Art. VII.—*Stability of Structures in regard to Wind-Pressure.*

Paper 2.—Bridges.

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[Read 10th June, 1886.]

Wind-pressure in connection with bridges assumes, for the engineer, its most important aspect. This is especially the case when the bridge is of large dimensions, and is used for railway purposes. Such a type will now be considered—viz., a large iron railway bridge upon iron columns.

Still following the method suggested in the first paper, it will be necessary to fix the probable maximum for the locality of the structures. As these are usually in exposed situations, and as everything demands the highest state of security, it would be wise to adopt a high maximum for the purpose of calculation.

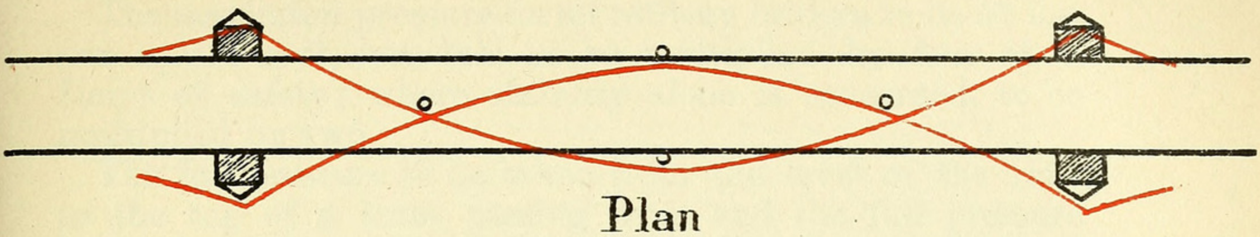
From 50 to 70 lbs. per square foot, the latter where the position is peculiarly exposed to high gales, would appear to be suitable pressures to take for this purpose.

The amount of force exerted upon one span of such a bridge will depend upon the area of the surface of the girders exposed, the area of the columns in the pier, the vertical area of a train passing over, and the height of the girders above the ground.

If the girders be of web construction, the pressure can readily be found; but if, as will probably be the case in a large structure, the girders be latticed, a little more difficulty exists.

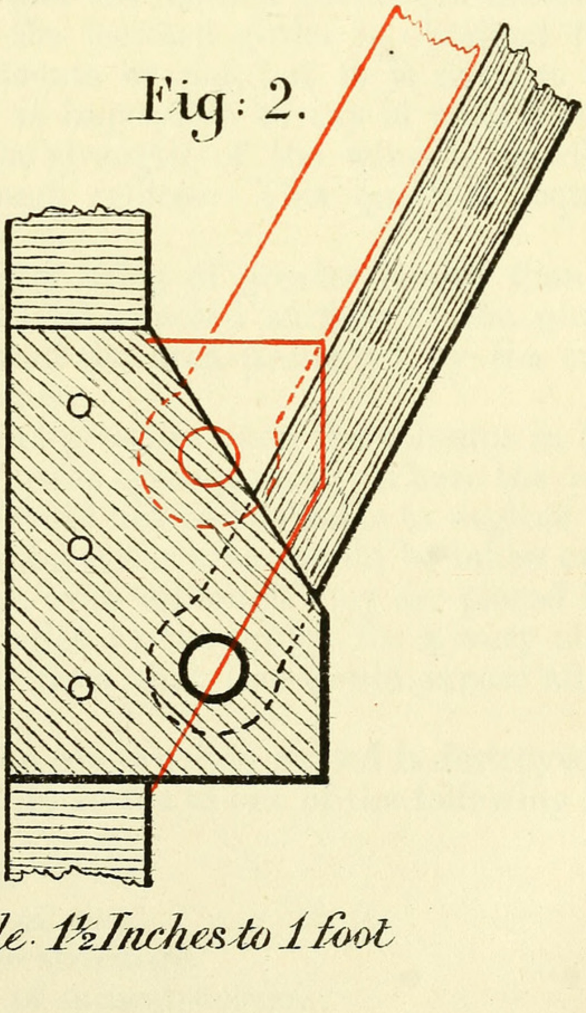
After the failure of the Tay Railway Bridge a commission of eminent engineers drew up a report upon the subject of wind-pressure on bridges, and the following method was recommended by them for determining the pressure upon lattice girders:—

Fig: 1.

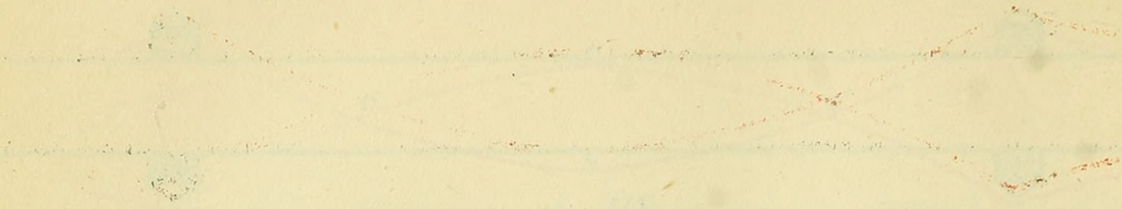


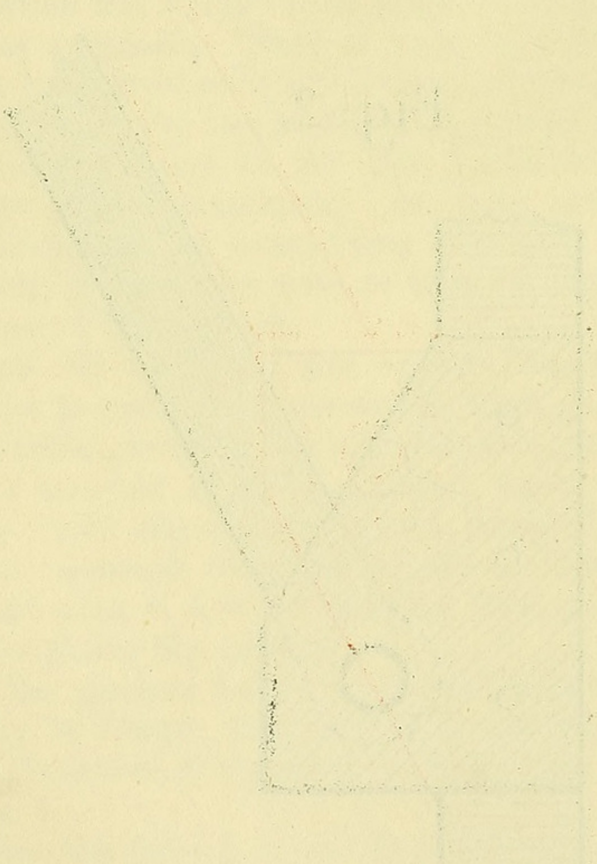
Plan

Fig: 2.



Scale. 1½ Inches to 1 foot





The maximum pressure for all railway bridges to be 56 lbs. per square foot, but this to be multiplied by four as a factor of safety; where stability alone is concerned, to be multiplied by two.

The full pressure to be taken from the level of the rails to the top of a train passing over, and the full pressure for all the area of girder exposed below and above this.

For all the vertical surface of the leeward girder below level of rails and above top of train the pressure to be taken as follows:—If the area of the open spaces does not exceed two-thirds of the whole area within outline of girder, the pressure to be taken at 28 lbs. per square foot. If such area be between two-thirds and three-fourths, the pressure to be taken at 42 lbs.; and if over three-fourths, to be taken in full.

The members of the commission were Messrs. Hawkshaw, Barlow, Armstrong, Stokes, and Yolland.

It is not stated whether the method adopted of determining the pressure upon the leeward girder is obtained from the results of experiments or not, but it is evident that without such data it is impossible to say in what manner and to what extent the strength of the wind is interfered with on passing through orifices. This question requires further elucidation.

In event of the spans being of greater length than the passing train, the area of exposed surface of the girders should be taken all round the area presented by the train, not only above and below.

The effect of the wind-pressure upon the columns in low-level bridges is not of great consequence. Where the piers are high, however, it would not be advisable to neglect this force; and in determining it the area should be taken of all the columns in the pier, even although they are placed in a single line at right angles to the bridge, for a very slight deviation of the wind from that line would expose all the columns to its force.

When a bridge of the construction named is destroyed by wind-pressure, the failure is due to one of the following four causes:—

Instability of pier.
Lateral weakness of pier.
Instability of superstructure.
Lateral weakness of superstructure.

1. *Instability of Pier.*—In this case, whilst the various parts maintain their respective positions, the whole pier overturns upon the base of the leeward column.

The overturning moment is the pressure upon the girders, upon a passing train, and upon the piers, multiplied by the distance of the centres of pressure from the foot of the leeward column. The moment of stability is the weight of the portion of the bridge considered, superstructure and piers, and the weight of the passing train, multiplied by the distance at which it acts from the leeward column—that is, half the width of the base of pier. The point in the leeward column to which the width should be measured, lies somewhere between the centre and the outside of that column. It would probably be advisable, however, in all calculations for the purpose of determining the width of pier in any proposed structure, to take the measurement to the centre of the column, except where these are of great dimensions compared to the width of pier.

In connection with the stability of the pier, no allowance need be made for factor of safety; there can be no imperfection of workmanship in the power of gravitation, nor any weakening of material by successive strains. If 60 lbs., then, be considered as the greatest wind-pressure the bridge will be called upon to bear, there is no necessity to make the pier stable under a pressure of 120 lbs. or 180 lbs. There are, however, other forces tending to keep the pier in position, of which no mention has yet been made, and which might act as a set-off to the chance, which is always within the range of possibility, of the structure meeting a gale of greater force than that for which it has been designed. These forces, though not as a rule calculable, are undoubtedly of considerable extent, varying according to the size and construction of the bridge, and the nature of the ground in which the piers have been sunk. First, there is the hold which the columns on the windward side of the centre have upon the ground, or if bolted to brickwork or masonry, the strength of such attachments; and, second, there is the sustaining power of the girders acting as a tie throughout the length of the bridge, for in a structure of some length those portions struck by the most violent gusts will be supported by the whole of the structure experiencing a force less than that necessary to overturn it.

The area over which the very high pressures of wind extend is another point, regarding which information would be of service to the engineer.

In connection with the sustaining powers of the girders, it may be recollected that the portion of the Tay Bridge which fell was deprived of this support; for its girders were above the rail level, and disconnected with those of the remainder of the bridge, which were below rail level. Had the whole of the bridge been of the continuous girder type it might not perhaps have stood, indeed, but it would have been better able to resist the force of the gale which destroyed it.

2. *Lateral Weakness of Pier.*—In this case the pier will fail by each column turning upon its base independently. The overturning moment may be determined in the same way as for the first case. The resisting force is provided chiefly by the bracing between the columns. When these are sunk in the ground additional resistance will be obtained from their strength as semi-beams; when they are bolted to brickwork or masonry, from the strength of the fastenings. In long columns, however, and especially in soft ground, such resistance will be but slight, and as well as that due to the attachments to masonry, might be neglected, &c; but where the piers are short, and the ground strong, this resistance must receive due attention.

It is usual to connect columns at intervals by somewhat massive horizontal strutts. These are intended to give the structure the necessary rigidity under passing loads. These braces are usually of sufficient strength to keep the columns perfectly parallel to one another, but to prevent them turning each on its own base diagonal bracing is requisite. Practice varies as to the design of this bracing. The method most in vogue appears to be two tension bars crossing in the centre of each square formed by the horizontal strutts.

This form is not the best, as from whichever side the wind blows, one-half of the bars—those which slope down from the wind—do no work, or, what is worse perhaps, are exposed to compressive strains.

Again, unless the tension-bars are fixed in position with some initial strain, it is quite possible that a certain distortion of the pier might occur before these tension-bars would exert the necessary resisting force.

A single diagonal strutt might be used where the distance between the columns is not so great as to involve a possible bending of the strutt.

The most satisfactory method would be two strutts crossing, and fastened in the centre where they pass one another. As the stresses in all the braces of the pier will be the same, the proper dimensions for the diagonal braces can readily be determined.

Besides collapsing from the weakness of the bracing, a pier may fail through weakness in the columns themselves; for suppose that the force of the wind, without being strong enough to overturn the bridge, is just sufficient to remove the whole weight from the windward columns, the burden must be borne by the leeward ones. In the case of a pier with two columns only, the leeward column would have to bear the whole weight of one span of the bridge. It would appear to be necessary, then, to design columns so as to meet the compressive strains and tendency to buckle, due to the imposition of such a load.

3. *Instability of Superstructure.*—In this case the girders would fail by overturning upon their bases. The overturning moment will be the wind's force upon the surface of the girder exposed, multiplied by half the height of the girder. The resisting power is in the stability of each girder independently, and the strength of the strutts and ties fastening the two together. This case is very analogous to that of the instability of piers, only as the overturning moment is very much smaller, the means of resisting it present no difficulty. The mode of attaching the girders together differs according to the position of the road and the girders. If the road runs through the girders and the headway is limited, arched braces usually connect the tops; if not, the cross-pieces are straight. When the road passes over the girders they are usually fastened in the same way as the columns of a pier—viz., by horizontal and diagonal braces. In this case, even more than in the other, diagonal strutts would appear preferable to ties, giving a greater rigidity to the superstructure under a passing load.

4. *Lateral Weakness of the Superstructure.*—Although there is not much danger of girders being actually broken by the wind's force, it is quite conceivable that in a long span they might be put into such a state of lateral vibration as would unduly strain, and even inflict damage upon, the structure.