*Discussion on Paper 6802**

Bridgeworks in the new town of Cumbernauld

by

B. J. Allan, A.M.I.C.E.

Mr C. T. Wyatt (Chief Engineer, Richard Costain (Civil Engineering) Ltd) congratulated the Author on his Paper and on the work described in it. He thought that the Author had raised two issues which went beyond the technical and engineering details of the structures themselves. Great Britain was in a situation of economic difficulty, and a steady growth in the economy was needed even if there were now doubts about reaching a full 4%. Earlier in the year the civil engineering and building industries had been told by N.E.D.C. that they would be incapable of meeting the kind of growth which was required for the national rate at which we were aiming, and that could only be disproved if the industries set about their work in the right way. Growth depended on productivity, which in turn depended as much on design as on the way the contractors went about the work on site.

90. One of the controlling factors in the amount of work which could be done the previous year had been the number of carpenters available. Mr Wyatt's firm was working on a number of motorway contracts, which included in situ bridges, some of which, being complicated, threw heavy demands on the number of carpenters. In the kind of design which the Author had prepared for the bridges at Cumbernauld, this problem was apparently being met. Mr Wyatt felt that in addition to the normal factors of design, such as meeting the loading specification and the cost, there was a need to look at the restrictions on total productivity.

91. In order to meet present needs it was important not to look only at economy. The cheapest engineering solution at a given time might not necessarily be the answer. What they built was built to last. The structures which were built would be there for a long time. It was important that they should not stand as a blot on the landscape for 40 or 50 years.

92. It had been a criticism of some precast structures that they were perhaps a little more awkward in appearance than some which had been created in situ. The designs in the Paper were a refutation of this argument, being elegant and visually attractive.

93. Mr Wyatt's first question concerned columns. He had thought that the precasting of columns to such a height and their transport to a site for erection was hardly economic compared with in situ work. An in situ column could be concreted to full height, and the form-work stripped and re-erected the following day. There was no great cost involved in erection and handling. Would the Author give more information on the handling arrangements for the columns and the beams? Were any special arrangements made for slinging? Were the cranes designed specially for careful handling? Was the Author convinced that the precast columns were more economic than the in situ?

94. His second question concerned the transoms to the piers, which were recessed into the deck, presumably to improve the aesthetic or visual appearance. This effect was achieved. Did the Author consider that the provision of transoms within the thickness of the deck involved any extra cost compared with providing a cap to the column?

* *Proc. Instn civ. Engrs*, vol. 29, November 1964, pp. 497–534.

95. Thirdly, from a design point of view, had there been a resulting increase in thickness of the deck through using precast beams instead of in situ, which, in a work associated with embankments and roadways, would lead to increases in embankment height, and thus to increases in cost outside the bridge structure itself?

Mr W. E. J. Budgen (W. E. J. Budgen and Partners) said that the Author had given the meeting a paper full of valuable information which provided much food for thought.

97. He, too, emphasized the wide approach to the problem, including not only the structural aspects but traffic engineering, economic considerations, and aesthetics. Aesthetics was a very dangerous word for an engineer because a pleasing appearance in a structure was not only, or not even, a question of correct structural design. It followed from a conscious choice of form and line, and unfortunately very few engineers had any training to enable them to make that conscious choice.

98. It was also interesting to note the changes of fashion in aesthetics. If some of the older members referred to Figs 19 and 20 they would remember the controversy over the alternative design by an eminent engineer for the failing Waterloo Bridge. One of the milder comments had been that it was a lot of planks laid on drain pipes. Yet the Author claimed twice in his Paper that one advantage of his design was the aesthetically pleasing and clean penetration of the column head into the deck without any protrusion. Many people would agree with this claim, but Mr Budgen had never found this aesthetically satisfactory. He had always regarded it as a weak point in the structure. This was probably because he had been brought up on columns and caps.

99. The use of precasting was a contentious question and a very difficult matter for an engineer to decide only on grounds of economy. There was a great deal of false thinking on this subject; much of the so-called economy in precasting arose from the discipline which was necessary to achieve the repetitive element. Often, if that discipline were accepted in an in situ structure, the same sort of economy could be achieved. He had rarely found it economic to precast columns. Apart from the question of economy, the difficulty of erecting precast columns and connecting them to their bases was serious.

100. The Author's solution to this seemed very simple. Mr Budgen was not certain whether he fully understood it, but he would have expected considerable trouble in welding the plates to the bars to ensure that the plate was at right angles to the axis of the column. Not only was it important to ensure that it was at right angles when it left the works, but if it were dropped slightly on to those rails, on one edge, there might be some trouble.

101. He was not clear whether the bars had been designed to take the whole load which was then transferred by the plate to the rails. Nor was he clear how the Author had ensured good contact between the ordinary concrete in the base and the soffit of precast column shaft.

102. There was a suggestion in Fig. 4 that the bottom of the column was cone shaped, but this did not seem to be so from the photographs of the casting of the column. He thought that with a 24 in. dia. rough concrete surface there was danger of air being trapped in the centre when the base was concreted.

103. Another point of interest in connexion with the columns was the detail at the top, where the shuttering for the in situ transoms joined with the precast columns. This must have been tricky and he wondered how the Author had solved the problem of preventing the in situ concrete from dribbling down.

104. In § 23 the Author stated that the concreting in the precast column showed a 28-day strength in excess of 6000 lb/sq. in. This had been subsequently confirmed by a non-destructive test on actual columns. He would like more information on that test.

105. In §§ 37 and 38 the mix of the normal concrete was not given, but it was

stated to have attained a strength of 7000 lb/sq. in. after seven days of normal curing. This was a very high result, and he wondered whether 'seven-day' was a misprint for '28-day'. If not, could the Author state what 28-day strength had been achieved subsequently. It would also be interesting to know whether he had obtained these results consistently. If so, in Mr Budgen's experience, this would be a very unusual occurrence. It had recently been stated that even with very good site control, there would be very wide variations in cube strength and that possibly 50% of these variations arose from matters over which the site had no control, such as cement. They had been told that there were differences of 1000 lb/sq. in. arising from a difference in the testing machine used. Did the Author obtain his high results consistently?

Mr J. W. A. Ager (Director, Costain Concrete Co. Ltd), in congratulating the Author, said that although the Author claimed that the structures were relatively small in a few of the bridge works, nevertheless this type of structure made up a very large proportion of the bridge work which was required in a country such as Gt Britain where most crossings were relatively small in length and there were no large rivers. He was to be congratulated on trying to push a little further the development of precast techniques in the construction of such bridges. In particular, he congratulated the Author on dealing with the horizontal and vertical curvature in bridge decks with precast elements. At the same time, he thought that in some cases it might have been better to use in situ concrete instead of precast concrete to form some of the external curves in the structures.

107. The choice of the precast column had been particularly good. He thought that the columns were pleasing structures and he even went as far as to suggest that an architect had given the Author a lead on their proportions. The result had been very pleasant looking structures.

108. He was reminded of some other bridges which had been built in situ and had columns of circular section, but which were not as attractive as the examples the Author had shown.

109. In these structures the Author had included precast beams and precast columns for the piers. Why had he not gone a little further? Was he contemplating going so far in the future as to include precast abutments? In most of the bridges shown, the Author had used open-type abutments, but clearly there were a number of cases in which closed abutments in tight situations were required, and it seemed that the precast techniques could be applied to these cases.

110. In fact another precast development which also took place in Scotland, by the Scottish Development Department, had led to the use of hollow precast blocks about 7 ft long, 3 ft 6 in. wide, and 3 ft deep for the construction of such abutments.

111. The Author had mentioned the value of having standard precast concrete columns produced nationally and held nationally. Was the Author thinking of having these precastings held in stock in particular lengths? In that event, would he not rather consider the block type of standard unit which could be erected rapidly and prestressed or grouted together on site to form the required height of column? Might not this be another line of approach?

112. In §§ 19 and 20 the Author stated that the adoption of these precast techniques for bridges and piers might reduce the cost of the project as a whole as well as the time of completion. Did he feel that these hopes had been realized? Had they been realized to such an extent that they gave him faith to go ahead with further developments of precasting techniques for bridges of this type in the future?

113. How had the concrete strength, referred to in § 23, been checked? He, too, wondered whether it had been confirmation of strength or confirmation of the method of test.

114. In §§ 24 to 26 the Author stated that the erection of a pier had taken half a day while the programme had allowed five days to carry out this work. This seemed

to be an error of ten times in the labour and plant involved in that operation, and showed how inaccurate estimating could be and how it must sometimes cause potentially good ideas to be rejected at the estimating stage.

115. In § 36 the Author had mentioned that the average beam took 10 to 15 min. to erect. How had that time compared with the time allowed for the operation in the estimates?

116. Had the Author any suggestions as to how one might produce estimates for new types of operation which closely approximated to what they actually ultimately cost?

117. In § 40 the Author mentioned the torsional stability of the beams and made the point that this torsional stability had produced no warping or twisting of beams as was so often noticed in standard beams. In this instance, did he mean warping or twisting or hogging? To which type of standard beam was he referring? In other cases—§§ 30, 40, and 50—reference was made to standard precast beams. Was that a particular type of standard beam, the well known P.C.D.G. design, a Cumbernauld standard design, or the manufacturer's standard design?

Mr A. D. Holland (Ministry of Transport) congratulated the Author on an interesting Paper and on his magnificent coloured slides, which perhaps designedly, had in most cases shown his structures to the best possible advantage.

119. One of the major points which arose from the Paper concerned increased productivity in bridge construction, which was tied directly to economy in the use of site labour. Experience so far had shown that economy in site labour by the use of prefabrication did not automatically lead to a saving; quite often it led to an increase in cost. Apart however from the speeding up of construction which this method permitted, there was also a likelihood of increasing shortage of skilled labour, such as carpenters and joiners. If skilled craftsmen were scarce, we might have to pay a price to economize in their use.

120. At the same time funds for road construction were limited, and the greater the cost of individual projects the fewer could be started. The cost of structures had to be watched closely.

121. In Appendix 1, the Author gave figures showing that in 1962 the contract rate per square foot of deck area had ranged from £5 18*s*. to £6 10*s*. He would probably agree that they were scarcely keen prices for that type of structure. Was he able to speak of his experience of the use of composite construction? Had he investigated the ruling prices for this in his part of the world, because in this way a form of prefabrication could be provided? In situ concrete was being used in any case in the prestressed concrete decks. If one used steel joists with reinforced concrete, support would be available for the shutters, whether temporary or permanent, and a deck of this sort should go a long way in cutting down on site labour.

122. The columns—fluted or textured—were elegant in proportion and spacing, and the choice of a circular section was sensible for structures curved in plan. Possibly the Author's enthusiasm for a flush soffit had somewhat tended to carry him away. It seemed that the flush transom had led the Author into difficulties. He had been obliged to design the beam with stepped ends, and had found it more costly than standard beams. Visually, the double-interruption of the fascia over the columns was not very attractive. It also seemed that the use of a transom and stepped-end beams in the Braehead bridges meant a different type of beam for each of the four spans and eight different edge beams. If the Author had used a capping beam and standard deck beams with a single butt joint, it was probable that the variations in the Braehead bridge could have been cut by half, and the appearance could have been improved. The interruptions in the fascia would have been reduced. As far as could be seen, the headroom was fairly generous, although this was not dimensioned on any drawings; it was certainly over 16 ft 6 in., and there was therefore space to accommodate a well-designed capped beam.

123. Mr Holland did not share the Author's doubts, expressed in § 33, about the ability of a 1⅛ in. dia. bar to develop the required bond for transverse moment. He had calculated that there was ample anchorage length, but he agreed with the Author that it was far more sensible to use two ¾-in. bars or three ⅝-in. bars. This led to easier handling, placing, and lapping.

124. In § 40 mention was made of warping and twisting. Was the Author referring to the Prestressed Concrete Development Group standard beams? The Author had implied that it was a design fault. If he meant the P.C.D.G. beam, was it a defect at the production end?

125. It seemed from § 50 that the Author was prepared to consider their use in the future. It would be of interest if the Author could expand his comments on the beams.

126. In §§ 45 to 47 the Author discussed the bridge barrier rail. It was not clear from the Paper where this was located. If it were intended to serve as a parapet to the bridge, he was then trying to marry a flexible barrier with a semi-rigid grid, which seemed a contradiction in terms. The function of a flexible barrier was to yield, and it must have enough freedom for that flexing to operate. The grid, on the other hand, would not of itself contain vehicles because it was not designed to do so.

127. In view of the care and attention which the Author had paid throughout the Paper to appearance, it seemed from the slides, that it would be worthwhile to arrange the placing of the parapet verticals so as to synchronize with the centres of the columns. In some of the slides they had appeared to be out of phase.

128. In Appendix 1 the Author had given a 1963 quotation for the columns. Presumably they were suppliers' quotations and for a true comparison with earlier rates it was necessary to add a general contractor's on-cost. Would the Author confirm that?

129. Fig. 4(a) included a table showing four different heights for these columns varying between 18 ft 8½ in. and 20 ft 5¼ in. It would be interesting to know what these variations cost. The Author had placed an emphasis on industrialization and standardization. Could he not rationalize the column heights?

Mr W. T. F. Austin (Messrs Freeman, Fox & Partners) said that he had read the Paper with considerable interest, particularly the references to four-span bridges, one of the most common types of bridge built in Gt Britain today. His firm had built dozens, and he agreed entirely with the Author's view that the bridges sitting direct on columns could look neat and pleasant. So far, however, his firm had not produced them in the way adopted by the Author and it was interesting to draw comparisons.

131. His work had been more with in situ reinforced concrete, and in comparing costs reinforced in situ work was much cheaper. He had checked costs on four different contracts for motorway bridges. The conditions when building rural motorways were rather different from those in the new towns. The final figures were £3·83, £3·93, and £4·10 per sq. ft—and the prices per sq. ft could vary considerably for the same item. Some final prices still had to be fixed, but the estimate was not bad. It was based on an area of the distance between parapets for width and the distance between faces of abutments for length. An allowance was included for a share of the general items. The prices therefore seemed to be considerably cheaper.

132. It was agreed that there was a shortage of carpenters. The skill and application to detail of some of the carpenters did not match such qualities found in contractors' quantity surveyors, and perfect finishes could not always be expected. In precast work, if the concrete finish on a particular member was not satisfactory it was hidden inside the structure and not used for the end column, or it was taken away. But it required great courage to make a man knock down in situ work, including the deck of the bridge.

133. Concerning appearance, rough board form work had been used by the Author. One question was how to touch up any blemishes.

134. Mention had been made of casting the concrete columns to full height. On an early contract Mr Austin had used in situ concrete. It was not imperative that the columns be cast to full height and in a few cases the contractors had produced a perfect looking column, but in others it had been possible to see where the horizontal construction joints had been made. In later contracts they had insisted on casting to full height and there had been no difficulty.

135. A great value of precasting was the ability to build over existing traffic. In the construction of the Maidstone by-pass, he was surprised to see the contractor precasting beams actually over the railway line and lowering them 2 ft into the final position. This had made him wonder whether precasting over a railway line was necessary.

136. The design of the in situ bridges on the M2 and on a motorway in Northern Ireland was such that columns could have been precast if the contractors had wished. They had been planned as in situ columns but with a little modification could be precast and erected in position. None of the contractors of the four contracts had expressed any keen desire to do this—which suggested a moral.

137. His firm had found that in a bridge about 33 ft wide, three columns could be placed across the width by in situ reinforced construction, whereas the Author had provided five because he had to combine all the transverse strength into the width of the transoms. The Author was looking for ways and means of saving money. Could he not obtain the same advantages which Mr Austin's firm had obtained in having a big width of deck by widening the transoms and increasing the spaces in the columns to 11–12 ft? This was possible and it tended to reduce the forest of columns.

138. The Author had given prices for underpasses, including £4500 for an 8 ft multi-plate steel arch, and £4800 for a reinforced concrete portal underpass. The difference was only £300. Was there some special explanation for this? Was it not cheaper in the long run to adopt the reinforced concrete portal?

139. It was of interest to note that in situ slab overbridges could normally be constructed in 3 to 4 months so they should not delay earthworks unduly, particularly as construction traffic could be passed under them by arranging suitable openings in the falsework.

Mr P. S. A. Berridge (Donovan H. Lee & Partners) recalling his experience on British Railways said the policy on the Western Region had been to make as much use as possible of prestressed concrete units precast in the makers' works. Although restricted line occupation often prevented the pouring of concrete for bridge superstructures on site, the true advantage of depot work lay in the better facilities for quality control and supervision.

141. A reference to the use of reinforced concrete for bridges prompted him to say that past experience with simply supported spans, particularly on the old East Coast route, had been so bad that orders had been issued discouraging the use of reinforced concrete over steam-operated lines. It seemed inevitable that the concrete on the soffit of an R.C. beam would crack due to the tension induced under a rolling load, and although such cracks might be very small they did lead to spalling and ultimately to a renewal of the structure after a surprisingly short life. The present policy was to insist on prestressed concrete for such spans.

142. Turning to Fig. 4(b), he drew attention to the notching shown in the elevation of the end block of the beam. Although this seemed to have been done so that the capping beam could be contained within the depth of the bridge beams for appearance sake, it was not good practice because the re-entrant angle introduced a weakness through the high concentration of stress so near the bearing.

143. Finally he asked if there had been any trouble in keeping the joints between the ends of abutting spans watertight. It often proved difficult to prevent leakage at such places, and nothing detracted more from the appearance of an otherwise pleasing bridge than the stains caused by water streaking down the piers and abutments.

Mr D. B. Scott (Costain Concrete Co.) complimented the Author on the pleasing lines of the structures and stated that in Scotland there had been a good deal of favourable comment on the pleasing appearance of the bridges at Cumbernauld.

145. Mr Scott felt that a number of engineers would be interested in the free fall of concrete from a height of 24 ft and he wondered if Mr Allen would give his opinion on the limit of this technique. Although the design of the concrete mix and the opportunity of placing the concrete in the centre of the mould so that the reinforcement did not obstruct the passage of the concrete were important factors, the critical limit to the length of the column was probably set by the ability of the operator to control the internal vibrator.

146. The edge beams were three or four times the weight of the internal beams. In view of the fact that the deck was also prestressed transversely could the size of the edge beams have been reduced in order to permit the use of smaller capacity cranes on site? Mr Scott suggested that the significant percentage of unstressed longitudinal steel, which was presumably required to satisfy ultimate requirements, contributed to the torsional stability of the units referred to by the Author.

147. With composite construction, stirrups usually projected from the top surface of the precast beams. It was not so in the case of the Cumbernauld units and therefore it was to be assumed that the concrete above the precast elements was not considered to be structural so far as the design was concerned. Could economies in design have been derived by considering the structural contribution of the concrete above the top of the beams?

148. With reference to points made by a previous speaker, Mr Scott confirmed that the welding of the plates to the reinforcement projecting from the base of the columns presented no difficulty to the manufacturer of pre-cast. Major variations in column length were accomplished by adding or removing a length of steel mould. Smaller adjustments were made by adjusting the position of the timber strap forming the check at the top of the column.

Dr K. Hajnal-Kónyi (Consulting Engineer), in congratulating the Author, said that the illustrations of the tests carried out on one of the beams were interesting. In Fig. 10 there were already cracks in the topping. This was stage 1. Stage 3 showed much further deterioration. He wondered whether the maximum load had not been reached at stage 1 and, if not, what increase of load could be achieved. Further, it would be interesting to know the factor of safety which had been found in the beam as against the design load. The Author had mentioned the use of mild steel in § 50. Why had he not suggested high tensile deformed bars instead of mild steel? Presumably that would be a saving and it would improve the bond—and the Author had emphasized in § 33 the importance of good bond.

150. In § 43 the Author said that he expected further savings by more prefabrication and less in situ work. The cross section of the beam in Fig. 3(c) was an ideal cross section combining precast and in situ work, and resulting in a monolithic body. If the in situ topping were omitted, the monolithic action would be lost. The Author said that he had found it necessary to prestress transversely, but later he said that this might be omitted. With an in situ compression flange, transverse prestressing was unnecessary, and it did not improve the efficiency of the structure.

151. It was not clear whether the spans were simply supported or continuous. Apparently they were simply supported. Why had not the Author considered the possibility of providing some non-tensioned reinforcement over the supports, so as

to obtain a structure acting as simply supported for dead load and as continuous for live load?

Mr O. A. Kerensky (Partner, Freeman, Fox & Partners) reminded the meeting of an earlier discussion on the Hyde Park Corner Scheme*, because out of this arose a comment in connexion with § 57 of the Paper which suggested that the Author had adopted a rough unlined finish to the underpasses in the middle of a busy new town. How did this as-cast concrete finish look after a few years? Was any nuisance committed on it, such as unpleasant writings and drawings, or chipping? Could it be washed and cleaned regularly?

153. He was in favour of as-cast finishes because a great deal of money was spent on lining and decorating underpasses which was not appreciated by the public who were usually in too much of a hurry even to notice the decorations.

154. The discussion about precast and in situ work was of considerable concern to all engaged in developing economic structures. Theoretically he was in favour of precasting whenever possible, but so far this did not prove to be economic in ordinary circumstances, i.e. when height or traffic were not involved.

155. Recently he had had circular columns cast in situ on four contracts, and in each case the contractor could have adopted precasting. Full height columns were cast in tubes on one site, which involved no carpentry. A steel shutter had been used on another site, again involving no carpentry. On yet another site a carpenter-shop-made timber shutter had been used.

156. In all of these cases the prefabricated shutters were used many times. He relied on the contractor's judgment and knowledge which was the cheapest way of doing the work.

157. A previous speaker had indicated that he did not trust reinforced concrete. Perhaps the concrete in the particular railway over-bridges built in the 20's and 30's had been bad. Modern concrete with low water-cement ratio, appropriate vibration and correctly designed and located reinforcement, which controlled the size of cracks, should be entirely satisfactory. In good designs the cracks were minute and the moisture did not penetrate to the steel. Such reinforced concrete should last nearly as long as prestressed concrete. Also, it should be realized that although prestressed concrete usually had no cracks across the prestressing tendons, there could be cracks parallel to them unless it was prestressed in two directions, which was very expensive.

158. Possibly shop-made concrete could be of better quality than that made on site, but ought they to strive for something better than good? He agreed with the Author that, with the number of bridges to be built, price should control design to a very considerable extent, provided that the result was durable and did not offend the eye.

159. An additional 25% on the initial cost of a bridge would, if deposited at 5% compound interest, pay for another such bridge in about 30 years' time and he wondered if in some circumstances one should not design for less than eternity.

The following contributions were received in writing:

Mr T. A. O'Neill (Davy and United Engineering Co. Ltd) wrote on a point he felt might be taken into account in precast concrete work. Referring to the mention of classical Greek columns in § 22, he suggested that precast columns might be shaped with a slight thickening up to four or five feet from the base and tapering off to the top, as the Greeks had done.

Mr R. W. Buchanan (James Williamson and Partners) referred to the comparative costs quoted in Appendix 2 for three types of pedestrian underpass. It appeared

* *Papers published October 1964, discussion in press.*

from these that a reinforced concrete underpass of the portal type could be provided at less cost than one of the multi-plate arch type. If this were in fact the case, it was difficult to see any justification, apart perhaps from speed of erection, for persisting with the multiplate type, which was certainly most unattractive to the pedestrian. Indeed, the additional cost of forming all the underpasses with three span reinforced concrete frames could hardly have been grudged in a New Town where so much emphasis was placed on the aesthetic appeal of its structures.

162. The Author was to be commended on giving such full information on all aspects of the work under his charge. The cost data was of particular value to those, such as Mr Buchanan, who had no specialized knowledge of bridgeworks, and to whom such information was not always readily available.

Mr P. C. Edwards (Design Engineer, Harris and Sutherland, Ltd) wrote that the Paper was of great interest in that it presented a clear example of two quite different aspects of urban motorway construction.

164. Cumbernauld was the only town in Britain designed for complete penetration by the motor vehicle in such a way that it could still exist as a working community, an example of the logical extreme postulated in the Buchanan report. It demonstrated a solution that could never be applied to a large town, and the illustrations had shown most clearly the immense scale of the roadworks (compared to the dwelling area) required for such a solution.

165. Cumbernauld had provided, not a model for the development of existing town roads, but developments in bridge construction that could have a universal application. Most speakers appeared to dispute this, at least if prefabrication was to be carried to the lengths suggested.

166. He wished to illustrate what he believed to be the main point of the Author's case by quoting the example of a typical urban motorway project in the home counties involving in situ bridge piers and abutments. Several major firms submitted tenders for the whole of the works. The contract was, however, let to a 'joint venture', bridge works being carried out by the lowest tenderer, earthworks and roadworks by another firm in association with, and presumably at the rates quoted by, the successful tenderer. The whole organization was under a joint project manager.

167. The dislocation of local urban traffic even during the opening phases of the work was quite serious; during later phases it was occasionally spectacular enough to be featured in newspaper reports. The works of the roadwork contractor alone, without this added complication, were quite sufficient to cause headaches for the bridge contractor.

168. He would be interested to know how the profits were divided and whether the actual cost of the bridgeworks to the Contractor were comparable with the amount paid to him by the client against bridgework items in the bill of quantities.

169. In how many cases were the true costs of urban motorway bridges and associated diversion works covered by inflated rates for roads and earthworks, or by a relaxation of the specifications for the materials and workmanship on the roads and earthworks, resulting in the high maintenance costs that appeared to be inseparable from motorway construction today? Perhaps it might not be out of place to reflect also upon the contractor's claims for delays which inevitably seemed to follow the construction of in situ concrete motorway bridgeworks.

170. Looked at in this light, he felt that Mr Allan's contention that overall rather than itemized costs should be considered, had some force.

Mr W. K. Mackay (Partner, Messrs Jamieson and Mackay) said that Mr Allan's stimulating Paper emphasized the recognition, in Cumbernauld, of the extent of interaction between roadworks and bridgeworks in grade-separated interchanges. This inter-action challenged designers to conceive structural forms tailored to the geometric requirements of flowing streams of traffic and to incorporate construction techniques which reduced erection time to a minimum and allowed rapid integration of the associated roadworks.

172. It would be interesting to investigate, for a particular project, the saving in roadwork costs attributable to a specific reduction in bridge construction time and also the savings to the road users for any shortening in completion time for the whole project attributable to the saving in bridge erection time.

173. Structural costs for grade-separated interchanges should not therefore be considered in isolation from the associated roadworks costs as the erection time of bridges affected the efficiency, and hence the cost, of constructing the adjacent roads and also affected the completion time of the whole project.

174. One aspect of the precast deck on the bridges affected the safe environment for traffic. This was the presence of bridge supports on the central reservation of the under road, particularly if, as in Cumbernauld, this reservation was only 10 ft wide.

175. In addition to the effect on traffic on the adjacent fast lanes, there was also danger of structural damage to the bridge supports unless these were adequately protected by guard-rails or some such unsightly element.

176. The presence of central piers became even more significant when the under road was on a sharp curvature, as was the case in the Muirhead Bridge referred to in the Paper.

177. Would the Author comment on any other considerations besides the facility for precasting, which conditioned the adoption of bridge supports in the central reservations of the under roads.

Mr J. A. Clark (Director, R. J. McLeod (Contractors) Ltd) wrote that he first became associated with Mr Allen's design for the bridges during the tendering stage of the contract. The aspect of prefabrication of the bridge works presented a challenge. His company realized that precasting of the columns as well as the beams would have considerable bearing on the time factor for construction provided (*a*) the units would be readily available, (*b*) no difficulty would be encountered in centring the columns accurately and fixing prior to base concreting.

179. The fixing of the columns proved to be a comparatively simple operation using the plate provided in the design, and a single row of scaffolding suitably cross-braced and shored held the units vertical before concreting the foundation. This last operation was completed the same day as the columns were placed. As the diameter to length ratio of the column was considerable, the question of sway could be dismissed, and the main difficulty that the Contractors were faced with, was the placing of the transom beams on the column heads. It must be remembered that in two of the bridges at Muirhead, extreme accuracy was essential as the columns followed the spiral of the east radial, while the transoms maintained a parallel alignment. This difficulty was overcome by plotting both position and cross section of one line of columns to a very large scale, and superimposing the transom outline. This outline was adjusted on a trial and error basis until a final alignment was obtained which was practical and which satisfied design requirements.

180. During the severe winter of 1962/63, major site working was suspended, but the precasting of the columns and beams continued under cover, allowing for rapid advancement of the bridge works in the spring of 1963. This was planned and it took six weeks for four major bridges from the time excavation started on the column footings until the in situ concrete infill to the deck was completed.

181. From this point of view, however, progress was slower due to the more intricate operations of waterproofing, deck screeding, transverse stressing, and above all, the construction of the in situ fascias. The latter operation, considering the small volume of concrete involved, required extensive scaffolding, which up to that point had been minimal.

182. He suggested that by introducing precast fascia panels, the delay in the latter

operation would be greatly reduced. These panels could be supported by incorporating some form of nib into the design of the main edge beams.

The Author, in reply, said that throughout the discussion he had the impression that no contributor had appreciated that he was discussing the bridges in a wider sense, as parts of a complex roads project.

184. He had been describing a case which dealt with a sophisticated, comprehensive urban development growing rapidly, where the speed of construction was a major target. His impression was that too often the bridge designer was working in isolation from the major planning problems of which a bridge was only one part. He was given certain crossings, be it river or dual carriageway crossings, and told to provide a bridge. This tended to distort the outlook on bridge design and, in the Author's opinion, there was far more to bridge design than merely the question of stresses and cost per sq. ft of deck. The organization for which he was working and the system which had been created encouraged team work of all the professions involved in urban development. This was considered essential to the success of such a venture.

185. He worked in close liaison with his colleagues responsible for roads, with the planners and the architects. The bridgeworks described in the Paper should be considered against this background. A point which had occurred regularly in the discussion had been that concerning cost, and it appeared that all the questions in this respect had been on the basis of bridge for bridge costs.

186. It was no use producing a bridge which, bridge for bridge, appeared cheaper if, at the same time, it considerably increased the costs of roadworks and created inconvenience to the public through prolonged construction time. He emphasized that speed of erection was the most important feature of the system described in the Paper. Some of the bridges of M.B.I. were actually erected in four months, while similar four span bridges constructed by traditional methods usually took 15 to 18 months. The speed of erection of bridgeworks associated with grade separation had a considerable impact on a roads project as a whole and such bridges should be considered in this context.

187. The Author appreciated Mr Wyatt's comments on productivity. With regard to the economics of precast columns versus columns cast in situ, he was convinced that for bridgeworks associated with grade separation, which required supports in the limited range of heights, the precast column was a more economic solution. Although to some extent this would depend on the main contractor's appreciation of the potentialities of the system, or erection being undertaken by the precast manufacturers.

188. The cranes used for handling columns were ordinary cranes as used for general civil engineering work. As far as handling was concerned the only precaution taken was to use rubber lined slings to prevent damage to the texture of the column.

189. Use of precast beams instead of in situ work would not result in increase in deck thickness, on the contrary it was more likely to reduce it in view of the higher quality of concrete obtained consistently in precast work. This permitted the use of higher stresses and also higher moduli of elasticity which minimized the effect of deflexion as a controlling factor in the design of slender decks.

190. The Author agreed whole-heartedly with Mr Wyatt's remark regarding productivity considered on a national scale. In this respect it seemed to him that the civil engineering profession and the industry must make a determined effort to reduce very substantially the time of bridge construction and the site work on bridges generally.

191. The Author was in agreement with the general statement Mr Budgen made on aesthetics except that he did not agree with what Mr Budgen said about aesthetics being a dangerous word for an engineer to use. Aesthetics, or the appreciation of

beauty, was not exclusive to a particular profession. It was basically an inborn quality, although it could be refined by education. To undo any possible damage that his particular comments on bridgeworks at Cumbernauld may have done, the Author quoted two authoritative sources expressing what he considered to be expert opinion on the subject. One was *Concrete Quarterly No. 57* which, referring to circular columns, stated, 'the total effect is one of classic elegance'; and then went on, 'If all the interchanges in Cumbernauld are of this standard they will definitely enhance the town's attraction.' His second reference was *Design No. 191*, November 1964 issue, which referred to 'some very attractive bridgeworks' at the Muirhead/ Braehead interchange.

192. The Author felt the above statement necessary as he had reason to believe that the type of structure developed for the Muirhead/Braehead interchange had created interest extending well beyond the confines of the new town of Cumbernauld.

193. The Author disagreed with Mr Budgen's advocacy of the column and cap system for reinforced concrete and prestressed concrete bridges. In fact, he considered the exposed cap or capping beam in so many of the post-war bridges in Great Britain as the ugliest feature, and the designers' lack of appreciation of the potentialities of a constructional medium such as concrete. The column and cap system no doubt served its purpose well while the principal constructional medium was timber, a medium of fibrous nature with little resistance to punching shear. The ability of concrete to be moulded and strengthened in any desired direction should be developed to the utmost and expressed as such in the structure. The Author hoped that this prehistoric system of column and cap would eventually disappear from reinforced concrete bridge design as well as from general building construction when the knowledge and potentialities of slabs and plates were better understood and developed.

194. Regarding the fixing of precast columns to their bases, it was indeed simple as Mr Budgen noted, and this was confirmed by other contributors to the discussion. The projecting bars were intended to carry the whole weight of the column itself. There was no need for any refinement in welding the plate to the bars. Accurate location of the plate in situ was easily achieved by means of the usual steelworkers' technique. There was no dribbling of the cast in situ concrete down the precast column due to the sealing action of the rubber rings, normally used for jointing water mains, and located in a groove at the top of each column immediately below the transom shutter. The non-destructive testing of concrete columns was carried out as a corroboration of the cube test and the instrument used was the impact hammer which in the Author's opinion was satisfactory to the extent of 10–15%, if used properly.

195. Regarding the strength of infill concrete there was no misprint in the statement that it attained 7000 lb sq./in. after seven days of normal curing using rapid-hardening cement. The 28 day strength of this concrete was in the region of 10 000 lb/sq. in. Considering the small amount of concrete involved in the infill, the minimum strength was the target (6000 lb/sq. in.) rather than consistency.

196. The Author was grateful to Mr Ager for his kind remarks and his appreciation of the Author's efforts, however limited, to push a little further the development of precast techniques and construction of bridgeworks associated with grade separation. The Author was fully convinced that as far as speed of completion of a roads project as a whole, not just the bridgeworks, was concerned and the overall economy of the project, the precast standard pier was an important element contributing very substantially to the realization of these two aims. It was surprising why it was not introduced into bridge construction a long time ago when the expansion of the roads programme began.

197. The Author felt, as far as the design was concerned, that perhaps too much effort was being spent throughout Great Britain in designing a variety of supports in a variety of shapes, while functionally all that was required was a plain vertical

element of 18 to 21 feet in length with little variation in cross section for most of the bridges associated with grade separation. It was a surprisingly versatile element suitable for a number of bridge sites as could be illustrated by the Muirhead/Braehead interchange bridges all of which differed in some respect. The Author was glad that Mr Ager commented on horizontal curvature of M.B.I. bridges and adaptation of precast techniques for this treatment.

198. The road geometry of the Muirhead/Braehead interchange could be described as a fairly typical example of grade separation in a compact urban area. It relied largely upon curved surfaces to effect easy flow of vehicles between roads at different levels. Therefore, in order to obtain efficient and safe movement of vehicles through the interchange the kinematic consideration had to be given priority over other design considerations. The road engineer was aware of this since the time when he introduced the transition curve which led the vehicle from a curve of infinite radius to a curve of a definite radius with a smooth adjustment of speed which contributed to safety and economy of movement.

199. The bridge engineer was, until recently, somewhat reluctant to introduce curves on bridge decks. Examples of this reluctance could be seen even on some of the most important projects in Great Britain, where some of the elevated roundabouts consisted of short lengths of straight between two curves.

200. Regarding future development in precasting techniques for bridges associated with grade separation, the Author intended to go ahead as far as it was in his power. In fact, there were two more interchanges being designed based on the M.B.I. system with certain improvements which, it was hoped, would bring about appreciable reduction in cost.

201. The time estimated for erection of precast beams at the pre-tender stage agreed reasonably well with the actual time on site.

202. Regarding estimates, in the Author's opinion the actual cost of a largely prefabricated bridge structure would be reasonably near to estimates and truly economic if

(a) the estimates were prepared by the precast manufacturer, and
(b) the precast manufacturer undertook the responsibility not only for the fabrication but for the erection as well.

203. The Author's impression was that, unless the manufacturer was able and willing to undertake site erection, the best ideas for a precast bridge system were likely to be stunted at the erection stage. This, of course, had long been recognized in steel construction and more recently in industrialized building systems.

204. Mr Ager wondered if an architect gave a lead on the proportioning of the column. The Author said that the bridgeworks described in the Paper were entirely an engineering concept including every detail of appearance. The architecture of the surrounding buildings, however, had a considerable impact on the appearance of bridges at the design stage. A conscious effort was made to produce structures which would convey a feeling of urbanity and affinity with the surroundings. Hence a light round column emerged as the principal structural member. It was thought that great masses of concrete, familiar along motorways, might have been out of scale with the surrounding buildings. Hence also an attempt to achieve flush soffit and omission of capping beams. It should be realised that in an organization where team work was essential, the Author would not have been able to build the bridges without the agreement of his architectural colleagues.

205. Mr Holland had referred to increased productivity in bridge construction as one of the major points in the Paper, but as the Author had said earlier, his intention was not so much to put the emphasis on increased productivity in bridge construction as such but to put the greatest possible emphasis on productivity on a roads project as a whole and to consider the bridgeworks in this context. As a rule the greater proportion of the money spent on a roads project was spent on items other than

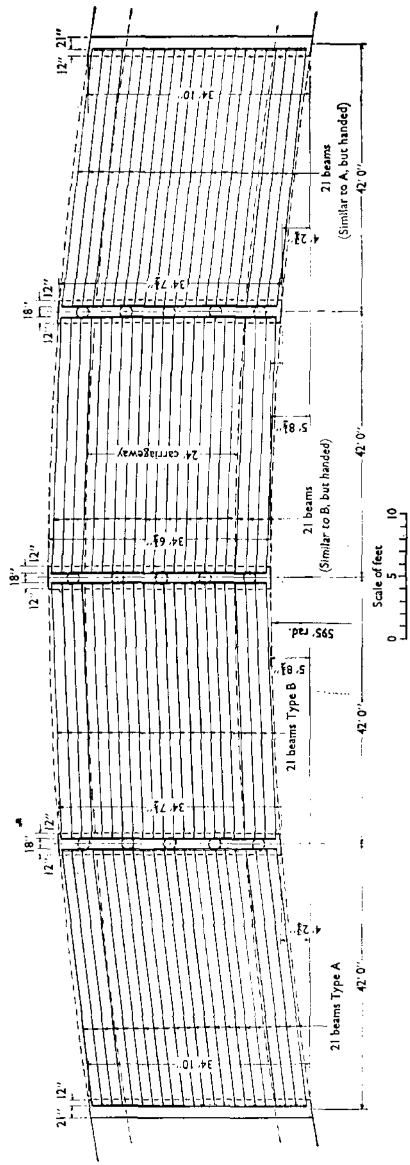

FIG. 23: PLAN OF WEST BRIDGE AT TRANSOM LEVEL

bridges and yet it was the bridgeworks which could make these operations more expensive by blocking the inter-site communications for long periods of time if the bridges were cast in situ. Although the Author did put in rates for the type of bridgeworks described in the Paper, as he felt this information might be of some value, it would be wrong to compare them on a bridge for bridge basis.

206. The Author was not sure what Mr Holland meant in his statement that the flush soffit created difficulties. Mr Holland might be right that exposed capping beams and butt-jointed beams would have cut by half the variation in types of beams at Braehead, but the Author would not agree that the appearance would have been improved. Actually, further development of the system used at Muirhead/Braehead interchange indicated that considerable improvement in reducing the number of variations was possible without resorting to the use of exposed capping beams. (See Fig. 23.) As far as appearance was concerned, bridges would be judged mainly by the general public for whom they were provided and there was no doubt in the Author's mind that the general public would find the clean penetration of the columns into the deck more pleasing than the sight of capping beams.

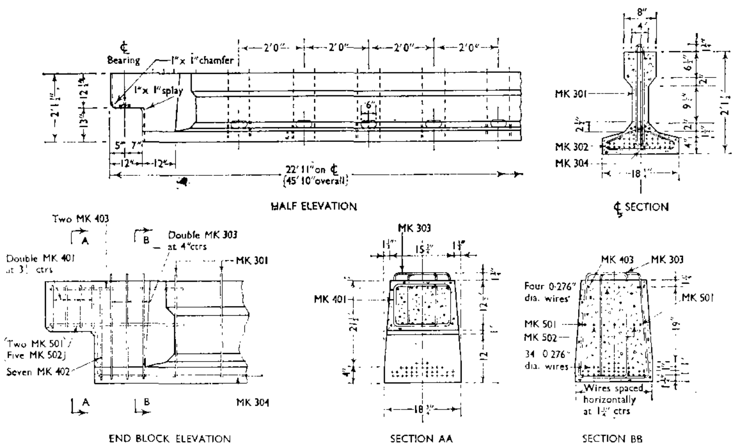

FIG. 24: MODIFIED STANDARD BEAM (P.C.D.G.)

207. Mr Holland did not like the appearance of short vertical lines on the fascia which were joints between transom and beams. The Author suggested that these were hardly noticeable against the general background of rough boarding. It was the disposition of masses and the attendant interplay of light and shade that was the more striking and it was in this respect that the Author found an exposed capping beam an offending feature in most cases.

208. The Author agreed, however, that appearance was very much a personal matter and if a designer preferred an exposed capping this could be put on the top of prefabricated columns easily and, provided that the width of the capping beam was no more than the width of the central reservation or twice the distance of the centre of the column from the hard shoulder kerb, the amount of clearance between the carriageway and the underside of the deck was quite irrelevant. In other words, the Author saw no practical limitation other than appearance to the use of exposed capping beams and prefabricated standardized columns.

209. Regarding the use of standard beams on future projects, the Author meant

the P.C.D.G. standard beams modified at the end to suit the flush soffit and tested as shown in Figs 10, 11, and 12. The details of such a modified beam were shown in Fig. 24. Although appreciable economies could accrue from the use of these beams, the Author had certain reservations regarding their geometric stability which might be partly due to a defect at the production stage but mainly was due to the design. He felt that a post-tensioned beam, especially one using concentrated prestressing steel, was less likely to warp and twist than a pre-tensioned beam in which it was much more difficult in practice to locate exactly the resultant centre of gravity of the steel and, of course, a small deviation vertically or horizontally of the resultant centre of gravity of the pre-tensioned steel was more than likely to produce distortions. In addition, the M.B.I. type of beam incorporated end blocks and the Author felt that these helped considerably the geometric stability. It would be necessary to provide end blocks in standard pre-tensioned beams as well, if the flush soffit was to be retained. This was actually being proposed for the Seafar/Langlands interchange and it would be interesting to see in practice whether the presence of a type of end block helped to produce greater geometric stability in a pre-tensioned beam.

210. Regarding the cost of columns given in the Paper, Mr Holland was right in thinking that these were based in both cases on the supplier's quotations excluding Contractor's on-cost, unlike the total cost of bridgeworks which included Contractor's on-cost. Therefore, the column costs were comparable. Actually the rate for precast columns in the bill of quantities was per lineal foot which in the case of the Braehead columns was £5–15. The difference between columns of different height for the same bridge could be assessed by straight line proportioning.

211. It seemed to the Author that it would be quite easy to rationalize the column height if one had to cater for a large number of bridges associated with grade separation, perhaps not more than six different heights in 6 inch steps would be required between the limits of 18 ft to 21 ft. Such rationalization certainly would be easier with the flush soffit. On the other hand, with exposed capping beams the column height could be almost anything less than 18 ft for most cases. Therefore it was not so easy to rationalize and hence standardize.

212. Mr Austin stated that his firm built dozens of four span bridges which was probably one reason why his bridges appeared cheaper. It was generally recognized that the larger the contract the cheaper would be the individual items. It would be quite wrong to compare the average cost of four bridges on one contract with dozens of bridges on another contract. However, it appeared to the Author that Mr Austin had missed an opportunity here. Contracts which included dozens of bridges would be ideal for standardization and industrialization, using precast techniques. It was obvious to anyone familiar with precasting that it benefited more from a number of repetitions than in situ work.

213. Mr Austin also stated that the main contractor was given the opportunity to precast but decided not to do so. The Author knew cases where the reverse had happened. Namely that the designers had refused to allow the contractor to precast because the project was designed as an in situ job and it would have taken considerable design work to change. Therefore, if a bridge was to be a precast structure it must be designed as such in advance. Generally, precasting demanded a great deal of pre-planning work before tendering, including planning of erection. If a bridge was to be precast the idea for precasting must originate from, and be planned by, the designer in co-operation with the specialist contractor. It might be easy enough to change a precast job into an in situ one without many alterations, but not vice versa.

214. Regarding the number of columns to be incorporated in a pier, the Author was convinced, after an extensive investigation, that five columns was the optimum number for decks carrying a 24 ft carriageway and using precast columns. The factors involved in this consideration were rate of production, ease of handling and, most of all, slender appearance of columns and the deck with flush soffit. Such columns were only 21 in. in diameter, which gave a column of the right girth for

the statutory headroom height of 16 ft 6 in. as far as proportions were concerned. On the other hand, using three columns as suggested by Mr Austin would probably result in columns approaching 3 ft in diameter for the same headroom height of 16 ft 6 in.

215. Mr Austin asked a question about the cost of underpasses. The small difference of cost between the R.C. portal and multi-plate arch was due to extensive protective work, such as hard surfacing to the banks, required when the multi-plate steel arch was used. It might be that in under-developed countries where no such refinements were required, the multi-plate steel arch was more competitive.

216. Mr Austin stated that slab overbridges could be constructed in three to four months. The Author said that while this might be true in theory, in practice this was not the case, particularly for four span bridges.

217. The Author appreciated Mr Berridge's concern about re-entrant corners, but did not agree with his use of the term 'bad practice'. Many awkward problems arose in reinforced concrete design and it was really a question of competence whether they could be solved. The stepped end beam with the notching which Mr Berridge questioned had been successfully used on many bridges throughout the world in the form of a suspended span between two cantilevers. A test to destruction of such a beam was described in the Paper, and even though the crushing of the beam at mid-span occurred at a much higher load than the design ultimate load, the notch itself did not fail.

218. Regarding leakage, there was no water streaking down the piers and abutments except when it was blown on to the structure from the side by a strong westerly gale.

219. The Author appreciated Mr Scott's remarks about the appearance of the bridges.

220. Regarding the relationship between the height of lift and free fall of concrete, the Author was of the opinion that this would depend on several factors:

(a) type of structural member involved,
(b) type of shutter,
(c) disposition of reinforcement, and
(d) type of concrete mix.

In favourable circumstances a member of between 20 in. and 30 in. diameter with reinforcement at the periphery and with the shutter capable of taking the hydrostatic pressure, a free fall of 50 ft might be acceptable on the understanding that a sufficient number of external vibrators could be applied. Thus a 50 ft high lift could be achieved.

221. The Author agreed that the significant percentage of mild steel which was required to satisfy the ultimate load factor, together with other factors, helped towards geometric stability. The concrete above the level of the precast beams was considered in the composite action in some cases, but the area directly above the neck of the beam was ignored, hence there was no need for stirrups, which would have added to the cost. In this respect, it was worth noting that the depth of infill concrete varied from about 9 in. to almost nothing due to road geometry (super-elevation and camber). Since it was the minimum depth which was the determining factor in such cases, infill concrete had to be ignored.

222. The Author was grateful to receive comments from Dr K. Hajnal-Kónyi. Regarding his questions about the various aspects of tests carried out and modified standard (P.C.D.G.) beam, the Author included a table of measurements taken during the test (Table 1). Dr Kónyi was right in thinking that the maximum load was reached at stage 1. At that stage, the load factor was 2·13. Final crashing of the top flange and the collapse of the beam occurred at load factor 2·4. It was worth noting that the beam included only part of the infill concrete, thus developing

composite action from the neutral axis up. Presumably, in the actual structure complete infill would have added a further reserve of strength to the desk.

223. There appeared to be certain misunderstandings regarding the use of mild steel for transverse reinforcement. When he worked under Dr Kónyi, the Author recalled that Dr Kónyi was at pains to emphasize that a cold-worked square twisted bar was basically mild steel. The Author had used square twisted bars for transverse reinforcement of the deck in conjunction with modified elongated holes through the web.

TABLE 1

Applied load *tons*	Deflexion *in.* Calculated	Deflexion *in.* Actual	Calculated tensile stress bottom flange *lb/sq. in.*	Principal tension *lb/sq. in.*	Shear stress end block *lb/sq. in.*
18	0·286	0·2	562	−110	173
20	0·318	0·25	802	−131	192
22	0·35	0·25	1032	−155	212
24	0·38	0·3	1272	−179	231
26		0·42		−201	250
28		0·7		−230	270
30		0·95		−255	289
32		1·42		−281	308
34		2·2		−310	328
36				−337	346

224. The spans in all the highway bridges described in the Paper were simply supported. It was considered that in view of speed of erection being the major target on the project, introduction of continuity would not be profitable.

225. Mr O. A. Kerensky had asked how a rough boarded finish adopted for the underpass in the middle of a busy town looked after a few years? The short answer was excellent. The Author added that the rough boarded shutter was laid to a predetermined pattern of boards which in itself created either vertical, horizontal or angular emphasis as required. Secondly the timber specified for the shutter was Douglas fir which has a distinct grain. The Author believed that no human product such as the tile, for instance, could match the random beauty of natural grain. Timber was not used in order to imitate the character of timber in concrete, but merely to obtain an attractive texture and Douglas fir happened to imprint such a texture on concrete. Water ripples could also produce an attractive texture, one could not use them for a shutter. In certain cases the roughboarded concrete was painted with a resinous waterproof paint in such a dilution so as not to destroy the texture imparted by wood grain. This was particularly helpful in long underpasses as the light coloured paint increased the reflective power of walls and roof thus increasing the light factor.

226. The Author did not agree with Mr Kerensky that the public did not appreciate their surroundings while going through the underpass, in this respect he repeated his statement that people may not notice what they see but nevertheless what they see usually affects their total well being.

227. It was nowadays fashionable to produce objects with built-in obsolescence, but for bridges which formed part of a permanent road system, the Author disagreed strongly with the suggestion implied in Mr Kerensky's last statement that they should be building bridges to last only 30 years. The motoring public would not tolerate the continuous turmoil involved in bridge reconstruction. They were being put to much inconvenience even now when bridges of 60 to 80 years old were being replaced. Furthermore, with the built-in inflation which has become a feature of the British

economic system a bridge that might cost £40 000 today might well cost twice as much in 30 years' time.

228. The Author noted that Mr O'Neill suggested reshaping of the precast columns so that they would approach more closely their classic prototype. This might perhaps appeal to some designers but as far as the Author was concerned he had made no attempt to imitate the ancient Doric prototype at the Muirhead/Braehead interchange. He merely decided on the use of a structural member which was as old as humanity itself and to use it in its purest functional form. He specified 2 in. timber board for shuttering but not for the so-called fluting or texture. This emerged as a spontaneous solution of the Contractor's joiner and the Author welcomed this contribution from a tradesman as expressing very appropriately the modern constructional medium using modern techniques. Only afterwards, when the job was complete, was some similarity to Greek columns noticed.

229. The Author was in complete agreement with Mr Buchanan regarding the use of reinforced concrete underpasses in preference to the steel multi-plate arch type. In fact, it had been decided that no more multi-plate underpasses would be built in Cumbernauld. As far as speed of erection was concerned the actual steel shell might be erected very rapidly, which on some pioneering scheme in an under-developed country would be of great advantage, but, in a more sophisticated surrounding such as a new town, a lot more work would have to be done on approaches and entrances before such underpasses would be acceptable to the public. On the other hand, work at the entrances and even retention of the banks were all incorporated in the design of a reinforced concrete underpass.

230. The Author found Mr Edward's contribution extremely perceptive of the wider issues involved in some of the matter presented in the Paper. In particular, his practical illustration agreed with some of the Author's own observations. It was common to see a roads project under way which was reminiscent of the lunar landscape, with the difference that the craters of bridge sites went on erupting almost throughout the duration of the contract which might last for two years, thus, introducing discontinuity into the work of the heavy mechanical plant necessary for each excavation and paving. These bridges, often constructed by slow, out-dated methods not only adversely affected the time of completion of the project as a whole, but also had a damaging effect on national economy by creating traffic bottlenecks on the adjacent existing road networks which were studded with temporary traffic lights, detours and diversions as the result of the activity on the bridge sites. This, of course, reduced the capacity of such roads and increased the rate of accidents. The bridge system for grade separated intersections produced at Cumbernauld might go some way towards alleviating the difficulties of bridge construction in the midst of large earthworks. Extensive prefabrication of bridgeworks organized on a large enough scale would not only reduce the cost of bridges as such, but would reduce the time of construction, thus reducing to a minimum interference with the normal pattern of traffic in the area. The Author could not agree with Mr Edwards' statement in § 164. Presumably Mr Edwards was not familiar with the basic planning aspects of Cumbernauld. The scale of roadworks might appear immense in photographs but actually the total mileage provided was about half that provided in other towns of corresponding population. Cumbernauld is a high density town and the designated area is about half the area of a town of similar population. This had a direct bearing on the cost of roadworks in the new town. With the road mileage being about half that in some of the older new towns of corresponding size, the total cost of roads per head of population would be about the same. The reason for this was that the roads were of a higher standard, incorporating grade separation and pedestrian-vehicular segregation. These two principles were advocated in the Buchanan report, but were actually built into the basic plan of Cumbernauld before the Buchanan report was published. The Author saw no reason why Mr Edwards should take such a pessimistic view regarding the practical implementations of the Buchanan

Report to other towns, new towns in particular. In the Author's opinion, Cumbernauld had shown how it could be accomplished successfully.

231. The Author appreciated Mr Mackay's contribution to the Paper. The question of supports in the central reservation was probably one to which engineers gave a great deal of thought as it was a question of prime importance. The Author had already expressed the view that it was essential that the bridge designer worked in full partnership with the engineers designing roads, the planner working on housing layout adjacent to the road, and the architect responsible for the house type in the vicinity of an urban motorway. Considered in this context the basic question of whether to bridge a dual carriageway with one span or two became largely one of economics. But economics in a wider sense than merely comparing the cost of a one span bridge against, say, a four span bridge. To bridge a dual carriageway with four 42 ft spans and open abutment the overall structural depth required would be about 2 ft. To bridge the same dual carriageway with closed abutments and one span of 85 ft would about double the structural depth. The comparative cost analysis quite often was limited to a simple assessment of the cost of one bridge against another and if the difference found on that basis was, say, of the order of 10% in favour of a four span bridge, preference would be given to one span which appeared more impressive and might give greater safety.

232. The Author considered that a comparison on a bridge-for-bridge basis was wrong and likely to be misleading in a sophisticated urban development. To illustrate this the Author considered the Muirhead/Braehead interchange in which grade segregation was achieved by three four-span bridges and one five-span bridge. Because Cumbernauld is a high density town, housing layouts and therefore road layouts are of a compact nature. If the bridges had been designed as one span structures the consequent increase of structural depth would not only have increased the cost of bridgeworks but it would have also increased the cost of roadworks, by altering the road geometry so that the layout would have to be expanded. This would have consumed greater land area of high commercial value. In fact, this simple factor of increased structural depth of bridge deck would necessitate a complete reappraisal of the roads layout, housing layout and house type with a consequent overall increase in cost.

233. Apart from this, roads and bridges would have become out of scale with houses and the whole feeling of a tightly knit urban community would have been lost. Instead a costly sprawl would have emerged.

234. Mr Clark's contribution usefully supplemented some of the Author's previous comments. The Author was glad that Mr Clark elaborated on the erection of the Muirhead bridges which were on a transition spiral—perhaps an unusual location for precast bridges—but it was a good example of the versatility of the precast system described in the Paper. Mr Clark's suggestion that precasting of the bridge system described in the Paper be extended to include precast fascia panels, merits careful attention. It was encouraging to the Author to have a favourable response from the contractor's point of view to the extensive use of precasting for highway bridges.

235. Perhaps the most significant reaction of the industry to the system of highway bridges for grade separation described in the Paper was shown in the latest tenders (June 1965) for the Seafar/Langlands interchange.

236. This interchange is a mirror image of Muirhead/Braehead interchange, and the Author found it gratifying to note that the cost of bridgeworks for S.L.I. showed a reduction of 23·5% in the case of one tender, and more in another tender, compared with tenders for M.B.I. received in 1962, in spite of general upward trend of prices in the industry.

237. The Author was convinced that this is mainly due to better appreciation by the contractor of the potential advantages of the system in the context of a roads project as a whole and the fact that the system proved itself in practice.