SHORING AND UNDERPINNING

C. Haden Stock

A TREATISE

ON

SHORING AND UNDERPINNING.

A TREATISE ON SHORING AND UNDERPINNING,

AND GENERALLY DEALING WITH RUINOUS AND DANGEROUS STRUCTURES.

BY

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WITH ILLUSTRATIONS.

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1882.

TO THE MEMORY

OF

THE LATE GEORGE EDMUND STREET, R.A.,

This Work

IS MOST RESPECTFULLY DEDICATED

BY

ONE WHO HAS EXPERIENCED THE VALUE OF HIS INSTRUCTION

AT THE ROYAL ACADEMY OF ARTS.

PREFACE.

The object which the author of the following treatise has in view is, as far as he can, to supply a want which has for some time been felt among the younger members of the architectural profession. It has been impossible hitherto, from the author's own experience, to get up the subject of shoring and underpinning, whether as a necessary part of the education of an architect, or for an examination, without a wearisome search in different libraries for the scraps of information on the subject, scattered about among the works of various authorities; and the difficulty of obtaining information in this way has also been considerably enhanced by the fact that two of the best authorities on the subject write in a foreign language. Consequently the student has been obliged, at a great sacrifice of time, to fall back upon the expedient of sketching and measuring existing cases; an admirable method in its way, but which would be more interesting and instructive (especially as what one most wishes to know is very often hidden out of sight) if some previous knowledge of the subject had been acquired. Accordingly the following pages comprise a careful collection of all the authorities, together with a few additional notes and sketches made from actual experience with the work.

The shoring and underpinning of the towers, columns, and arches of mediæval churches or other old buildings, which have succumbed after having served their purpose well for many years, is a subject too wide and complicated to be thoroughly investigated in a text book such as this; a few examples however are given in Chapter VI., and methods are described in which some one or two suppositional cases should be treated. Instances of this class are, however, comparatively rare, and so varied in their character, that each requires to be treated in its own peculiar way; and it is impossible to lay down any fixed rules, or to prescribe any definite methods by which shoring and underpinning may be successfully carried out in every case. But in the more general cases of shoring, such, for instance, as are met with every day in London or other large towns, where one house is so much like another in its purpose and construction, it *is* possible, more or less, to prescribe methods which will answer as well in one case as in another; and it is more the purpose of this book to explain *these* methods, and the rules involved in them, as they are more useful to the student, and come into the every-day practice of the majority of architects.

Shoring and underpinning, and dealing with ruinous and dangerous structures, is one of the subjects of which a knowledge is required in the new examination for admission into the Royal Institute of British Architects; and the author has consequently been careful to compile this treatise with a view, as far as possible, to enable a student to answer any question that may be set on this subject.

CECIL HADEN STOCK.

PARLIAMENT MANSIONS,
VICTORIA STREET, WESTMINSTER.

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LIST OF WORKS CONSULTED,

AND FROM WHICH LITERAL EXTRACTS HAVE IN SOME CASES BEEN MADE.

'Builder,' March 15th, 1861.

'Building News,' February 7th, 1873.

'Building News,' August 24th, 1877.

'Building News,' September 14th, 1877.

Burnell, on Limes, Cements, and Mortars.

Burnell, on the Operations carried out at Chichester and Bayeux Cathedrals. Trans. R.I.B.A. 1860–1862.

Dion et Lasvignes, Cathédrale de Bayeux.

Dobson, on Foundations.

Nash, on Failures in Construction. Trans. R.I.B.A., vol. 14.

Scott, on the Shoring of the Tower of St. Mary's, Stafford. Trans. R.I.B.A., 1860–1862.

Seddon, on the Shoring of Grosmont Church Tower. Trans. R.I.B.A., vol. 14.

Tredgold: Barlow's edition.

Tredgold: Hurst's edition.

Viollet-le-Duc: 'Dictionnaire de l'Architecture,' tome 5.

The author has also been greatly assisted by the kind co-operation of Messrs. J. and J. Greenwood, the contractors for the shoring executed by the Metropolitan Board of Works.

A TREATISE

ON

SHORING AND UNDERPINNING.

CHAPTER I.

INTRODUCTORY.

There is, perhaps, no place where the principles of Shoring and Underpinning ought more fully to be understood than poor London, founded upon treacherous clay, built of bricks, and abounding in ruinous buildings, where everything is done in such a desperate hurry that anything that comes to hand seems to be used as a building material by so many of our builders, with, no doubt, the reflection on their part, "At all events it will last our time." The delinquencies of the builder and the treachery of the soil are, however, evils which are common to most places; and the student in the art of shoring can hardly complain of a scarcity of examples to examine. In London, at all events, he has only to turn sharply round the corner of a street and he will run against a huge obstruction in the middle of the footpath, the feet and sole-piece of a system of raking shores. He will, doubtless, at once take out his note-book and rule, and jot down the scantlings and the position of the separate struts; but when he comes to examine how the whole system is wedged up, he finds that he is baffled by the sole-piece being so buried in clay and dirt that he can elicit no definite information from it. This is nearly always the case when work is examined without any previous acquaintance with its principles; and it is the desire of the author to instil into the mind of the reader a sufficient acquaintance with the principles and the terms used in shoring and underpinning, that he may afterwards with confidence perfect himself in the practical knowledge of the subject by sketching and measuring, and by questioning foremen engaged upon the work.

It is always necessary, in attempting to obtain information from a workman, to go well armed with terms; for as a rule he takes it for granted that you understand the phrases he uses, and vouchsafes no explanation concerning them. However, this is always the best way to gain practical knowledge upon anything: see the work begun and carried out to the end, go into its object, criticise it if possible, and consider whether, from your knowledge of the subject, it could not have been done better some other way. No student should be content with the knowledge he had gained simply by reading a book.

The mathematical investigation of the nature of the forces brought into play in the case of raking shores, though it can hardly be said to be absolutely necessary, is still well worth the attention of the reader; for it gives him an altogether superior grasp of the subject, and makes him feel competent to undertake the most difficult problem it can afford. The investigation of the nature of strains comes, of course, into many other of the studies of an architect, and the time spent in considering the proof of formulæ employed can never be said to be spent in vain. But, for the convenience of those who may not be acquainted with the science of trigonometry or statics, the theoretical has not been allowed to interfere too much with the practical side of the subject; and the mechanics of raking shores have been banished to a chapter by themselves at the end of the book, so that those who do not understand them need not trouble themselves to read them at all.

As there are now so many and varied subjects connected with our profession, making it almost an impossibility to gain a sufficient practical knowledge of all of them, there is every reason to believe that there will be in the future a demand for specialists: that is to say, an architect having on hand some work which has not before come much within the range of his practice, might be glad to consult with some other member of his profession who had made a special study of that one particular subject. And so, if any of the readers of this book feel that they have any inclination to make a special study of shoring and underpinning, and generally dealing with ruinous and dangerous structures, they will find it a pleasing and interesting pursuit, having an element of danger and excitement about it sometimes which gives it a superior charm over many other of the architect's duties.

When once the study and practice of shoring has been acquired, there will always be found, especially in London, ample scope for the specialist in this branch of the profession to exercise his ingenuity; for there is scarcely ever a house cleared away for the erection of a new building without its being necessary to shore up its neighbours on either side. And so this subject cannot be too well understood by all architects, for many accidents occur from the shoring being left to the rule-of-thumb of the foreman employed on the works, without any supervision by some more responsible person.

We shall now proceed to describe the different methods used in shoring and underpinning, taking first into our consideration the ordinary every-day cases to be met with in London and other brick-built towns.

PLATE, 1.

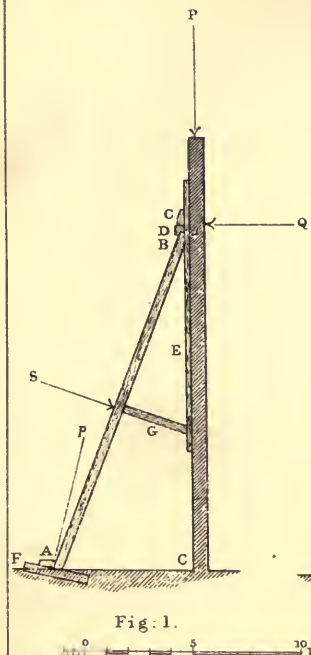


Fig: 1.

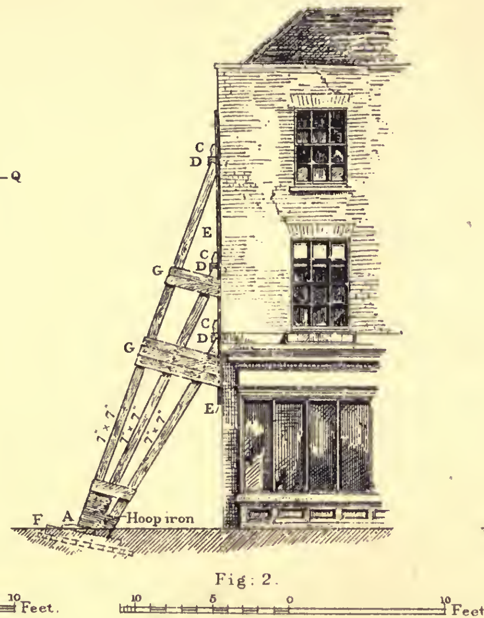


Fig: 2.

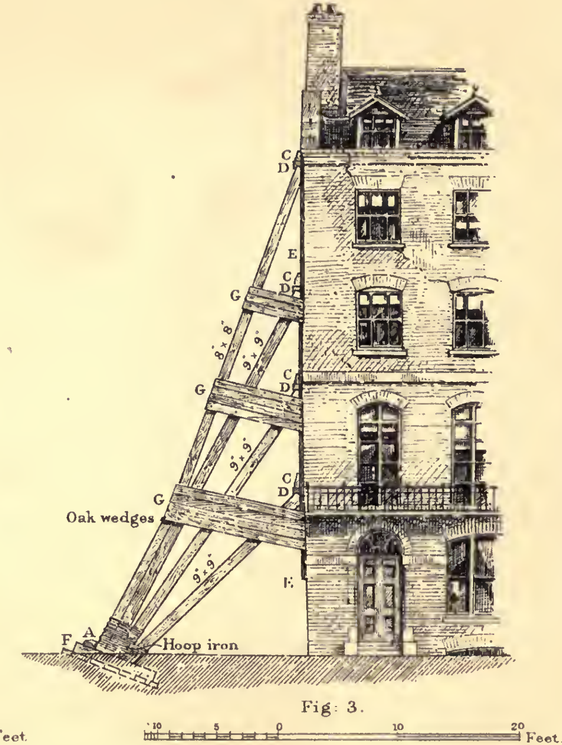


Fig: 3.

C. Haden Stock Inv et Del.

J Akerman Photo-lith, London W.C.

CHAPTER II.

ON RAKING SHORES.

We shall describe in this chapter only the ordinary use of raking shores, reserving the different varieties of this method to be considered by themselves in another chapter.

In Plate I., Fig. 1, there is depicted an example of the raking shore in its most simple form, i.e. with only one principal strut. Let us suppose it to be supporting a brick-wall, 9 inches thick and 20 feet high from the ground, A C; then A B is the principal strut, called a shore. E is a deal, called the wall-piece, 9 inches wide and 3 inches thick, and long enough to take the foot of the secondary strut G. In this wall-piece, about 2 feet from one end, a rectangular hole is cut and a small piece of wood D, called a needle, or by some workmen a tossle, or joggle, is inserted, projecting about $4\frac{1}{2}$ inches on either side of the deal. A half header is taken out of the wall near the top and the wall-piece placed in position, the needle fitting into the hole thus prepared. The other end of the needle, projecting beyond the face of the wall-piece, serves as an abutment to the head of the shore at B. For additional security a wedge-shaped piece of wood, C, called a cleat, is nailed on to the wall-piece just above the needle, and prevents it from being forced out of its place by the upward pressure of the shore AB. F is a balk of timber, called the footing block, or sole-piece, let into the ground, or if the ground be soft, laid upon a small platform of timber. A cleat is nailed upon the upper side of the sole-piece at A to prevent the foot of the shore from slipping. All these parts in connection with the shore will be taken more in detail further on in this chapter; at present let it suffice only to name them and describe their functions.

Now, the object of this shore is to prevent the wall from being turned over by the thrust caused by a house leaning against it. In considering the resistance to be offered to this thrust, though it may but seldom be the case, yet we must always be prepared for it at its greatest magnitude, and that will be when it is great enough to upset the wall. The direction of this thrust will of course be at right angles to the wall, and it will act at a point near the top, i.e. where the head of the shore presses against the wall, as shown by the line Q in the figure. Now, the most convenient way to overcome such a thrust, would be, of course, to place a strut at right angles to the wall, or in other words, in a line with the direction of this thrust Q (as in the case of a flying shore). But when this cannot be done a raking shore is necessary, and it is easy to see that as soon as the position of the strut is altered from a horizontal to an inclined position, a certain percentage of force is wasted in an endeavour to thrust up the wall; so, taking into consideration the fact that action and reaction are the same, there may be said to be two forces brought into play in the case of a raking shore, one the thrust (Q) of the wall, and the other a force, P, exercised vertically by the weight of the wall above D upon the head of the shore, tending to keep it down, in which the weight of the shore itself must be taken into account. These two forces, acting at right angles to each other at the point B, must have by the law of forces an equivalent single force acting in some direction between the angle of the directions of these two forces; and this force is called the resultant. Now, this resultant does not act down the direction of the shore itself, but in some direction which varies as there is more or less thrust, Q; and this direction is found by mathematics to be always outside the angle which the shore makes with the horizon, as the line *p* A; consequently the balk or sole-piece must not be put at right angles to the direction of the shore, but at an angle, as near as can be judged, at right angles to a mean of all the directions the resultant may take; and this will be, as near as possible, at right angles to the line *p* A.

Now in practice this truth is of the greatest convenience, for the foot of the shore, being gently levered along the sole-piece, is compressed tighter and tighter, and so the necessity of wedges is dispensed with entirely. In order to facilitate this operation of levering the shore into its place, a groove or slot is cut in the underside of the foot of the shore, large enough only for the carpenter to insert the end of a crowbar as a lever. (See Plate II., Fig. 6.) This is the method employed in most of the shoring executed for the Metropolitan Board of Works, and it may be considered the best; for, in dealing with structures that are really in danger of falling, the greatest care must be taken to avoid all blows with a hammer or mallet, such as are necessitated by the use of wedges at the foot of the shore.

From what has been said about the tendency of the shore to lift the wall, and the consequent reactionary force P, which keeps the head of the shore down, it is obvious that the needle must not be placed too near the top of the wall; for, unless there is sufficient weight upon its head, the shore will rise and burst up the courses above it.

There is yet another force brought to bear upon a raking shore which we must not forget to mention, and that is a cross strain, S, acting at right angles to the shore and tending to bend it inwards, the truth of which may be investigated in the chapter on the Mechanics of Raking Shores, at the end of the book. It is to counteract this cross strain that the secondary strut G is necessary, and in cases where three or four shores are combined in one system, as in Figs. 2 and 3, this strut answers the double purpose of counteracting the cross strain and binding the shores together.

Having now considered briefly the nature of the forces brought into play in the case of this single raking shore, and the practical lessons that they teach, it only remains to be said that where there are any number of shores in a system, each separate shore in that system is subjected to the same forces or strains as have been described in the case of Fig. 1. In fact, this figure may be considered as the outer shore in a system of two or more shores. It has been used here more for convenience of description than as a method to be adopted. As a general rule, two or more shores should be used in a system.

With regard to the scantlings of the timbers used in raking shores, as they are for the most part but temporary erections, builders generally use such timbers as they may have by them, which are too rough for better work. But in order to be quite sure that the timbers are strong enough to resist the utmost strain that can be put upon them, it is always as well to use the formulæ, which are appended, with an example, at the end of this chapter.

We will now go on to consider Fig. 2 in Plate I. This is the raking shore most commonly seen; it is simply a triple arrangement of that described in Fig. 1. The wall-piece is made much longer in consequence, and has three holes cut in it, and three needles inserted with their cleats nailed above each. The outer shore is called the top raker, the middle shore the middle raker, and the lowest is called the bottom shore. As the top raker of this system is a much longer shore than that shown in Fig. 1, it will be necessary to strengthen it with more than one secondary strut. This is done by nailing pieces of timber about 1 inch thick and from 6 inches to 9 inches wide on either side of the shores, as shown at G in Figs. 2 and 3. These braces are brought home against the wall and nailed to the sides of the wall-piece (which, if wider than the shores, is best notched out to receive them), and their position is generally just below the points where the needles enter the wall. As the bottom shore cannot conveniently have a secondary strut, it is generally tied up by a brace similar to those at G; this brace is also useful to bind the three shores together as they approach each other at their feet, and helps to render the whole a homogeneous system, incapable of turning about or warping when tried by the thrust of the wall. Hoop iron is also nailed round and round the feet of the shores, to prevent any possibility of their separating.

In Plate I. Fig. 3, we have a much larger and more complicated system of shores. It differs from the other in this respect, that the top raker or rider shore, as it is called in this case, instead of coming down to the ground as before, is made to spring from the back of the shore immediately below it. This is, of course, done because it would be impossible, except at considerable expense, to obtain so long a piece as would otherwise be required. In some cases the foot of this rider shore is made to rest upon a large cleat, nailed to the back of the shore below, but the best method is to let it rest upon another piece of timber of the same scantling, which, secured to the back of the shore below, goes down to the sole-piece, as shown in the Fig. 3. This rider shore may be of a smaller scantling than the others.

Now this plan, though it answers very well in a case like Fig. 3, should not be allowed in the case of Fig. 2 (unless there was great difficulty in obtaining a piece long enough for the top raker), for this reason, that the power of wood to resist compression is very much impaired by any cross strain that may be put upon it. But still, if in the case of Fig. 2 the house was really in imminent danger of falling, or was very much out of the perpendicular, it would not only be advisable, but even absolutely necessary, to keep the top raker in two pieces, and fix it as in Fig. 3, because the disturbance and blows upon the wall, which would be caused by the moving about and fixing so large and heavy a piece of timber, might result in bringing about what it is the object of the shores to prevent, viz. the total wreck of the house. But whenever the method of a rider shore is adopted, the shore below it must be made proportionately stronger, to enable it to resist the cross strain.

In these two cases—Figs. 2 and 3—the method described for Fig. 1 of levering the shores into their positions on the sole-piece is used; but if it is found impracticable to compress sufficiently the two middle rakers in this way, oak wedges can be used, care being taken to drive them home gently, the object being to support the wall, not to thrust it over. The rider shore, Fig. 3, is compressed by two oak wedges, gently driven home on either side of the foot where it meets the timber secured to the shore below, as shown in Plate II., Fig. 1. The system of shores which has only two struts is a very common one, its principles and construction being in every way similar to what we have already described.

The following paragraph may be taken, as a general rule, for the number of shores to be employed in each system and the scantlings that should be given to each :—

PLATE, II.

Fig: 1.

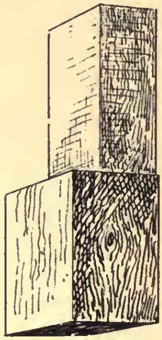


Fig: 2.

Fig: 3.

Fig: 4.

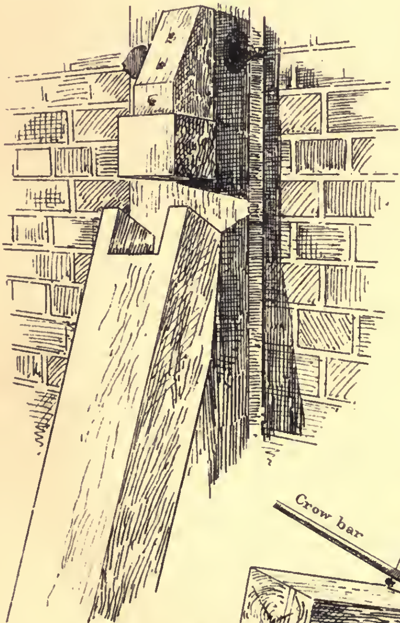


Fig: 5.

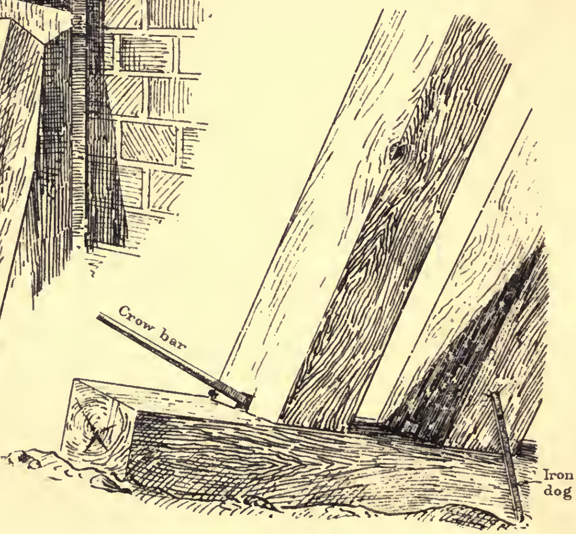


Fig: 6.

C. Haden Stock Inv. et Del.

J Akerman Photo-lith, London, W C

For walls from	15 ft. to 30 ft. high,	two shores are necessary in each system.	
Ditto	30 ft. to 40 ft. ,,	three	ditto.
Ditto	40 ft. and upwards,	four	ditto.

Taking the angle of the shore at 60° to 75°,

For walls from	15 ft. to 20 ft. high,	4 in. × 4 in., or 5 in. × 5 in., may be the scantling for each shore.	
Ditto	20 ft. to 30 ft. ,,	9 in. × 4½ in. or 6 in. × 6 in.	ditto.
Ditto	30 ft. to 35 ft. ,,	7 in. × 7 in. ,,	ditto.
Ditto	35 ft. to 40 ft. ,,	6 in. × 12 in., or 8 in. × 8 in.	ditto.
Ditto	40 ft. to 50 ft. ,,	9 in. × 9 in. ,,	ditto.
Ditto	50 ft. and upwards,	12 in. × 9 in. ,,	ditto.

The systems of shores should not if possible be more than from 12 feet to 15 feet apart; but if they are placed nearer to each other than this the scantlings may be made lighter, which will be of great advantage in the case of a really dangerous structure for the reasons mentioned above.

The general arrangement and construction of the raking shores which are most commonly used having been explained, it now remains only to say a few words with regard to their details. As these can best be explained by the figures on Plate II., it will be sufficient merely to refer to them, pointing out their uses.

The meaning of Fig. 1 has already been explained; the oak wedges, which compress the rider shore, have been driven home, and sawn to a neat appearance. Fig. 2 is the needle which in good shoring is made out of a piece of wood about 4 inches square and 1 foot long, cut down at one end to the size required to fit the hole made in the wall; a shoulder is thus formed to butt against the wall-piece, and a good strong abutment is afforded for the head of the shore. Fig. 5 is a sketch showing the needle in position in the wall-piece, with the cleat above it, and the manner in which the head of the shore is notched to fit the under side of the needle. This is a very necessary expedient; for the author has known an instance of the top raker in a system of shores, a long and heavy piece of timber, having been blown down by a sudden gust of wind —seriously injuring two workmen who were underneath it at the time—from the neglect to notch the head of the shore, or otherwise secure it in case of its becoming loose. Iron braces, as Fig. 3, called iron dogs, are sometimes used for this purpose, as also for securing the feet of the shores to the sole-piece, and the foot of the rider shore to the shore below it. It will be noticed that, in the sketch Fig. 5, the wall-piece is secured to the wall with iron hooks, a detail of which is shown in Fig. 4; these are convenient to hold it in position during the insertion of the needles and fixing of the shores. Fig. 6 shows the method of levering the feet of the shores along the sole-piece. A cleat should be nailed to the sole-piece against the foot of the outer shore, and the spaces between the shores, if they do not quite touch, should be filled in with a bit of stuff.

The greatest care must be taken that the sole-piece rests upon a firm foundation of solid ground, for the efficacy of the shore depends so much upon an unyielding base. It should first be ascertained that there are no cellars or vaults under the spot that the sole-piece is to occupy, and all made ground, soft clay, &c., should be avoided if possible; but if, as often happens, it is impossible to obtain a firm foundation without going to a considerable depth, the sole-piece must rest upon a carefully made platform of timbers, laid across each other, which will press equally upon the ground all over. This platform may be laid level, and the sole-piece raised to the required inclination by wedge-shaped pieces of oak fixed upon it; or it may be laid at once to the inclination of the sole-piece. In some cases, where great pressure is likely to come upon the shore, a good bed of concrete is prepared, and the platform which takes the sole-piece laid upon it.

When a space has been cleared away, and raking shores are erected to support the surrounding buildings, they must not be put up indiscriminately, without reference to the plans and sections of the new building which is to occupy the space; but care must be taken that they shall interfere with the building operations as little as possible. As the new building rises to the under side of the bottom shores, they are taken down, the middle and top rakes being left in position till they are reached in their turn. The foundation of the shores should be left untouched until all are taken down.

It is obvious that the more inclined the shore is with the horizon, the greater is the lateral thrust it will exert. An angle of 40° is considered to be the best inclination for raking shores; but there is very seldom room for so great a spread at the foot as this requires, and they are more often raised to an angle of 60° or 70°. But it should always be borne in mind that the more the shores are brought in at the feet, the less will be the lateral thrust they will exert against the wall.

Formulæ for determining the pressure brought to bear upon a raking shore by the house which it supports.

Referring back to the example (Plate I., Fig. 1), we have seen that there are two principal forces, P and Q, brought to bear upon the shore. Before we can determine what effect these two forces have in compressing the shore, we must first discover the magnitude of each of them separately.

To find the maximum horizontal thrust Q exercised upon the wall (Q being in cwts.), we must use the following formula:—

$$Q = \frac{W \times t}{2\,BC}, \quad \ldots \quad I.$$

Where W is the weight of the wall in cwts., t is the thickness of the wall at the ground line in feet or parts of a foot, and B C is the distance of the head of the shore from the ground, also in feet.

To find the vertical force P, to be expressed in cwts. :—

$$P = Q \tan. \theta^* - \frac{w}{2}, \quad . \quad . \quad . \quad . \quad \text{II.}$$

Where θ is the angle the shore makes with the horizon, and w is the weight of the shore itself in cwts.

Having found by the above formulæ the values of Q and P, we can now find the compression F down the shore which they produce, by the formula—

$$F = P \sin. \theta + Q \cos. \theta, \quad . \quad . \quad . \quad . \quad \text{III.}$$

where F is in cwts. and θ is the angle the shore makes with the horizon.

Now, taking the example in Plate I. Fig. 1, a wall 20 feet high, with a frontage of 10 feet, is supported by a raking shore of fir, 4 inches by 4 inches, the head of which B is 16 feet from the ground A C. The angle θ, or B A C, is 70°, and by referring to a table of natural sines, &c., we find that sin. θ is ·93969, cos. θ is ·34202, and tan. θ is 2·7474. Taking the wall at 1 cwt. per cubic foot, its weight W will be 150 cwt., and its thickness t is 9 inches, or $\frac{3}{4}$ of a foot. The weight w of the shore itself is $\frac{5}{8}$ cwt.

The value of Q is obtained from I.

$$Q = \frac{W \times t}{2\,BC} = \frac{150 \times \frac{3}{4}}{32} = \frac{112\frac{1}{2}}{32} = 3\tfrac{1}{2} \text{ cwt. approximately,}$$

i. e. the maximum horizontal thrust is $3\frac{1}{2}$ cwt.

The vertical pressure P is obtained from II.

$$P = Q \tan. \theta - \frac{w}{2} = 3\tfrac{1}{2} \times 2{\cdot}7474 - \tfrac{5}{16} = 9\tfrac{1}{4} \text{ cwt.}$$

The compression F down the shore is found from III.

$$F = P \sin. \theta + Q \cos. \theta = 9\tfrac{1}{4} \times {\cdot}93969 + 3\tfrac{1}{2} \times {\cdot}34202 = 9\tfrac{7}{8} \text{ cwt. approximately.}$$

i. e the shore as a post has to resist a pressure of $9\frac{7}{8}$ cwt.

* The reader, even if he has never before been acquainted with the trigonometrical symbols, sin., cos., tan., &c., need not be at all alarmed at their appearance here; for if we know how many degrees there are in the angle θ, we have only to refer to some table of natural sines, cosines, tangents, &c., and we shall find that the expression tan. θ is transformed into a convenient decimal. For instance, the shore A B in Pl. I. fig. 1 makes an angle of 70° with the horizon, A C. We look, say in Molesworth's 'Pocket-book of Engineering Formulæ,' for the tables of natural sines, &c., and we see that tan. 70° is 2·7474.

To find whether the shore is strong enough to resist this pressure, we must use the formula for a long, square post,

$$L = a \times \frac{d^4}{l^2},$$

where a is 15·5 for fir, d is the width in inches, and l is the length in feet; L being the safe load in cwts. that may be put upon it.

Very often, however, the breadth of a shore is double its width, i.e. the sides of the section bear a proportion to one another of $\frac{2}{1}$; consequently, as we get twice the resistance, we multiply L as found by the above formula (in which d in this case is the lesser side) by 2 for the safe load required.

When the section is 6 inches by 4 inches, for instance, the sides bear a proportion to one another of $\frac{6}{4}$ or $\frac{3}{2}$, consequently we multiply L as found by the above formula (in which d is the lesser side) by $\frac{3}{2}$ for the safe load required; and so for all scantlings.

It has, however, been found by experience to be always best to make shores of square timber. The shores erected by the Metropolitan Board of Works are generally of a square section, and timber of this kind can easily be obtained from 4 inches by 4 inches to 13 inches by 13 inches.

In the example before us the shore has a square section; then,

$$L = 15 \cdot 5 \times \tfrac{256}{289} = 13\tfrac{3}{4} \text{ cwt.}$$

i.e. the safe load which the shore will carry is slightly in excess of the compression F, to which it is actually subjected.

In this manner the top raker in a system of shores can be tested.

The compression down the middle raker and bottom shores can also be determined in the same way, a separate value of Q being worked out for each. It will be found that this compression increases as the shores are placed lower down the wall; but as the power of resistance in the lower shores is also considerably increased from their being so much shorter than the top raker, they will be quite strong enough if made of the same scantling.

PLATE, III.

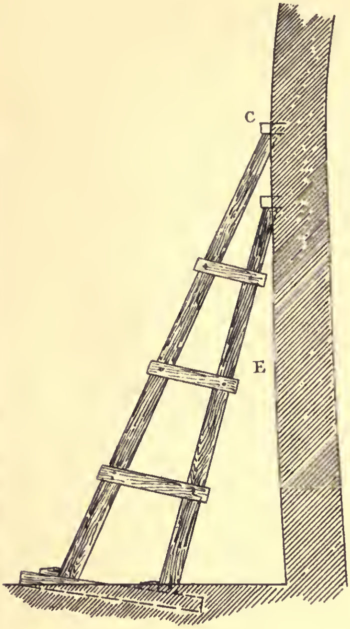


Fig: 1.

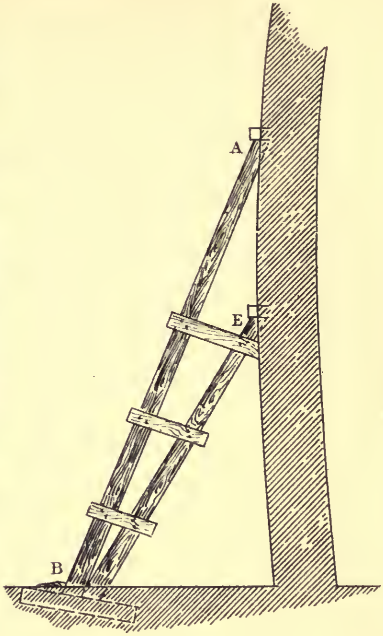


Fig: 2.

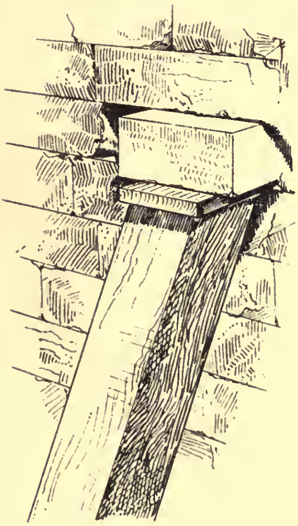


Fig. 3.

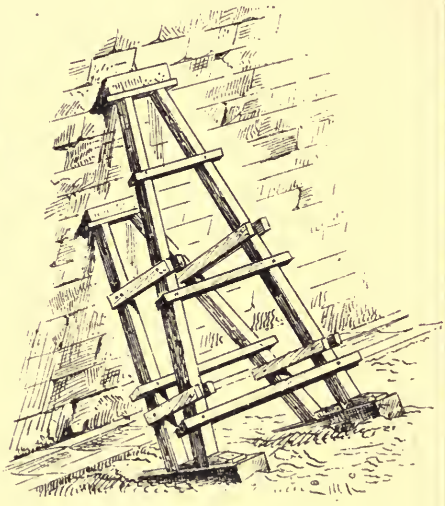


Fig. 4.

C. Haden Stock Del.

J. Akerman Photo-lith London, W.C.

CHAPTER III.

ON A FEW ADDITIONAL PRINCIPLES, VARIETIES, AND USES OF THE RAKING SHORE.

Though we but seldom see any other modifications of the raking shore than those which have already been described, yet there are certain cases which call for special adaptations of this system; and it is for the carpenter to prescribe that method in each case, which his skill suggests or his experience dictates. It would, of course, be needless to describe every variety and use of the raking shore; but the few additional remarks (for which, with the diagrams, the author is indebted to M. Viollet-le-Duc's article on Shoring), may possibly be useful.

It is usual in most cases, where more than one shore is used in a system, to spread them out at the top and bring them together at the foot; but this should not be done if there is a sharp bend in the wall, as at C in Plate III. Fig. 1, but the shores should be placed as is indicated in the figure, i. e. they should be farther apart at their feet than at their head. For (as it is necessary, in all cases where there is a prominent bend or rupture in a wall, that the head of the outer shore should rest exactly above the point where this bend or rupture occurs), if the usual method be adopted the head of the lower shore will act at the point E; but it will be dangerous to exert a horizontal pressure upon the wall at this point, for it will only tend to aggravate the rupture below the bend at C. But when a wall is bent in a uniform manner as in Fig. 2, the shores are best placed in the usual way, approaching together at the foot; for while the upper shore A B takes the load, the lower shore E B can exercise a more effectual resistance to the bend of the wall. Thus it is always best to employ more than one shore in a system.

Fig. 3 shows the way in which the head of a raking shore may be fixed in a masonry wall. A hard header of stone is built into a hole made in the wall, projecting beyond the face of the old work, and a piece of heart of oak is placed underneath it as a seating for the head of the shore.

When two or more shores are employed in a system they should never be parallel, but (to quote M. Viollet-le-Duc), " they should always form a triangle or a portion of a triangle, for this reason, that a triangle can never be thrown out of shape; when braced, shores which are not parallel present an entirely homogeneous resistance; whereas if they are parallel they will become bent however well braced they may be."

This truth may be extended further; and when two systems are combined in one, as is sometimes done when great strength is required, they should not be placed parallel to each other, but they should form a triangle on plan, as is shown in Fig. 4 in perspective. This kind of shore, if it is well braced, is exceedingly strong, and suitable to prevent the pressure of the earth from overturning a terrace wall.

It is often possible to make use of a raking shore, not only as a support, but also as a means whereby a wall may be pushed back again from a leaning to an upright position. An instance of this has come under the author's notice in the case of one of the walls of a large warehouse, which had gradually been pushed out of the perpendicular. The foundations were examined and found to be in a comparatively good condition, and the face of the wall, though out of the perpendicular, presented a uniform appearance, i. e. there were no serious bulges or cracks perceptible on its face; and consequently the idea of restoring its perpendicularity seemed possible to be put into execution, without any danger to the wall itself. Accordingly, raking shores were placed at intervals along the wall, and a powerful screw jack fitted under the sole-piece of each system; the connections of the quoins with the return walls were then cut away, and the roof and floors of the buildings, having first been propped up with posts and struts from the basement to the topmost story, were also cut off from all connection with the wall. A wedge-shaped fissure was next cut in the brickwork, at a point near the base of the wall on the internal face, and the space thus cut out was filled up with sand. The screw jacks were turned evenly and gently, and the wall, squeezing the sand out of the fissure, was gradually pushed back by the shores into its original position. The roof and floors were again firmly connected with the brickwork, the posts and shores taken down, and the whole then presented an appearance as strong and satisfactory as when it was first erected.

Another method used for bringing back into the perpendicular the two opposite walls of a building, which have been thrust outwards by a roof or vault, though it is perhaps hardly *à propos* here, may as well be mentioned. It consists in fixing bars of wrought iron across the building from one wall to the other, which pass through to the outside, and are then screwed to large nuts, or washers, placed against the external face of the walls. Fires are lighted under these bars, and as the metal expands the washers are screwed up as tightly as possible. The fires are then extinguished, and when the bars begin to cool, the force of their contraction gradually draws the walls together.

But to return to the raking shore, another of its many uses is to steady a wall whilst it is in process of being underpinned; these raking shores should be left in position for some time after the works have been carried out, so as to enable the wall to take its bearing upon the new work without danger of disruption.

The best wood in which all shores should be made is undoubtedly the fir, because its grain is always straight, and it can be obtained in long pieces. It is difficult to make good shores of oak, as it is generally of a middling length, has a twisted grain, and is heavy and more troublesome to lift in consequence. Oak ought to be used, however, in preference to all other woods for the wedges, seatings, &c., and even for the sole-piece (though this is seldom done), because its texture does not crush under the load like that of fir.

Care should be taken that the shore is thoroughly well put together, that all the joints are made to fit exactly, and that the foot of each strut has a perfect bearing upon the sole-piece. Nothing is more satisfactory than to see a shore well made, and those who design and construct in this art cannot help feeling, in such a case, a pang of regret when their handiwork is cleared away.

CHAPTER IV.

ON HORIZONTAL OR FLYING SHORES.

When a house is taken down in a street, and the party walls of its neighbours on either side require supporting, if the space between the two is not greater than about 32 feet or 33 feet, horizontal struts, reaching from one wall to the other, are employed; these are called flying shores.

In Plate IV., Fig. 1 is depicted the usual method of constructing these shores. Two wall-pieces E are provided and a rectangular hole cut in the centre of each for the insertion of the needles D, which rest in holes cut in the walls, just as has been described in the case of raking shores, a cleat C being nailed below them for additional security. The horizontal strut A B is compressed by oak wedges driven together above the needles D, and it is stiffened by the raking struts G, which butt against cleats C on the wall-pieces, and against straining pieces F, securely nailed to the top and under side of the horizontal strut A B.

It will be easy to see that by this method a very effectual resistance is offered to any inclination of the houses to fall in upon each other; but it will also be necessary, in most cases where flying shores are employed, to support the angles of the walls towards the street with raking shores, as shown at H in Fig. 1. Of the two houses, however, here represented, the one on the left hand is secure, and needs no shoring at all, having been built independently of the house that has been cleared away, or in other words, the return wall belongs to it exclusively, and has not been shared as a party wall by the house adjoining; consequently the flying shore has to resist the thrusts of the opposite house only. But when both are party walls it will be best to allow sufficient strength in the shore to resist the thrust of both the houses together; and it will also be necessary to support the angles of both the walls, both in the front and at the back, with raking shores.

The thrust exercised by the wall of the house on the right hand side in Fig. 1 may be found at any point in its height by the useful formula,

$$Q = \frac{W \times t}{2\,BC},$$

where Q is the thrust in cwts., W is the weight of the wall in cwts., t is the thickness of the wall at the ground in feet or

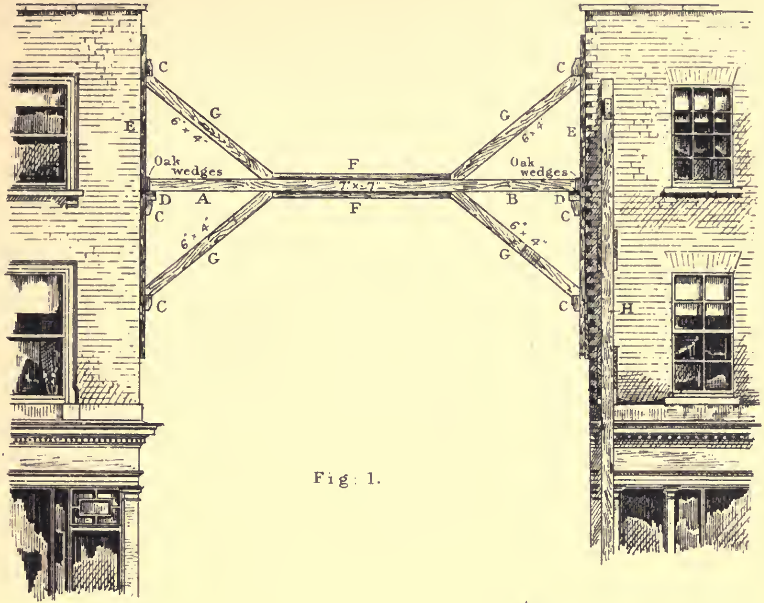


Fig: 1.

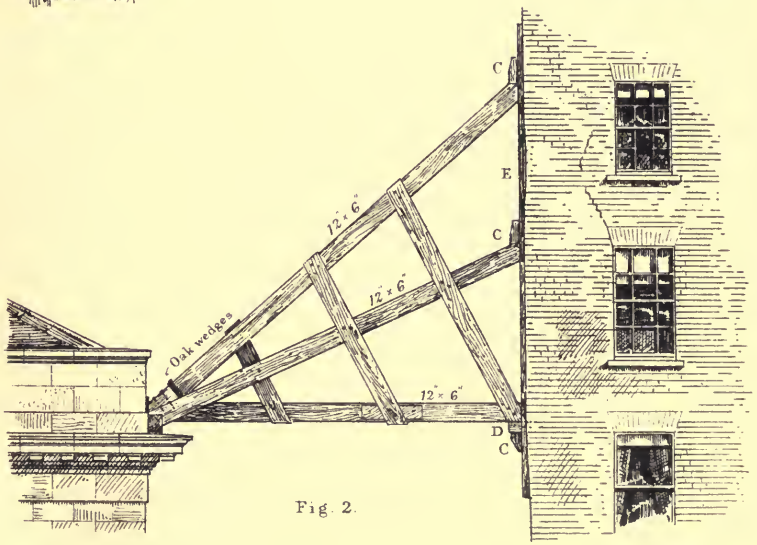


Fig. 2.

Scale of 10 5 0 10 Feet

C. Hadon Stock Inv. et Del.

J Akerman Photo-lith, London, W.C.

parts of a foot, and B C is the distance, in feet, from the ground to the point at which it is desired to ascertain the thrust.

It is obvious from the laws of leverage, that the best position for the shore to occupy is near the top of the wall, as shown in the figure; and by working out examples by the above formula, which is framed on the supposition that the wall is just falling, it will be found that the thrust will increase considerably as we come lower down the wall. Consequently, if from some inconvenience, the shore cannot be placed near the top of the wall, it must be made proportionately stronger the lower it is brought down. It is a common and a good practice to place two or more flying shores one above the other, in the same perpendicular plane, thus holding up the wall at every point in its height. In this case it is best if possible to have the wall-pieces in one length from the top to the bottom of the system. If the wall bulges at certain points, as in the figure, or if any projections occur upon its face, the wall-piece must be packed up behind with firring pieces, and so made to press equally against the wall at every point in its length.

The reason why the span of a flying shore was limited, apparently so dogmatically, at the commencement of this chapter, to 32 feet or 33 feet, is because ordinary Dantzic fir cannot easily be obtained in pieces of a greater length than this. Scarfing or joining two lengths into one is not a wise practice in shoring; for unless the scarf is executed with greater care than is warranted by the temporary character of the work, it is worse than useless. For it cannot be guaranteed that the horizontal strut will only be compressed in the direction of its axis, but the wall, if it leans forward uniformly, will make its thrust first felt down the upper raking struts, and so produce a cross strain upon the principal strut; and the power of the principal strut to resist this cross strain, even though it is stiffened by the lower raking struts, would be very much diminished by a scarf, especially if the span is considerable, as of course it would be if a scarf was necessary. Thus it is always best to use only one whole piece of timber for the principal strut; and if this cannot be obtained long enough in Dantzic fir pitch pine must be used, which can be procured in pieces, if necessary, 66 feet long. But unless the houses to be shored are a great height, say from 70 feet to 80 feet high, it would be more economical to make use of raking shores.

With regard to the scantling that should be given to the timbers of a flying shore, the following may be taken as a general rule:—

For spans not exceeding 15 feet, the scantling for the principal strut may be 6 inches by 4 inches, and for the raking struts, 4 inches by 4 inches.

For spans from 15 feet to 33 feet, the scantling for the principal strut may be from 6 inches by 6 inches to 9 inches by 9 inches, and for the raking struts from 6 inches by 4 inches to 9 inches by $4\frac{1}{2}$ inches.

In both cases the straining pieces must be stout enough to give a good bearing to the ends of the raking struts.

The scantlings given above are for shores which occupy a position at about three-fourths of the distance from the ground line to the top of the wall, and which are placed at intervals of not more than 10 feet to 15 feet from each other.

It may sometimes happen that when it would be more convenient and economical to support a house with flying shores, an objection is raised by the owner of the house which it is proposed to use as an abutment, either because he is afraid of his wall being pushed in by the pressure brought to bear upon it, or because the unsightly appearance of the shores may be prejudicial to his premises. This objection he has a perfect right to make, and he can compel his neighbours—of course at his own risk—to tie in the wall from the back, or, if there is room on their property for the erection of raking shores, to adopt this method of supporting the wall. There is an instance of a case of this kind on the Thames Embankment, opposite the Temple Station of the District Railway, where, although the wall of the house which requires support is over 60 feet high, and there is an admirable abutment for flying shores close at hand, yet the more expensive method of raking shores has been adopted, no doubt because the adjoining owner has objected to have his premises disfigured, as they certainly would be by flying shores butting against them. The raking shores used in this case are, by the way, excellent examples of their kind; and if they are still in position when this book is published, the London reader cannot do better than pay them a visit; for, although they are not accessible to the two-foot rule, yet it is possible to get near enough to them to examine them satisfactorily. It will be found that they are of a lighter scantling than that laid down in the general rule in Chapter II., but this is accounted for by the interval between them being not more than about 7 feet.

Apologising for this digression, we will go back to consider Plate IV., Fig. 2. This is a contrivance which must be employed if the house to be supported is higher than the house which is used as an abutment. It is more convenient, more economical, and more effectual than a raking shore springing from the ground would be, especially if the height of the building is considerable. In fact, in all cases where the span is not more than about 33 feet, and there is no difficulty in obtaining a good abutment, it is always best to employ flying shores in preference to raking shores; for, apart from the consideration of economy, they present a more direct resistance to the thrust, are well out of the way of any building operations that may be carried on below them, and can remain in position without danger of being disturbed; whereas the feet of raking shores are always in the way, and the excavating and pumping which is so often carried on around them, unless great care is taken, is almost sure to loosen their foundations, and so to render them useless.

CHAPTER V.

ON NEEDLE SHORING AND UNDERPINNING.

We have hitherto been dealing only with those methods of shoring which are used more particularly when some precautionary measures must be taken to arrest a dangerous movement in the wall of a building, but which may be said only to assist the foundation in the real task of supporting the wall. We now come to consider the case when the support of the foundation is no longer to be relied upon, and the wall is to be gripped and held suspended in the air by the shores alone, while its lower portion is cleared away entirely, either to be replaced by new work or to remain open for a doorway or shop front. The method employed to support the wall in such a case is called needle shoring: in principle it is the most simple of any, and needs but little explanation; but in practice it requires the greatest care.

It consists merely in cutting holes about 14 inches square through the wall of a building, at intervals of from 5 feet to 7 feet from each other, and inserting through these holes short balks of timber called needles, which are propped up at either end by stout posts, resting upon sole-pieces laid upon timber platforms on the ground. Oak wedges are driven together at the feet of these posts, or the sole-pieces are laid at a slight inclination, and the posts are levered into position in the same way as the feet of raking shores. The needle is thus pressed tightly against the under side of the brickwork, and after raking shores have been fixed as an additional security in supporting the wall, the lower portion can be taken down without fear; the whole weight of the wall and floors being carried by the needles, and transmitted through the posts to the ground. The wall is supported on the principle of a corbel springing from either side of the needle, and finding its way through the perpendicular joints, until it is met by the line of the corbel springing from the neighbouring needle. It might be supposed from this that the triangular space between the corbels, having nothing to support it, would fall out; but this is not the case in practice, for the adhesion of the mortar is sufficient to hold all the bricks together if the distance from one needle to the other is not greater than about 6 feet or 7 feet. However, if there is any tendency on the part of the bricks in this space to fall, they must be temporarily strutted up from below. In this kind of shoring there is nothing to be gained and everything to be lost by using timber of a small scantling. For the needles, and for the posts as well (unless they are very securely braced to each other), whole timbers (i. e. about 13 inches by 13 inches) should be used.

The above brief description brings us to an end of the three methods of shoring usually employed to support a building; but before we give a practical example of this last method, it may be as well to say a few words here upon the general subject of ruinous and dangerous structures.*

The first thing of course to be done when a structure is found to be unsafe is to shore it up at once on all sides, either with raking or flying shores, as may be most convenient; but, before we can determine how it can best be restored to a sound condition, a careful survey must be made of all the walls, so that we may find out from the nature of the cracks and bends, and other guiding marks, what is the cause of the failure, and in what direction the fault lies; for in this way only can we know with certainty how and where to apply a remedy. There are, of course, many causes to which the failure may be attributed, all of which should be considered when the building is examined, such, for instance, as the use of bad mortar, the overloading of the wall, the thrust of a vault, or, more commonly, some defect in the foundations.† But as it would be an impossible and useless task for us to go into all the cases of failure that are likely to occur, and to prescribe here what should be done in the way of remedy in every instance, we must content ourselves with the investigation of one example only, and let it suggest in principle at least what should be done in many other cases.

The failure of the foundations is, as we have said above, the most common cause of ruin in a building, and the method of restoration known as underpinning which is employed in such a case is of every-day occurrence; consequently we cannot do better than select this subject in considering the treatment of ruinous structures.

If, after a thorough examination has been made of a dangerous building, and from the nature of the cracks and bends and other evidences of failure in the walls, it is proved beyond doubt that the fault is not to be found in the superstructure, then inspection trenches should be cut, and the foundations examined. At one time it may be discovered that the footings have been built with bricks or stones which are both bad in themselves

* For the convenience of the London reader, the law concerning dangerous structures in the metropolis is appended at the end of this Chapter.

† The reader is referred to an excellent paper, by Mr. Edwin Nash, on "Failures in Construction," recorded in the 'Transactions of the Royal Institute of British Architects,' 1867, vol. xiv.

and improperly bonded in the work; for this is, unfortunately, a very common practice with some builders, to get rid of all their bad bricks, or odd bits of stuff, in the work below the ground. Nothing leads to more disastrous results; for it should be remembered that the lower a stone or brick is placed in a wall the greater is the weight it has to carry, and consequently the very best materials should be used in the foundations of a building. At another time it may be found that the footings have buckled up at either side into the shape of the letter V, from the offsets being too great, or from the fact that back joints have been allowed beyond the face of the upper work. Only heading courses should be allowed in footings, stretching courses should only be used when the footing courses are doubled, and then the stretching course should occupy a position under the heading course. It may often happen that the concrete or the mortar used for the brickwork below the ground, if the situation is a very damp one, has never properly set from the want of hydraulic properties in the lime used; or the concrete and foundation generally may have been dislocated by the expansion and contraction of the clay on which it rests. Again, the failure may be caused by some defect in the design of the wall below the ground, such for instance as piers standing upon inverted arches which have not sufficient abutment; or if the building be an old one, the materials of which the foundation is composed may have decayed so much in process of time as to be no longer strong enough to carry the superincumbent weight.

Instances such as these may be enumerated by the score, and the time spent in their investigation can never be considered as wasted, for they teach us what to guard against in the future; and in examining a dangerous structure the knowledge of defects in other cases often helps us in finding out the reasons of failure in the case before us.

If a wall whose foundations have thus been discovered to be at fault is in all other respects in a comparatively sound and homogeneous condition, i. e. if there are no very serious cracks or sharp bulges perceptible on its face, or if it is only a few inches out of the perpendicular, it can be restored to a perfectly sound and healthy condition by removing the bad foundations and replacing them, either wholly or in part, with good and reliable new work. This operation is called underpinning.

It is carried out in the following manner:—Raking shores are first erected to assist in supporting the wall, and the ground on either side of it is then dug out at one point only, generally at the centre; and it will depend upon the condition of the brickwork or the masonry of which the wall is composed as to how many feet along the wall this excavation may extend. Good brickwork will carry itself over a span of 6 feet or even 7 feet, and the same may also be said of most kinds of dressed masonry; but when the foundations of a wall have failed the homogeneity of the material of which it is composed is partially destroyed, and it will not be safe to underpin, on an average, more than 4 feet or 5 feet at a time. All the foundation comprised within this dimension, whether it be brick, stone, concrete, wood, or iron, is removed entirely, and a new foundation is commenced upon the solid ground, and built up within the cleared space to the under side of the old work.

Before, however, this new work is commenced the ground on which it is to be built must be thoroughly examined, and if necessary inspection shafts should be dug for this purpose; for the neglect to examine the ground may have been the original cause of the failure. After it has been proved satisfactorily that the ground is fit to be built upon, a good bed of Portland cement concrete should be carefully laid in a trench cut to receive it. It should not be allowed to be thrown in from the ground level as is so often done, for in that case all the larger stones fall first; but it should be let down in buckets and quietly deposited, and, after it has been well rammed, the cement on the top should be flushed off to a level surface. If brickwork is to be built upon this concrete, slabs of York stone are often laid over it to receive the footings. A good workman will measure the distance from the surface of this stone to the under side of the wall above, and will so arrange his courses that they will fit into the space exactly, allowing for the breadth of the joints; but if, when the work has been carried up, it is found that the last course does not quite reach to the under side of the old work, a carefully laid course of pamment tiles or slates must be pinned into the space, and well grouted with liquid cement. The whole of the new work throughout must be built in cement; for cement possesses the quality, invaluable in this case, of expanding as it sets, and consequently it causes the whole of the new work to rise slightly and press against the under side of the old work.

When this new pier, as we may call it, has been finished, and the cement has set hard, similar spaces may be cleared away and new work built and bonded into it on either side; and so we can proceed until the whole of the old foundations have been removed and replaced by new work, which will carry the superstructure with perfect safety for all time to come.

We have stated above that in all underpinning operations the new work throughout should be built in cement; this is certainly correct for all brickwork or masonry, but an exception may be made to this rule as far as concrete is concerned. All concretes, whether lime or cement, will expand when they set. The ordinary lime concrete used in and about London, composed of six parts of ballast to one part of greystone lime, will expand as much as three-eighths of an inch to every foot in height, and the size thus gained the concrete never loses. Consequently, if the underpinning is all under the ground, lime concrete, which is infinitely cheaper than brickwork or masonry in cement, may be the sole material employed; but, and this is important, some artificial means must be employed to force it up against the under side of the old work.

A very successful example of underpinning in lime concrete only, is thus described by Lieut.-Colonel Sir William Denison, R.E., in Mr. Burnell's work on 'Limes, Cements, and Mortars':—

"One of the large storehouses in Chatham Dockyard having for some time exhibited serious defects in its walls, the attention of the Admiralty was directed to it in the year 1834, and Mr. Taylor, the Civil Engineer and Architect, was directed to report on the best mode of obviating the evil.

"Upon investigation, the foundation of the storehouse (a building 540 feet in length and 50 feet in breadth) was found to be in a very bad state; the front wall, nearest the river, had orginally been built upon piles, while the rear wall was laid upon an upper stratum of 5 or 6-inch planking, supported by two rows of transverse and longitudinal oak sleepers lying on the surface of the ground, which in this case was of a variable consistence, containing flints bedded in a sort of clay, quite pervious to the water, which at high tide rose some height upon the foundation. The sleepers and heads of the piles at the front of the building, thus exposed to alternate moisture and dryness, were in a state of rapid decay; in some places they were even reduced to a powder, and it was possible for a man to move under the walls in the space previously occupied by the timber. In the rear, the case was pretty much the same; the sleepers were universally in a state of decay, but in some places were much further advanced towards decomposition than in others.

"The state of the storehouse requiring immediate attention, it was resolved to attempt to underpin the walls. This the patentee for the new description of concrete, or artificial stone, undertook to do, having adopted a plan proposed by Mr. Taylor, for forcing the soft concrete against the under part of the wall; and he proceeded to execute this contract in the following manner.

"I must premise that the storehouse was vaulted underneath, and that the piers, or cross walls, required as much underpinning as any other part of the building.

"The walls were laid open to their bottom, both inside and outside the building; in the front, the heads of the piles and the sleepers were removed for a depth of about 4 feet below the bottom of the wall, and for lengths of about 5 feet at one time. In the rear, all the planks and sleepers were removed for the same distance. A mass of concrete, composed of one-eighth of Halling lime (reduced to a powder by grinding, and in a perfectly caustic state) and seven-eighths of Thames ballast, mixed up with so much boiling water as to reduce the whole to a pasty consistence, was then thrown from a height of about 15 feet underneath the wall: it was allowed to project about a foot on each side, where it was confined by planks, and after being roughly levelled, it was well rammed, to give it as much consistence as possible. This mass was raised about 3 fect, or to within 1 foot of the bottom of the wall; it was then carefully levelled, and covered with ½-inch slates. A kind of framework was then placed on the slates, consisting of two cross-plates of iron, placed perpendicularly to the direction of the wall, about 1 foot wide, and long enough to project about 1 foot on each side of the wall.

"To these were fixed two frames parallel to the wall, about 4 feet long, each carrying two sockets for screws. Within these frames were placed two movable planks, long enough to pass just free between the cross-plates, and wide enough to fit nearly the space between the slates and the bottom of the wall. Upon these planks were sockets for the heads of the two screws, by which the planks were pushed forward or withdrawn at pleasure.

"When the apparatus was fixed, and the movable planks ready on both sides of the wall, about two barrowfuls of concrete, mixed as stated, were thrown in from above; the workmen below then commenced turning the screws on each side simultaneously, moving the two planks towards the centre of the wall, and forcing the concrete before them into all the vacant spaces, and against the bottom of the wall. When the plank was forced forward as far as it would go, by the strength of two men to each screw, the concrete was allowed to rest for about five or ten minutes, by which time it had set hard enough to stand by itself, and its expansion in the act of setting completed what the pressure of the screws might have left undone. The planks were then withdrawn, another charge thrown in on each side, and compressed as before, and this was continued till the whole space between the frames was filled with concrete. The screws were then removed, the boards and frames unbolted and taken out, and lastly, the side-plates were withdrawn, leaving an interval of about ¾ of an inch between each mass of concrete, which spacc was afterwards filled in with grout.

"The above description is given from notes taken at the time. The proportion of lime to gravel is as 1 to 6; and such is the efficiency of the concrete in the mode in which it was applied, that no settlement has taken place since the work was completed."

The majority of underpinning operations are carried out by some such methods as these that have now been described; but this way of dealing with a ruinous structure may be considered rather in the light of a prevention than a cure, for unless a building is thus treated at once when its foundations first show signs of giving way, the evil will gradually increase, and render it imperative not only that the foundations should be renewed, but also that a considerable portion of the wall above the ground should be taken down and rebuilt.

If we look, for instance, at the wall of the house depicted on Plate V., Figs. 1 and 2, we shall see that it is ruined for several feet above the foundations. This might, perhaps, have been prevented if it had been underpinned at once, when the failure first showed itself; but no such steps having been taken, it has cracked badly in many places, bulged forward, and dragged the return walls out of the perpendicular.

The reason why the foundations have so signally failed in this case to carry the superstructure, is because the house has been made to encroach upon the site of an old pit or trench, shown by the dotted line in the section, Fig. 2, which has been filled up for many years, so that its existence has perhaps never been suspected; and as the foundations do not go down to any great depth, it is quite possible that it may not have been noticed when the wall was built, or the contractor may have chosen rather to risk a settlement than go to the extra expense of excavating the made ground and building up from the virgin soil.

It is now too late to underpin this wall in the ordinary way that we have just described, for the evil has spread so far that it would still be unsafe, even though its foundations were renewed; but after it has been well shored up with raking shores, the method of needle shoring must be employed to support the upper portion (which, though it has been squeezed in a little towards the centre, is otherwise comparatively sound and homogeneous), and the whole of the lower portion of the wall for a distance of about 12 feet from the ground must be removed entirely. Accordingly four needles, which it is best to make whole timbers, i. e. about 13 inches by 13 inches, are inserted through holes cut in the wall well out of reach of the cracks, and above the point where the bulge is most pronounced, and these are supported by eight posts of the same scantling. In consequence of the peculiar nature of the case, the posts must be placed upon two continuous sole-pieces, laid on either side of the wall, and stretching well across the treacherous ground. On the exterior of the wall, the sole-piece must rest upon a carefully laid platform of stout planks, laid in such a way that the bearing of the two central posts may be spread over so much of the surface that it will be impossible for them to sink when the weight comes upon them. On the inside, the sole-piece

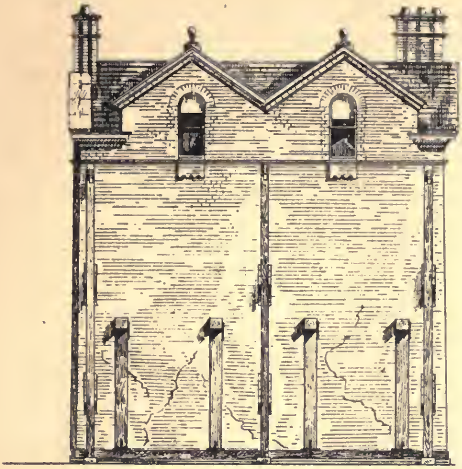


Fig: 1. Elevation.

Scale of 10 5 0 10 Feet

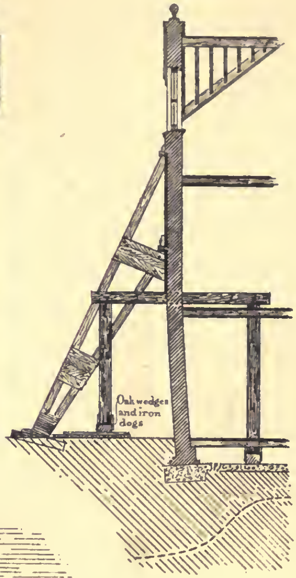


Fig. 2: Section.

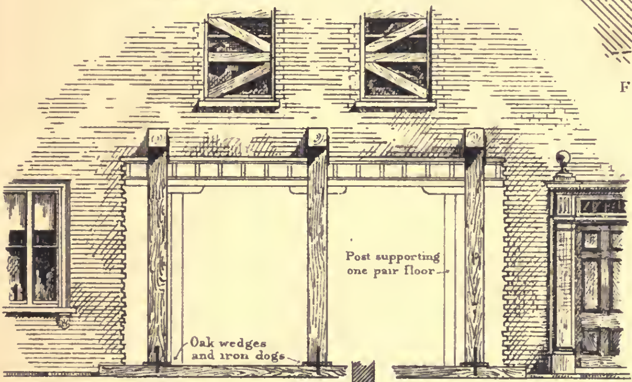


Fig: 3. Elevation.

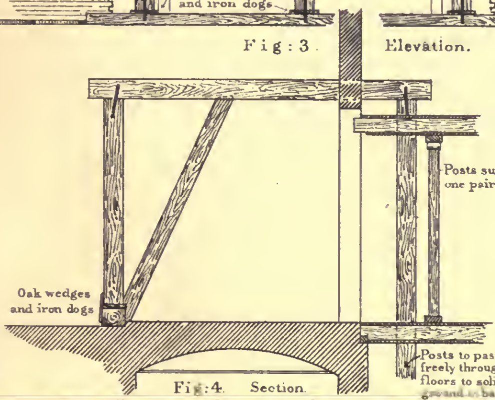


Fig: 4. Section.

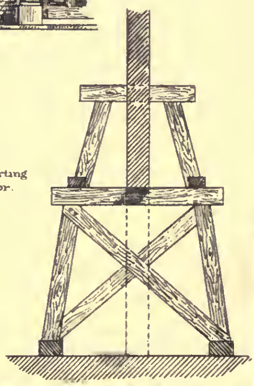


Fig: 5

Scale of 10 5 0 10 Feet

C. Haden Stock Inv. et Del.

J. Akerman Photo-lith. London, W.C.

may rest upon the concrete under the floor, if it is in a good condition; but if not, it must rest upon a similar platform of timber to that on the outside of the building. Great care must be taken in arranging these platforms, that there may be no possibility of their being disturbed when the ground is excavated for the new foundations.

It will be noticed in the section, Fig. 2, that the needles pass through the wall just above one of the floors. This is the best and most usual position for the needles to occupy; for the brickwork at this point, and for some way above it, is perfectly sound, and has not been cut into for the insertion of plates and joists. This floor must, of course, be strutted up independently of the wall, and a hole cut through it and the ground floor to allow the posts which carry the needles to pass freely to the ground. If, however, this cutting through of the floors would be a very costly and troublesome business, platforms of timber may be placed upon the floor and on the under side of the ceiling, spreading the weight over as many joists as possible, and the posts set up in different pieces.

The needles having been wedged up tightly against the under side of the old work, the whole of the brickwork below the needles must be taken down, the made ground under the wall dug out, and a good trench cut in the virgin soil to receive the bed of new concrete. The rest of the work may then be built up again in cement to meet the wall above, in the same way as has been described already.

It should always be borne in mind, that even after this new work has been finished and the cement has set, it is still the needles and posts which do the real work of carrying the wall; and the greatest care must be exercised in removing them, that the weight is transferred gradually, and not all at once, upon the new work. The needles should first be eased a little by knocking out the wedges at the foot of the posts a few inches, and then, after a day or two has elapsed, the wedges may be withdrawn entirely and the needles taken out; but the raking shores should remain in position for about a week after the wall has settled down upon its new bearings.

With regard to the responsibilities incurred in case of the failure of underpinning operations, Mr. Edwin Nash, in his paper on "Failures in Construction,"* makes the following remarks:—"When we see that accidents under this head may cause verdicts of manslaughter to be recorded against architects, as was the case against Mr. Abraham, after the noted fall of a house in the Strand in 1853, we must be awakened to the necessity of so arranging the business part of such operations that the architect shall not be made responsible for details he cannot control. It is often a sort of work that requires intelligent

* 'Transactions, R.I.B.A.' 1876, vol. xiv.

watching during every moment of its progress, and this is not the architect's business; and if this view be not recognised by courts of law, it behoves us to define the responsibility in a written document between architect and builder before commencing the work."

It is not, however, in connection with ruinous structures that we must look for the most general use of needle shoring, for walls are, as a rule, underpinned at once, without its aid, when the foundations first show signs of giving way; but it is much more commonly employed in cases where some alteration is to be made in a building which is perfectly sound—such, for instance, as the addition of a new basement, or the insertion of a shop-front. As an example of the former case, the Gaiety Restaurant in the Strand may be cited. It was necessary, in order to obtain the space now occupied by the magnificent Grill Room, that the walls should be taken down to a greater depth than was previously the case; accordingly needle shoring was employed, and the whole building stood for many weeks as it were upon crutches, while the new foundations were being built. In consequence of the weight of the walls, and to obviate some difficulty in supporting the floors, the needles were doubled, i. e. placed one above another in the manner shown in the sketch, Plate V., Fig. 5.

An example where needle shoring is required to support a wall during the insertion of a breastsummer and shop-front is illustrated in Plate V., Figs. 3 and 4. The needles in this case must be made longer than usual to span the vaults under the pavement; consequently it will be as well to strut them as shown in the section, Fig. 4. Raking shores need not be used unless the wall is of a great height, or in a bad condition; but the window openings, immediately above the needles, must in any case be well strutted, as shown in the elevation, Fig. 3, or they will be squeezed in, and the frames, as well as the glass, will be broken.

When the opening has been made in the wall, and substantial piers have been built at either end of it, the girder or breastsummer is fixed in position, and a plate fitted to its lower flange to take the joists of the first floor. A 3-inch York stone template is then bedded on the top of the girder, and a course or two of brickwork built up in cement to meet the under side of the old work.

It will now be unnecessary to give any further illustrated examples of this simple method of needle shoring; but before we go on to consider its use in cases of a more complicated character in the next chapter, there are one or two further points to which it may be as well to draw the reader's attention.

If it should be required, for instance, to clear away the lower portion of a party-wall, so as to throw the premises on the ground floor into one large shop or office, before the needles, which will carry the wall during this operation, are inserted, the following points should be considered :—

1st. If there are any chimney breasts in the wall, they should be well supported; two or even three needles, if the width of the breast is considerable, should be inserted under them, with as good a bearing as possible.

2nd. If there are any piers or corbels in the wall, a needle should be inserted under each.

3rd. If the upper floors are double, or framed floors, the needles should be inserted in the same perpendicular plane with the binding joists or girders.

4th. Care should be taken in arranging the position of the posts which are to carry the needles, that they shall not interfere with the proper adjustment of the girders and stanchions which are eventually to carry the wall.

The needles must be inserted above the first floor for the reasons mentioned above, and also to allow of the girders being fixed on a level with this floor. In the case of a warehouse, if the structure is in a bad condition, it will be as well to remove all goods which are stored upon the floors above the needles, or at all events to shift them, so that their weight is carried by the story posts or by another wall. But if this could not be done except at great inconvenience to the proprietors, the floors must be strutted up from the ground, and so made altogether independent of the support of the party-wall.

In the example we have given above of the underpinning of the storehouses at Chatham, it was not deemed necessary to move the goods at all during the operations, though they were very heavy, comprising all sorts of ships' tackling, such as cables, blocks, ropes, spars, &c.; but it will be recollected that in that case the walls were not needled, and only underpinned in short lengths at a time. However, all such considerations as these depend upon so many things, that they can only be left to the judgment of the architect in each particular case.

At the commencement of this chapter it was laid down as a general rule that whole timbers should be used in cases of needle shoring, and for this reason, that although the scantling of whole timber may be found by the usual formula to be larger than that required to carry the weight with safety, yet it should be borne in mind that all beams of timber will deflect a little when a weight comes upon them, and it is important in the case of a needle that this deflection should be reduced to a minimum. Again, there is always the possibility of there being some unforeseen defect in the timber, and the greatest care should be taken, even when a needle is made of whole timber, that it is perfectly sound throughout: the same may also be said of the posts which carry the needles. If, however, economy or space should require that smaller timbers should be used, we must employ the following formulæ, from 'Tredgold's Carpentry,' for the scantling of beams supported at both ends and loaded in the centre, and posts compressed in the direction of their axis:—

To find the scantling for a rectangular piece of timber that will sustain a given weight in the centre, when supported at the ends in a horizontal position.

When the breadth is known or settled,

$$D = \sqrt[3]{\left(\frac{L^2 \times W \times a}{B}\right)};$$

When the depth is known or settled,

$$B = \frac{L^2 \times W \times a}{D^3};$$

where L = length of bearing in feet;
W = weight to be carried in pounds;
a = ·01 for fir, and ·013 for oak;
B = breadth in inches; and
D = depth in inches.

To find the scantling of a rectangular post capable of sustaining a given pressure in the direction of its length:

$$D = \sqrt[3]{\left(\frac{L^2 \times W \times a}{B}\right)};$$

where L = length in feet;
W = the weight to be sustained in pounds;
a = 0·00133 for fir, and 0·0015 for oak;
B = breadth in inches; and
D = thickness required in inches.

Part II. of the Metropolitan Building Act, 1855 [18 & 19 *Vict.* c. 122], *relating to Dangerous Structures.*

Survey to be made of dangerous structures.

Sect. LXIX. Whenever it is made known to the Commissioners hereinafter named that any structure (including in such expression any building, wall or other structure) is in a dangerous state, such Commissioners shall require a survey of such structure to be made by the District Surveyor, or by some other competent surveyor, and it shall also be the duty of the district surveyor to make known to the said Commissioner any information he may receive with respect to any structure being in such state as aforesaid.

Definition of "Commissioners."

LXX. In cases where any such structure is situate within the City of *London* or the Liberties thereof, hereinafter included under the expression "the City of *London*," the expression "the Commissioners" shall mean "the Commissioners of Sewers of the City of *London*"; but when such structure is situate elsewhere it shall mean "*the Commissioners of Police of the Metropolis,*" *or such one of them as may be authorised by one of Her Majesty's Principal Secretaries of State to act in the matter of this Act.**

LXXI. Upon the completion of his survey, the surveyor employed shall certify to the said Commissioners his opinion as to the state of any such structure as aforesaid. Surveyor, on completion of survey, to give certificate.

LXXII. If such certificate is to the effect that such structure is not in a dangerous state, no further proceedings shall be had in respect thereof; but if it is to the effect that the same is in a dangerous state, the Commissioners shall cause the same to be shored up, or otherwise secured, and a proper board or fence to be put up for the protection of passengers, and shall cause notice in writing to be given to the owner or occupier of such structure requiring him forthwith to take down, secure, or repair the same, as the case requires. Proceedings to be taken in respect of certificate.

LXXIII. If the owner or occupier to whom notice is given as last aforesaid fails to comply, as speedily as the nature of the case permits, with the requisition of such notice, the said Commissioners may make complaint thereof before a Justice of the Peace; and it shall be lawful for such Justice to order the owner, or on his default the occupier, of any such structure to take down, repair, or otherwise secure, to the satisfaction of the surveyor who made such survey as aforesaid, or of such other surveyor as the said Commissioners may appoint, such structure or such part thereof as appears to him to be in a dangerous state, within a time to be fixed by such Justice; and in case the same is not taken down, repaired, or otherwise secured within the time so limited, the said Commissioners may with all convenient speed cause all or so much of such structure as is in a dangerous condition to be taken down, repaired, or otherwise secured, in such manner as may be requisite; and all expenses incurred by the said Commissioners in respect of any dangerous structure by virtue of the second part of this Act shall be paid by the owner of such structure, but without prejudice to his right to recover the same from any lessee or other person liable to the expenses of repairs. On non-compliance with notice, Justice to summon owner, &c., and make order to comply with requisition.

LXXIV. If such owner cannot be found, or if, on demand, he refuses or neglects to pay the aforesaid expenses, the said Commissioners, after giving three months' notice of their intention to do so, by posting a printed or written notice in a conspicuous place on the structure in respect of which or of part of which they have incurred expenses, or on the land whereon it stands, may sell such structure; and they shall, after deducting from the If owner cannot be found, Commissioners may sell structure, giving the surplus to owner, &c.

* This last clause, printed in italics, has since been repealed (32 and 33 Vict. cap. 82), and jurisdiction is now given to the Metropolitan Board of Works, instead of the Commissioners of Police of the Metropolis, in respect of dangerous structures not in the City.

proceeds of such sale the amount of all expenses incurred by them, restore the surplus (if any) to the owner.

[The following amendment of the above section has since been passed in the Metropolis Management and Building Acts Amendment Act, 1878 (41 & 42 Vict. c. 32)]: Where under the provisions of the Metropolitan Building Act, 1855, and the Acts amending the same, with respect to dangerous structures, any structure is sold for payment of the expenses incurred in respect thereof by the Board in manner prescribed by section seventy-four of the said Act, the person to whom the same is sold (hereinafter referred to as "the purchaser"), his agents and servants, may enter upon the land whereon such structure is standing for the purpose of taking down the same and of removing the materials of which the same is constructed; and any person who refuses to admit the purchaser, his agents or servants, upon such land, or impedes him in removing such materials, shall be liable on conviction to a penalty not exceeding ten pounds, and to a further penalty of five pounds for every day after the first day during which such refusal continues.

When the proceeds of the sale of any such structure under the said seventy-fourth section are insufficient to repay the Board the amount of the expenses incurred by them in respect of such structure, no part of the land whereon such structure stands or stood shall be built upon until after the balance due to the Board in respect of such structure shall have been paid to the Board.

[This amendment does not apply to dangerous structures in the City.]

Payments by or to the Commissioners, how made.

LXXV. All payments hereby directed to be made by or to the Commissioners shall in the cases of payments in respect of any structure situate within the City of *London* be made by or to the Chamberlain of the City out of or to the Consolidated Rate made by the Commissioners of Sewers, and in the cases of payments in respect of any structure situate elsewhere within the limits of this Act be made by or to the Receiver of Metropolitan Police, in the same manner in which payments are made by or to such Chamberlain and Receiver respectively in the ordinary course of their business; but no Commissioner or other officer shall be liable in respect of any loss that may be sustained by any person in consequence of the exercise by the said Commissioners of the powers hereby given them, unless such loss happens through the wilful default of such Commissioner or other officer.

Surplus, how to be applied if no demand made for it.

LXXVI. In cases where any surplus is hereby made payable to any owner, if no demand for the same is made by any person entitled thereto within one year, then the same shall be paid into the Bank of *England* in the name and with the privity of the Accountant-General of the Court of Chancery, to be placed to his account there to the credit of the owner (describing him so far as the Commissioners can) subject to the control of the court, and to be paid out to the owner on his applying by petition, and proving his title thereto.

LXXVII. There shall be paid to the District Surveyor, or to such other surveyor as aforesaid, in respect of his services under the second part of this Act, such fees, not exceeding the amounts specified in the second part of the second schedule hereto, as may from time to time be directed by the said Metropolitan Board. **Fees to District Surveyor.**

LXXVIII. If any special service is required to be performed by the District Surveyor, or by such other surveyor as aforesaid, under the second part of this Act, for which no fee is specified in the said schedule, the said Metropolitan Board may order such fee to be paid for such service as they think fit. **Metropolitan Board may appoint special fees for services not provided for.**

LXXIX. All fees paid to the District Surveyor, or to such other surveyor as aforesaid, by virtue of the second part of this Act, shall be deemed to be expenses incurred by the said Commissioners in the matter of the dangerous structure in respect of which such fees are paid, and shall be recoverable by them from the owner accordingly. **Fees to be deemed part of expenses.**

LXXX. In cases where a structure has been certified by a District Surveyor, or such other surveyor as aforesaid, to be dangerous to its inmates, a Justice of the Peace may, if satisfied of the correctness of such certificate, upon the application of the said Commissioners, by order under his hand, direct any inmates of such structure to be removed therefrom by a constable or other peace officer; and if they have no other abode he may require them to be received into the workhouse established for the reception of the poor of the place in which such structure is situate. **Justice of Peace may cause inmates to be removed from dangerous structures.**

LXXXI. Subject to the approval of one of Her Majesty's principal Secretaries of State, the said Commissioners may appoint such persons at such salaries, and make such regulations, as they think fit for carrying into execution the second part of this Act; and all expenses incurred by them not hereby otherwise provided for shall, in the case of expenses incurred by the said Commissioners of Police, be deemed to be expenses incurred by them in respect of the police force of which they are Commissioners, and be payable accordingly; and all expenses incurred by the said Commissioners of Sewers shall be paid out of the said Consolidated Rate. **Powers of Commissioners to appoint officers.**

CHAPTER VI.

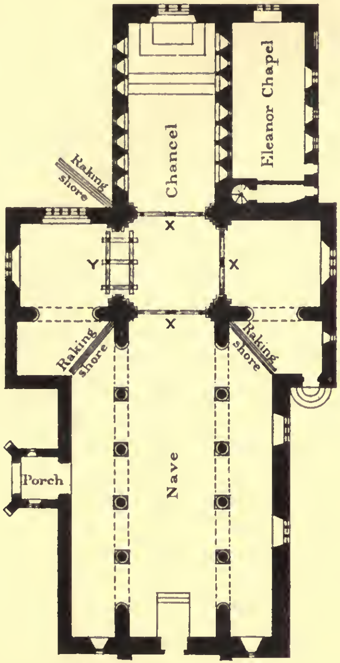
ON THE SHORING AND UNDERPINNING OF MEDIÆVAL BUILDINGS.

THE practice of the art of shoring and underpinning does not always confine itself to the meaner buildings in a crowded town, but the sphere of its greatest usefulness and fullest development is to be found in the restoration of our venerable churches and cathedrals, many of which, but for its timely aid, would long before this have fallen victims to the ravages of decay. Every architect who loves his art must be glad to be the means of saving from destruction even one stone of those wonderful and beautiful works executed by the masons of the Middle Ages; and there have been many instances in which the ponderous towers and steeples of cathedrals have been saved from impending ruin by an opportune application of this useful science. Such were the works of Rondelet at the Church of St. Geneviève at Paris, of Flachat at the cathedral at Bayeux, and in our own country of Cottingham at Hereford; and had it not been for the interference of the elements, the underpinning at Chichester would no doubt have been successfully carried out, and the original tower and spire of the cathedral might still have been standing.

The gigantic shores and centres used in cases such as these require, however, a fuller description than can be given in this treatise; and the reader is referred for an example to the excellent description and drawings of the shoring of the central tower and lantern of the cathedral at Bayeux by MM. Dion and Lasvignes. But instances of shoring on so vast a scale are rare, and more the work of engineers than architects; and it will be better to describe here a more humble example, and one which is more likely to be of service to us in ordinary practice.

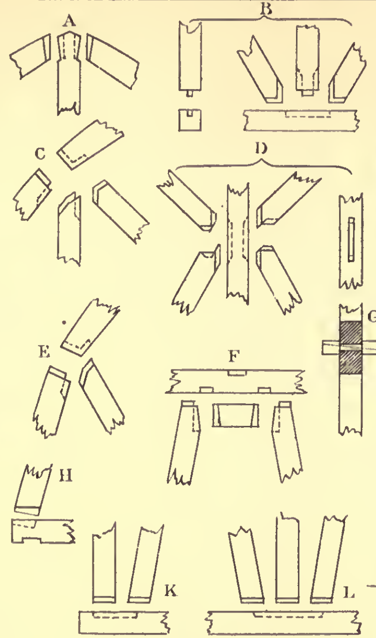
At a meeting of the Royal Institute of British Architects, held on Monday, 3rd February, 1873, an excellent paper was read by Mr. J. P. Seddon, F.R.I.B.A., on the shoring, &c., of the tower and spire of the parish church of Grosmont in Monmouthshire. We cannot do better than quote here Mr. Seddon's own remarks upon that building, describing the state of decay in which he found it, and the subsequent measures which were employed in its restoration. The diagrams on Plates VI. and VII. are copied from the drawings made by Mr. William Ed. Martin to illustrate Mr. Seddon's paper, and which afterwards appeared in the *Building News* of February 7th, 1873.

PLATE, VI.



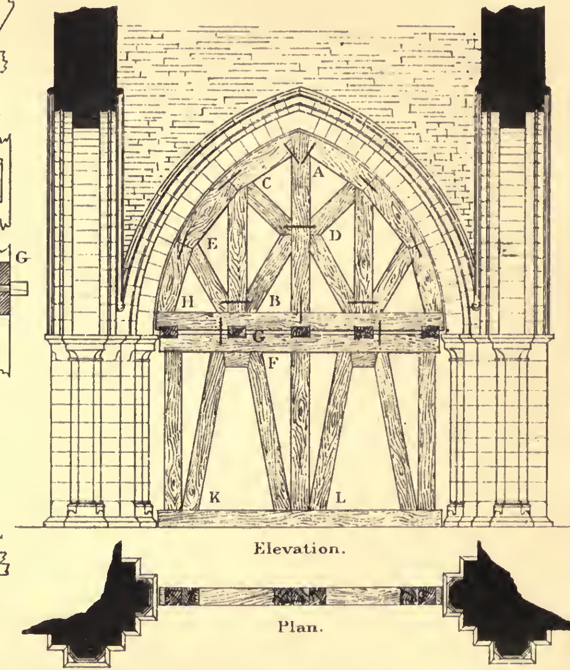
Key Plan of the Church

Scale of Feet.
10 5 0 10 20 30 40



Detail of Joints of Framing.

Scale of 12 6 0 5 Feet



Elevation.

Plan.

Grosmont Church; Shoring of Tower.

Centres under East, West, and South Arches at X on Plan.

Scale of Feet.
10 5 0 5 10

C. Haden Stock Del.

J Akerman Photo-lith London, W.C.

"The parish church of Grosmont, dedicated to St. Nicholas, in the diocese of Llandaff, is situated in Monmouthshire, near to where the border of that county joins those of Herefordshire and Breconshire—a very beautiful and retired part of the country.

"The structure is one which by its historical interest and architectural value justifies the pride taken in it by the inhabitants of the surrounding district; but it has even wider claims for consideration, and particularly in connection with this metropolis, distant though it may seem to be.

"It owes, if not its origin, at least its enlargement and embellishment, to the same munificent patronage which directed those on a grander scale at the Abbey of Westminster; and though Grosmont Church is, as befits its position, a comparatively humble structure in point of style, it may claim some resemblance to its nobler contemporary. Had the same caution been exercised in its case as in that of the Abbey, and had only a modest lantern surmounted its crux, I should not have the following chronicle of disaster to bring before you. But the substructure was in all probability never intended to support the ambitious though elegant central octagon tower and spire which at a later period were piled upon it, exemplifying a temerity of which mediæval architects were often guilty, and which brought ruin in the case of Chichester and serious danger in that of Salisbury.

"The church, the plan of which is a Latin cross, consists of a nave 67 feet by 18 feet 6 inches, and aisles 9 feet 6 inches wide, separated by arcades of five bays (with responds deeper than ordinary, obviously to give more abutment to the crux arches), central tower and spire, transepts with aisles on the western sides, of the same width as those to nave; chancel and chapel south of same. There is also a porch on the north side opposite the central bay of the main arcades. The crux arches and transept are the earliest portion, being in the style of the Transition between Norman and Lancet. The chancel is fully developed Lancet.

"It is now many years since I was first called in to examine this church, and then it was in a condition which cannot be described as other than tottering from old age. In this part of the country it must always have been a difficulty to obtain proper building sand, and the loamy sand at hand would soon destroy the value of any amount of lime mixed with it. From this cause the mortar of the walling throughout had become little better than earth, and the whole of the external walls exposed to the weather were grievously dilapidated.

"Under the great weight of the tower and spire which were added, the earlier crux, piers, and arches have been crushed and twisted out of shape, and this pressure has been transmitted in the directions of north, south, and west, by the several arches, which had themselves become distorted so as actually to thrust outwards the end walls of nave and transepts. The more solid walls of the eastern side of transepts and of the chancel had yielded less, yet still in some degree.

"The whole eastern limb, viz. chancel and Eleanor Chapel, by far the richest architecturally, was in the worst condition, and imperatively needed rebuilding. Under the circumstances described, however, it seemed a perilous operation to undertake, as even the temporary removal of such support as they gave the central tower might accelerate the ruin of the rest of the fabric. Funds adequate for this work only having with difficulty been collected, this was effected with great care. The chancel and Eleanor Chapel were in 1869–70 almost entirely taken down and rebuilt under my directions.

"Careful examination was made before and after the execution of this work of the state of the crux, piers, and arches, and marks set to show whether these yielded at all by reason of settlement in the new masonry. This, which was mostly to be feared at the north-east angle pier, does not seem to have taken place to any great extent. But still I received reports from time to time that the original mischief was proceeding, and I caused a close examination to be made, from which it appeared that the cracks were surely though slowly extending, particularly in the north-west pier. In consequence of this, I reported that it was, in my opinion, essentially necessary that the tower and spire should be so shored up and supported by centres as to be independent of the piers, which then, as funds were procured, could be made good; after which the restoration of the arches and superstructure could at any time be taken in hand.

"I estimated the cost of this preliminary work of supporting the failing arches at about 400*l*., and received instructions from the vicar, the Rev. W. H. Twyning, to direct it to be done at once.

"The failure of the substructure of the tower is primarily traceable to two causes. First, errors in design; and, secondly, errors in construction. The design is in fault from the weight of the tower being carried upon insufficiently abutted arches; and the construction, from the imperfect execution of the dressed stone-work and the masonry of the walling.

"From the first cause (imperfect design) four distinct *classes* of failure are to be traced:—(1) Spreading of arches at their springing; (2) flattening of the arch curves, thus neutralising the keying, and rendering the arch insecure by the liability of voussoirs to fall out; (3) thrusting of the vertical supporting piers under the tower arches out of the perpendicular; and (4) transmission of the thrusting force to all adjoining piers, arches, and walls, throwing them out of the normal stable condition—verticality.

"From the second cause (imperfect construction) three classes of failure may be traced:—(1) The crushing of the wrought stone facings which form the casing of the piers; (2) the bursting asunder or drawing of the bonders, of the various members of which the piers are composed; and (3) rents or fissures of the walling generally.

"The most prolific causes of failure in building are generally two, viz.: unequally yielding of foundation trenches, and uncompensated thrusts, whether from roofs or arches. The case now under consideration is a signal example of failure from the latter cause—an *equally unyielding* foundation having contributed in some degree to intensify this failure.

"Writers of books on building generally assume it as a fact not to be questioned that a solid rock foundation, roughly levelled or stepped where necessary, is the foundation most to be desired; but an attentive consideration of the present case would lead to the belief that such a foundation, if not absolutely dangerous as a base for a building erected in the ordinary way, is at least very undesirable unless extraordinary precautions are used in the selection of the materials for the walls, in the bonding, and in the elimination of all unequal settlement from a greater number of mortar joints in any one portion of the walling, than in another on the same level. In this case the functions of the tower piers were to transmit the weight of the tower to the foundations; the latter being rock and incompressible, the piers became crushed between two unyielding forces, which would not have been the case had the foundation been of a partially yielding nature, such as a stiff clay or gravel.

"Taking the various classes of failure enumerated in detail: (1) The spreading of the tower arches at the springing. The four arches carrying the tower spread as follows:—North arch, ·584 feet (7 inches); east arch, ·375 feet (4½ inches); south arch, ·75 feet (9 inches); west arch, ·625 feet (7½ inches). This spreading has not taken place equally at both sides of the original central line of each arch; the abutments to some of the arches, being more solid and stable than others, remain almost in their original positions, whilst the spreading has taken place on that side of the centre line towards the weakest abutment.

"Spreading of the arches leads naturally to the second class of failure, viz.: flattening of the arch curves. This flattening has not taken place regularly; the arches preserve in some parts their original curves, whilst in other places the curves have been forced into straight lines. The general outlines now assumed by the soffits of the arches are irregular lines not amenable to any known mathematical curve.

"Spreading of the arches also involves the third class of failure, viz. thrusting the piers supporting them out of the perpendicular. It is evident that the piers could not have remained upright when the arches spread, except on the supposition that the springers of the arches slipped back on the abaci of the caps; but this would have been impossible, for the vast weight of the superstructure augmented the friction between the two stone surfaces to such an extent as to make the last stone of the cap and first stone of the arch practically one stone. Hence the number of inches by which the faces of two opposite piers are out of plumb becomes a correct measure of the spread of the superincumbent arch.

"The fourth class of failure noticed is the transmission of the thrusts of the tower arches to the extremities of the building in all directions. It will be well to remember that those forces *commenced* and continued to act whilst the walling generally was *green*, and the mortar in a soft condition, thus facilitating to some extent the accommodation of the surrounding abutments to the thrusting forces, without involving any sudden violent or dangerous fractures; while the gradual subsequent piling on weight when the tower and spire were added continued to increase the distortion.

"The forces generated by the thrusting of the north and south tower arches are in the directions of the nave arcades to the westward, and the chancel flank walls to the eastward; the latter being comparatively solid walls—on account of the narrowness of the lancet window openings—have sustained the thrusts in a fairly efficient manner; but on account of the large openings and small piers in the nave arcades they formed but an indifferent abutment; hence every pier and arch is thrust westward, the west gable itself being thrust out of the perpendicular, overhanging its base $5\frac{3}{4}$ inches. The east and west tower arches, acting through the transept flank walls which are their abutments, have thrust out of the perpendicular the north and south transept and walls—the former $4\frac{3}{4}$ inches, and the latter $8\frac{1}{2}$ inches.

"An inspection of the ground plan of the building will show the north-west and south-west piers to be those most deficient in abutment, and in reality it is found that these two piers are those that have suffered most, and are in the most dangerous condition. The south-west pier had to be cased some forty years since with carefully coursed wrought masonry, increasing the area of the pier by about 10 feet superficial; and the present extremely dangerous condition of the north-west pier compels its reconstruction before any other portion of the building.

"The first class of failure arising from the second cause is the crushing of the dressed stonework in the pier facings. This has taken place from the undue concentration of the weight on this facing; the backing being composed of rubble walling, with a greater number of mortar joints than in the facing, has settled down, leaving the casing to do the work of carrying the tower, and thus reducing the working area of each pier from 18 feet to 8·34 feet.

"The second class of failure under this head is the drawing of the bond stones or bursting asunder of the piers. This is a very unusual mode of failure; and is due in this case to imperfect footings under some members composing the piers. The footings were crushed or squeezed away from this particular part of the foundations; hence the bursting or drawing of the bonders or headers in the quoins immediately over this defective work.

"The last class of failure to be noted is that most commonly found in nearly every building, ancient or modern, viz. splitting of the walling in a direction at right angles or inclined to the beds, commonly called settlements.

"Settlements result from the non-elastic nature of the materials composing a wall; no one part of the walling being free to sink, or settle down, or change its position, vertically or horizontally, without fracturing or splitting the stones, bricks or mortar joints in a greater or less degree; always in proportion to the depth of settlement. From the description already given of the movements of the arches and piers with their abutments, it will be no matter of surprise to find the masonry of the walls generally, in contact with the tower, fractured, and thrust and crushed in every direction, horizontally as well as vertically. The entire subject affords an interesting and instructive example of the effect produced by a weight of 600 tons acting upon four pointed arches for a space of 500 years, and serves to demonstrate conclusively the necessity of neutralising thrusts effectively, whether such thrusts be created by the exigencies of style or design.

"The state of the tower, piers, and arches, was, as may be imagined, the subject of much talk in the village of Grosmont. The oldest inhabitant recollected the structure to have been in exactly the same state ever since he first saw it, and by some extraordinarily subtle process of reasoning deduced this valuable conclusion, viz. that as the tower had never fallen in his time, it was never going to fall. Almost every village in this part of the world contains at least *half-a-dozen* of such old inhabitants, whose inexorable logical deductions are supposed to silence most effectually the objections of any unfortunate professional man who happens to disagree with them.

"It having been decided in the autumn of the year 1869 to restore the chancel of Crosmont Church, the opportunity of seeking to determine if the failure of the tower substructure was at all progressive was seized. With this object all the fissures in the stonework were filled with cement, and the extent of the fissures lineally determined by drawing lines across the end of them in transverse directions. The structure thus prepared was left, after the chancel had been rebuilt, up to the end of November, 1872 (about two years), when a careful inspection of the parts so prepared revealed the following startling facts: first, that all the fissures which had been sealed up with cement were open again; and, secondly, that the transverse terminal lines of the fissures of 1870 were left 2 inches or 3 inches, in some cases as much as 6 inches, behind by the extension of the fissures up to 1872. This discovery compelled immediate attention to the dangerous condition of the tower, and notwithstanding the renewed protests of the oldest inhabitants, I did not hesitate to recommend the taking of immediate steps to restore the four disabled tower piers and arches, and in the event of the necessary funds not being available to effect this restoration, at least to shore up three of the arches, thus relieving the piers, and to needle the fourth arch, leaving a clear space under it for its restoration should the funds obtainable be sufficient to cover the expense.

"An idea suggested itself that the piers and arches might be restored by taking out a damaged stone here and there, and replacing the stones so removed with other sound stones, thus effecting the restoration with comparative safety and by slow degrees; but on consideration this plan was abandoned, because some parts of the piers should of necessity be entirely recased or rebuilt, of course vertically. This would have the effect of reducing the width between the piers to something about 9 inches less than the width of the arch at the springing, which would be a reversal of the proper way of treating the arches, viz., by having them, as originally constructed, 2 inches narrower at the springing than the space between the piers supporting them. It was therefore decided that the piers and arches should be entirely removed and rebuilt, using in all the old stone not damaged, and that this should be first tried upon the arch and piers on the north side, the arch proposed to be needled, this being in the most unsafe condition of the four.

"As in constructing an effective system of supports to the tower arches, a safe unyielding bottom was a primary consideration, it was determined in this case to clear away the entire space immediately under the tower, tower arches, and for a space of 3 feet all round outside or beyond the tower piers, right down to the solid rock, and to refill the space so cleared with carefully made cement concrete well rammed. The site to be thus operated upon was encumbered with old seats, fittings, and wood floors, all of which having been cleared away, the excavating commenced, *planked runs* having been laid down through the church and across the churchyard to pits or graves dug to receive the human remains disinterred; the soil itself being spread over the surface of the churchyard at some distance from the building.

"On removing the soil immediately under the floors it was found that the bodies had been at some time interred with not more than four inches of soil over the coffins, which accounted for a hitherto 'unaccountable smell' that had frequently sickened some members of the congregation during their attendance at Divine Service.

"Lower down, at about two feet under the floor level, five distinct springs made their appearance, evidently the drainage from the hill at the north side of the building. These springs flooded the space already excavated, preventing further progress. A drain six feet deep was cut through the south transept and discharged through the south transept wall into the churchyard, which is lower at that side. This drain kept the working from being submerged, and discharged during the heavy rains 60 gallons of water per minute.

"The excavations were continued until solid rock was reached at an average depth of 5 feet from the floor level. The entire soil removed was of a very dark colour, light in weight, and spongy in texture, containing human remains in various stages of decay; in fact the whole mass had apparently been used over and over again for burials, the most recent having been apparently thirty-one years ago. This appeared from the coffin breastplate, which, with its gilded lettering, was as fresh as the day it was put in, although there was no trace whatever of the coffin, which was stated to have been of oak by a party who recollected seeing it lowered into the grave.

"Some graves were hollowed out of the solid rock below the tower foundations, others with steined half brick sides, covered with stone slabs; the latter were found to be filled with a black fluid, emitting a stench so horrible as to be perceived even in the most remote parts of the building. All human remains disturbed were reverently cared for and interred in the churchyard. The entire space dug out was now filled up with cement concrete well rammed; 135 tons of concrete having been consumed in this operation. A drain was laid on the rock bottom under the concrete to drain the springs which continued to flow in from the north side of the building. A finer concrete was spread upon the surface between the piers under the tower arches, and upon this a bed of cement 18 inches wide was floated off to a level to take the centerings.

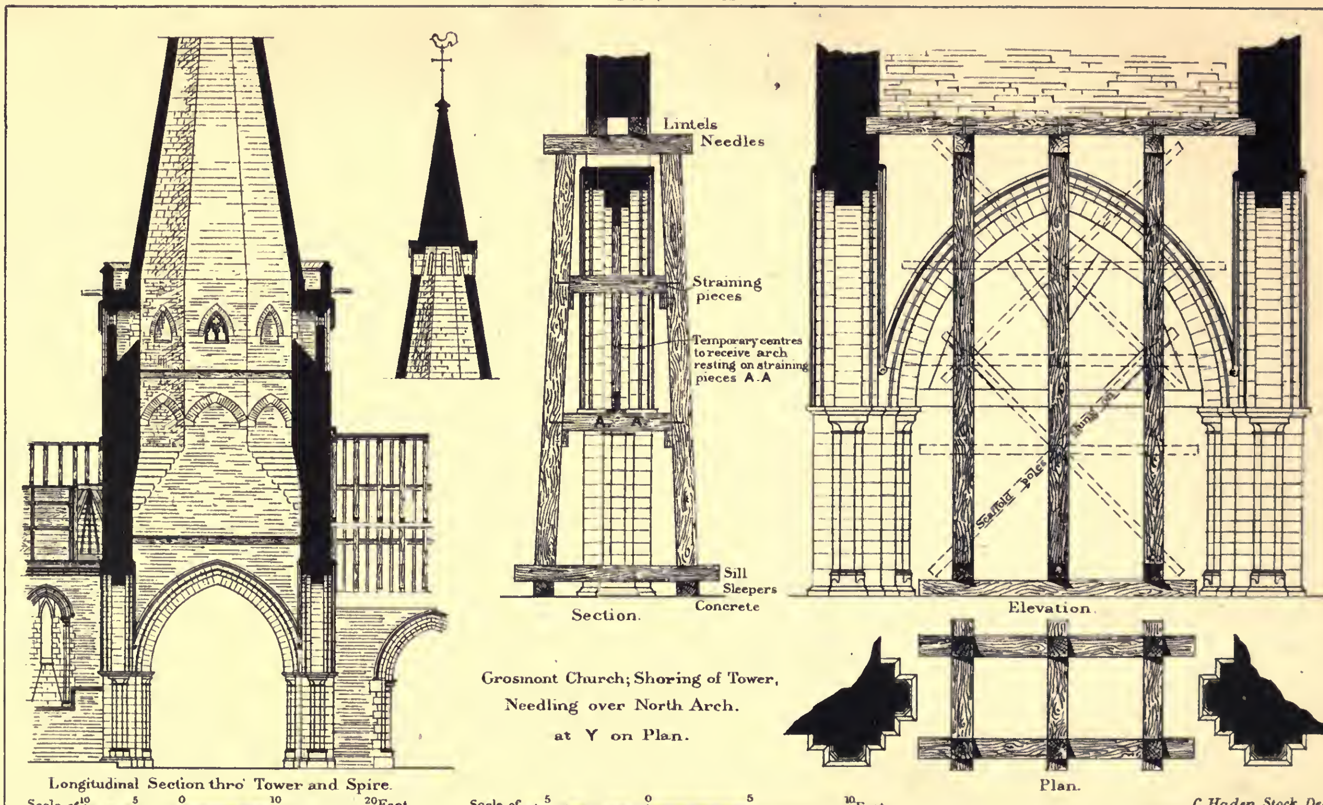
"The shorings to each arch are constructed in two separate portions, the lower portion on 'tressel' and the upper portion on centre proper. This system has been adopted to facilitate 'wedging up' or 'striking' the centres when and where required. The exact outline of each arch was obtained by 'scribing' the soffit of the inner member of the arch to which the centre was to fit, on a skeleton template of $\frac{3}{4}$-inch boarding, sufficiently wide to include the whole curve of the arch, which template was securely fixed against the sides of the arch during the scribing. This template was shaped by the line so scribed, and the permanent framing worked to it; thus the centres when fixed fitted accurately all the irregularities of the arches. The timber used in the shoring generally is from 10 inches to 12 inches square, some having been selected 14 inches wide to allow of getting out the curved backs without reducing the working section of the timber below 10 inches by 10 inches.

"All the joints in the frames are tenoned (see Plate VI.), the tenons being 2 inches thick in the centre of each piece, and from $2\frac{1}{2}$ inches to 3 inches deep; the joints are all shown on the drawings precisely as they were executed. The framework was fitted together on the nave floor first, and having been numbered at the joints was knocked to pieces to facilitate the removal and re-erection under the tower. Each tressel was afterwards built up in its proper place, and when the three tressels were securely fixed in their respective archways, a temporary scaffolding was erected on them to make a platform for the putting together and hoisting of the centres. The springing piece of each arch was laid down on its side in that arch, and the centre framed to it and secured together with $\frac{7}{8}$-inch wrought-iron dogs; a *tackle* was then rigged up to the bell beams with a *fall* to the floor, and each centre was thus hoisted to its proper position under the various arches, and securely wedged up to the soffit with oak wedges.

"In ordering the first lot of timber for this framing it was assumed that timber in the log, with one side only sawn, would answer every purpose required as well as timber sawn all round; but this proved to be a mistake, as it was found to be an impossibility to square to the tenons, mortices, shoulders, and bearings, without having at least three sides of every piece sawn die square. There being no sawpits near the building, this timber was squared with adzes and planes where required, causing some loss of time; but the next consignment of timber, having three sides sawn square, much facilitated the work of fitting together and makes much better work in every way.

"Three arches having been shored up with centering, as described, the fourth arch was treated as follows: a hole about 18 inches square was knocked through the tower wall over the apex of the arch, and about 2 feet above it, to allow sufficient head room for the introduction of a hammered stone discharging arch over the wrought stone arch. Two more holes were

PLATE VII.



Grosmont Church; Shoring of Tower, Needling over North Arch. at Y on Plan.

J Akerman Photo-lith, London, W.C.

knocked through the wall of the same size, about 2 feet lower down on either side,* about half-way between the centre of the arch and the transept flank walls. Three holes were thus made to take needles at distances of about 4½ feet apart.

"Needles 12 inches by 12 inches were inserted through these holes and supported by uprights inclining inwards at the top, and stiffened at the height of every 5 feet by means of straining pieces secured with dog irons. The walling over the needles was pinned up, and wedged in every case with flat stones bedded in cement; and when the cement had set, a temporary centre was fixed under the arch, the key removed, and all the arch stones safely taken down one by one; one-half the piers on either side were also removed, and the entire space occupied by the arch and piers cleared away to allow of the erection of the new work." †

The three remaining arches were afterwards similarly restored, and the tower and spire now stand upon a base which will remain immovable for all future time.

* The arrangement in the drawing on Pl. VII., which shows lintels inserted over the needles, and the needles themselves all on the same level, is considered by Mr. Seddon to be better than that actually executed and here described. The framing also is shown as fitted to a restored arch, it having been found impracticable to delineate the actual distortion of the piers and arches.

† The following details of the weight thus carried, with the calculations as to the manner in which it was distributed, and the breaking weights of the several portions of the timber framings employed, are appended by Mr. Seddon at the end of his paper:

By actual experiment, ashlar in spire is found to weigh 1·527 cwt. per cub. ft.

" " rubble masonry in tower weighs 1·33 cwt. per cub. ft.

There are in spire 2,534 cub. ft., weight (at 1·527 cwt. per cub. ft.) = 3869·418 cwt. = 193·47 tons.

There are in tower 9·016 cub. ft., weight (at 1·33 cwt. per cub. ft.) = 11991·28 cwt. = 599·564 tons.

There are six bells, framing and floor, weighing about 5 tons.

Total weight at arch springings = 798·034 tons.

There is no discharging arch over tower arches. Actual working sectional area of each arch, 3·45 ft. super. Many stones fractured.

Sectional area of each pier, wrought facing, 8·34 ft. super.; rubble core, 9·66 ft. super.: total area, 18 ft. super.

Weight on each pier, 199·5 tons = 11·08 tons to the ft. super. On failure of the rubble coring, the ashlar facing doing duty for the whole pier carried 23·92 tons, and was crushed.

Actual total weight per ft. square on foundation, 11·71 tons.

Breaking weight of the three needles, 216 tons; weight of one side of tower at level of needles, 170 tons; estimated actual weight of the needling, 70 to 75 tons. (The corbelling to octagon, with arching over, throws from 40 to 50 tons on each quoin N.W. and N.E. These quoins rest on the parts of the piers allowed to stand.) The load on the needling being only temporary, a co-efficient of safety of only 3 was adopted.

Actual breaking weight of *each* warped-up centre, 1050 tons; weight on each, 199·5 tons; safe working permanent load, 210 tons; co-efficient of safety, 5.

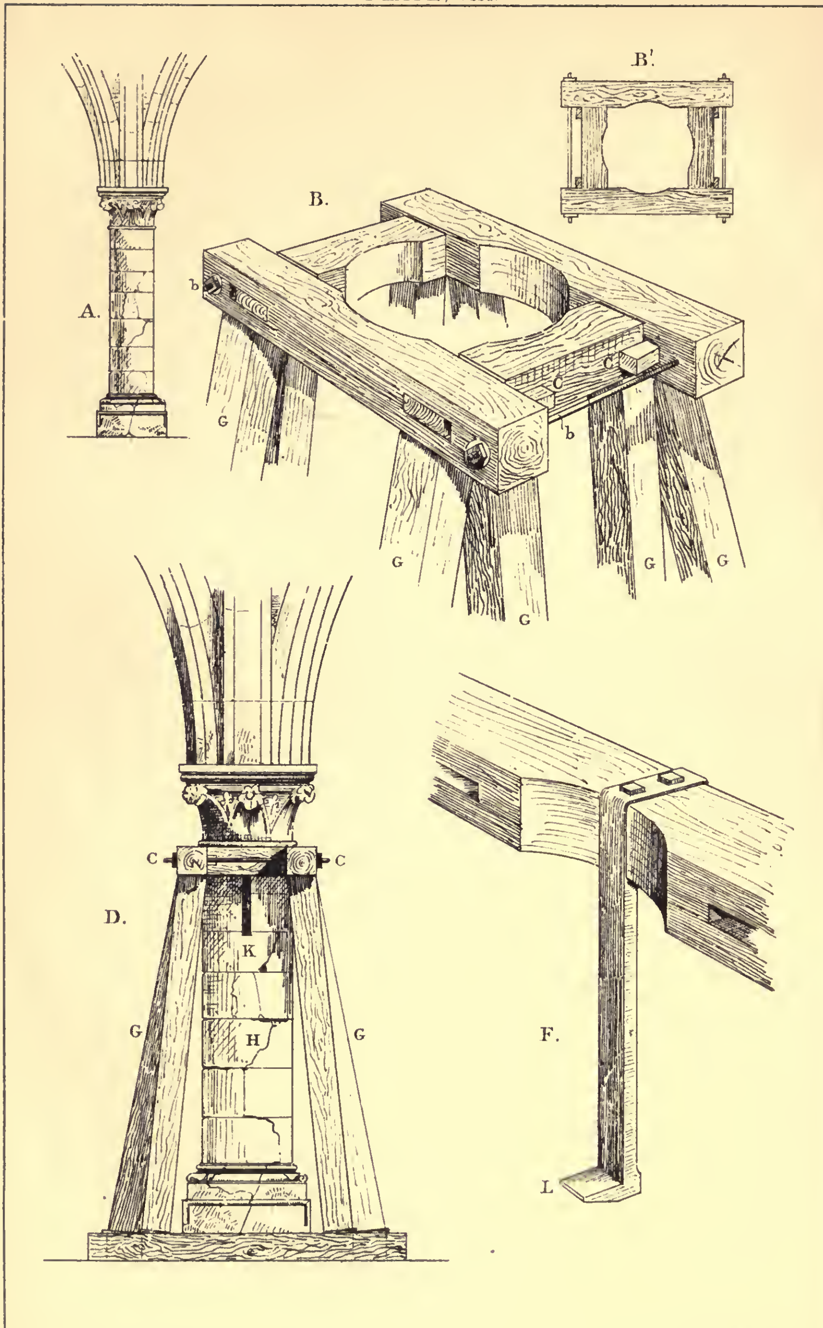
The most important lesson to be learnt from this example is the same as that taught us by the memorable fall of the tower and spire of Chichester in February, 1861, viz., that when a heavy load is to be placed upon piers and arches, it is madness to build the piers in rubble masonry with ashlar work only as a casing. The piers which are to carry such a load should be built in ashlar or dressed stone-work throughout their entire thickness, as was done by Mr. Scott (afterwards Sir Gilbert) in the rebuilding of the piers at Chichester. If such a method is found to be impracticable on account of its cost, the core of rubble masonry must at all events be built in cement, so that there can be no possibility of its settling down and leaving the weight to be carried by the casing only.

The method of restoration adopted at Grosmont may be briefly recapitulated as follows:—All the four arches and piers being unsafe it was determined to restore them, i. e. replace them in new work; there being only funds enough to admit of the restoration of one arch, it was decided to restore that arch which, with its piers, was found to be in the most dangerous condition, consequently the wall above this arch (the north arch) was needled, and the other three arches were temporarily centred to prevent their falling before they could be attended to in their turn. The arch under the needles was then taken down and half the piers on either side, to be replaced in new work set in cement. Now it must be remembered that although the north wall of the tower was carried on the needles and the east and west arches had centres under them which would only break under a load of 1050 tons, yet the north-east and north-west quoins of the tower (which were estimated by Mr. Seddon to weigh 50 tons each) had nothing to carry them but the portions of the piers which were allowed to remain standing; these must in this case have been strong enough to carry this weight; but the reader's attention is drawn to this point, because in many instances of similar restoration, the core of rubble work may be so decayed as to be utterly incapable of bearing the quoins, even for so short a time as would be necessary; in such a case the quoins themselves, and all the four walls round the tower, must be shored with needles and posts, so as to take as much of the superincumbent weight off the piers as possible: it is a mistake to suppose that centering under the arches entirely relieves the piers of their load.

The reader will have noticed in Mr. Seddon's paper that the idea suggested itself of restoring the crushed piers and arches of the tower at Grosmont by taking out a damaged stone here and there, and replacing the stones so removed with other sound stones; this method, though found to be impracticable in this case because of the piers being so much out of the perpendicular, has still been carried out with complete success in many other cases. But when such a method is adopted, the greatest care must be taken that the piers to be recased are first almost entirely relieved of their load by shores and centres, and that only small portions are renewed at a time.

These old Gothic buildings require the most gentle handling; for if they have once been damaged by fire or storm, or if at any previous time they have sunk down or become distorted, it takes very little to upset the state of equilibrium into which they have settled, though they may have remained in that state for hundreds of years. The fall of the tower at Chichester, though hastened by the storm of wind which raged during the night before the catastrophe, was no doubt originally brought about by the disturbance caused to the equilibrium of the piers by the removal of the organ screen, which spanned the nave at their feet, and also by the manner in which it was attempted to recase the piers after their dangerous condition had been discovered. So, whenever it is necessary to make any alteration or to underpin a building, every possible precaution must be taken that the equilibrium is not upset or the building shaken. In a speech delivered at the Institute of British Architects, and recorded in their 'Transactions' at the time of the Chichester disaster, Sir Gilbert Scott thus describes the work that was carried out under his supervision at the Church of St. Mary at Stafford, which is an example of the stone-by-stone method of restoration:—

"The first operation," he says, "was to bind the tower round (internally) with very strong iron bars, with right and left screws, which were screwed up as tight as possible. This was done at two different levels. We then dug round the base of the tower as low, at least, as the bottom of the foundations, removed the remains from all surrounding graves (which had, as is too often the case, done very great mischief, being much deeper than the foundations), and filled up the whole space with a solid mass of concrete. Having shored the arches and the piers, so as to carry as much as possible of the superincumbent weight, we began gradually to remove the loose stonework and to put in new (or rather additional) foundations, spreading out upon the new concrete. This operation requires a system of movable shoring quite distinct from the more permanent shoring already mentioned. This secondary shoring is continually being moved upwards as the work proceeds, no part of the old work being taken out at one time beyond what is necessary to give room for the insertion of the new portions actually in hand at the time. In each course, or at short intervals in the height, we inserted chain bars (which are best of copper) in short lengths, but so constructed as eventually to form continuous ties all round the pier. In effecting these operations, I was brought to the conclusion that it is impossible to exaggerate the danger and the difficulty that exists in providing shoring of sufficient strength; for in this, as in every work of the kind in which I have been engaged, I found that all the shoring that I could by any possibility get in was only barely sufficient for the purpose. I have seen enormous timbers bend under the pressure to which they have been subjected, and I wish to offer my most decided opinion that in most cases it is absolutely necessary, before a single stone is removed, to insert all the shorings which can be brought to bear within the space to be operated upon. I would also advise that in no case should the shores be half timbers, or timbers of an oblong section, but that they should be of square or round timbers, so as to have no tendency to bend in one direction more than in another (in large works, indeed, the shores must be larger than single timbers). In one case (a minor work) which I had in hand, I had expressly provided for the use of whole timbers in the specifications; but the clerk of the works had permitted half-timbers to be used, and the consequence was that the shoring gave way very perceptibly, much to the detriment of the work. Another precaution I would recommend is the use of the hardest stones which can be procured, for if this be neglected, the new work is almost sure, when the shoring is removed, and the weight brought to bear upon it, to split; and it is needless to say that cracks in such supplemented masonry are far more dangerous than in a new structure, for by throwing the weight upon the old core (if any remains), or upon piers not yet repaired, or upon other old work, such partial failure of the new stonework may lead to the most serious consequences. Under no circumstances, therefore, should anything approaching a soft stone be made use of, whatever may be the materials of the old pier. The next thing I would urge is the avoiding of ordinary *lime* mortar, and the use of *cement*. Besides setting the new work and pinning it in cement, it has been my practice to run the core behind with liquid cement, first pouring in water and then the cement grout, which, when thus used, I have found in some cases to penetrate the interstices to a depth of 9 to 10 feet below the level at which it was poured in, as if it were so much quicksilver. While engaged upon these works on one occasion a loud report was heard by the workmen, like the report of a gun, and it was found that one of the pillars of the chancel (quite unconnected with the tower) had split almost from bottom to top, owing to some indirect pressure brought upon it by the operations going on at the tower, which shows that the shoring should not be limited to the tower itself, but should in some degree be extended to adjoining parts. The shoring should have in all cases a special foundation provided for it. The floor of the church is wholly insufficient for the purpose, and it would be a fatal error to trust to it."



C. Haden Stock Del.

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The reparation of the tower of Hereford Cathedral by the late Mr. Cottingham, though on a much larger scale, was in all other respects nearly identical with Sir Gilbert Scott's work at Stafford, which has just been described. In all these examples, a good foundation of concrete for the shores was of paramount importance. M. Flachat, before he erected the mammoth shoring which held up the tower and lantern over the crossing at Bayeux Cathedral, sank around the feet of the four piers to a hard stratum no less than twenty wrought-iron tubes of 4 feet diameter internally, which he filled up with concrete; and upon these tubes, and between the foundations of the piers, he laid a bed of concrete 9 feet thick, the top of the tubes entering 3 feet into this concrete. The weight of the shores and the tower which they had to carry was of course very considerable, and fully justified the extreme caution taken with these foundations.

A brief description of this work is thus given by Mr. Burnell in a paper published in the 'Transactions of the Royal Institute of British Architects':—"Upon the concrete bed," described above, "M. Flachat erected a double set of frames of whole timbers on either side of the centres originally placed to support the arch (before M. Flachat was called in), for the purpose of forming a seating for a set of needles carried upon a series of screw-jacks, and made to support the masonry of the square part of the tower, a little above the vaulting of the nave and transept. The tower was carefully hooped with iron bars keyed up whilst they were still hot, so that their shrinkage actually closed the masonry which had previously been fissured over the openings; and before altering the centres to the form M. Flachat thought requisite, he also surrounded the springings of the arches of the nave with a strong wrought-iron cradle, intended to resist the lateral thrust. The centres were then strengthened and modified so as to allow the easy underpinning of the piers; and the lateral arches of the nave, choir, and transepts, which had participated in the movements of the piers of the tower, were carefully shored up. Every precaution was taken to protect the original mouldings of the vaulting, and the sculpture of the capitals, columns, and bases, by enclosing them with rubble masonry, against which the shores were made to act directly." (It should be mentioned that the four quoins of the tower were needled by a system of needle shoring, totally independent of that already described on each side of the centres of the great arches. The needles carrying the quoins were each made of three wrought-iron girders bolted together with four timber flitches, forming one exceedingly strong beam; four of these needles lying across each other, and forming a square on plan, were inserted just under the neckings of the caps, at the top of each of the four piers, and were carried by sixteen massive posts, each made of nine whole timbers strongly bolted together, in the same manner in which the masts of a ship are constructed. These posts were each 16 metres high (52·59 feet), and conducted the weight of the quoins straight down to the bed of concrete on the ground.) "It is to be observed that the needling was totally independent of the centres of the great arches, and was designed solely to support the weight of the tower and octagon above the line of the vaulting; the arches and the spandril fillings were all that bore directly upon the centres themselves."

When all this shoring was erected (and it completely filled up the crossing, being braced across and across the space), the piers were entirely removed from under the tower, and rebuilt from their foundations, and the arches were restored by the stone-by-stone method.

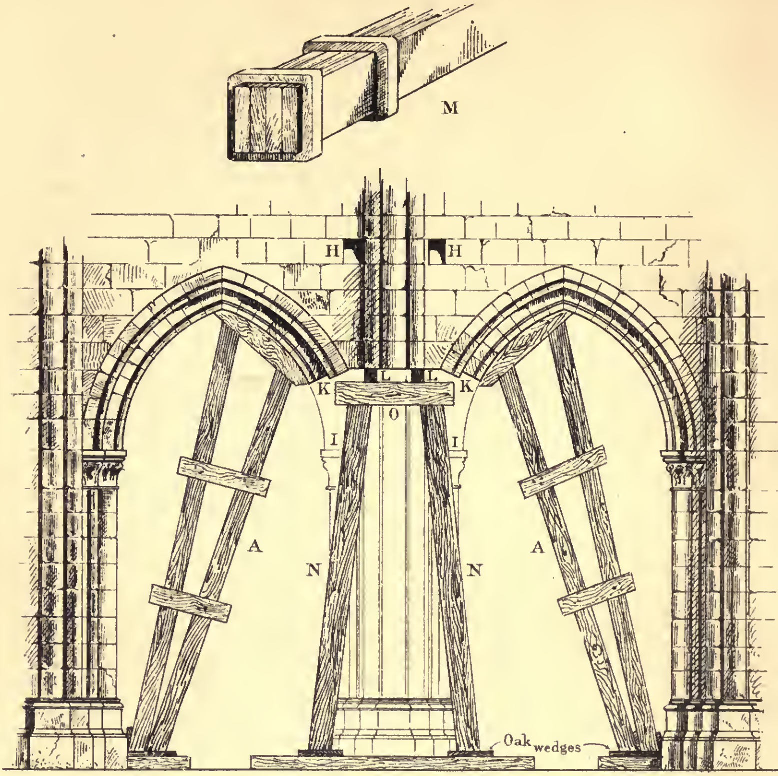
The cost of this work was 32,220*l.* M. Viollet-le-Duc, whose opinion was consulted before it was decided how the tower should be treated, gave it as his opinion that the simplest and cheapest plan was to pull it down altogether and rebuild it from its foundation, and he estimated the cost of this at a sum considerably smaller than 32,220*l.* But even if M. Viollet-le-Duc was right, there will always be a satisfaction to archæologists, at least, that the original tower was preserved intact. On the top of the Gothic lantern there was an Italian Renaissance dome, which was removed before the tower was underpinned.

The success of this operation is, however, considerably marred when it is compared with the stone-by-stone underpinning of the tower of Hereford Cathedral by Mr. Cottingham, where although the weight underpinned was double that at Bayeux, the money expended was less than one-fourth. The weight of the spire at Chichester was also nearly double the weight of the tower at Bayeux, and as it would have been necessary to employ the same method to restore it satisfactorily as was used at Bayeux, on account of the rottenness of the piers, it is perhaps as well from an economical point of view that it fell down, especially as not a life was lost nor a limb broken.

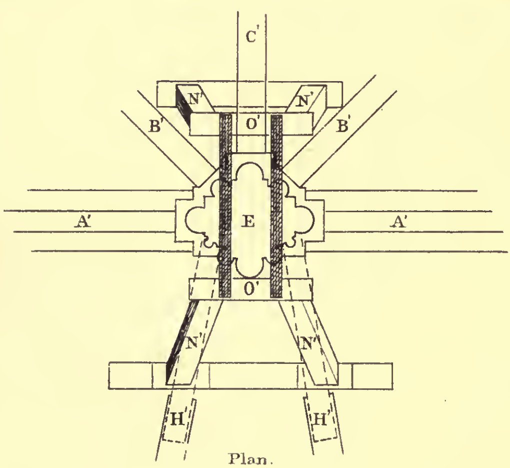
The cost of rebuilding it was in round numbers 50,000*l.*, and had it been underpinned as the Bayeux tower, the operation would probably have cost much more than this.

We will now go on to consider the suppositional cases of underpinning, depicted on Plates VIII. and IX., which are copied from M. Viollet-le-Duc's dictionary under the word "Étai." The following is a synopsis of the treatment of these cases described in that work.

Taking the first case on Plate VIII., the cylindrical column A, which carries vaulting ribs in all directions, and one or two stages of similar columns above, has become crushed under the load, as shown in the sketch. In order to enable the damaged stones to be removed we must construct a square frame of oak,



Elevation.



Plan.

C.Haden Stock Del.

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as indicated in the sketch, B in perspective, and in B′ in plan, with sides tenoned into gaping mortices, into which wedges are driven at C, which with the bolts *b* insure the frames being fitted tightly against the face of the cylinder. This frame is fitted (as at C, in the sketch D) under the necking of the capital, and is carried by eight stout posts G, inclined sufficiently to allow the new stones which replace the old at KH to pass in freely. Should there be any sound stones below the necking, four wrought-iron straps must be screwed, as shown in the sketch F, to the sides of the frame, and their feet L inserted in the joint, to catch the under side of the last sound stone; the rest of the column can then be removed and replaced in new work.

If the whole of this lower column is crushed, together with the springing stones of the vault, the vaulting ribs must be centred, and the column above must be treated in the way we have just described for the lower column, the eight posts passing through the vaulting panels to the ground below.

The second case depicted on Plate IX. is a neat application of the principle of needle shoring. A pier E which carries two main arches A′, two diagonal arches B′, and one transverse arch C′, as well as the weight of the upper vault, has become crushed under the load. In this case, where it will be necessary to use so many timbers in so small a space, we must take care to arrange them so that they will not interfere with the building of the new work. "To shore is nothing, but to shore in such a way that one can build between the shores is often a difficult problem to solve." The transverse and diagonal arches having been centred, the two main arches should be supported as shown at A in the elevation, and the springing stones of the arches from I to K, which have shared in the ruin of the pier, can then be taken out and notches cut to receive the needles at L L. The needles, in order to occupy as small a space as possible, are each made of four strong pieces of wrought iron, bound together with hoops as shown at M; they are made to rest upon strong pieces of oak at O in the elevation and O′ on the plan, and are carried by the four stout posts N and N′. It will also be necessary to support the wall above the needles with raking shores at H and H′.

When the old work has been removed and the new work finished, the posts and needles should be taken down first, then the centres under the arches, and last of all the raking shores at H and H′.

CHAPTER VII.

ON THE MECHANICS OF RAKING SHORES.*

We will suppose C B (Plate X.) to represent the section of a wall that requires to be supported by the raking shore A B, resting on the ground at A; A C being the ground line. Let there be a horizontal force T near the top of the wall at *d*, tending to overturn it about its bottom edge C; the moment of this force, which measures its tendency to overturn the wall is—

$$T \times C d.$$

This is resisted by the weight of the wall (W) acting vertically at its centre, and having a moment about C of

$$W \times C e,$$

where C *e* is generally half the thickness (*t*) of the wall. When these forces just balance, the wall will be about to fall over, and the two moments will be equal; therefore—

$$T \times C d = W \times C e.$$

Now, in order to restore the wall to its original condition before the force T acted upon it, we must find some means of completely balancing this force, and this can be done by placing the shore A B against the wall at B, where it is firmly fixed against a plank or *walling piece* by means of a *needle* driven through both the plank and the wall; then by wedging up the base A, a horizontal pressure (Q) is produced against the wall, such that the moment of Q about C balances that of T, or

$$Q \times BC = T \times C d$$
$$= W \times C e$$
$$\therefore Q = \frac{W \times t}{2\,BC} \quad \ldots \ldots \text{(I.)}$$

In this formula, B C and *t* should be expressed in feet, W and Q in cwts. If the shore presses against B with a horizontal force Q, there must also be a reaction of the wall against the shore equal and opposite to Q, so that Q represents a horizontal pressure against the head of the shore.

In order that the raking shore may have its full effect in counteracting the outward thrust or reaction Q, it is essential that it should be prevented from sliding upwards by having a

* Copied from an article in the *Building News*, Sept. 14, 1877.

sufficient weight of wall above B, so that when the pressure Q comes upon it, the head of the needle may be kept immovable by means of the superincumbent load. If, therefore, the top of the shore is put very high up against the wall, it will be of little service in preventing it from being overturned. Let P be the vertical pressure necessary to resist a horizontal thrust outwards, equal to Q at B, and w the weight of the shore itself, acting at its centre g. Then the sum of the moments of P and w, about A, the base of the shore, must balance the moment of Q about that point; therefore, we have—

$$Q \times A\,q = P \times A\,C + w\frac{A\,C}{2},$$

B q being a horizontal line meeting a vertical from A at q. This equation may be put into the form—

$$Q \sin.\,\theta = \left(P + \frac{w}{2}\right)\cos.\,\theta.$$

θ being the angle B A C which the shore makes with the horizontal; and from this we obtain—

$$P = Q \tan.\,\theta - \frac{w}{2} \quad . \quad . \quad . \quad . \quad (\text{II.})$$

So that when Q and w are known, and also the angle of inclination of the shore, we can find from this equation what vertical pressure (P) must be brought to bear on the head of the shore, in order to keep it in its place when the force Q tends to thrust it out. If the value of P is known beforehand, we can also find what amount of horizontal force (Q) it will be able to counteract; for

$$Q = \frac{2\,P + w}{2\tan.\,\theta} \quad . \quad . \quad . \quad . \quad (\text{III.})$$

The horizontal and vertical forces at B being thus determined, we can find the compression (F) down the shore by resolving P and Q, in the direction of A B, and adding their resolved parts together; therefore, we have—

$$F = P \sin.\,\theta + Q \cos.\,\theta \quad . \quad . \quad . \quad . \quad (\text{IV.})$$

In order to find whether the shore is strong enough to resist this compression, we must use the formula for a long pillar, namely

$$L = a \times \frac{d^4}{l^2}.$$

Where $a = 15{\cdot}5$ for fir, d is the diameter or width in inches, and l the length in feet; L being the safe load in cwt. that may be put on the pillar. As, however, the depth of a shore is usually double its width, we shall get twice the resistance, as obtained by the above formula, or F should not exceed—

$$\text{Safe load} = 31 \times \frac{d^4}{l^2} \quad . \; . \; . \; . \; (\text{V.})$$

There will also be produced a cross-strain S, acting at right angles to the shore, and tending to bend it inwards, which is equal to the resolved parts of P, Q, and w—namely,

$$P \cos. \theta, \; Q \sin. \theta, \; w \cos. \theta.$$

And since these strains are uniformly distributed over the entire length of A B, the total amount of cross-strain at the centre is equal to half their sum, or

$$S = \tfrac{1}{2} \{ Q \sin. \theta + (P + w) \cos. \theta \} .$$

If we substitute for P its value as found from (II.), we have

$$S = Q \sin. \theta + \frac{w}{4} \cos. \theta \quad . \; . \; . \; . \; (\text{VI.})$$

To find the deflection (D) in the middle which the cross-strain S will produce on a beam of fir, we use the formula—

$$D = \frac{S}{27} \times \frac{l^3}{b \, . \, d^3} \quad . \; . \; . \; . \; (\text{VII.})$$

The dimensions, D, b, and d, being in inches, and l in feet; S is to be expressed in cwt. If the value of D thus obtained is an appreciable quantity, it will be advisable to counteract the cross-strain by a strut $g\,h$, so as to prevent the resisting power of the shore from being impaired; and the force S will represent the compression down this strut. If we wish to find what ratio S bears to the breaking-weight of the shore, we can use the formula—

$$\text{Breaking-weight} = 3{\cdot}2 \times \frac{b \, . \, d^2}{l} \quad . \; . \; . \; . \; (\text{VIII.})$$

b and d being in inches, and l in feet; the breaking weight is found in cwt. The strain S must not exceed one-sixth of the breaking weight thus obtained.

We can now determine the magnitude and direction of the resultant (R) of all the forces, its point of action being at the base A of the shore. Suppose this resultant to make the angle ϕ with the horizontal A C, then by the rules of mechanics we have

$$R \, . \cos. \phi = Q$$
$$R \, . \sin. \phi = P + w$$

from (II.) $$= Q \, . \tan. \theta + \frac{w}{2}.$$

$$\text{But, } R = R \sqrt{\sin.^2 \phi + \cos.^2 \phi}$$
$$\therefore \; R = \sqrt{Q^2 + (P + w)^2} \quad . \; . \; . \; . \; (\text{IX.})$$

from which we obtain the magnitude of the resultant R. To find the direction of R or the value of the angle ϕ, we have

$$\tan.\,\phi = \frac{R\,.\,\sin.\,\phi}{R\,.\,\cos.\,\phi} = \frac{P + w}{Q}$$
$$= \tan.\,\theta + \frac{w}{2\,Q} \; . \; . \; . \; . \quad (X.)$$

This last formula shows us that the greater we make the horizontal force Q, the more nearly will the angles ϕ and θ approach to equality, or the direction of R get nearer and nearer to that of the shore, for the quantity $\frac{w}{2\,Q}$ diminishes with the increase of Q. The minimum value that Q can have is when P is nothing, or the head of the shore merely rests against the wall, and is not pressed upon by any vertical force, in which case we find from (III.) that the value of Q is

$$Q = \frac{w}{2\,\tan.\,\theta},$$

and substituting this value for Q in (X.) we obtain

$$\tan.\,\phi = 2\,\tan.\,\theta,$$

In this case, therefore, the direction of the resultant becomes that of the line A E. We see, then, that the resultant force R may have any direction between A E and A B, according to the amount of the pressure Q; but it will generally lie nearer to A B than to A E, and consequently it is advisable to have the abutment at A very nearly at right angles to the shore A B, in order that any horizontal thrust at A may be counteracted by the resistance of the earth.

Example.—We will now show the practical application of these ten formulæ, by taking the case of a brick-and-a-half wall, 40 feet high and 10 feet frontage, supported by a raking shore of fir 12 inches by 6 inches, the top of which is 30 feet above the base of the wall, and its spread at the foot 6 feet. The angle θ, or B A C, will be 78° 41′, $\tan.\,\theta = 5$, $\cos.\,\theta = \cdot 19623$, $\sin.\,\theta = \cdot 98056$, and the weight w of the shore is 4·5 cwt. Taking the wall at 1 cwt. per cubic foot, its weight W will be 467 cwt.; its thickness t being $\frac{7}{6}$ of a foot.

We first find the maximum horizontal thrust Q from (I.)

$$Q = \frac{W\,.\,t}{2\,.\,B\,C} = \frac{467 \times \frac{7}{6}}{60} = 9 \text{ cwt.}$$

The vertical pressure P, which Q produces, is obtained from (II.),

$$P = Q \tan.\,\theta - \frac{w}{2}$$
$$= 9 \times 5 - 2\tfrac{1}{4} = 43 \text{ cwt., nearly.}$$

This is the least value of the pressure upon the top of the shore that will counteract the outward thrust Q; but, as in this case, the actual weight of wall above B is 117 cwt., or nearly three times as much as the above value of P, we see that there is but little danger of the shore being pushed out by Q, provided it is tightly wedged up at A and B, as the shore cannot be turned about the base A without its head being lifted up, which would cause the needle to rise, and also the wall above it. For, if we put $P' = 117$, we find from (III.) the value of Q' necessary to make the shore lift this load,

$$Q' = \frac{2\,P + w}{2\,\tan.\,\theta} = \frac{238\cdot5}{10} = 23\cdot85 \text{ cwt.}$$

which is more than $2\frac{1}{2}$ times the maximum value of Q as given above.

The horizontal and vertical forces (P, Q) being known, we can find the compression F which they produce on the shore in the direction of its length from (IV.),

$$\begin{aligned} F &= P\,.\,\sin.\,\theta \times Q\,.\,\cos.\,\theta \\ &= 43 \times \cdot98056 \times 9 \times \cdot19623 \\ &= 44 \text{ cwt.} \end{aligned}$$

From (V.) we can ascertain what is the safe load that such a pillar will sustain, the length being $30\cdot6$ feet, and the diameter 6 inches;

$$\begin{aligned} \text{Safe load} &= 31 \times \frac{d^4}{l^2} \\ &= 31 \times \frac{6^4}{(30\cdot6)^2} = 43 \text{ cwt.,} \end{aligned}$$

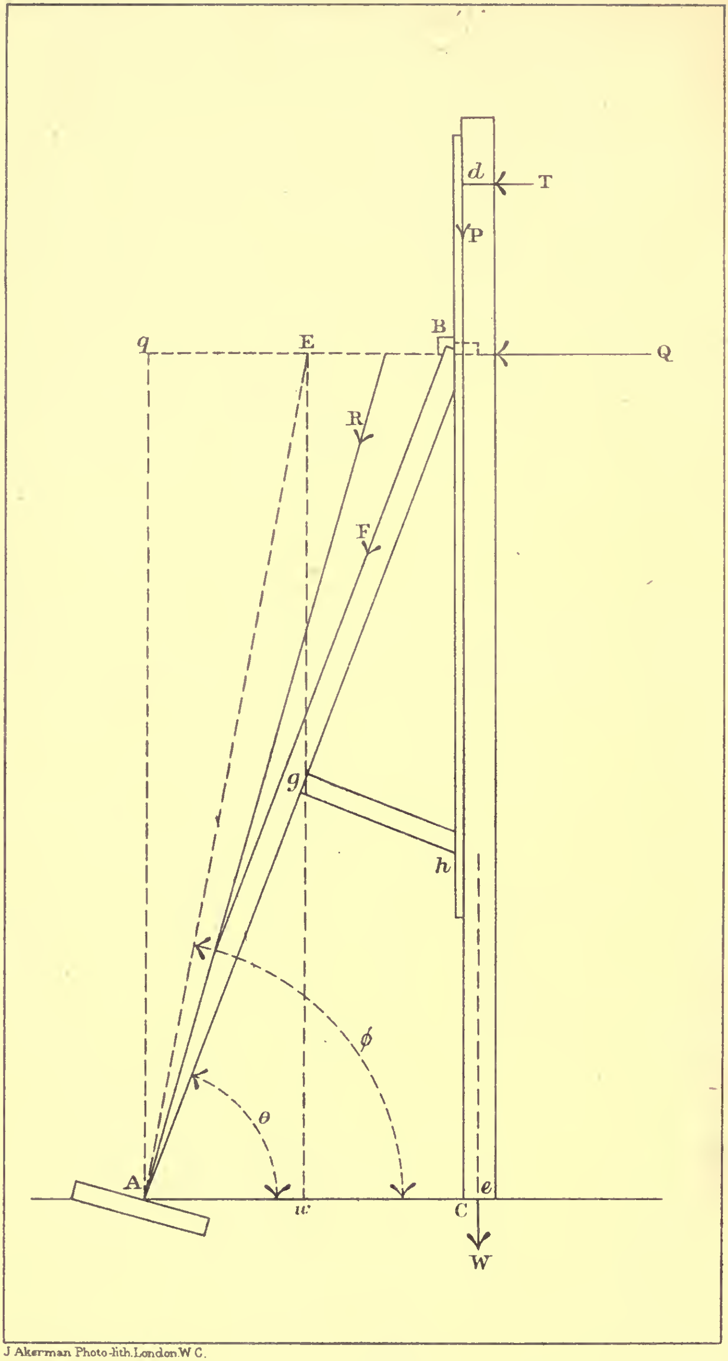
which agrees very nearly with the value of F obtained above.

The cross-strain S produced at the middle of the shore, and acting at right angles to its depth, is found from (VI.)

$$\begin{aligned} S &= Q\,.\,\sin.\,\theta + \frac{w}{4}\cos.\,\theta \\ &= 9 \times \cdot98056 + 1\cdot12 \times \cdot19623 \\ &= 9 \text{ cwt.} \end{aligned}$$

From (VII.) we can find the deflection which this strain of 9 cwt. will cause at the middle of the beam,

$$\begin{aligned} D &= \frac{S}{27} \times \frac{l^3}{b\,.\,d^3} \\ &= \frac{9}{27} \times \frac{(30\cdot6)^3}{6 \times 12^3} = \cdot92 \text{ inch.} \end{aligned}$$



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In this case, as there is a deflection of nearly 1 inch at the middle of the shore, it will be advisable to introduce a strut $g\,h$, otherwise its resisting power as a pillar will be impaired. The compression down the strut will be the above value of S, or 9 cwt.

The breaking-weight at the middle of the shore may be found from (VIII.)—

$$\text{Breaking-weight} = 3\cdot2 \times \frac{b\,d^2}{l}$$
$$= 3\cdot2 \times \frac{6 \times 144}{30\cdot6} = 90 \text{ cwt.}$$

which is ten times the strain S, which we have just obtained.

The pressure which the resultant force R exerts on the base A can be calculated from (IX.)—

$$\begin{aligned} R &= \sqrt{Q^2 + (P + w)^2} \\ &= \sqrt{9^2 + (45 + 2\cdot25)^2} \\ &= 48 \text{ cwt.} \end{aligned}$$

The direction in which this force R acts at A, or the angle ϕ, which it makes with A C, is found from (X.)—

$$\tan.\,\phi = \tan.\,\theta + \frac{w}{2\,Q}$$
$$= 5 + \frac{4\cdot5}{18} = 5\cdot25.$$

By referring to a table of natural tangents, we find that $5\cdot25$ is the tangent of 79° 13′, so that the direction of R makes an angle of only half a degree with the shore itself, when Q presses with its maximum force against the head of the shore.

When P is nothing, the direction of the resultant is A E, and $\tan.\,\phi = 2\tan.\,\theta = 10$, in which case the angle E A C = 84° 18′; the value of the angle ϕ, therefore, will in any case lie between 79° and 84°, according to the amount of the reaction (Q) at B.

The above example, it should be borne in mind, is taken for the case of one shore only in a system of raking shores; but when two or more shores are erected against a wall in the same perpendicular plane, each shore must be considered as resisting the outward thrust of its own portion of the wall only, and a separate value of Q must be found for each of them.

It is perhaps needless to say that in practice it would not be necessary to make use of all the formulæ which have been proved and demonstrated in this chapter, but for the sake of those who are fond of mathematical investigation the whole science has been laid down in its completeness. An example which shows the application of the more useful of these formulæ has already been quoted at the end of the chapter on raking shores, and it will be found that the rules there given will be all that are really necessary in actual practice.

In conclusion, I must apologize to my readers for the somewhat condensed form in which the proofs of the several formulæ are worked out; but as I had previously stated that this chapter is only intended for those who are well acquainted with the science of Trigonometry and Statics, I concluded that any more elaborate explanation of the way of arriving at the different steps in the proofs would be unnecessary.

THE END.

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