

less constant, such as staging, plant depreciation, and so on. These will be found to form a considerable proportion of the total cost. In addition, it will frequently be found in jetty works that the outer and more accessible bays are complicated by the provision of raking struts, whilst the bays farther from the berth face are free of these but call for longer runs of hose and other compensating factors. All these considerations preclude the use of a costing system based on area or volume of material placed; by taking units of deck area of the structure under consideration, some figure will be reached on which reasonable reliance may be placed.

In the present case, the cost of each season's work has been calculated on the basis of superficial feet of deck-area of the structure affected, including labour, material, and plant depreciation. In the 1936-1939 period this cost worked out at between $10\frac{1}{2}d.$ and 1 shilling per superficial foot. In comparison, the reconstruction in slightly heavier sections of reinforced concrete of a portion of the 1893 quay cost, in 1938, complete with rails and crane track, £1 2s. 6d. per superficial foot.

ACKNOWLEDGEMENT

The Author wishes to acknowledge the help and encouragement given by Mr. M. G. J. McHaffie, M. Inst. C.E., Chairman of the Works and Harbour Committee of the Southampton Harbour Board, and by Mr. E. E. Mann, M.Sc., Assoc. M. Inst. C.E., of University College, Southampton, who read and criticized the original draft Paper.

The Paper is accompanied by six sheets of drawings and six photographs, from which the figures in the text and the half-tone page plates have been prepared.

Discussion.

The Author introduced the Paper with the aid of a series of lantern-slides.

Mr. H. D. Morgan observed that he was particularly interested in the work described in the Paper because he had had some experience of similar work which had been carried out by Sir William Halcrow about fifteen years ago on the Whitehead Torpedo Company's firing range at Portland Harbour. Water had penetrated the concrete columns and considerable corrosion of the bars had occurred, whilst the concrete had been split off in all directions and many of the links had to be replaced before the guniting was done.

Recently he had had an opportunity of inspecting a reinforced-concrete pier constructed by the late Mr. C. S. Meik in 1904, which was a very early date for reinforced concrete, and had found it to be in remarkably good

condition. A brown line was showing here and there in the columns, in line with some of the bars, and when that occurred the practice was to cut the part out and make good. The pier had been very well maintained, and remarkably few of the columns had had to be treated. It had to carry greater loads than formerly, as heavier cranes were being used, and small modifications had been made in order to strengthen the deck, but the original columns had not been altered.

With regard to guniting beams, Mr. Morgan considered that one could not hope to restore bond by applying gunite, and surely successful results from the point of view of development of stress, could be expected only when—as was usual—the bars were well anchored. When they were lapped over the supports they could still be effective, but the kind of adhesion that was obtained in a normal reinforced-concrete beam could not be restored. The factor that made repair possible was that, as a rule, the bars were well hooked deep into the concrete, where that kind of damage did not take place.

He wished also to refer to a jetty, at Alderney, on concrete cylinders, which had been constructed in about 1906 by a person whom he could only describe as an enthusiastic amateur and who had seen reinforced-concrete construction, but was rather a business man than an engineer, and had built the jetty in order to export stone from the island. Although the island contained some of the finest stone in the world for aggregate, yet the whole of the concrete had the texture of a slight sponge cake. It could be penetrated by water anywhere, and at every beam and column it had been split off and was lying about on the ground. No concrete was left covering a bar, except just over the columns, where it had been deeply buried. That jetty was an extraordinary sight and formed a complete contrast to the pier built by Mr. Meik, where there had been proper supervision of the type of concrete and of the cover.

He agreed with the Author's view that for sea structures 2 inches of cover should be provided; and even then the concrete work should be very well supervised.

Mr. Jack Duvivier observed that he had been very interested to hear Mr. Morgan's harrowing story of the Alderney jetty, because it had been his experience that enthusiastic amateurs, when constructing reinforced-concrete structures, invariably buried their reinforcement on the neutral axis. That was a very good idea from the point of view of cover, because it gave the maximum, and he was surprised at the condition of the Alderney jetty.

In watching the slides shown by the Author, he had been struck by the horrible condition into which reinforced concrete could get when it had been subjected to tidal action over a period of years. When the engineer inspected the structure shown in the slides, he must have found it very difficult to decide whether to pull it down and start again or to undertake some other form of treatment.

In 1937 or 1938 Mr. Duvivier's firm had been requested by the Newlyn Harbour Commissioners to report on the reinforced-concrete quay which had been constructed in about 1906 or 1907 along the north pier. It was an interesting structure, and he believed it was one of the first reinforced-concrete structures built in Great Britain. The Commissioners had taken rather a gloomy view of the situation and had asked for an estimate of the cost of filling the structure solid. As that estimate amounted to about £23,000, the possibility of repairing the quay by gunite was investigated, and a contract was made for encasing the whole of the underside of the decking with gunite. The work was done in the summer months—the most suitable time for marine work. The decking consisted of cross deck beams with slabs spanning the spaces between the beams, surfaced with granite sets. Gunite $1\frac{3}{4}$ -inch thick was applied. The sand was a mixture of equal volumes of $\frac{1}{8}$ -inch Penlee chippings, $\frac{1}{16}$ -inch downwards Penlee crushed grit, and some Falmouth sand. The proportion passing a standard sieve with 50 meshes per linear inch was less than 20 per cent. The work comprised 4,800 super feet of $1\frac{3}{4}$ -inch reinforced gunite, and also involved the construction of about seventy new raking members, consisting of 6-inch by $3\frac{1}{2}$ -inch steel channels totally encased in $1\frac{1}{2}$ inch of reinforced gunite, with a few repairs to the solid masonry pier. The total cost was about £930. The surface finish was the natural characteristic gunite finish and it was not touched by a trowel. Light timber shooting strips were fixed along the corners of all the beams, to assist in obtaining reasonably true lines to the finished work. The reinforcement consisted of square-mesh 8-gauge-diameter rods at 3 inches apart centre to centre in both directions, and rustless "Crapo" wire was used for the binding. The fabric was supported by means of Rawlplugs drilled into the concrete at 3-foot centres in both directions. Mr. Duvivier had not seen the work since its completion about 8 years ago, but he had been informed that it was in as good condition now as when it was carried out.

He hoped that in the course of the discussion some information would be forthcoming with regard to the encasement of greenheart or jarrah piles with gunite. His firm had been faced with a good deal of that kind of work in the maintenance of rather old timber structures in which the timber had been very severely attacked by *limnoria*, particularly around the bolt-holes, which invariably became enlarged and allowed the *limnoria* to get down between the bolts and the timber, rendering maintenance very difficult. The usual practice, when dealing with small jobs, was to encase the joints in mass concrete; but in the case of a timber jetty of any size it was well worth while to encase the joints and the main body of the piles in gunite; and he would welcome any information in regard to carrying out such encasement of timber.

He questioned whether reinforced concrete structures exposed to maritime conditions should ever be allowed to get into the condition of the Southampton quay and the other structures illustrated by the Author's

slides. In the early days of reinforced concrete it used to be said that the material was practically permanent, and he supposed that was true to some extent, inasmuch as if a structure was built up of pre-cast members made under controlled conditions and vibrated, so that it was possible to maintain the correct amount of cover and spacing and a sufficiently dense concrete, the structure would probably require no maintenance at all. On the other hand, it was a lamentable fact that the bulk of reinforced-concrete structures which were built in situ between tides began to deteriorate after a few years. What usually happened was that binding wire was left projecting through the side of the member and insufficient cover was maintained between the reinforcement and the side of the mould, and sometimes there was insufficient tamping. The result was that usually after about nine or ten years extensive maintenance work had to be carried out.

It was the duty of his firm to maintain a number of old reinforced-concrete structures for the Royal National Lifeboat Institution, some of which had been in existence for thirty years or even longer. Those structures were visited and examined every third year, and it was usually found that some of the beams were beginning to show signs of splitting—generally longitudinal cracks along the line of the main reinforcing-rods, and rust spots. The rust spots were cut out and the cracks opened out to a sufficient depth to enable a fairly stiff mortar to be trowelled in and pointed up. That kept the structures in a reasonably good condition, and no major gunite repairs had been necessary so far. Admittedly some of the structures were found to have deteriorated so badly that it was necessary to break away the concrete from the bottom of some of the beams. In that case the whole of the concrete was cleared away to some little distance behind the main reinforcement, the rust was chipped away, and the base of the member was completely remoulded. In the past, a method of coating reinforced concrete, by applying a mixture of sal-ferricite and aluminous cement had been tried. The mixture was in the form of a paste and was brushed on to the reinforced concrete. Mr. Duvivier had visited a number of structures which had been treated in that way and had found that the mixture acted as a very valuable coating, which prevented moisture attacking a member and causing it to deteriorate. The specification was as follows: "The concrete to be thoroughly cleansed and damped down with water. Apply with a stock brush a slurry composed of 3 parts of *ciment fondu* and 1 part of sal-ferricite by volume, plus sufficient water to form a creamy mix. This gauging should be evenly and thickly brushed over the concrete, taking precautions to see that the material is well stirred during its use so as to prevent any settlement occurring."

Mr. J. E. Goode observed that concrete was not foolproof. Ninety-nine per cent. of it was permanent, and it was only the remainder that gave trouble to engineers.

He was interested in the reasons suggested for the failures that had occurred, including electrolysis, which apparently occurred whether the

concrete was wet or dry or alternately wet and dry. He had had experience in India, Europe, and America, as well as in Great Britain, and he had found that in all cases the deterioration occurred between high and low water. Could the Author explain how the electrolysis took place, or its effect in comparison with that of salt water penetrating to the steel and rusting it, the steel then drying out, and then salt water penetrating again?

In Mr. Goode's experience lack of sufficient cover did not apply except in the case of the stirrups, which were usually put on the outside. Owing to insufficient cover, they deteriorated and rusted and burst away the concrete; but the main bars were nearly always behind the stirrups. He considered that most failures were due to porous concrete, insufficient tamping, or trying to get the concrete in too wet.

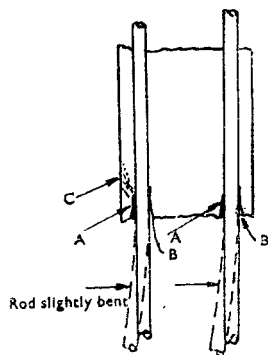
In his opinion, $1\frac{1}{2}$ inch of gunite on an overhead surface was too much; $\frac{3}{4}$ inch should be used on overhead surfaces and up to 2 inches on vertical surfaces.

The encasement of wood piles in gunite had been adopted extensively on the Pacific coast of America. In many cases the piles were covered with gunite before they were driven. It was then necessary to adopt a method of lifting them up without cracking the gunite, but no damage was done in driving them.

Mr. S. C. Carter observed that it was not clear whether the Author invariably removed all the concrete from behind the reinforcement or if he sometimes gunited with, say, half the rod exposed. It appeared to be rather risky to apply a covering over only half the bar, because the adherence of the gunite material would not be so good. Had the Author ever confined the guniting to part of the surface of the rod and not placed it right round.

Fig. 13 showed a section of a pile. It appeared to be rather drastic treatment to beat off the initial rust with a heavy sledge-hammer, especially

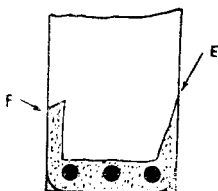
Fig. 13.



because there was always a tendency for the bar to bend slightly and to crush the concrete on side (A) rather badly and to leave a gap on side (B); moreover, the use of a heavy sledge-hammer might cause minute cracks at (C), which would never be filled by gunite. Similar remarks applied to beating off damaged concrete with a sledge-hammer. That treatment was too drastic, because it might bruise the surface of the concrete into cracks so fine that the concrete did not come away, but through which moisture would percolate in years to come and corrosion continue.

The Author had referred to flaky edges such as those shown in *Fig. 14*. They always presented difficulties, because there was a tendency for the

Fig. 14.



gunite to crack again on the plane (E). From experience of all kinds of masonry repairs, Mr. Carter would never expect gunite to stay on a thin wedge. He suggested that it was best to cut in with a dove-tail formation (F), so that the new material had a key. It was true that, in the case of a large reinforced-concrete structure, that would involve much work; but he would, at all events, endeavour to cut a square. The work should be finished with some kind of a key, even if only rough-cut. Admittedly that was very expensive, but he would consider it worth while.

The work at Southampton had been done by direct labour, but such repairs were very often carried out by a specialist firm. Such firms did wonderful work and they had considerable experience, but he thought that they had a tendency, on account of that experience, to lay down the law on how the work should be carried out, whereas a contractor, doing a straight job on drawings and specifications, would be less inclined to dogmatize. The engineer in charge of the job and responsible for the expenditure, should know in his own mind exactly how far he would let the contractor go—in other words, what he would allow and what he would not allow. In work of the kind in question, the engineer should not be guided entirely by the experience of a firm, but should have his own views on the matter.

Mr. A. Jackson observed that the success of the remedial treatment in question depended principally on two operations, namely the fixing of the reinforcement and the application of the gunite. The former was often regarded as a minor operation, but it was really one of the most important. Whereas the Author had relied on fixing the reinforcement,

in the case of piles, to the corner bars, Mr. Jackson considered that it was better to fix the reinforcement to the face of the piles. Wherever the gunite was applied, the force of its application produced a rebound effect, which had a tendency to lift the reinforcement back towards the face of the gunite, and there was a danger of that happening in the case of a 16-inch pile which had reinforcement fixed only at the corners. Moreover, when the gunite was applied, again there was a tendency for the binding wire to be "lifted" out towards the face of the surface coat of the gunite, which eventually caused rust spots. The use of a rustless wire for binding would save much trouble.

With regard to the shooting strips, he considered that the right course to adopt was to put light shooting strips at the corners of the beam. For instance, it was possible to put two light shooting strips at each corner, fixed on to the existing bars; to shoot in between them and obtain the thickness without any fear of rebound; and then to remove the strips and complete the operation round the sides and the corners. Especially in the case of a pile, shooting strips were useful from the point of view of cover. The cover could not be tested by taking the depth of the original surface, because at that particular portion of the pile the deteriorated concrete had been cut away and, wherever the trial was taken, the depth behind the original structure was unknown. Therefore, it was much better to bring the whole thing out to the dimensions that one knew were covering the corners. Without shooting strips the only satisfactory method was to stop work and cut the gunite out while it was still unset and re-shoot it. The shooting strips did not affect the question of rebound, and they gave a very pleasing effect; the structure might look even better than in its original form.

With regard to rust spots appearing after guniting, cutting out and re-shooting was feasible, but it was very difficult. Mr. Jackson had tried many times to cut out a 2-foot square panel with a 1-inch rendering of gunite. It was a very hard dense material, and an attempt to cut it out invariably shattered the surrounding material and cracked it. If one cut out a small rust spot, one got rebound into it when one re-shot it. The Author said that the gunite process lent itself to easy repairs, but Mr. Jackson thought the process should be carried out in such a way that repairs were not necessary.

With regard to the repair of timber piles by guniting, his firm had had considerable experience of that at Blyth and Plymouth. The Blyth job was a very straightforward one. They had used $1\frac{1}{2}$ inch of gunite with very light mesh tacked to the timber and had gone down to within 1 foot of low water. There was very little, if any, wave action, and the method proved to be very much more economical than the shuttering and pouring which had been used before. He had seen the work six years after it had been done, and it was then in good condition. The timber pile jetty at Plymouth was rather different. It was very much decayed, so extra

reinforcement was introduced, and gunite was used successfully. He thought there was very great scope for gunite work in the protection of timber jetties.

He agreed with the Author that gunite repairs should be examined and reported on and all the data obtained, because if they were to be a success it was necessary to have experience on which one could depend.

Mr. G. M. Treharne Rees observed that gunite had been used during the construction of two of the large "Phoenix" units of the Mulberry harbour. The two units had been built in the Dockyard at Portsmouth, and Sir William Halcrow & Partners had been the Consulting Engineers. Concrete of insufficient soundness was found near the bottom of the swim ends, and it was decided to cut those out. The concrete was in the sloping portion, which was leaning at an angle of 30 degrees to the horizontal, so that the work was not easy. It was all overhead work to replace the concrete. The areas were extensive, and it was found necessary to cut 13 inches into the work when cutting out. In some cases the areas extended behind the second row of reinforcing-bars. Gunite was applied and the whole of the damage was made good. The maximum thickness of layers that could be applied was used; in fact, the gun continued to be used until each layer more or less flowed. That had to be done, because it was necessary to adhere to a time programme. In order to ensure that the gunite which had been applied in such thick layers was satisfactory, four sets of cubes were made, with three cubes in each set. Each cube box was placed on its side and half filled with gunite making a 3-inch layer in the bottom of the box. That was allowed a few hours to set, and then the rest of the cube was filled in an upright position. When they were crushed at 4 days the four cubes showed an average strength of 3,677 lb. per square inch, indicating that the strength was sufficient. In order to test the bond between the concrete and the gunite, one cube was half-filled with 4-to-1 concrete from the unit and left for 3 days to set. Then, after the surface had been just scratched over, the cube was filled with gunite and was left for 4 days to set. The cube was then crushed and showed a strength of 2,800 lb. per square inch. It was interesting to watch the crushing. The concrete, which had been maturing for 7 days was observed to crush before failure appeared in the gunite. The cube was crushed on its side and no failure appeared at the junction of the two materials.

After using the extreme thicknesses of gunite and watching it carefully, he agreed with the Author that not more than 2 inches should be applied at a time. He would prefer 1 inch or $1\frac{1}{2}$ inch, but in the case to which he had referred the work had to be done against time and the maximum permissible thickness was applied.

Had the Author any details of the test-cube which showed a compressive strength of 10,000 lb. per square inch at 7 days? That strength seemed to him rather extraordinary, and he would like to know whether the conditions were special. Obviously it was a laboratory specimen; he considered

that test-cubes should be taken under the conditions under which the work was carried out.

Further, had the Author any figures in connexion with the waste of material in applying gunite. In the case to which Mr. Rees had referred the gunite was applied in an overhead position and when the work was finished a large quantity of gunite aggregate—at least 30 per cent., and perhaps 50 per cent.—appeared to have rebounded from the work on to the floor of the dock. The quantity was difficult to judge owing to broken concrete from the faulty work also lying on the floor.

The Author had stated that dry sand was not essential; but unless the nozzleman was extremely skilful the sand should be very nearly dry, because the slightest excess of moisture in the sand made a great deal of difference with regard to the adherence of the material.

Mr. G. E. Scott observed that it was often said that engineers learned more from their failures than from their successes. Many engineers had avoided the use of reinforced concrete in salt water, but the introduction of gunite had brought to light a method of repairing the defects which occurred when reinforced concrete was used in salt water. In his own limited experience of sea-water structures he had had several cases of bad failure of reinforced concrete, not only in the tropics in sea-water, where conditions seemed to be especially bad, but also in bridges over brackish tidal creeks. The failure of reinforced concrete appeared to be due, as had already been mentioned, to electrical currents, possibly caused by the action of the salt water on the iron. That was surely a matter for chemical investigation. He believed that the Sea Action Committee of The Institution had had the subject under consideration to some extent, but no Report had been issued by that Committee for some time.

Had the health of the men working the nozzles been affected in any way? Silicosis occurred in various other trades, and it seemed possible that the workmen using the nozzles might be liable to be affected by the combination of cement and sand.

When structural members of reinforced concrete were practically dismantled and reconstructed with gunite, the strength might be considerably affected; had the Author carried out any tests on the strength of such members after they had been repaired?

Mr. A. G. Orr-Ewing observed that, with one small exception in Italy during the war, the works upon which he had used the cement-gun had not been connected with maritime structures.

The job on which he had had occasion to make the greatest use of gunite was the construction of underground oil-fuel storage reservoirs. The internal face of one long reservoir had been entirely lined with gunite, in order to render the original concrete lining even more impervious to the seepage of Diesel oil, which it eventually held, and in all the remaining reservoirs of the installation the construction joints had been given a sealing of gunite.

The Author had stated—and most users of gunite would agree—that absolute dryness of the sand was not essential; but in practice, it seemed rather dangerous to allow that impression to gain ground, particularly where the sand was being supplied on site by someone who was not connected with the gunite company. The tendency was then to assume that the dryness of the sand did not matter at all, with the result that choking occurred in the gun-to-nozzle tubes, especially if the lead was more than 100 feet and if the lifts were high. In the case of the underground oil-fuel storage reservoirs to which he had referred, the lifts were high, because the reservoirs were 30 feet high to springing of the roof arching, with a further 15 feet approximately to the soffit. He considered that it would be better to insist on a limiting moisture-content for the sand, and to fix that limit so that no loss of cement would occur during the processes of mixing and placing the sand and aggregate into the machine.

What grading of the sand used at Southampton had been found to give the best results? The sieve analysis of the sand used on the reservoirs was as follows:—

Size of sieve	$\frac{3}{16}$	$\frac{1}{8}$	$\frac{1}{16}$	30	50	100	F.M.
Percentage retained . . .	Nil	5.9	23.97	60.3	92.5	98.7	2.82

It was observed, however, when shift to shift sieve analyses were taken, that the best compaction and the least rebound were obtained when the sand-content was mainly between $\frac{1}{8}$ and $\frac{1}{16}$, and eventually stock-piles of sand of that size were brought in and added to the incoming sand as found necessary. The grading of the sand as finally used was as follows:—

Size of sieve	$\frac{3}{16}$	$\frac{1}{8}$	$\frac{1}{16}$	30	50	100	F.M.
Percentage retained . . .	0.6	16	43.8	60.3	92.5	98.0	3.00

Mr. Orr-Ewing considered that the preparation of the parent face was one of the most important parts of the operation of guniting. At Southampton the preparatory work had not, apparently, involved the cutting of many chases which were narrow in comparison with their depth, so that perhaps the formation of pockets, due to the whirl or the eddy of the sand in such confined spaces, had not constituted a major problem. In the storage reservoirs, where many thousands of feet of construction joints were sealed, the formation of pockets due to the rebound had certainly constituted a problem, and it had been found that, unless the chases were splay sectioned with all angles rounded, pockets were liable to form. The use of dovetailed cuts, or of right-angled cuts with sharp edges, was therefore carefully avoided. In the case of the reservoir which was lined throughout with gunite, the entire internal face was scarified to a depth of 1 inch and was then cleaned with an air-and-water jet, and the reinforcement, which was of exactly the same gauge and mesh as that used by the Author at Southampton, was then slung on the dowel-pins let into the concrete and fixed at about $\frac{1}{2}$ inch from the parent face, so that when the gunite

was applied its building up forced the reinforcement out to approximately 1 inch from the finished face of the gunite. No sand-pockets were found even when the gunite was sounded or when parts were cut away for observation.

With regard to finishing of the day's work, Mr. Orr-Ewing's practice had been to finish to a feathered edge and then to cut away that edge to give a depth of about $\frac{1}{2}$ inch, but he regarded that as rather wasteful. Had the Author found that a satisfactory bond could be obtained by building up on a feathered intermediate finish?

Mr. J. E. G. Palmer observed that the Author had stated: "Gunite is, therefore, a concrete having virtually zero slump." Mr. Palmer preferred to think in terms of the water/cement ratio, and he believed that a zero slump corresponded to a water/cement ratio of 0.45. He considered that it would be very difficult to measure the water/cement ratio of the gunite as deposited, but if the Author had made such a measurement, it would be interesting to learn the figure that had been obtained.

He wished to congratulate the Author on the fine set of photographs that he had obtained in very difficult circumstances. *Fig. 6* showed a raking strut with the whole of the concrete cut right through and just the four bars remaining at the construction joint. How had the Author set about guniting that completely blank space?

On a job carried out by the Admiralty, on a jetty near Portland (he did not know whether it was the jetty to which Mr. Morgan had referred), the gunite repairs were started in 1934, but the system was given up because it was found that so much of the old concrete had to be cut away, and the damaged parts of the jetty were eventually rebuilt completely. A considerable area was, however, covered before the system was abandoned, and the cost worked out at 5s. per square foot of gunite.

Mr. Treharne Rees had raised the question of the waste due to rebound. In the case of a concrete oil reservoir near Rosyth it was found that the loss of aggregate due to rebound amounted to 25 per cent.

Another repair job was at the Crombie jetty, which was built in 1915 from good quality concrete, but there was only $\frac{3}{8}$ -inch cover to the stirrups, so that repairs had to be started about 1920. For many years the method of repair adopted was to cut away and re-concrete, a granite aggregate being used. The cover given was $2\frac{1}{2}$ inches, and the work was first class. In 1938 and 1939 repairing with gunite was started, 2 inches of cover being given, and that work also was first class. The density, however, was 10 per cent. less than in the case of the former repair, the reason being, he thought, that in the former case a granite aggregate was used and in the latter case only sand. The gunite work had been done for only six years and it was considered to be too early to judge whether it was successful or not, because the protection which the gunite had given was possibly due to a very fine hard surface finish, and the old reinforcement at the back might still be rusting.

Mr. A. S. Grunspan observed that he had had a good deal to do with certain land structures—bunkers and water towers in rather exposed positions—which had suffered a fate somewhat similar to that of the structures illustrated by the Author. A bunker, 114 feet in height, in a colliery, was subjected to sulphur fumes and moisture, with the result that it got into a condition similar to that described by the Author, and in some places even worse, because some of the bars of the columns had buckled and the links surrounding the column bars were completely eaten away. The method of repair adopted was to cut away the bad concrete and insert new links in two halves U-shaped, in addition to new vertical rods.

The columns were 30 inches by 27 inches. In addition to the above, on one of the faces, where the concrete had not been so badly damaged, a fabric of a specification similar to that given in the Paper was dowelled to the concrete. A very satisfactory job had been made of the repair. On inquiring how long the structure had been in the state in which it was found just before the repair was carried out, he had been told that it had been so for some considerable time. In contrast, a water-tower on which work was started at a very early stage of the deterioration had needed very little repair.

Preparation was very important. There was a tendency to be satisfied with too little hacking; but Mr. Grunspan considered that the concrete should be very carefully hacked and in some cases re-hacked even after the fabric had been erected, whilst it should be very carefully cleaned. The most important point was to get the rust off.

One lesson to be learned from the failures which had occurred was that it was advisable to design the column with the core to take the full load, without any cover.

Mr. R. P. Mears observed that apparently the trouble in the piles and beams occurred at the corner, and the tendency was for concrete to shrink round a bar—especially a large bar—causing the initial trouble, which frequently developed afterwards.

One hardly ever saw an octagonal pile; yet an octagonal pile could contain any number of quite small bars, which were much better than large ones, and there were no sharp corners. Would the Author recommend octagonal columns in place of square columns?

Fig. 15.



Trouble seldom arose in the slab itself. As a rule there were no longitudinal cracks under slab reinforcement, but cracks usually developed at beam corners. Why should not a beam be concreted as shown in *Fig. 15*, and have no sharp corner?

* * * **Mr. T. W. Moran** observed that the defects described in the Paper were similar to those which he had seen in other cases, whilst the vertical range of defects on piles and braces was also similar, namely, extending downwards 5 feet or 6 feet below high-water-mark. The soffits of deck beams sometimes suffered more severely than the pile bents and it might be advantageous, in new construction, to form the soffits sloping slightly to one side with a small drip projection, instead of making them horizontal with chamfered edges. In general, provided that the steel reinforcement had adequate cover of dense concrete, deterioration was unlikely to occur, but it would seem to be well worth while to give new maritime reinforced-concrete structures a coating of tar as an additional protection.

Corrosion of the reinforcement sometimes began through pieces of binding wire being left exposed, and steel fixers should be trained to go over their tie-wires on completion and turn all ends inwards. As a further precaution, Mr. Moran had for a number of years used one of the brands of "rustless" binding wire which were on the market.

A type of defect which was frequently found in the older reinforced-concrete jetties of rigid design without raker piles was the fracture of the front row of piles at the level of the lower horizontal bracing. Adjacent diagonal bracing might be similarly fractured. That damage arose from the impact of ships coming alongside at too high a speed. Repairing or re-casting the damaged members afforded no guarantee against recurrence of the trouble, and it would seem advisable in such cases to introduce some form of spring fenders or suspended fenders to absorb the impact stresses.

There could be no doubt that the cement gun provided a suitable method of repairing the type of damage described by the Author, provided always that a high standard of workmanship was secured. Mr. Moran had seen several attempts to repair such defects by rendering or re-casting with poured concrete, but in each case the repairs had failed.

He considered that the type N.2 cement gun was rather large for the kind of work described and a slightly smaller size, for example, type N.1, or its equivalent in other manufacturers' machines, would be more convenient and would impose less strain on the nozzle operator; the spray would also be of more manageable dimensions, particularly if an extended nozzle were used so as to give a more confined spray cone. A marked advantage was obtained by fitting a moisture-separator on the air-line to prevent condensed moisture from entering the cement-gun and causing premature hydration. The separator also extracted condensed oil from the air.

The water-supply to the nozzle was taken direct from the mains in the works described. That was not always advantageous, as main pressures might fluctuate when other parties were drawing off water. It was desir-

* * * This and the following communication were submitted in writing.—SEC. INST. C.E.

able to have the water-pressure at the nozzle a constant amount higher (say 10 to 15 lb. per square inch) than the pressure used in the cement-gun. That enabled the nozzle-operator to exercise more effective control over the quantity of water admitted for hydration. The water-supply would be drawn from pressure tanks coupled directly to the air-compressor manifold.

When using pneumatic chipping hammers it was preferable to operate them at a pressure of not less than 90 lb. per square inch. The efficiency of the tools decreased considerably at lower pressures and, if the quantity of work to be done was considerable, the use of a separate air-supply for the pneumatic tools might be justifiable.

In exposed waters Mr. Moran had carried gunite repairs down to half-tide level without damage by wave action, and in sheltered tidal waters to within 1 foot or 2 feet of low water of spring tides.

The selection of fabric reinforcement was important, as it was desirable to have a material which could be bent accurately and positioned accurately so that the ultimate cover would be as specified. A hard-drawn steel wire fabric fulfilled those requirements better than a mild steel fabric. A heavy material was usually not necessary, and in most cases a 3-inch by 6-inch mesh of 8-gauge wires would be found adequate.

The Author had emphasized the need for elimination of all cracked or defective concrete and the cleaning of reinforcement to a mill surface. Mr. Moran doubted whether the latter was really essential. The removal of all loose rust or scale was absolutely necessary, but it was not essential to clean down to bright steel, as was occasionally specified. If a steel bar were thoroughly encased in a dense material with adequate cover, so that both moisture and atmosphere were excluded, corrosion would not continue. A third essential in preparation was the roughening of any smooth concrete surfaces so as to provide a key. Open picking was insufficient and really close hacking was desirable. The ideal preparation was bush hammering, but that was rather slow and costly. Wet sand-blasting, as described by the Author, was useful in certain cases, it was more efficient than wire-brushing, but inferior to bush-hammering. Wet sand-blasting with ordinary concrete sand and with pressures in the neighbourhood of 30 lb. per square inch gave results inferior to those obtained in workshop practice with very sharp flint sand and higher pressures.

In the application of gunite, the present-day tendency was to use pressures rather higher than 25-30 lb. per square inch, and appreciably better results were secured with pressures in the 35-40 lb. range; pressures of up to 70 lb. per square inch had been used with good effect.

The danger of pockets of rebound occurring was real, but it would be minimized by a thoroughly skilled nozzleman and by maintaining a high level of supervision.

Mr. Moran concurred with the Author that a cover of 1 inch of well-deposited gunite formed an adequate protection against sea-water; but it was very desirable that that cover should be 1 inch in the clear, and that no

odd ends of steel fabric or pieces of binding wire should be left projecting. He considered that it was better practice to build up the thickness in coats not exceeding $1\frac{1}{2}$ inch on vertical work and not exceeding 1 inch on overhanging work, than to attempt to supply a thickness of 2 inches in one operation. In one method of ensuring adequate cover and avoiding rebound, the member under repair was first thoroughly cleaned and all disintegrated material cut away, and the surface was thoroughly roughened. The wire fabric was then fixed in position and spaced about $\frac{1}{2}$ inch off the original surfaces, being bent to shape and size, with sharp corners, on a bench. Light timber profiles, say 3 inches by 1 inch, were then fixed in position on the four corners with their edges $1\frac{1}{2}$ inch away from the original surface of the concrete. Two opposite sides of the member were then gunited up to $1\frac{1}{2}$ inch thickness. When the gunite had hardened the profiles were removed and the work was inspected. If any sand pockets existed they were cut out and filled up with gunite. After the work had set a final coat of $\frac{1}{2}$ inch was applied all round. That procedure gave a rather squarer finish than that shown in *Fig. 8*, and it had the advantage of ensuring adequate cover everywhere.

With regard to the working organization and the personnel employed, much more rapid progress would probably be made if six or eight men were allocated to cleaning the old work and fixing reinforcement in advance; otherwise the cement-gun would be operating intermittently and the costs would be increased. Output and quality alike depended upon team-work in the gang, and a good foreman was essential for that purpose. Repairs of the type described entailed, if successful, doubling the life of the structure at a fraction of the cost of reconstruction, and a high standard of engineering supervision, with constant insistence on quality, was desirable. Concentration on good technique alone would not secure the best results.

Most foremen, inspectors, and clerks of works were accustomed to handling concrete or mortar when placed with the shovel or trowel. When using the cement-gun it was necessary to appreciate that a new medium was being employed, and that the mixture was not being placed by any form of hand tool, but the individual particles were being conveyed in suspension in a fast-moving current of compressed air. If the stream of particles were handled in the wrong way, air-eddies might be set up where the blast impinged on the treated surface, and bad work might result. If, however, the characteristics of that method of applying concrete were appreciated from the outset, it was possible to produce repairs of a standard superior to that obtainable by other means.

Mr. C. A. Wilson observed that it would be generally agreed that the use of the cement-gun as a method of repair for brick and concrete structures was effective and was becoming increasingly common. As a rule, if the work were carried out by contract the price tended to be high where traffic or other conditions did not permit of a straightforward job. The Author was to be congratulated on his decision to purchase the necessary

plant and employ direct labour. On the costs given, that appeared to show a substantial saving on contract prices of more than 100 per cent.

The method employed appeared to conform to standard, with the compressor having a good margin of reserve pressure, which was reflected in the absence from breakdown; the working details were interesting and should be extremely useful as a guide where direct labour was employed.

In *Fig. 12* the operator seemed to be wearing a special type of cap and goggles, although the latter were not in position: was their use necessary when working in confined situations, and were any ill-effects felt by the nozzle operator at any time?

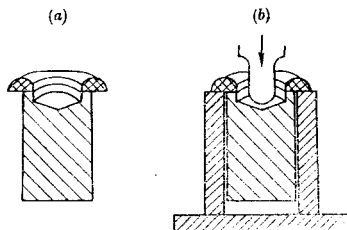
In quay traffic operations, presumably there was vibration from the cranes and wagons, and possibly from other vehicles. Had that caused any ill-effects on the work, either during execution or after?

Mr. Wilson had used the cement-gun process for repairs to brick-arch bridges and aqueducts since 1934, and in all cases the work done was as good as when the repair was first carried out.

The Author, in reply, said that his principal object in presenting the Paper had been to tap the combined knowledge of other people who had had experience of gunite work, in order to be able to start his post-war gunite programme a stage ahead of his original work. As a result of the very stimulating discussion which had taken place, he felt that he would be able to avoid some of the pitfalls into which he had fallen in the past.

He was extremely interested in the question of bond, to which Mr. Morgan had referred, and he was endeavouring, in conjunction with University College, Southampton, to carry out some tests on the bond strength of gunite. For some years he had been trying to develop a suit-

Fig. 16.



OLLARD'S ADHESION TEST FOR ELECTRO-DEPOSITED METALS.

able test-piece, and some time ago he had seen a design of a test-piece¹ for testing the bond strength of electro-deposited material, where a bond face was built up by electro-deposition in the manner shown in *Figs. 16* (reproduced by permission of the Institution of Mechanical Engineers).

In that method a cylindrical test-piece was "stopped-off" with wax;

¹ A. W. Hothersall, "The Repair of Worn or Over-machined Parts by Electro-deposition." *Proc. Instn Mech. Engrs*, vol. 152 (1945) p. 8. (June 1945).

a minimum thickness of about 0.1 inch of nickel was deposited on the exposed end; the wax was removed and the deposit machined; and the adhesion of the annulus of deposit was then determined in a testing-machine by measuring the load required to detach it from the specimen.

He was developing an idea on those lines, whereby a moulded test-piece, not necessarily dimensionally similar to the one shown in *Figs. 16*, but something like it in shape, could have a reinforced gunite addition to it, so that by designing the test-piece to fail at the bond surface the approximate bond strength could be obtained. Comparisons could be made by breaking test-pieces cast throughout in one operation or with a cast bond surface. Tensile or shear results would be made by shooting on gunite in an appropriate form. There could be no question that the bond strength in gunite was very important.

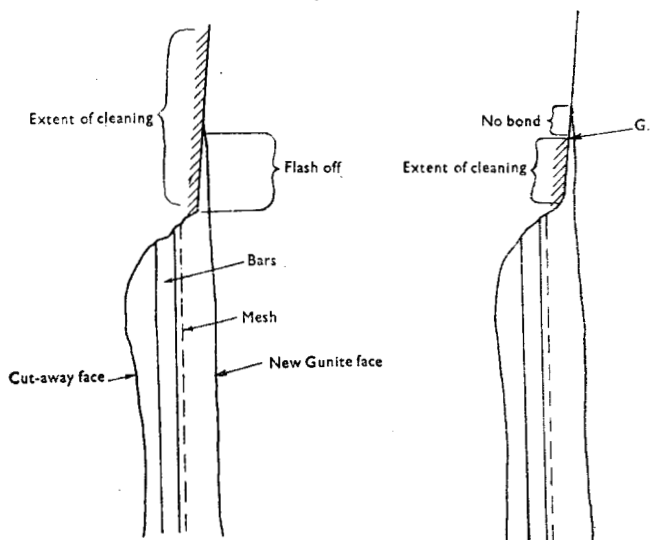
A few timber piles at Southampton had been covered with gunite to make up for loss due to the action of *limnoria*, but very few timber piles there carried loads directly. There was a very large number of timber fender piles, but he considered that for fendering the timber should present its face plus any rubbing strip; therefore no timber fender piles had been built up. He could not see any need to build up greenheart piles with gunite, because at Southampton some greenheart piles 50 years old, in structures which were very subject to attack by *limnoria*, were still in very good condition.

He believed that electrolysis might possibly play a bigger part in the deterioration of steelwork than had been realised in the past. As a result of failures of steelwork through the proximity of other metals, he had carried out some tests and had found surprising potential-differences in sea-water action on metals which were not very dissimilar in an electrolytic sense. A scientific study of the problem would be very profitable for all engineers engaged in maritime work.

He considered that the danger in using the heavy hammer was not so great as the risk of not getting off all the defective material, and, despite the warnings which had been uttered, he would continue to use a heavy hammer.

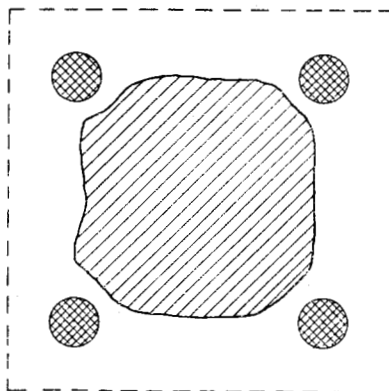
Mr. Carter had shown a construction at the edges such as that illustrated in *Fig. 13*, but, so far as the work at Southampton was concerned, there was so much to do that he could not slow it down for any such detail as that. For cutting away, however, he would in most cases proceed as shown in *Fig. 17*. The gun-spray was not a pencil-point spray but a rather broad spray, and one could not finish off as at F in *Fig. 14*. The gunite would overlap and there would be a flash-off possibly 6 inches in width. He wished to emphasize that the surface on which the flash-off came should be clean. If it were left in the condition brought about by the sea and oil, a good bond would not be obtained and cracking away would start at G (*Figs. 17*). The crack might not do any harm at the time, but future failures might commence to build up there. Mr. Carter had asked

Figs. 17.



if the Author invariably exposed the whole bar before applying gunite. In the case of columns or struts the old material was cut away as shown in *Fig. 18*. That was usually done in two operations, guniting the first half before cutting the second. An exception to that practice occurred in the case of the Kahn reinforcement, which was in most cases only partially exposed. Such differences in method bore largely on the final remarks in Mr. Jackson's contribution in regard to the engineer's views on the methods to be adopted.

Fig. 18.



Mr. Jackson's description of the shooting strips was a useful addition to the technique. The value of 10,000 lb. per square inch given in Mr. Pearson's Paper referred to cubes cut from slabs built up with the cement gun.

The waste of material, to which Mr. Treharne Rees had referred, was a point which might be raised by people who were fortunate enough to do gunite work on dry land, but at Southampton the material went into the sea and helped to silt up the harbour.

If the sand used was completely dry, some waste of cement might occur. Before the correct degree of hydration was reached, a certain quantity of material might be shot on, and if the mix was very dry cement might be wasted. Also—which was more important—by the sea there was usually a breeze, and cement might be lost in the earlier operations. The question of the dryness of the sand was one in regard to which some degree of intelligent discretion might be used by the operators or the supervisor. As stated by Mr. Orr-Ewing, other than absolute dryness might lead to abuse, and in that connexion some measure of control would be a help: whilst, if the sand was too damp choking would occur.

Mr. Orr-Ewing had also referred to the finish of the day's work. In that connexion the Author was more fortunate in the work at Southampton, because the repairs there were to a large number of small individual units, and it was not necessary to start any work that could not be finished the same day.

He appreciated Mr. Palmer's favourable comment on the photographs. Most of them had been taken from a boat, the camera being held against an adjacent pile while the boat was bobbing up and down and all hands were on deck, holding the boat to the pile, while a 30-second exposure was carried out. As an amateur photographer, he might say that the wastage of film in getting the photographs was greater than the wastage of sand in the guniting process.

In reply to Mr. Mears's question on shrinkage, he did not propose to enter the arena on that side of design, but he thought it possible there might be something in what Mr. Mears had said on the subject. There were no octagonal columns in the work at Southampton.

No tests had been carried out on the strength of members repaired at the Town Quay. Mr. Pearson's Paper¹ included details of some interesting tests on full-scale structural members repaired with gunite.

In reply to Mr. Scott, the sand blasting of old work was invariably done with a water and air jet, no dry dust passed, and no ill-effects observed on the operators had been observed.

A number of joints between members had been cut away as shown in *Fig. 6* and had been gunited by placing a "shooting board" in position as a shutter to take the first placing; gunite was then progressively built up from one side.

¹ *Loc. cit* p. 4 *ante*.

The Author agreed with Mr. Palmer that it was possible to find a structure so badly deteriorated that complete rebuilding was the only remedy. In such cases it was probable that damage by causes other than corrosion, for example, impact of shipping, contributed to the general deterioration.

Mr. Moran's remarks on preparation could not be too strongly emphasized. The bush hammering of the original face adjacent to portions cut away would ensure a good bond between the flashed edge and the old work.