Discussion.

The Author, in introducing his Paper, said that it might perhaps seem to many that the subject of surface finishing of concrete structures was one of secondary importance at the present time. Good finishes to concrete structures were, however, just as important in war time as at any other time, since they reflected, to a very large extent, the care and efficiency exercised in controlling labour and materials during all stages of construction. Control of the quality of the work almost invariably led to economy; it was, for example, far more economical to plan the work so that when the forms were struck the exposed surfaces would present a dense and uniform appearance than it was to relax control and rely upon patching and after-treatment to conceal the blemishes of badly placed concrete.

One very important fact should always be borne in mind, namely, that surface blemishes tended to become accentuated as the concrete aged. Thus, a slightly more porous pocket of concrete which on removal of the form differed only slightly in colour and texture from the surrounding concrete would, owing to its greater porosity, not only tend to be more easily eroded on exposure to the weather but would also accumulate grime more readily on its surface; patches also became more apparent with the passage of time.

Fig. 30 showed three successive mixes of concrete. The first was deposited quite well, and it was a well-consolidated mix; the second was probably under-sanded and poorly compacted, and the concrete had been allowed to find its own path through the formwork, with the consequence there was segregation and a honeycomb patch. No attempt had been made to obtain a really good construction joint, and the concrete had weathered badly. In one place particularly one could actually see the concrete tending to spall, probably owing to weathering in the porous layer. No attempt at serrating the surface would mask those defects.

The effect of the weathering of concrete surfaces varied considerably according to the conditions of exposure. Thus tests had shown, as would be expected, that concrete darkened more rapidly in an industrial town with a relatively high content of solids in the atmosphere than in one less polluted. In another town, owing probably to a higher acid-content in the atmosphere, slight etching of the surface of the concrete might occur, which might tend to offset the darkening of the surface. Rainwater tended to cleanse concrete on which soot and grime had been deposited, and concrete was therefore generally less dirty on surfaces facing in the direction of the prevailing wind than on less exposed areas, although the

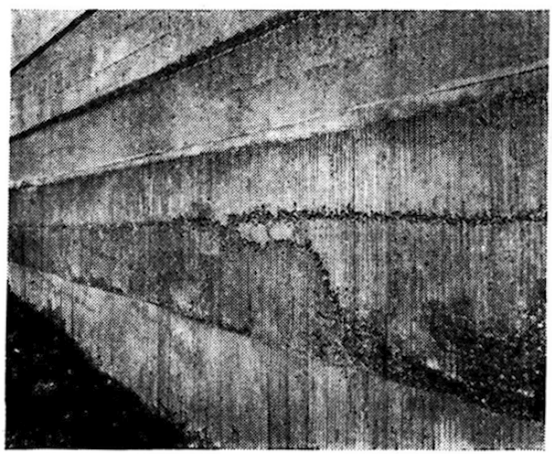
surfaces tended to become streaky and patchy owing to rain dripping or flowing unevenly down the surface.

He wished to emphasize the importance of using well-designed weatherings on all projecting features, so that rainwater was thrown clear of the walls. Probably more disfigurement to concrete surfaces resulted from lack of attention to that matter than from any other cause.

In the example shown in *Fig. 31*, rainwater had run along the sill and flowed down the surface of the wall, carrying grime with it and causing a very unsightly stain.

Fig. 32 illustrated a very simple device, namely, a form of metal weathering which allowed the water to be collected and thrown clear of the

Fig. 30.



wall. The projecting metal was placed well out from the wall, and an important feature was the turn-up at the end of the sill to prevent the water running over the end. Most of the disfigurement was caused by water running over the end of the sill.

He had not referred in the Paper to the equally important problem of producing concrete surfaces offering good resistance to wear—for example, heavy duty floors in factories and warehouses; but judging from the many inquiries for information on the subject and from the reports of failures of wearing surfaces received at the Building Research Station, that problem appeared to merit much closer attention and study. The techniques followed in laying and surfacing concrete floors varied very considerably, and guidance was needed as to the best methods. Similarly, information was scanty on the problem of finishing the surfaces of oil-storage tanks to make them impermeable to oil.

Fig. 31.

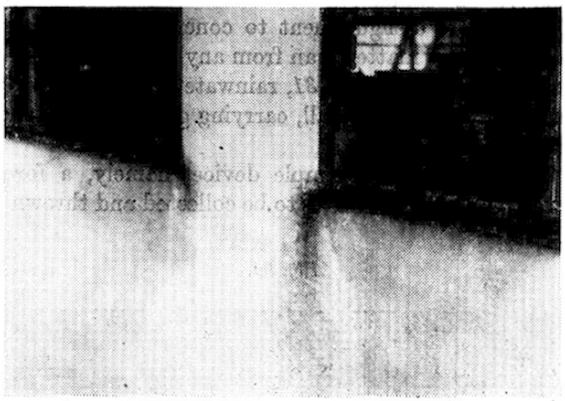
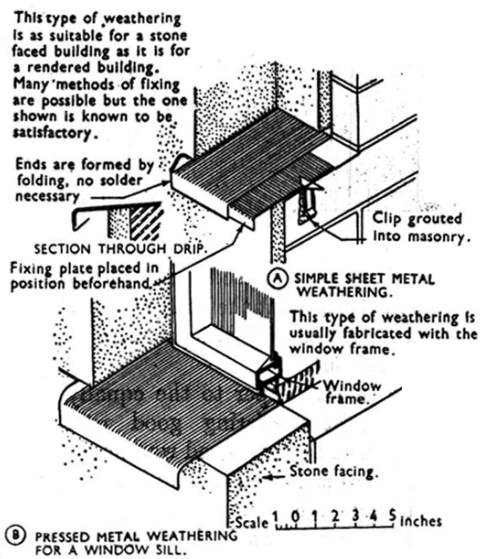


Fig. 32.



Another and perhaps more topical subject that had not been dealt with concerned the repair of war-damaged concrete buildings. The problem of patching and re-surfacing damaged concrete was not always so simple as would appear at first sight, but further investigations were in progress.

The President said that The Institution had recently taken an active interest in the aesthetics of engineering structures, and the Paper formed a valuable contribution to that subject. It dealt with beauty of complexion rather than with beauty of form; in fact it might be said, in the terminology of the beauty-specialist, to deal with facial treatment, which was, of course, extremely important. It was a mere truism to say that beauty of form in a structural building or in any structure could be marred and entirely disfigured by something repulsive in the way of a complexion. In concrete buildings and other concrete structures, beauty of complexion had been in the past too often conspicuous by its absence; but the Author had given instructions for rectifying that defect.

Mr. F. E. Wentworth-Sheilds considered that the Paper represented an immense step forward in the endeavour to render structures more pleasing in appearance, and it went farther than that, in that it contained the essentials of what might be called good workmanship in concrete, which affected more than the appearance of the structure. For instance, the Author had given a description of the best way of making satisfactory horizontal joints, which would provide much food for thought to all engineers who erected concrete structures. They all, the dock engineer in particular, knew how difficult it was to make a really satisfactory joint when placing a new layer of concrete on top of an old one, because he found that, in erecting a quay wall, and especially a graving-dock wall, if a bad horizontal joint were made the water came weeping through that joint, causing him to weep also! The Author had suggested that the set concrete should be thoroughly roughened, the surface should be washed and saturated with water, a layer of mortar should be laid on, and finally the new concrete deposited. Usually the old-fashioned engineer, in putting up large mass concrete walls, did not do what the Author appeared to suggest should be done, namely, hack the surface all over with a pick; but he did wash the surface and brush it, and sometimes laid a layer of mortar over it. Generally speaking, satisfactory results had been obtained by that method, and it was not quite clear whether or why it should be necessary to hack the surface of the old concrete, in view of the fact that one could put down concrete in a pile-mould for instance, on a plain board surface, and obtain a perfectly good surface on the under-side of the pile. Probably the answer to the question was that a neat and watertight joint could be obtained without hacking, but that hacking ensured closer contact, and therefore a stronger joint.

Dr. W. H. Glanville said that he had felt at first that the Paper dealt with a subject which engineers should not think about in war time,

but perhaps it was good that they should consider the subject, because in many ways they were becoming very slipshod under war conditions, with a consequent loss of efficiency. It was very important that engineers should take the care about their structures which was essential in order to obtain the strength required. The Author had emphasized the meticulous care that should be taken in all the processes described, and that was clearly the basis of the Paper. Good quality concrete could never be obtained without care, and that applied particularly to the finish, because the worker in concrete operated more or less in a blindfold condition; he could not see the surface that was produced until the form had been struck, therefore it was very important that engineers should consider how such care was to be brought into operation. It was really a question of educating the craftsman. The people who were to construct the formwork and those who were to make the concrete had to be educated, so that they would use good quality material and understand its essential properties. Many who made concrete to-day, and had made it for many years, did not really understand the basic principles.

He had been very interested in the weathering-machine illustrated in *Fig. 2* and also in *Figs. 4* and *5*. He had found it difficult to discover a correlation between any of the results under different conditions and the results furnished by the weathering-machine, and he would like to know whether any information was available to show that the results from the weathering-machine could be correlated with practical results. The matter was closely related to the work that had been done in the Road Research Laboratory on the use of road machines to accelerate wear. It had been found extraordinarily difficult to reproduce the sort of wear that occurred in practice. All kinds of weathering devices and wear devices had been produced, but without really satisfactory results.

Dr. David Anderson observed that Members might be interested to know that the Paper formed part of a programme. As a result of Dr. Faber's Paper on "Aesthetics of Engineering Structures"[1], The Institution had set up a small committee to consider and report upon what action might be taken to investigate the question of surface or finish of concrete structures, with particular reference to aesthetic treatment. That committee had decided that two-fold action could be taken in spite of the war, namely, (*a*) A Paper embodying practice and research to date based upon work already done by the Building Research Station in collaboration with the Cement and Concrete Association (hence the Paper by Dr. Davey); (*b*) That the committee be empowered, as a further step, to confer with individual engineers experienced in the design of structures built of concrete, and thereafter to report whether and, if so, how far, principles relating to the aesthetic treatment of the surface of such structures might be defined.

[1] Journal Inst C.E., vol. 17 (1941–42), p. 139 (April 1941).

Dr. Anderson considered that it would be of great advantage if, when the work of the committee was completed, the results of their labours, including Dr. Davey's Paper, should be issued as a separate publication by The Institution. Further research would be needed, but that might have to wait until after the war.

He wished to make the following comments on the Paper.

Figs. 7, showing the darkening of concrete surfaces during exposure in London, appeared to indicate that, no matter what aggregates were used or what treatment the surface underwent, after about 3 years all came to a common value of 40 per cent. reflected light. In plain English, all became dirty. The Author had indicated numerous other defects that arose and the various ingenious methods that had been adopted to overcome them and to obtain pleasing results: but dirt still remained the enemy to concrete structures in large, dirty towns. Further research might discover means of overcoming that evil.

The Author had referred, on page 203, *ante*, to applied coverings, including glazing and metal spraying. Further research might make them more useful in the struggle against dirt.

It might be that in the long run it would be found economical and legitimate to use permanent shuttering as a finish instead of temporary shuttering for constructional purposes only. That might seem like a confession of failure, but if it resulted in structures resplendent in finishes of stainless steel, copper, or other metals, marbles (natural or artificial), plastics, or other new invented materials, engineers would be able to credit themselves with structures not only stable in themselves, such as they had long been accustomed to produce, but also pleasing to the eye and with a finish that time and weather could not affect.

Dr. Anderson could see room for vast improvements if care, forethought and imagination were applied, and he regarded the Paper as a valuable step in that direction.

Mr. G. L. Groves thought that if engineers, or any other body of discriminating persons, were asked to vote on the question: "Are you satisfied with the quality of finish in concrete structures in this country to-day?" an overwhelmingly large majority would answer: "No", and that majority might be even larger if the question were limited in its application to such purely utilitarian structures as retaining walls, bridge piers, and so forth, where special surface treatment, such as was described in the Paper, or the concealment of construction joints by special methods, would be out of place on economic if not on aesthetic grounds. In all structures of the kind to which he was referring it was very important to avoid the flaws and disfigurements which were a too familiar feature in work to-day; but if there was to be an improvement (and he thought the Paper pointed a way to it) he suggested, speaking in general terms, that there should be a revision of existing methods, and perhaps to some extent a change of heart.

How were engineers to take advantage of the knowledge of the improved technique described in the Paper ? He suggested that, in the first place, many engineers' specifications required to be re-written and expanded, and for the amended documents he could think of no better framework than the Author's admirable Paper. To mention only one point in that connexion, the Author had drawn attention to the prime necessity of rigid control of the mix with regard to surface finish. That was a matter which had probably had far too little insistence put upon it so far as mass concrete was concerned, however meticulous engineers might have been in regard to reinforced concrete ; although in their control of the latter, engineers had probably been much more concerned with quality of strength than with quality of finish.

Secondly, he would suggest that the supervision of work by the engineer's representatives required to be closer and more knowledgeable. How many resident engineers, he wondered, discussed with the contractor details of the making up of formwork, the care of formwork when out of use, the orderly disposition of construction joints, and many other points which were shown by the Author to make all the difference in the result.

Thirdly, he thought that many contractors—he might even say most contractors—should make a fresh and unprejudiced approach to several factors affecting concrete surfaces.

In all the three points that he had mentioned, however, it was for the engineer to take the initiative. He might specify perfection, but he would not obtain perfection or anything like perfection unless he had the full co-operation of those who were carrying out his instructions on the ground and the understanding co-operation of the contractor.

It might be argued by some that enhanced costs would go hand in hand with a higher standard of finish. Setting aside such shoddy workmanship as ought never to see the light of day at any price, Mr. Groves doubted whether an improvement in the results generally obtaining would cost more if the methods of carrying out the improved technique were thoroughly appreciated and properly applied. Many engineers had experience of contractors who spent a good deal of money in endeavouring to doctor a structure where bad formwork or faulty control of mixing had resulted in lipped joints and honeycombing. He had a shrewd suspicion that a number of contractors included a percentage in their price for such doctoring. That money would be very much better expended in prevention than in attempted cure. In any case, workmanship which fell short of a standard where justifiable criticism could not legitimately be offered, should not be acceptable to any engineer, and if any of the work to-day fell short of that standard it was time that an improvement in the quality of workmanship became the rule. The Author, he thought, had given very clear and practical directions for the attainment of that improvement.

Mr. W. K. Wallace believed that a concrete job which had a good surface was probably a job which was well done throughout. He agreed

with Mr. Groves that a better result might not, in the end, cost any more once the technique had been learned, provided the job was of sufficient magnitude to permit a reasonable repetition of the use of forms, so that a well-made form, properly designed for re-use, could be employed a reasonable number of times. Owing to the large areas available for reconstruction in some cities at the present time, there should, in the future, be larger jobs which would admit of more re-use of forms.

He would have liked to see in the Paper some more information about the absorbent form lining, which he knew was being developed rapidly in America. Further, in the United States, pre-cast concrete slabs had been used recently as formwork on exposed faces on a very large scale on war-time buildings; and he thought that was a very interesting attempt to obtain a good face. On some buildings under erection in Great Britain precast slabs were being used in that way.

The work of Mr. J. J. Earley in America was largely architectural decorative work, but the mixes which he used to obtain his excellent surfaces were very interesting. Mr. Wallace thought he was right in saying that Mr. Early used only two sizes of aggregate; that was absolutely contrary to the ideal of graded aggregate which engineers in Great Britain were normally brought up to consider the proper thing. The walls of Meridian Park, Washington, D.C., had been up for a considerable number of years and the surface was still quite attractive. Mr. Wallace was aware that the atmosphere of London was much dirtier than that of Washington, but if the walls of that park had been built in Great Britain they would have formed a very much better job than much of the work that was seen there. One of the chief troubles in Great Britain was that insufficient attention was devoted to lining the forms. Often on going to look at a job one was told: "It is all right, except for that little bit at the far end"; and it was that little bit at the far end that one always saw afterwards. One hesitated a long time before ordering a contractor to take down set concrete and put it up again, because, although the new work might be better aligned, a nasty joint would occur between the new work and the old. The consequence was that a good deal of unsatisfactory work went through.

With regard to roughening the upper surface of a lift of concrete, he agreed with the Author; but he would like to ask whether there was any objection to roughening the top of a lift of concrete shortly after it had begun to set, but before it had become hard, in other words, when it was a job for a stiff brush or a steel brush rather than for a pick.

There was only one point which he wished to criticize in the Paper, and that was very small. The Author had shown a recessed joint in a vertical surface with the break half-way up the joint. Mr. Wallace thought that it would have been better to make it farther up, so that the junction between the two lifts was masked by the shadow of the recess.

Mr. R. Carpmael said that he wished to emphasize the importance of

correct forms and good workmanship. He had first made the acquaintance of mass and precast concrete at Fishguard, under Mr. G. Lambert Gibson, M. Inst. C.E., and had been taught to regard it as an axiom that if surfaces required retouching after the moulds had been released the work had been badly done. The best example of finish of concrete using natural stone in the aggregate was, in his experience, at Fishguard harbour, where, as it was desired to carry out a colour scheme for the station buildings, certain slabs were required to be chocolate coloured and others light yellow. Some tunnels in Devonshire were then being opened up, and Mr. Gibson, who at that time was also in charge of work at Plymouth, thought that the Dawlish rock which was being obtained would be very suitable for the darker slabs, and it was so used. The upper slabs were coloured with pigment (ochre). These slabs had stood for 38 years, and, although he had not seen them lately, he was quite sure that they were as good now as when they were erected. It was true that they were under a glass roof, but they were exposed to the action of salt air and often salt spray. The coping stones of the quay wall at Fishguard were of precast concrete made of the local natural stone—a very hard igneous rock ; after the blocks were released from the moulds the top surfaces and the faces were rubbed down with brick, in order to remove the laitance and expose the chippings. Those copings had been in existence for the same period as the station buildings, and had been subjected to the customary hard wear of quay walls in constant use for shipping.

One of the most unsatisfactory features in the use of precast concrete blocks for house building and wall building was the terribly drab uniformity of the pattern. It was true that there might be three or four patterns, A, B, C and D (if as many), but that was about the extent of the variation, and a house or wall built of blocks of even those few stock patterns was almost intolerably monotonous. A much better effect would be obtained if the blocks, before they were perfectly hard, were cleaved along pre-arranged lines, leaving a draft margin, so that half the surfaces were slightly convex and the others slightly concave. In that way a much greater variation of pattern could be obtained. That method had been used, with very pleasing effects, for a Great Western Railway viaduct at Newquay, and on the new electric line from Acton to Ruislip.

The Author had referred to the question of the accentuation of joints by projecting V-shaped joints. An alternative method was to recess the "V"; that lightened the effect, and if there were any inequalities, due perhaps to bad workmanship, they would not be so evident. Such joints had been used on several Great Western Railway structures.

He was interested in the Author's brief reference to glazed or polished concrete. That process, after extensive experimental work, had been successfully employed by the Great Western Railway on urinal stalls and had proved to provide a sanitary and economical substitute for glazed earthenware.

Mr. P. G. Bowie felt that to some extent the outstanding feature of the Paper was the emphasis which the Author had laid upon craftmanship —the actual making and placing of the concrete—that was, the operatives' work. Bearing that in mind, it seemed to him that it might be advisable to stimulate the training of operatives by the formation of a definite trade of "concreter," because a man who was a tradesman, such as a bricklayer, had a definite interest in turning out a good job, and would take particular care that such accidents as the Author had indicated, at joints and other places, should not happen. No resident engineer could be in several places at once, but with well-trained men who were keen on their work, many of the abuses of concrete, as they had been called, would not arise.

Mr. W. G. Newton said that he felt rather like Daniel, because he was a representative of the architectural profession. Reference had been made in the Paper to certain structures with which he had been fortunate enough to be associated, and he was very glad to attend the meeting, because he felt that the more engineers and architects could see eye to eye and march shoulder to shoulder the more progress they would make and the more weight they would carry.

He was surprised that none of the speakers in the discussion had referred to the little devil, that was, the laitance or cream that developed on the outside of the concrete, which after 3 years was grey, and after 5 years was a black cobweb over the whole structure. Many structures which looked beautiful in their virgin days, shining and bright, 5 years later looked like old discarded landladies with cobwebs in their hair.

The method adopted at the Marlborough College laboratories was to chamfer the edges of alternate 6-inch boards, so that at every 12 inches there was a line running through, and directly the formwork was taken down the concrete was brushed with a stiff brush, which removed nearly all of the treacherous cream, so that very little was left to look unsightly afterwards. Probably the experience of others was similar to his own, namely, that one could not really say how difficult it was going to be to get all the laitance off. If the work was being done in soft rainy weather it could be removed fairly easily, but on a hot summer day the removal was much more difficult. He considered that without such removal the finish could never be regarded as satisfactory, because of its unsightly appearance after a few years.

The making of lines across the surface of concrete was simply a method of distracting attention from the lifts. Concrete could be treated as the Americans and the Swiss very often treated it, namely, it could be bush-hammered, but Mr. Newton regarded that as the wrong way of treating a material like concrete. It produced a broad-cloth effect instead of a Harris tweed effect, whilst in his opinion, concrete was like Harris tweed, an easy-going kind of material which should be treated in an easy-going way. Little lines on it and little chips here and there were in keeping with the Harris tweed nature of concrete, and the less it was "fussed over"

the better. There was no doubt that, so far as its exterior appearance was concerned, concrete was a very unforgiving material. If anything went wrong, it could never be righted.

He felt it an honour to be allowed to address the meeting, and he thought it was very desirable that whenever possible engineers and architects should discuss together such problems as those with which the Author had dealt.

Mr. Alister MacDonald considered that the Paper presented not necessarily a new idea of concrete, but another picture of it as something which was very human after all. The Author had described it as the most abused of materials, and he was obviously right. It was fascinating to think that if one did anything wrong in concrete it would never forgive one, and thanks were due to the Author for showing how initial mistakes could be avoided.

Mr. MacDonald thought that the point which had been made about the importance of co-operation by the operatives should be stressed. Mr. Bowie had suggested that operatives should be taught more, and Mr. MacDonald considered that they should be given the Author's Paper to read. He had derived considerable amusement from endeavouring to obtain good surface finishes to concrete by discussing the subject with operatives and with builders, sitting down on the job and making little samples, and apart from standard practice, using all kinds of things to try to get a good effect. Technical education in the building industry after the war would be strengthened by architects (he put them first because he was an architect himself), engineers, and operatives all studying together such Papers as the Author's. They would then put up much better buildings and be doing their combined part to make the community a better place in which to live.

A very important point had been raised by the Author in connexion with formwork, and the setting out of constructional lines to decide beforehand where the lifts were going to show and where they should be, and another very important point to which reference had been made in the Paper was that it might be necessary to re-mix some of the concrete nearer the actual seat of operations. Architects would often like to have concrete re-mixed nearer the seat of operations, but they dared not suggest it because an extra would be involved which would have to be explained to the client, or the builder would have to cover up that extra by doing some inferior work somewhere else. Therefore, he would like to emphasize the Author's contention that the whole of the work should be planned beforehand, should be shown on drawings in the same way as joinery details were shown, and should be described in so much detail that the builder would know every process and every cost of mixing, at whatever part of the job the work might be required. Then the job would be priced properly, and architects and engineers could exert their authority to see that it was carried out properly.

He had read with horror the suggestion of squirting metal on to concrete, and he hoped that that would not be encouraged. Surely it would bottle up the natural drying-out process which should take place, and he wondered how far that might affect the ultimate value of the structure. To a smaller degree the same thought went through his mind when he read about staining by chemical reaction. That was a very interesting line, and he hoped that more would be heard about it; but, again, if chemicals were used to get certain reactions, how far would that interfere with the ultimate quality of the concrete?

He would like to echo what Mr. Newton had said with regard to co-operation. Architects and engineers must work much more closely together, and he ventured to suggest that the architect could help the engineer on the aesthetic side of the subject, whilst the engineer could help the architect in the design of the weight-bearing part of the structure. Those were old questions, but they were questions which so far had been discussed underground, and he felt that Papers such as the Author's brought them very much to the surface. He hoped that one result of the Paper would be that engineers and architects would be able to discover common grounds of discussion, so that not only would they put their own professions into proper and efficient working order, but also by working conjointly they would do a work of real value to the community as a whole and put up buildings that used materials properly and rationally.

Sir Leopold Savile, referring to the question raised by Mr. Wentworth-Sheilds with regard to making a good horizontal joint, quoted the Author as stating that after the surface of the set concrete had been picked over and washed a layer of mortar should be spread over it before pouring the new lift of concrete. Some years ago Sir Leopold had found, when taking down a dock wall made of very good concrete, that when he reached construction joints the concrete separated and came away at those joints quite easily. He was subsequently informed by the late Mr. Felkin, the contractor's engineer in charge of that work, that those joints had been made exactly in the manner recommended by the Author and a layer of mortar had been laid on the old concrete before depositing the new. When Sir Leopold remarked that, "In spite of that it came away," Mr. Felkin replied: "On account of that, in my opinion, it came away." Sir Leopold inquired whether that point had been considered and practical experience gained in regard to the effect of the mortar, as his own experience confirmed what Mr. Felkin had implied.

*** **Dr. E. Probst** observed that, generally speaking, the provision of a surface finish depended upon the nature of the structure. A warehouse would require a finish different from that of a factory, for aesthetic as well as for practical reasons. The surface treatment of bridges of plain or reinforced concrete might be different from those and from mass concrete

*** This and the following contributions were received in writing.

work, such as high dams or other hydraulic structures. The investigations of the U.S. Cement Association at Chicago, a few years ago, on high dams throughout the country, proved that for many years the value of a special membrane or any other kind of special surface treatment had been overestimated, whilst the importance of the densest possible concrete body of the structure had been underestimated.

The influence of expansion joints in all kind of concrete and reinforced-concrete structures upon the surface treatment was evident, because it affected possible cracking. It should be borne in mind that any structural movement was followed by a movement in the surface coating. Any discontinuity in the core was followed instantly by that of the coating. Any rusting of reinforcing-bars caused staining in the surface finish similar to that illustrated in *Fig. 8*, facing p. 190, *ante*.

Moreover, the method of making, depositing, and controlling the concrete construction would affect the type of surface treatment to be chosen.

The foregoing showed that various factors of design and construction, as well as individual and local conditions, in addition to aesthetic reasons, affected the surface finishing. Generalization or schematization should therefore be avoided.

The questions of board-marked textures, and of smooth or rough surfaces, as shown in *Figs. 18–26*, had been widely discussed in Europe and, even more, in the United States, during the years between the two wars. The ideal structure would have a surface finish with no coating at all, and a treatment adapted to the design of the structure. The Author had rightly emphasized the importance of producing a good concrete material, whatever subsequent treatment of the surface was to be adopted. At the same time special attention should be devoted to the design of an unexceptionable formwork.

The Author's recommendation that the mixing-plant should be installed as near as possible to the point where the concrete was being deposited did not apply to ready-mixed concrete, as successfully used in the construction of the 595-foot-span arched Tranebergssund bridge at Stockholm (built in 1935), shown in *Fig. 18*. The main feature of that work, besides an excellent formwork, was a far-reaching control of the concrete-making in a factory not very near to the construction-yard. The concrete, transported in special watertight trucks with agitators, had to be deposited not later than 1 to 2 hours after mixing.

The Author had advocated that the designing engineer should consider very carefully where the contractor was likely to make construction joints, and that he should indicate at elevations the exact positions of those joints throughout. Whilst Dr. Probst agreed that the designer should specify very closely the surface treatment to be employed, he was rather doubtful whether a useful purpose would be served by asking the contractor to observe the exact position of such joint, because it was not always

possible to indicate in advance where the concreting was to be interrupted. Much depended upon weather conditions, so essential to the progress of the construction. If the desired co-operation existed between engineer, architect, and contractor, it would not be necessary to fix the construction joints in the drawings, and experience had proved that no difficulty was found in producing such joints as strong as they ought to be. On the other hand, details of shuttering and formwork, as well as the method of finishing concrete structures, could and should be decided upon before construction was started.

Dr. W. L. Lowe-Brown observed that several speakers had referred to the Author's suggestions for securing good horizontal joints, namely :—

(1) roughening the surface of the old concrete ;
(2) cleaning and wetting ;
(3) applying a layer of mortar to the wetted surface before beginning to place concrete.

The necessity for the first depended upon the nature of the surface on which the new lift was to be laid. If the previous lift had been deposited wet, and if the interval between lifts had been long enough for the laitance to have become quite hard, roughening in addition to a key was very important. Dr. Lowe-Brown did not question the advantage of the second step. The need for a layer of mortar depended upon the wetness of the mix. He considered that with a good dry mix it was definitely beneficial to use mortar. His opinion was based upon the following experience, in constructing a tunnel lined with mass concrete with wall approximately 20 inches thick and a mixture of 1 : 3 : 5 made with crushed granite aggregate to pass a 2-inch ring, and kept rather dry. The invert was placed first, leaving a horizontal joint at the base of the curved side-wall. There was usually an interval of a week or more before placing the side-wall. The concrete of the side-walls was well worked and the resulting face was first-class. After the forms had been removed leakage occurred at many points along the joint between the invert and the side-walls where the tunnel was below ground-water level. To stop that leakage the concrete was cut away and replaced by a stronger mixture. At every point where that joint was exposed, it was found that the concrete at the face, which had been thoroughly worked to get a good surface, was quite dense, but the back portion for a depth of 3 inches or more was almost invariably slightly honeycombed. Since then he had noticed similar honeycombing at the joints wherever concrete walls had been cut away and a section of a joint exposed. That led to the conclusion that it was much more difficult to work the concrete properly at the bottom of a lift where the tools used for that purpose came in contact with the hard surface of the previous layer than higher up where the coarse aggregate could be worked into the quaking mass. To overcome that difficulty Dr. Lowe-Brown always specified a layer of 3 inches of comparatively soft mortar at the bottom of each lift,

so that the coarse aggregate above could be worked into it and so start the mass quaking and produce conditions similar to those which would automatically occur higher up in the lift.

Mr. E. E. Morgan observed that when a Paper giving particulars of the results of scientific research was submitted, the first thing the practical engineer did was to see whether, and to what extent, the results presented were capable of direct application under modern conditions of engineering practice.

Whilst the Paper contained much information of exceptional practical value, the Author had omitted to give any information on one very important point, namely, the workability of the concrete. Could he say what degree of workability was used, preferably in terms of the compacting factor, since that appeared to be the only suitable standard that could be used as a measurement of workability ? Would he also state which water/cement ratios were found to be satisfactory for any tests that might have been carried out on the more common aggregates, such as granite and gravel, and what were the maximum sizes used ? Were the variations in the gradings of the fine aggregate referred to on page 185, *ante*, those that were common in the natural sands ?

It was reasonable to infer that for most works it was the Author's intention that the concrete which was used against the shuttering would also be used in the main structural members. With modern conditions of control to produce within close practical limits a mix having a specified water/cement ratio, it should be possible to design the mix so that not only should it have the required specified minimum strength, but also that its workability should be the most suitable for obtaining a satisfactory surface without risk of honeycombing or segregation. As the test-pieces were compacted by vibration, it would be necessary to use vibratory methods in the structure itself for the same workability. Even if that were not possible, the workability could be adjusted to allow for hand-compaction, using the Author's figures as a guide. Could he recommend a suitable degree of workability in terms of the compacting factor for concrete surfaces where compaction was carried out by hand ?

On page 191, *ante*, the Author had stated that " the slump of the mix to be used for the various portions of the work should be clearly stated in the original specification." Remembering the extreme difficulty of controlling the water-content of the concrete by means of the slump test and the fact that a 1 : 2 : 4 mix by weight, having a water/cement ratio of 0·62, might produce slumps ranging from about 1 inch to 6 inches, or even more, according to the nature of the slump—Mr. Morgan's information was confirmed by a publication issued by the Department of Scientific and Industrial Research—was the Author confident that any very satisfactory results would be obtained by that method of control ?

Mr. Morgan suggested that although the compacting factor apparatus was not yet available as a yardstick for measuring workability, the Author

would be quite justified at the present time in recommending that the required degree of workability should be regulated by proportioning the mixes by weight, adjusting them as required to compensate for the water in the form of moisture which was included in the weight of the aggregates and working to a definite water/cement ratio. That method had been carried out with complete success on road and other works by the Surrey County Council for several years with little, if any, additional cost.

Mr. H. E. Steinberg observed that the subject had been thoroughly investigated during the past 25 years, and it was a tribute to the Author that he had found something novel and stimulating to say about it.

In order to obtain a tolerable surface finish straight from the shuttering, it was essential to have vertical stopping-off boards against which the concrete could be properly punned. Work such as was shown in *Fig. 30* should never be tolerated, and it was difficult to understand how, in that case, such a large area of wall could have been done without someone in authority changing the contractor's methods.

Vertical joints could be easily dealt with by stopping-off boards, and became almost invisible, but horizontal joints were more troublesome. The suggestion to stop the concrete temporarily behind small taper battens, as illustrated in the Paper, had emanated from Mr. Steinberg's office about 15 years ago, and had been widely and successfully adopted. He suggested, however, that it was not practicable to fix in advance the positions of stopping-off points on work of any size, as that depended upon the type of plant installed by the contractor, the number of men employed, the length of the working day, and the caprice of the weather.

The references to the Twickenham bridge, in the design of which his Company had collaborated with Mr. Maxwell Ayrton, were interesting, but there were several other different types of surface finishing on that bridge from which useful lessons could be learnt. One of the most satisfactory surfaces had been obtained by the use of uncrushed flint aggregate of small size, from which the surface cement had been rubbed away with rough canvas and water before thoroughly set. The resulting concrete was smooth to the touch, as well as pleasing in appearance. The bridge had been in existence about 12 years, and no unsightly defects had developed. The soffits of the arches were cast on ply-wood shuttering, and subsequently lightly bush-hammered. There was no patching.

Chiswick bridge was done at the same time, in collaboration with Sir Herbert Baker, A.R.A., but in that case most of the visible surfaces were faced with Portland stone. The soffits of the arches were also cast on ply-wood and bush-hammered after removal of the shuttering. The workmanship was not so good as at Twickenham, but nevertheless the result was above the average.

Mr. Steinberg agreed with Sir Leopold Savile that it was inadvisable to grout the horizontal surfaces, where concreting had been temporarily stopped. Usually it was not practicable to rake the concrete at those

points, owing to the quantity of reinforcement, and to the fact that the shuttering to the back and front surfaces was usually in position.

The Author, in reply, expressed his thanks for the very kind reception which had been given to his Paper. He considered that the main purpose of roughening horizontal joints was to remove the laitance film, which, if left on the concrete, prevented a good bond to the new work. Removal of laitance scum was obviously desirable; it could be removed soon after deposition of the concrete, that was after the initial hardening—the next day or the day after—by wire-brushing. The operation also served to expose the new aggregate and so obtain a better bond. If the concrete was very hard, wire-brushing would probably not be sufficient and resort to bush-hammering or scarifying would be necessary.

He agreed that the use of too much mortar might be detrimental in causing a shrinkage crack to develop in the rich mortar layer. With leaner mixes for mass work it was important to put in a thin layer of mortar. Mixes of 1 : 1½ : 3, or richer, were already fairly heavily loaded with mortar, and probably the extra mortar against the joints was not so important.

He had dealt with the subject elsewhere [1], and the conclusions arrived at were, briefly, that if the concrete had been placed for more than 4 hours, but not longer than 3 days, the surface should be cleaned and the laitance film removed by wire-brushing and by thorough washing with clean water; it was inadvisable to disturb the surface of such concrete by bush-hammering or scarifying unless the concrete had become exceptionally hard. A layer of cement mortar of similar composition to that embodied in the new concrete should then be applied to the prepared surface and should be followed at once by the new concrete, which must be well tamped into position. If the concrete were more than 3 days old its hard surface should be roughened and cleaned by bush-hammering and wire-brushing and thoroughly washed to remove all loose particles; a slurry of neat cement should then be brushed upon the prepared surface and well worked in; a layer of cement mortar of similar composition to that embodied in the new concrete should then be applied before the slurry dried and should be followed immediately by the new concrete, well tamped towards the joint.

The results produced by the artificial weathering machine were purely arbitrary, and could not pretend to reproduce the conditions on any one or more sites, but it had been found that they corresponded fairly closely with the conditions in an industrial town, which happened to have a fairly heavily polluted atmosphere. He did not consider that the weathering-machine could be used for ascertaining how a particular concrete specimen

[1] "Construction Joints in Concrete", Building Research Special Report No. 16, 1930; "Bonding New Concrete to Old", Building Research Bulletin No. 9, 1930.

would weather, for example, in Birmingham or Leeds or Sheffield, because the degree of weathering would vary with the pollution of the atmosphere. The weathering-machine was useful, however, in helping one to say whether one mix with a particular type of aggregate was likely to stand up better than another; it was therefore a method of pre-selection.

Dr. Anderson had referred to concrete becoming dirty and to the indications in *Fig. 7* that all the concrete showed a common level of dirtiness after a few years. That was quite true, but the point which was not brought out in the curves was that some concrete, although it became dirty, did so uniformly. For instance, it had been found that whilst a bush-hammered granite concrete became very dirty its appearance was not objectionable, because it weathered uniformly. That made a considerable difference; slight griminess did not matter so long as the concrete maintained a uniform appearance; it was streakiness or patchiness in the concrete which was objectionable.

He was sorry that he was unable to give Mr. Wallace much more information about absorbent linings for concrete shutters than was contained in the Paper, which had been prepared a few months previously. That development was in an experimental stage. Just recently, however, he had seen in an American journal an advertisement of absorbent linings for shutters, and he assumed that the linings had now come on to the market; they were very similar to absorbent wallboard. He had carried out a few tests at the Building Research Station, and had found that absorbent lining certainly produced a very fine mat surface for concrete and prevented the formation of the objectionable laitance.

With regard to the position of the break in *Fig. 13*, he agreed with Mr. Wallace that that should be as near the top of the recessed joint as possible.

In reply to Mr. Morgan the water-content of the 1 : 2 : 4 concrete with different types of aggregate used for the series of tests described in the Paper was as follows:—

Portland stone aggregate	0·90 (by weight of cement).
York stone	0·90
Welsh granite	0·60
White marble	0·60
River gravel	0·60

The slump varied between 1 inch and 2 inches. The coarse aggregate was graded to give 66·7 per cent. by weight between $\frac{3}{8}$ inch and $\frac{1}{2}$ inch and 33·3 per cent. between $\frac{3}{16}$ inch and $\frac{3}{8}$ inch. The fine aggregate contained equal proportions by weight of material between the following sizes:— No. 7 sieve to $\frac{3}{16}$ inch, No. 14 to No. 7; No. 25 to No. 14; No. 52 to No. 25; and No. 100 to No. 52. The straight-line grading of the fine material might be taken as a fair average between naturally occurring sand and stone artificially crushed. Generally, natural sands would contain a

rather higher proportion of material below No. 25 sieve, whereas those artificially crushed might be expected to contain a lower proportion.

With regard to the degree of workability in terms of the compacting factor which should be used where compaction was to be carried out by hand, the Author considered that the compacting factor should not be less than 0·92. Whereas he agreed with Mr. Morgan that the compacting-factor test developed at the Building Research Station was possibly a more scientifically accurate method of judging the workability of a concrete mix, particularly if changes in the grading of the aggregate were likely to occur, he regretted that the slump test had not been more frequently used in Great Britain. He felt certain that, despite its limitations, much of the poor work that had been carried out might have been avoided by its use. It was probably correct to say that no other single test had contributed more to the production of good concrete than the slump test; in America, particularly, it was still regarded as a reliable measure of the relative water-content of mixes, but only within certain limits of concrete workability and provided other variables, such as batch weights, grading of the aggregate, and temperature of the mix remained practically uniform.

He also agreed that to obtain the best results materials should be proportioned by weight. It had always been the practice to do that at the Building Research Station, and every endeavour had been made to encourage others to do so.

He did not think that Mr. MacDonald need be afraid that metal spraying would ever be used for large surfaces. It was expensive, and it had been used only for decorative relief.

He wished particularly to thank Mr. Newton and Mr. MacDonald for the kind remarks which they had made as architects.