*Discussion on Paper No. 6925**

The construction of Wuya Bridge, Nigeria

by

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AUTHOR'S INTRODUCTION

Mr Samuel said that since lack of space in the Paper had prevented more than a reference to the river training works, a brief description might be of interest.

121. The Kaduna River meandered in a wide plain at Wuya and was currently eroding the east bank and depositing sand on the west bank. The west abutment of the bridge rested on the bank of sand, and it was necessary to protect the abutments from erosion by river training works. The west sandbank was heavily overgrown and fairly well established with tall grass. There were overflow channels which cut across it and carried water in the flood seasons. A high earth embankment was constructed across the sandbank from the west abutment, carrying the approach road to the higher ground which must many years previously have formed the old river bank. It was necessary to construct guide banks at each of the abutments and a spur embankment about ½ mile upstream from the bridge. The side slopes of the embankments continued below river bed level.

122. The most difficult section was the underwater excavation in the river bed. Some of the excavations were required to extend about 20 ft below the bed level, in extremely loose running sand. The guide banks and spur carried heavy armouring which extended down into the excavations. Use of a drag line for excavation would have been tedious and it was decided to import a small dredger. An 8 in. cutter suction machine was transported in sections, with the main pontoon and the side pontoons transported by rail to within 75 miles of the site, and then brought by road from there to Wuya. It worked very well. One of the snags was that in the very sharp sand of the west bank there was considerable wear on the pump and the pipes, and there was about 50% down-time as a result. When the machinery was working, it performed excellently, and dug out the underwater excavations true to the required lines and levels.

123. On the east side, the problem was somewhat different in that this was clay, and although there was not very much down-time, progress was very slow. There was also trouble because of lumps of ironstone which had been dropped into the water the previous season to protect the temporary bund from which the bridge was constructed. In the end it was necessary to send a diver down to recover the ironstone before dredging could continue. Ironstone, overlying a gravel bed, was also used to form the armouring to the guide banks and spur.

124. The ironstone occurred naturally in lumps of up to 24 in. on local hill slopes, this and the gravel being supplied by local contractors. These materials were placed underwater from floating rafts which were moved along the spur and along the guide banks at intervals to ensure the correct thickness of armouring.

Mr S. Serota (McKinney Foundation Engineering Joint Venture) said that he would like to enlarge on Mr Samuel's remarks on the method of constructing the foundation piles.

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126. The method used was a standard procedure in the U.S.A., but he was not aware that anyone had previously put in piles at an inclination of 1:6. It was thought that the method would be easily applicable to this site, but every job had its surprises, particularly below ground level, and this one was certainly no exception.

127. Fig. 13 showed the type of auger used. Its main purpose was to stir up the earth overlying the rock into a column of mud, by the addition of bentonite. The majority of the holes were inclined at a rake of 1:6. When rock-head was reached, the 4 ft diameter casing was slid through the mud and driven with a Vulcan hammer to a cut-off into the rock, which was a weakly cemented sandstone with layers of clay and loose sand. Drilling then proceeded 14 ft into the rock with a smaller auger, still under bentonite, because of the sand layers sandwiched within the rock itself. The reinforcement cage was then set and it was intended that the concrete should be placed by tremie until a plug was formed to a satisfactory height within the casing. The concrete would then be allowed to set, and the piles completed in the dry by cleaning out to the plug.

128. It was impossible to follow this method, principally because it was necessary to maintain a mud density in the region of 120 lb/cu. ft. With a lower density the sand ran into the holes. Concreting by tremie through a mud whose density approached that of the fluid concrete imposed great difficulties. By using a fluid, rich, sandy mix with plasticizer and retarder it was possible to place the concrete satisfactorily, provided the process continued without interruption. The temperature reached 114°F in the shade, and because of the very hot weather any delay in concreting permitted the concrete to stiffen, with the result that it would not flow from the tremie. The consequence was that the tremie had to be withdrawn and this always left a 'sugar loaf' of concrete about 20 ft high standing up in the mud and confined by the reinforcing cage. Despite all efforts, this inevitably necessitated breaking out the 'sugar loaf' with pneumatic hammers. It was for that reason that it was impracticable to cast a plug in the bottom of the casing to enable subsequent concreting to be done in the dry. For the same reason it was not practicable to shorten the tremie pipe during concreting, because the brief ensuing delay permitted the concrete to stiffen.

129. The method finally adopted was to use an unbroken tremie pipe. The platform was permanently welded onto it and it was suspended by the Michigan crane and fed by the 1 yd skips, using the Ruston. The end of the tremie was usually embedded 20 ft or more below the surface of the deposited concrete and, once the operation was under way, never less than 10 ft. With this method the concrete above the bottom of the tremie moved only vertically, so that it swept all the mud before it with a piston action. Pouring went on continuously until clean concrete emerged from the top of the casing. A considerable wastage of material ensued, but the final results were good. The system necessitated the continued raising of the tremie until, by the time the pour was completed, the platform was about 40 ft above ground level.

130. Many attempts were made to reduce the density of the bentonite in order to make the concreting easier, but never with success. Experts were consulted, but no single explanation fitted all the facts consistently. Almost certainly the biggest single factor was the very loose state of the sand strata.

131. Working in a river bed between seasonal flooding was a nerve-racking experience, particularly in very remote sites. The penalty to the whole contract for failing to reach a particular stage in the construction before the onset of the floods would have been, to say the least, financially crippling. No doubt all concerned were spurred on by this anxiety, and everyone worked very hard, despite the heat. There was also a first-class spirit of co-operation between the Main and Subcontractors, and the Engineers which might easily have evaporated in the climate which had to be endured. In that connexion, he wished to express his gratitude to Mr Samuel who ran the job with all the zest and goodwill that one would hope to find in easier and more temperate conditions.

FIG. 13: TYPE OF AUGER USED

Mr A. S. McDermott (Messrs Scott Wilson, Kirkpatrick & Partners) said the Paper was useful and factual. Indeed, it was so factual and correct that, although he was closely associated with the design of the project and, to a lesser extent, with the construction, there was nothing about which he could disagree strongly with the Author. He proposed, therefore, to mention some features of the design.

133. From a design aspect, the major problem presented to the Consulting Engineers was that of the river. In comparison, the design of the bridge was a simple and straightforward matter. The Kaduna River was of a typical meandering type and changed its course over the years, with considerable scour and movement of sandbanks occurring during each flood season.

134. The major problems to be overcome therefore were:

(*a*) how to assess with reasonable accuracy the waterway to be provided and the depth of scour to be expected;

(*b*) how to ensure, at minimum cost, that over the years the river would continue to flow through the bridge rather than behind it, leaving the bridge high and dry;

(*c*) how to ensure that the river would flow through the bridge sensibly parallel to the piers so that the cylinders, cylinder caps and piers were not subjected to considerable transverse forces, which would have necessitated a much larger and more expensive foundation;

(*d*) how to assess the forces from the river acting on the sub-structure (the cylinders, cylinder caps and piers).

135. Although in the initial stages calculations were made to assess the probable figures using various empirical formulae, it was decided that a sound and economic design could only be produced by resorting to a model analysis. The Hydraulics Research Station was therefore requested to carry out field measurements and a model analysis in order to find the answers to the problems. He had no doubt that the use of such model analyses resulted in a sound design and in the saving of a large sum of money.

136. Turning to the choice of design, a major consideration which had had to be taken into account was the desirability of producing a design which would not involve the placing of falsework in the river to support the deck during construction. Not only would there have been danger of this being swept away during the flood seasons, but because of the loose sand and gravels in the river bed the foundations for such temporary works would have been very expensive. The obvious choice was to use some form of deck construction which could be pre-cast.

137. Another problem was the optimum balance between the cost of the deck and the cost of the foundations, i.e. what span would give the least overall cost. It was found that significant changes in span only marginally affected the cost of the bridge as a whole, the difference in cost being such that it was probably outside the accuracy of the estimate.

138. Dealing with the foundation design, it was perhaps not realized that the height from the river bed level, when the full anticipated scour had taken place, to the top of the deck was about 85 ft, or approximately the height of an 8 storey building. Bearing that in mind, any form of driven pile or small diameter bored pile was not practicable due to the reduction in the allowable stress which would have had to be made to take the slenderness into account.

139. Only three types of foundation were therefore worthy of serious consideration. The first possibility was building up on top of reinforced concrete caissons, which could be constructed in situ. The second was the use of steel sheet piled cofferdams into which mass concrete could be placed, and the third, which was used, was with large diameter cylinders. The first two designs were rejected, as estimates showed that they would be more expensive than the cylinders, and would have been slower to construct. The remarkable point was that after the initial difficulties had been overcome, the cylinders (of which there were 169) were constructed in about four months.

140. In regard to the shape of the beams, they were of the type commonly known as fish-belly beams. They had been used before, and he was surprised they were not used more often. The shape was adopted, first, because it was logical for a simply supported member where the bending moment was greatest at the centre and where the shear was not critical, and secondly, because the saving in the concrete by tapering the beams to the end not only reduced the weight to be launched but also resulted in a reduction in the prestressing force required. Admittedly, the shutter was more complicated, but with the number of uses which was obtained from the shutters the capital cost was a very small proportion of the total cost of the beams.

141. The standard of workmanship on the project was, in his opinion, above the average obtained in Britain, and he congratulated the Contractor, the Sub-contractors and the Author on producing such a high standard of construction under difficult conditions, and in something under two years, which was ahead of schedule.

Mr P. Ackers (Hydraulics Research Station) said that he had been concerned with the earlier phases of operations, namely the hydraulic model study of the bridge and its training works.

143. The work of the Hydraulics Research Station was carried out under the instructions of Messrs Scott & Wilson, Kirkpatrick and Partners, and was aimed principally at the following problems:

(*a*) checking the adequacy of the proposed waterway in passing the design flood;
(*b*) developing an economical and effective system of training works to protect the bridge abutments and approach embankments against possible outflanking;
(*c*) determining the effect of the bridge and approach embankments on river levels, having regard to the fact that flow over the flood plains would be prevented;
(*d*) studying the possible depths of scour at the bridge and at the training works, at various stages of the development of the meander pattern;
(*e*) confirming the sizes of stone and thicknesses of aprons and armouring for the training works;
(*f*) determining the forces on the bridge piers under possible skew attack.

144. The original scheme for training works incorporated guide banks on each side of the river, through the bridge, and an upstream spur intended to provide a strong-point limiting the extent of any outflanking action. The model was a free-boundary one, and it was dependent on an ability to produce the proper conditions for meandering in the laboratory. The model study proper was preceded by a feasibility study in an outside area of sand of 0·17 mm median diameter.

145. The experimental area was some 300 ft long. By a comparison of meander lengths, channel widths, mean depths, etc., with those occurring in nature, suitable scales were determined, namely 1 in 300 horizontally and 1 in 45 vertically.

146. In the initial stages of model-prototype comparison, the flood plains were covered with polythene film, on which small cement mortar blocks were placed to reproduce the frictional effects of prototype vegetation. The model was out of doors, and the polythene protected it from the elements, and reduced the need for remoulding in the proving stage. The cover was removed when the river banks were allowed to erode.

147. The model was operated with a varying discharge, representing the natural variation from wet to dry season with superimposed floods. A typical annual hydrograph was computed and factored to yield successively wetter years for imposition in turn in the model:

108 000 cusec	peak 1961 flood
152 000 ,,	,, average year
200 000 ,,	,, 1957 flood (highest recorded up to that time, but equalled in 1962)
275 000 cusec	80% of design flood
350 000 cusec	design flood of about 500 year frequency, according to a statistical analysis.

These were followed by a repeat of the average year.

148. Early tests on the original scheme for training works showed that modifications were needed, both to the guide banks and to the upstream spur. The spur was provided with a more streamlined nose, it was shortened somewhat, and moved downstream to lie a distance of ¼ meander length upstream of the bridge.

149. In addition to the general model study, special natural scale models were used to investigate apron protection, the scales being 1:45 both horizontally and vertically. The aprons of broken rock at the toe of the guide bank would 'launch' to provide a pavement to any adjacent scour. Fuller information on these model studies would be found elsewhere.[5,6]

150. A 1:80 scale model was used to investigate the forces which the flowing water would impose on the bridge piers. Velocities of up to 12 ft/s were investigated at angles of attack of up to 14°, which was the maximum skewness that had to be allowed for, according to the general model study. Overall forces on the model pier were measured by a transducer, the supports being initially a system of steel strip spring hangers giving parallel motion, later replaced by knife edges to determine the effective line of action.[5,6] In future years, it was hoped to find out to what extent the training works which were designed achieved their purpose.

Mr B. P. Wex (Freeman, Fox & Partners) was interested in the Paper because the method of construction of the foundations formed the precursor of a method which Foundation Engineering had used for his firm a year or so later on a job in West Pakistan.

152. One of the points which emerged from the Paper was the fact that large diameter bored cylinders were extremely useful in the kind of river conditions which were found in countries such as India and Pakistan, where there were flat meander plains with large deposits of sand, silt and perhaps clay, going down to great depths. The traditional method of forming foundations for bridges in such conditions was the construction of caissons, either in concrete or in brickwork, sunk by open dredging. There were many snags involved in this method. Without any doubt the technique of the large diameter bored cylinder could save much time and where suitable rigs were readily available the technique should save a tremendous amount of material and money.

153. Some of his questions related to design, and perhaps those concerned with design could reply. He was not clear for what depth of scour it was decided to design the pile foundations. The piles were formed with steel shells. Was it part of the construction technique to use steel shells, or was this a feature of the design? If the designers had asked for steel shells to be used, did they consider using them when calculating the structural strength of the piles?

154. The piles were given a rake of 1:6 which was new for this technique. With a large number of 4 ft diameter piles forming a group, would it not have been possible to carry the lateral forces by using the piles in bending rather than resisting lateral loads by direct thrust on raking piles. The steel skin could be of considerable help in resisting the bending moments, provided that the casings were effectively connected throughout their lengths to carry the resulting stresses due to bending. The possibility of corrosion might be one objection to utilizing the strength of the steel plate in such a manner, but it would be possible to coat the piles with some suitable material to inhibit this.

155. Was the steel plate for the shells imported from the U.K.? Presumably fabrication of the shells was carried out locally. Was this in a fabricator's yard or was consideration given to rolling the plates into the cylindrical lengths on site?

156. In the light of their experience would the Engineers have attempted to get the steel casings down to the very bottom of the hole, insert a plug, pump dry and concrete simply from the top of the pile? Would they now have significantly modified the techniques which were actually used?

The following contributions were received in writing.

Mr V. F. Lindsey (formerly Public Works Department, Nigeria) suggested that a little more background information might add to the already considerable interest of the Paper.

158. It would seem that provision was made for a European staff of about 16, i.e. sufficient people to fill the posts shown in the chart on p. 376. What labour was it found necessary to recruit locally? Were local artisans available, or had these to be trained on the job? How did the staff, particularly its European members, stand up to the trying climatic conditions?

Mr M. Herbstein (Ghana National Construction Corporation, Accra) asked if the Author would give details of the nature of the contract between the Clients and his firm and of the relationship between Alhaji Audu Bida and Costain (West Africa) Ltd in the joint venture. A breakdown of the sum of £1 100 000 mentioned as the cost of the bridge and approaches would also be of interest.

160. A frequent complaint made against foreign contractors operating in West Africa was that they treated their construction methods as trade secrets and were reluctant to employ and train local engineers. In the past this might have been attributable to a real shortage of suitably qualified personnel, which in itself was a consequence of the deplorable neglect of higher education, particularly in science, engineering and technology, during the colonial era. Judging, however, from the many Nigerian names which appeared in the recent lists of admissions and elections to membership of the Institution, this would seem to be no longer such a problem. His own experience has been that European foremen and gangers often regarded it as beneath their dignity to take instructions from African engineers. He hoped that the Author might be able to report that there were at least one or two Nigerian engineers employed on this job, learning the practical details of the techniques of piling, concrete quality control, prestressing, beam launching, etc. Further details of the number of Nigerian and expatriate staff employed on the job would be of interest.

161. It was surprising that the results of the preliminary subsoil investigation gave no warning of the difficulties experienced with the bored pile foundations. Would the Author give particulars of the scope of this investigation and its cost? Were the strata as uniform and level across the river bed as Fig. 12 would seem to suggest? Was any further information available on the founding stratum, referred to in Fig. 12 as 'sandy silty clay cemented to a very hard consistency' and in § 29 as 'cemented sands'? Was the foundation design wholly the responsibility of the Consultants or were the Contractors given an opportunity to make alternative proposals?

162. The description of the difficulties encountered in concreting the piles would be clearer if the Author could explain the apparent overlap in the functions of the drilling mud and the steel tube. In particular, what function did the mud serve once the collapse of the upper sediments into the pile shaft had been prevented by the introduction of the tube? There would seem to be a reasonable doubt as to whether the tremie concrete would be successful in displacing the thin layer of drilling mud adhering to the reinforcement and he wondered what bond had been established between steel and concrete. Were it not for the steel cylinder there might also be concern about the danger of corrosion of the reinforcement, since concrete cast under mud was unlikely to be flawless. Such concern might be compounded by the impossibility of inspecting this part of the structure. Were the steel tubes introduced with this in mind? Would the Author be willing to hazard a guess at the useful life of these piles and therefore of the bridge as a whole?

163. The contraction in the channel width from 2 miles to just over ¼ mile was bound to result in extensive local scour around the piles. Could the Author give particulars of the maximum flood and deepest local scour level expected?

164. In the weather details given in Appendix 3, the particulars for 1963 and 1964 were identical. Was the weather at Wuya in fact so uniform or were these precontract predictions rather than site records? Monthly records of relative humidity and temperature would enhance the value of the Paper. The programme showed that most of the concreting took place during the dry season. During the harmattan, the humidity was generally very low. Was the high humidity mentioned in § 19 restricted to the vicinity of the river? The point was by no means trivial since the problems of concreting in hot wet and hot dry climates were certainly not identical.

165. With regard to the high-strength concrete mixes, were any attempts made to

design a suitable 6500 lb/sq. in. concrete with the available river gravel or, alternatively, with a mixture of river gravel and crushed stone? The advantages gained in respect of workability might well have outweighed the sacrifice in the strength of the aggregate. Further details of the method used for estimating the variation in water content with relative humidity and temperature would be of interest. Was any consideration given to concreting at night or, alternatively, to roofing over the whole area used for the storage of materials, concrete mixing and casting of the beams?

166. While the Author's claim that this was the first time that a 6500 lb/sq. in. minimum strength concrete had been used in Nigeria was probably correct, he had reservations about the wisdom of specifying such a mix in the prevailing conditions. The development of prestressed concrete in Nigeria had certainly not been as slow as § 83 might lead one to believe. There had long been a factory manufacturing precast prestressed concrete products at Abeokuta, and to give only one example, a large tobacco factory in Ibadan, completed in 1961, was roofed by continuous prestressed concrete cylindrical shells.

167. If the Author had the opportunity to start this job again from scratch, what alterations to the design and method of construction would he require?

Mr E. S. Armitage (Department of Civil Engineering, Queen's College, Dundee) wrote that the construction of the Wuya bridge, which required extremely high standards of quality control on a relatively inaccessible site in a climate of extreme heat, represented a civil engineering work of considerable skill and ingenuity. No doubt there were major problems in obtaining and maintaining supplies throughout, particularly in the seasons of flood, and a few comments upon the transport arrangements would have been interesting.

169. In § 7 it was mentioned that the eastern bank was currently being eroded, yet the abutment, of open type and consequently less likely to protect the approaches from erosion by the river flow, was placed at the bank. Were there reasons to suppose that the bank had greater stability here than at other parts of the river bed? It was to be hoped that the training works would prove to be wholly effective, but from some experience of Northern Nigerian rivers which meandered in a wide sandy bed Mr Armitage suggested this was somewhat optimistic. Perhaps it was outside the scope of both contract and Paper, but a plan showing the layout of training works relative to the bridge would have been instructive.

170. The approach roads were described as 2½ miles long constructed on a high embankment. With such a wide flood plain possibilities of meander were endless and one wondered if any provision was made within this length for flood relief. This question might be linked with the bridge length of 1470 ft when compared with the width of the river in flood. Would the Author comment?

171. The problems of manufacturing high-quality concrete were well described and the Author properly drew attention to the importance of trial mixes. Considerable effort was involved in obtaining supplies of high-quality aggregates and it would be interesting to know what aggregate crushing values were obtained for the Zungeru granites. Some of these fine grained granites had been known to be rather brittle. From possibly inaccurate memories of the river bed sands at the bridge site, Mr Armitage thought they showed rather a high degree of coarseness, and were not entirely suitable for the concrete of the beams. A typical grading curve of the aggregates used for the concrete of these beams would be appreciated.

172. The Author described, in § 73, that painting the water-tanks, beam moulds, and concrete skips white and erecting sunshades over the batching plant had the effect of producing an immediate improvement in the concrete strength. These observations would seem to suggest that the difficulty of attaining high-strength concrete in tropical conditions might be related only to the temperature during mixing, placing and setting, and not to the temperature in the subsequent hardening. Consequently, it would be interesting to know if any concrete was placed at night when temperatures might have been, say, 30°F below those of daytime.

173. Ridley[7] had described the improvements in concrete strengths of very similar mix proportions (1:1·34:2·46 compared with 1:1·33:2·66 at Wuya) attainable by the addition of flaked calcium chloride. Was consideration given to this additive in the production of the beams? In view of the fact that it did not appear to have been used, were there any reported disadvantages?

174. Finally, Mr Armitage wished to record his respect for the admirable system evolved for the launching of these heavy beams into bridge.

Mr S. B. Patel (Consulting Engineer, Bombay) wrote that the Author had mentioned in §§ 72 and 73 that concrete strengths improved immediately when the concrete equipment was painted white and the batching plant shaded. Could the Author provide figures indicating the degree of improvement resulting from this procedure? Were air-entraining or water-reducing agents tried at any time in establishing the concrete mixes?

The Author, in reply, thanked all those who had taken part in the discussion; the contributions from the speakers added very considerably to the value of the Paper.

177. Mr Wex and Mr Herbstein had asked about the function of the steel shells in constructing the piles. From the point of view of construction it would have been difficult to complete the holes without some sort of support at the upper part of the excavation. The upper layers of sand in the river bed were disturbed every year by the floods, and the sand was redeposited during the dry season. The layers were therefore extremely unstable, and the shells were a great help in enabling the excavations to be completed. The reason that the shells did not continue to the full depth of the excavation was to meet the Consulting Engineers' requirement that the lower 14 or 15 ft of pile should be left uncased, as the surface friction over this length was necessary to enable the piles to develop their full resistance to load.

178. Although the steel tube prevented the collapse of the upper layers of sand into the excavation, there were found to be lenses of sand in the older sediments surrounding the 14 ft of uncased pile, and it was therefore necessary to complete the lower part of the excavation also with the use of bentonite. The preliminary subsoil investigation had given warning of the difficulties likely to be encountered. It was however the degree of difficulty that had not been foreseen, as previous experience had shown that bentonite was successful in stabilizing excavations in loose material. As Mr Serota had remarked, every job has its surprises.

179. The Author was unable to give Mr Herbstein details of the scope of the site investigation or its cost, as these fell outside the scope of the contract on which the Author was engaged. The strata were not level across the site and pile lengths varied by up to 10 ft.

180. The founding stratum was as described: 'sandy silty clay, cemented to a very hard consistency'. Core samples recovered from the bottoms of excavations looked similar to soft sandstone, and were of similar hardness to sandstone. It was found that the sample disintegrated on immersion in water, and the Consulting Engineers insisted that pile concreting had to be begun within one hour of completing the drilling. The foundation design was the responsibility of the Consultants but based on a method proposed by the Contractors.

181. The question of bentonite adhering to the steel reinforcement was not overlooked. The concrete scoured the mud from the surface of the steel as it rose up the excavation from the bottom of the tremie. To ensure that the pile contained only clean concrete, the pile casing was left about 6 ft too high, the concrete was allowed to flush out over the top, and the surplus concrete was dug out to the correct level while still fluid. The excess tube length was subsequently cut off. Inspection at the surface showed that in every case the steel and concrete were in direct contact and there was no reason to believe that this was not so over the full length of the pile.

182. The shells were fabricated from imported steel sheet by Messrs Dorman Long

and Amalgamated Engineering Limited in Lagos. The Consulting Engineers allowed the diameters to be varied very slightly in order that the tubes could be slipped one inside the other, and the nesting assisted in transporting them to site. They were sent by rail to Zungeru station and transported the 75 miles from there to site by road.

183. The steel liners were not designed to take any of the bending in the cylinders.

184. The taking of the sideways forces in bending rather than in direct thrust, i.e. not raking the piles, should not present much of a problem if the rake was of a reasonable amount. The rake of 1:6 was not a problem after initial difficulties. There was no arrangement of a pile that could remove the bending. Whether it was better to take it all in bending and not to rake at all would involve the economics of the design.

185. The steel shells were left in during concreting in order to ensure that the cylinder was full of concrete and not of sands and gravels. In the circumstances of the job, it would have been an added difficulty for the Contractor to have removed the lining. The concrete went off very quickly, and it would have been necessary to pull it at the same time as concreting; he could not have left it until the whole cylinder was finished.

186. Mr Samuel hoped that the queries raised by Mr Herbstein and Mr Armitage regarding scour, river channel width, and embankment protection, were largely answered by his introductory remarks on the river training works, and by Mr McDermott's and Mr Ackers's contributions to the discussion.

187. Although the river overflowed its banks in full flood and so extended over a width of more than 2 miles, the main channel, approximately ¼ mile wide, still provided the bulk of the flow capacity. A careful analysis of the required waterway at the bridge had been done at the Hydraulics Research Station in Wallingford, U.K.

188. The completed west guide bank was shown in Fig. 14. The pitching extended under the water almost to the first pier and the extent of the excavation in the west sand bank could be clearly seen.

189. Turning to Mr Lindsay's and Mr Herbstein's comments on labour and staff, it was difficult to find skilled craftsmen indigenous to the Bida area and although an attempt was made to recruit as many artisans of Northern Nigerian origin as possible, many of the skilled workers originated from the southern part of the country. The

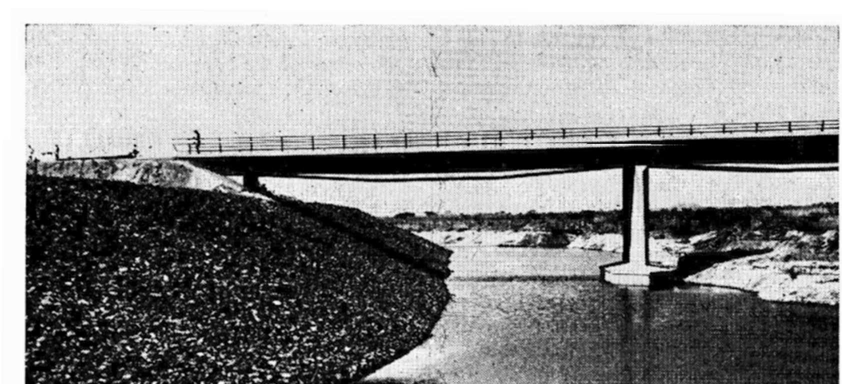

FIG. 14: WEST GUIDE BANK

project employed about 350 people at peak when the river training works and bridge were under construction.

190. The maximum number of expatriate personnel employed by the Contractors was 13. This figure excluded the American staff and drill rig crews employed by the piling subcontractor.

191. The joint venture between a Nigerian contractor, Alhaji Audu Bida, and a locally registered expatriate company, Costain (West Africa) Ltd enabled the indigenous contractor to participate in the execution of projects which would otherwise have been beyond his normal scope. The pooling of financial resources and the combination of local knowledge with imported technical and management expertise produced an organization well equipped to undertake large projects in Nigeria, and many such jobs had been successfully undertaken in this manner. That there were no trade secrets in the joint venture construction methods was evidenced by the publication of the Paper.

192. In reply to Mr Armitage's remarks on the high strength concrete, Fig. 15 showed typical grading curves for the beam concrete aggregate. Aggregate crushing values of the order of 20% were obtained from the Zungeru granite. The Author agreed with Mr Armitage that the Kaduna River sand was rather coarse at Wuya, although deposits at different sand banks showed some variation. It was a case of making the best of the materials available, and only the production of trial mixes could give the answer.

193. Mr Armitage and Mr Patel had asked about the improvement in concrete strengths after the concrete mixing and handling equipment had been painted white. The Author leant towards the view that the temperature at which concrete was mixed and placed was more significant than the temperature during subsequent curing as far as concreting in hot weather at Wuya was concerned. Possibly this was because a significant quantity of water was evaporated from the mixer drum in the hot weather,

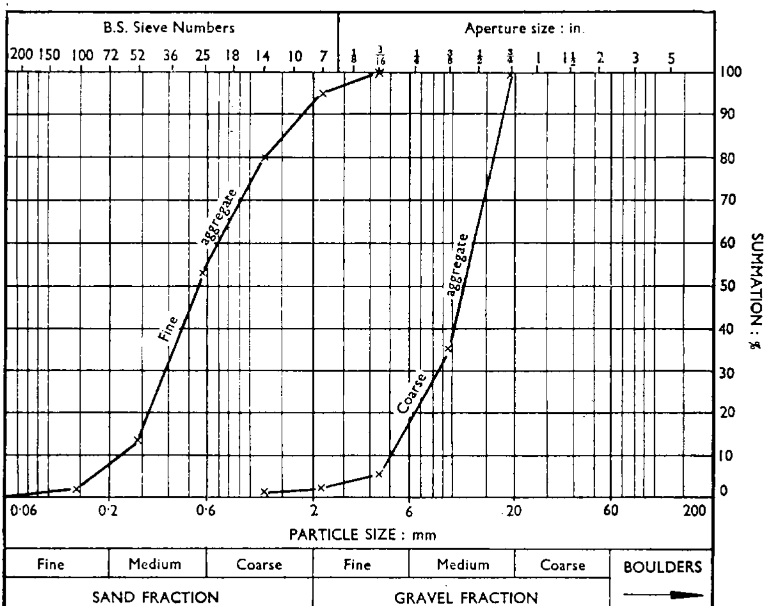

FIG. 15: PARTICLE SIZE DISTRIBUTION

and the amount of water needed in compensation, to maintain a given degree of workability, lowered the concrete strength. The very high strength concrete was not placed at night, although this was considered.

194. Much consideration was also given to the use of calcium chloride and Mr Ridley's paper on this subject[7] was studied carefully. The Consulting Engineers were not in favour of using calcium chloride, however, on the grounds that it encouraged the corrosion of reinforcement. Various other additives were tried in the experimental stages, but their effect was negligible and the Contractors did not persevere in their use. Fortunately the problem was overcome by keeping the concrete 'cool' during mixing, and strengths improved from around 8500 lb/sq. in. to 9000 lb/sq. in., and ultimately to 10 000 lb/sq. in., the last figure being reached when experience had been gained in producing and placing very uniform mixes of low workability.

195. Reference was made in § 19 to high humidity. This should be taken as a relative term as the climate in the north of Nigeria was generally dry. The Bida area was, however, more humid than some northern provinces, and this was particularly true at Wuya. The Author would describe the climate as being generally hot dry, rather than hot wet.

196. Graphs of water content in the mix against ambient temperature and against humidity were plotted during beam concreting. Using these graphs for subsequent pours it was possible to predict the amount of water to be added at the mixer for a given temperature. Acting on this prediction obviated the rejection of concrete which might otherwise have failed to meet the compaction factor requirements.

197. The weather details given in Appendix 3 of the Paper were average figures obtained from meteorological office records, and were used in planning the works. Actual weather conditions were of course recorded at site.

198. The cost analysis requested by Mr Herbstein was as follows:

	£
General items (R.E. offices, housing, furniture, laboratory survey instruments, etc.)	42 500
Site clearance and demolitions	3 300
Approach roads	125 000
Piling	432 800
Pile caps and piers	102 900
Beams and deck	388 400
Total bridge and approaches	1 094 900
River training works	441 500
Variation in price: Labour	7 000
,, ,, ,, : Materials	800
Total contract cost	1 544 200

199. Finally, in reply to Mr Herbstein's last query, the Author was pleased to record that Alhaji Audu Bida and Costain (West Africa) Ltd had been awarded a contract to construct the piers and superstructure to a shorter, but otherwise identical bridge over the Gongola River in Northern Nigeria, and no alterations to the method of construction were contemplated.

References

5. Hydraulics Research Station. *Hydraulics research, 1963.* London, H.M.S.O., 1964.
6. Ackers P. A study of the effects of flood hydrographs in training works in the meandering Kaduna river. *Proc. 11th Cong. int. Ass. Hydr. Res.*, Leningrad, 1965 (in press).
7. Ridley T. Investigation into the manufacture of high-strength concrete in a tropical climate. *Proc. Instn civ. Engrs*, 1959, **13** (May) 21–34.