fied as follows: (1) Arches (steel)—(a) three-hinged; (b) two-hinged. (2) Simple spans. (3) Cantilever structures—(a) with suspended span; (b) without suspended span. (4) Suspension bridges. I have purposely omitted masonry and concrete arches as structures not coming clearly within the scope of this paper. Steel arches have a rational application only where nature has provided natural abutments, as at Niagara Falls, for instance, or where natural surroundings lend themselves to ornamental construction.

Crooked River Arch.—I have recently completed an arch bridge for the Oregon Trunk Ry. in the Crooked River Canyon. It is a two hinged spandrel braced arch. Three hinged arches are now seldom used for a railway bridge because they are less rigid than two hinged arches. They still have a good application in roof trusses which are not subject to heavy and rapidly moving loads. In several large arch spans the central connection offered considerable difficulties. The reason is that the top chords at the centre of a purely two hinged arch are calculated to have stresses in them, due to dead load and temperature, when the span is riveted up and ready to receive the rolling load. These stresses had to be introduced by powerful jacks, or other means, before the final point could be riveted up. To avoid this difficulty, I have proceeded as follows in the Crooked River arch. It was assumed that the dead load and temperature stresses at 60 deg. Fahr. in the top chord at centre are zero. This being the case, the arch acts as a three hinged structure under those conditions—namely, with all dead load in place and at 60 deg. Fahr. The span was, therefore, erected as a three hinged arch, all dead load, or the equivalent, including the decking, was placed thereon, and at a time when the temperature was very nearly 60 deg. the centre panel of the top chord was inserted and riveted up. The calculations were simple. The dead load stresses were calculated as in a three hinged arch, the temperature and live load stresses as in a two hinged arch, and the various results combined.

Types of Span.

A two hinged spandrel braced arch is probably the best type to use for railway traffic, where the natural abutments permit of sufficient rise; which will often be the case where the arch type of bridge is a logical solution. This particular type of arch is more rigid and less subject to vibration than the other types of arch, and presents the advantage of easier erection, which can then be simply performed by treating each half as a cantilever arm held back by suitably temporary anchorages until the centre connection is made. An arch bridge is a somewhat special structure, and is rarely used for very long spans, except, as I remarked before, where nature has provided abutments.

SIMPLE SPANS.—Twentyfive or 30 years ago the system of truss most favored for long simple spans was a double intersection Pratt truss with parallel chords. Nowadays the type most used is a single intersection Pratt truss with subdivided panels and curved top chord. The curved top chord is an element of economy. The single system has also a slight advantage of more definite stresses. It has its disadvantages, such as, for instance, the lack of uniformity in deflection, about which I will speak more in detail in connection with cantilever system. There is no doubt that a bridge composed of simple truss spans is a better bridge than a cantilever system or a suspension design, chiefly because of its rigidity. This rigidity results from the fact that a load placed on one span has no lifting action on the adjacent spans, as in a cantilever system, or on other portions of the same span, as in a suspension bridge. But long simple spans must be erected on falsework or floated into position. The first method is often admissible on account of the necessity of keeping the channel open for navigation or excessive depth of water combined with navigation requirements, or other local conditions. The floating of a span into position is not only costly but hazardous. It has been successfully performed, but is not always feasible or safe. Then, too, generally speaking, a cantilever bridge is more economical for long spans. These considerations often lead to the adoption of a cantilever design in preference to simple spans. A cantilever span can always be erected without false work, although the adjacent or anchor spans must generally be erected on falsework. Sometimes simple spans are erected without falsework.

The length of simple spans has been growing from year to year. The Cincinnati Southern bridge at Cincinnati, built in 1877, contains a simple span of 515 ft. In 1891 G. S. Morison built the Cairo bridge, connecting a span 518 ft. in length, single track. The Municipal bridge in St. Louis has three simple spans of 668 ft. in length, 110 ft. high at the centre, double track and road ways. The metropolis bridge over the Ohio River, if the present design is carried out, will have a simple span 720 ft. long, double track. This increase is due largely to the use of high grade materials, such as nickel or chrome nickel steel, and to the improvement in shop and field methods.

And here we may say a few words about wind forces. In small spans the action of wind rarely affects the main members of the span, and the wind bracing used is calculated more to make the structure rigid against lateral motion under rapidly moving loads than to take care of actual wind stresses. As the length of span increases, this element of wind becomes more and more important, until in very long spans it may become as important as the moving load. In a simple span the heaviest members, as well as the greatest height of truss, occur near the centre of the span. In other words, the resistance to wind per lineal foot of truss in a simple span is greatest at the centre of the span, and, owing to the overturning moment due to wind, grows in importance with the height. In a cantilever span the greatest height of truss and the heaviest members are near the piers, hence the greatest resistance to wind per lineal foot of truss is near the piers. This remark is sufficient to explain why wind stresses are easier to provide for in a cantilever structure than they are in a simple span of the same length.

PROPORTIONS OF SIMPLE SPANS WITH CURVED TOP CHORDS

	Per cent ratio height to length	Per cent ratio width to length
Municipal bridge, St. Louis, Mo. . .	16.47	5.24
Cincinnati, Ohio, over Ohio River. .	15.41	5 60
Pennsylvania Rd., over Delaware, Phila.	15.76	5.82
Ohio Connect'ng Ry., Pittsburgh. .	14.5	5.57
McKinley bridge, St. Louis, Mo. . .	15.07	5.73
Merchants bridge, St. Louis, Mo. . .	14.47	5.80
Mobridge, Mo.	15.18	5.48
New Brunswick bridge, N.D.	16.25	5.50
Quebec suspended span.	17.19	. . . .
Thebes suspended span.	15.03	. . . .
Average.	15.56	. . . .

LONGEST SIMPLE SPAN.—No hard and fast rule can be laid down as to the length at which a simple span becomes uneconomical as compared with a cantilever span. Generally speaking, considering the present knowledge of materials, a simple span of 700 ft. may be taken as the practical economical limit, beyond which it is not advisable to go without a thorough investigation and comparison with a cantilever system. Where conditions require unusual methods of erection this limit may be much lower. For instance, in the Thebes bridge it was necessary to erect the 671 ft. channel span without falsework. A simple span would have required the addition of a considerable amount of metal, both in the span itself and in the adjacent spans, to permit of its being erected as a cantilever; this excess of metal would have been useless after the completion of the bridge, and its cost would have made the bridge more expensive than the adopted cantilever design.

DIMENSIONS OF SIMPLE SPANS.—In designing long simple spans the following general principles should be observed. The width, centre to centre of trusses should not be less than one-twentieth of the span, preferably one eighteenth. In double track spans the width required for clearance generally governs, except in very long spans. The height at centre of span, for a Pratt system of truss with subdivided panels, should be from one seventh to one fifth of the length. The table on this page shows the proportions of the width and height to the length of span in some of the curved top chords bridges built recently. The height at the ends should be only sufficient for an effective portal. A rigid mathematical research by Jos. Mayer, Principal Assistant Engineer of the Quebec bridge, leads to a theoretical proportion between the height at centre and length of span equal to 0.18, or somewhere between one fifth and one sixth, for heaviest loads and double track spans.

PANEL LENGTH.—The best panel length is not so easy to determine. Since the economical inclination of diagonals is very nearly 45 deg., it would result that in a Pratt truss with subdivided panels their length should approach one half of the height of truss. This would mean that in a truss with a curved top chord the panels in the centre should be longer than those near the end. This has been done at least in one instance, namely, in the Municipal bridge in St. Louis. The advantages of such an arrangement are a slight economy in the weight of steel and an improved appearance, since the diagonals have nearly the same inclination throughout. The equal panels, however, present, in my opinion, two decided advantages, which may more than offset the advantages of the former system, namely, that, all panels being equal, there is a greater duplication of parts, the floorbeams are all alike, except at ends, the stringers are all alike, the length of bottom chord eyebars is the same throughout; and, further, that the falsework may be built in uniform panels, and the traveller, which is usually designed with a view to have the uprights in proper relation to the panel points, so that the connections may easily be made, preserve its relation to the various panels points as it is moved from panel to panel. For these reasons uniform panels should be preferred in the majority of cases of simple spans.

Maximum Span Lengths.

I have already stated that the greatest practical length of a simple span is about 700 ft. With the use of certain known alloys of steel of greater strength than medium carbon steel this limit may become as much as 750 ft. Beyond this limit the weight of simple spans becomes so great, in comparison with cantilever spans, that the latter must be considered. A mistaken idea sometimes prevails that the weight of steel in a span increases in proportion to the square of the length. This is, in a measure, true for short spans, say 100 to 300 ft. This ratio of increase, however, is not a constant, but increases with the span. A simple span above 1,200 ft. in length increases in weight approximately as the cube of the length, and this exponent increases more and more