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 *k l* reads downward or is thrust. If we read L K, it must apply to its upper end, and *l k* 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.

March 2d.

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; $\text{I H} = 840 + 840 = 1680$ 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

soon slide off. Therefore a weight of 12 pounds per *horizontal* square foot, for the upper rafters only, is taken for the maximum snow load, and, as the horizontal projection of I C + D H is $33\frac{1}{3}$ feet, that load will be

$$12 \times 33\tfrac{1}{3} \times 8 = 3200 \text{ lbs.},$$

laid off from k to g, in the diagram marked S. The end portions, $k\,i$ and $h\,g$, are each 800 pounds, and $i\,h$ is 1600 pounds. The division into two equal reactions at the points of support gives a. This diagram much resembles the other, but there is one point worth noticing; the lines of stress, ic and hd, cross in the first diagram, but do not in the second; while the reverse is the case with ed and bc. The result is that the stress of C D is reversed by the maximum snow load, and, as this stress is greater in amount than the one for the weight of roof and truss, C D will be a compression member whenever such a load of snow falls on the roof; and will be in tension when that load is removed. The stresses from these two diagrams are marked on the truss above each piece on its left with the usual signs. This strain sheet is more convenient than the table of § 44.

48. **Wind from the Left; No Roller.**—When the rafters do not slope directly from the ridge to the eaves, but are broken into two or more planes of descent, we shall have wind pressures of different directions and intensities on the two portions, I C and K B. From the table of wind pressures, § 34, we see that the intensity of pressure on K B will be 40 pounds, and on I C 16.9 pounds, normally, per square foot of roof. The total pressure on K B therefore will be $40 \times 16\frac{2}{3} \times 8 = 5333$ pounds, of which one-half will be supported at the joint L, and the other half at the joint J, as indicated by the two arrows perpendicular to K B. The pressure on I C will be $16.9 \times 17\frac{1}{2} \times 8 = 2366$ pounds, or 1183 pounds on each joint.

If the truss has no rollers under it, the diagram marked W. L., I. is obtained. On a scale of 4000 pounds to an inch,

$hi = ij = 1183$ pounds; $jk = kl = 2667$ pounds. For ij and jk may be substituted ik, if desired, the resultant of these two components at J.

To find the supporting forces:—Prolong the resultants of the wind pressure from the middle point of each rafter to intersect the span L F. The resultant K will be resisted at L and F by two reactions parallel to it, and *inversely* proportional to the two segments into which this resultant divides L F, as shown in § 36. The same will be true for the resultant I. By scale, or from the known angles, it will be found that resultant K cuts L F at $16\frac{2}{3}$ feet, or one-third the span, from L, and that resultant I cuts it at 22.4 feet from the same end. Dividing jl at $\frac{1}{3}$ its length, we have la' for one component of the reaction at L and $a'j$ for one component of the reaction at F. If we divide hj at $\frac{22.4}{50}$ of its length, ja'' will be a component of the supporting force at L, and $a''h$ at F. By drawing the parallelogram $a'ja''a$ we shall bring the component reactions for each wall together, and shall have, for the supporting force at L, or L A, la' and $a'a$, or their resultant la; and for that at F, aa'' and $a''h$, which combined give ah, properly called A H in the truss, since the letters from F to H are not in use at present. Take care to lay off the component reactions on the proper ends of the wind-pressure lines.

The polygon of external forces, when there is no roller under the truss, is therefore hi, ik, kl, la, and ah. The completion of the diagram, by drawing lines parallel to the several pieces, will be easy without further explanation. That the point e should apparently fall on ik is accidental. The signs affixed to the lines will enable one to see readily that the stresses in B C and E A are now reversed, the pressure I K obliging us to use a strut to keep that joint in place. The resultant, however, from the combined stresses in E A is still tension. The amounts given by diagram W. L., I. have not been placed on the truss, as we prefer to treat it from another point of view. Had they been used, it would be unnecessary to draw a diagram for wind on the right, for the different members of the truss would exchange stresses symmetrically; that is, A B would have the stress of E A, and E A that of A B; D H of C I, etc., C D remaining the same.

49. **Wind from the Left; Roller at Left.**—If rollers are placed at L, to permit of movement resulting from change of temperature, the supporting forces will be modified, L A becoming vertical. The diagram marked W. L., II. shows the effect of this change. So far as drawing the lines of wind pressure $hijkl$, the polygon of external forces will be obtained in the same manner as before. We may then draw the parallelogram and locate the point here marked a'; then draw $a'a$ horizontally, and we shall get la, the vertical reaction at L, equal to the vertical component of la of the figure just preceding.

In case the former diagram has not been drawn, a readier way to determine la will be as follows:—Draw hl, plainly the resultant of hj and jl; then, having prolonged the dotted arrows at I and K until they meet, draw a line, parallel to hl, through their intersection. This line will give the position of the resultant of the wind pressures, and lh is now to be divided in the inverse ratio of the two segments into which the resultant divides the span L F. The point of division will fall at a'', from which draw horizontally $a''a$, and the reaction la is thus determined. This method will not answer for finding the supporting forces if they are both inclined, as it will make L A and A H parallel to one another. The reaction at L being la, the one at F is ah, requiring the resistance at F of the entire horizontal component of the wind pressure.

A comparison of the two W. L. diagrams will show that the stress in every piece is changed very decidedly in amount, and that in a number of pieces the stresses are reversed by rollers at L. These latter stresses are marked on the truss, at the right of each piece.

50. **Wind from the Right.**—When the wind blows from the right, the diagram marked W. R. will be obtained. The lines $ihgf$, representing the wind pressures, will correspond in value with $hikl$ of the preceding figure, and, since the other diagram has been constructed, the vertical reaction at L will now be obtained by drawing the horizontal line $a'a$, from either the angle of the parallelogram or the proper point of division of the resultant if, so as to give ai, the smaller part of the vertical component of the wind pressure; that, is la from W. L., II., plus ai from W. R., equals the vertical projection of the polygon of external forces.

51. **Results.**—When this diagram is completed by the customary rules, a comparison of it with the one preceding will make clear the effect of wind on different sides. The stress in the rafters is much greater when the wind blows on the side farther from the rollers, but it is always compressive. The forces in the braces are all reversed.

The weight of the roof and truss may be the only external force, or snow may be added; and, in either case, the wind may also blow on one side or the other. Selecting then those stresses which may exist together, we find the maximum tension and compression marked below each piece. The rafters are always compressed, and A B is always in tension. The other pieces must be designed to resist both kinds of stress, although the compression in D E is quite insignificant.

52. **Curved Roof Truss: Example.**—If the truss has a curved exterior outline, the pressure of the wind will make a different angle with the horizon for every point. But there will be no sensible error if the pressure on each piece is assumed to be normal to the curve at its middle point, or, what is practically the same thing, perpendicular to the straight line joining its two extremities. Thus, in the truss of Fig. 20, the wind pressure on C T is taken as perpendicular to a straight line from B to the next joint in the rafter.

The span of this truss, drawn on a scale of 30 feet to an inch, is 60 feet; height at middle of rafters 15 feet, at middle of main tie 6 feet. The curves are arcs of circles, the radii of the upper and lower members being respectively $37\frac{1}{2}$ feet and 78 feet. The rafters are spaced off at intervals of $11\frac{1}{2}$ feet each way from the middle, and the tie is divided into $10\frac{1}{4}$ feet lengths. The end portions will differ slightly from these measures. The trusses are to be 10 feet apart. From the data, radius $37\frac{1}{2}$ feet, and half-chord or sine $5\frac{3}{4}$ feet, it is easy to calculate that the chord of the first piece of rafter from the middle will make an angle with the horizon of $8° 49\frac{1}{4}'$. The second piece will be inclined three times as much, or $26° 28'$, and the last five times as much, or $44° 6'$. The intensity of normal wind pressure will then be, when interpolated in the table, § 34, 8.6 pounds per square foot for the upper length, 23.7 pounds for the next length, and 35.6 pounds for the lowest piece. Multiplying these intensities by $11\frac{1}{2} \times 10$, we get 989 pounds, 2725 pounds, and 4094 pounds, respectively, represented by the small arrows, as if concentrated at the middle points of E, D, and C. The steady load is taken at a small figure, 2300 pounds per piece of rafter, to allow the disturbing effect of the wind to be more marked.

The diagonals in this truss are light iron rods, not adapted to resist compression, and therefore, if a compressive stress would occur in a particular diagonal, in case it were alone in a panel, we substitute the other diagonal, which will then be in tension. In lettering the figure, that *tie* which is required for a particular distribution of load is supposed to be present, and the other diagonal is not taken account of. Thus, in the panel through which the dotted arrow is drawn, if the brace which goes from the top of O P to the bottom of Q R is under stress, it will be called P Q, while the rafter will be Q E and the bottom tie P A. If the other diagonal is strained, the rafter will be called P E and the main tie Q A.

53. **Steady-Load Diagram.**—The diagram for weight of roof and truss is drawn on a scale of 8000 pounds to an inch. The vertical load line is *i b*, and the polygon for the point of support B is *c b a t c*. On passing to the next joint in the top or bottom member we find three pieces whose stresses are unknown. Both diagonals R S cannot be in action as ties at once; therefore suppress one, for instance that which runs to the upper end of S T. We then shall have only two unknown stresses at the upper joint, and can draw *t s'* and *s' d*. The lower joint will then give *s' t*, *t a*, *a r'*, and *r' s'*. But *r' s'* will be a compressive stress, as we read from *r'* to *s'*, and this diagonal is not the desired one. Taking the other, and trying the lower joint first, we have *t a s t*, and the upper joint then gives *d c t s r d*, where *s r* is tension. Notice that change of diagonal affects the stresses in no pieces beyond those which bound the quadrilateral or panel in which the diagonal is changed. Analogy will rightly lead us to take the other diagonals which slope the same way, that is, down towards the middle. It is therefore easy, after the first attempt, to decide which diagonal to reject and which to retain.

54. **Remarks.**—If *d r* had been slightly more inclined, so as to strike *s*, no diagonal R S would have been required for this distribution of load. It will be seen that the stresses, all tensile, in the bracing are very small as compared with those in the main members, a fact due to the approximation of the rafter outline to the equilibrium curve or polygon for a load distributed as in this case. See § 88. If the outline of a truss coincides with the equilibrium polygon pertaining to a certain distribution of load, no interior bracing will theoretically be needed for such distribution; but if the distribution or direction of the external forces is at any time changed, bracing will be called into action. Further discussion of this subject comes in Parts II. and III.

The length of *h k*, etc., as compared with H K, etc., shows the necessity of drawing the truss skeleton on a large scale, to secure parallelism of the respective lines in each figure. As a slight change in the inclinations of the rafter and lower tie lines will change the magnitude of the stresses in those pieces quite materially, we are warned by the appearance of the diagram to provide, by an increase in size of these pieces, against such a change in the truss as would be caused by slight errors in construction or by deflection under the load. Stress diagrams are particularly serviceable in this way.

55. **Wind and Steady Load.**—We might analyze the effect of the wind separately upon the truss, but, as there is a likelihood that the wind will reverse the stress in some of the diagonals which experience tension from the steady load, and that we shall be obliged, therefore, to substitute the other diagonals in such panels, it seems better to draw the diagram for the wind and the weight of the roof in conjunction. Therefore the two diagrams marked W. R. and W. L. are drawn for the maximum force of wind on either side, combined with the weight of the roof, etc. The external load line $b\,i$ of one case is the exact reverse of $i\,b$ of the other. An explanation of the construction of W. R. will suffice for both.

When the wind blows from the right, there is only the steady load on the left half of the truss. Beginning therefore with the joint at I, lay off vertically $h\,i = 1150$ pounds, or one-half the load on H K; next $g\,h = 2300$ pounds, load at G H, and so on to F E, as in the steady-load diagram already discussed. At F E we find, in addition to 2300 pounds vertical pressure, an inclined force perpendicular to the tangent at E, or to the chord of the piece, and equal to one-half of 989 pounds, the wind pressure before computed for E. We thus get the inclined line as far as e in the diagram. The joint D E gives $d\,e$, manifestly made up of the other half of 989 pounds, of the vertical 2300 pounds as usual, and finally of one-half of 2725 pounds from the next length of rafter, and perpendicular to it. The forces for the remaining joints C D and B C will be plotted in the same manner, and we therefore see that, commencing at B, as is proper for this load line, we lay off the vertical and inclined forces in regular succession from one side of the truss to the other. If one draws a straight line from c to d, it will be the resultant of the combined external forces at C D.

56. **Reactions and Diagrams.**—Connect b with i by the dotted line, which will be the resultant of all these forces. As the resultant of the dead weight, symmetrically distributed, acts in the line of the vertical O P, and hence through the centre of curvature of the rafters, and as the wind pressures all point to the same centre of the circle, the resultant, parallel to $b\,i$, must pass through the same point. Therefore draw the dotted arrow through the centre from which the rafter was struck, and parallel to $b\,i$. This arrow cuts the span B I, by measurement, at $25\frac{1}{4}$ feet from B, or $34\frac{3}{4}$ feet from I. The resultant $b\,i$ scales 20,620 pounds. If the supporting force at B were parallel to this resultant, it would be found by taking moments about I, when we should have

$$B \times 60 = 20{,}620 \times 34\tfrac{3}{4}\,; \quad \text{or} \quad B = 11{,}942 \text{ lbs.}$$

Lay off this force from b to a'. If rollers are placed at B, that reaction will be vertical, and the horizontal component of $a'\,b$ must be resisted at I. Let fall $b\,a$ vertically, determining the point a by drawing $a'\,a$ horizontally, and connect i with a. The two supporting forces will be $i\,a$ and $a\,b$.

In the W. L. diagram the point a' comes nearer to b than to i,—that is, the quantity just obtained now applies to the point of support I,—and a falls very near to, but just outside of f, in the prolongation of the vertical line.

If there are no rollers under the truss, find the supporting forces for each oblique pressure separately, as in § 48. The same course must be pursued when the curve of the rafters is not circular, as the forces will not then meet at a common centre. Having thus completed, in either case, the polygon of external forces, the remainder of the construction will be made as in any example. After the first trial to ascertain the proper diagonal, it appears that, in each case, the diagonals all slant one way; so that, for wind on one side, one set of diagonals is in tension, and for wind on the other, all of the other set are strained.

57. **Change of Diagonal.**—The effect on the five pieces of a panel, top, bottom, two sides and the diagonal, of drawing the diagram so as to give compression in a diagonal, is shown anew in the W. L. figure for the panel P Q. Instead of op and qr, we get op' and $q'r$, considerably increased in amount but the same in kind; for ep and aq are substituted eq' and ap', unchanged in kind, but having practically what is taken from one added to the other; while the diagonal stress is, as we said, reversed, but very nearly the same in amount.

It might be practicable to deduce some rule for determining beforehand the diagonal which would have the desired kind of stress, but the tentative process seems easy. We find it convenient to draw the lines parallel to the rafter and main tie first, as ep and ap', then to sketch roughly two lines for the suspending piece and diagonal, see whether that diagonal comes in tension, and finally draw the right ones carefully.

58. **Resultant Stresses.**—It is not necessary to put the signs + and − on these lines, for it may be seen that all the rafter is compressed, the whole lower member extended, and all of the diagonals are in tension, as well as all the suspending pieces except O P and Q R, which are compressed a trifle when the maximum wind comes from the right. Such pieces are easily selected, if one notices that op and qr in the W. R. diagram are drawn in a direction opposite to the prevailing one.

The stresses are given in the following table. The lengths of rafter are denoted by a single letter. The pieces of the main tie, having the letter A in common, have also the letters which stand before the stresses in the proper columns. The inclination of the diagonal is shown by the sign prefixed to the stress. The effect of the wind on the roller side is to materially reduce the stress in a large portion of the main tie. The light bracing required is a marked feature of this type of truss, and the predominance of tensile members favors the use of iron bars. The two compressions, marked +, are too insignificant to require an increase of section.

TABLE OF STRESSES FOR FIG. 20.

		S. L.	W. R.	W. L.	Max.
Rafters	C	12,600	18,900	16,200	+ 18,900
	D	11,400	17,500	15,600	17,500
	E	10,800	15,000	16,200	16,200
	F	10,800	13,300	17,900	17,900
	G	11,400	12,700	20,100	20.100
	H	12,600	13,100	21,800	21,800
Main Tie.....A		K 9,600	K 5,500	K 19,500	− 19,500
		L 9,500	L 5,500	M 18,000	18,000
		N 10,400	N 7,200	O 16,000	16,000
		Q 10,400	P 9,000	Q 14,200	14,200
		S 9,500	R 10,900	S 12,300	12,300
		T 9,600	T 12,800	T 12,300	12,800
Diagonals	L M	╲ 900	╲ 1,800	╱ 1,800	
	N O	" 400	" 2,100	" 2,400	
	P Q	╱ 400	" 2,400	" 2,200	
	R S	" 900	" 2,200	" 2,100	
Suspenders	K L	1,200	700	1,200	− 1,200
	M N	1,000	200	900	1,000
	O P	900	+ 100	700	900
	Q R	1,000	+ 50	1,000	1.000
	S T	1,200	400	1,600	1,600

If the designer proposes to proportion the pieces with regard to minimum as well as maximum stresses, he can readily select the former from the table.

If a fall of snow is supposed to be uniformly distributed over the roof, the increased action of the several pieces can be easily obtained by proportion from column S. L. But, if it is thought that the inclination of the portions near C and H is too great to permit of snow accumulating there, a diagram for snow should be drawn. The horizontal projection of a piece of the rafter is properly taken when reckoning a snow load.

We think the reader will have no difficulty in drawing diagrams for a truss of similar outline, but with only a system of simple triangular bracing.