time not exceeding the length of floor panels found to be most desirable. For many years Whipple's truss was the standard form for long spans, the longest constructed, it is believed, being the 515-foot span in the Ohio River Bridge at Cincinnati, built in 1877.

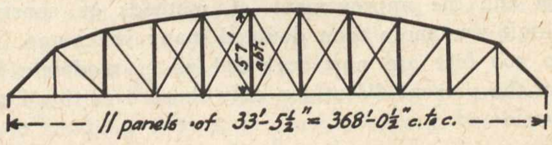
The uncertain nature of the stresses due to the presence of redundant members, and the resulting lack of economy, in the Whipple truss gradually caused its abandonment in America, though its use, and the use of statically indeterminate structures generally, has persisted abroad till the present day. Especially strongly have British engineers defended this type of construction. They claim that failure to support the members of one system of webbing by those of another system introduces greater irregularities than those resulting from redundancy; that multiple systems enhance the stiffness of the structure; that all dependence should not be placed upon one member, but upon as many as possible, regardless of the knowledge of the load that each one carries. The position of those in opposition to this view is well se forth by Mr. Frank H. Cilley in the Proceedings of the American Society of Civil Engineers for October, 1899, where an attempt is made to accurately analyze the stresses in statically indeterminate structures. Mr. Cilley demonstrates that errors of workmanship, producing variations of lengths of members well within the range of good shop practice, might easily offset the assumptions made in the stress calculations. The truss with superfluous members is shown to possess no advantage over the statically determinate structure as far a deflection is concerned, though the connection of such members at their intersections gives a considerable degree of freedom from vibration. The maximum economy of material is found to result when the stresses in the redundant members are zero, or, in other words, when they are non-existent. Between these two positions it is difficult to judge. Undoubtedly there is wisdom in each. Practice in America almost universally conforms to the latter view, while abroad, particularly in Great Britain, the former is generally held.

The superseding of the Whipple truss for long spans began when the Warren or triangular truss was adapted to such conditions by introducing sub-verticals. These carried the ends of the floor beams, and were attached to the upper chord panel points, and also to the centres of the main diagonals, as shown in Fig. 1 (b). An economical floor system was secured in this manner, while at the same time not rendering reasonably accurate stress calculation impossible. The 525-foot span built at Henderson, Ky., in 1885, was of this type. Its chief disadvantage was long compression members in the web system.

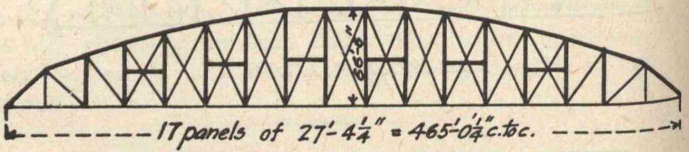
Though the principle of panel sub-division applied to the Warren truss made it possible to construct very long spans economically, spans of considerable length have been built without subdividing the panels. For example, single intersection Warren trusses of about 354 feet span, as shown in Fig. 2 (a), were used in the bridge erected over the Indus River in 1899 for the Kotri Rohri Section of the Indian State Railways.

In Europe, although the single-intersection Warren truss is employed for fairly long spans, multiple systems of webbing are commonly used, thus rendering the structures essentially the same as those of the Whipple type. Thus, in the new bridge over the River Tyne at Newcastle, England, completed in 1906, double-intersection Warren trusses of 300 feet span were used, as shown in Fig. 2 (b). Such trusses have been used to some extent in America for highway spans, but because of the uncertainty in the stresses, due to concentrated moving loads, they are not regarded with great favor for railway bridges. A good example of double-intersection Warren trusses used in highway spans occurs in the bridge over the St. Francis River at Richmond, P.Q.. built in 1903. The two spans of 370 ft. 10 in., c. to c., each are among the longest, if not the longest, riveted highway spans in America. The outlines of these trusses are shown in Fig. 2 (c). Sub-verticals are dropped from the intersection of each pair of diagonals to carry the ends of the floorbeams at these points, and are produced up to the top chord to support it in a vertical plane. Connecting sub-verticals to the intersection of diagonals in this way introduces an uncertainty in stress calculations, for the reason that the diagonals cannot then act independently.

Since the economical modification of the Pratt truss by using curved top chords, it has frequently been used for long spans. The 368 ft. ½ in. spans of the Cornwall Bridge, built in 1898, over the St. Lawrence River on the line of the New York and Ottawa Railroad, are an example. An outline diagram of one of these trusses is given in Fig. 3 (a). Probably the longest simple truss highway span in America, he 465 ft. span over the Miami River at New Baltimore, Ohio, built in 1901, is of this type. The form of the truss is shown in Fig. 3 (b).



(a) Cornwall Bridge, 1898



(b) New Baltimore Bridge, 1901

Fig. 3–Pratt Trusses

Applying the principle of subdivision of panels to the Pratt truss with parallel chords, the Baltimore truss was devised by the Baltimore Bridge Company. The intersection of a sub-vertical with a main diagonal is connected by a strut to the nearest lower chord panel point towards the pier, or by a tie to the nearest upper chord panel point towards the centre of the truss. These secondary members are called, respectively, sub-struts and sub-ties. Though both are used in practice, the sub-strut is less economical of material than the sub-tie, but contributes to the stiffness, or freedom from vibration, of the bridge. In Fig. 4 (a), which represents a truss of the 380 ft. fixed span of the bridge built in 1904 over the Fraser River at New Westminster, B.C., sub-struts are used. Horizontal struts connecting the posts midway between the chords serve to stay these compression members laterally. Sub-ties were used in the trusses of the Bellefontaine Bridge, built in 1895, over the Missouri River, as shown in Fig. 4 (b).

The most perfect truss yet devised for very long spans is a modification of the Baltimore truss obtained by curving the top chord, thus increasing its economy, and at the same time considerably improving the appearance. The resulting structure is commonly known as the Petit truss. In it sub-struts or sub-ties are employed for supporting the main diagonals at their intersection with the sub-verticals. This type of truss, of which a number of examples are shown in Fig. 5, has been criticized severely by the engineers of the "lattice" or "multiple-intersection" school, particularly after the collapse of two 546½ ft. spans of the Louisville and Jeffersonville Bridge on December 15th, 1893, while being erected (see Fig. 5 (b). Though it was shown that the failure was due to insufficient precautions against high winds during erection, much adverse comment on the form of the truss itself was made, particularly by Mr. Geo. H. Pegram, the advocate of a rival truss. It was held, among other things, that there were too many extra members, the purpose of which was merely to hold the load-bearing members in place, and that as a consequence dangerous bending stresses were induced in the primary members, due to elastic changes in the length of the latter; that the great variation in the size of the members gave rise to high