

Cumberland Basin bridges scheme

1. Planning and design

by

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and

2. Construction

by

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Messrs Vavasour and Wilson, in introducing Part 1 of the Paper, emphasized the need for the improvement. They illustrated this with figures of timed journeys between the city boundaries through Cumberland Basin before the scheme was started. These ranged from a maximum of 81 min when peak flows coincided with bridge openings, and a minimum of 18 min for an unobstructed run. This latter time was the expected norm for the completed scheme.

205. They explained that the scheme formed a junction on an all-purpose route which, with its linking roads, was never likely to have a speed limit in excess of 40 mile/h and consequently the somewhat restricted standards of geometric design caused by the congested nature of the site were considered acceptable.

206. In outlining the design of the fixed bridge the Authors said that the difficulty of placing the very heavy precast beams had been realized at the design stage, but they considered that the various advantages outweighed the disadvantages.

207. Various alternatives for viaducts, including the estimates of cost, were demonstrated. The Authors considered that, once a simple form of construction had been chosen, the success of the scheme depended on attention to details, not the least important of these being the complete elimination of all visible drainage.

208. In the section dealing with the swing bridge there was a correction in §§ 29 and 113 where °C should in both cases read °F.

Messrs Baldwin and Wolley, in introducing Part 2 of the Paper, commented first on the great accuracy that the mechanical sub-contractor had achieved in setting the 40 ft dia. rack and track for the swing bridge, and the fact that this had resulted in very smooth swinging of the bridge. Mention was also made of the difficulties of assembling the bridge in a cantilevered condition, which necessitated a great deal of calculation to achieve the correct end levels. They also referred to the fact that the scheme was not repetitive: each span of the approach viaducts was individually detailed and involved its own problems in construction, which had the effect of increasing the numbers of supervisory and design staff required.

210. Slides were shown to illustrate the handling of the precast beams for the Avon Bridge, the heaviest ever handled in Great Britain. Two methods had been used, one being by mobile crane and the other by jacks, the former method being quicker but considerably more expensive.

211. The various works used by the Contractor for the construction of the fixed bridge, which was in some ways complicated by the fact that the centre line of the road did not coincide with the centre line of the bridge, were demonstrated.

212. Finally, it was mentioned that the finish achieved by the Contractor was to a good standard, and in order to enhance the scheme and make it a desirable addition to the area as well as an efficient road system, considerable effort and money had been spent on landscaping.

Mr R. J. Willy (City Engineer's Department, Bristol) said that he had joined the City Engineer's Department just before the last war to work on the Cumberland Basin bridges scheme, but the work had been held up by the war and subsequent reconstruction. By the time that Mr Wilson had arrived, thinking on traffic problems had matured sufficiently for it to be possible to see the kind of scheme which was required. Their first objective then had been to produce the best possible traffic scheme without, for the time being, taking any account of other considerations, engineering, financial or otherwise. In this way the scheme for the elevated roadway through the basin area, with its underpasses to the junctions on its route, had come into being.

214. About 100 homes had had to be pulled down to make way for the scheme and as the City Council did not wish to employ compulsory powers, a meeting of the people concerned had been held in the local church hall and the scheme explained to them. The considerable traffic survey which had been carried out was valuable in enlightening their support.

215. In due course the scheme had found a place in the Minister's programme and the City Engineer had then become extremely concerned that it should be finished on time. It had therefore been decided to split the scheme into two, leaving the swing bridge and the northern approaches to the City Engineer's staff and retaining the services of Messrs Freeman, Fox & Partners for the fixed bridge and the southern approaches. At that time the B.S. specification for the design of steel highway bridges had been under review and Mr Kerensky had been an active member of the committee engaged upon this work. It had therefore been decided to ask Messrs Freeman, Fox & Partners to also act as Consultants on the design of the swing bridge superstructure. This process had naturally led to the scheme being produced in two separate contracts, and it had been felt that it might be in the Corporation's interest to have one contract only. They had therefore gone out to tender at the same time with uniform contract documents, the tenderers being asked to indicate what reduction they would make in their tender if they were appointed to both contracts. In this way the City Engineer had proved, as he had expected, that the way to do the job was with one contractor.

216. At the same time arrangements for the Ashton Gate scheme had proceeded, and the work was now in hand. When this was finished users of this route would have the best possible approach to the City of Bristol.

Mr D. A. Holland (Ministry of Transport) congratulated the Authors both on the scheme with which they had been associated and on the extremely interesting Papers. He had two general comments to make. The first concerned the foundation construction of the south pier of the fixed bridge. The Engineer had considered that a cofferdam would be difficult to seal and had therefore provided in the contract documents for a caisson. The Contractor had put forward a modified cofferdam solution at a saving of £10 000, and this had been accepted. In practice it had proved impossible to obtain a seal and work had had to be carried out on a tidal basis in the cofferdam. It was stated in § 159 that the consequential pumping and silt removal had taken time and money.

218. Considering the time aspect, it was stated that during the 2 year contract period the weather had been better than average and only 10 working days had been lost because of bad weather. Contract No. 1 had been extended by 11 weeks and

Contract No. 2 by 12 weeks. Possibly the circumstances recorded in §§ 128 and 196 had some connexion with these extensions. If the return on the £2 million capital investment in the basin scheme was calculated at 8%, this worked out at £440/d, and £37 000 for 12 weeks. This might be taken as some measure of the denial to the general public of the use of the facilities during this period. As for the money which was lost, he would be interested to have the Contractor's opinion on the relative economy in actual money terms of the cofferdam as compared with the caisson.

219. At the present time, emphasis was properly placed on the need to afford the maximum scope to the very considerable practical knowledge possessed by contractors, but in general it might be remarked that the appraisal of alternatives put forward called for no less considerable judgement and experience on the part of the engineer, because it was the engineer on whom the employer depended for the finished product in all its aspects, and this included not only quality but also time and cost.

220. He drew attention to §§ 195 to 197 and the references to the difficulties experienced in finding skilled labour, particularly joiners. This had obviously contributed in some degree to the delay in completion, since the formwork and shuttering for the cast-in-situ concrete for the 40 ft span viaduct must have called for a fair amount of this skilled labour. At the time the design had been prepared, in-situ construction appeared to be more keenly priced than the use of prefabricated components. But the difficulty of finding skilled labour was likely to get worse rather than better, and, allowing for this, and also allowing for the loss in capital return arising from delays in completion, it seemed obvious that greater attention must be paid to the use of prefabrication in bridge construction.

221. The Ministry were giving close study to this, in conjunction with the steel and concrete industries. Over 7000 of the national standard prestressed concrete beams had been used in bridge construction up to the beginning of 1965. Ways were being sought to increase the possible uses of these beams including reduction in the variables which necessitated special tailoring, for example by working to specified angles of skew. The steel industry intended to follow up the forthcoming issue of Code of Practice 117 (Part II) dealing with the composite construction of bridge decks, with tables for optimized composite designs. These would make widely available an alternative and largely prefabricated type of deck based on the most up-to-date design methods, which it was hoped would prove highly competitive.

222. He had two minor comments to make on other parts of the Paper. Referring to § 27, he asked the Authors what was the basis for assessing the proportion of lorry traffic as about one-third of the total. If by 'lorries' they meant vehicles weighing 2 tons and over, in this locality one would have expected the proportion to be somewhat higher.

223. In § 130 it was stated that the use of a tremie skip to place the concrete resulted in considerable cement loss and contamination of the concrete by marl suspended in the water. It would be interesting to know what methods the Authors would now adopt on a similar occasion.

Mr J. A. Derrington (Sir Robert McAlpine & Sons) said that he wished to take issue with the Authors on three minor points and to comment on three other aspects. He thought that their criticism of the Contractor for requiring 3 months to get to grips with the job was somewhat unfair. The time spent on the initial planning of the job had paid off in the long run, and it was incorrect to state that the difficulties in the excavation of the south abutment for the fixed bridge had been the cause of the delay in completing the bridge. The 10 days' loss of work in 2 years due to bad weather was worse rather than better than normal experience in works of this nature. The time lost on contracts of this kind was probably exaggerated by contractors, and this led to a wrong impression of how much time was lost on jobs of this nature under average conditions.

225. The Bristol area was notorious as one in which deep foundations were difficult to construct. The marls were extremely variable in nature, and the levels of water in them and in the sandstone underneath were completely unpredictable. A great deal of detailed planning in the area of the swing bridge had been necessary in order to deal with obstructions. The Engineers' approach had been to try to keep the holes in the ground to the minimum size possible. This was why, in a large part of the job, the Contractor had felt it expedient to suggest large-diameter piles instead of large excavations for certain of the pier foundations as it was felt that the complications of underground culverts could be most effectively dealt with in this way.

226. Both the Authors and Mr Holland had commented on the concrete mix. The question was how to eliminate a certain amount of silt or fine marl which settled in the concrete when it was placed under water. One of the problems was the removal of the tube for large cylinders. He agreed with the Authors that increasing the slump of concrete to 8 in. and omitting the specified vibration had been most successful and showed that the concreting of large cylinders could be satisfactorily carried out in this way.

227. There was a tendency to use concrete additives for purposes for which they had never been designed. It had been discovered that one particular additive could produce a flash set with sulphate-resisting cement, although the additive in question was designed to densify concrete and was used as a retarding agent. It was essential to carry out preliminary tests with samples of concrete when a widespread use was made of additives, but he strongly disagreed with the Authors about the additive which was rejected on the ground that it contained a calcium chloride. It would probably have produced 0.05% calcium chloride in the concrete mix, which was far less than that commonly found in cements which were used quite freely.

228. Comment had been made on expansion joints in viaducts of this nature. In § 90 the Authors spoke of viaducts separated into suitable units. From a series of curved viaducts of this nature it would be interesting to record what movements resulted from temperature changes. A straightforward expansion and contraction would probably not have been found in practice. Had the Authors any experience of the way in which the viaduct distorted under varying temperatures?

Mr P. B. Ahm (Ove Arup and Partners) said that a comment had been made that dividing the contract into two parts designed by two teams, who worked closely together, had worked very successfully. He made the general observation that it must be considered best if the whole project were under one control so that the team was conceived as a whole. Perhaps the Authors could elaborate on the extent to which this had been teamwork.

230. He agreed with the choice of a low elevation for the swing bridge; the choice was perhaps obvious, for a high bridge would have had an unfortunate influence on the centre of Bristol. But he questioned the choice of moving the bridge, and asked if the Authors had considered whether the figures told the whole story. Other cities, such as Amsterdam and Copenhagen, had recently arrived at a different answer, but both answers might, of course, be right.

231. Secondly, was a more integrated box design incorporating the deck (which seemed to be separate) ever considered for the swing bridge? If so, was this rejected on the grounds of cost or construction difficulties?

232. Turning to the fixed-bridge contract, the Authors had said that the scheme was for an elevated motorway. Was this fact considered in the design of the bridge, in the sense that it might have been closely linked to the design of the viaduct as a whole? On what grounds was this possibility rejected? The Authors made the point that the bridge was made to harmonize with the swing bridge, and it was difficult to assess from the Paper how this had worked. He had not yet seen the scheme and would like the Authors' comments.

233. The Authors stated that they had considered three designs for the bridge, two of which were rejected. Mr Ahm thought that the way to proceed was not necessarily to produce three different schemes independent of one another and then to choose one of them, but to progress step by step, making decisions governing the next step all the time.

Mr O. A. Kerensky (Messrs Freeman, Fox & Partners) congratulated the Authors and commented on the excellent teamwork which had existed between his firm and the City Engineer, both acting as 'Engineers' on the site. The danger of dual control had been appreciated and one Resident Engineer had been appointed to supervise the two Contracts—as it were serving two masters. Mr Kerensky did not advocate this method but the experience had shown that it could work very well, provided all concerned, including the Contractor, were willing! The set-up for the design of the superstructure of the swing bridge was perhaps even more unusual in that Freeman, Fox & Partners were appointed by the Ministry of Transport to check the City Engineer's design, and in that capacity fully co-operated with the Engineers in the design and construction of the bridge.

235. In § 35 it was implied that the $\frac{9}{16}$ in. thickness of the deck plate should reduce the cost of maintenance. While a thick plate might enhance the life of the asphalt surfacing, the cost of painting would be the same whatever the thickness of the plate, and additional thickness did not reduce the cost of maintenance of steel. The protective treatment of the steel with 'Metalife' was of interest. It was being tried out on a bridge for the first time as an experiment and carried a 5 year guarantee. The paintwork looked very well and was not easily damaged. If it was as good as it looked it should last 10 to 15 years. He strongly advocated that protective treatment (cleaning and painting) should be carried out by a responsible firm and be guaranteed for a reasonable period of years. Then all the trouble from bad painting on moist and dirty steel would be eliminated, nor could there be any argument as to who was responsible for failure, should it occur.

236. Referring to the foundations for the main piers of the fixed bridge, the Designers thought that a cofferdam would be difficult to build on the south side, and a caisson was therefore provided. The Contractor offered a reasonable reduction in price if he was allowed to use a cofferdam instead of a caisson, and this offer was accepted. However, he was quite satisfied that if a cofferdam had been originally specified, it would have cost the Client a great deal, because of the difficulties which were actually encountered. The north pier cofferdam also gave trouble, but on the whole the adopted design was economic.

237. Mr Holland had commented on the extension of time and on the cost of this to the Client, and had wondered if this could have been avoided by the use of caissons. The construction of the piers might perhaps have been easier, but the time and cost would have been greater. Although foundation difficulties did delay the construction of the fixed bridge there were also other delays due to diversion of services, shortage of labour, landscaping, etc. For one reason or another most of the Contracts were late and the Contractor always seemed to produce plenty of reasons why it was not his fault. The shortage of carpenters was proverbial on civil engineering works, and the Cumberland Basin scheme was no exception. The industry should be re-organized so that formwork carpenters could be trained as such. This should take 1 or 2 years instead of the 5 years now required by the Unions.

238. On the whole he did not think that the contract time should be stipulated by the engineers. It should be part of the contractor's tender, supported by a reasonably detailed programme and a critical path diagram. The contractor should then be made to stand by his programme and significant penalties and bonuses should be provided. He was certain on the whole that the liquidated damages collected by the client were very much less than the amounts paid by the client to the contractor on account of extension of contract time.

239. With regard to the choice of cast-in-situ reinforced concrete viaducts supported on discrete columns without cross beams, much thought was given to the cost and appearance of this major urban development in a city conscious of its associations with Brunel. It was gratifying that the most satisfying solution also proved to be the most economical, but even if it had not, a little extra for good appearance would, he felt, have been justified in the circumstances.

240. During the planning stage, parapet lighting had been seriously considered. He hoped that the City Engineer was pleased that it was not adopted. Parapets on urban viaducts were continuously hit by vehicles. On the curved spans of the Cumberland Basin they would be even more vulnerable than those on the straight Hammersmith Fly-over, which had been seriously damaged on several occasions. The damage to electrical fittings with the consequent blackouts would aggravate the situation after an accident.

241. Comment has been made on the use of asphalt surfacings on reinforced concrete decks. Much time and money had been spent on the deck slab of the main and approach spans of the Medway Bridge in an effort to ensure a high-quality surface, both during construction and later by the use of special grinding machines. Even this was not really successful and making-up by asphalt was eventually necessary. He had seen photographs of quite elaborate machines used in America and on the Continent, but considered that the economic answer was to accept irregularities of the concrete surface and provide for a making-up course of asphalt in the Bill of Quantities. Practical limits of tolerance should be set and insisted upon instead of striving after impossible ones.

Mr T. H. Butler (Messrs Head, Wrightson Teesdale Ltd) said that his main interest was in the superstructure of the swing bridge, which had been covered in great detail in the Paper. Members might be interested in a little further expansion of details relating to the site erection of the swing-bridge superstructure which, together with the shop fabrication, had been the responsibility of his company.

243. The first point to consider in any erection contract was the scheme of operations. In this instance the Company had considered several methods, the most interesting of which had been the fabrication of the bridge in one piece at Thornaby, and its launching into the River Tees. It would then have been towed round the coast to Bristol and landed and rolled into position at the site. This technique had been successfully developed by the Company and had been used for dock gates, large vessels, and for the Narrow Street swing bridge over the entrance to the Regents Canal in the London Docks.

244. In this case, the structure, though inherently buoyant, had been a very awkward shape both to launch and to tow, as it drew approximately 11 ft at the centre with the ends just out of the water. Although there had been a convenient 'grid iron' at the entrance to the Brunel lock for dry-docking ships at low water, a considerable amount of falsework would have been necessary on which to land the structure, in view of the high tide range. Another disadvantage was that marine insurance premiums would have been high.

245. On the credit side, only one assembly would have been required instead of two, and the bridge could have been built in workshop conditions rather than on a difficult site. Deflexion problems would have been simplified, the long haul of heavy and large loads by road would have been avoided, assembly could have taken place in less difficult circumstances at the works and the welding could have been undertaken in better sequence to suit the shape. In fact, the estimated costs of the methods had been comparable, but it had been felt that the risks expected did not warrant the method being adopted.

246. Another more conventional method which had been considered was the use of the P200 Pignon Tower Crane on the island. This would have given good coverage at 10 to 15 tons, but the fact that the crane would have to vane in 'out-of-service' conditions, and this over a working lock, made it unacceptable. The erection of the crane

would have been a problem, too. Consideration had been given to catheads or other craneage on the deck of the bridge but the feeding of these would have had its problems.

247. Another possible method had been the use of a derrick on piled supports in the disused Brunel Lock. The considerable amount of silt and the stone lock bottom had made this unacceptable, as the latter would have had to be made good. Free-standing gabbards on the lock bottom had also been ruled out because of the silt.

248. The scheme eventually used had worked very well. One of the snags at the beginning had been the fact that the road across the Brunel bridges had had to be left open to traffic as a relief road for the swing bridge at the east end of the basin. This would have been a public road with a considerable amount of traffic running across the middle of the site under the swing bridge structure. In the event this road was closed to traffic. There had also been problems of feeding material to the crane working on the island erection. Everything had to be lifted over by the derrick, which had been tedious.

249. It had been decided to build the bridge fully supported over the central 80 ft to Stage 2 because it had then been possible to support fully and so have an accurate start. The decision to cantilever from then on at both ends had been made. At the south end the decision had been dictated by the lack of any location for support. There could have been some provided at the north end, but because the south end had had to be cantilevered, tedious calculations were required and there were several advantages in having one scheme instead of two. Calculations of the end deflexion produced by virtually every piece erected had been made and these had applied for both ends. Having the bridge in balance at all times had been specified. In fact this method had helped to make it a straightforward operation to keep the bridge perfectly level so that all levelling could be done by instruments.

250. The main difficulty had undoubtedly been the distortion due to welding. On a structure of this type, where full use was made of thin plating (which was virtually all welded at one side only), distortion was almost inevitable. It was certainly difficult to overcome. Shop fabrication of large sub-assemblies, with the many facilities available, could be regulated to produce a reasonably accurate section but, after handling and long transport, this accuracy might not always remain. It was then necessary to put it right on site with the limited resources there, and this was not always easy, particularly when working 'out on a limb'. The fact that the transverse deck welds had been staggered had caused difficulty because the uncontracted inner deck sections had to be erected into fully contracted spaces between outer deck sections already completed. The problem mentioned in the Paper of maintaining the end levels at each stage, although well catered for by means of adjustment, had been made difficult by the uplift experienced due to weld contraction of the transverse deck welds. As much as $\frac{3}{8}$ in. contraction had been recorded across $\frac{9}{16}$ in. weld. This effect on the end of a 40 ft section with a moment ratio of 5:1 or 10:1 had been considerable. When the weld was made, the end lifted up. It had to be kept low to counteract this effect. Moreover, the contraction had not been constant and had varied from welder to welder. No two welders worked in exactly the same way or put the same heat into the weld.

251. He asked the Designers whether, after experience on designing and following through with site construction, they still assumed that such a structure as this could be erected perfectly to line and level? If not, had they reassessed their ideas of what would be reasonable tolerances for this type of structure?

Mr K. A. Goodearl (Messrs Freeman, Fox & Partners) said that his remarks were confined to § 27 dealing with the check for fatigue of the superstructure of the swing bridge.

253. Up to the time when the design of this structure was begun in 1961, fatigue had generally been considered to be a disease suffered only by highly stressed railway bridges and one from which highway bridges were immune, as they rarely

carried anywhere near the full design load. However, as this relatively light structure experienced complete reversal of stress during swinging, and in view of the results of the British Welding Research Association's fatigue tests, it had been considered necessary to carry out a check on this bridge.

254. No loading spectra had been available at the time, so two rough spectra had been produced, one for elements of the battled deck based on wheel loads, and the other for the main girders giving the numbers of cycles of various percentages of the full HA design loading.

255. Mr Holland had drawn attention to the traffic count in Bristol where, according to Mr Goodearl's records, the commercial vehicles of 2 tons and over had accounted for only one third of the traffic. No doubt this had been due to the large number of private motorists using the area during the peak hours.

256. The wheel-loading spectrum had been obtained from traffic observation in Bristol and in fact it had been found that commercial vehicles accounted for about one third of all traffic. These vehicles, assumed to average 5000/d on the slow lane, were divided into three groups, those with two, three, and four axles, and by assuming a weight range for each group and a distribution between empty and fully laden vehicles, a wheel-load spectrum had been arrived at as shown in Table 3. These were the numbers of wheels assumed to pass over any small area of deck of the slow lane. There were no wheels over $4\frac{1}{2}$ tons and it had been assumed that the wheel load of $4\frac{1}{2}$ tons was rarely exceeded.

257. It was of interest to compare this spectrum with one produced recently by the Road Research Laboratory, based on observations of commercial vehicles in various

TABLE 3

Wheel load tons	No. per day
$4\frac{1}{2}$	500
4	1 000
3	2 000
2	3 000
1	4 500
$\frac{1}{2}$	8 000
$\frac{1}{4}$	11 000

TABLE 4

No. per day Cumberland Bridge spectrum	Wheel load tons	No. per day R.R.L. spectrum
—	6	50
—	5	500
500	$4\frac{1}{2}$	—
1 000	4	1 000
2 000	3	1 000
—	$2\frac{1}{2}$	1 000
3 000	2	13 000
4 500	1	10 000
8 000	$\frac{1}{2}$	3 000
11 000	$\frac{1}{4}$	6 000

parts of the country, the distribution between cars and lorries on the slow lane of the M1 and the maximum design capacity of a motorway lane. These figures were shown in Table 4. This corresponded to HA loading, and the effects of various levels of abnormal (HB) loading were taken into account by applying annually in line some 800 7 ton wheels, 280 at 9 tons and 120 at $11\frac{1}{4}$ tons. The Road Research Laboratory wheel-load spectrum was uncorrected for lateral distribution and not all the wheels necessarily passed over any given element of deck.

258. The design of elements of the deck in accordance with the fatigue clause of B.S. 153 showed that for a given maximum design stress, a life of, say, 100 years under the Bristol spectrum would be reduced only slightly to about 70 years under the worst interpretation of the Road Research Laboratory spectrum, but would be increased considerably if lateral distribution of wheel loads was taken into account.

259. Mr Goodearl's lane-loading spectrum had been obtained on a rather more arbitrary basis, the following being used.

<i>Lane loading</i>	<i>Daily frequency</i>
Full HA	5
$\frac{1}{2}$ HA	20
$\frac{1}{4}$ HA	200
$\frac{1}{8}$ HA	2000
$\frac{1}{16}$ HA	5000

260. The equivalent Road Research Laboratory spectrum was based on simply supported stringers and varied with loaded length and spacing of members. The nearest equivalent to the Cumberland case gave the following figures.

<i>Stress level</i>	<i>Daily frequency</i>
0.35 HA	600
0.25 HA	1700
0.15 HA	5400
0.05 HA	4300

The effect of the HB vehicles must be added to this. Here the design life of 100 years would be doubled under the Road Research Laboratory spectrum, due largely to the pessimistic assumption that full HA loading occurred five times a day, whereas it was doubtful whether it occurred even once in a day.

261. These comparisons showed that the results of the early efforts to produce load spectra were in reasonable agreement with the results derived from the recent Road Research Laboratory spectra, and that the fatigue life of the bridge should not give occasion for any concern.

Dr T. A. Wyatt (Imperial College) commented on the difficulties of tightening high strength bolts, referred to in § 181. At Imperial College he had done a number of tests on the tightening of structural bolts, using a test set-up which gave a reasonable simulation of a real joint. The tension in the bolt was indicated by electric resistance strain gauges on the shank of the bolt. Fig. 25 showed some typical results.

263. The first curve referred to $\frac{7}{8}$ in. diameter waisted-shank bolts of EN 16V steel, using a shouldered nut with a special thick washer. The grip length was $2\frac{5}{8}$ in. The tests started from the so-called hand-tight condition, in this example a torque of 130 lb/ft, although the actual torque value chosen for the datum was not critical within the range of from 100 to 400 lb/ft. For a turn of the nut between $\frac{3}{4}$ and $2\frac{1}{4}$, the tension was close to 30 tons: the wide margin was available because the whole shank length stretched.

264. The tests showed that the total extensibility of the bolt ($2\frac{5}{8}$ in. grip) was equivalent to a plain cylindrical bar about $\frac{3}{4}$ in. longer than the grip. For a short bolt, say 1 in. grip, the equivalent total length would thus be $1\frac{1}{4}$ in. On this basis the necessary turn of the nut would be only half of that for the longer bolt, or half a turn

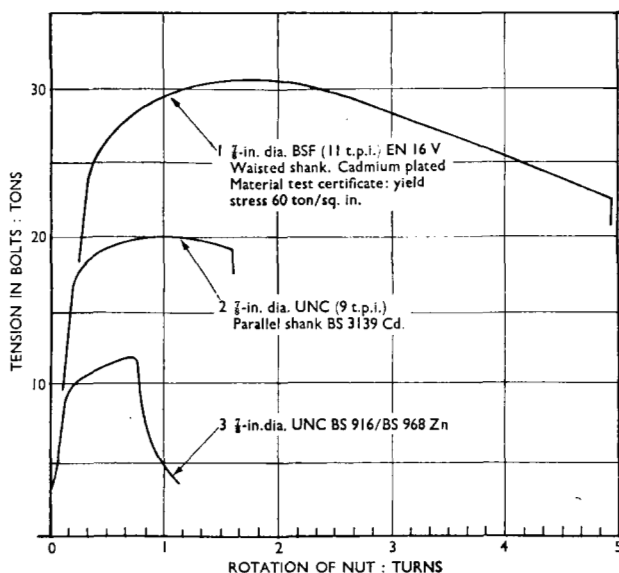


FIG. 25

for full tension, leaving about two turns margin on breaking the bolt. He had found this method of correcting for grip length to be generally satisfactory.

265. The second curve referred to the more common pattern of high-strength bolt where a margin of extensibility was obtained by having a substantial threaded length of the bolt within the grip rather than by reducing the diameter of the whole shank. The third curve referred to the conventional structural bolt, using high yield stress steel to B.S. 968.

266. Dr Wyatt felt that this repetition of known facts was justified to emphasize two points. First, that the threads of a modern bolt were expected to do up to three times the work of what had previously been regarded as a high-tensile bolt. Second, that there should still be ample margin. This should be true even when the bolt was rather short: using the shouldered nut and special washer, it had been found possible to tighten bolts when over two turns of the nut were required to bring the bolt flush with the face of the nut, and within this limit it was impossible to strip the thread, provided it was clean and undamaged.

267. If an erector damaged the thread of a black bolt getting it into place, this was perhaps just an added safeguard against subsequent working loose, but a high strength bolt was quite a different matter. Grit and corrosion were two other enemies, and lubricant was a doubtful ally. A molybdenum disulphide lubricant certainly reduced the torque required, but very careful supervision was required to prevent excess, and it increased the danger of picking up grit.

268. Dr Wyatt suggested that there was a big problem in supervision and education of erectors to treat the modern bolts with proper respect: he asked the Authors if they shared this opinion, or whether there had been any particular defect in the bolts used on the swing bridge which had contributed to their problem.

Mr D. R. Mansergh (City Engineer's Department, Bristol) said that as he had been concerned with the basic design, specification and installation of the mechanical and

electrical plant for the swing bridge at Bristol, he felt that some more detailed comment might be of interest on the design and operating experience to date.

270. A comprehensive specification had been prepared and close attention given to the detailed choice of materials for the main components of the turning machinery, using British Standards wherever possible, for example, for the centre bearing main components, the centre wedges and seats, the main turning rack and track, where the 0.45% carbon steel castings had a minimum tensile strength of 35 tons/sq. in., and the main turning pinions where the 0.55% carbon steel forgings had a minimum ultimate tensile strength of 45 tons/sq. in.

271. The basis of gear design had generally been in accordance with B.S. 436. Assuming that all the load was carried on one tooth, a 6 in. face width had been selected to meet all the requirements of strength and wear to the above standard. Some months had been spent in the Bristol City Engineer's office preparing the basic design and specification of the machinery, but this had been well justified as the machinery tenderers had generally accepted the requirements for materials and gear design and this had made the comparison of tenders comparatively easy.

272. Latitude had been given to the tenderers as to the design of the prime movers, the basic requirements being that under normal conditions the main turning load was shared equally by the four main pinions, and that complicated interconnecting shafting and differential gear units should be avoided. An interconnected hydraulic system had been considered ideally suited to meet these requirements.

273. The overall system was now operating satisfactorily, but a number of minor troubles had become evident during commissioning. With this bridge structure it had been decided that the nose-end jacking sequences should be synchronized, necessitating the transmission of electrical control impulses from pressure-sensitive switches over fairly long multi-core cables.

274. The hydraulic systems themselves were also complex, particularly the four synchronized lifting jacks under each nose end. The machinery contractor had met the requirements of the specification after modifications to the hydraulic link between each set of nose-end jacks between the ends of the bridge. As the swing bridge had been in operation for nearly 12 months, and with the experience gained, he asked the Authors whether each set of nose-end jacks could have been independently operated in sets of four.

275. The necessity for complete reliability of operation had determined the standard of equipment provided. This, together with the duplication of all main items of plant, should ensure that no hazard to shipping existed, in view of the vulnerable position of the swing bridge at the entrance to Cumberland Basin. An emergency stop was provided, the action of which was to disconnect all electrical apparatus, stop hydraulic pumps and immediately apply control brakes on the prime movers in the event of a possible danger to shipping. The use of the emergency stop had given cause for certain anxiety, but during recent tests with the bridge moving at full speed the emergency stop had been applied and the bridge stopped within 5° with no detrimental effect on the turning machinery. This had been repeated at intervals with success.

276. Although the financial value of the machinery was a small proportion of the total cost of the scheme, certain problems had been encountered during the installation of the mechanical and electrical equipment. Most of the installation work had been carried out during the winter months. Although certain civil engineering works had to be carried out after the main items of plant were installed, it would have been preferable had more been finished beforehand. The mechanical and electrical sub-contractors had been harassed by water, dust and dirt, which was not ideal when it was necessary for them to have complicated switchboards opened or to instal machined parts.

277. In his experience as a mechanical engineer, this was not an uncommon experience. However hard one tried, whenever a completion date had to be met, the mechanical and electrical contractor had to do his best with a limited programme. He

submitted that civil engineers in general should take a more careful look at their programme commitments and their responsibilities to the nominated mechanical and electrical sub-contractors. The Authors might wish to comment on this aspect.

Mr K. R. Burren (G. Maunsell & Partners) said that he would confine his attention to the concrete used for the bridge superstructures which apparently exhibited high shrinkage characteristics. The Authors of Part 2 of the Paper had stated that compacting factors had been used as the main control criterion and that water/cement ratios and cement contents had been kept to a minimum. Unfortunately, the compacting factor values had not been included in the mix details listed in Appendix 5.

279. The Authors referred in § 144 to cracking in the earlier bays of the dual carriageway where a fairly workable concrete had been used and stated that heavily reinforced sections were concreted with a more workable mix, as were all piles. Did this mean that slumps of 5–8 in. had been used, as referred to in § 131?

280. In §§ 165 and 166 there were references to cracking in the webs over the piers of the fixed bridge prestressed superstructure. Although the water/cement ratio of the 600 lb/sq. in. concrete was not stated, the concrete was described as a very workable mix with a high cement content necessitated by the narrow webs. Initially the base slab and webs had been cast first but a change in the placement order had prevented crack formation.

281. The superstructure of the fixed bridge had been constructed of a 6000 lb/sq. in. concrete ($\frac{3}{4}$ in. max. aggregate size) with a 9 in. web thickness in timber shutters. It was of interest to compare this with the larger but similar Medway Bridge where a 7500 lb/sq. in. concrete ($\frac{3}{4}$ in. max. aggregate size) was placed in a 9 in. web in timber shutters, using external and internal vibration and placing a low workability mix at a compacting factor of 0.88 and a water/cement ratio of 0.4.

282. Would the Authors please elaborate on the necessity for the very workable mix used for the fixed bridge superstructure and give details of the placement and vibration techniques used?

The following contribution was received in writing:

Mr J. E. Golden (Messrs Freeman, Fox & Partners) asked the Authors if structural aluminium had been considered for the swing bridge.

284. The reduced weight would have resulted in lower capital and running costs on the mechanical and electrical side and in a smaller (and hence cheaper) centre foundation. The use of aluminium alloy would have reduced bending and shear in the 'swinging' condition, when the loads were those due to self-weight, so that any increase in plate sizes might be quite small. It would also have resulted in lower maintenance charges, though these might not have been considered in any cost comparison.

285. If these assumptions were correct, on what grounds did the Authors rule out the use of aluminium?

The Authors said that Mr Holland's comments on the trouble encountered with the south cofferdam for the fixed bridge inferred that the change from the original caisson proposal had resulted in an extension of time and extra cost to the Client. The Authors pointed out that this in fact was not the case as the change to cofferdam had been proposed by the Contractor who had been forced to overcome the problems at his own expense and without any extra time being granted for the work. The extension of time that had been granted was in respect of the difficulties encountered on the north cofferdam which the Engineers had originally specified to be a cofferdam. The Authors expressed confidence that the right approach had been taken in specifying a caisson for the south pier, leaving it to the Contractor to decide whether or not to risk attempting the use of a cofferdam.

287. With regard to Mr Holland's reference to the shortage of joiners, the

Authors' experience to date was that in-situ construction was usually cheaper than precasting, although all forms of construction were always considered. In this particular scheme the complex shape of many of the viaducts would have made any form of prefabrication very difficult.

288. Mr Holland's observations on the proportion of lorries were partly answered by Mr Goodearl's contribution. The counts for the loading spectra were taken in summer when the proportion of cars was probably higher than normal; also it was hoped that within 8 years the western by-pass would be in use, when much of the lorry traffic associated with the docks would be diverted from the swing bridge.

289. Regarding the placing of concrete in large diameter bored piles, where contamination of the concrete and cement loss in the water was experienced, the Authors were of the opinion that if a properly fabricated tremie pipe was used concrete could be placed under water without any difficulty. In fact this was proved on a number of piles where the concrete was placed with such a pipe instead of a tremie skip and no contamination occurred.

290. Mr Derrington said that the 3 month period of initial planning was warranted, but the Authors maintained that if an extended planning period left less time for actual construction then it was of doubtful advantage. However, they made the observation that as most contracts allow a 10% financial contingency, perhaps they should also allow a 10% time contingency.

291. The Authors agreed with Mr Derrington that the conditions over much of the site favoured the use of piles, and for this reason deep excavations were only proposed where the position of existing sewers was uncertain. The Contractor proposed the alternative of large diameter bored piles and undertook to locate the sewers before piling. Despite this they were struck several times during piling, necessitating the re-siting of piles and re-design of foundations, and in one case repairs to the sewer.

292. Referring to Mr Derrington's remarks about concrete additives the Authors agreed that care should be taken when using an additive particularly when using it for a purpose for which it was not designed. It was pointed out that in the case in question, preliminary tests were carried out but they did not show the tendency to flash sets that had been experienced in practice.

293. Regarding the expansion and contraction of the viaducts, this was a subject that was still under observation and no conclusions could at present be reached about the manner in which such complicated structures moved.

294. Mr Ahm had raised the matter of the problems associated with the use of two independent design teams on one project. Whilst agreeing that it was not the ideal solution, the Authors said that, in fact, there had been no appreciable difficulties. They liked to think that the personalities concerned had been a major contributory factor to that state of affairs, but if the terms of reference were well defined and if, as Mr Kerensky had pointed out, the aims were common and co-ordinated there should be no great problems. Obviously, there had been points of detail on which they had agreed to differ but the unified appearance of the completed scheme and the harmonious manner in which it has been achieved were measures of the degree of co-operation obtained.

295. The choice of type of moving bridge had been queried. The costs given in Table 1 had been prepared 3 or 4 years previously but nothing had transpired in the meantime to suggest that they were not substantially true for this site, where the peculiarities of foundation conditions tended to favour a swing bridge. In other circumstances, possibly a bascule bridge might have been cheaper. This would accord with continental and American practice in situations where land costs were high and waterways congested and where the opening time was of paramount importance.

296. The Authors assured Mr Ahm that the main object of the form of construction chosen for the superstructure was to make full use of the deck as an integral part of the twin box girders.

297. In designing the fixed bridge consideration was given to achieving as close an integration with the viaducts as possible. Owing to the much larger bridge spans the most economical form of construction was necessarily different, and the construction depth greater than that of the viaducts. At one time it was thought that the adjacent viaduct spans might be made deeper to merge with the bridge, but this would have been messy on the north side and entirely artificial and the idea was abandoned.

298. The Authors agreed with Mr Ahm that designs should be developed step by step with each step influencing the next, but considered that in the initial stages alternative designs must be developed to some degree of detail to test the economics and other advantages of each. After this stage had been reached the selected design must then be fully developed.

299. Referring to Mr Kerensky's remarks about parapet lighting, the number of incidents where the parapets were damaged was quite high. So far they had been hit by vehicles approximately once every 2 months.

300. Mr Butler had concluded his remarks by asking whether the Engineers had reassessed their ideas of reasonable tolerances for thin-plate structures such as the swing bridge. As far as this particular bridge was concerned, the Authors saw no reason for relaxing the requirements. Surface deviations on the deck plate, for instance, would have produced variations in the thickness of asphalt surfacing with consequent problems in the balancing of the bridge about the centre pivot. The web plates of the main box girders revealed the pattern of the internal stiffeners on the exterior when freshly painted with a gloss coat, but these welding distortions were generally found to be acceptable when actually measured, and after the gloss finish had dulled the irregularities disappeared. It had been considered necessary, however, to correct the distortion in certain web panels where the amount of bulge exceeded half the web thickness.

301. In reply to Dr Wyatt's suggestion that the difficulty encountered with the high-strength bolts was due to careless handling by the erectors, the Authors pointed out that trouble had only been encountered when the length of bolts was calculated to ensure that the bolt did not protrude from the nut after tightening, and when no allowance had been made for the increased thickness of plates due to protective coating and rolling tolerance. Under these conditions approximately 3% of the bolts had stripped their threads and a much higher proportion of the bolts had extruded a thin sliver of thread metal during tightening. When the bolts were replaced by longer ones which resulted in the bolt protruding from the nut when tightened, no further occurrences of thread stripping were encountered yet the actual method of tightening and supervision of the tightening was exactly the same.

302. Mr Mansergh had asked whether each set of nose-end jacks could have been independently operated in sets of four.

303. The specification called for the linking of all jacks so that the movement of any jack would be checked, if the load on it increased to 10% more than that on the remainder, until all loads became equalized. This was considered necessary to prevent racking and tilting of the superstructure.

304. Having seen and heard the effect during the early stages of commissioning of one end of the bridge being supported on and then lowered by only one outside jack, the Authors felt sure that Mr Mansergh would agree with the necessity of inter-linking the four jacks at one end of the bridge.

305. As each set of nose-end jacks could transmit a force of 140 tons, if there were no linkage between the two ends it was possible to imagine a situation where one set of jacks could operate alone and require a stabilizing force of several hundred tons at one balance wheel assembly to maintain equilibrium. It was deemed to be a minimum necessity to link the jacks at both ends of the bridge until they all came under load rather than to design the balance wheels and appropriate support girders to take the large stabilizing force. The added refinement of providing linkage throughout the full working range seemed to be a logical requirement.

306. The Authors agreed in general with Mr Mansergh's observations regarding civil engineers and their mechanical and electrical sub-contractors. More consideration might have been given to accommodating the requirements of the mechanical and electrical sub-contractor when the Contractors' programme was drawn up. However, initial delays due to foundation problems and commitments towards the completion date, which fully extended the Contractors' resources throughout the site, later made the task of providing the desired civil engineering support very difficult. It was also pointed out that whilst mechanical and electrical sub-contractors were able to execute the majority of their work under ideal factory conditions similar facilities would be unlikely to be provided by the main civil contractor on site.

307. In reply to Mr Burren the Authors said that the workability of the concrete in the earlier bays of the dual carriageway viaduct was not of the order of 5-8 in. slump, and details of the compacting factors for various mixes were given in Table 5.

308. The cracks that had occurred in the webs of the fixed bridge had been situated over the piers, and had been caused by deflexion of the falsework. It had been found possible to eliminate this cracking by altering the method of concrete placing to ensure that the falsework deflexion took place first so that it did not affect partially set concrete.

309. The concrete used in the webs of the fixed bridge with a compacting factor of 0.92 was necessary as the duct size to take twelve $\frac{1}{2}$ in. dia. strands was large, so that the clearance between them and the mild steel reinforcement was only a little over 1 in.

TABLE 5: CONCRETE COMPACTING FACTORS

Class	Mix	Compacting factors
A	A	0.90
B	B	0.92
C	C	0.89
C	P	0.87
D	D	0.88
D	J	0.92
D	K	0.93
D	L	0.92
D	R	0.88
D	S	0.87
D	T	0.88

310. With regard to Mr Golden's contribution, in the initial design stages the possibility of using aluminium was explored with a view to reducing self weight to a minimum. The best information available at that time threw considerable doubt on there being any savings in the capital cost of the superstructure.

311. The savings to which Mr Golden referred should be viewed in the light of the fact that the total cost of the centre foundation as now constructed only represented 5% of the cost of the bridge and the bulk of the cost of the mechanical and electrical sub-contract involved items such as the control equipment and electrical installations which were common to all schemes.

312. It was decided that the anticipated savings in maintenance and running costs were not sufficient to favour the use of aluminium for a bridge of this type and size in view of the deflexion and expansion problems which would have to be faced.

313. In conclusion, the Authors wished to thank all those who had taken part in the discussion for their enlightening comments and kind remarks.