Structural Paper No. 53

Masonry arch bridges: a study †

by

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Discussion

The following contributions were received in writing.

Mr A. A. Osborne (Resident Engineer for Messrs Howard Humphreys & Sons) referred to the Authors' statement in § 2 that a rational method of assessing arches without carrying out actual tests was urgently needed. It was surprising that arch-bridge load-classification tables had not been issued earlier by the Ministry of Transport, since the army had used fairly reliable tables for military load classification since 1941.

224. Mr Osborne had been responsible in 1942 for bridge classification of existing bridges from Bone in Algeria to the Tunisian front and for checking rebuilding of bridges in Italy and found that tables for the strength of masonry arches as issued by Engineer Sections of various HQ's were invaluable.

225. He had compared the results in Table 1 of the Paper with such military tables and in seven cases where dimensions were comparable with those available in the tables the maximum loading compared favourably.

226. The higher military load class only allowed for 20-ton max. single axle load or 40-ton 2-axle bogie at 4 ft centres, but it was noticeable that the military loads agreed well for maximum crown deflexion up to 0·1 in. and load results in Table 1 that exceeded the military figures occurred where the test deflexions were between 0·1 and 0·2 in.

227. The remarks of Mr Jones regarding the replacement of the filling over the "bouncing" arch bridge with concrete drew attention to the need for including in load-classification tables for arch bridges an allowance for filling of a minimum specified strength.

228. While the nature of the abutment backing was given in Table 1 details of the filling over the arch was important information that was lacking. It should have been possible to have taken boring samples of the filling to enable it to have been graded according to soil mechanics tests as in normal site investigation.

229. Many arch bridges that appeared to be below the load classification required could be re-classified to suit backfilling over the arch in concrete or stabilized soils. Standard load-classification tables with such standard filling-strength requirements included would simplify that sometimes nebulous aspect of the rapid assessment of arch-bridge load-classification particularly when replacement of the filling could raise the classification to that required.

Mr R. C. T. Allen (Concrete Manufacturer) asked whether it had been necessary to move a trailer of a total weight of 110 tons from Hampshire to Durham. If a tank had been used instead of a concrete block it could have been loaded with water from the river under the bridge being tested or from a public main. The tank could have been constructed of standard sections or surplus government materials with some strengthening to take the cantilever load.

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† Proc. Instn civ. Engrs, vol. 7, p. 723 (Aug. 1957).

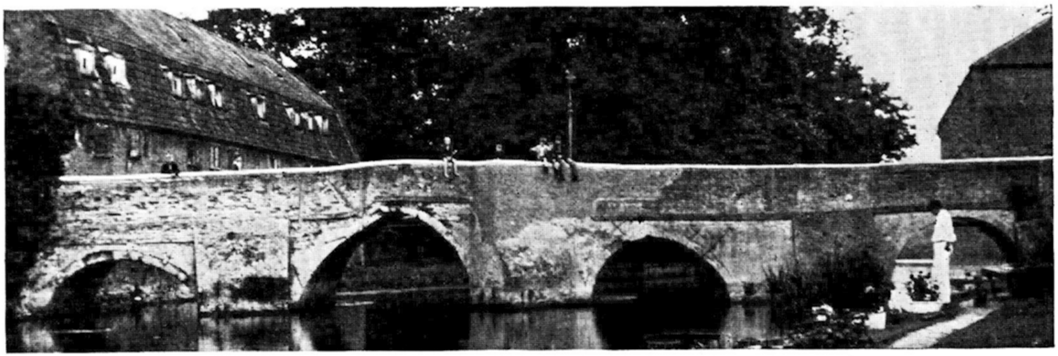

FIG. 32

Mr P. C. Dewhurst (retired) called attention to the very remarkable case of a bridge-arch, which, although completely disrupted, continued in effective use. The bridge, mostly of brick with stone arch-rings, had spanned the River Little Ouse at Brandon in Suffolk, but it no longer existed.

232. Fig. 32 showed how in one of the arches, which had split completely from side to side near the crown, the two surfaces of the separated portions had ridden one over the other in a fantastic manner. In that condition the arch—and bridge—had continued for many years to carry normal heavy main-road loads, forming an integral part of a trunk route. It had finally collapsed under excessively heavy war-time vehicles between 1939 and 1945.

233. The bridge had been built in the dry on piles, the river being afterwards diverted to flow under it. Its massive piers can be seen in Fig. 32, which also shows that other portions of the bridge, apart from the defective arch, had been rebuilt or patched from time to time. The bridge was severely cranked in plan and from above appeared rather like a series of single arches not laid out in line.

234. What was the Authors' opinion as to the possible sequence of events connected with the fracture—the middle pier seemed to have moved bodily towards the warehouse—and how the arch had managed to support heavy main-road traffic for so many years?

The Authors, in reply, stated that the Military Classification Tables mentioned by Mr Osborne had been prepared by a committee to which Mr Chettoe had been co-opted. These tables were based on the pre-war Building Research Station tests and the subsequent *ad hoc* tests carried out during the war (see § 2 (b) in the Synopsis, p. 723) . They did not, however, attempt to cover with any accuracy different arch shapes. Some account had been taken of filling depths and the results had been obtained largely by interpolation and extrapolation based on judgement from actual test results. Loads in excess of 40 tons depended entirely on extrapolation and the tables were, therefore, inadequate as a guide to the strength of bridges required to carry modern heavy indivisible loads weighing 150 tons or more. These modern loads varied considerably in the arrangement and spacing of wheels, and the tables provided no help in this respect while, of course, one of the main limitations to the use of tables was that they could cover only a discreet number of examples. However, there was no doubt that tables or charts of some sort were desirable in order to cover the majority of cases. The object of the series of tests had been largely to provide a rational basis on which these could be computed.

236. It was of interest that the maximum loading given in Table 1 of the Paper compared favourably with those in the military tables, but it should be pointed out that these maximum loadings indicated the greatest test load applied and were not necessarily the maximum load which it was considered should be permitted in use of the structure. In general the Authors considered that a deflexion of 0·1 inch would be excessive in bridges of average span and dimensions for "use" as against test purposes.

237. Mr Osborne had drawn attention to the need for including, in load-classification tables, for arches infilled with concrete or similar material, basing the allowance on a minimum specified strength. The Authors fully appreciated the need for taking the filling material into consideration, but considered that this could not, with concrete, be thrown in simply as an allowance on the calculation of the arch.

238. Where concrete infill had been used, a straightforward analysis of the concrete structure as a solid spandrel arch would be the solution. Such an arch would probably be so stiff in the haunches that the assumption of pins at the ends would greatly simplify calculation and make little difference to the result. In fact, in the greater number of cases sound judgement would give the assurance that an arch, so infilled with, perhaps, reinforcement at the crown, would be adequate for the heaviest loads now using the roads. The Authors had adopted this method of treatment for many weak arch bridges and found it both economical and very satisfactory.

239. If a reasonable thickness of fill existed over the crown of the arch, and the filling material would accept an adequate amount of grout, the same could frequently be said of

grouted fill, but this, of course, depended entirely on the strength of the grouted material.

240. Infilling could act in two ways: as a dispersing medium which spread the load over the arch; and as a structural component. Undoubtedly it would be useful to take boring samples of the filling over an arch, and to make use of these in arriving at the dispersal and intensity of loading on the arch vault. It was unlikely, however, that this would be an attractive proposition to those involved in the problem of assessing arch bridges, and the Authors considered it beyond the scope of this investigation. Soil classification and soil mechanics techniques are well covered in other works, and, in the meantime, the Authors had put forward a simple rule which seemed to work fairly well.

241. It was felt by the Authors when they reached the conclusion that structural analysis gave the only satisfactory rational approach to the problem of these arches that further complications should be avoided so far as possible. To follow a thorough soil mechanics investigation to its natural conclusion, one would become involved in loading of varying intensity, both horizontal and vertical on the vault (see § 204).

242. The Authors had indicated in the Paper that they had found no conclusive evidence of filling acting composite as a structural medium. That it did so, in some cases, they were in no doubt, but how to be assured that composite action did take place in any specific structure was very difficult, if not impossible to say. If one could be assured of such action, the analytical problem of dealing with composite materials of widely varying values of E, the one material having a constant moment of inertia, the other a rapidly changing one, was almost insuperable for normal purposes. In any case there was always the great risk that subsequently some public undertaking would excavate a trench through the fill for its authorized purposes and so destroy the basis of one's assumptions.

243. Mr Allen's suggestion that a tank filled with water would have been more suitable as a test load had been considered before developing the present test vehicle. There had been considerable snags, however. Water was generally not available within a reasonable distance from the bridges tested, for many of them were in rural areas and over railways. To select bridges over water or near a water supply for testing would have complicated the already very difficult problem of finding suitable specimens. Moreover, it was desired to use a vehicle for testing rather than a static load; this made it an economic necessity to use the trailer described in the Appendix, for it was possible to buy this second-hand at an almost nominal price. Consequently, the load on the trailer had to be of the order of 80 tons. This required about 3,000 cu. ft of water which made the shear bulk of the load inconvenient. Time of assembly and filling of the tank also had to be taken into consideration, for nearly all the tests had to be carried out against a very tight time-table.

244. Mr Dewhurst had drawn attention to what he rightly called the very remarkable case of the old Brandon Bridge, now replaced by a modern structure. It was indeed surprising that the main arch had carried the traffic of a Class I main road for many years though seriously deformed. This deformation, which occurred in the extreme form shown in the illustration on the west side of the arch only, appeared to have been caused by the left pier tilting transversely because of unequal settlement at its two ends. The arch crown, though broken at the west side, was held up, partly at least, by an iron clamp across the break which brought the strength of the parapet into play. Also, of course, the half of the centre part on the right of the illustration would abut on the fill opposite, so that, in this particular case, the fill could be said to be acting as a structural material.

245. The Authors had under observation another three-span arch structure where one pier had been subjected to fairly large mineral settlement over a period of a few months, while the adjacent abutment, on rock at the side of a fault, had not moved. The same type of fracture and distortion of the vaults was observed. Along the intrados at the crown crushing failure of the masonry was taking place, while in the vicinity of the quarter near the settling pier, intrados joints were beginning to open. This bridge was an excellent specimen for observation of the effect of unequal settlement, since the differential movement was taking place fairly rapidly, and the damage was attributable to this sole cause.