departments concerned were the responsibility of Mr. A. E. Blyth, O.B.E., A.M.I.C.E.; and Mr. N. A. L. Cooper, A.M.I.C.E., Resident Engineer, Newhaven, Dover, and Folkestone, was responsible for the immediate local arrangements. The Author wishes to take this opportunity of expressing his thanks to all the gentlemen named above for their ready co-operation in the execution of the 1947 programme, and in particular to Mr. Blyth for his assistance in the preparation of this Paper, including the assembly of the drawings by which it is accompanied, for which he was wholly responsible.

The Paper is accompanied by seven sheets of drawings and six photographs, from which Plates 1 and 2, the half-tone page plates, and the Figures in the text have been prepared.

Discussion.

The Author introduced the Paper with the aid of a series of lantern-slides. He stated that the obligation to programme a maintenance operation to fit in with the tides was one with which all dock and harbour engineers were familiar, but it was not often that the restrictions of working, not only to tides but also to a selected range of tides, in combination with other factors, imposed such a rigid time-schedule.

The technique finally evolved, of carrying out the compressed-air operations outside the dock, would increase the range of tides on which it was possible to return the outer gate to position. The problem of taking out two gates at once was an exceptional requirement. On the other hand, when the work had to be carried out again, it would almost certainly be necessary to fit in the operations with a much more intense ferry service, with perhaps three or four arrivals and departures at the dock in one day.

Moreover, the method of bringing the gate into place flat and turning it up in position could be carried out only in the very calmest weather—such weather, in fact, as could not be anticipated with any assurance at Dover, particularly at those seasons when the work would probably have to be carried out. A large flat object such as the gate, lying on the surface of the water with a very large area on the water plane, was obviously much more susceptible to any movement of the sea than in the upright position, riding deep, when, in fact, the draught was only a few feet less than that of the *Queen Mary*.

In writing the Paper, he had tried to convey something of the sense of urgency which the tidal schedule imposed on everybody concerned with the work. He hoped it would be agreed that the large degree of improvisation in the arrangements involved no discredit, because to purchase special equipment and plant for carrying out the work would have been very expensive, and probably it would not have been possible to obtain delivery of it in the time available after the decision to paint the gates had been made.

Figs 13, Plate 2, would probably be more easily understood if read in conjunction with *Fig. 4*, which showed part of the sill casting. The hatched profile to which the anchor clip was shown as fastened in Figs 13, Plate 2, was, in fact, the keel bearing casting shown at the right-hand end of *Fig. 4*. The clip was lowered completely assembled, with the loose plate bolted to its bottom edge, hooked under the flange of that casting, and prevented from falling out of place while the bolts were tightened by the retaining triggers, which simply dropped into place after the clip had been put down.

The Paper might not, perhaps, have been clear as to the effect of the gates being slightly different in size. In Fig. 1, Plate 1, the pull-off wires were shown in two different positions, namely, when the gate was up and when it was down. In the latter case the pull-off wire was completely disengaged from the gate, and engaged with it only a few feet before the gate made contact in its final position. As the gate rose, the pull-off sheaves on its top engaged with the pull-off wire and lifted the counterweights which were available to start the gate moving in lowering it. As mentioned in the Paper, when the outer gate was in position the pull-off sheave on one side was about $1\frac{1}{2}$ inch out of gauge, so that, in rising, instead of the wire being met fairly in the centre of the sheave, it struck the latter on the rim and, although that was just enough to turn the wire into the sheave instead of kicking it over the edge, it was sufficiently near the second condition to give cause for anxiety. The deflector provided was simply a tapering piece bolted on to the main lifting gear, which, as it rose, scraped against the pull-off wire and pushed it over into its correct alignment with the sheave. That was a temporary arrangement until the sheave could be re-aligned on the gate.

In any future operation the system, tried tentatively towards the end, of tension indicators in the controlling wires, would certainly be extended. It would be very helpful to know that any particular wire had just enough tension to hold the gate in position, and no more. It had sometimes been difficult to decide whether it was safe to let out on one or two of the tackles, and equally difficult to decide whether it was safe not to let out, because the tackles appeared to be becoming extremely tight and something might part, whilst if the tackles were let out too far the gate might begin to wander out of the correct position.

The Author hoped that it would be possible to develop some satisfactory method of conducting a continuous survey of the gate's position. Possibly, if the gate could be put into place through perfectly clear, transparent water, the problem would not be quite so exciting; a diagram on which someone, by watching certain lines and levels, could continuously reproduce the position of the gate relative to the bearing which it was trying to enter, would be very helpful.

There was also room for improvement in the cone wedge gear. The present arrangement was too rigid; the cones were rigidly connected with a single rod; the rod was restrained from bending by brackets at the side

of the gate; and there was no room for the cones to take up any slight misalignment of the bearings. If they were mounted rather more flexibly, so that if one bearing was slightly non-coaxial with the other two, the cone could wander out to take up its correct position; and if the cones could be floating on the operating rod, controlled between two fairly powerful helical springs; then if one cone jammed or took a bearing earlier than the others, it would simply stop and the controlling springs would compress it, whilst the other cones could continue to move down and take a bearing also. At present the first cone to take a bearing would invariably take nearly all the bearing.

The Chairman observed that those who had had to deal with similar problems knew how difficult they were, especially when they had to be dealt with on a rising or falling tide. He would much prefer to deal with ten gates on the inside, where the water-level could be controlled, than with one where there was a rising and falling tide. Owing to the shape of the gates, with their depth very much greater than their beam, they were very awkward and difficult floating bodies to control and, despite all the planning and all the precautions that might be taken, they were liable to do the most unexpected things. He congratulated the Author on the success of the operations.

The gates had been made of copper-bearing steel of rather high alloy-content, and it would be interesting to learn the condition of the steel when they were taken out. At Liverpool, gates of ordinary mild steel were in quite good condition after 20 years, and he wondered why it was necessary, with a copper-bearing steel, to take the gates out after only 10 years.

Mr. J. W. Sutton observed that the gates had been brought into commission in 1936. In 1939 a number of engineers of the Southern Railway Company who were visiting Dover asked various questions and proposed various schemes for maintenance of the gates. The impression which he had gained was that maintenance repairs to the gates should be attended to very quickly, or something would happen. He had been rather surprised, as the life of a gate between slipping was usually reckoned at from 12 to 15 years. However, many schemes were prepared, even including a design for the structure of a slipway to take the gates; but he believed that it had been possible to convince the Southern Railway representatives that the gates could be taken on the Harbour Board's slipway. Had the Author been able to locate all those papers?

Was the Author satisfied that the greenheart keel was standing up to continuous use? There appeared to be very considerable wear and tear; it was almost in a mud pocket at each gate, and the mud was very finely divided sand with a little clay. Further, what was now considered to be the period between slipping dates?

Mr. Sutton had witnessed both the operation in 1946 and that in 1947. The 1946 operation had been carried out without any previous experience

of that particular gate at Dover, and everyone had admired the way in which the job was handled. On each occasion the work was carried out to the programme laid down. The Board were naturally anxious that the slipway should be made available on the date given, and that was done.

Mr. G. A. Wilson inquired whether, when the gates were taken out, any marked signs of wear were evident, and whether corrosion in any particular place was severe. The copper-bearing steel had been tested by the Sea Action Committee and, so far as he knew, the conclusion reached had been that it was not particularly resistant to seawater; it was better in an industrial atmosphere.

The Port of London Authority had recently taken out a gate which had been in place for about 27 years; the plates had been found to be really very good, and the solution which covered them had stood up extremely well.

How much wear had occurred on the trunnions and their bearings at Dover, and had there been any marked wear on the sluices? Mr. Wilson believed that sometimes the venturi action of the water passing through produced definite wear on the inner edges, and that severe pitting might occur. He would also like to know the condition of any timber fendering and what types of parasites existed in Dover harbour and attacked timber.

Mr. Harry Ridehalgh observed that very little had been published so far on the subject dealt with by the Paper, which had raised several important points for consideration when deciding which type of gate to use for a particular job. The Author had helped to show that no hard and fast rule could be laid down, and that each case should be judged on its merits. In view of the difficulties encountered during the overhaul, had the right type of gate been selected? Doubtless the swell conditions in Dover had influenced the decision to use a box gate, because in Mr. Ellson's Paper dealing with the construction of the Dock it was stated that swells of 5–6 feet were fairly common, and swells causing waves 12–16 feet in height also occurred at times. Under what maximum swell conditions was it possible to operate the present gates?

If it were assumed that the box gate was the right type of gate to use, could not better arrangements have been made for carrying out the necessary overhauls? He was not conversant with docking conditions at Dover, but if, for instance, the dock could have been pumped down, it would have been possible to carry out all the chipping and painting of the inner gate in position, and a large part of the outer gate could also have been dealt with in position. At the worst it would be necessary to change both gates round to carry out the whole of the chipping and painting. The Author had stated that it was only possible to maintain a head of water of 7 feet in the dock. Was that due to the design of the gates or of the dock, to the pumping equipment, or to some other cause?

Had any serious silt deposit been found in the tidal compartments of the gate? In a case which Mr. Ridehalgh had encountered recently, 37

tons of silt had been deposited on the decks of a mitre gate, which had contributed to ultimate failure of the top collar—fortunately without any serious consequences.

Mr. Ellson's Paper had stated that tar was used for coating the gate when it was put in, and now Wailes-Dove bitumastic had been substituted. Had tar as a protective coating been found inadequate ?

Mr. F. M. Easton observed that the box gate was a comparatively new type of construction. Had the decision to adopt that type of gate for the entrance to the train-ferry dock been influenced by the possibility of adopting trunnions, which would need a 13-degree pull-off before the gate could be floated out, even accidentally, and would it not have been simpler to have a gate which could be lifted out and dropped back in the vertical position, and held by its natural preponderance of weight, with a key to prevent the trunnions slipping out of place ?

What would happen to the gate at Dover if the outer tapering surface were struck by a vessel intending to enter the dock ?

At the Debate on mitre gates held by the Division on the 24th February, 1948, Mr. Easton had been surprised that nobody had arisen as a protagonist of the box gate. All the discussion had centred upon the advantages of sliding caissons, whereas he considered that, especially for dry-dock purposes, the box gate was a serious rival to the mitre gate.

During that Debate horrific pictures had been drawn by the opponents of the mitre gate, who believed it was becoming obsolescent, of the terrible consequences likely to happen in the event of collision ; but what happened to the box gate in the event of collision ? If the outer gate were struck on the back, it would be necessary either to leave it in place and close the dock, or to drop it into its recess at the bottom of the entrance ; and then, because the buoyancy would probably have been destroyed, there would be no means of access to the damaged structure, and the problem would arise of lifting 300 tons of structure from a submerged position.

The operation described in the Paper was a very instructive and detailed example of the full control necessary in handling the box gate, in comparison with the greater flexibility possible with mitre gates, which could be unstepped in almost any condition, provided that enough water was available to float the gate freely once it had been thrown out of its recess. The mitre gate could be thrown from the recess and prevented from plunging too far across the lock or entrance by check-wires ; and that was all there was to it.

With regard to the box type of gate, he wished to ask whether the operating wires required much maintenance. He imagined, from the statement made in Mr. Ellson's Paper, that they were of large circumference —probably 6 inches. They had to take a 45-ton pull, rising to a maximum of 60 tons. How often had they to be renewed or taken up ? Mr. Easton believed that a considerable amount of maintenance would be required.

In service, the tidal and isolating valves were not used, and he could

imagine that, if ever it became necessary to handle the gate in an emergency, it would be found, as it had been found in the case of similar valves in his own experience, that they were not in order. Unless they were used regularly, they were not maintained ; emergency apparatus was not usually maintained in a serviceable condition.

Reference had been made in the Discussion to the copper-bearing steel. He shared the surprise already expressed that it had been found necessary to take out the gates after a period of only 10 years, during about 5 years of which—roughly, from 1940 to 1945—he believed they were not in every-day use. That would not affect the deterioration of the steelwork, but if, as he believed, the gates had originally been painted with a bituminous composition, 10 years was a comparatively short life. The Paper did not indicate any action taken to clean out and recondition the interiors ; apparently it was only the exteriors which needed scraping and painting. The service conditions were not so bad as they might have been, because the aspect of the gates was east and west, and they would not suffer so heavily from the action of the sun. In gates with a southerly aspect, that would lead to considerably accelerated corrosion, owing to heat and moisture.

If the steelwork had originally been pickled, that would make it less likely that the gates would need to be taken out after 10 years of service. It was not an uncommon experience for gates coated with bituminous enamel inside and outside to last for 20 years with only a little touching up.

He would not have expected the timber to be at all deteriorated, because the keel loading was only about 38 tons per square foot pressure under the worst conditions when the gate was in place, and the rubbing pressure was quite small, since it was only the resolved component of the hauling wires. With regard to the keel bearing, had the steel stood up or had it been found to be badly corroded ? A fair amount of corrosion might be expected with ordinary steel, and he assumed that alloy steel—nickel or nickel-molybdenum-chrome steel—had not been used.

Finally, why was it decided to flatten the gate on its face, instead of on its back in accordance with the original design ? He could see no special advantage in that, except that it would be easier, if the gate were flattened on its back, to do any timber work when dressed in the downward position.

Mr. J. P. M. Pannell observed that the first item of interest to him was the weather aspect of a job of the kind in question. The Author had drawn attention to the uncertainty of the weather, and in carrying out the operation there were many times when the weather was very important. Apart from gale interference with the operations, reference had been made in the Paper to a clearance of 1 foot 5 inches, and to the level of high tide being 2 feet 6 inches below the predicted level. That was quite a serious matter, and Mr. Pannell considered that if it had happened on the actual day when the gate was to be taken over the sill, with only 1 foot 5 inches clearance, the operations would have been seriously delayed.

The weather could affect the type of operation in question in the most surprising ways. In a dock gate job about 20 years ago, when a temporary slipway was to be erected on a river bank which was roughly pitched with copper slag of about 12 inches cube at random, about 12 inches of snow on that river bank had made the running of levels, which had to be done owing to the time-factor, extremely difficult and hazardous.

With regard to the difficulties in re-locating the gate, the question whether some provision might be made of a temporary nature, incorporated in the design or subsequently added, for assisting that location, the Author had referred to a scheme for locating by ancillary methods ; but Mr. Pannell considered that perhaps some more direct method of location might be used. He had in mind a fabricated device rather like the idea of the anchor clip, but in the form, say, of an A-frame, which might be put on the top of the sill, or, if that was not practicable owing to clearances, on the face, so that the trunnions could be guided into position, using the erection as a kind of jig.

He was assured that, in shipbuilding, a 350-foot ship would be expected to be within about $\frac{1}{2}$ inch of its nominal size, so that, for gates of the size of those at Dover, which might be regarded as a shipbuilding job to some extent, the dimensional differences were rather large, and, as the Author had stated, could lead to quite serious difficulties in interchanging.

To a maintenance engineer the Paper was of particular interest, because it drew the attention of designers to the great difficulties which could arise out of what might appear to be trivial matters of detail. Reference had been made to lay-out of pipes, the gudgeon attachment, and the types of valves. All the difficulties in the case described were successfully overcome, but they might have led to considerable trouble, and they had inevitably caused a good deal of worry to those responsible for executing the work.

Several references had been made to the copper-bearing steel. From his own observation, he was convinced that the more homogeneous the steel was, as steel, the better would be its properties for resisting corrosion. Adopting that line of attack on the problem, he believed that the inclusion of copper in steel was just the opposite of what should really be done if it were desired to keep the steel as close as possible to the 50-year old technique of rather slowly manufactured steel, which experience showed was far more homogeneous than the product now being received. The fact that the steel at Dover was copper-bearing seemed, therefore, to be a distinct disadvantage.

Mr. J. S. S. Ramsay observed that the gates had been built to meet very special conditions and were of the only type of gate that could meet those conditions. The operations described by the Author were governed by those conditions and were further complicated by the circumstance that only the outer gate could be used, owing to the erection of temporary gantries on the ferry-boats. Therefore the operations described referred

only to the Dover gates and to a unique set of conditions for those gates, and did not apply to box gates generally.

Every speaker so far had referred to the question of painting and to the copper-bearing steel. The Author had stated that, after 10 years, the chipping and painting was long overdue. How many years was it reckoned to be overdue ? Mr. Ramsay had been interested to hear Mr Wilson speak of a gate which had been in use for 27 years without having been chipped and painted ; that was a wide variation.

Presumably the copper-content in the steel used for the Dover gates was a kind of second line of defence in the event of the painting being completely perished ; otherwise it could never have any action of an anti-corrosive nature. Could the Author state what, in his opinion, was the measure of resistance that the copper-content was supposed to give ? In the discussion on Mr. Ellson's Paper, Dr. Brysson Cunningham had stated that the value of a copper-content of the order of from 0·25 to 0·35 per cent., was problematical ; complete immersion tests in sea-water at Gosport on sand-blasted specimens of ordinary and 0·5-per cent. copper-bearing steel had shown that the rate of rusting was practically the same with both kinds of steel ; if anything, the odds were slightly in favour of the ordinary steel.

In dealing with the first removal of the inner gate, the Author had stated (p. 12) that the first removal of the inner gate was carried out on the 9th March, 1946, when certain defects in the arrangements came to light. It might be inferred, after reading the list of defects, that they were in the gate itself ; but Mr. Ramsay suggested that some of them might possibly have been in the arrangements for the removal of the gate. The Author had also stated that the gate had originally been designed to be slipped on its back and the various air- and water-pipes had been disposed accordingly, as near as possible to that face ; and Mr. Easton had asked why that procedure was not adopted. Mr. Ramsay understood that the reason was that it was better for fixing and dressing the greenheart to have the face upwards, and also for fixing and removing extra timber when the gates were first erected in a temporary position on the caisson ; but he wished to ask whether it was not possible to remove and replace the gates with the air- and water-pipes in the original position, and whether that was not actually done several times when the gates were originally installed. He assumed that the U-pipes under J deck, connecting the end tanks to the centre tanks, were also re-positioned when the riser pipes were altered.

It was necessary to bring the inner gate into the free floating position shown at B in Fig. 6, Plate 2, in order to get the gate into the dock. That was the only reason for bringing it into that position, but was there any need to do that in the case of the outer gate ? In any case, the gate could be turned from that position on to its back. Would it be better on its back to avoid any damage to the greenheart keel and jamming when slipping ?

Also, was it really necessary to cut the end plating of the gate as shown

in section AA, Figs 12, Plate 2, in order to release the gudgeon ? If a tail bearing had been unbolted and the pulleys dismantled, the gudgeon could have been withdrawn inwards without cutting the end plates at all, and put back in the same way.

It was interesting to note that, although one gate was 1 inch longer than the other, there was no insuperable difficulty in interchanging them. He had been very interested to hear that ships 350 feet long were built to within $\frac{1}{2}$ inch ; he had always been under the impression that 3 inches or 4 inches did not matter very much in the length of a ship of that size, and he would be surprised to learn that there were many ships within $\frac{1}{2}$ inch of their drawing dimensions. In the present case, the only thing which was affected was the pull-off wires, which formed a special feature ; they were not a usual feature on box gates, and were not necessary, but were used at Dover because of heavy wave action. Normally, therefore, for box gates 1 inch did not matter very much one way or the other. That was one of the many good things about the box gate. For mitre gates, the tolerance had to be reckoned in thousandths of an inch, or something of that kind.

Mr. H. R. Boyce observed that reference had been made to the possibility of using some method by which it would be known when the trunnions reached their final position. It seemed to him that if two A-frames were erected on the top of the gate, and a corresponding light framework were set on either side of the dock wall, the locus of the trunnions could then be traced as the gate was moved into position.

The Author, in reply, observed that most of the speakers had referred to the question of corrosion. One or two of the slides which had been shown indicated the extent of incrustation and the condition of the coating on the gates after they were removed. No drill tests were taken to ascertain whether the plates were substantially thinner, because that was not expected ; the intention of the operations was to replace the protective coating after it had disappeared and before corrosion of the steel could have become serious. Another point which militated against the temptation to postpone operations was the fact, to which reference had been made in the Paper, that by doing the work at that time no interference was caused to the peace-time time-table service. If such interference ever had to be caused, he considered that the operation would be extremely difficult and, from the point of view of the British Railways, Southern Region, extremely expensive, measured in terms of loss of traffic while it was going on.

It should be made clear that both the inside and the outside of the gates were painted. The emphasis in the Paper was intended to be more on the operation of removal and replacement, and not so much on the painting ; but the inside was painted and, in addition to the painting, a certain amount of repair work was required on the gates. The greenheart keel was in fairly good condition, but some short pieces of it required renewal.

With regard to the question of why the gate was slipped on its front, instead of on its back, two principal arguments had dictated what was done. One was the fact that the gate, when it came away free and was allowed to take up its own position, leant forward considerably, and matters were simplified by pulling it forward the rest of the way rather than pushing it back and turning it through the whole 90 degrees the other way. Secondly, by slipping on its front the access to the interior for painting purposes was made much easier. The covers were taken off and people could go down, instead of climbing up a wall or up through a hole.

Apart from the meeting face and the keel, there was very little timber on the gates ; there were no fenders down the back or front into the water. Extensive timber fendering was provided at the train-ferry dock, but it received such continuous punishment from the ferry vessels that no parasites had a chance of living there.

The restriction to 7 feet of the limiting head—the maximum head on the outside which could be allowed over the water-level on the inside—was dictated by the conditions under which the floor of the dock was constructed and the stratum on which it lay. If any greater head should develop, there was a danger that the floor might rise. The matter was strictly controlled in the pump-house, and various warning devices lit up and sounded as soon as the difference in head attained became more than 7 feet. That was a feature of the dock design which had to be accepted. The replacement of the outer gate at Dover was not the only example of a difficult box gate to replace.

On p. 18 it was mentioned that when the inner gate was being put back in the last phase of the operation it missed the bearing twice. That had not mattered on that occasion, because the water in the dock was pumped up and a second and a third attempt were made ; but it showed that it was possible to miss the bearing.

The technique of burning out the gudgeon-pins was developed in a considerable hurry during the first year's operation. The Author had not been present at the time, so that he could only repeat hearsay. In the first instance the attempt was made to withdraw the pins, and jacks and similar tackle were brought into play, but time was going on and the tide was receding, as it always did, without regard to what man's operations required, so that the only thing which could be done in the emergency was to burn round the plate and so release the pin. It was, therefore, decided to adopt that method on the second occasion, with the outer gate, and to adapt the plating of the brackets so that in future it would be simply a matter of unbolting them and lifting them out.

The possibility of a ship striking the gate while it was in position was very remote, because there was no particular reason why any ship, except one of the ferry vessels, should approach the dock gates at all, and when a ferry vessel was in the vicinity and trying to make the dock, the gate would be down. But even if the gate were struck, he could hardly imagine such

damage being done that it would cease to rotate in its bearing, and it would still be possible to lower the damaged gate to the bottom and raise it again, so that some work of sealing it could be done, perhaps between services, and an opportunity could be taken later to remove the gate. Very extensive damage would have to be caused before the gate would be entirely unworkable and irremovable.

He had no data immediately available as to the renewal of the lifting wires, but would try to obtain some. Not very much silt deposit was found inside the compartments of the gate. As the gate rose, water rushed out through all of the openings in the back, and that exercised an efficient scouring action. An inch or so of silt might be caught in the corners but, generally speaking, no great weight of silt was likely to affect the weight to be lifted.

At the Dover train-ferry dock double mitre gates would be required, because it was sometimes necessary to hold a higher level of water on the outside while the ship was docking at the ordinary level of the track on the inside. A double mitre gate would occupy considerably more room in the length of the dock, with the two gates shut, than the box gates. His only criticism would be that the gates were able to do rather more than was required of them, in the sense that they could hold the head of water either way ; but they were never required to do that, because for most of the time the ferries were docking with the docking-level above the lower tide below them, and were seldom required to dock with a lower level of water in the dock than outside. When that did take place, the difference in level was much smaller than the range of difference which occurred the other way. From that point of view, the box gates might be described as an excessive provision. If it were possible to make use of the dock as a complete dry dock, which was precluded by the 7-foot limit, the use of the reverse gate would be much more valuable.

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