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Potentialities of Welded Deck Bridges of Triangular Cross Section

Möglichkeiten geschweißter Brücken mit dreieckförmigem Querschnitt bei obenliegender Fahrbahn

Possibilités des ponts soudés de section triangulaire, avec tablier supérieur

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It seems reasonable to predict that bridges of the future will achieve considerable economy due to the utilization of the favorable characteristics of three-dimensional structures, in combination with welding. The aircraft field has long recognized the efficiency of three-dimensional frames and closed shell construction employing the *torsional* strength of such structures to take eccentric loads.

The advantages of a triangular-section bridge, though recognized by the structural engineering profession for almost a century, have never been fully exploited, probably in part because of the difficulties with shapes and riveted connections for a space structure of this type, and also because of uncertainty as to the structural behavior of such a bridge. Certainly the introduction of one or two new rolled shapes, together with the employment of welding for connections, would easily overcome the former difficulties; and the fact that the structural action of the truss as a space frame can be analyzed with certainty and without undue difficulty is attested by those few bridges of this type which have successfully withstood the test of use.

Many writers, even in very recent times, have recognized the potentialities of the welded triangular-section truss for bridges. The recent revision of the text by L. E. GRINTER [1], for example, contains the statement:

"It is possible that the introduction of arc-welded bridges may lead to the use of deck bridges with a single lower chord. There is the obvious advantage of the elimination of lower laterals and sway frames..."

The space truss of triangular cross section results essentially from bringing together the two lower chords of the parallel trusses of the conventional double-plane bridge. The space framework thus formed offers the advantages of great stiffness and better appearance by virtue of its unusual compactness, with economy effected by the elimination of the bracing required by specifications. In America, for example, these bracing requirements in highway bridges are listed in AASHO specifications [2], Sec. 3.6.67 and 3.6.68, respectively.

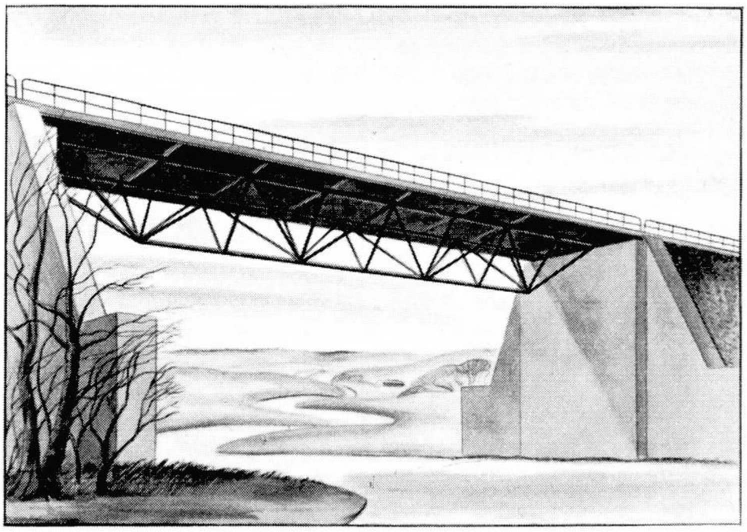


Fig. 1

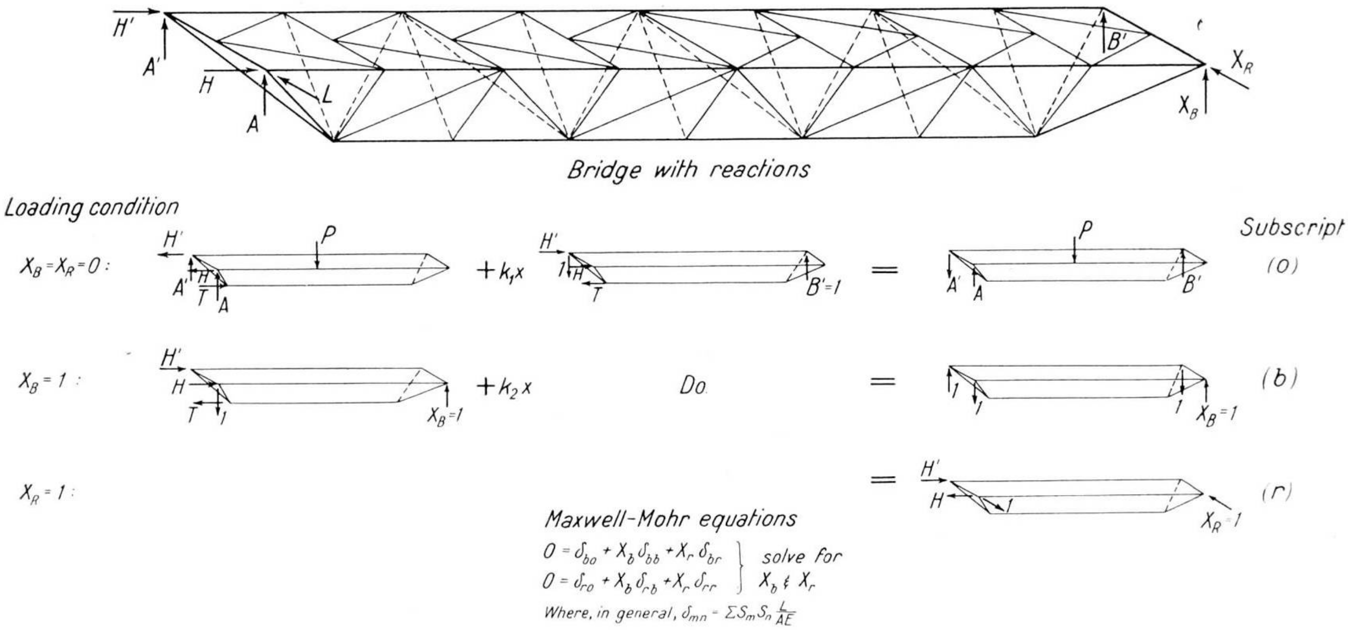


Fig. 2

Additional savings which become apparent in the detail design include lowered bending moments in the floor beams due to the more favorable placement of their supports, and lowered direct stresses in truss chord members caused by extreme off-center live loads, by virtue of the space-frame action of the structure. This latter characteristic of structural action depending on torsional rigidity is illustrated on Fig. 2 for the specific design shown, and has been noted in the past by PETERSEN in a patent in 1899 and by LEONHARDT in a design for one of the Rhine bridges [3], in which the chords were found not more stressed for eccentric loadings than for centrally applied loads.

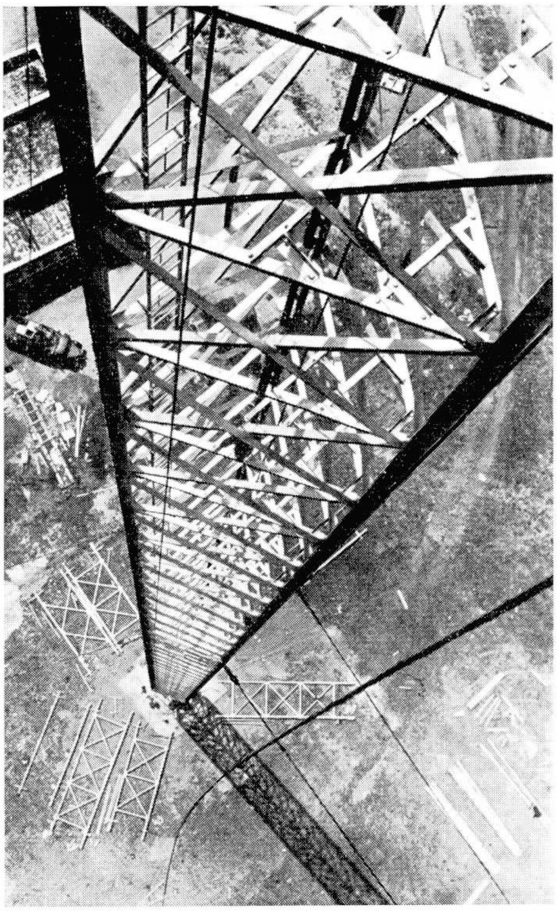


Fig. 3

Fig. 4

The earliest noteworthy triangular bridges were employed by the English engineer BRUNEL [4] in the Chepstow bridge (1852) and the Saltash bridge (1859), both having tubular compression chords. The latter structure had two 455 ft. spans. An English patent for a triangular bridge was granted to JOHN SHIELDS, in 1898. German engineers have from time to time espoused the cause of this type of structure, the best known design being the two-track railroad bridge [4], [5] built at Duren, Germany, with a single span of 256 ft. There is also record [6] of a three-chord truss railroad viaduct of 45-meter span and 15,1-meter width at Beuthen, Germany, and of other examples of this type of bridge [7]. Recent proposals by HAUPT [3] claim an extended utility for this type of structure in modified form.

There is no question but that a bridge of this type can be constructed with welding, particularly when it is considered that a space truss is in essence a series of plane trusses, and the literature is replete with examples of successfully executed two-plane truss bridges. A welded Warren truss bridge of the conventional two-plane design was successfully employed by the Swiss in 1932, in a span of 121 ft. for a deck road bridge (with truss height averaging 14 ft.) over the Rhone near Leuk [8]; other examples of successful through-truss bridges are the Chicoppee Falls bridge (135 ft. span) built in 1928, and the Skoda works bridge, Czechoslovakia (162 ft. span) built in 1932. The 131 ft. span bridge of Joncherolles near Paris (1938), and the highway and railway

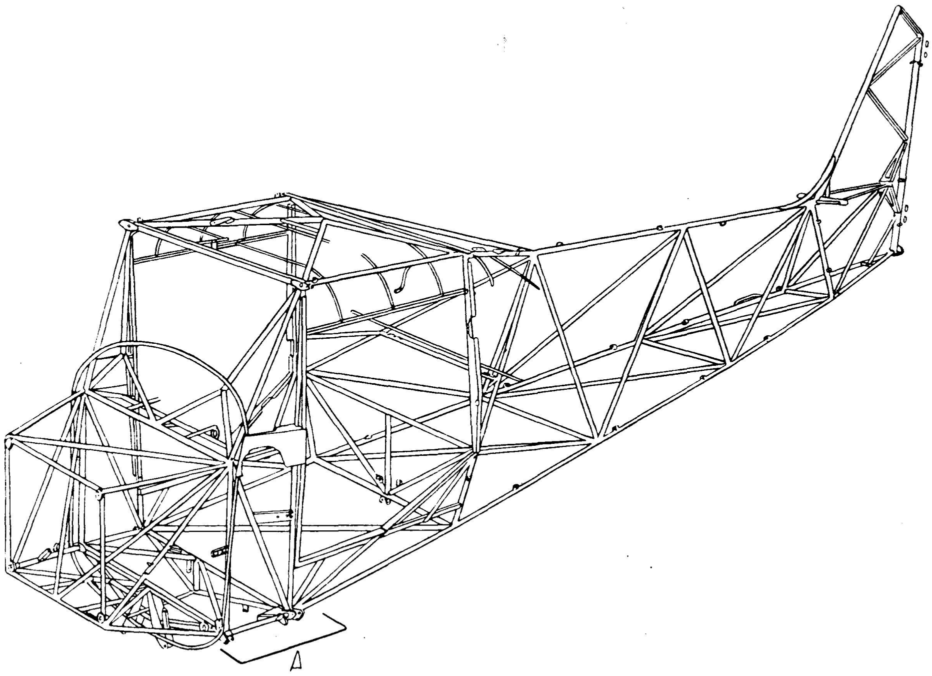


Fig. 5

swing bridge at Le Havre [9] with 142 ft. span, are examples of other truss bridges of comparable span successfully built by welding, while, of course the Hawkesbury bridge (1944) in New South Wales, Australia, with its spans of 438 ft., has demonstrated the adaptability of welding to very much longer spans. There are numerous other examples of successfully completed welded trusses which have proved the feasibility of arc welding processes to plane truss frames and, therefore, to space frames as well.

It is perhaps interesting to note in this connection that the U.S. Naval Ordnance welded launcher bridge (300 ft. span) at the Morris Dam Torpedo Range [10] was designed for torsional loads, and therefore assumed the properties of a space structure. The welded Tordera Bridge (1945) at Barcelona, Spain, with a maximum span of 177 ft., [9] also employed a modified triangular system with considerable success.

Triangular-section trusses have been employed in many other structural fields, both with welded and riveted connections. Applications in radio and television towers (Figs. 3, 4) are perhaps the most well known, although triangular trusses have been employed also in aircraft fuselages (Fig. 5), and in building work (Fig. 6). In their execution of diagrid structures, for example, PANDYA and FOWLER [11] employ triangular trusses members as roof ridge and valley booms or chords. A triangular section welded crane boom (Fig. 7), of 28 ton capacity and 150 ft. length, is described [16] by STREITHOFF.

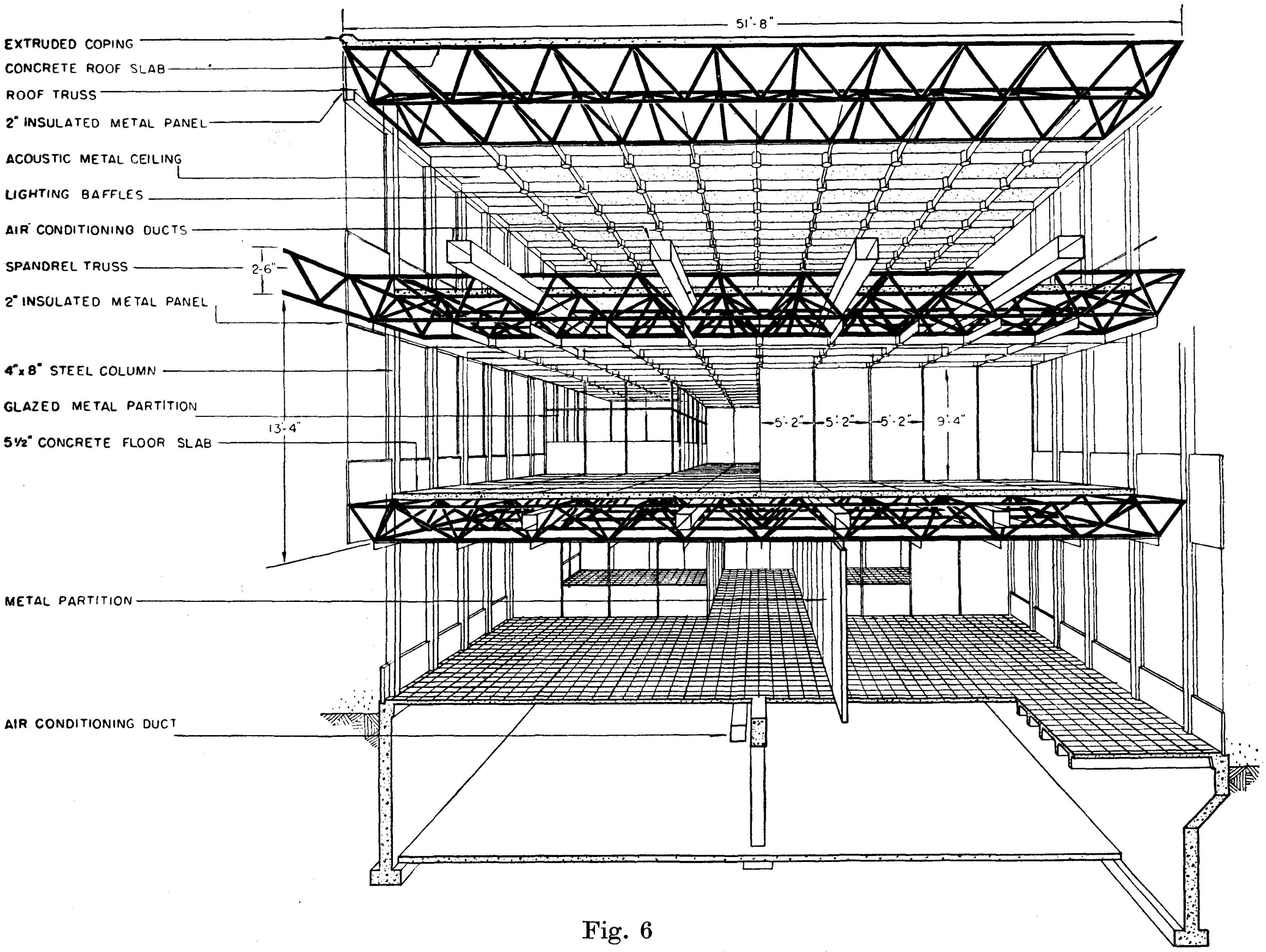


Fig. 6

To illustrate the possibilities of this type of structure in the bridge field, a welded two-lane deck highway bridge of 120 ft. span is considered (Figs. 2, 8, 9 and 10), subject to the specifications of the American Association of State Highway Officials for Highway Bridges [2]. Some freedom has been exercised in this design in the selection of specially rolled shapes more suited to welding, but this in no way restricts the advantages of the truss system as applied to ordinary construction employing bent plates and standard rolled shapes.

From an analysis standpoint, the stresses are calculated for the structure as a space framework. While this may appear formidable, the problem is actually simplified by the fact that with a space frame having plane faces of the type shown, the forces may be resolved into components parallel to the planes involved, and the analysis is carried out in large measure by methods of plane truss analysis. By virtue of the minimum number of supports required from a practical standpoint (Fig. 2), the structure is externally statically indeterminate to the second degree. The sequence of analysis by the Maxwell-Mohr method is straightforward, however, as may be gauged by the illustrative schematic analysis shown on Fig. 2 for a single concentrated load. It is to be

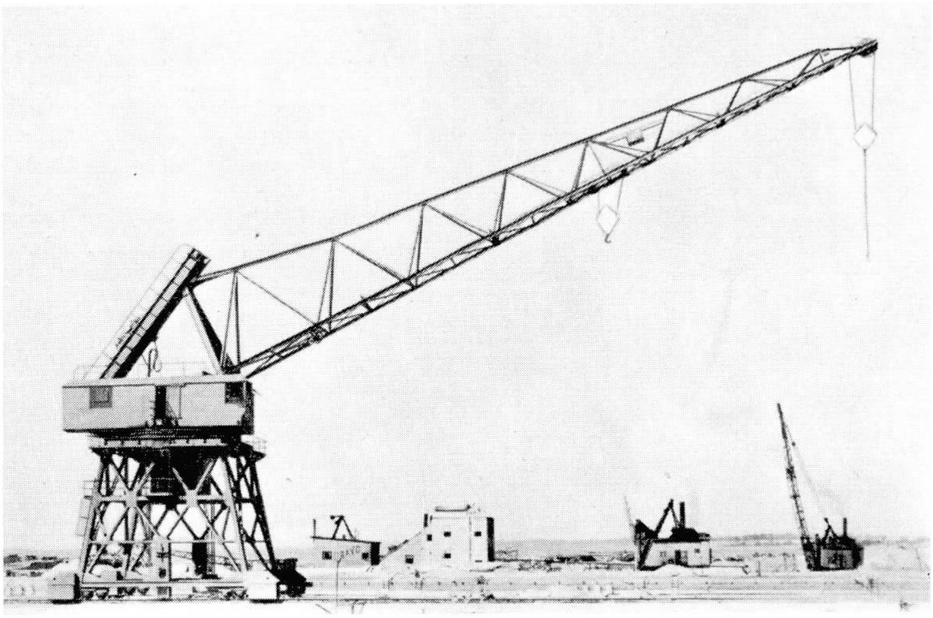


Fig. 7

noted that the use of a temporary false strut (T) simplifies the analysis by reducing it to the calculation of a series of cantilevered plane trusses. The bridge has been analyzed for two-lane live loading, both contrally loaded and with a maximum off-center loading; also for maximum off-center loading of a single lane of live load. Additional examples of analysis of the triangular structure may be found in the literature cited [5] [12] [13] [14].

The design illustrated, using parallel chords, is obviously the simplest type of structure and probably the most economical from the standpoint of detail. Certainly it is to be expected that more elaborate schemes of triangular section employing curved chords would not be adopted generally until long after the fundamental design shown has found more widespread use. In like manner, it is equally feasible to employ girder type structures based on the triangular principle, though for longer spans they will probably not be as economical as the truss types.

Welding offers a particular advantage in simplicity of detail at the complex joints required by skew three-dimensional connections, with the elimination of gussets and angles normally needed with rivets. The elimination of rivet holes further increases the economy of the design of tension members. Maintenance is improved by welding because the joints present smooth surfaces, easily accessible for cleaning and painting; and corrosion is reduced by the simplified details of shapes and connections.

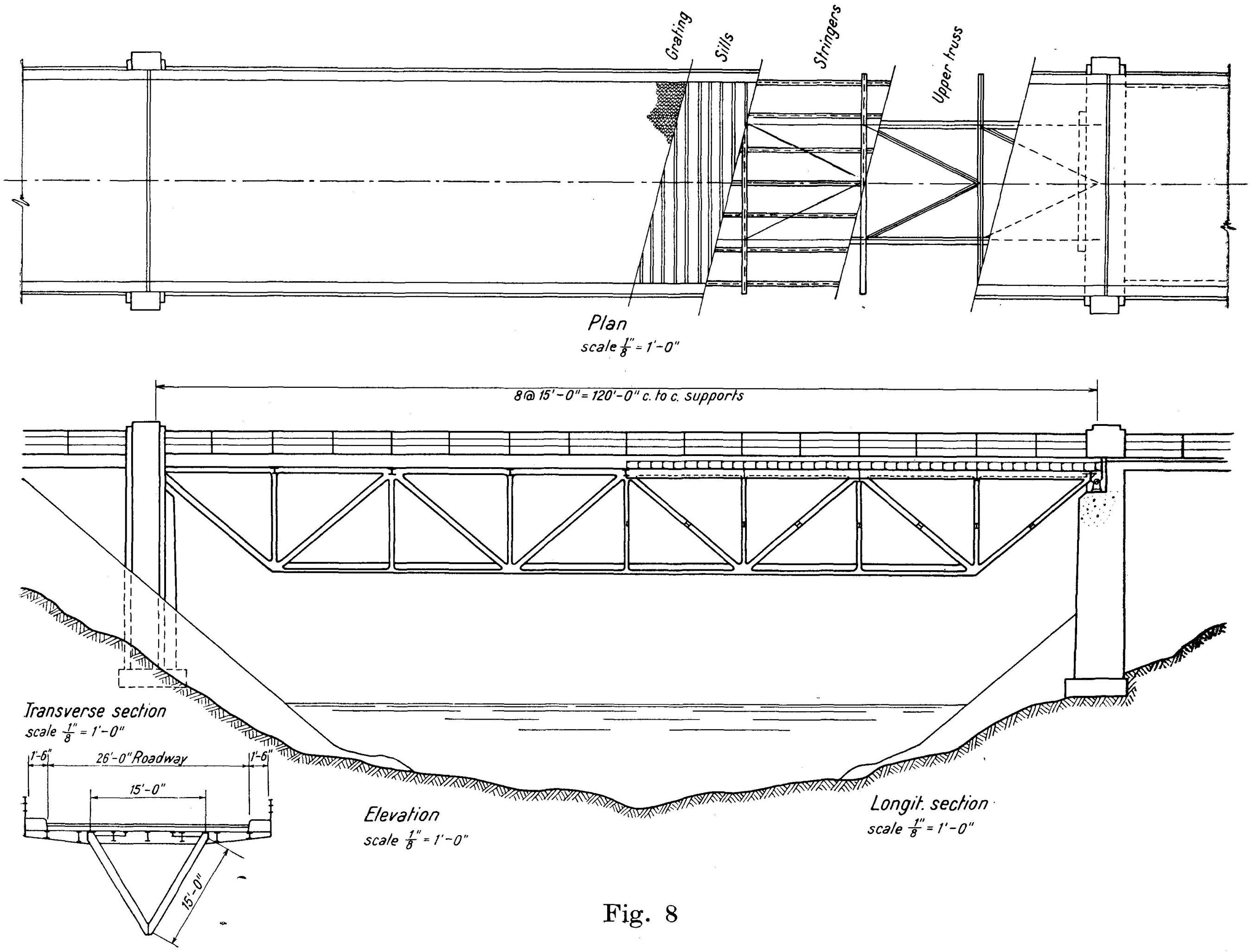
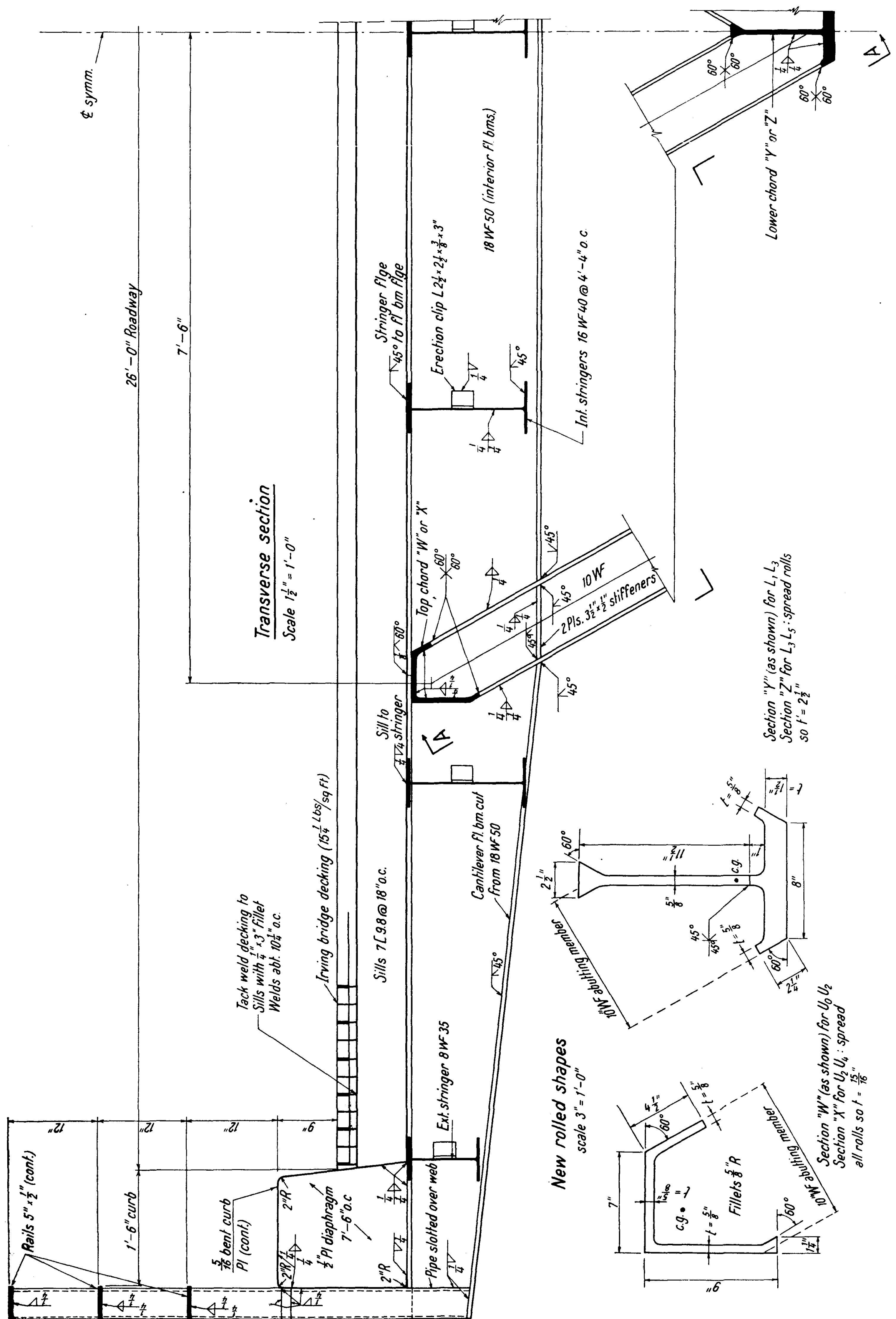


Fig. 8

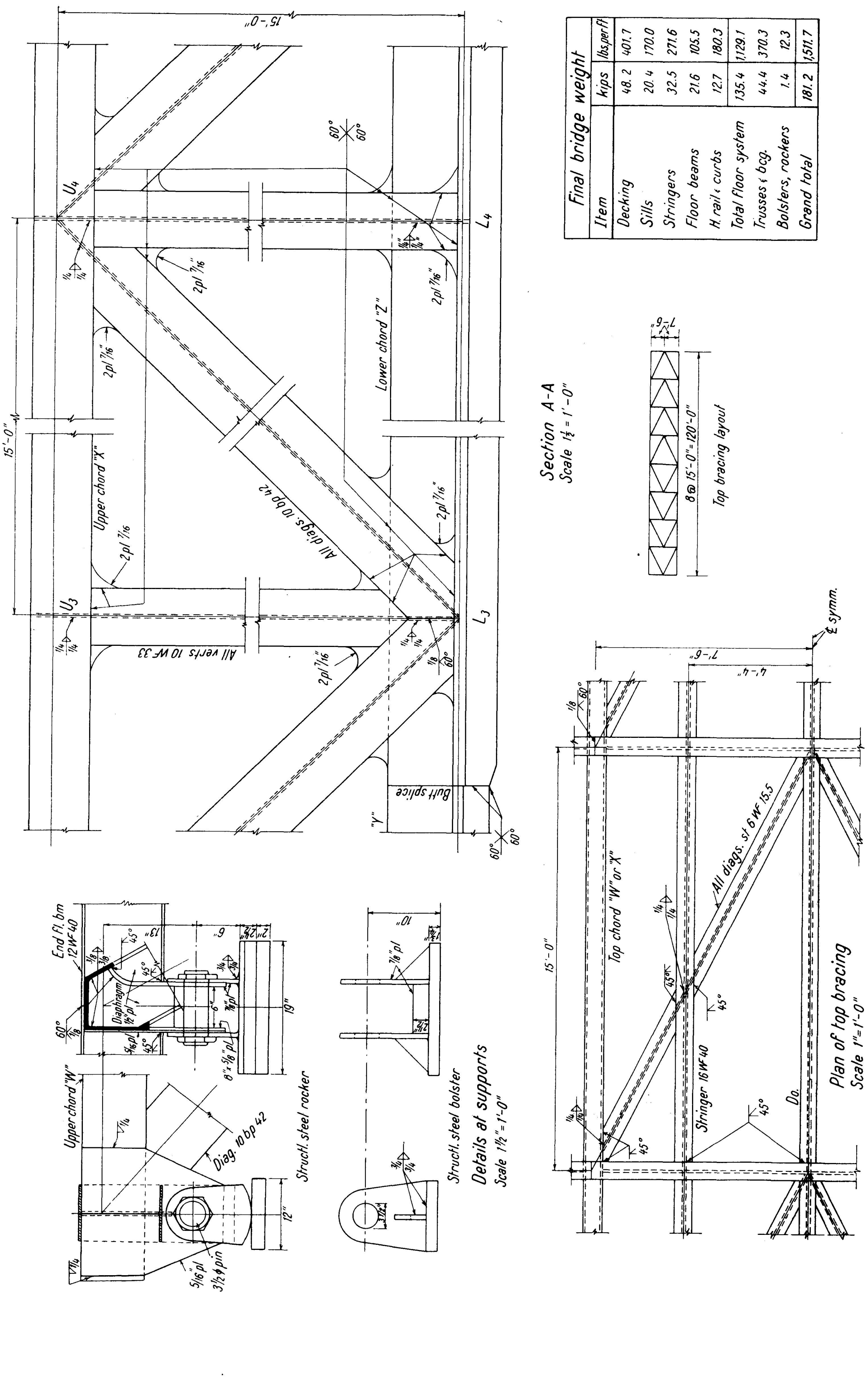
A catwalk — or even pedestrian walk — may be easily installed within the triangular structure below the roadway, permitting safe and convenient repairs and maintenance without impeding traffic. The use of grating flooring, while not an essential feature of this design, permits considerable savings in maintenance, particularly during bad weather conditions, such as with snow removal.

It is difficult to assess the appearance of a truss of this type from a two-dimensional picture, but the rendering shown in Fig. 1 will assist somewhat in gauging the space characteristics of the bridge. The framing is exceedingly compact, and blends in an excellent manner with the flooring.



Transverse section
Scale 1½" = 1'-0"
℄ symm.
26'-0" Roadway
7'-6"
1'-6" curb
Rails 5"×½" (cont.)
5/16 bent curb Pl (cont.)
¼" Pl diaphragm 7'-6" o.c
Pipe slotted over web
3½" φ ex.str. pipe
2"×5/16" strap
Tack weld decking to Sills with ¼"×3" fillet Welds abt. 10¼" o.c.
Irving bridge decking (15¼ Lbs/sq Ft)
Sills 7[9.8 @ 18" o.c.
Ext. stringer 8 WF 35
Cantilever Fl. bm. cut from 18 WF 50
Sill to stringer
Top chord "W" or "X"
2 Pls. 3½"×½" stiffeners
10 WF
Stringer flge 45° to fl. bm. flge
Erection clip L2½×2½×3/8×3"
18 WF 50 (interior Fl. bms.)
Int. stringers 16 WF 40 @ 4'-4" o.c
Lower chord "Y" or "Z"
New rolled shapes
scale 3" = 1'-0"
Fillets 5/8" R
10" WF abutting member
Section "W" (as shown) for U0 U2
Section "X" for U2 U4 : spread all rolls so t = 15/16"
Section "Y" (as shown) for L1 L3
Section "Z" for L3 L5 : spread rolls so t' = 2⅛"

Fig. 9



Final bridge weight		
Item	kips	lbs.per ft
Decking	48.2	401.7
Sills	20.4	170.0
Stringers	32.5	271.6
Floor beams	21.6	105.5
H. rail & curbs	12.7	180.3
Total floor system	135.4	1,129.1
Trusses & bcg.	44.4	370.3
Bolsters, rockers	1.4	12.3
Grand total	181.2	1,511.7

Fig. 10

Actually the framework in cross section (a) in Fig. 11 occupies only 50% of the space volume of the framework (b), and only 27% of the space volume of the structure (c). Viewed from many angles the framework is not visible at all.

Several schemes of erection are possible, depending upon local conditions. It is feasible, for example, to shop-assemble plane panels comprising upper stringers, floor beams and one top chord; also one side truss in units between chord splices; with final job assembly in a jig into complete triangular bridge sections between the chord splices. These sections are light and can be lifted into place by crane, assuming use of falsework is possible. The cantilever flooring can be added afterwards in the form of shop welded sections, after the supporting triangular span is in place. The emphasis in any case would be to place a maximum amount of welding in the shop, without involving panels of undue size.

Ideally, the tubular or box sections employed in aircraft work would offer maximum use of materials for a bridge of this type, but some specifications [15] prohibiting the use of one-sided butt welds may make difficult the practical utilization of these shapes. Under such circumstances, it appears that the transmission of loads through open flanges by direct butt welding will still afford the most practical joint for some time or until the present difficulties with one-sided butt welds are overcome.

It is of interest to compare the quantities and costs of a design such as the one illustrated with more conventional designs. The final steel quantities of the welded design shown are summarized below:

Flooring:	Grating & Sills	68 600 lbs.
	Floor Beams, Stringers, Curbs, Railings, etc.	66 879
	Total Flooring	135 479 lbs.
Truss Structure:	Chords, Diagonals, Verticals, Laterals, Rockers, Bolsters, etc.	45 810
	Total Steel Weight	181 289 lbs.

A takeoff of deposited weld metal indicates a ratio of total weld weight to total weight of steel of 5,73 lbs. per ton.

A comparative riveted 2-plane conventional design, using the same floor system, with trusses $14'-0''$ deep and spaced $27'-6''$ on centers, yields the following quantities:

Flooring:	Grating & Sills	68 600 lbs.
	Floor Beams, Stringers, Curbs, Railings, etc.	82 933 lbs.
	Total Flooring	151 533 lbs.
Truss Structure:	Chords, Diagonals, Verticals, Laterals, Rockers, Bolsters, etc.	68 450
	Total Steel Weight	219 983 lbs.

This riveted conventional design is 21% heavier than the weight of the welded triangular bridge. Omitting the very sizeable item of flooring which is more or less common to both bridges, the remaining carrying structure is 49% heavier than that of the welded triangular type.

A similar analysis, using a two-hinged spandrel braced deck arch, with a 22′ – 0″ rise and 5′ – 0″ depth at center, revealed a 30% greater weight than the welded triangular design for the entire bridge; or on the basis of the carrying structure alone, approximately 67% more weight.

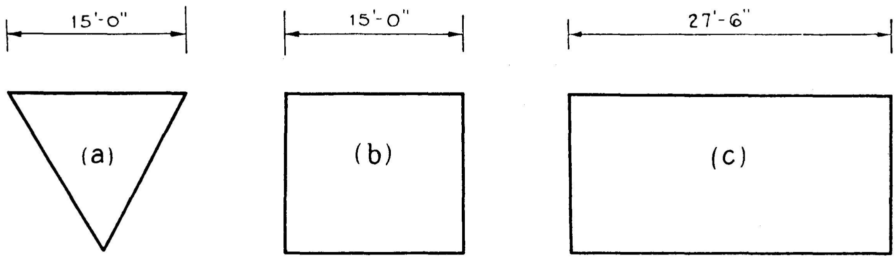


Fig. 11

Detailed cost estimates indicate the following costs for the complete superstructure of the three designs indicated above:

Welded triangular section truss bridge . .	$ 20 921
Riveted conventional 2-plane truss bridge .	$ 24,087
Riveted 2-hinged spandrel braced arch . .	$ 26 000.

It is pointed out that the above costs are somewhat variable, depending on conditions of site and shop, but the intention here is to show that the weight reduction results in proportional dollar savings. There is undoubtedly some savings in fabrication costs possible with welding as compared with riveted construction, but the fabrication costs for welding in the above comparisons was deliberately placed on the conservative side in order to allow for uncertainty as to shop conditions.

While no detailed comparison was made between the welded triangular bridge vs. plate girder spans, some indication may be obtained from Ref. [17], wherein for a 120-ft. span steel rigid frame bridge the steel requirement is given as 10,090 lbs. per foot of width, with 8,3 cu. yd. of concrete per ft. of width of floor, backslab and encasement of vertical legs only (excluding footings, retaining walls, etc.). While no further information is given, the above is sufficient to indicate that for a bridge of the width of the one used in the illustrative design, the quantities of materials for such a bridge in the form of a rigid frame would be considerably above any of the designs previously indicated.

Acknowledgment:

Acknowledgment is made to the James F. Lincoln Arc Welding Foundation, who have consented to the release of the above material, which is abstracted from a design submitted for their 1949 "Welded Bridges of the Future" program.

Summary

A study is made of the utility of the triangular-section structure, using welding for connections, for deck highway bridges with spans around 120 ft. The framework is a space structure of extreme compactness and high torsional rigidity, possessing a number of noteworthy properties which enable considerable cost reduction. It is demonstrated that savings of from 30 to 40% of the supporting truss weight may be achieved, and that the economies effected will probably range from 15 to 20% of the superstructure cost. The appearance of the structure is improved to a marked degree, and the structural framework is hardly visible from many important angles of view. The space volume occupied by the framework is reduced by from 50 to 75% over other designs. The structure possesses an inherent grace and slenderness which will easily adapt itself to curved designs, and which if recognized may well reverse the present trend away from the use of truss bridges.

Zusammenfassung

Es wird die Zweckmäßigkeit einer Bauart mit Dreieck-Querschnitt für Straßenbrücken mit obenliegender Fahrbahn bei Spannweiten um 36 m und unter Anwendung der Schweißung für die Verbindungen untersucht. Das Tragwerk ist ein räumliches Gebilde von großer Geschlossenheit und hoher Torsionssteifigkeit und besitzt eine Anzahl bemerkenswerter Vorzüge, die eine beträchtliche Kostenersparnis ermöglichen. Es wird gezeigt, daß beim Gewicht der Tragkonstruktion Ersparnisse von 30—40% erreicht werden können, während sich bezüglich der Kosten des Oberbaues Einsparungen von ungefähr 15—20% ergeben dürften. Das Aussehen des Bauwerks ist auffallend verbessert, und das tragende Fachwerk ist aus mancher wichtigen Blickrichtung sozusagen unsichtbar. Der durch das Tragwerk beanspruchte Raum ist im Vergleich zu anderen Bauarten um 50—75% verringert. Das Brückensystem besitzt eine eigenartige Schönheit und Schlankheit; es wird sich leicht auf gekrümmte Bauwerke anwenden lassen und dürfte, wenn es einmal anerkannt ist, sehr wohl die gegenwärtige Auffassung über die Anwendung und Ausbildung von Fachwerkbrücken umstellen.

Résumé

L'auteur examine l'opportunité d'une disposition avec section triangulaire, pour les ponts-routes soudés à tablier supérieur admettant une portée de 36 m. La partie portante est constituée par une structure très homogène et serrée, de haute résistance à la torsion; elle présente un certain nombre d'avantages dignes de remarque et qui permettent de réaliser une notable réduction du prix de revient. L'auteur montre que cette disposition conduit à une économie de poids de 30 à 40% pour la partie portante et à une diminution de prix de revient de l'ordre de 15 à 20% pour la superstructure. L'aspect de l'ouvrage est notablement amélioré et le treillis porteur lui-même est pour ainsi dire invisible de plusieurs directions essentielles. L'espace occupé par la partie portante est réduit de 50 à 75% par rapport aux autres modes de construction. Cette disposition présente une élégance et une finesse particulières; elle peut être aisément modifiée pour la construction d'ouvrages incurvés et doit largement contribuer à modifier les conceptions actuelles concernant les formes et les possibilités d'emploi des ponts en treillis.

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