ſea, or a river where there is a tide, and they are to keep up the water at a certain height, their width and depth are alſo determined from the nature of the ſituation; and in general, the width and depth of a ſluice is always known from its ſituation, and the uſe it is intended for.

This being premiſed, we ſhall give a general conſtruction of a great ſluice with two pair of gates, in ſuch a manner as to be applicable to any particular caſe, provided a proper allowance be made for the various circumſtances that may happen, in regard to their uſe and ſituations, which may change ſome of the parts, as ſhall be mentioned in its proper place.

To conſtruct the PLAN *of a* SLUICE.

Plate XXVI. Suppoſe half the width OC to be divided into ſix equal parts, or the whole into twelve; theſe parts ſerve for a ſcale, whereby the dimenſions of the work are determined: through the point O, draw the line AB at right angles to OC; take OB on one ſide of the point O equal to 30 of theſe parts, or, which is the ſame, equal to two widths and a quarter; through the points A, B, draw the lines A R, B S at right angles to A B; let the lines passing through the point C, and parallel to A B, meet these last lines in M, Q; then if M N, P Q be taken each equal to 9 parts, and each of the lines M R, Q S equal to six, the lines N R and P S will determine the wings of the sluice, and N P the body. If the lines A R, B S be produced so as the parts R V, S T are each 6; they will determine the faces.

The part B O of the length exceeds the other part O A by one fourth of the width, because we suppose a turning bridge is to be placed on that side for a communication from one side of the sluice to the other; but when there is no occasion for such a bridge, O B is made no longer than O A; and then the total length will be but four times and a half the width, which is esteemed by Mr. *Belidor* the best length that can be given to a great sluice.

To determine the chamber and the position of the gates, take O D, O L, each equal to four parts, and draw the lines D G, L H parallel to O C; then if the lines G K, H I be drawn so as to make the angles D G K, L H I, each of 35 degrees, and 16 minutes, that position will be the best that can be given, by art. 566 of our *Elements of Mathematics*; or, because a linear construction is preferable to that by angles, the position of the lines G K, H I, is determined in the same manner as the line A E in fig. 7, plate the fifth, page 90, of this work.

The cavities *z*, *y*, are a foot each way in large sluices, and but 9 inches in middling ones; they serve for letting down square timbers to form a batardeau on each side, in case the gates or floor want to be repaired.

The recesses G *a*, H *b* in the wall, are made to receive the gates when open, and are of such a depth that they may be flush with the wall, and not make that part narrower than the rest of the sluice.

The

The thickneſs of the wall from N to P is equal to four fifths of the depth of water, the parts R N R, P S, three fifths, and at V, T two fifths. The counterfort W, is determined by producing the lines L H, D G, and projects beyond the wall by one fourth of the width of the ſluice.

Observations *on the* Construction.

As we differ in ſome parts of our conſtruction from that given by Mr. *Belidor*, it will not be improper to acquaint the reader with the reaſons that have induced us to do ſo. *Firſt*, We made the length L D, equal to 8 parts inſtead of 7, to avoid a ſubdiviſion of parts; the difference of one part being immaterial. 2. According to our conſtruction, the length G K of the gates comes out to be 7.34 parts nearly; and as Mr. *Belidor* makes the lines D K one fifth of the width, the length of his gates is 6.46 parts nearly; but as our conſtruction gives the moſt advantageous poſition, and that of Mr. *Belidor's* depends on no ſubſtantial reaſons, we imagine that the diſpoſition here given is preferable to his: It is true, he has endeavoured to prove that his poſition is that which the gates ought to have, but all his reaſoning is grounded upon wrong ſuppoſitions; beſides, as the length of our gates does not differ above 38 inches in the largeſt ſluice that is made, from the length he gives, we imagine that this difference is more than recompenced by the true poſition. 3. Mr. *Belidor* makes the lines M R, Q S, 7 parts inſtead of 4, which difference is very little.

As to the thickneſs of the ſide-walls, Mr. *Belidor* makes it equal to the depth of water in the ſluice, in order, as he ſays, that they may be ſo ſtrong as to reſiſt in all accidents that can happen; beſides, he adds five counterforts on each ſide; their length is equal to the thickneſs of the wall, and the mean thickneſs five eighths of their length.

It

It is certain, that in constructing such works as these, particular care should be taken to make them strong and durable; yet it ought to be considered, that by making use of more masonry than is necessary, it encreases the expences considerably, and therefore all excesses should be avoided.

Now the proper thickness of these walls may be determined in the same manner as that of those which support earth, by comparing the specific gravity of water to that of stone or brick; but it must be observed, that the triangular section of water has its base at the bottom instead of being above, as in the section of earth: by this method it will be found, that if the thickness of a stone wall be four fifths of the depth of the water, as we have made it, it will be able to support a pressure four times greater than that of the water; which in my opinion is sufficient upon all occasions whatsoever: but when the wall is made of brick, its thickness must be equal to the depth of water, in order to have the same strength.

Hence it will be found, that the quantity of masonry contained in a sluice, according to our construction, is to the quantity, according to Mr. *Belidor's*, as 542 to 723, or as 3 to 4 nearly; therefore, if one one fourth of the masonry can be saved, as it appears by what has been said, without making the walls too weak, the method we propose has greatly the advantage of that given by Mr. *Belidor*.

It may be observed, that the walls have been supposed to have no slope; but in practice they have, or ought to have one on the outside, and as there is likewise the pressure of the earth, which helps to support the wall; by these means its resistance is still greater than we have supposed it to be.

It must also be observed, that as the width of the sluice is divided into as many parts as there are inches in a foot; each part will be as many in inches as the width is feet; so that when the width of a sluice is given in feet, the value of each part is known; thus if the ſluice is to be 42 feet wide, each part will be 42 inches, or 3 feet 6 inches, and ſo in any other caſe.

When a ſluice is built in a place where a great quantity of water is to paſs, two or more paſſages are to be made; that is, two or more ſluices are built at the ſide of each other; theſe paſſages have ſometimes the ſame width, and at others not, according to the circumſtances that render them more uſeful one way than another.

Whence in a ſluice that ſerves to form an inundation, or to keep up water, theſe paſſages are made of an equal width; but in canals and large rivers that ſerve for navigation, the one is made ſo wide as that large veſſels may go through it, and the other ſerves for ſmaller veſſels. This has been done in the canal at *Mardick*, where the largeſt is 44 feet, and of conſequence wide enough for the ſecond rate of men of war to paſs through it, and the other is 24 feet, which ſerves for ſmaller veſſels.

Of the Timber-grates *under the* Floor *and* Foundation.

If the foundation be bad, we ſuppoſe piles to be driven under the croſſings of the ſleepers *m*, and the tie-beams *n*, in the manner mentioned in the ſeventh ſection of the third part; and to prevent the water from getting under the foundation, ſix rows of dovetail piles are driven, *viz.* one at each end, one at each of the angles N, P, marked *p*, and one on each ſide of the chamber; and it muſt be obſerved, that, excepting thoſe at the angles E, P, the reſt are all driven between two ſleepers, in order to keep them tight and cloſe together. The ſleepers and tie-beams are partly let into each other, and bolted together; but before this is done, the looſe earth is removed from between the ſleepers for about two or three feet deep, and filled up with maſonry

sonry before the tie-beams are laid: this masonry is carried on so, as that when a bed of mortar is laid over it, it may be even with the upper surface of the sleepers; then the inside of the sluice is covered with a floor of three inch thick oaken planks, laid long-ways, and nailed to the sleepers; this floor extends a few inches on each side over the foundation of the side-walls, to prevent the water from penetrating through the edges of the floor.

Bricks are used preferably to small stones, to fill up the parts between the grating, as lying much closer, and filling up every part exactly; they are laid in terrass mortar as well as the rest of the foundation. This being done, the frames made to support the gates at the bottom, are laid in their proper places, which are composed of a sell *r*, two hurters *s*, two braces *v*, and a tong *t*. The sell enters about three feet into the side-walls, and the sockets to receive the pivots of the gates are placed in it; the tong ought to be so long as to cross three sleepers, to which it is fastened in a strong manner. The sell, tong, and the hurters, ought to have the same dimensions, and their height must be such as to be a foot above the last floor of the sluice, as well as the floor of the chamber; for which reason, the piles under the chamber are left a foot higher than the rest.

After this another row of sleepers is laid exactly over the first, and a row of tie-beams, so as to answer likewise those underneath; which being let into one another, and bolted together as before, and the vacancies between them being filled up with masonry, and a bed of mortar laid over it, so as to be even with the upper surface of the sleepers; then a second floor is laid, of the same dimensions and extent with the former; and when this is done, the side walls are built in the manner which will be mentioned presently.

Upon the second floor is laid another of two inch thick planks only, which does not enter the wall, in order that it may be repaired when it is wanted. This laſt floor may be made of yellow deal, and its ſeams muſt be well caulked to prevent the water from penetrating through them.

The walls muſt be made about three feet higher than the greateſt depth of water, to prevent the waves from paſſing over them: the facings are made with the largeſt ſtretchers and headers that can be had, laid in terraſs mortar, and crampt together; the reſt of the work is done with good common mortar.

The foundation muſt be made larger than the wall, and in proportion to the weight it is to ſupport, and the top muſt be covered with large flat ſtones or bricks ſet long-ways laid in terraſs mortar, to prevent the water from penetrating into the maſonry, which otherwiſe would deſtroy it in a ſhort time.

When the wall is finiſhed, a bed of clay is rammed againſt it of two feet thick all round the outſide, beginning as low as the foundation, and raiſed as high as the wall.

To prevent the water from carrying off the earth by its fall, at the ends of the ſluice a falſe floor of faſcines is made of as many fathoms long as the water in the ſluice is feet high; this bed or falſe floor is ſunk into the ground as far as is found neceſſary; but firſt of all a bed of clay is laid, and well rammed, then beds of faſcines are laid long-ways, and faſtened with pickets; when the faſcines are nearly level with the floor of the ſluice, pickets are driven acroſs in rows three feet diſtant from each other, reaching a little above the faſcines, and about eaeh row two branches or poles are twiſted of about an inch diameter, ſo as to croſs each other between the pickets, which being beat down with a mallet, will keep the faſcines very cloſe and tight together; the cavities between theſe rows of pickets and branches are filled up with a pavement of hard ſtones a foot long, ſet long-ways, well beat down, ſo as the current may not tear them open.

For

For a greater security, a row of dove-tail piles is driven at each end; and it may be observed, that both floors must have a gradual descent from the chamber of about a 48th part of the length, in order that the water may run off clear, when the sluice is laid dry and any repairs are wanted to be made.

Aqueducts are sometimes made in the side-walls going round the chamber, and coming out before the gates, in order that the water may pass upon occasion from one side of the sluice to the other, without being obliged to open the gates; they have a shutter near each end, that slides in grooves, which are drawn up, or let down, when there is occasion for it. But as wickets are commonly made in the gates, which may serve for the same purpose, unless on some occasion where the chamber is required to be left dry, and yet it is absolutely necessary that the water should pass from one side to the other; we have therefore not marked them in the plan, but they may easily be made whenever it is thought proper.

The cross-section shews the position of a row of piles, and the sleepers above them into which they are tenoned; the sections of the tie-beams; the floor between them; the sell, and the two floors above it; there is also seen a row of dove-tail piles, broken off in the middle, in order to see part of the masonry *a*, *a*, between the piles and under the sleepers. The outside of the grates are likewise seen in this section; how the planks are joined to the frame; the shutters *x*, *x*, and the irons both of the gate and shutters. In the construction of gates, particular care should be taken, to join the several pieces together in such a manner, that the whole frame may be as strong as possible, and not to make them heavier than needs must be, to prevent their sinking, which is not easily done in large sluices; nor yet too weak, for fear of their not being able to sustain the great pressure which is against them.

The principal frame of a grate consists of two stiles or uprights; that which is next to the wall and to which the pivots are fixed, is called the pivot-post, and the other the chamfered stile, from being edged off on the inside, so as to make a plain joint with the other gate: these two stiles are joined by two rails which are tenoned into them. The other pieces, which are not seen in this section, but serve to strengthen the gate, consists of several rails placed not nearer to each other than 24 inches, nor farther than 30; and of several braces which form the same angle with the pivot-post as the joints of the planks on the outside, and they are tenoned into the rails; lastly, of two monions or short uprights to form the wickets.

As it is too nice a calculation to find the proper strength of each piece in such a manner as may be depended upon in practice, we shall give their dimensions, such as are inserted in Mr. *Belidor's* works, and which, he says, have been taken from those most approved of in practice.

The pieces of the principal frame are generally made of the same dimensions, though some will have the chamfered-stile less than the pivot-post, and the rails to diminish gradually; and others say that the gates should be stronger below than above, on account that the pressure of the water is the greatest there; but as the gates are supported below by the hurters, that diminition ought rather to begin at about one third of the height distant from the bottom. However, we shall suppose the pieces of the principal frame to be of the same dimensions, which are as follows. In all sluices from 8 to 12 feet wide, the pieces of the principal frames are to be 8 inches thick, and 10 broad; the intermediate rails 6 by 8; the braces and monions 4 by 6; and the whole covered with two-inch thick planks as well as all the gates of sluices under 37 feet wide.

In sluices which are from 13 to 18 feet wide, the pieces of the pricipal frame are to be 10 by 12 inches; the intermediate rails 8 by 10; the braces and monions

4 by

4 by 6. In ſluices from 19 to 24 feet wide, the pieces of the principal frame are to be 12 by 14 inches; the intermediate rails 10 by 12; the braces and monions 5 by 7. In ſluices from 25 to 30 feet wide; the pieces of the principal frame are to be 14 by 16; the intermediate rails 12 by 13; the braces and monions 6 by 8. In ſluices from 31 to 36 feet wide; the pieces of the principal frame are to be 15 by 17 inches; the intermediate rails 13 by 14; the braces and monions 7 by 9. It muſt be obſerved, that when the gates are very high, the middle rail is made of the ſame dimenſions as thoſe in the principal frame.

In all ſluices from 37 to 42 feet wide, the pieces of the pricipal frame are to be 16 by 18 inches; the intermediate rails 14 by 16; the braces and monions 7 by 9; and covered by planks of two inches and a half thick; or rather with two rows of planks of that thickneſs, in order that the ſeams of the under row may be covered by the upper one. Laſtly, in all ſluices which are from 42 to 48 feet wide, the pieces of the principal frame are to be 18 by 20 inches; the intermediate rails 15 by 18; the braces and monions 8 by 10; covered by planks of two inches and a half thick as before.

It may be obſerved, that theſe dimenſions depend on the width of the ſluice only; the depth of the water has not been conſidered, though it ſhould have been done; ſince the greater that depth is, the preſſure is likewiſe the greater, when the reſt is the ſame; conſequently the dimenſions here given muſt be increaſed in great depths, and diminiſhed in ſmall ones.

As to the number and ſtrength of the irons in the gates of a ſluice, they ought to be in proportion to the largeneſs and weight of the frame; the principal ones in ſmall ſluices are reduced to two ſtraps, which ſerve to bind the under and upper rails to the pivot-poſt, which they embrace on both ſides; they are let into the wood, ſo as to be even with the ſurface of the gate, and faſtened with 5 or 6 iron bolts riveted with burrs, or with rings and keys; the length of these straps ought to be about one third of the width of the gate. Sometimes the chamfered-stile is bound to the rails above and below, with strait straps like the former, but oftener with bent ones, such as are represented in the section, one on each side, bolted together in the same manner as the former.

When the gates belong to a large sluice which contains a great depth of water, the middle rail is likewise bound to the pivot-post, and the chamfered-stile by two straps in the form of a T, both within and without, bolted together as before; and when the gates are very large, two straps are used to fasten the upper rail to the pivot-post, because the greatest stress lies in that part; and to secure it still more, another strap is bolted upon the edge of the upper rail, and bent against the pivot-post; this last strap is of grater use to keep the gate from sinking than any other, for which reason, it is seldom omitted, whether the gates be small or large.

The various contrivances that are made to open and shut the gates, require some notice to be taken of them; but as in so small a work as this, it is not possible to give a compleat description of every particular part; they therefore must be left to the sagacity and prudence of the builder. It must be observed that as the wickets are made to let the water into the chamber before the gates are opened, in order to ease them from the great pressure of the water on the outside; there seems to be no reason for placing them so low, nor so far from the pivot post as is commonly done; for provided they are low enough to let in so much water as will rise to the same level within as it is without, it will be sufficient; consequently the lower part of the wickets should never be below the middle height of the water without, whereby the weight of the irons will be diminished. And the nearer the wickets are to the pivot-posts, the less the pressure would be upon the gates, when the wickets are to be opened; besides, all possible

means

means should be used, to lighten the farther end of the gates, to prevent their sinking, which they will do nevertheless, especially when they are large: this however may be remedied, by placing brass-casters under them, at above two thirds of their width from the pivot-post; but then a piece of timber must be placed upon the floor, of a circular form, for the roller or caster to move upon.

Sometimes the gates of large sluices are made in the form of a part of a cylindric surface, whose base is a twelfth part of a circle; this is done in view to strengthen the gates against the pressure of the water; in such a case the curve of the rails must be natural, and according to the grain of the wood, otherwise the gates will become weaker instead of being stronger; since a scantling cut across the grain of the wood will always be weaker than any other of the same dimensions, and the same kind of timber.

Various methods are used to shut sluices under twenty four feet wide: in sluices from ten to fifteen feet wide, a single gate is made, which is sometimes opened by means of a capstane; at others the upper rail of the gate is made so as to go beyond the pivot-post, and from thence made much thicker and heavier, to be a kind of a counter-balance to the gate; the end of which being pressed downwards by several people, and then turned round, opens the gate easily.

Sometimes single gates are used of a much larger size than the former; these gates have their pivot-post nearly in the middle; so that the largest part of it turns towards the stream when the gate is to be opened, and the least the contrary way. The pivot-post must be placed in such a manner, that the pressure of the water against the largest part may keep the gate shut close, and at the same time that there may not be too great difficulty to open it. It has been found by experience that when the pressure against the largest part exceeds that against the lesser by one sixth part, it is sufficient;

whence

whence it is easily proved from the known principles of hydrostatics, that if the width of the smallest part is to the width of the largest, in the proportion of 12 to 13, it will answer the said proportion of the pressure.

These gates are certainly the most convenient that can be; but as there must be laid a strong timber across the sluice to support the upper pivot, no vessels that have masts can pass through them; for which reason, they cannot be used but in sluices that serve to keep up the water for raising an inundation, or in those that are built at the entrance of a canal, which runs into a harbour, for the sake of clearing and carrying away the sand and shingle that have been driven in by the tides.

Wickets have been made in this manner, and found very convenient; because the great pressure of the water against the common sort, makes their opening very troublesome; whereas this sort are opened and shut with great ease, and very little labour.

Sometimes sluices are made in fortresses at the side of stone-bridges; this is done by making the piers to project beyond the bridge, and in the projected part cullises are contrived so as to let down square timbers, which being kept close and tight, the water may be raised to any height: in short, many other sorts of sluices are made upon various occasions, which it would be inconvenient to mention in this work.

Of AQUEDUCTS.

The intent of aqueducts is generally to bring water from a spring or river to a town, but they are likewise used to carry canals over low ground, and over brooks or small rivers: they are built with arches like a bridge, only not so wide, and are covered above by an arch to prevent dust or dirt from being thrown into the water. The ancient *Romans* were remarkably curious in these sorts of works, for they not only supplied all the parts of *Rome* with water for common uses, but likewise for a great number of public baths; and that nothing might be be wanting, created a public magistrate, whose only business was to take care of them, either to repair those already made, or to construct new ones where they were wanted; sometimes the same work served for both a bridge and aqueduct; then the water was led through two covered canals, one on each side of the road, for carriages.

As these kinds of aqueducts differ very little in their construction from common bridges, of which we have treated before, we shall not enter into any paticulars here concerning them; but when a canal is to pass through a country crossed by rivers, it must be observed how high, in respect to the bottom of the canal, the water rises at the time of its greatest flood, in order to know whether these waters can be carried under the bottom of the canal by means of aqueducts, and have yet a sufficient declivity to run off.

The same thing is to be observed in regard to those arising from the rains and the melting of the snows, which when led into a ditch made along the highest side of the canal, may from thence be carried off to the other side underneath the canal: These waters should never be carried into the canal, unless it be impracticable to do otherwise.

It requires great precaution, as well as circumspection, in determining the place of aqueducts, so as to give them sufficient room when they have but one passage, which is to be widened at the entrance, and at the outlet in a proper manner: if there is not a sufficient depth to construct one of such a bigness, as the quantity of water that is to pass requires, two or more passages must be made at the side of each other, to prevent an inundation, that otherwise might ensue; but it must be observed, to make them in such a manner as to be easily cleared from the sand and mud deposited there by the water, for want of its having a sufficient velocity.

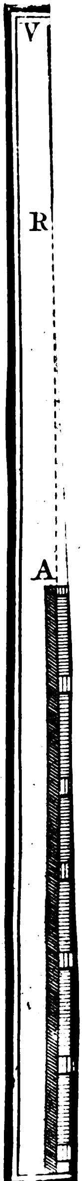
Therefore,

Therefore, when the water on both sides is nearly level with that in the canal, it must be avoided as much as possible, to make the aqueduct in the form of a syphon, in order to carry the waters under the bottom of the canal; but rather to let the water into the canal on the highest side, and out on the other, by means of small sluices with shutters.

When the waters are below the bed of the canal, it is carried over them by means of an aqueduct, in the form of a bridge with several arches, through which the water passes; there are many of this kind in the famous canal of *Languedoc*. In this case, after having determined the interval between the two abutments, according to the quantity of water that is to pass through the arches in the time of the greatest flood, and agreed on the number of arches, in respect to the width it is convenient they should have, so as not to multiply the number of piers without necessity, for fear of diminishing the passage of the water; in short, after having taken all the necessary precautions, in consequence of the level of the canal, to determine the height of the arches, and their thickness at the key-stone; then the parts between the arches are filled with good masonry to make the upper part level, and a bed of cement is laid all over, with the same care and manner as has been explained in the section where we have treated of under-ground arches, to prevent the water of the canal from penetrating through any part of the arches, which otherwise would destroy them in a short time, were this precaution not used.

The width of the aqueduct must be such, that the largest vessel used may pass conveniently; or if the canal is much frequented, it ought to be such, that two or more vessels may pass a-breast; and at the sides passages are also made for the horses which draw the vessels.

When the surface of the waters is nearly level with the bottom of the canal, the aqueduct must be lower in the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the middle than at the ends; in such a case, cess pools must be made on each side, of sufficient depth and breadth, so that the water may run in first there, to settle and deposite its mud, before it passes through the aqueduct; but this should never be done when it is possible to do otherwise, by placing the aqueduct either something higher up the canal, or lower down.

Besides those kinds of aqueducts we have mentioned already, there are others placed on the tops of hills, which serve as a reservoir for water to be from thence carried through pipes into gardens to make water-works for pleasure: and the water is brought into them, by means of pumps and other engines; the most famous one of this sort, in *Europe*, is that at *Marly*; and as it is admired by all travellers that have seen it, the reader will perhaps be pleased with a description of it, which we have made upon the spot, in company with some other gentlemen.

The length of this famous aqueduct is 400 yards, and supported by 36 arches; its greatest height is 82 feet, and lowest 75 feet, so that the slope of the canal is about 7 feet from the highest part to the lowest; the width of the arches is 8 yards, and the height of the highest 52 feet, the breadth of the piers is equal to the width of the arches, that is 8 yards, and their thickness 5 yards below reduced to 7 feet above, because the building has a slope on each side; the walls which inclose the canal of the water are each a foot and a half thick, and an arch goes over it; so the canal is about 4 feet wide, and about the same height in the middle.

This aqueduct is 500 *French* feet above the surface of the river *Seine*, and at 1220 yards distance from it: as this height is too great for a single set of pumps to force the water up at once, let them be ever so strong; it has therefore been divided nearly into three equal parts: the first set of pumps raises the water to a height of 150 feet, the next set, which is 300 yards distant from the river, raises it 175 feet, the third set, which is is 648 yards from the river, raiſes the water up to the aqueduct, that is 175 feet more.

From this aqueduct, two pipes of 18 inches diameter lead the water into a baſon at *Marly*, and from thence it goes to the ſeveral fountains in the garden; there is likewiſe another pipe of 8 inches diameter that leads the water from the aqueduct to *Verſailles*.

There are 253 pumps employed to force the water up to the aqueduct, and from the laſt ſet it is carried up by 6 pipes, each being 8 inches in diameter the quantity of water raiſed formerly in a day was 779 cubic fathoms, but at preſent, it raiſes ſcarcely above half that quantity; which may be owing to ſome decay in the machine, or neglect in its repair.

Notwithſtanding the wounderful contrivances of the author (one *Ranequin* of the country near *Liege*) in the diſpoſition of the ſeveral parts of this machine, yet many pretended judges find fault with it; though none of them are capable to invent a new one that can be compared to this; but it is cuſtomary amongſt the preſent virtuoſi, to find fault with the performances of their maſters, and think themſelves better ſkilled than thoſe they can barely imitate.

But amongſt the critics of this wounderful machine, I except Mr. *Belidor*, who has really ſhewn ſome defects in the bodies of the pumps, and at the ſame time, how they might be amended: and as he has given a full deſcription of it, together with proper plans and ſections, we refer the reader to his works for a full account of this machine, which we have only mentioned, as being partly connected with the aqueduct, the deſcription of which alone we propoſed to give here.

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