CHAPTER IV.

WIND PRESSURE ON PITCHED ROOFS.

33. **Action of Wind.**—The forces hitherto considered have been vertical; the wind pressure on a roof is inclined. It was once usual to deal with the pressure of the wind as a vertical load, added to the weight of the roof, snow, etc., and the stresses were obtained for the aggregate pressure. This treatment manifestly cannot be correct. The wind may be taken without error as blowing in a horizontal direction; it exerts its greatest pressure when blowing in a direction at right angles to the side of a building; it consequently acts upon but one side of the roof, loads the truss unsymmetrically, and sometimes causes stresses of an opposite kind, in parts of the frame, from those due to the steady load. Braces which are inactive under the latter weight may therefore be necessary to resist the force of the wind.

It will not be right to design the roof to sustain the whole force of the wind, considered as horizontal; nor will it be correct to decompose this horizontal force into two rectangular components, one perpendicular to the roof, and the other along its surface, and then take the perpendicular or normal component as the one to be considered; for the pressure of the wind arises from the impact of particles of air moving with a certain velocity, and these particles are not arrested, but only deviated from their former direction upon striking the roof. Yet the analysis applicable to a jet of water striking an inclined surface cannot be used here, for water escapes laterally against the air, a comparatively unresisting medium, while the wind particles, if we may so term them, deflected by the roof, are turned off against a stream of similar air, also in motion, which retards their lateral progress and thus causes

them to press more strongly against the roof. We are obliged, therefore, to have recourse to experiments for our data, and from them to deduce a formula.

34. **Formula for Wind Pressure.**—It appears that, for a given pressure exerted by a horizontal wind current on any square foot of a vertical plane, the pressure against a plane inclined to its direction is perpendicular to the inclined surface, and is greater than the normal component of the given horizontal pressure. Unwin quotes Hutton's experiments as showing that, if P equal the horizontal force of the wind on a square foot of a vertical plane, the perpendicular or normal pressure on a square foot of a roof surface inclined at an angle i to the horizon may be expressed by the empirical formula

$$P \sin i^{1.84 \cos i - 1}.$$

If, then, the maximum force of the wind be taken as 40 pounds on the square foot, representing a velocity of from 80 to 90 miles per hour, the normal pressure per square foot on surfaces inclined at different angles to the horizon will be:

Angle of Roof.	Normal Pressure.	Angle of Roof.	Normal Pressure.
5°	5.2 lbs.	35°	30.1 lbs.
10	9.6	40	33.4
15	14.0	45	36.1
20	18.3	50	38.1
25	22.5	55	39.6
30	26.4	60	40.0

For steeper pitches the pressure may be taken as 40 pounds.

Any component in the plane of the roof, from the friction of the air as it passes up along the surface, or from pressure against the butts of the shingles or slates, is too slight to be of any consequence.

The above maximum is a sufficient amount to be provided for, although wind gauges have been known to register somewhat higher pressures at rare intervals.

35. **Example: Steady Load.**—The truss of Fig. 17 is supposed to be under the action of wind pressure from the

left. If the truss is 67 feet span, and the height is 15 feet, the angle of inclination will be 24° 7′, and the normal wind pressure, interpolated from the table, will be 21.8 pounds per square foot. The rafter will be 36.7 feet long. If the trusses are 10 feet apart, the normal wind pressure on one side will be

$$36.7 \times 10 \times 21.8 = 8000 \text{ lbs.}$$

For steady load of slates, boards, rafters, purlins, and truss, let us assume 11 pounds per square foot of roof, or

$$36.7 \times 10 \times 2 \times 11 = 8074 \text{ lbs.; total vertical load.}$$

The truss is here drawn to a scale of 30 feet to an inch, and both diagrams are drawn to a scale of 6000 pounds to an inch. In actual practice these figures should be much larger, the diagrams showing perhaps 1000 pounds or 800 pounds to an inch.

We will, in the present case, treat the two kinds of external force separately. The diagram on the right for steady load needs no description. Each supporting force will be 4037 pounds, and the weights at the joints of the rafters will be, 673 pounds for the end ones, and 1346 pounds for each of the others. The above weights are laid off on a vertical load line and the diagram then drawn. The stresses in the various pieces for half of the truss are given in the table to follow, the sign + denoting compression, and the sign −, tension.

36. **Wind Diagram; Reactions.**—The normal pressure of 8000 pounds distributed uniformly over the whole of the left side of the roof, and on that alone, will have its resultant, shown by the dotted arrow, at the middle of that rafter. To find the supporting force on the right we may take moments about the left-hand wall, remembering to multiply each force by the lever arm drawn perpendicular to its direction: or

$$AP \times HT = 8000 \times HK,$$

or

$$AP \times 61.15 = 8000 \times 18.35;$$

whence AP = 2400 pounds, and AH = 5600 pounds.

But since these arms, HT and HK, are proportional to the span and the left part of the horizontal tie cut off by the resultant, an easier way to get the supporting pressures due to an inclined force is to prolong this force until it cuts the horizontal line joining the two abutments, when the two reactions will be inversely proportional to the two segments into which the horizontal line is thus divided, the larger force being on the side of the shorter segment, or, for ordinary pitches, on the side on which the wind blows.

The pressures on the joints will be 2667 pounds each on IK and KL, and 1333 pounds each on HI and LM, as denoted by the arrows. Draw *mh* by scale, equal to 8000 pounds, so inclined as to be in the direction of the given forces, that is, perpendicular to the roof; divide the reactions of the supports by means of the point *a*, and lay off the joint forces in their proper order, *ml*, *lk*, *ki* and *ih*. Before going further be sure that the external forces and the reactions follow one another in their proper order, down and up the load line; for, through heedlessness, the reactions are sometimes interchanged.

37. **Wind Diagram; Stresses.**—Proceed with the construction of the diagram by the usual rules, remembering that wind alone is being treated. After the joint KL has given *lkcdel*, the joint EA gives *edafe*. Taking next the apex LM, and passing along *ml*, *le* and *ef*, we find that there will be no line parallel to FG, since *gm*, parallel to GM, will exactly close on *m*, the point of beginning. As no stress passes through FG, the remainder of the bracing on this side can experience no stress, and therefore the compression *gm* affects the whole of the right-hand rafter while the tension *af* is found in the remainder of the horizontal tie. The stress triangle for the point P will therefore be *mgam*. That the above result is true will be seen if we notice that the piece QR, having no wind pressure at its upper end, can, by § 17, have no stress. Then it follows that RS is now free from stress, and next SG and lastly GF, all by § 17. Further:

imagine all of the braces in the right half to be removed; it is evident that the right rafter is a sufficient support to the joint L M, conveying to the wall the stress *g m* which compresses its upper end, while the tie A F keeps the truss from spreading. If the lower tie or the rafter was not straight, some of the braces would come into action, as will be seen later.

38. **Remarks.**—At another time the wind may blow on the right side. Then the braces on the right will be strained as those on the left now are, and those on the left will be unstrained. The wind stresses are placed in the third column of the table. As in this truss they are all of the same kind, in the respective pieces, as those from the steady load, they are added to give the total or maximum stresses. The force *g m*, being smaller than, while it is of the same kind as *l e*, is of no consequence; for, with wind on the right, M G would have to resist a stress equal to *l e*.

A combination of the two components of the supporting forces at each end, as shown in the figure, by either the parallelogram or triangle of force, will give the direction and amount of each reaction from the combined load. Wind on the other side will exactly reverse the amounts and bring them on the opposite side of the vertical line.

Table of Stresses for Fig. 17.

Piece.		Steady Load.	Wind.	Total.
Tie	A B	– 7520 lbs.	10,440 lbs.	17,960 lbs.
	A D	– 6020	7,160	13,180
	A F	– 4520	3,900	8,420
Braces	E F	– 1830	3,990	5,820
	C D	– 1500	3,280	4,780
	B C	+ 1230	2,670	3,900
	D E	+ 1840	4,000	5,840
Rafter	I B	+ 8240	9,530	17,770
	K C	+ 7690	9,530	17,220
	L E	+ 5760	6,550	12,310

If the truss is simply placed upon the wall-plates, and either of the supporting forces makes a greater angle with the

vertical than the angle of repose between the two surfaces, the truss should be bolted down to the wall; otherwise there will be a tendency to slide, diminishing the tension in the tie, perhaps causing compression in that member, and changing the action of other parts of the truss. This matter will be treated of further.

If the weight of snow is also to be provided for, it may readily be done by taking the proper fraction of the stresses from the steady load and adding them to the above table.

39. **Truss with Roller Bearing; Dimensions and Load.**—We propose, in the example illustrated by Fig. 18, to consider the truss as supported on a rocker or rollers at the end T, where the small circle is drawn, to allow for the expansion and contraction of an iron frame from changes of temperature. It is therefore plain that the reaction at T must always be practically vertical. The truss is supposed to be 79 feet 8 inches in span, and 23 feet in height, which gives an angle of 30° with the horizon, and makes the length of rafter 46 feet. It would be proper usually to support the rafter at more numerous points; but our diagram would not then be so clear, with its small scale, from multiplicity of lines, and one can readily extend the method to a truss of more pieces.

This frame supports 8 feet of roof, and the steady load per square foot of roof is taken, including everything, as 14 pounds. The total vertical load will then be

$$14 \times 46 \times 2 \times 8 = 10{,}304 \text{ lbs.},$$

or 1717 lbs. on each joint except the extreme ones.

We find, from the table of § 34, that the normal pressure of the wind, for a horizontal force of 40 pounds on the square foot, may be taken as 26.4 pounds per square foot of a roof surface inclined at an angle of 30°. The total wind pressure, normal to the roof, will therefore be

$$26.4 \times 46 \times 8 = 9715 \text{ lbs.},$$

or 3238 lbs. and 1619 lbs. on the middle and end joints respectively of one rafter. The truss is drawn to a scale of 40 feet to an inch, and the diagrams to that of 8000 pounds to an inch.

40. **Diagram for Steady Load.**—The diagram for steady load, having a vertical load line, is the one above the truss, and a little more than one-half is shown. The only piece at all troublesome is G F. On arriving in our analysis at the apex of the roof, or at the middle joint of the lower member, we find three pieces whose stresses are undetermined: but as we have reached the middle of the truss, we know that the diagram will be symmetrical, and therefore that *gf* will be bisected by *a l*. In the case of an unsymmetrical load we can recommence at the other point of support and close on the apex. The stresses caused by this load are given in the first column of figures in the table in § 44, compression being marked +, and tension −. If it is thought necessary to provide for snow, in addition to the stresses yet to be found for wind, make another column in the table, of amounts properly proportioned to those just found.

41. **Wind on the Left; Reactions.**—Upon turning our attention to the other diagrams, we shall find that the rollers at T cause something more than a reversal of diagram,—often a considerable variation of stress, when the wind is on different sides of the roof. Taking the wind as blowing from the left, we draw the diagram marked W. L. The line *q m*, 9715 lbs., § 39, is divided and lettered as shown for the four loads at the joints where arrows are drawn. The resultant of the wind pressure, at the middle point of the rafter, when prolonged by the dotted arrow, will divide the horizontal line or span in the proportion in which the load line should be divided to give the two parallel reactions, if there were no rollers at T. This proportion, for a pitch of 30°, is 2 to 1; it locates the point *a′*, and gives $ma' = 6477$ lbs., and $a'q =$ 3238 lbs.

But the reaction at T must be vertical, and consequently only the vertical component of *a′ q* can be found at T, while

the horizontal component of *a′ q* must come, through the lower member, from the resistance of the other wall. Therefore draw *a′ a* horizontally and we shall get *a q* as the vertical reaction at T, while *m a*, to close this triangle of external forces, must give the direction and amount of the reaction at M.

42. **Verification.**—It may, at first sight, strike the reader that this analysis will not be correct; for, if only the vertical component is resisted at T, and if we decompose the resultant of the wind pressure at O, where it strikes the roof, into two components, we get results as follows:

Vert. comp. of 9715 lbs., for angle 30° = 8414 lbs.
Hor. " " " " " = 4858 lbs.

The vertical from the middle point of the rafter will divide the span at $\frac{1}{4}$ M T. Therefore, amount of vertical component carried at T = 2103 lbs., and the remainder is supported at M, with all of the horizontal component. But take next into account the moment, or the tendency of the horizontal component at O to cause the truss to overturn. It naturally decreases the pressure at M and increases that at T, or, in other words, the couple formed by the horizontal component at O and the equal horizontal reaction at M with an arm of half the height of the truss must be balanced by an opposite couple, composed of a tension at M and an equal compression at T, with a leverage of the span. Making the computation of this tension, or compression T, we have

$$4858 \times 11.5 = T \times 79\tfrac{2}{3}, \text{ or } T = 702 \text{ lbs.}$$
$$2103 + 702 = 2805 = \tfrac{1}{3} \text{ of } 8414 \text{ lbs.}$$

as obtained by the first process.

Still another way to find the supporting forces is to prolong the resultant until it intersects the vertical through T, then to draw a line from M to the point of intersection, and finally to draw *m a* and *q a* parallel to the lines from M and T. This method depends for its truth on the fact that the three external forces which keep the truss in equilibrium, not being parallel must meet in one point.

43. **Diagram for Wind on Left.**—Having completed the triangle of external forces, and laid off the pressures on the joints, we can readily draw the diagram. It will be found, as in Fig. 17, § 37, that braces on the right experience no stress, the lines gf and eq closing the polygon which relates to the joint P Q. If the lower tie were cambered to the joint D C, we should find a stress from wind in E F and C D, but not in B C or C E, as explained in § 37.

Upon combining with the inclined reaction ma the steady load reaction also marked ma, the direction of the resultant supporting force at M will be found; and it may be so much inclined to the vertical that provision against sliding on the wall-plate at M should be made. The stresses given by this diagram for wind on the left are found in the table to follow, in the column marked W. L. It will be seen that all of them agree in *kind* with those for steady load.

44. **Diagram for Wind on Right.**—This diagram is marked W. R. The supporting force at T, while still vertical,

TABLE OF STRESSES FOR FIG. 18.

Piece.		Steady Load.	W. L.	W. R.
Rafters	B S	+ 8570 lbs.	5600 lbs.	8480 lbs.
	C R	+ 6850	5600	6540
	E Q	+ 5700	5600	5880
	I P	+ 5700	5880	5600
	K O	+ 6850	6540	5600
	L N	+ 8570	8480	5600
Tie	L A	− 7440	11400	0
	H A	− 5450	7050	0
	D A	− 5450	4850	2150
	B A	− 7440	4850	6480
Braces	B C	+ 1720	0	3800
	C E	+ 1520	0	3300
	E F	− 1000	0	2150
	F G	− 2300	2500	2500
	G I	− 1000	2150	0
	I K	+ 1520	3300	0
	K L	+ 1720	3800	0

is greater in amount than before. If diagram W. L. has been already constructed, the reaction at T can be taken as that portion of the vertical component of the wind pressure not included in aq of that figure; that is, $aq + ta =$ vertical component of qm or pt. If this should be the first diagram drawn, find the supporting forces in one of the three ways given above. The reaction at M is rightly denoted by ap, for, when the wind is on the right, there is no external force to divide the space from M to P.

The point a is moved considerably from its place in diagram W. L., and this change affects the amounts of stress in the horizontal member, but not in those pieces which bear similar relations to the two sides of the truss; in other words, I P and E Q interchange stresses, etc. In some forms of truss, however, we find more material changes. In the present example it happens that the vertical fg strikes the point a, so that ip, the stress in the rafter, coincides with ap, the reaction at M; the wind on the right consequently causes no stress in L A and H A. The stresses from this diagram are found in the last column of the table.

45. **Remarks.**—There is no need to tabulate the stress in K H, if that in I G is given, nor gh, if ki is given. Notice that the joint K G or C F gives a parallelogram in each diagram, the stress in K I passing to G H without change, so that the diagonals which cross may be considered and built as independent pieces. It will be seen on inspection of the table that the combination of steady load with wind on the left gives maximum stresses in I P, K O, L N, L A, H A, D A, G I, I K, and K L, while the remainder, with the exception of F G, have maximum stresses for wind on the right. F G is strained alike in both cases.

These wind diagrams may be drawn on either side of the line of wind force, as in the case of steady load, by changing the order in which the supporting forces are taken, going round the truss and joints in the opposite direction. Although there exist two four-sided spaces C and K, the structure is sufficiently braced against distortion; for these spaces are surrounded by triangles on all sides but one.

It may perhaps not be amiss to suggest again how to determine the kind of stress in any member without retracing the whole polygon for any joint. Notice, from the load line, whether the forces were taken in right-hand or left-hand rotation. Read the letters of a piece in that order with reference to the joint at one end of it; then read the stress in the diagram in that same order, and it will show the direction of the stress in the piece, either to or from that joint. Thus diagram W. L. is written in left-hand rotation; K L is then the reading for that brace at its *lower* end, and kl reads downward or is thrust. If we read L K, it must apply to its upper end, and lk acts upwards or thrusts against the joint near N.

Wind diagrams for the truss of Fig. 21 can now be drawn. The apex of the roof can be treated first, and the stresses, obtained in the dotted lines, can then be transferred to the ends of the upper horizontal member. The truss proper goes no higher.

CHAPTER V.

WIND PRESSURE ON CURB (OR MANSARD) AND CURVED ROOFS.

46. **Truss for Curb Roof; Steady Load Diagram.**—To have a definite problem we will assume that the truss of Fig. 19, drawn to scale of 20 feet to an inch, is 50 feet in span, that the height to ridge is 20 feet, to hips $14\frac{1}{2}$ feet, and that C D is 14 feet. The sides K B and G E are practically $16\frac{2}{3}$ feet long, at an angle of 60° with the horizon, so that their horizontal projection is $8\frac{1}{3}$ feet. The upper rafters are $17\frac{1}{2}$ feet long, and therefore make an angle with the horizon of 18° 19′. The trusses are assumed to be 8 feet apart, and are loaded at the joints only. The rafters in a larger truss would commonly be supported at intermediate points; but more lines would make our diagrams less plain.

The steady load is taken at 12 pounds per square foot of roof surface, or

$$(2 \times 16\tfrac{2}{3} + 2 \times 17\tfrac{1}{2})\,12 \times 8 = 6560 \text{ lbs., total load.}$$

The joint L will carry one-half the load on K B, or 800 pounds; the joint I K will carry one-half the load on K B and one-half of that on I C, or 800 + 840 = 1640 pounds; I H = 840 + 840 = 1680 pounds, etc. These weights are laid off, in the diagram marked S. L., from l to f by a scale of 4000 pounds to an inch, and the diagram is drawn. It shows that the rafters are in compression, marked +, and all the braces in tension, marked −.

47. **Snow Diagram.**—In treating this truss for snow load, it is considered that K B and E G are too steep for any weight of snow to accumulate there, as whatever fell on them would