A 1083 ft span steel arch bridge in Czechoslovakia

J. ZEMAN

Mr D. W. Smith, Messrs Mott, Hay and Anderson

The construction of the fourth largest arch span in the world must obviously be of great interest to bridge engineers everywhere and several aspects of the Orlik Bridge deserve study. Not least among these is the excellent way in which the structure fits the site. The geology, the valley depth and width, the lake filling programme, all seem to have united to demand exactly this bridge: its type, its span, its rise, and the positions of the pins in the arch.

74. This is now the third time that a large steel arch has been built, exceeding by less than one metre the span of another already built or being built. The Bayonne Bridge over the Kill van Kull with a span of 1652 ft (503.5 m) is 2 ft (0.6 m) longer in span than the Sydney Harbour Bridge (and was completed before it in 1931). The Runcorn-Widnes Bridge has a span of 1082 ft (329.8 m) which exceeds that of the Birchenough Bridge by 2 ft (0.6 m), most of which excess was absolutely demanded by the requirements of shipping and the limitations on pier positions in the river. The Orlik Bridge is described modestly in the title to the Paper as a 1083 ft span steel arch (330 m) as this is the distance between the pins, but the clear gap bridged seems to be approximately 360.7 m and it would be interesting if the Author would confirm this figure.

75. The information given in §§ 14–18 is just sufficient to whet the appetite. Could the Author please enlarge on the theory and method used in the structural analysis of the arch? How large were the second order effects, and how great was the divergence from a straight line relationship between load and stress (§ 15)? What exactly were the reasons why the method of permissible stresses proved uneconomical? Was it simply that the application of the usual strut formulae would have been equivalent to assuming a greater initial deviation than the 200 mm referred to in § 18?

76. Permissible stresses for a short-span two-pinned arch can be established to a sufficiently close approximation using a usual strut formula based on L/R as follows:

- (a) the effective length for permissible stresses at the quarter point is the chord length from the pin to the centre of the arch, since the first mode of buckling would be about a node near this point;
- (b) the effective length for permissible stresses at mid-span is one third of the span, since buckling due to a load concentrated near mid-span would be about two nodes near the third points;
- (c) the effective length for permissible stresses at the pin is zero.

Thus the permissible stresses at three points in each half arch are established. These three points can be joined by a sine curve to establish the permissible stresses elsewhere.

77. For so large a span as that of the Orlik Bridge it was obviously necessary to go back to first principles as the designers did. Could the Author give any conclusions following the study of this bridge which may point to more reliable simplified design rules for use on future arches; and could he give an indication of the range of span for which he would think such rules likely to be sufficiently reliable?

78. While sympathizing with the designers' wish to avoid welding for the main site joints in the arch, one wonders whether such a large amount of riveting was really

DISCUSSION

necessary, since compressive forces can be carried from one part to another by direct bearing of steel on steel. What proportion of the total compressive force in the arch rib were the riveted joints designed to take? The splices in the main tower legs on the Forth Road Bridge are devoid of cover plates, and the entire compressive force is carried from part to part in direct bearing.¹ More recently (and not yet published in detail) the arch ribs of the New Scotswood Bridge over the river Tyne, spanning 328 ft (100 m), were constructed without cover material, the end plates of the separate boxes being simply connected by a few locating bolts.

79. Accurate machining of the members to exact length and angle of splay is of course necessary if splice material is to be dispensed with. However, the accuracy needed in drilling rivet holes for cover plates is almost as great. It would be interesting to know the fabrication procedure followed to ensure that the site-riveted joints in the Orlik Bridge gave the correct length and curvature to the arch ribs.

80. The presentation of a paper to the Institution of Civil Engineers in the UK about this most interesting project in Czechoslovakia is very welcome. It is to be hoped that similar action will be taken with many more projects of international interest.

Mr J. K. Anderson, Consultant

It was my privilege to visit the site of the works with the Author and Professor F. Faultus in 1965 when the bridge was under construction. The construction of the steelwork was then virtually finished, leaving the deck to be constructed. I feel I want to congratulate the Author on his attractive design.

82. My interest in it was first aroused when I found it compared in size with the Runcorn-Widnes Arch Bridge, the central span of which is 1082 ft, i.e. 1 ft less than the Žďákov Bridge. The total length of the Runcorn-Widnes Bridge arch and steel side spans is 1628 ft, compared with 1774 ft at Žďákov. Carriageways are 33 ft and 34 ft 5 in. and footpaths 6 ft and 4 ft 1 in. for Runcorn and Žďákov respectively. The designs are of course radically different,² but it is interesting to note that the total tonnages of steel are approximately 5500 tons and 4400 tons for Runcorn and Žďákov. The side spans of the latter were much simpler in view of easier site conditions.

83. Reference is made to 1500 tons of temporary steel in the structure, whereas apart from the side spans very little was used at Runcorn. The use of reinforced concrete in the main side towers was an economy in steel. To assist in the comparison it would be very helpful if some information on costs could be given, i.e. the total cost of the project—with subdivisions on (a) substructure; (b) steelwork (including temporary works for erection); (c) decking and finishings.

84. On the question of design, I consider that it would have been preferable if the arch-rib stiffeners had been fixed inside the box members and if the overhang of the flanges could have been avoided. A smooth exterior finish offers less opportunity for holding dampness and corrosion. I learned much on the Runcorn-Widnes Bridge design myself in this regard and recent welding techniques have made possible the avoidance of such ledges. Would the Author now favour welded box design?

Ing. Zeman

I should like to thank Mr Smith for his kind words of appreciation of the Orlik Bridge.

86. In proposing the bridge there was no intention of exceeding any other bridge in span. Fig. 21 gives some information on the clear bridged gap.

87. The bridge was designed following the theory of limit loads based on the equation:—

$$\sum \frac{c\mu_i P_i}{F_i} = \sum \frac{\mu_i P_i}{F_i} \leq k\sigma_T$$

Fig. 21

Fig. 22

where c = coefficient of contemporaneity

for main load = 1.00

for dead load = 1.00

for live, wind and temperature loads = 0.87

n_k = coefficient of overloading

k = coefficient of homogeneity of material = 0.90

μ = coefficient with the following values:

For loading	Main load	Total load
Dead load . . .	1.30	1.30
Live load . . .	1.55	1.30
Temperature . . .	—	1.10
Wind load . . .	—	1.10

σ_T = yield stress of class 52 steel = 3600 kips/sq. cm.

88. Figure 22 shows the influence of the second order theory on the moments of the arch. Comparative figures for other bridges are given in Table 1.

Table 1

	Span m	Load	Second order effects	
			ΔM	$\Delta \sigma$
Malarsee fixed arch, Stockholm	205	1.8P	33%	9%
Niagara Falls fixed arch	289	1.83P	18%	6%
Orlik, two-hinged arch	330	1.45	100%	41%

DISCUSSION

89. The arch was principally calculated by means of an iteration, that is, the calculation of a two-hinged arch following first order theory repeated step by step on a deformed arch until the increment of the deformations was negligible.

90. To carry the normal compressive forces in the joints of the arch by a simple contact of steel on steel (although there was also considerable tension) would no doubt be convenient for such a case and I have myself given it serious consideration, especially in connexion with the use of high-strength bolts, but the final decision was to use the traditional method. The universal riveted joints were designed for full forces.

91. The arches were pre-assembled in the factory in segments about 70 m long, in a horizontal position, each arch rib separately. Thus accurate assembly on site was considerably facilitated.

References

1. ANDERSON J. K. *et al.* Forth Road Bridge. *Proc. Instn civ. Engrs*, 1965, **32** (Nov.) § 2.20.
2. ANDERSON J. K. Runcorn-Widnes Bridge. *Proc. Instn civ. Engrs*, 1964, **29** (Nov.) 535-570.