PLATE I.

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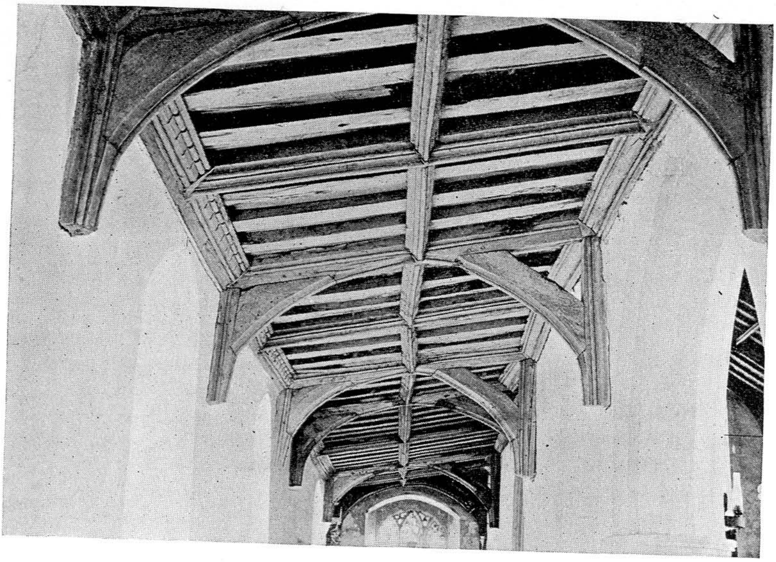
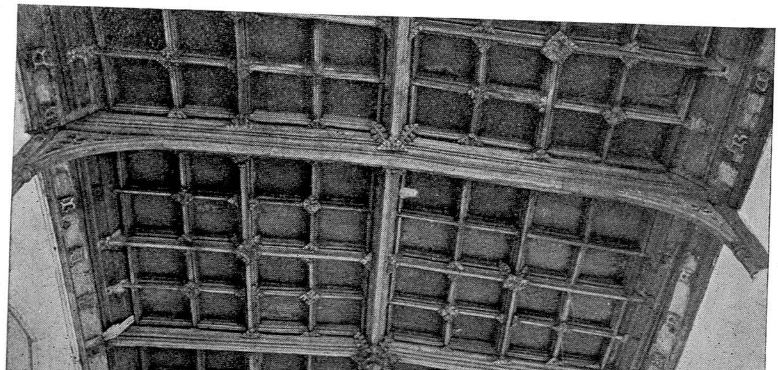


NO. I. SOUTHACRE, NORFOLK: NORTH AISLE, INCLINED-BEAM ROOF.



[F. H. Crossley, phot.

NO. 2. AXBRIDGE, SOMERSET: NORTH CHAPEL. CAMBERED-BEAM ROOF.

ON THE CONSTRUCTION OF MEDIAEVAL ROOFS.[1]

By F. E. HOWARD.

INTRODUCTION.

It seems to be generally accepted that the timber roofs of our country surpass all others in the beauty of their design and the ingenuity of their construction. Yet some foreign antiquaries are inclined to make light of this English triumph, holding that the timber roof is so inferior to the stone vault as to be almost beneath notice. They forget that, while a roof is a necessary part of a building, a vault is not essential. A house or church without a vault may be both beautiful and convenient, but a building without a roof is neither. It is therefore reasonable to claim that those builders who turned the necessary roof into a thing of beauty achieved a greater triumph than those who, despairing of ever bringing it into harmony with the rest of the structure, concealed it with a vault of masonry.

Very few archaeologists know how many thousands of fine roofs we still possess, and still fewer appear to take any real interest in them. Indeed it would seem that no one has undertaken any serious research into the subject since the Brandons' great book on the *Open Timber Roofs of the Middle Ages* appeared in 1849, sixty-six years ago, for almost all the accounts of roofs which have appeared since that date repeat their statements with a fidelity which can only be described as slavish.

The Brandons' *Open Timber Roofs of the Middle Ages* is a magnificent book, including a very fine set of carefully measured drawings and views, chiefly of East Anglian examples, and archaeology is under a great debt to them for their conscientious and painstaking labour in collecting such a valuable mass of material. The text, however, is on an altogether different plane, rising little above the level of the rest of the architectural books of the period. There is no attempt at the orderly arrangement of the examples, save that four of the main types of roofs are named. The authors appear to have been unaware of the existence of a

[1] Read before the Institute, 3rd December, 1913.

number of types of roofs altogether different from those which they illustrate, and, basing their theories on the trade practice of their day, they failed to appreciate the real principles of mediaeval roof-construction. For instance they, and most later writers accepting their statements without question, seem to regard all the beautiful mediaeval systems of bracing and strutting as so many vain and ineffective attempts to truss the roof and so to take the pressure or thrust off the walls. They proceed on the false assumptions (1) that the old manner of jointing with wooden pegs, like the modern system of iron bolts and straps, is capable of withstanding the extraordinary strain which would inevitably be brought upon the joints were it not for the resistance of the walls, and (2) that the thirty-inch mediaeval walls, like modern walls of nine-inch brick-work, cease to offer any resistance to the thrust of the roof the moment that they are pushed out of the vertical.

It is the purpose of this paper to supplement the Brandons' series of examples[1] with others less known, or of entirely different types, not neglecting the plainer roofs, the construction of which is often more ingenious than that of more pretentious ones; to set out a system of classification based upon primary constructional principles, showing the relation which one form of roof bears to another; and to inquire into the purpose of the various members of roofs and the strains which they undergo. The questions of design and decoration and local variations of type do not come within its scope.

I. THE MATERIALS AND METHODS OF ANCIENT AND MODERN ROOF-CONSTRUCTION COMPARED.

DEFINITION.

A roof is a framework of timber (or occasionally of stone or ironwork), carrying a layer of more or less impervious material, intended to protect a building from the effects of the weather.

[1] With the exception of the small figures in the text, the illustrations are all drawn to the same scale, namely $\frac{3}{16}$ inch to one foot. They are to be regarded as sketch-elevations for comparison and to explain details of construction rather than as accurate records. The principals are shaded, to distinguish them from the common rafters and their bracing.

I am indebted to my friend Mr. Crossley for several of the photographic illustrations, and to Messrs. B. T. Batsford for permission to reproduce plate viii, no. 1.

MATERIALS.

Walls. In mediaeval times practically every village appears to have worked its own local quarry, and materials for building walls were plentiful and cheap, though often of poor quality. The walls were therefore of great thickness, partly for strength, partly to exclude the damp, and though brickwork is stronger than rubble and does not allow the damp to penetrate so easily, yet the tradition of building thick walls was so strong that the mediaeval brick walls are almost as thick as those of stone. Such walls are naturally capable of resisting a great deal of overturning pressure, since they are so heavy and have so wide a base. Nowadays building materials are so much more perfect and so expensive that modern walls are built much thinner. Consequently they are much lighter and do not stand on so wide a base as the old walls, and consequently they cannot be expected to resist any roof thrust.

Timber. Five hundred years ago there were yet in existence enormous forests of oak trees in most districts, and oak was so cheap and strong that scarcely any other timber was used. It could be obtained in great lengths and sizes and, as it was generally sawn up locally, it was possible to select naturally-bent timber for curved braces and cambered beams.

At the present time English wood is so scarce that almost all timber, and that chiefly deal, is imported from the continent. It is expensive and weak, and as it is converted into regular stock sizes abroad, naturally-bent timbers are practically unobtainable.

Roofings. Mediaeval roofs are generally covered with the local roofing material. The most noticeable exception is the employment of lead. Lead is the most perfect of natural roofings, and indeed the only one which can be satisfactorily laid on very flat roofs. It is not surprising that it was in general use all over the country when it could be afforded. Slates were the roofing material of Cornwall, Devon and Wales; stone tiles were general in the Cotswolds, Northants. and in Leicestershire, Rutland

and south Lincolnshire. Heavy stone slabs were employed in Yorkshire, Surrey and other places; and tiles were used in those places where neither slates nor stone tiles could be obtained. In districts which produced no brick-earth it was frequently necessary to employ thatch; this was particularly common in the eastern counties. Mediaeval tiles and slates were hung to rent battens by means of oak pegs, driven tightly into holes near the top of the slate.

The present-day materials are the same, but their production has become commercialised. Any kind of roofing can be used in any part of the country, for distance is now no object, and all materials are produced in such mechanical perfection that roofs have lost all their external picturesqueness. Worse still, tiles are hung with nibs, and slates are nailed to sawn battens. Consequently the lines of the roof are hard and regular. It is interesting to note that experience is proving that this mechanical regularity does not necessarily mean efficiency.

METHODS.

A LEAN-TO ROOF slopes in one direction only and is very generally used over an aisle.

A GABLED ROOF slopes in two opposite directions.

Any kind of roof may occur in either form.

THE PITCH of a roof is the angle at which the rafters slope, that is, the angle between the underside of the rafters and the horizontal. The pitch is governed by two practical considerations, the internal height required and the material with which the roof is to be covered. Generally speaking, the more impervious the roofing the flatter the roof may be pitched. Lead is generally used on the very flat roofs but may be laid on a roof of any pitch, though it is found to creep down, owing to the expansion and contraction, if the pitch is very acute. Slates are rarely fixed on a roof of lower pitch than 35 degrees, and tiles, being more porous, are found to be unsuitable for a roof of less than 45 degrees. Stone slates require a slope of 47½ to 55 degrees, except those from Yorkshire and Surrey, which are so weighty that they drag too heavily upon the battens when laid on a pitch of over 40 degrees or thereabouts. It is found that thatch can be used on a roof

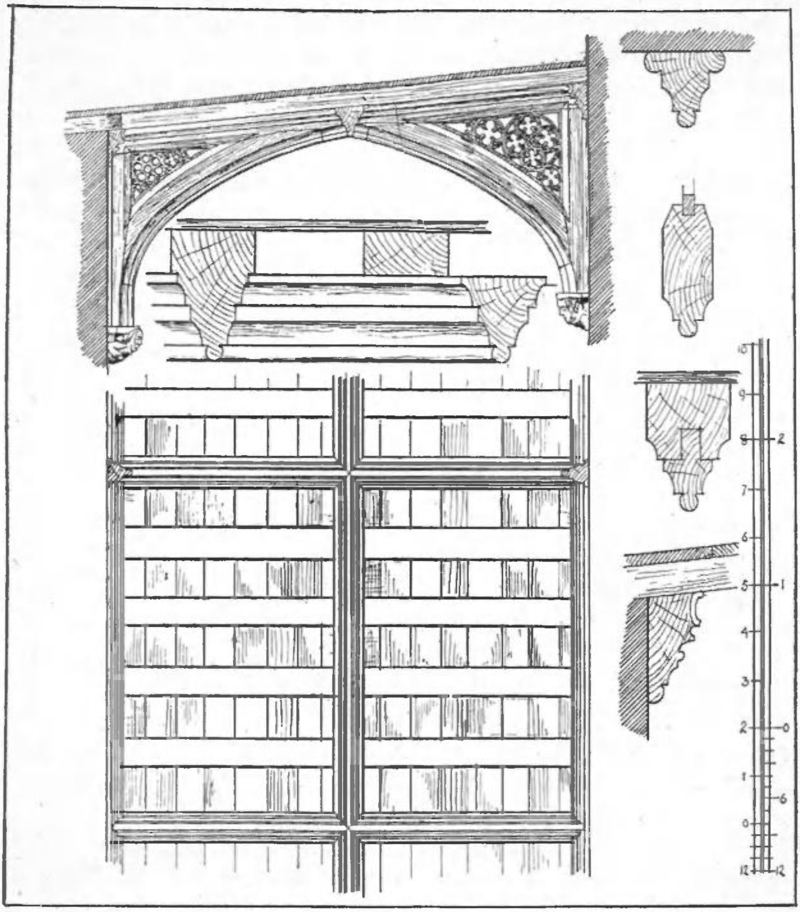


FIG. I. NORWICH, ST. JOHN MADDERMARKET.

of 40 degrees pitch,[1] but a steeper slope is better, owing to the necessity of throwing the water off at once, for straw or reeds are anything but impervious.

Some years ago it was an article of faith that a high

[1] The fine hammer-beam roof of the nave of Potter Heigham, Norfolk, which retains its thatch, is of not more than 40 degrees pitch.

pitch was superior in every way to a flat one. As a matter of fact, each has its own advantages. The high-pitched roof affords greater internal height, admits the use of a cheaper roofing material, and the higher the pitch the less is the thrust. On the other hand it requires more timber and roofing material, is much heavier, exposes a greater surface to the pressure of the wind, and tends to dwarf a tower or other high structure and spoil the proportions of a church.

SINGLE-FRAMED ROOFS. Experience has shown that the best way of constructing the slopes of a roof is to fix more or less steeply-inclined beams, called rafters,[1] at intervals of eight to eighteen inches, and to nail battens or boarding over them, on which to carry the roofing material. The rafters are fixed at their lower ends or feet to long beams, called wall-plates, laid along the top of the side walls. These are fixed to the walls and serve to distribute the weight of the roof over the whole of the wall, and also to prevent the rafters from sliding off.

The rafters of a small roof can support themselves, but if the span is great, self-supporting rafters would need to be so large and strong that such a roof would be very wasteful of timber and unnecessarily heavy. It is far more economical to strengthen each couple of rafters by means of auxiliary timbers. If these timbers are horizontal they are known as beams; if vertical they are called posts; if inclined they are called struts or braces.[2]

A roof constructed in this manner, with each pair of rafters independent of the rest, is said to be *single-framed.*

DOUBLE-FRAMED ROOFS. A more economical and effective method of construction is to support the rafters

[1] The old rafters were large and were laid flat, not on edge as in modern roofs (fig. 1). Sometimes they are as wide as the spaces between them, as at Sall, where the rafters and the panels between are painted with the same design of red scrolls and monograms on a white ground. In this case, and in hundreds of East Anglian roofs, the boards run parallel to the rafters, into which they are rebated, an arrangement which avoids the irritating effect of joint-lines at right-angles to the rafters. In some modern roofs the boarding is in very narrow widths and the effect is extremely weak and fussy as compared with the wide boards used by the mediaeval carpenter. The use of diagonal boarding affected by the Gothic revivalists is even more strongly to be condemned, and is never employed in mediaeval roofs.

[2] The upper end of a brace points *towards* the middle line of a roof-principal, while that of a strut points away from the centre line.

in the middle of their length, or at equal intervals if they are very long, upon longitudinal timbers called purlins. Unless the distance between the gables of the building is short, as in a small porch, the purlins need intermediate support, which must be provided by fixing strong frames, bridging across the building at intervals of several feet. These frames are known as principals. Each consists either of a beam on which the purlins are supported, directly or on props, or a pair of extra strong rafters, suitably strengthened by beams or braces. These are called principal rafters, while the others are known as common rafters.

Roofs in which purlins and principals are introduced are termed *double-framed.*

Nearly every kind of roof can be built on either the single or the double-framed system.

The single-framed system has the advantage of requiring small timbers only, while the double-framed roof demands a proportion of large ones. On the other hand the double-framed roof uses less timber and has an important mechanical advantage which the other does not possess. The entire weight and thrust of the rafters is taken up by the purlins and wall-plates, and transferred to the principals, which are arranged so as to rest on the strongest portions of the wall, usually between openings, or directly over the apex of arches. Thus the stresses are concentrated upon certain points of support, which can be strongly reinforced with buttresses. This is a far better and cheaper method than strengthening the whole of the wall.

It will be seen that the double-framed roof has the same advantage over the single-framed roof that the cross-vault has over the barrel-vault.

JOINTING. No ironwork is used in mediaeval roofs, save nails to fix the boarding to the rafters. The joints are made with the mortise and tenon, the slot and tenon, the halved or the notched joint, and are secured with wooden pegs only. Provided the walls are immovable it should be possible to withdraw all the pegs without affecting the stability of the roof. This system is admirable when the timbers are so arranged that one tends to push against the other, for in that case all the strain is taken by the shoulders, not by the tenon or the peg. But when the timbers tend to pull apart, the strain is entirely upon the tenon and the peg, and it has been found from actual experience that the joint fails in one of two ways: either that part of the tenon which lies beyond the peg is torn out, or the peg is sheared clean through (fig. 2).

Strains. Owing to the limitations of the jointing, as many members of a mediaeval roof as possible are arranged so as to be in compression or cross strain. Indeed the only tensional members in common use are the tie-beam, the hammer-beam and the pendant wall-post.[1] The collars and braces of mediaeval roofs were never meant to be in tension. They were intended to strut the rafters so that they might not sag under the weight of roof and wind pressure, not to tie the rafters together and prevent them from spreading. It can be proved that they never succeed in eliminating thrust. For instance, it sometimes happens that the walls of a building have fallen outwards, owing to bad foundations.

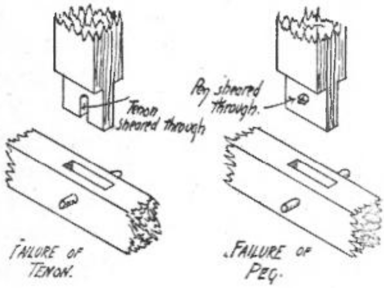


FIG. 2. THE FAILURE OF A JOINT.

In the case of a roof with tie-beams it is found that the wall-plates have not moved out with the walls; on the contrary they have been left behind, and now oversail considerably, and there is a space between the wall-post and the wall.[2] Now if it were possible for a collar and braces to prevent a roof spreading, one would naturally expect to find similar conditions in the case of a roof with these members but no tie-beam, but it is always found that the plate has moved out and that the wall-post and wall-

[1] In a modern trussed roof, all the strains except that of dead weight are borne by the roof-timbers, and are most strongly felt at the joints. In a mediaeval roof the strains were chiefly borne by the walls, relieving the weak joints as far as possible.

[2] As in the case of the roof of the nave, at Addlethorpe, Lincoln.

plate are still tightly pressed against the wall[1]: in other words, in spite of the collar and the braces the roof is thrusting still.

The joints of modern roofs are secured with iron straps and bolts and nuts. Consequently they will resist almost any amount of strain, and it is possible to screw or wedge the timbers of a roof into a truss, exercising not the slightest thrust, even without a direct tie. The collars and braces of such a roof are frequently in tension. Without ironwork, trussing is practically impossible,[2] so it is wrong to speak of a hammer-beam truss or a collar-truss,

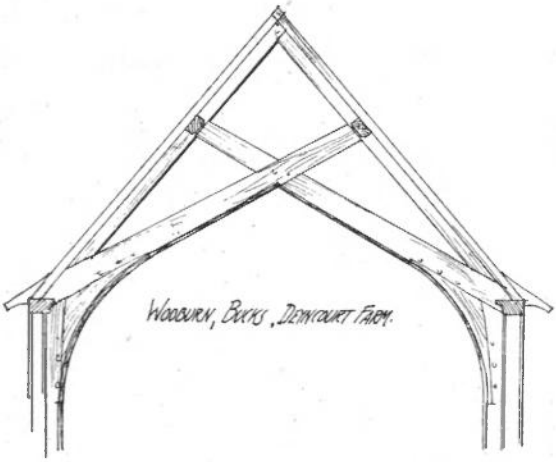


FIG. 3.

and there is really no such thing as a mediaeval trussed rafter roof. The only common English mediaeval roof that can be called a truss is that with principal rafters framed into a tie-beam.[3] In this case, though the tie-beam is in tension, there is no tendency for the timbers to pull apart at any of the joints, so it is possible to truss this form of roof without the assistance of ironwork. Some

[1] As at Cawston, Sall, and many other East Anglian roofs.

[2] On the continent, roofs, particularly those over vaults, were generally trussed, and ingenious but clumsy methods were invented of making more or less secure joints between members which tended to pull apart. These expedients are far too unsightly to be used in an open timber roof.

[3] Plates x and xi.

forms of the scissor-beam roof are also true trusses, even when constructed without ironwork (fig. 3).

TRIANGULATION. It is a well-known fact that a rectangular framework is a deformable structure, while a triangular framework is absolutely rigid. Therefore modern roof principals are divided up into triangles to ensure rigidity. It is generally accepted that elasticity of structure and the balance of opposing thrusts are the leading principles of mediaeval construction, and it is not surprising to find that no such system of triangulation was employed by the mediaeval carpenters, who preferred to stiffen their roof-timbers with the aid of angle-brackets, braces and struts.

II. CLASSIFICATION OF THE METHODS OF BRACING PRINCIPAL OR COMMON RAFTERS.

GENERAL CLASSIFICATION.

According to the Brandons there are four kinds of mediaeval roofs.

(1). Roofs with tie-beams.
(2). Trussed-rafter or single-framed roofs.
(3). Roofs framed with hammer-beams and braces.
(4). Roofs constructed with collars and braces or with the latter only.

They made no attempt to sort out the various kinds of lean-to roofs.

This system has proved very useful, and has been accepted by practically all later writers. It requires some courage to attempt to alter and extend a system which has been in use for so long, but mediaeval roofs are far too complicated to be classed in this manner. These four divisions are not a scheme of classification, but merely one of nomenclature.

A system of classification must be based on primary constructional principles. *The thrust or the absence of thrust is the all-important element in roof-construction.* In some roofs there are no inclined timbers; the framework is rectangular and therefore has no tendency to thrust. In others the thrust is met by the resistance of the wall. In others it is counteracted by trussing. Thus there are three absolutely different classes of roofs, namely those which do not thrust, those which do thrust, and those which are prevented from thrusting: that is, beam-roofs, thrusting roofs and trussed roofs.

Beam-roofs. Single-framed beam-roofs can be easily distinguished because they have no inclined timbers. Double-framed beam-roofs have beams, but no principal rafters. Brandon did not distinguish between this type and what he called tie-beam roofs, notwithstanding the

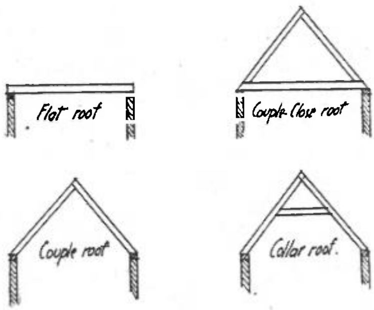


FIG. 4.

fact that there is no tension whatever in the beam. The primary type of this class is the flat roof (plates I–III and figs. 5–11).

Thrusting or arch roofs. These have neither beams nor tie-beams. The primary types of this class are the couple-roof, representing all roofs in which the rafters are connected only at the apex; and the collar-roof, representing all roofs in which the opposite rafters are strutted one from the other. The so-called trussed-rafter roof, the collar-braced roof, and the single and double hammer-beam roof are included in this class (plates IV–IX and figs. 12–22).

Trussed roofs. These are of two kinds, those in which the thrust of the rafters is overcome by means of tie-beams or scissor-beams, and those which, having no tie-beams, are screwed up into a truss by means of iron bolts, straps, and nuts. The latter kind cannot be considered as true carpentry. Mediaeval trussed roofs can generally be distinguished by their having both tie-beams and principal rafters. The primary type of this class is the couple-close roof[1] (plates X and XI and figs. 24–30).

DETAILED CLASSIFICATION.

BEAM-ROOFS. The simplest of all roofs is composed of beams only, laid at intervals across the shortest span. These beams are called joists if horizontal, rafters if inclined.[2] The double-framed version of this kind of roof consists of stout beams placed over the piers, carrying purlins for the support of the rafters.[3] Such a roof is absolutely flat, and will not throw off the water unless one of the wall-plates is fixed at a higher level than the other, so as to tilt the rafters, in which case a lean-to roof is produced (plate I, no. I). A double slope must be obtained by other means. The beams may be cambered (plate I, no. 2)[4], or they may be tapered off towards either end,[5] or a slope may be built up by laying wedge-shaped firring pieces upon them (plate II).[6] If a con-

[1] The primary types: The flat is probably the most primitive form of roof, but the couple-roof is obviously almost as ancient. The collar-roof is a development of the couple-roof, while the couple-close roof is a combination of the flat and the couple-roofs. All four types have been in use from the earliest times down to the present day.

This system may be put into tabular form as follows:

BEAM-ROOFS including *Single-framed:* Flat. *Double-framed:* Beam-roof.	THRUSTING ROOFS including *Single-framed:* Couple, Collar and "Trussed-rafter" roof. *Double-framed:* Couple, Arch-braced, Hammer-beam, and Double Hammer-beam.

TRUSSED ROOFS
including
Single-framed: Couple-close.
Double-framed: Tie-beam roofs, Iron-trussed roofs, Scissor-beam roofs.

[2] Harwell, Berks. and Toot Baldon, Oxon. (fig. 5).

[3] Fritwell, Oxon. (fig. 5).

[4] See also fig. 7.

[5] The roof of the porch at Peasenhall, Suffolk, is composed of cambered and tapered rafters.

[6] See also fig 8.

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PLATE II.

BLEDINGTON, GLOUCESTERSHIRE: NAVE. FIRRED-BEAM ROOF.

[*F. H. Crossley, phot.*

BARKING, SUFFOLK: NAVE. POST-AND-BEAM ROOF.

siderable slope is required any or all of these methods can be combined. It is obvious that if a beam-roof is double-framed this treatment need only be applied to the principal beams. The purlins are generally tenoned into the principals a few inches from the top of the latter, so that the rafters may rest upon the purlins and yet be level with the top of the principals. In a few exceptional cases, however, the purlins are framed into the principals so that the under sides are level, and each rafter is strutted off the purlin by a short post.[1]

Another series of methods of obtaining a single or double slope can be applied only to double-framed roofs. In these methods the rafters are made to slope by fixing the purlins at different levels (figs. 9, 10, and 11). In the most elementary form the central purlin rests on the principal, while the side purlins are tenoned into it as usual. The next step is to get a sharper pitch by propping up the centre purlin with a block of wood, or a short king-post (fig. 10). If a still sharper slope is required, the side purlins must also be strutted up, the wall-plate, of course, being at the usual level. Inclined struts are sometimes substituted for queen-posts, affording better resistance to the pressure of the wind.[2] If a very high pitch is essential, the posts are necessarily so tall that they must be stayed, or they will not keep upright (fig. 11). This may be done in several ways. A king-post may be stayed by means of braces or struts from the beam,[3] from the rafters,[4] or from the ridge purlin.[5] In a very few instances curved braces are used instead of queen-posts. These lean against one another and form an arch, carrying the purlins upon its haunches.[6] This method of construction is very nearly akin to that of the tie-beam trussed roofs to be described later, for the prop system is mildly triangulated, and the arch form necessarily causes a certain amount of tension in the middle section of the beam. In some less primitive examples the queen-posts are stayed by a pair of arch-braces, framed into the

[1] As in the roof of the nave, Fishlake, Yorkshire.

[2] Stamford St. John (fig. 10).

[3] Maidstone, Kent; archbishop's stables (fig. 11).

[4] Harwell, Berks. nave (ibid.).

[5] Newnham Murren, Oxon. nave (ibid.).

[6] Morton, Lincoln: see Brandon, *Open Timber Roofs*, p. 13.

posts and into a pair of rather stout common rafters notched over the purlins.[1] In this case the roof is practically trussed.

The beam-roof is certainly a relic of pre-Gothic days. It would seem that the roofs of the Greek temples were constructed on this system, judging from the marks remaining at the back of the gables or pediments. The mediaeval builders, however, made it essentially Gothic by the introduction of a number of improvements. In spite of cambering, there is a grave tendency for the beams to sag under the great cross strain. This was prevented by supporting them midway upon a great timber arch, springing from corbels in the side walls,[2] so a wall-post was placed against the wall under the extremities of the beams, to carry the weight down to the corbels, affording good fixing for the arch-braces, and spreading their thrust over a larger area. In the roofs of the fifteenth century it is rarely found that the arch-braces meet in the centre of the beam. More generally they are quite separate and support the beam at two points, instead of in the middle only, so that the cambered beam forms the middle section of the arch.[3] The wall-post is sometimes omitted, particularly in small roofs, and in this case the arch-brace takes the form of a triangular bracket. When the corbel is omitted the wall-post is sometimes termed a pendant post. In this case the post is in tension and serves to support the lower ends of the arch-braces and to steady the wall.

When large enough timbers cannot be obtained for the arch-braces, each is divided into two sections by a horizontal beam tenoned into the wall-post after the manner of a hammer-beam. Thus the lower section is framed into the wall-post and the hammer-beam, and the upper section is framed into the hammer-beam and the beam.[4]

THRUSTING ROOFS. The construction of these roofs is best considered under two headings.[5]

[1] Thame, Oxon. (fig. 30).

[2] Blythburgh, Suffolk, aisle (fig. 6).

[3] Walpole St. Peter, Norfolk, aisle (fig. 6).

[4] Bere Regis, Dorset, nave: see F. Bond, *English Church Architecture*, pp. 806, 807.

[5] These remarks are equally applicable to both single and double-framed roofs; i.e to principal or common rafters.

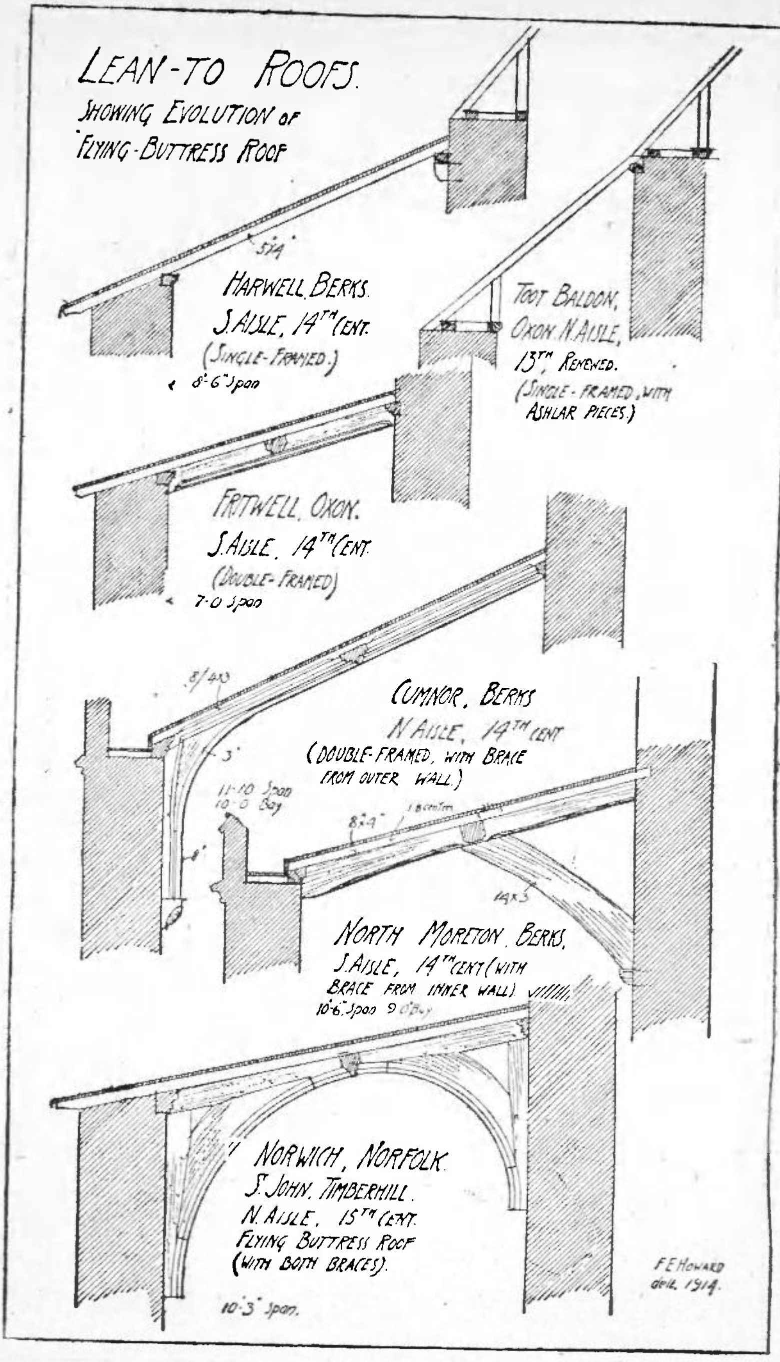


FIG. 5. INCLINED-BEAM ROOFS.

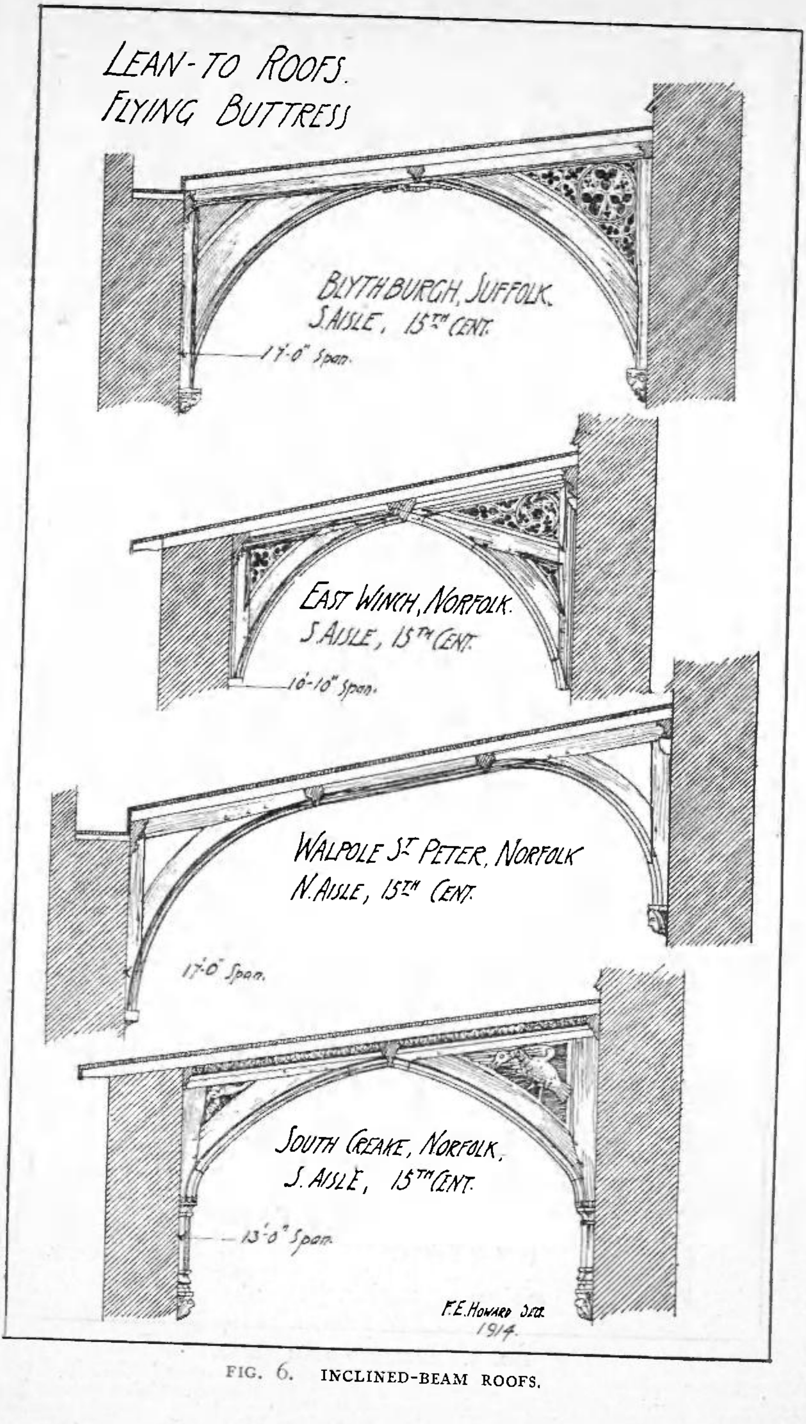


FIG. 6. INCLINED-BEAM ROOFS.

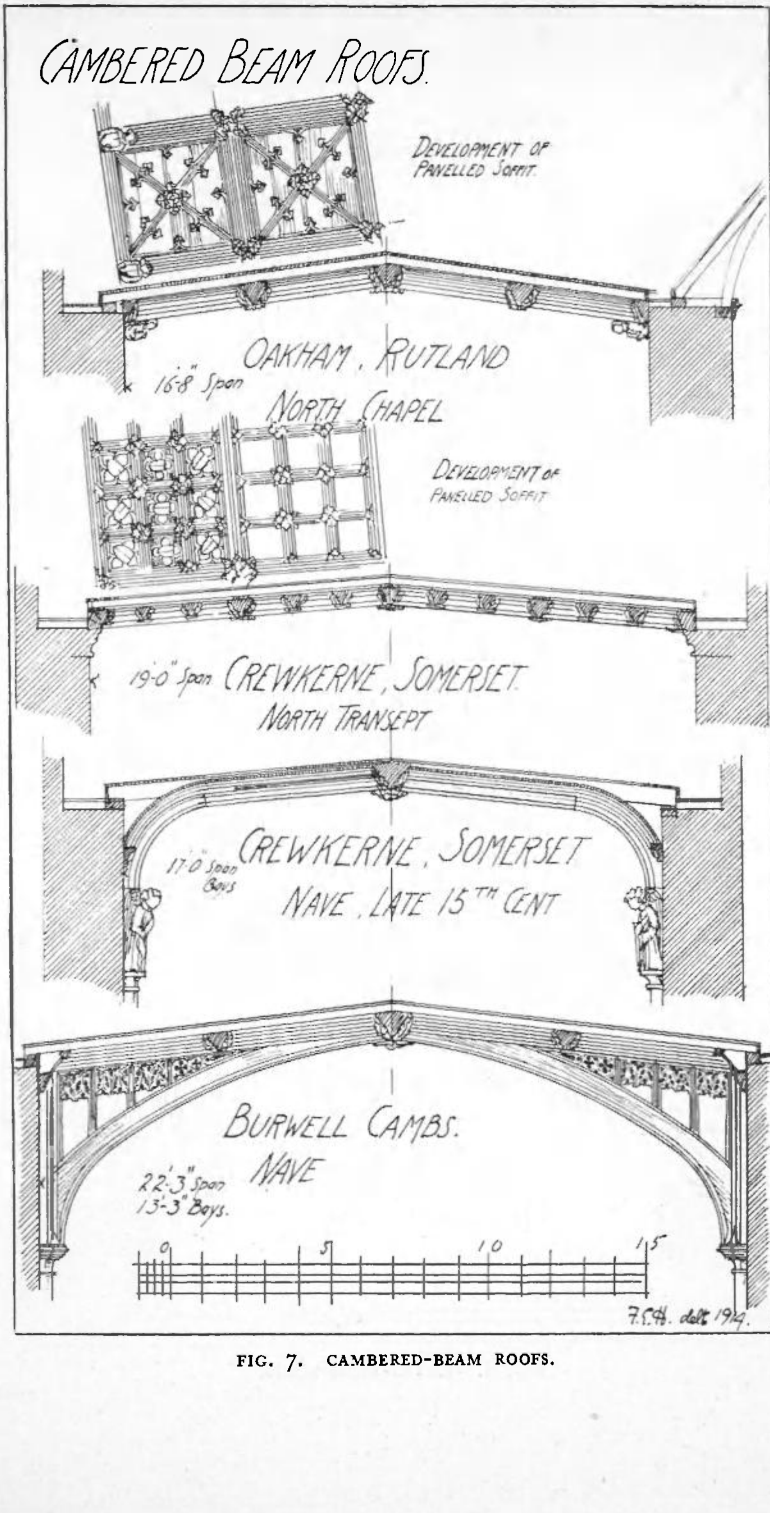


FIG. 7. CAMBERED-BEAM ROOFS.

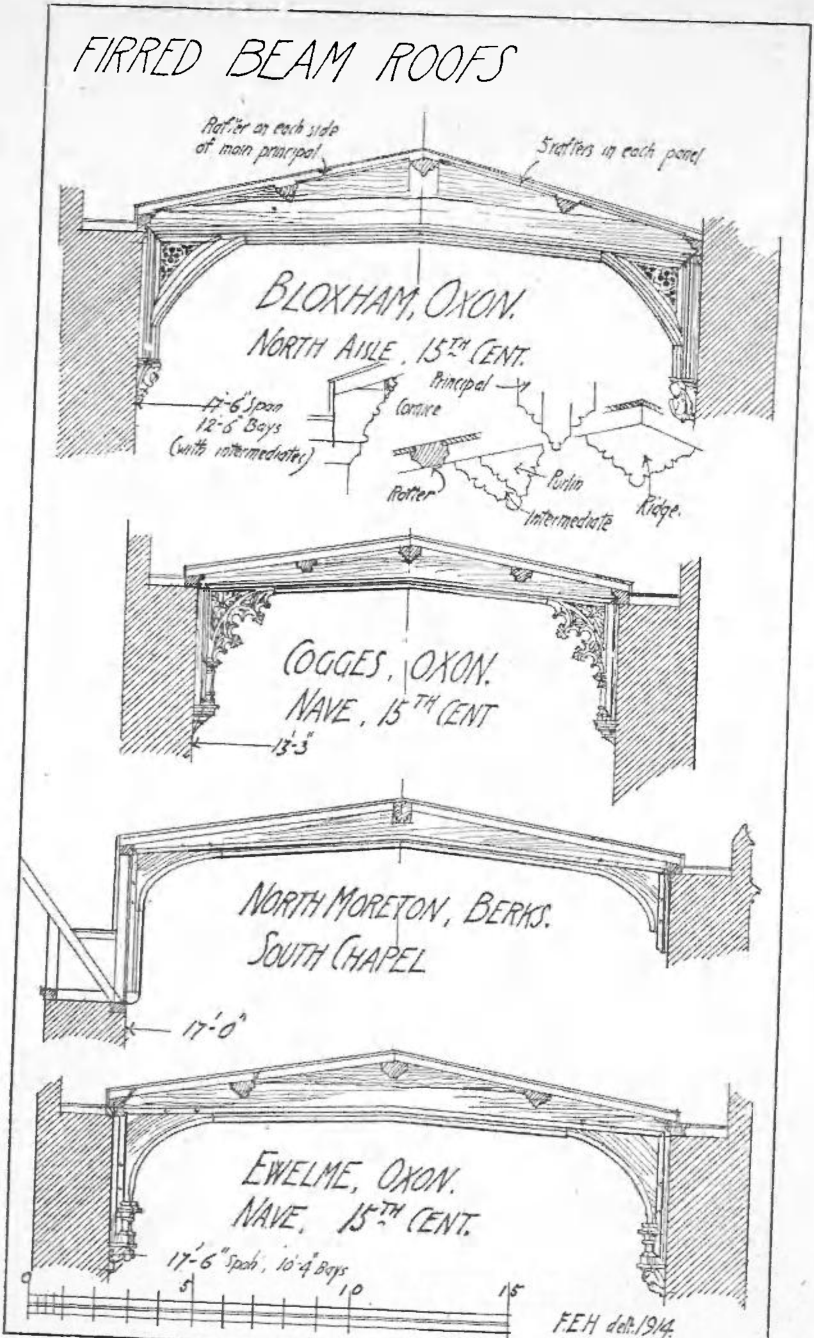


FIG. 8. FIRRED-BEAM ROOFS.

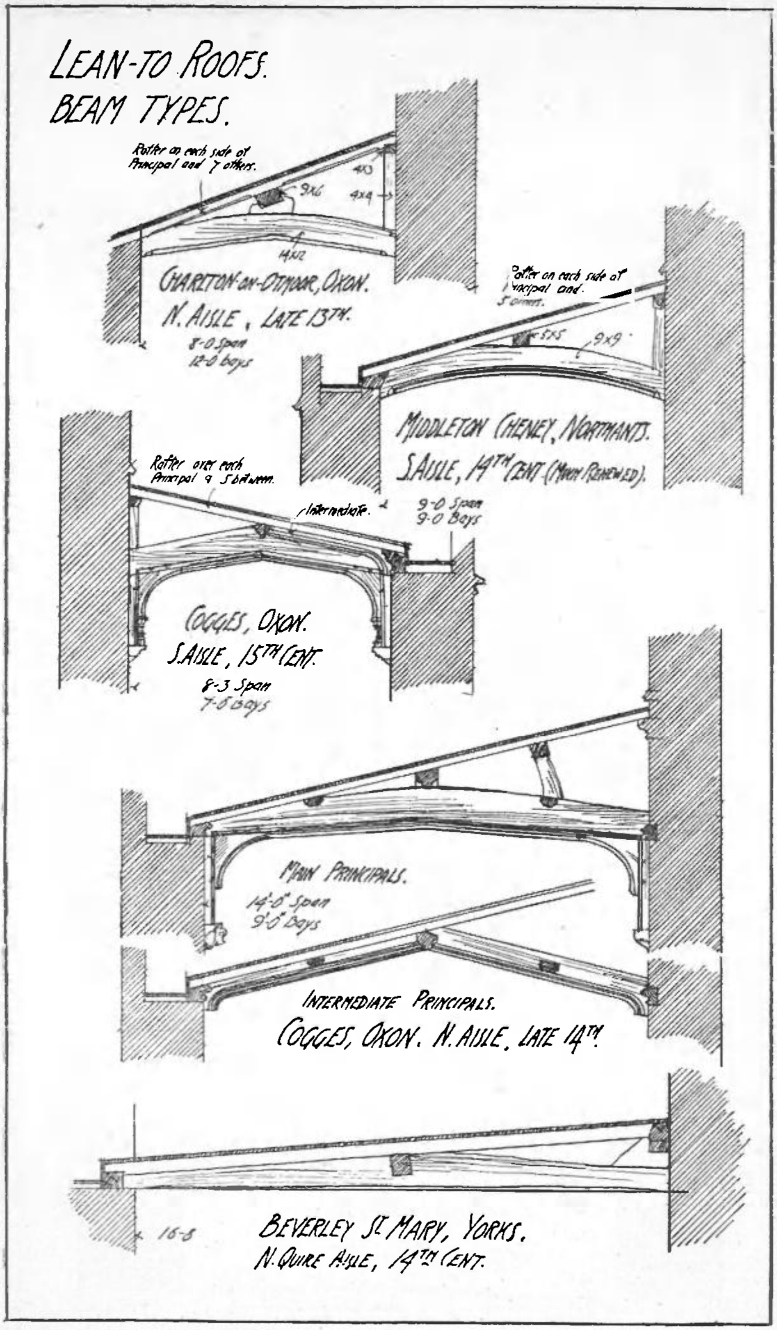


FIG 9. LEAN-TO POST-AND-BEAM ROOFS.

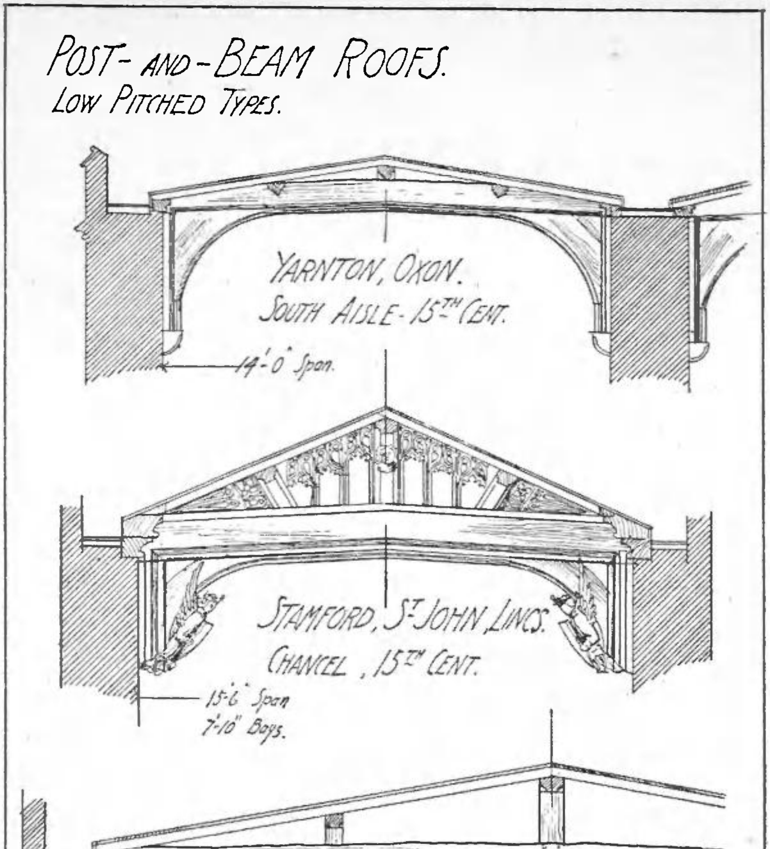


FIG. 10. LOW-PITCHED TYPES OF POST-AND-BEAM ROOFS.

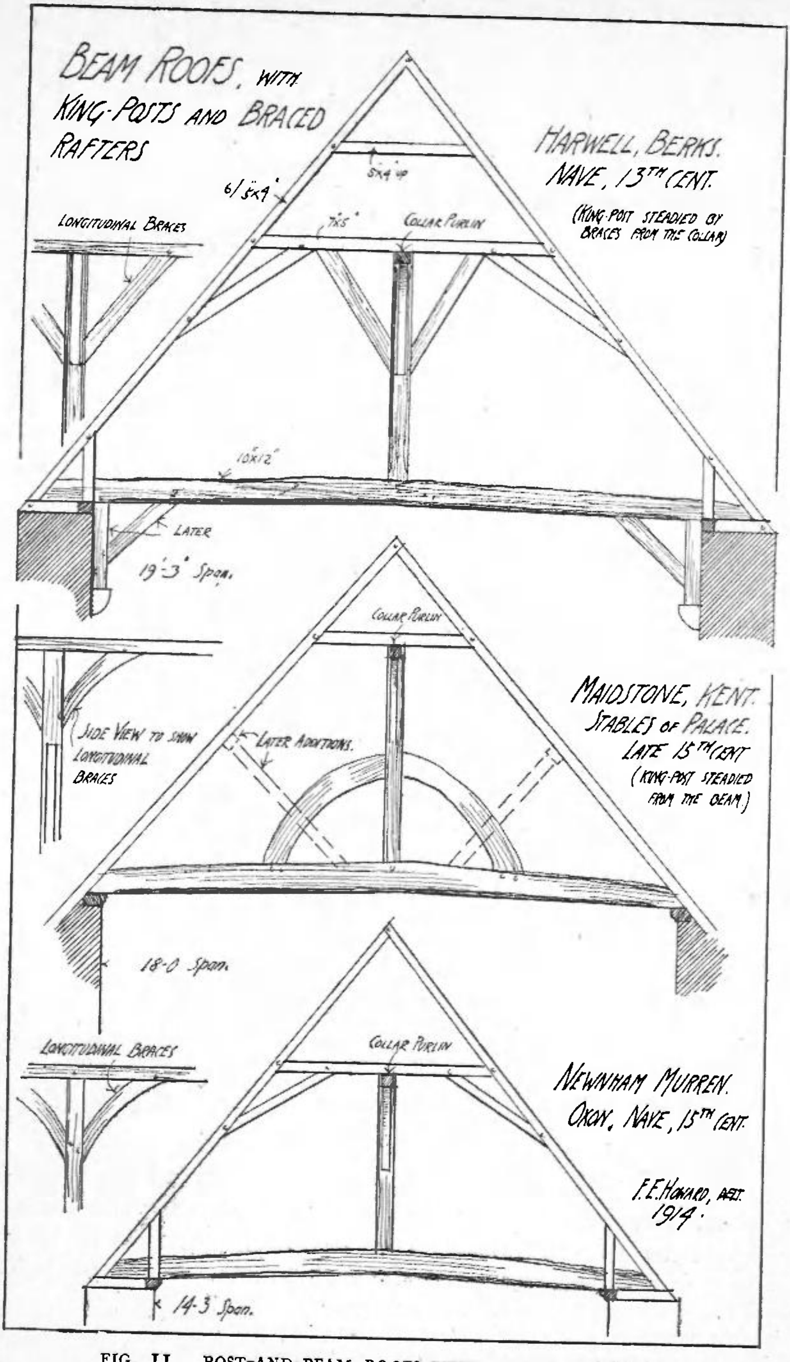
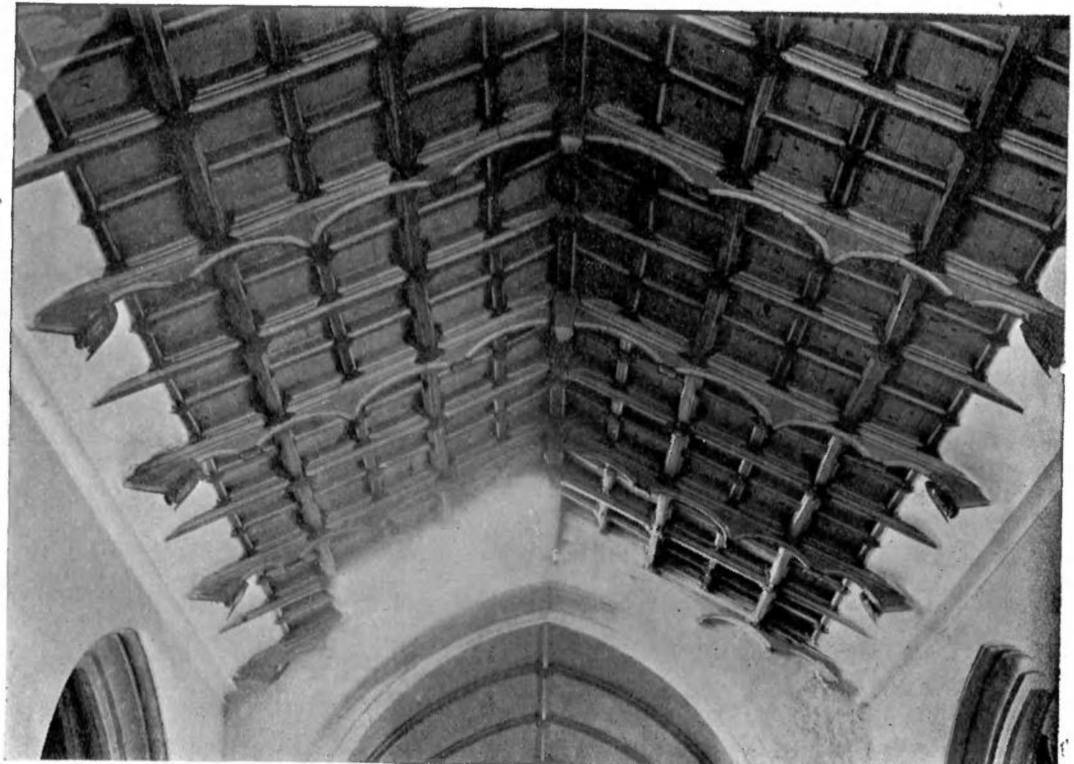


FIG. II. POST-AND-BEAM ROOFS WITH BRACED RAFTERS.

(1) The construction at the apex of the rafters. The simplest case is the ordinary couple-roof (fig. 12). The two rafters of each couple are halved or slot-tenoned and pegged together, and may be considered as hinged at the apex, since there is not the slightest attempt to neutralise the thrust by the rigidity of the joint. It is quite impossible to overcome the thrust of this form of roof, even if the joint is bolted together, for the couple-roof is very nearly akin to the arch, and its stability depends on the power of the wall to resist overturning (plate IV). A similar construction in stone, a late survival of which is not uncommon in pre-Conquest work, was probably the first step to the invention of the arch proper. At any rate it is certain that all mediaeval developments of the couple-roof tend to convert it into a more and more perfect arch. Thus the rafters are frequently strengthened by means of arch-braces, either worked in the solid[1] or, more commonly, framed into them (plate VII). It is extraordinary that some authorities seem to be under the impression that these braces are intended to tie the roof in. It is impossible that they should do so, owing partly to the mechanical conditions of the case and also to the limitations of the pegged tenon joint. Their purpose is to prevent the rafters sagging, and their effect is to turn each pair of rafters into a true arch. There are various important developments of this manner of construction. The joint at the apex is difficult to make and the construction is much improved by introducing a pendant king-post, into which both rafters and braces are framed.[2] A wedge-shaped block may be substituted for the king-post, thus affording better abutment to the rafters and braces.[3] The pendant king-post is sometimes considerably prolonged, so that the braces are very broad, or in some instances, are not wholly engaged with the rafters.[4] The effect of this is to deepen the arch so that the rafters are splendidly supported. The two braces, together with the king-post, may be said to act as a collar, strutting the rafters apart to prevent them from sagging. When the king-post is omitted and both the arch-braces are cut out of a

[1] St. Peter Hungate, Norwich (fig. 21).
[2] Westhall, Suffolk, south aisle (fig. 19).
[3] Blakeney, Norfolk (fig. 21).
[4] Southacre, Norfolk, nave (fig. 21).

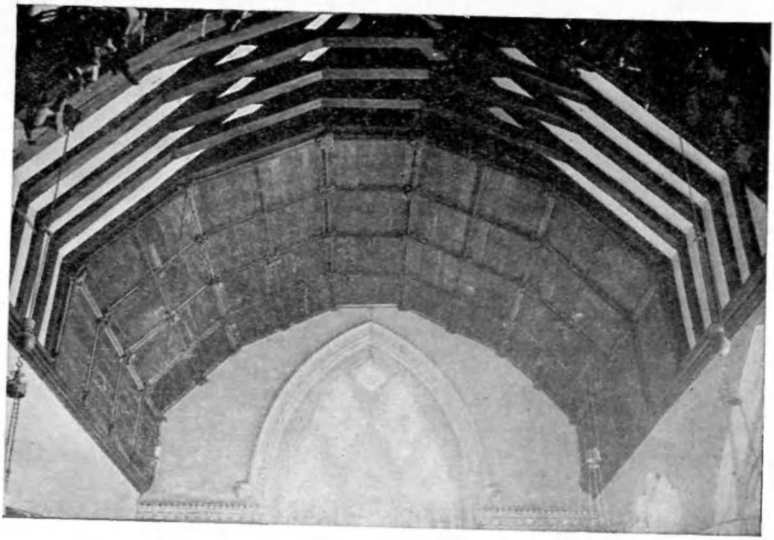
To face page 314.



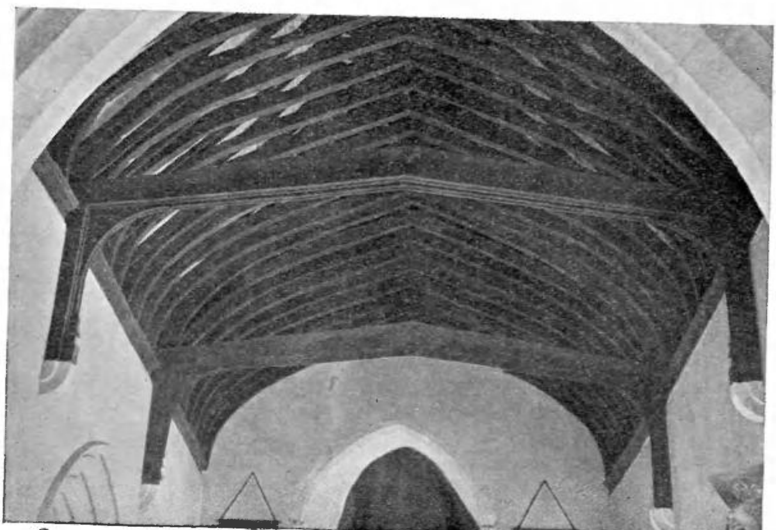
HINTON ST. GEORGE, SOMERSET: NAVE. COUPLE ROOF.

PLATE IV.

To face page 315.



NO. I. EAST HENDRED, BERKS: CHANCEL. BRACED ROOF.



NO. 2. COGGES, OXON: CHANCEL. ARCH-BRACED ROOF WITH TIE-BEAMS.

single block, the latter form an arched collar.[1] This chain of examples shows how the couple-roof may be gradually elaborated until it merges into the collar-roof.

A similar chain shows the simplification of the collar-roof into the couple-roof. The collar is most effective when fixed midway between the plate and the apex, thus dividing the span of the rafters into two equal sections.[2] Often greater height is required inside the building, and the collar must be fixed higher up, in which case the rafter is divided unequally.[3] The higher the collar is fixed, the greater the major span of the rafter becomes, until a point is reached where the collar becomes a mere block to facilitate the jointing at the apex of the rafters.[4] At this point the collar-roof merges into the couple-roof. It will be seen from the above that arch-braced and hammer-beam roofs are met with in both *couple* and *collar* forms.

On the other hand the collar-roof may be elaborated and developed. Suppose that for reasons of height the collar must be fixed at least two-thirds of the way up. Struts may be introduced from the collar to the middle of the lower span of the rafter (plate v, no. 1); in this case the rafter is supported at two points (fig. 13). Again, a pair of inclined timbers known as scissor-beams may be used as a substitute for the collar, also affording support for the rafter at two points.[5] Three points of support are provided if both collar and scissor-beams are employed,[6] or when a secondary collar is introduced in addition to the usual collar and struts.[7] The effect of the collar and struts is to produce an approximate arch (plate v, no. 1). When curved braces are substituted for the struts a perfect arch is formed, admirably fitted to carry the rafters and to resist the pressure of the wind, but exercising considerable thrust against the side walls[8] (plate v, no. 2).

A few more details remain to be noticed. If the collar is fairly low down, the upper part of the rafter needs support, so braces may rise from the collar to the rafters.[9] Again, if the collar is long and slender it may be stayed by dropping

1 Palgrave, Suffolk: see Brandon, *Open Timber Roofs*, plates 21 and 22.
2 Sutton-at-Hone, Kent (fig. 13).
3 Maidstone, Kent (fig. 11).
4 East Winch, Norfolk, nave (plate vi).
5 Stuston, Suffolk, porch (fig. 14).
6 Lympenhoe, Norfolk, nave (fig. 14).
7 Harwell, Berks. nave (fig. 11).
8 Figs. 14–20.
9 South Wraxall, Wilts. (fig. 18).

a king-post upon it from the apex or from the short upper collar.[1]

It will be noted that these remarks apply equally to all roofs without beams, whether "trussed-rafter," arch-braced, or hammer-beam.

(2) The construction at the wall-plate and the lower section of the rafters. Wall-plates are generally fixed or bedded on the inner side of the wall for two reasons. Firstly, the span of the rafters is thereby reduced as much as possible; and secondly, there is less chance of the plate sliding off the wall. The rafters of a thrusting roof are sometimes fixed to the plate by bird's-mouthing or notching.[2] Neither is a perfect solution of the difficulty of fixing the roof to the wall. The wall-plate is sometimes of great width, so as to spread the weight over as large a part of the thickness of the wall as possible, and in some cases it is wide enough to afford a base from which to spring a brace to strengthen the lower section of the rafter.[3] Another means of spreading the weight over the thickness of the wall is to employ cross wall-plates, called sole-pieces, for the rafters to pitch upon.[4] In order to make full use of the sole-piece the rafter should pitch on to the middle of it, but in this case the outer half of the sole-piece would be exposed to the weather, unless sprocket-pieces are employed.[5] A special piece of construction is therefore necessary. The rafter pitches upon the *outer* extremity of the sole-piece and a short post, or ashlar piece, usually vertical and flush with the surface of the wall (figs. 13 and 14), or a curved brace (fig. 16), is tightly wedged between the rafter and the inner end of the sole-piece, so that the weight is applied to both ends of the sole-piece. The effect of this construction is to give each rafter a broad foot, and it is found that the thrust is brought down in a more vertical direction when this method is employed.

In the earliest instances the sole-pieces are fixed to the wall by a small plate, bedded in the middle of the

[1] Beckley, Oxon. chancel.

[2] Wells, Vicars' Close (fig. 18).

[3] Brympton d'Evercy, Somerset, priest's house (fig. 18).

[4] Lympenhoe, Norfolk (fig. 14).

[5] Sutton-at-Hone, Kent, chapel (fig. 13).

wall[1] over which the sole-pieces are notched, but it is evident that the ideal wall-plate should be of the entire width of the wall. Such a wall-plate cannot possibly be obtained in one piece, so it must be framed up. A framed wall-plate generally consists of an inner and an outer plate, connected by cross pieces, tenoned into them at intervals.[2] Such a plate forms a splendid base for the framed-up rafter feet, but it is rather wasteful of timber. Often the sole-pieces are omitted and the ashlar pieces are tenoned in to the inner plate, while the rafter feet pitch upon the outer plate (fig. 15). In another variety of construction the outer plate and the cross pieces are omitted and both the ashlar pieces and the sole-pieces are tenoned into the inner plate.[3] In this case there is sometimes a central plate in the heart of the wall.[4] Occasionally the wall-plate is fixed at a lower level than the sole-pieces, which are therefore tenoned into the ashlar pieces, instead of the wall-plate.[5] This is an excellent method of securing the rafter feet to the wall, for the roof cannot spread without pushing off several courses of masonry. In some cases the top of the wall slopes inwards, producing the same effect.

It has been said that in most cases the ashlar pieces are vertical and flush with the wall-face. If they lean forward they reduce the span of the rafter, but the thrust is slightly increased. Very frequently the ashlar pieces take the form of curved braces. Generally the curve is a continuation of that of the upper braces, so that each pair of rafters is carried by a wooden arch, springing from the wall-plate;[6] the upper and lower braces may even be in one piece if the roof is a small one.[7] Sometimes, however, the lower brace is of an entirely different curve and the arch is a cripple.[8] This is not nearly so serious in timber construction as in masonry, for the timber can resist the cross strain with ease. Where special strength is required, as in the principals of double-framed roofs, both ashlar pieces and arch-braces are retained.[9]

[1] Sutton-at-Hone, (fig. 13) and Stuston (fig. 14).

[2] Sennen, Cornwall (fig. 17.)

[3] Cogges, Oxon. chancel (fig. 14).

[4] Heckington, Lincoln, porch. See Brandon, *Open Timber Roofs*, plate 1.

[5] Tedburn St. Mary, Devon (fig. 16).

[6] Sutton Courtney, Berks. chancel (fig. 15).

[7] South Wraxall, Wilts. hall (fig. 18).

[8] Swinbrook, Oxon. chancel (fig. 15).

[9] Ewelme, Oxon, grammar school (fig. 18).

A method of strengthening the rafters, which leads to important discoveries, is to run the sole-piece out, so that it projects beyond the inner surface of the wall, and acts as a cantilever, from the end of which a queen-post, an arch-brace, or both, rise to support the rafters. By this means the span of the arch supporting the rafters is much reduced. When the sole-piece projects from the wall, it is called a hammer-beam, so that this is the most elementary form of hammer-beam roof. It will be seen that the invention of the sole-piece, not later than the Norman period, made the discovery of the use of the hammer-beam inevitable. The hammer-beam is a pure cantilever, the wall-plate being the fulcrum, while the rafter-foot is the point of application, and the brace, carrying the rafter, is the weight. By its means the very weight and thrust of the roof helps to support the rafter at its weakest point.

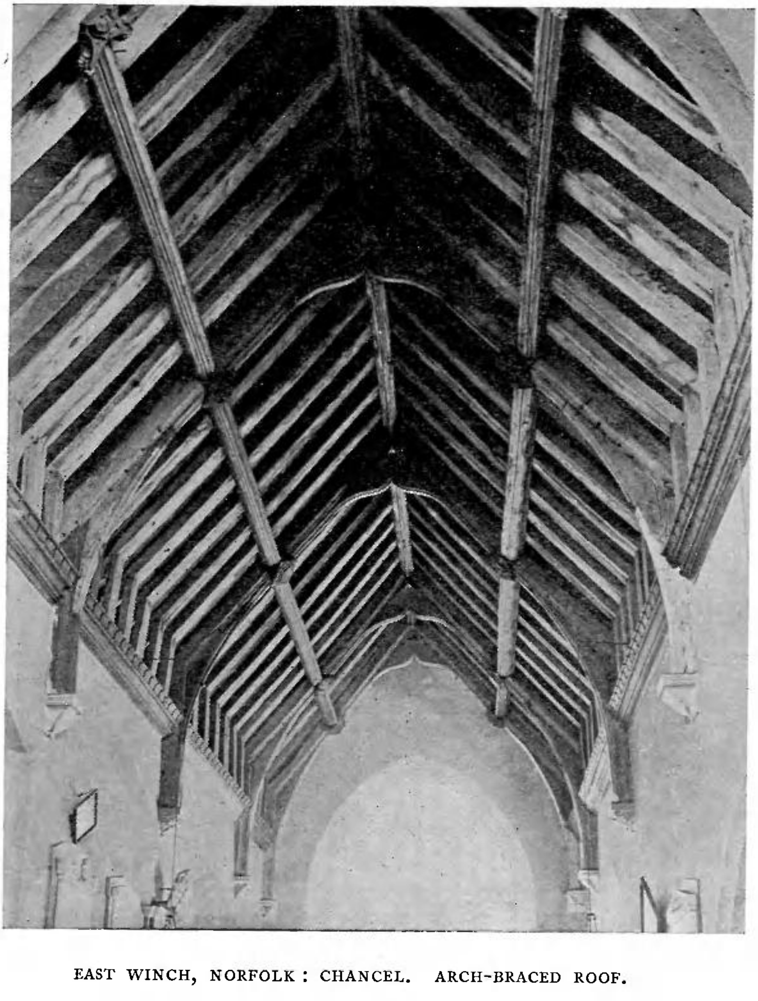
When the hammer-beam projects far from the wall (and the further it projects, the more effective it is), it must be supported upon a bracket, or it will bend down under the strain brought upon it by the brace.[1] This bracket may consist of a solid triangular block of wood, which may be framed into a wall-post,[2] or it may consist of a wall-post and a brace.[3] In addition to supporting the cantilever or hammer-beam, the bracket performs another duty of almost equal importance. The roofs described before are entirely dependent upon their fixing to the wall-plate and the wall. Now that the bracket is added the roof cannot slide outwards without pushing off the top courses of the wall. Moreover, the wall-post and the rafter are so securely fixed together that they form one bent rafter, springing not from the wall-plate, but from the corbel of the wall-post, some feet below. Thus the thrust of the roof is reduced, for the roof has become more acute, and the thrust is brought down to a point where the wall is more stable, and where the weight of the masonry above helps to load it and keep it from overturning.

In some places the hammer-beam roof appears to have

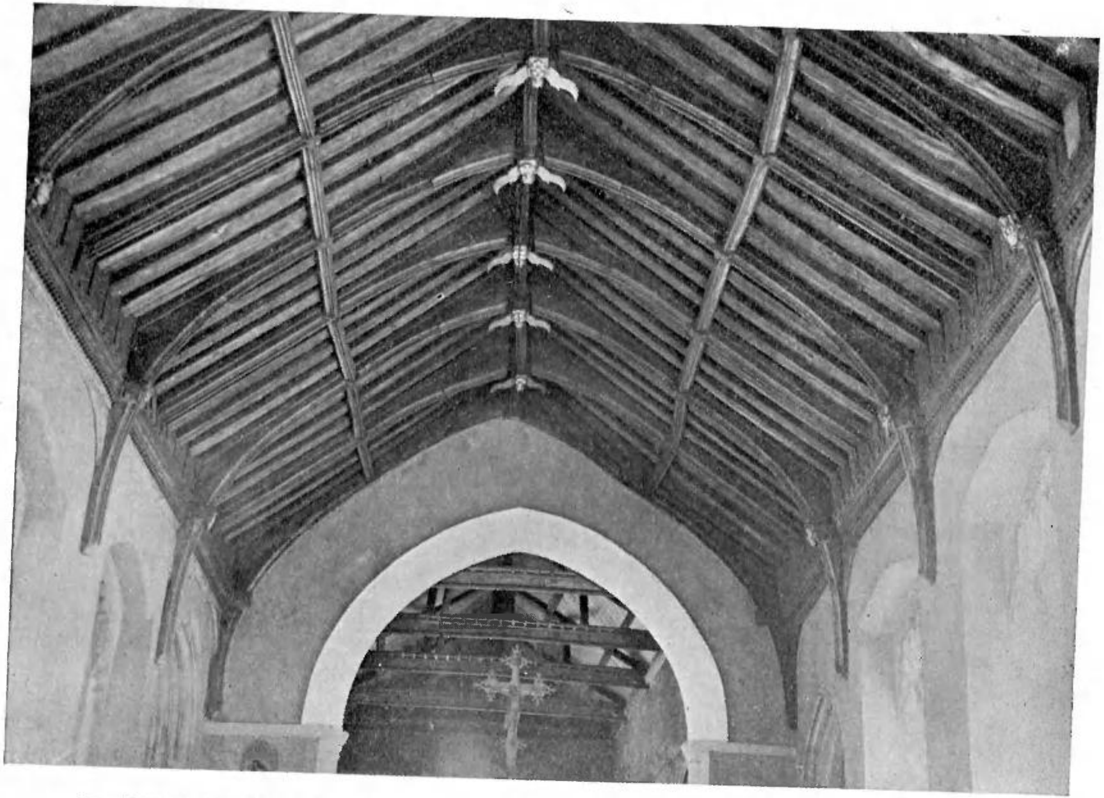
[1] The brackets are often omitted in East Anglia, where the hammer-beam is often cut into the form of an angel.

[2] Southwold, Suffolk, nave (fig. 21).

[3] Blakeney, Norfolk, nave (fig. 21).



EAST WINCH, NORFOLK: CHANCEL. ARCH-BRACED ROOF.



ST. MICHAEL-AT-PLEA, NORWICH, NORFOLK: NAVE. ARCH-BRACED ROOF WITH HAMMER-BEAMS.

To face page 319.

been evolved in a somewhat different manner. Starting from the case where the rafters pitch down upon a single wall-plate, the tendency of the roof to slide off the wall is the first defect to remedy. A block of wood fixed to the foot of the rafter serves to check this. It is sometimes carved into the form of an angel.[1] The next step is to tenon a wall-post into the rafter, but this naturally tends to fold up under the strain, unless other steps are taken to prevent this occurring. The wall-post may be tenoned into its corbel to prevent its collapsing,[2] or a triangular bracket may be substituted, or the wall-post may be kept at a rigid angle with the rafter by means of an arch-brace.[3] This is by far the best method, for not only does the brace prevent the collapse of the wall-post, and thus carry the thrust down to the lower end of the post, but it also supports the rafter. Unlike the cases first described, the brace springs from the wall-post instead of from the wall-plate. The wall-post may be prolonged beyond the brace in order to bring down the thrust lower.[4] When sole-pieces are introduced in addition to the wall-post (and they are rarely omitted),[5] the strength of the construction is much increased, for the wall-post and the ashlar piece are made continuous, and the sole-piece helps to keep them at a fixed angle with the rafter, and so to carry the thrust down as low as possible. The larger the brace, the lower the thrust is brought down, but large timbers for such braces are difficult to obtain, and cannot easily be jointed end to end.[6] As a remedy the sole-piece is projected from the wall as a hammer-beam, dividing the brace into two sections, the lower tenoned into the wall-post and the hammer-beam, the upper tenoned into the hammer-beam and rafter[7] (plate VII). The effect of this expedient is that, while the framework is even stronger than before, the braces are of a reasonable size.

The curves of the upper and lower sections of the

[1] Bradford Abbas, Dorset, nave (fig. 12).

[2] Worcester, Guesten Hall (Dollman, *Ancient Domestic Architecture*).

[3] Trunch, Norfolk (fig. 12).

[4] Trunch, Norfolk (fig. 12). Sall is a still more notable example of the elongation of the wall-plate.

[5] Snettisham, Norfolk, nave, has an arch-braced roof with wall-posts, but no sole-pieces.

[6] Edington, Wilts. nave. The end bay has huge arch-braces, each in two sections (fig. 20).

[7] St. Giles and St. Michael-at-Plea, Norwich (fig. 20).

arch-brace need not necessarily be continuous.[1] When the curves are struck from the same centre, the upper brace is rather flat. If it is brought further forward and tilted up at a sharper angle it affords more direct support to the rafter,[2] and incidentally it produces the trefoil arch characteristic of the hammer-beam roof (plate VIII).

An extension of this system of bracketing leads to the invention of the double hammer-beam roof (plate IX and fig. 22). The lower brace supports the lower hammer-beam, the lower hammer-beam carries the ashlar piece (which by its removal from the wall has become a queen-post), and this in its turn holds up the rafter. The latter is so well supported at this point that it can serve as a point of support for another bracket formed by a second hammer-beam, framed into the rafter and prevented from dropping by a brace rising from the lower hammer-beam. The upper hammer-beam carries another post and brace, supporting the rafter at yet another point. The system might be extended indefinitely, and triple or quadruple hammer-beam roofs are within the bounds of possibility.[3]

The effect of the double range of hammer-beams is so beautiful that it was often copied by carpenters who had not realised its true meaning. In many instances the purpose of the upper hammer-beams (that is, to support the queen-post and brace) is overlooked, the queen-post is omitted and the brace springs from the rafter, as in a single hammer-beam roof, while the upper hammer-beam projects uselessly into the empty air.[4] These false double hammer-beam roofs are by no means uncommon. Some are not so futile as others, while all, in spite of their illogical construction, have a magnificent effect (plate IX, no. 2).

It is possible for a double system of arch-braces to be applied to a roof with the aid of hammer-beams. Generally one of the sets of braces forms a pointed arch

[1] St. Giles, Norwich (fig. 20).

[2] Blakeney, Norfolk (fig. 21).

[3] The extraordinary roof of Hinton St. George, Somerset, nave (plate iv), with its pendant posts and arch-pieces between, may be compared with the double hammer-beam roofs. Also the beautiful roof of the chancel of Ufford, Suffolk, where the pendant posts between the braces produce the effect of a double hammer-beam roof.

[4] Tilney All Saints (fig. 22).

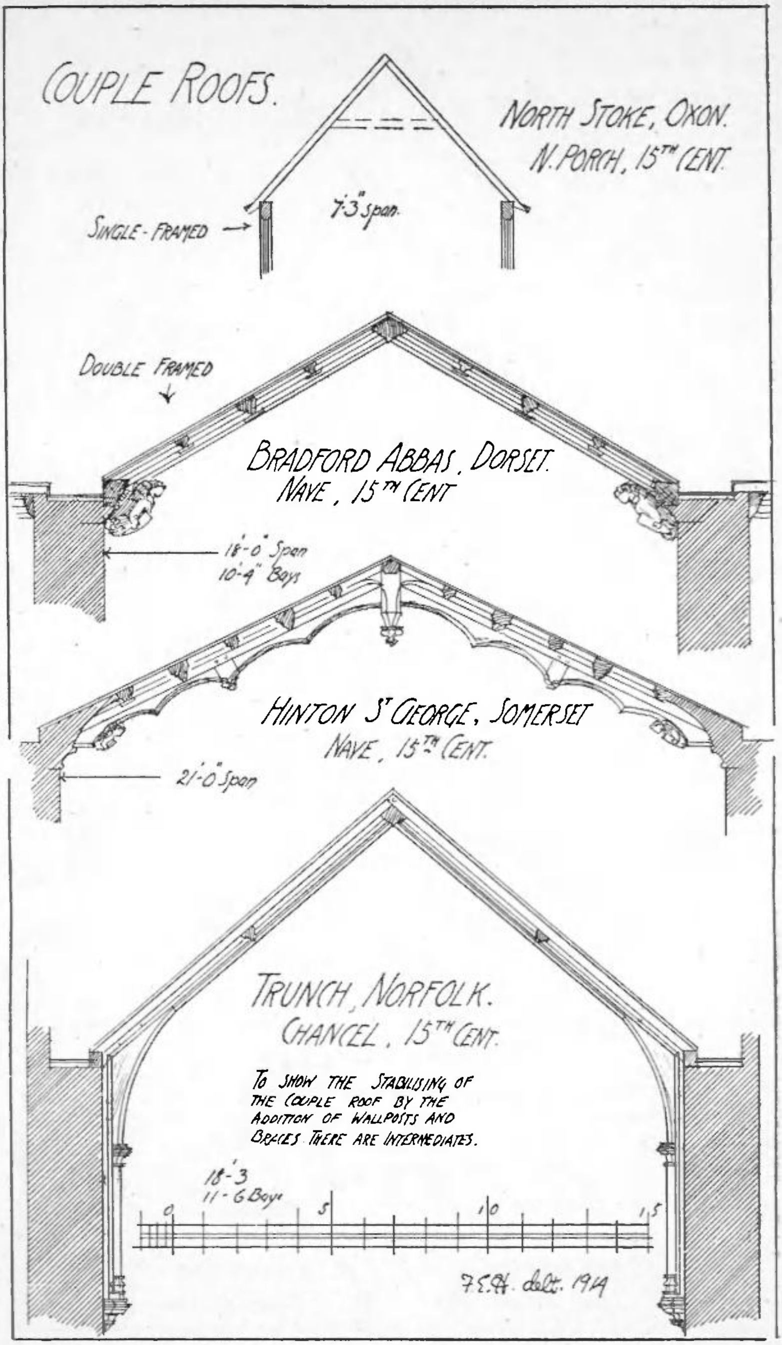


FIG. 12. COUPIE ROOFS.

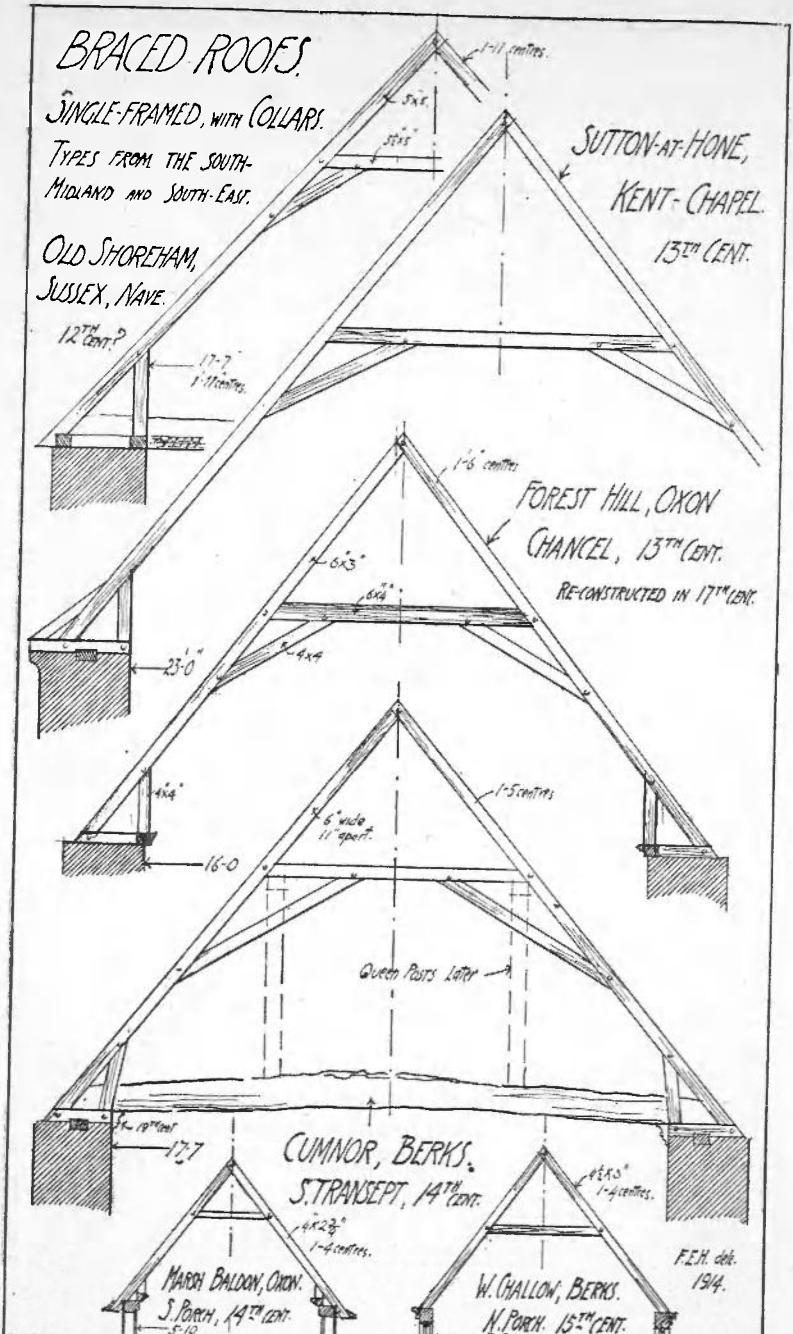


FIG. 13. BRACED ROOFS.

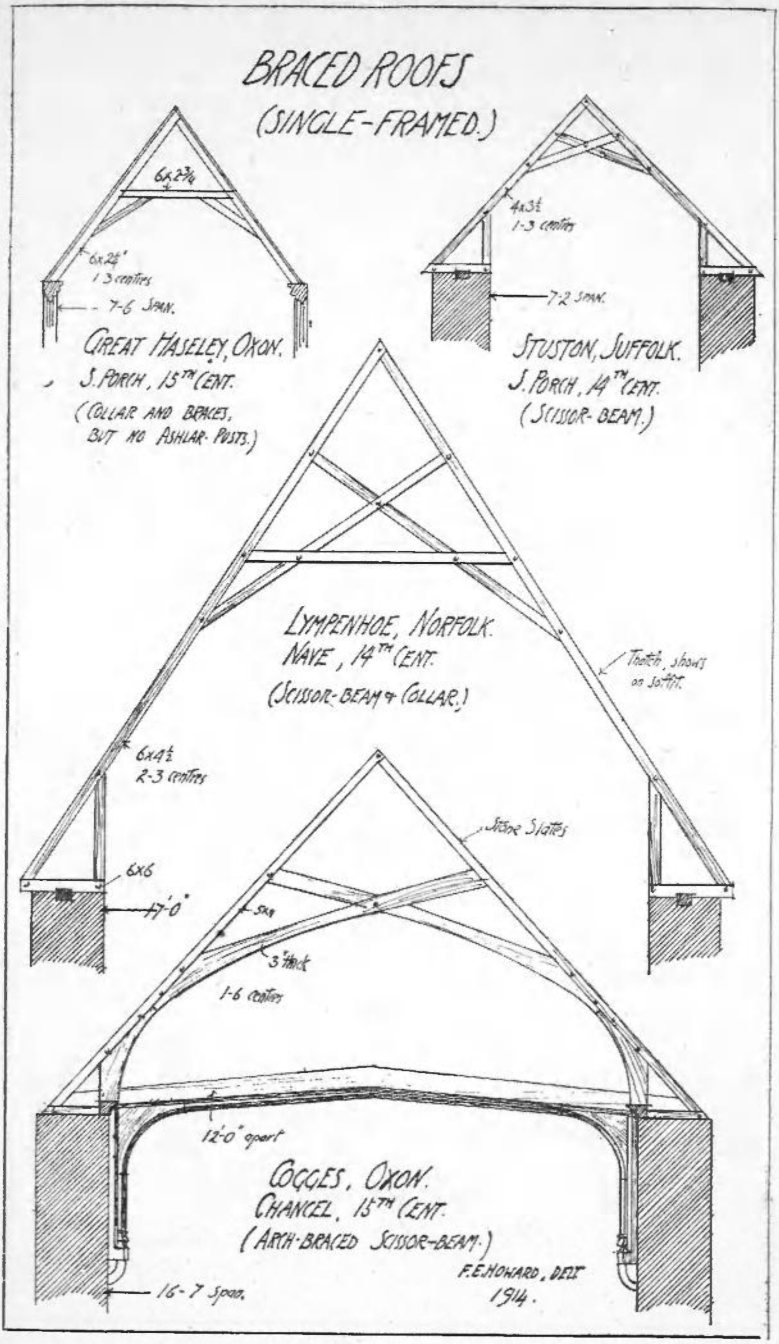


FIG. 14 BRACED ROOFS, INCLUDING SCISSOR-BEAM TYPES.

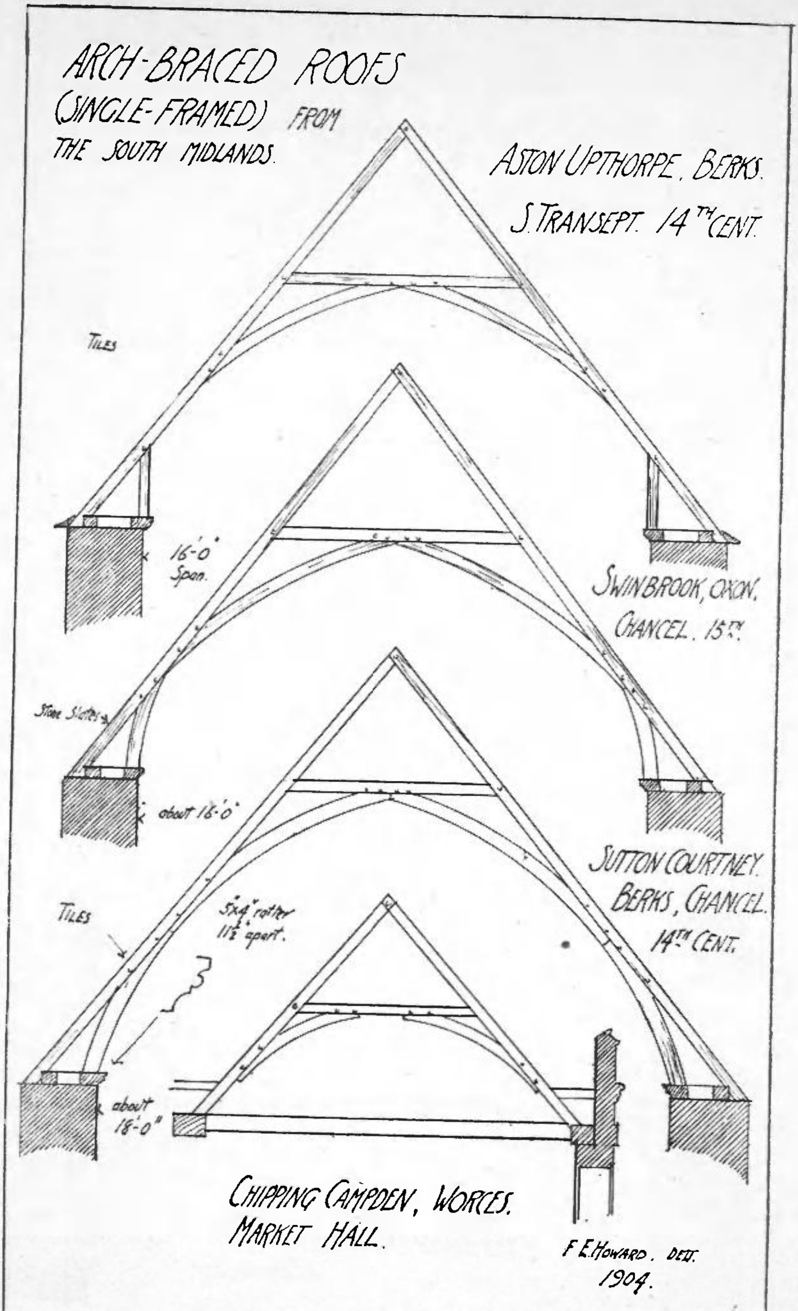


FIG. 15. ARCH-BRACED ROOFS.

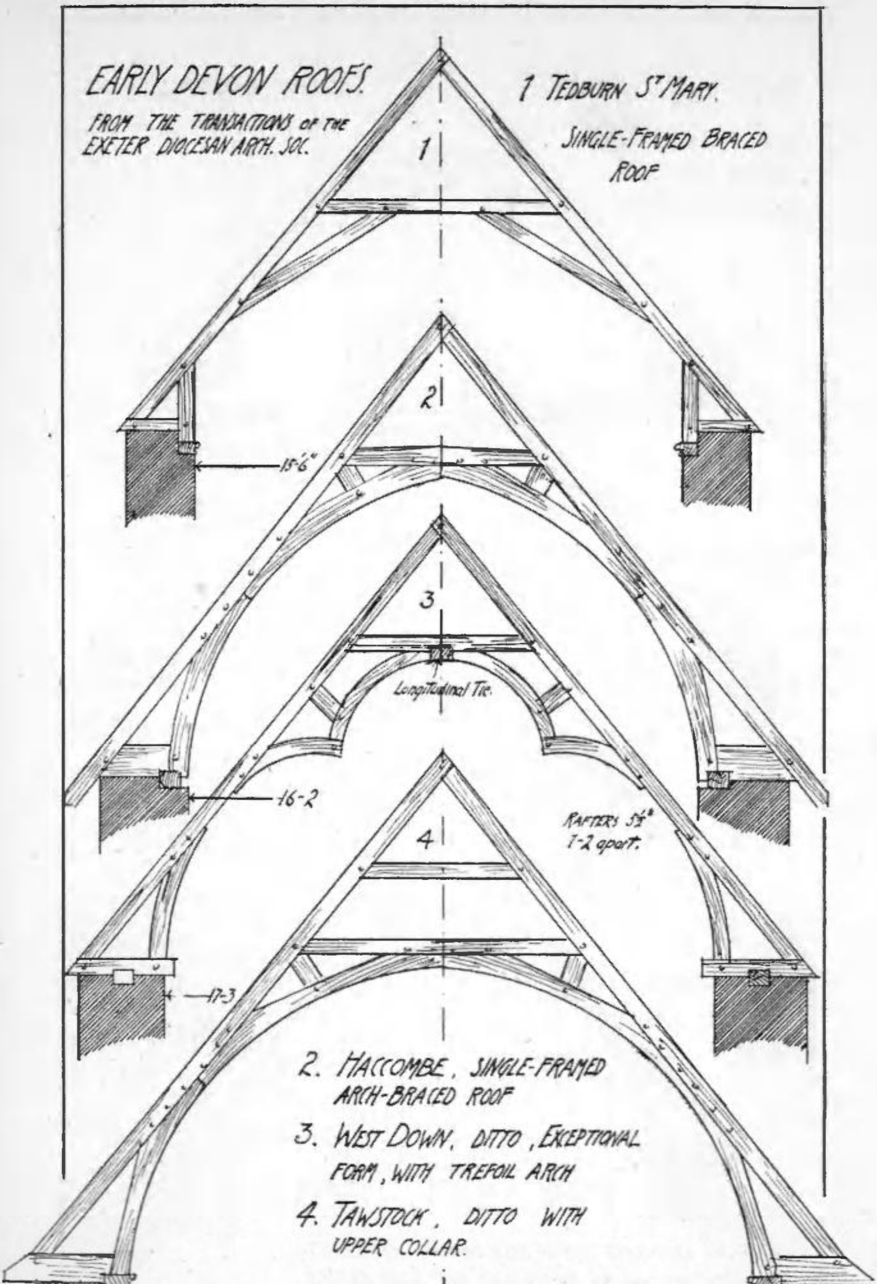


FIG. 16. ARCH-BRACED ROOFS.

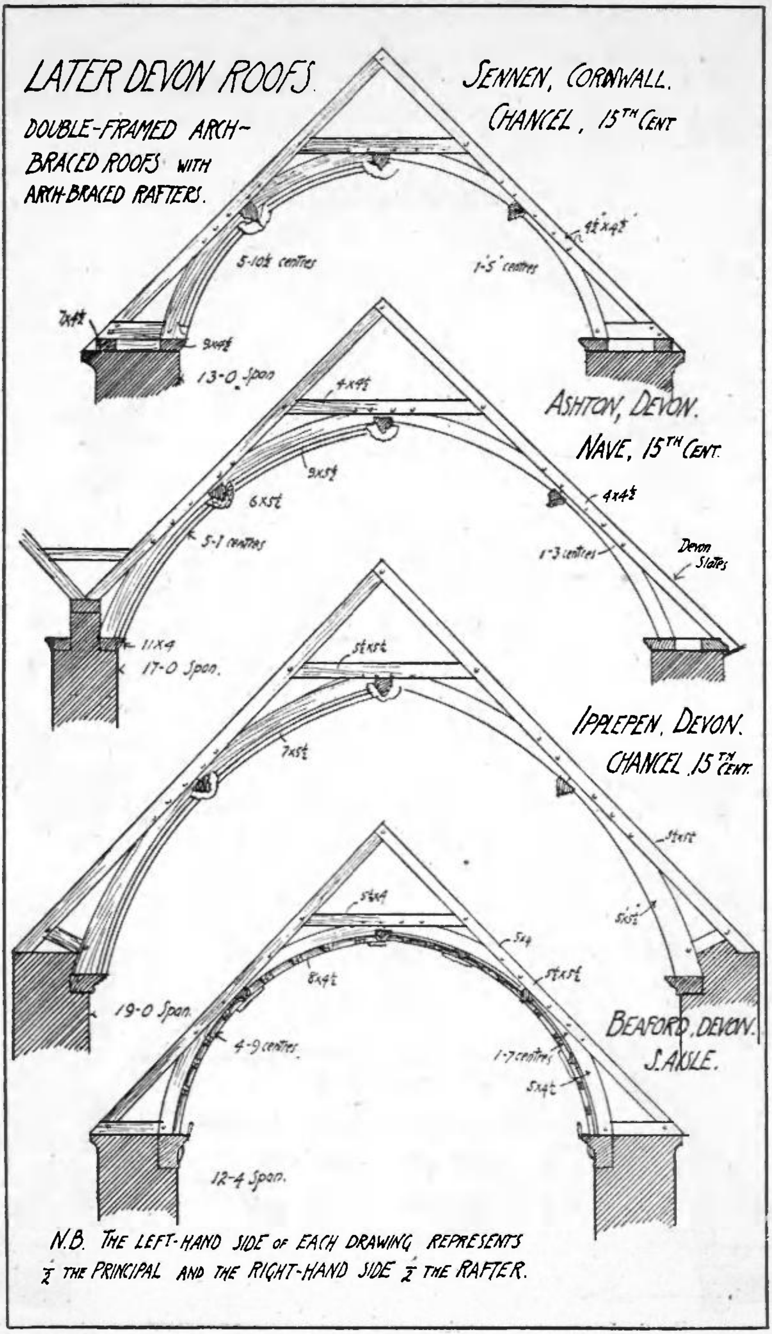


FIG. 17. ARCH-BRACED ROOFS, DOUBLE-FRAMED, WITH ARCH-BRACED RAFTERS.

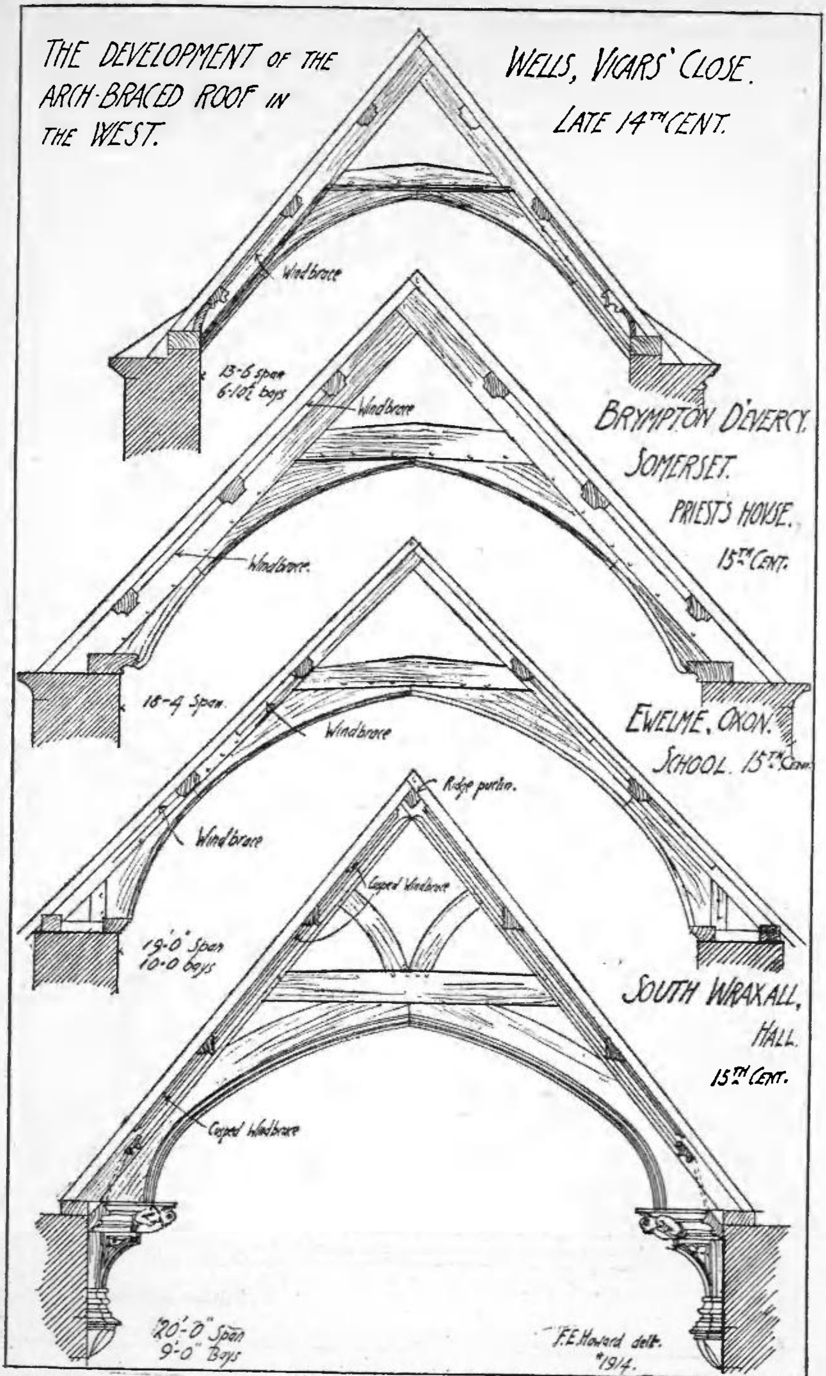


FIG. 18. ARCH-BRACED ROOFS, DOUBLE-FRAMED, SHOWING DEVELOPMENT OF THE HAMMER-BEAM.

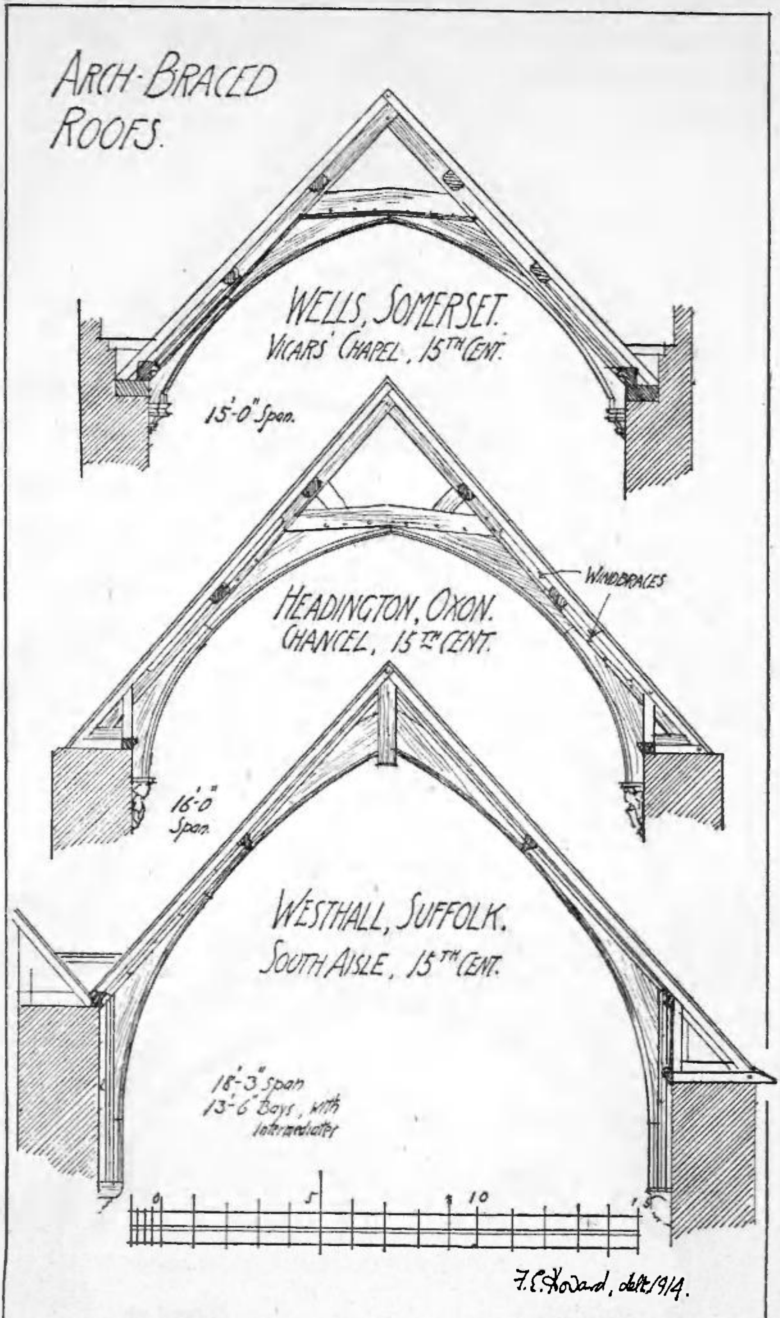


FIG. 19. ARCH-BRACED ROOFS, SHOWING DEVELOPMENT OF THE WALL-POST.

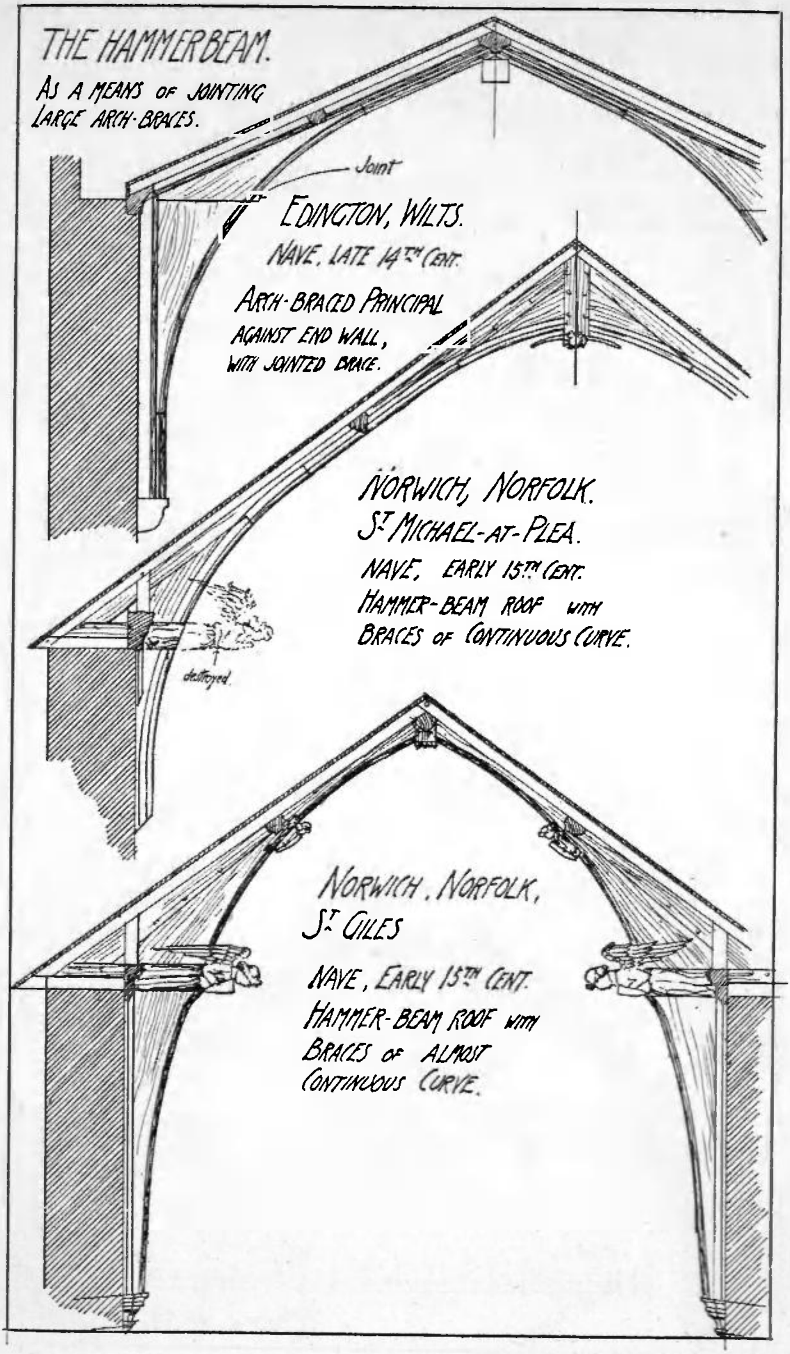


FIG. 20. ARCH-BRACED ROOFS, DOUBLE-FRAMED, SHOWING DEVELOPMENT OF THE HAMMER-BEAM.

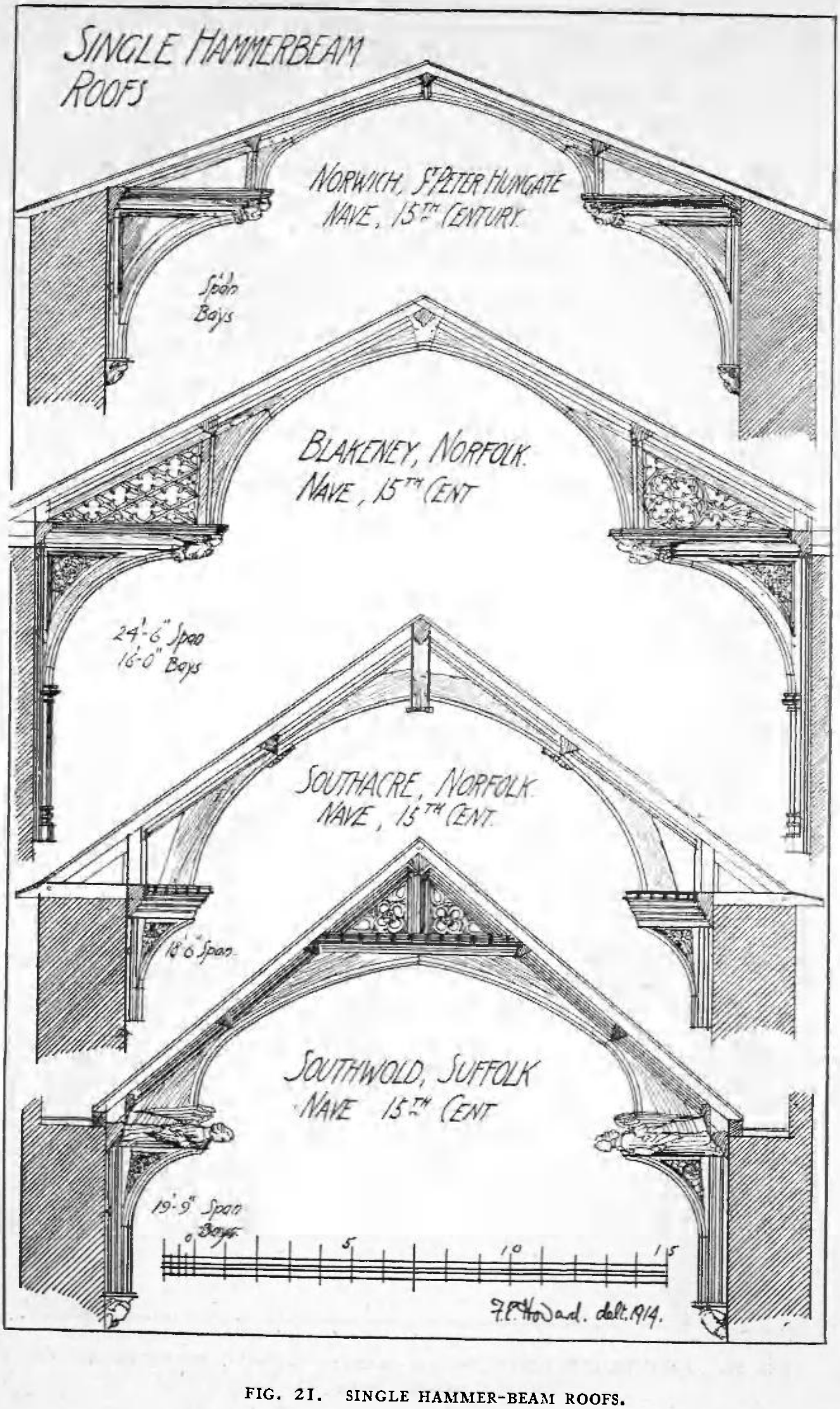


FIG. 21. SINGLE HAMMER-BEAM ROOFS.

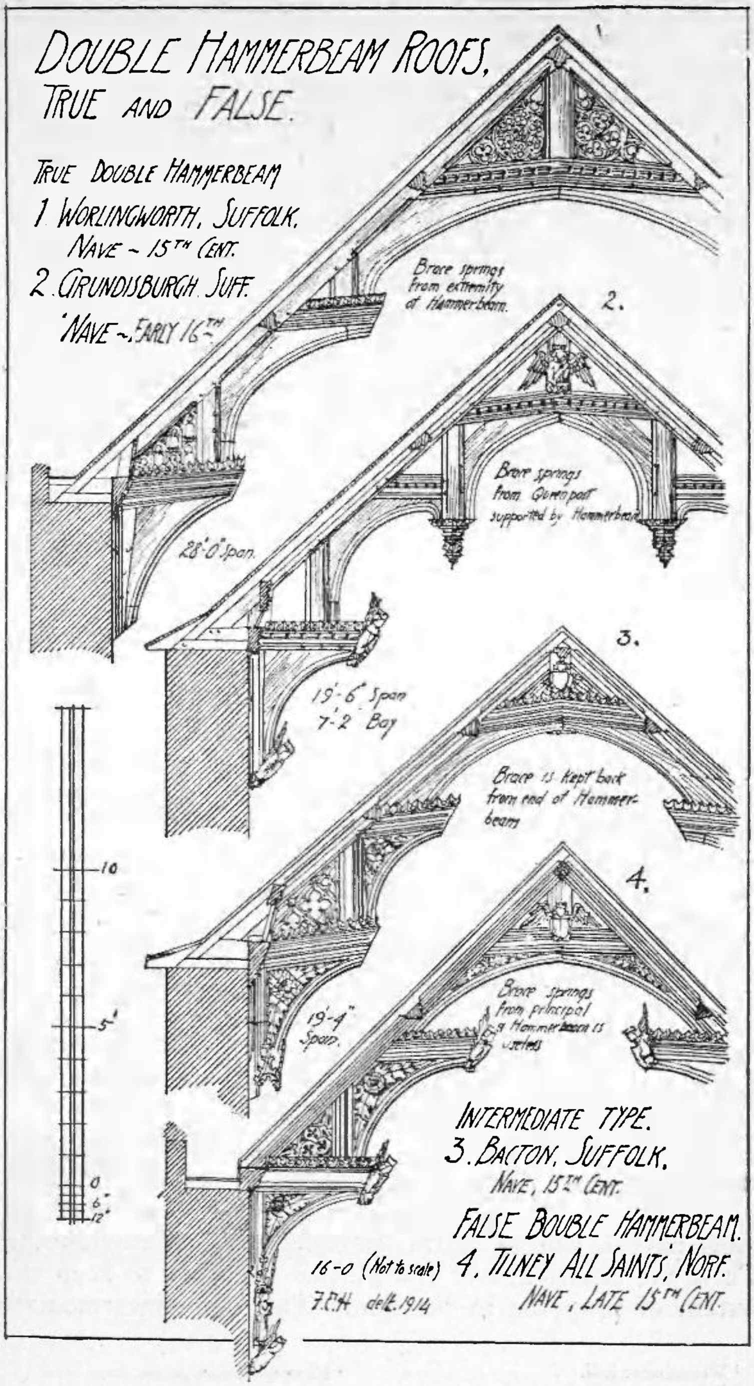


FIG. 22. DOUBLE HAMMER-BEAM ROOFS.

struck from two or four centres, while the other is a trefoil. The hammer-beams and the queen-posts run through the braces and divide them into convenient sections. This method of construction is remarkably strong, and the timbers required are all of moderate length, so that it is very suitable for roofs of great span. Sometimes the pointed arch is of enormous strength while the trefoiled arch is comparatively insignificant.[1] In other cases both arches are of equal importance,[2] while in others the strength of the roof lies mainly in the trefoiled arch, and the pointed arch is only retained as an extra safeguard.[3]

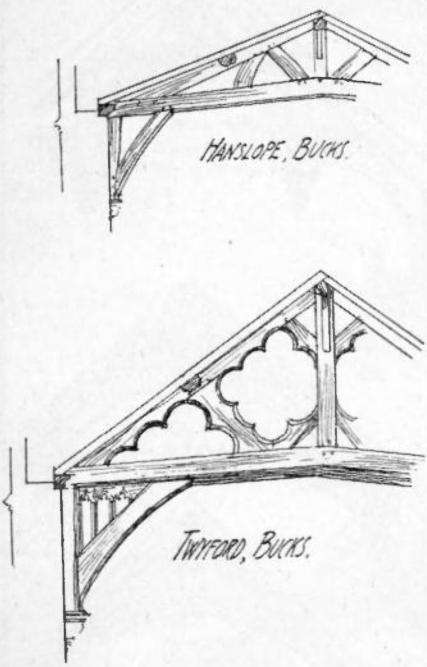


FIG. 23.

Trussed Roofs. It has been said that it is practically impossible to truss a roof without the aid of a tie-beam or a pair of scissor-beams unless ironwork is employed to secure the joints. Roofs which depend for their strength upon iron straps and bolts cannot be considered as true carpentry, and so do not come within the scope of this paper, so this section is chiefly concerned with the consideration of tie-beam roofs.

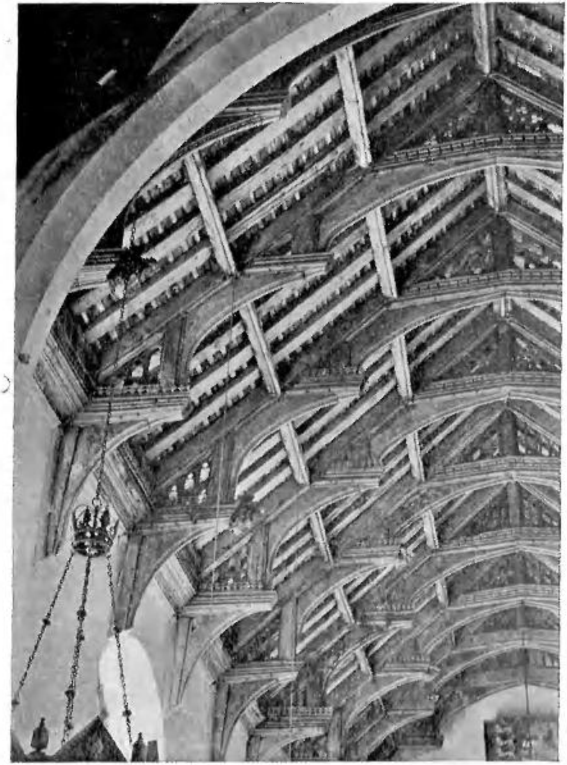
Practically all mediaeval tie-beam roofs are double-framed, and may be distinguished from beam-roofs by their having principal rafters. It is true that some beam-roofs have a pair of extra stout rafters over each beam. These are notched over the purlins and help to keep the system of propping in position. This is an intermediate

[1] Westminster hall.
[2] Eltham palace, hall.
[3] Hampton Court palace, hall.

[F. H. Crossley, phot.

NO. I. BADINGHAM, SUFFOLK: NAVE. HAMMER-BEAM ROOF, COLLAR TYPE.

NO. 2. THORNHAM, NORFOLK: NAVE. HAMMER-BEAM ROOF, COUPLE TYPE.



[F. H. Crossley, *phot.*

NO. I. WORLINGWORTH, SUFFOLK: NAVE. DOUBLE HAMMER-BEAM ROOF.

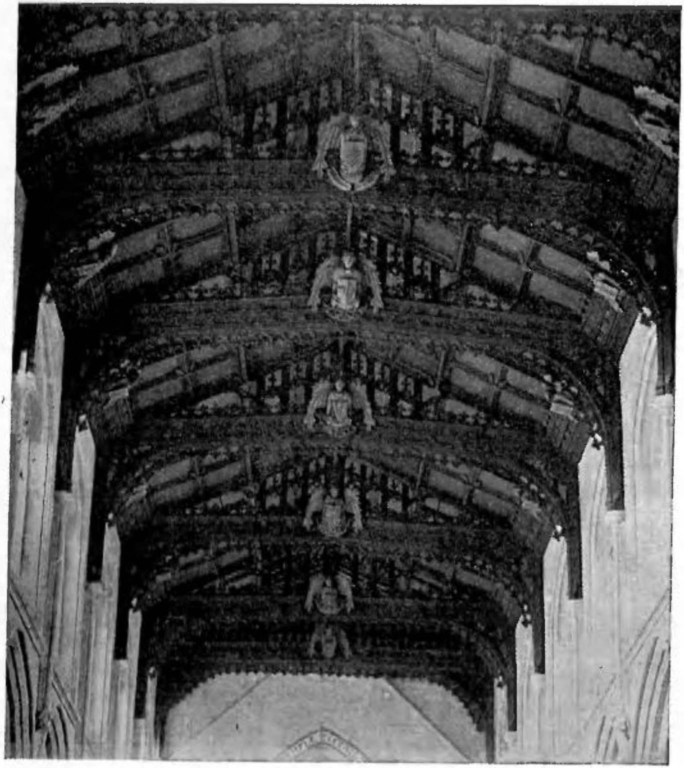
To face page 332.

PLATE IX.

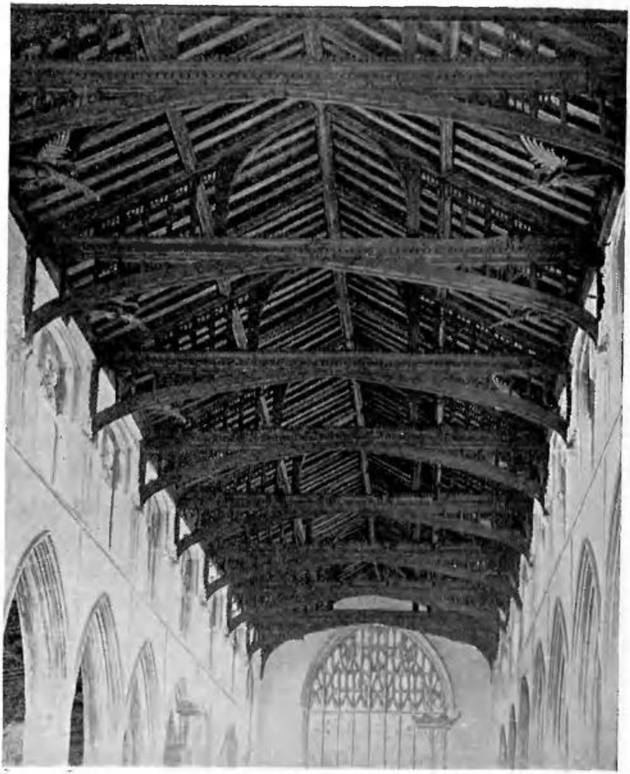
[F. H. Crossley, phot.

NO. 2. WOOLPIT, SUFFOLK : NAVE. FALSE DOUBLE HAMMER-BEAM ROOF.

WALPOLE ST. PETER, NORFOLK: NAVE. COUPLE-CLOSE ROOF WITH RUDIMENTARY QUEEN-POSTS.



NO. I. ST. CUTHBERT, WELLS, SOMERSET: NAVE.
KING-POST ROOF.



NO. 2. ST. NICHOLAS, LYNN, NORFOLK: NAVE.
QUEEN-POST ROOF.

To face page 333.

form, between the beam and tie-beam roofs. In a true tie-beam roof the purlins are carried by the principal rafters.

Again, such a roof as that of Hanslope (fig. 23), where the pitch of the principal rafters is very flat, and the system of braces and struts very elaborate, may also be regarded as an intermediate type. The tension in the beam is almost wholly relieved by the braces and the weight is thrown on the tie-beam.

Some trussed roofs consist merely of two rafters pitching against each other, with their feet framed into the tie-beam. This is the couple-close roof (plate x). The rafters, like those of a couple-roof, tend to sag under the weight of the purlins, and may be strengthened in the same ways. For instance, by a collar (fig. 25) or collar and braces combined.[1] Ashlar pieces are frequently used,[2] and as there is no particular reason why they should be kept back upon the wall, they are often moved towards the centre of the beam, becoming true queen-posts (plate XI and fig. 30). Arch-braces are sometimes framed into these posts and the rafters, so that the latter are carried by, or rather, form part of, a perfect arch (fig. 30). Occasionally the lower arch-braces are used without a queen-post or ashlar piece.[3] When king or queen-posts are employed there is frequently a series of minor posts on either side of them.[4] These are generally too slender to afford the rafters much support, but they certainly help to give strength to the construction. It is, however, safer to regard them as an ornamental filling like the pierced tracery[5] or carved panels[6] which sometimes occur in the same position.

The king-post of a modern roof is so trussed up with ironwork that the tie-beam is actually suspended from it. In other words, the modern king-post is a tensional member. In a mediaeval roof the king-post is only in tension when braces spring from it to support the rafters.[7] Otherwise it is either neutral, serving only as a good means of

[1] Ferry Hinksey, Berks. nave (fig. 27).

[2] Aston Upthorpe, Berks. (fig. 27).

[3] Walpole St. Peter, Norfolk, nave (fig. 24).

[4] As in the fine tie-beam roofs of the Fenland and Somerset.

[5] Ilminster, Somerset, chancel (fig. 24).

[6] Wellow, Somerset, nave.

[7] Stanton Harcourt, Oxon. nave (fig. 26).

connecting the principal rafters, or it is in compression, helping to minimise the thrust and strain in the joints at the feet of the rafters, and often carrying the ridge purlin[1] (plate XI, no. 1). Even in this case the side purlins are carried upon the principal rafters, so that their thrust is often considerable, and there is still a certain amount of tension in the tie-beam.

The tie-beam, particularly that of a flat-pitched roof, thus has to bear a considerable amount of cross strain, and is generally strengthened, like the beams of a beam-roof, by means of braces or brackets, with or without wall-posts (plates X and XI).

III. THE PLANNING OF ROOFS:

ARRANGEMENT OF THE RAFTERS AND PRINCIPALS.

Up to this point we have been concerned only with the various means of strengthening a pair of rafters, common or principal. But a roof consists, not of a single pair of rafters, but of a series of pairs. It remains for us to examine the various ways of combining the different manners of bracing so as to produce an efficient and beautiful roof.

It has already been stated that, while some kinds of roof are essentially double-framed,[2] any kind of single-framed roof may also be built on the double-framed system, that is, with principals at intervals, carrying purlins and common rafters. In the earliest roofs the principals are all duplicates of one another, but towards the middle of the fourteenth century it was discovered that there was no reason why all the principals should be of the same type. On the contrary it is frequently of great advantage to the construction and to the appearance of the roof if their design is varied. For instance, it often happens that the beam of a wall-principal would cut across a window or arch in the gable wall, so the beam is

[1] The huge king-posts of the Somerset roofs are evidently intended to be in compression, carrying the ridge-purlin and reducing or neutralising the thrust of the principal rafters.

[2] The post-and-beam roof (figs. 9, 10 and 11).

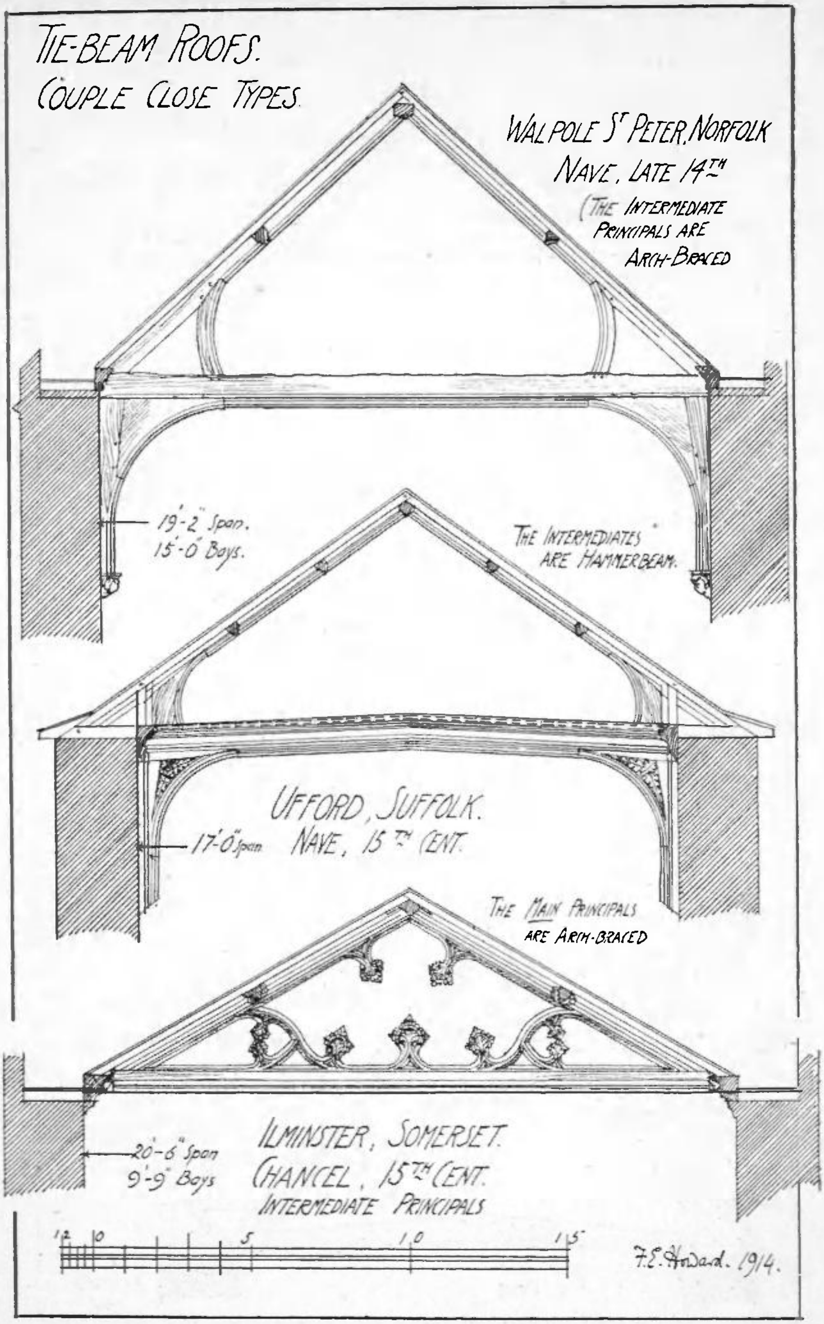


FIG. 24. TIE-BEAM ROOFS, COUPLE-CLOSE TYPES.

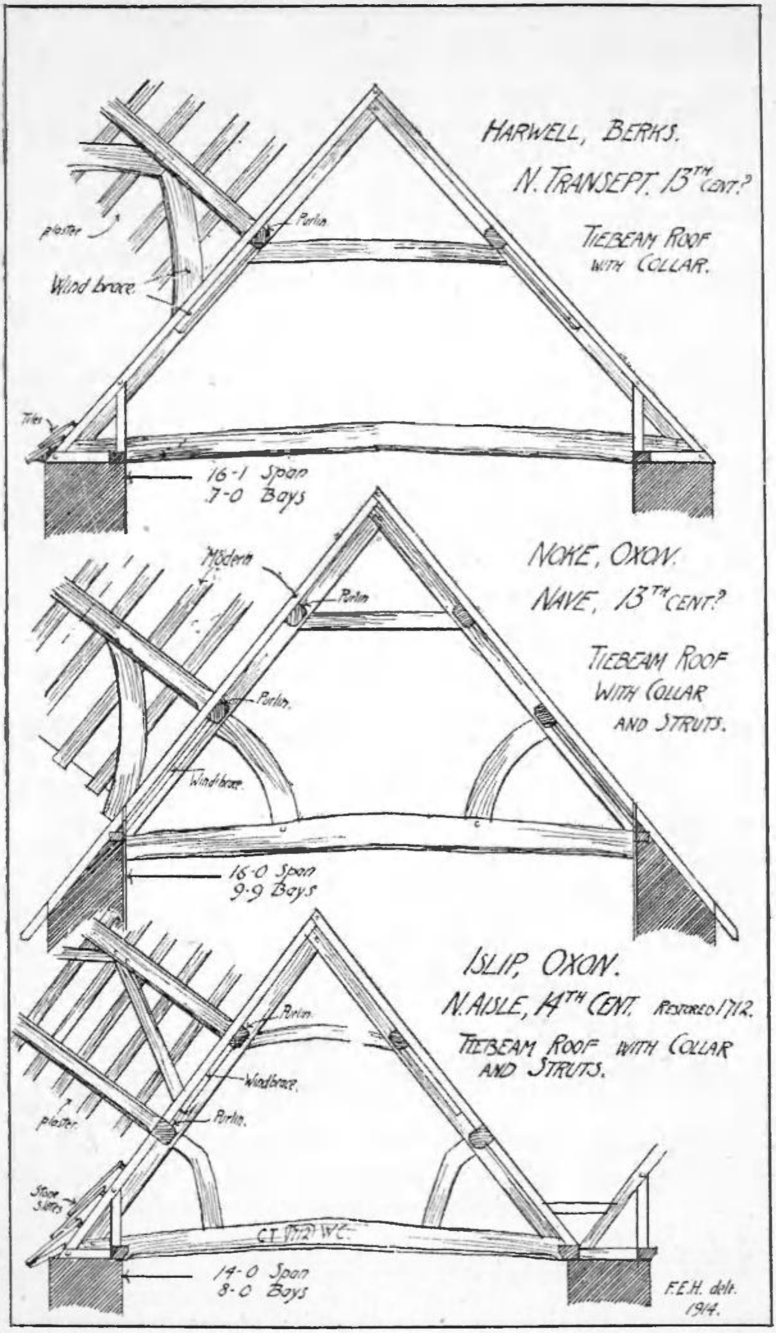


FIG. 25. TIE-BEAM ROOFS WITH COLLARS.

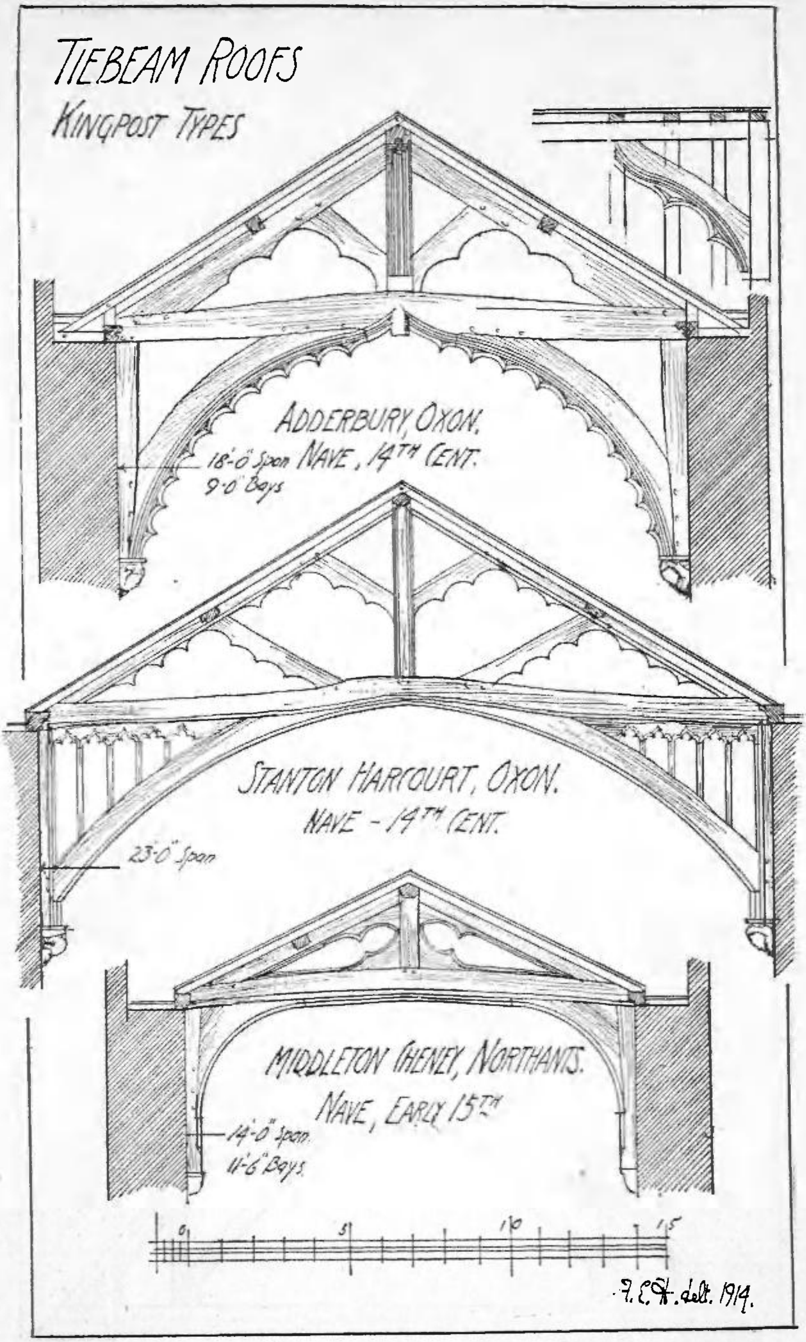


FIG. 26. TIE-BEAM ROOFS, KING-POST TYPES.

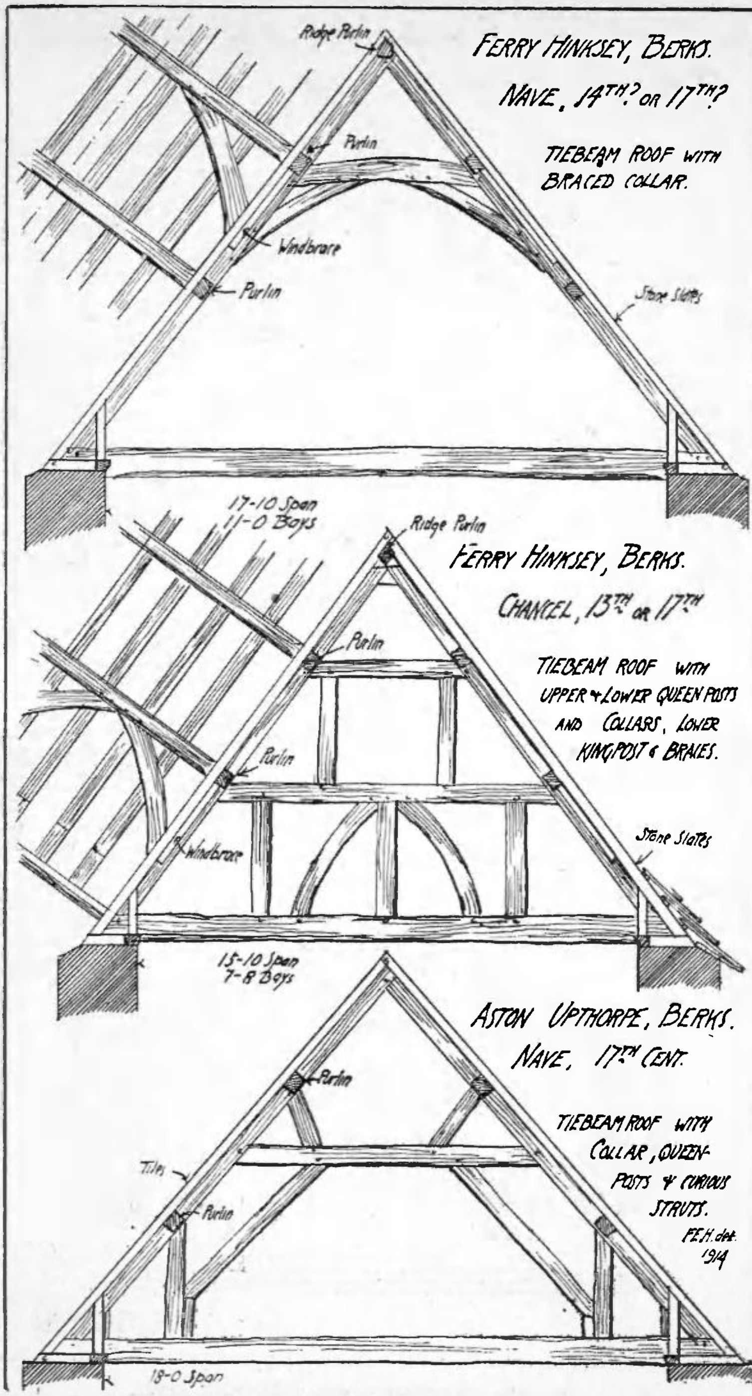


FIG. 27. TIE-BEAM ROOFS WITH COLLARS OR QUEEN-POSTS.

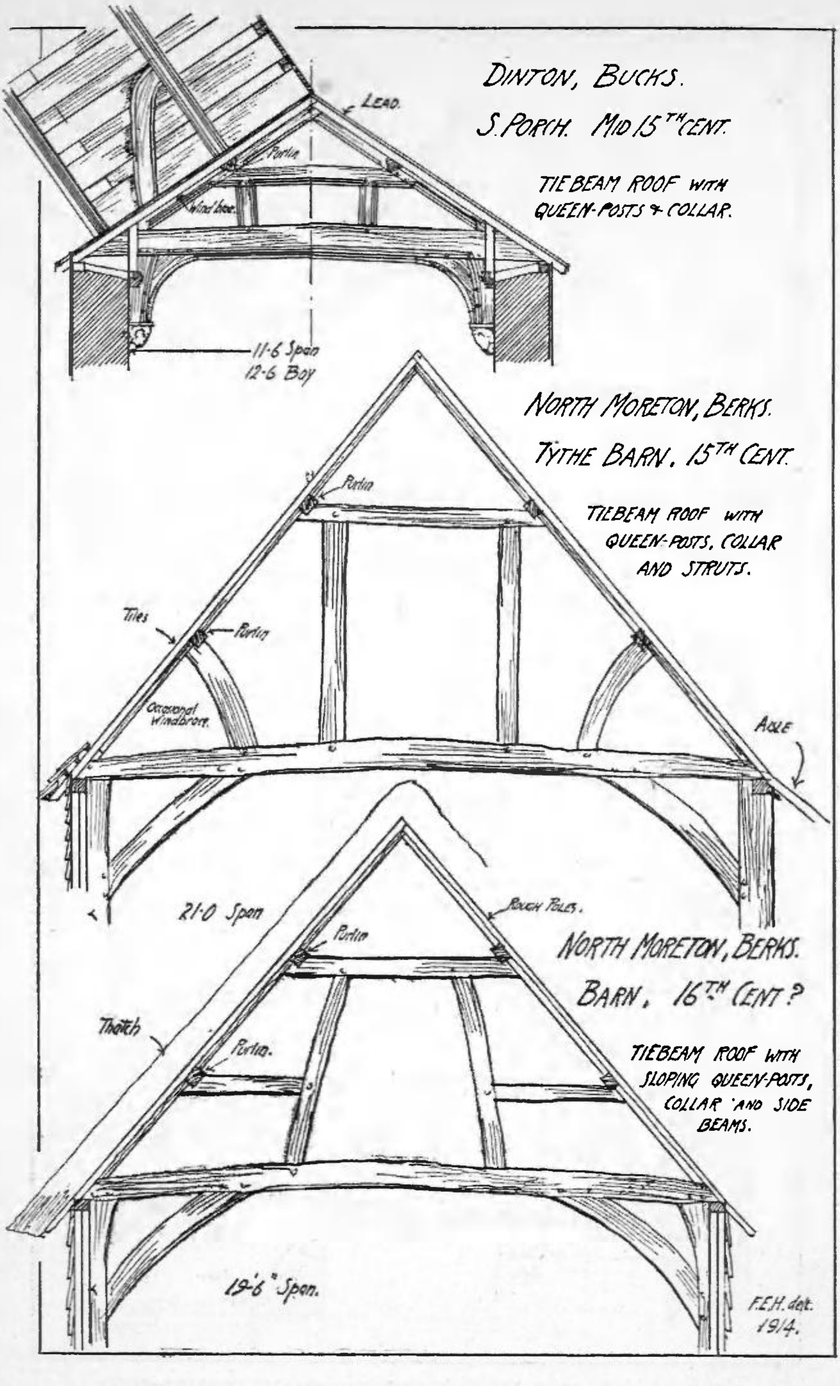


FIG. 28. TIE-BEAM ROOFS WITH COLLARS AND QUEEN-POSTS.

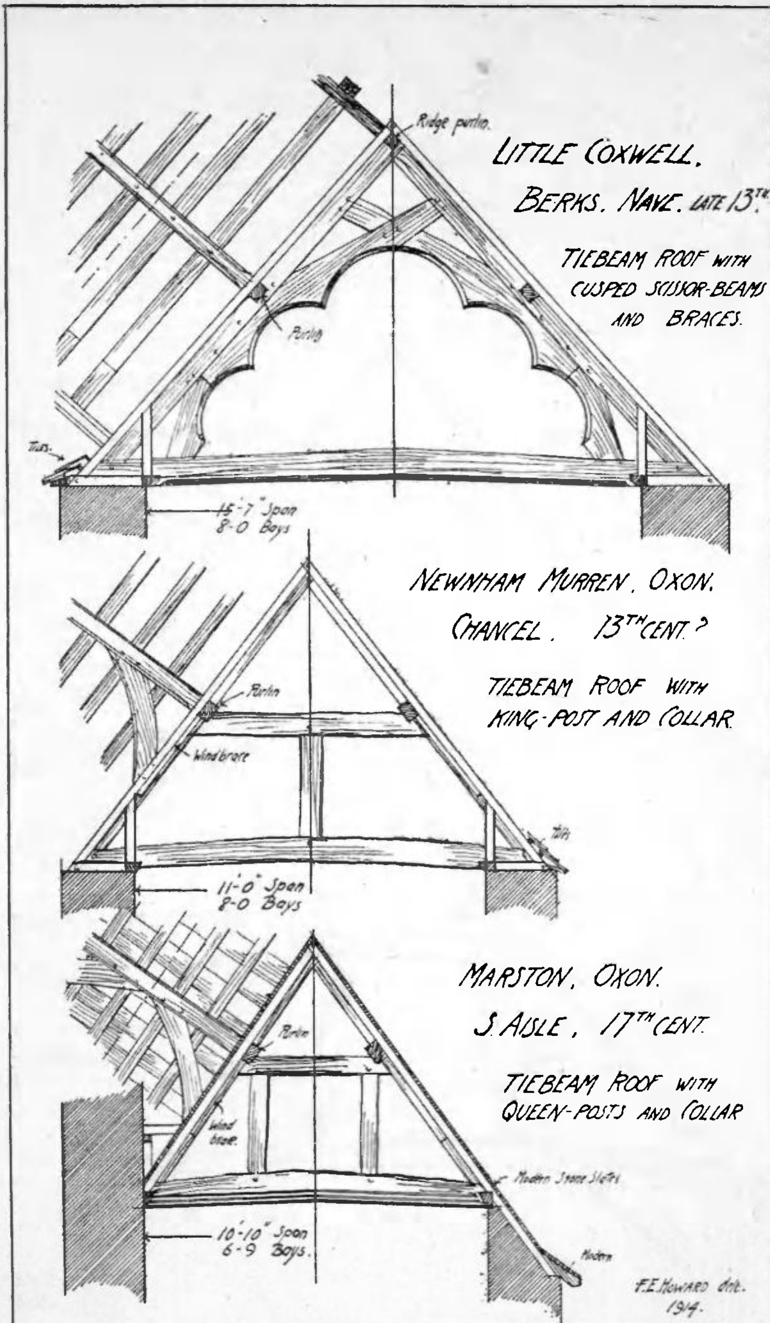


FIG. 29. TIE-BEAM ROOFS WITH SCISSOR-BEAMS OR KING-POSTS.

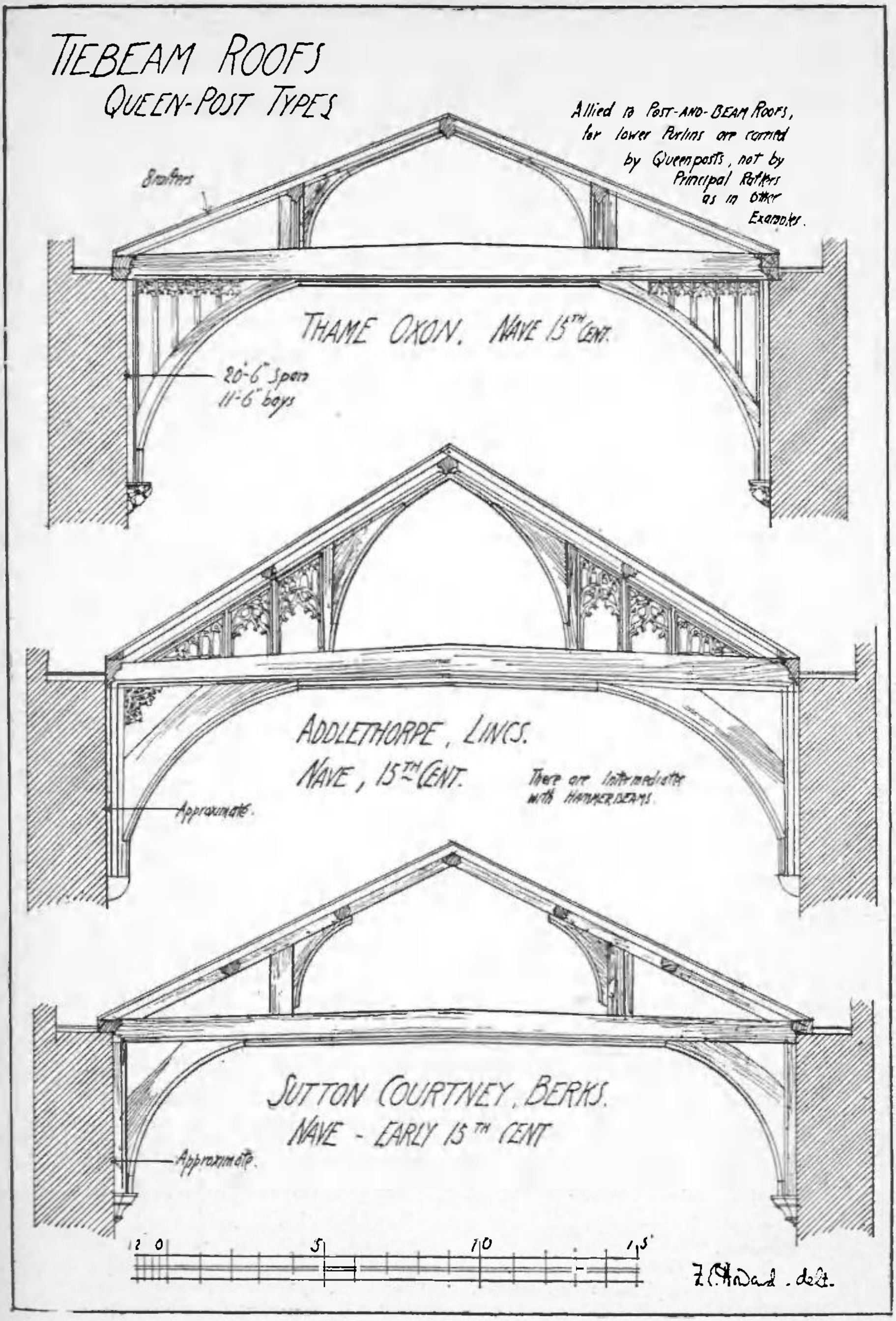


FIG. 3C. TIE-BEAM ROOFS, QUEEN-POST TYPES.

omitted and the end principals are framed up with arch-braces instead of beams.[1] On the other hand, when a long building has a thrusting roof, one of the principals towards the middle of the length may have a tie-beam,[2] and when the gable wall is much weakened by a large window or arch the end principals may have tie-beams,[3] to avoid the pushing out of the angles of the building, which would otherwise result under the combined thrust of arch and roof.

It is found that the principals of a roof ought not to be more than ten feet apart. Otherwise the span of the purlins is so great and the weight they carry is so excessive, that huge timbers are required, both for these and for the principals. Now if the bays of the building were arranged to suit the roof, the piers would have to be spaced at about ten feet intervals, and this would be very obstructive and inconvenient. Generally the bays of a parish church are as wide as twelve to sixteen feet, though of course there are exceptions, particularly in small buildings, such as the Devon churches. The methods of dealing with this difficulty of reconciling the bay division of the roof with that of the structure are very interesting and appear to have escaped notice hitherto.

Sometimes there is no attempt whatever to make the bays of the roof to correspond with those of the structure. In the case of a roof which has none of its members below plate level,[4] this is fairly satisfactory, though the principals may occur in very bad positions; for instance, over the haunch of an arch. In absolutely sound construction the principals should rest on the piers; or over the apex of an arch, so as not to load it unsymmetrically. When there are wall-posts the latter sometimes encroach upon the windows or arches, and thus seriously affect their spacing. When a clerestory is added at the same time the windows may be planned to suit the roof, disregarding the arcade bays.[5] But when the roof is added to an existing building it is inevitable that the wall-posts should in

[1] Edington, Wilts. nave (fig. 20).

[2] Cullompton, Devon.

[3] Knapton, Norfolk, nave: East Harling, Norfolk, nave.

[4] For instance, the Devon type of roof (fig. 17).

[5] Ufford, Suffolk (fig. 24) where the arcade of the fourteenth century is in irregular bays and the clerestory of the late fifteenth century is in regular bays, much narrower than those of the arcade.

some cases interfere with the arches, unless they are cut off or otherwise modified.[1] Naturally when the bays of the roof do not correspond with those of the building, there is no possibility of concentrating the weight and thrust of the roof upon the buttresses, so this solution must be considered as imperfect, and certainly anything but Gothic in its principles.

A more satisfactory system is to space the principals so that they correspond with the piers of the building, to make them specially strong, and to reduce the span of the purlins by means of longitudinal braces, rising from the beams, king-posts, or queen-posts of the principals.[2] This is a picturesque method, but very wasteful of timber.

The best solution of all is to use intermediate principals. These are generally constructed in the following manner. The ridge purlin of a gabled roof or the upper wall-plate of a lean-to is made specially strong, or is reinforced by longitudinal braces, and intermediate principal rafters are framed into it, affording support for the side purlins at the centre of their span.[3] A pair of intermediate principal rafters looks at first sight like a couple-principal thrusting out the narrow strip of wall over the arches,[4] but this is not the case. They have no tendency to thrust while the ridge purlin remains firm, for they are fixed to it, and by its means their weight and thrust are transferred to the main principals.

The pairs of intermediate principal rafters are often strengthened by means of collars, with or without pendant king-posts,[5] with arch-braces,[6] or even with hammer-beams.[7] There is always the possibility of the ridge-purlin sagging, thus allowing the intermediates to thrust, so it is wise to apply wall-post construction to them, but as they generally come over the apex of the arches there is rarely room for more than a very much curtailed version of those of the main principals. The posts are necessarily cut short and the curve of the braces has to be modified.[8]

Sometimes the difficulty of spacing the roof principals

[1] Worlingworth, Suffolk (plate ix, no. 1)

[2] Adderbury, Oxon. nave (fig. 26).

[3] Adderbury, Oxon. transept.

[4] Particularly in the Somerset tie-beam roof (plate xi, no. 1).

[5] Bruton, Somerset, nave.

[6] Walpole St. Peter, Norfolk, nave(plate x).

[7] As in the Fenland type of tie-beam roof (plate xi, no 2).

[8] Trunch, Norfolk, nave.

is solved by arranging two windows in each bay, whether of the aisle or the clerestory, so that piers are provided for both the main and the intermediate principals. In this case the principals may be all of the same design, but the effect of a long series of principals so closely spaced is monotonous, and it is more usual to alternate two different designs. The most usual combinations are tie-beam and hammer-beam,[1] tie-beam and arch-braced,[2] or hammer-beam and arch-braced principals.[3] In most cases the wall-posts of the different principals all spring from the same level, but this is not invariable.

Even in a double-framed roof the common rafters may be reinforced with braces and struts as in a single-framed roof. The result is often extremely picturesque and remarkably strong. The most common instance of this is the use of ashlar pieces in practically all roofs of fairly high pitch, except when there is a parapet. Again, it is not unusual to provide all the rafters with collars.[4] When this is done the central purlin is generally fixed so as to support the collar, instead of under the ridge.

FIG. 31.

Occasionally the bracing of the rafters is so elaborate that the function of the principal may be overlooked, as in the so-called trussed rafters of the midland and south-eastern counties. These roofs are of three kinds. Those with braced rafters only are single-framed thrusting roofs.[5] When their wall-plates are connected by a tie-

[1] Luton, Bedfordshire, nave.
[2] Walpole St. Peter (plate x).
[3] Southwold, nave.
[4] Maidstone, Kent (fig. 11).
[5] Sutton-at-Hone, Kent; Forest Hill, Oxon. (fig. 13).

beam the conditions of the roof itself are not altered[1]; the thrust is there just the same counteracted by the pull of the tie-beam instead of by the push of the wall. But when there is a king-post carrying a collar-purlin,[2] and still more, when the purlin is prevented from sagging by means of longitudinal braces,[3] the thrust is entirely overcome and the roof becomes a beam-roof with strutted or braced rafters.

In Devon, where the double-framed arch-braced roof is supreme, all the common rafters are arch-braced like the principals (fig. 15). In a few cases the main principals are of the hammer-beam type, while the intermediate principals and the rafters are arch-braced.[4] The possibilities of such combinations are endless.

In some roofs it is found that certain rafters have extra members.[5] These are sometimes introduced for the sake of avoiding monotony, but when some of the rafters of a single-framed braced roof are provided with wall-posts or arched brackets below plate level, these serve the very useful purpose of clipping the roof to the wall.[6]

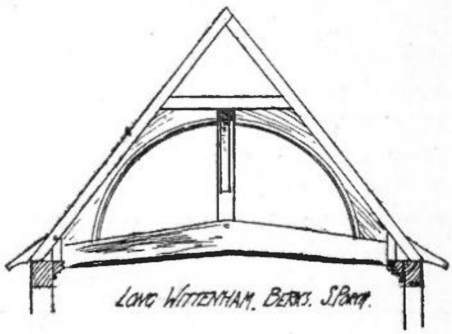


FIG. 32.

THE ABUTMENT OF ROOFS.

In the case of a building in one span the problem of abutment presents no difficulty. The thrust of the roof, if any, is met by the direct abutment of thick walls if the roof is single-framed, or by buttresses if the weight

[1] Old Shoreham, Sussex, and Cumnor, Berks. (fig. 13). Brize-Norton, Oxon. porch (fig. 31).

[2] Strangers' Hall, Norwich.

[3] Harwell, Berks. nave (fig. 11).

[4] Cullompton, Devon, nave, and Cleeve abbey, Somerset, frater.

[5] Long Wittenham, Berks. porch (fig. 32) where the collar-braced rafters over the post-and-beam principals are reinforced with braces.

[6] Dennington, Suffolk, nave.

and thrust of the roof are concentrated upon principals. When, however, a building has aisles the problem of designing the roofs so that the thrust is conveyed over to the outer walls is distinctly interesting.

When there is no clerestory and the aisles are narrow, as in the typical early midland parish church, the rafters of the main roof may be continued over the aisle; thus all the thrust is carried on to the outer walls.[1] This construction is remarkably strong, but it has a serious defect. Unless the ridge of the main roof is abnormally high, or the roof is very flat, the side walls are so low that there is practically no room for windows, so that the building depends almost entirely upon the gable windows for its lighting. When more adequate light is desired it is necessary to raise the aisle walls, and to flatten the aisle roof; the other alternative, the raising of the nave wall-plate as well as that of the aisle, is generally too expensive. In this case the thrust of the nave roof is carried over to the aisle wall as before, but it is not brought so low down, so stronger buttresses are needed. When the aisle windows are very large it is sometimes necessary for the aisle wall-plate to be at the same level as that of the nave. When this is done the thrust of the nave roof is brought over to a point dangerously high above the ground, and it is well for the aisle principals to be fitted with wall-posts and braces, so as to bring it down to a point where the abutment is more secure.[2]

When the aisles are wide a high-pitched lean-to roof cannot be used unless the nave wall-plate is very high up, or the side walls are exceedingly low. It is generally necessary either to put a flat roof, or to roof the aisle under a separate gable of its own.[3] In the latter case the thrust of the aisle roof meets that of the nave and neutralises it, provided that the plates are fixed at about the same level, and the spans are about equal. Even when the span of the aisle roof is less than that of the nave, the extra thrust of the nave roof is carried out to the outer

[1] Toot Baldon, Oxon. (fig. 5). Long Stanton, Cambs. see Brandon, *Open Timber Roofs*, plate 2.

[2] Figs. 5 and 6 show the development of this useful "flying-buttress" roof.

[3] This is specially characteristic of the West country churches.

walls, and counteracted by the buttresses as in the case of the lean-to. The great disadvantage of parallel gabled roofs is that the long gutter between them tends to get choked up by leaves in autumn and by snow in winter, unless cleared out at frequent intervals. Sometimes, in order to avoid the gutter, a flat lean-to roof is constructed which connects the ridge of the aisle roof to the wall of the nave.[1] When this is done the nave roof has to be raised above the plate-level of the aisle.

When there is a clerestory the difficulties increase. It must be remembered that the wall of an aisled nave stands on isolated piers and is in no position to resist thrust. Unless the roof has beams or tie-beams there is certain to be more or less thrust, which must be transferred across to the outer walls and their buttresses. This is done by making the aisle roofs act as continuous flying buttresses, or by framing the principals after the manner of the flying shores which are used to this day, when a house is being demolished, to prevent the adjoining houses from collapsing (figs. 5 and 6). Even when none of the roofs is of the thrusting kind a great deal of care is needed in combining roofs, particularly when the walls are pierced with many large windows. Though the roofs cannot spread, the foundations of the walls may be unsatisfactory, and often the piers are so slight that the structure is very largely dependent upon the staying of the roofs with their arch-braces and long wall-posts.

Unless special precautions are taken the thrust of the nave roof misses the abutment of the aisle roof; and the wall over the arcade is caught between two forces, the aisle roof pushing the arcade over and inwards, and the nave roof thrusting the clerestory outwards.[2] It is imperative that the thrust of the nave roof should be brought down by means of wall-posts and arch-braces so that it is exercised at a point where the aisle roof affords abutment. It is well if the beams of the aisle roof can project through the wall to form corbels for the wall-

[1] The most striking instances are, (1) the usual aisle roof of Somerset, e.g. Bruton, Wrington and Yatton, and (2) Wymondham, Norfolk. See Brandon, *Analysis of Gothic Architecture*, plates 17 and 18.

[2] Many failures of this kind may be observed in the great churches of Norfolk.

posts.[1] In this case, if the wall-posts are tenoned into the projecting extremities of the aisle beams, the roof cannot possibly escape the abutments of the aisle roof, unless the wall-post is prolonged so far below the brace and is so slight that it bends under the strain.

Of course the thrust of a timber roof, like that of a stone vault, might be met by flying buttresses of masonry, but this was rarely done, perhaps on account of the expense, or perhaps because the carpenter wished to do everything himself. Generally, when flying buttresses occur, it will be found that they are later additions, intended to counteract some settlement of the walls, owing to bad foundations or the excessive thrust of the roof.[2] By exception at Fotheringhay the range of flying buttresses on either side of the nave is known to be original. These are not intended to resist thrust, for the nave roof is of beam construction, and is merely a dead weight upon the walls; but the clerestory windows are very large and the piers between them slender, so they are useful in steadying the walls, which cannot be pushed inwards owing to the resistance of the roof beams with their wall-posts and braces.

[1] This is illustrated by St. Giles, Norwich (fig. 20). Other instances are Blakeney, St. Peter Mancroft, Norwich, and Sall, all in Norfolk.

[2] Worstead, Norfolk.

A GLOSSARY OF TERMS USED IN ROOF-CONSTRUCTION.

BAY. That section of a roof which lies between the centres of two adjoining main principals. The 'unit of repeat' of a roof.

BEAM. A horizontal timber, usually intended to carry weight, in which case it is in cross strain, but also used as a tie to prevent rafters spreading, in which case it is in tension. Often a beam is used to strut timbers apart, in which case it is in compression.

BRACE. A timber used to turn a couple of rafters into a true arch, or to keep two intersecting timbers at a rigid angle with one another. Always a compressional member, unless the joints are made with ironwork, as in the hammer-beam trusses of the Gothic revival, in which case it may be in tension.

COLLAR-BEAM OR COLLAR. A horizontal timber, framed at each end into the rafters. In a mediaeval roof it is a compressional member, used to prevent the rafters from sagging by strutting them apart. In a modern roof, reinforced with ironwork, it may serve to some extent as a tensional member to prevent spreading.

COLLAR-BRACE. A piece of timber, framed into the rafter and the collar, converting both into an arch.

COMMON RAFTER. Common rafters are small inclined beams, fixed at short intervals, on which boarding or battens are nailed or laid to carry the roofing material. They are in cross strain from the weight of the roofing and the wind-pressure, and also in compression from their natural tendency to thrust against each other at the apex and against the wall-plate at their feet.

COMPRESSION. A crushing strain, usually tending to reduce the length of a piece of timber.

CORNICE. A more or less elaborately moulded or carved wall-plate. Cornices are often formed by panelling the space between the wall-plate and the lower purlin.

CORNICE BRACE. An arched piece of timber framed into the wall-post and the cornice, to prevent the latter from sagging between the principals.

CROSS STRAIN. A strain tending to bend the timber,

FOOT. The lower end of an inclined timber.

FRAME (TO) To fix timbers together by means of mortice and tenon.

HAMMER-BEAM. A beam projecting from the wall, like a cantilever, to reduce the span or to facilitate the jointing of an arch-brace. Usually in tension and cross strain.

HAMMER-BRACE. A curved timber rising from the wall or a wall-post to support the outer end of the hammer-beam and so to prevent it from sagging under the weight of the rafter brace. Also serves to prevent the principal from sliding off the wall.

HEAD. The upper end of an inclined or vertical timber.

KING-POST. An upright timber in the exact centre of a principal. It is sometimes used merely as a means of jointing the rafters at the apex, and may be neutral, but more often it is used as a strut or prop to support a purlin or the rafters. In a modern truss, screwed up with iron bolts, it is actually used as a suspension rod to hang up the tie-beam to the rafters, and is in violent tension.

MORTISE. A rectangular hole cut in a timber to receive the tenon of another timber which it is required to fasten to it.

PITCH. The slope of the rafters. The angle of pitch is the internal angle which the rafters make with the horizontal. But Brandon gives as the pitch of a roof the angle at the apex. The latter definition is not used in the trade at the present day.

PLATE. A horizontal timber, running the whole length of a building, to which the feet of the rafters are fixed.

POLE-PLATE. A horizontal longitudinal timber generally fixed against a wall, framed into the principals, like a purlin, serving to support the feet of the rafters. A pole-plate is in cross strain and is used instead of a wall-plate in order to ensure that the whole of the weight and thrust of a roof is carried by the piers.

POST. Any vertical member of a roof is called a post.

PRINCIPAL. A strong framework of timber bridging across a building to afford support for the purlins at a point between the gable walls, or fixed against the latter.

PRINCIPAL RAFTER. The strong rafters which are the chief members of most principals, into which the purlins are framed. Like the common rafters, they are in both compression and cross strain.

PURLIN. A longitudinal beam used to support the common rafters, carried by the gable walls, or framed into the principals.

PURLIN-BRACE. A timber rising from the principal or the queen-post of the principal to support the purlin, by reducing its span. It lies in a vertical plane, unlike the wind-brace, which lies on the inclined plane of the rafters.

QUEEN-POST. When a pair of posts is used instead of or in addition to a king-post they are called queen-posts. In a mediaeval roof they are in compression, in a modern roof they are turned into tensional members with the aid of wrought iron. The usual function of a queen-post is to prop up a rafter or a collar from the beam or hammer-beam.

RAFTER. See COMMON RAFTER and PRINCIPAL RAFTER.

RAFTER-BRACE. See BRACE.

RIDGE. The apex of a gabled roof.

RIDGE-PIECE. A thin piece of board against which the heads of the rafters pitch, and to which they are nailed in a modern roof. Ridge-pieces are never employed in mediaeval roofs.

RIDGE-PURLIN. The purlin fixed under the ridge. At this point, unless they are very flat, the rafters prop one another up, so the ridge-purlin would appear at first sight to be of little use, but as a matter of fact it is a most important member of the construction of a mediaeval roof. In the first place the common rafters are halved and pegged together at the apex so that, if the ridge-purlin is fixed a trifle higher than its usual position, they hang over it like clothes on a line, and all their thrust is taken up by the ridge-purlin and transferred to the principals, instead of pushing against the walls between the buttresses. In the second place the ridge-purlin often serves to carry the upper end of the intermediate principals.

Ridge-brace. An arched piece of timber rising from the beam or queen-post of the principals to the ridge-purlin to reduce its span.

Scantling. The two least dimensions of a piece of timber, usually its width and depth.

Sole-piece. A cross-timber bedded on the top of a wall as a substitute for, or in connexion with, a longitudinal wall-plate.

Span. Generally used to denote the net distance between the side walls of a building (clear span), or the distance between two points of support.

Strut. An inclined timber used to keep two pieces of timber apart, and consequently in compression. A straight brace.

Tenon. Part of a timber reduced to about one-third of its thickness in order that it may fit into a mortise in another timber.

Tension. A pulling strain, tending to increase the length of a piece of timber.

Tie-beam. A horizontal timber connecting the feet of a pair of rafters or the wall-plates of a thrusting roof, in order to take the strain off the side walls by preventing the roof from spreading. A tie-beam is always in tension, and may also be in cross strain.

Wall-plate. A longitudinal timber bedded on the top of the wall to which the feet of the rafters are fixed, serving to spread their weight over the surface of the wall, and to fix the roof to the actual structure.

Wall-post. A vertical timber placed against the wall and framed into the rafter or hammer-beam, serving to prevent the principal from spreading off the wall. It also serves as a point from which to spring arch-braces to support the rafter, tie-beam or hammer-beam. When used in this manner in conjunction with arch-braces it is found that the wall-post and rafter are bound into one, so that the roof may be considered as springing from the level of the lower end of the wall-post instead of from the plate. In this manner the thrust of the roof is greatly reduced by the use of the wall-post, and is brought down to a point where the wall is better able to resist the overturning pressure. When there is a corbel below the foot of the wall-post the latter may carry the whole weight of the roof, and as the ends of the tie-beams soon decay when they are bedded on the wall, the presence of wall-posts and corbels has saved many a neglected roof from disaster. When the corbels are omitted the wall-post becomes a mildly tensional member and is of no use to carry weight. The importance of the wall-post in Gothic roof construction cannot be exaggerated.

Wind-brace. A curved timber rising from the principal rafters to the purlin. Its purpose is to reinforce the purlin against the thrust of the rafters, a large portion of which is due to the pressure of the wind on the opposite slope of the roof, and so to enable it to transfer the thrust to the principals and so to the buttresses, instead of allowing the rafters to push against the wall-plate between the buttresses, which would inevitably happen if the purlin were to sag. Occasionally intermediate principals are carried on the lower purlins. In this case wind-braces serve to carry their weight and thrust on to the main principals.[1]

[1] Street appears to have been much puzzled as to the purpose of wind-braces, and entirely misunderstands their purpose. After alluding to them as the arched-braces largely used for the support of purlins, he goes on to say that "they stiffen the whole construction and help to support the underside of the common rafters, but they in no way support the purlins." Thus he contradicts himself in the course of a few lines and makes a serious mis-statement, for in many cases the wind-braces are quite clear of the common rafters and cannot possibly afford them any support, except through the purlins. See G. E. Street on "Mediaeval Wood-work" in *Trans. R.I.B.A.* vol. v, n.s.