

## Discussion.

**Mr. Elsdén** showed a number of lantern-slides illustrating the work described in his Paper.

**Mr. Allen** showed a series of lantern-slides in illustration of his Paper.

**Sir Leopold Savile**, Vice-President, wished to express his regret that his senior partner, Sir Alexander Gibb, Past-President Inst. C.E., had not been able to be present that evening, because Sir Alexander was particularly interested in the model and had really been responsible for recommending to the Rangoon Commissioners that they should deal with their problem by means of a model. It would be generally admitted that Sir Alexander had taken a bold step in embarking on a model-experiment involving the expenditure of about £10,000 at a time when the advantages to be obtained by such an experiment were considered by many engineers to be very doubtful. That Sir Alexander was justified in his decision would be clear, as in spite of the fact that the navigable depth of the channel had been growing less for many years, it had been possible to advise the Commissioners, as the result of the experiments, that the deterioration would appear to have reached its limit, and that there was a reasonable prospect, without any large expenditure being undertaken on walls or dredging, of the conditions improving, or at any rate not deteriorating any further. That that advice had been justified so far would be borne out by Mr. J. Guthrie Brown, M. Inst. C.E., later in the discussion.

It would no doubt be realized that the results of the model-experiments could not have been obtained but for the work done on models by Professor A. H. Gibson, M. Inst. C.E., and others. It was due to the work that Professor Gibson had done and to the generous help that he gave that it had been possible to take advantage of the practical problems which he had already solved and to develop the model in the way that had been done. In addition to the experience gained in former work on models, reference should also be made to the enormous amount of work which had been entailed on the part of the technical officers of the Rangoon Port Trust, because it would be readily realized that a large amount of data and a great many observations had to be obtained and made; Mr. W. D. Beatty, M. Inst. C.E., the Chief Engineer of the Rangoon Port Trust, and his engineering staff, and Commander C. M. L. Scott, R.N. (retired), Deputy Conservator, and his surveying staff, were to be congratulated on the manner in which they supplied all the requirements under what were very often exceedingly difficult and hazardous conditions.

Last, but not least, Sir Leopold wished to record the great appreciation of himself and his partners of the fact that the Governing Committee of

University College, London, had placed a large basement at the disposal of the Rangoon Port Commissioners, and that Professor E. G. Coker, M. Inst. C.E., and later Professor G. T. R. Hill, of the Faculty of Engineering, and Professor F. G. Donnan and Mr. Henry Terrey, of the Faculty of Chemistry, had rendered most valuable assistance. It was only right to record that the satisfactory results obtained would not have been possible without the assistance and advice which had been received.

**Mr. G. J. Griffiths** remarked that he would confine his remarks to Mr. Allen's Paper. He had always considered that sooner or later there would be a controlled channel extending downstream some considerable distance below Connah's Quay, and he was very glad to see that the matter had been so thoroughly investigated. At the same time he would like to utter a warning in regard to the results of the model-tests, particularly from the point of view of the erection or forming of training walls. The sands in the Dee estuary were very unstable, and great care would be necessary to ensure the stability of the foundations of the training walls. It might also be possible to construct groynes at right-angles to the training walls, and hence gradually to reclaim the whole of the foreshore.

The Paper showed how valuable the use of aerial photography was in surveying an estuary of the kind in question, and in fact for all classes of work. He had not the time to consider all the details of the various schemes which Mr. Allen had investigated, but from a wide experience of both the Mersey and the Dee estuaries, he felt sure that those concerned were correct in not trying to keep the controlled channel too near to the Flintshire coast; he thought that it might be well that they should carry out additional investigations with regard to the width of the mouth of the controlled channel before they proceeded further into the matter, because that factor was all-important.

He agreed that a barrage would be useless. With regard to the training walls, he hoped that the southern wall would always be kept above the level of high-water spring tide, its extensions being gradually followed by those of the northern wall, also kept above spring-tide level, so as to assist in the reclamation of both foreshores.

**Captain G. A. Wright** said that he was the instigator of the investigation of which Mr. Allen had given such an interesting account. The lack of financial resources had prevented the River Dee Catchment Board from carrying out an instrumental survey of the Dee estuary and it could, therefore, be said that the Board's poverty had resulted in the study by Mr. Matheson of plan-projection from obliquely-taken aerial photographs, and subsequently in the construction of the model described by Mr. Allen from the survey prepared in that way. He wished also to point out that, although the river was called the Cheshire Dee, only 5 miles of its course lay in Cheshire, the remainder being in Wales or forming the boundary between Wales and England.

**Mr. Oscar Borer** said that he was particularly interested in the size

of the bed-material chosen for both the models described in the Papers. In the case of the Rangoon model, he noticed that Mr. Elsdon stated that the grain-size was approximately three-quarters of the size of the material found in nature, a proportion which Mr. Borer had found to be fairly satisfactory. What size sand had Mr. Allen used in his models?

In the Rangoon model silt was introduced in suspension. Since the banks were referred to as being alluvial, presumably some form of alluvial silt was introduced. In Mr. Borer's experiments alluvial silt had been introduced, but had produced a very bad effect; when that came down with the fresh water and entered the salt-water portion, representing the sea, there was at once coagulation of the material and it settled on the bed, so that after the first few tides—a matter of a few months in natural time—the whole of the bed coagulated. He would be interested to know whether any effect of that kind had been found in connexion with the Rangoon model.

Mr. Allen stated that no silt in suspension was supplied to the model of the river Dee. He assumed that the Dee carried silt only at certain times, and that therefore the investigations had been confined to the movement of the bed itself. It sometimes seemed to him that discussions in regard to silt in suspension did not lead very far, because, after all, if material were in suspension it did not matter whether or not it moved up and down the river, and he thought that Mr. Allen had discussed the problem correctly; it was with the movement of the grains of sand along the bed that the engineer was concerned.

Mr. Allen had used a second model, and Mr. Borer thought that that had gradually come to be the practice with regard to tidal models. At the Poona research station three models had recently been used when dealing with tidal problems. It was not possible to be quite sure that one model was going to give the exact results, and since there was a great sum of money involved in the actual works, it was desirable to check the results by means of a second model.

On p. 38 Mr. Allen referred to a strong ebb current impinging on the foreshore seaward of the walls, the current being apparently induced by the construction of the walls themselves. That was an effect which might be expected, because if an attempt were made to divide an estuary artificially by putting in high training walls, there was sure to be some portion of the estuary which would not receive its proper amount of tidal water, and therefore a cross current would be bound to be set up in the endeavour of the tidal waters to restore equilibrium throughout the whole estuary; the inevitable result of that, especially with high training walls, would be to set up a flow behind the walls. He knew that the experiments with regard to the Dee walls had not continued for a very long period of time, but from what he could see of some of the soundings that were given, there seemed to be a tendency for a scour to be set up at the back of the walls. If that were so, it would make the construction of the walls extremely difficult. Such a tendency was natural, moreover, since, as

the water was coming off from the estuary and could no longer find its way into the channel into which it naturally flowed, it naturally flowed against the only obstruction which could possibly bear against it, and so gradually the water from either side of the training wall would tend to flow outside it. If the channel were partially filled with silt, however, there would probably not be much tendency to scour it clear again. The construction of the training walls would in any case not be easy.

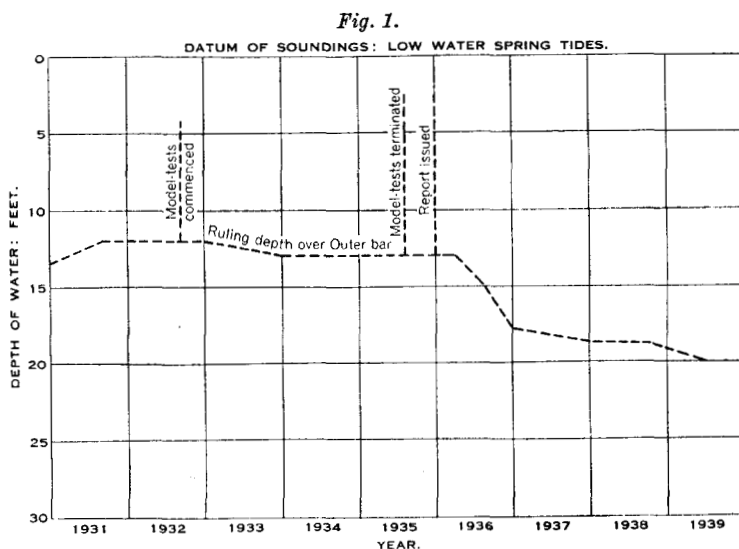
He wished to make a brief reference to the use of the barrage. Mr. Allen referred to the fact that a hole appeared below the barrage, apparently suggesting that the fresh water was held up, and said that it was discharged in the lower part of the ebb. If the gates were only partly opened, so that there was a discharge underneath them, with an artificial head, local scour was certain to occur, with a great deal of shock through the head of water being discharged into the area below. If, however, as soon as the level at which it was desired to operate the barrage (perhaps 1 or 2 feet below the impounded-river level) was obtained, the gates were opened fully, local scour was no longer created; the surface-slope of the whole river would be steepened, and the effect would therefore be very different from that of leaving the gates partially closed and thereby inducing local scour. A great deal of investigation would be involved if there were to be any hope of a barrage being at all successful on the river, and he would be interested to know whether or not the Author had attempted to see what would happen if he simply made use of the water stored behind the barrage to create a greater head, and therefore a greater surface-slope, which would have an effect for some considerable distance below the barrage itself.

**Mr. J. Guthrie Brown** observed that the Rangoon model was based on the principles brought into the realm of practical engineering by Professor A. H. Gibson, M. Inst. C.E., in recent years. It was doubtful whether a model had ever been used before to deal with such a large number of variable factors, and with so little information at the start with which to allow for them; at the time it was the largest tidal model to be constructed in Great Britain.

The behaviour of most models was extremely temperamental, especially in their early stages, and there were many initial difficulties to be overcome in the Rangoon model. The extensive problems which had had to be solved were very well described in the Paper, and satisfactory information had been obtained on all the unknown factors. The confidence felt in the accuracy of the model in foretelling the future enabled Sir Alexander Gibb to indicate, as a result of its operations, that the conditions at the bar, which had suffered as the result of deltaic degeneration of the river mouth, with consistent loss of navigable depth, for the greater part of a century, would appear to have reached their climax. The Commissioners, who had contemplated as an essential requirement an extensive and expensive system of river-training, were advised that any such expenditure would be worse than useless, that a policy of masterly inactivity was all that was

necessary, and that the conditions would become no worse and would in all probability improve. Such advice would have been inconceivable without the guidance of the model, and it was gladly accepted by the Commissioners. Whilst that was most gratifying to those concerned with the model, what was even more encouraging was that the conditions had improved as forecast by the model.

The first reasonably detailed chart available of the river mouth was dated 1860, when there was a ruling depth over the bar of 24 feet at low water spring tides. This depth continually decreased until in 1931 the depth available was only 12 feet; the model-experiments were then commenced. *Fig. 1* showed the depth of water over the bar during the last 9 years. There had been a period of 3 years, during which the model was



RANGOON OUTER BAR: RULING DEPTHS AT LOW WATER SPRING TIDES.

operated, when the 12-foot ruling depth was still about the same. Up to that time there had been no justification for hoping for an improvement. The model-results, however, indicated that the conditions would, in fact, improve, and in due course they had started to improve; the results had proved the accuracy of the forecast, because up to date there was a ruling depth of 20 feet over the bar, there having been a gradual and continuous improvement.

**Mr. J. M. B. Stuart** said that on p. 7 of Mr. Elsdén's Paper were given some of the possible causes of the trouble at the outer bar. No. (3), "Silt brought down by the other mouths of the Irrawaddy and washed eastwards by tidal streams", and No. (5), "Changes in the tidal streams due to widening, straightening, and other changes in the Rangoon river mouth", were probably the most important factors; No. (3) was probably

a more or less constant factor over a number of years, whereas the changing factor was No. (5).

The purpose of the model was to find the cause of the growth of the outer bar and to ascertain whether or not anything could be done to improve conditions there. There were apparently no questions concerned with the Rangoon river itself to be investigated by the model, and, whilst there might have been good reasons for what had been done, it seemed to him that it might have been possible to have dispensed with the labyrinths of the Panhlaing and Pegu rivers and of Pazundaung creek, and to have had one combined labyrinth for the Rangoon river and the channels which ran into it at the upper end of the Hastings shoal. That would have simplified the model-arrangements.

On p. 17 it was stated that provision was made in the case of the Sittang labyrinth to reproduce the effects of the Alok cut, which was a cut-off which shortened the course of the river by between 30 and 40 miles. On p. 13 the Author seemed to have gone away from the idea of representing things accurately as they happened in the Sittang river, because it was there stated that only one-half of the calculated discharge was supplied to the model, it being considered that only half the actual river could be said to flow into the modelled area. He would like to know why those comparatively small channels, such as the Twante canal and the Bassein creek, were included in the model; they could hardly have any effects on the problem under investigation.

The mouth of the Sittang river oscillated from side to side over periods of time. During recent years there had been an accretion on the east side of the Gulf of Martaban, and erosion on the western side of the mouth of the river. It was possible that those changes in the gulf and the coast-line might have had some effect on the increase in height of the Outer bar. Great trouble had been taken in the model to give special consideration to all the rivers that entered the area, but it seemed to him that the coastline and the changes in the gulf could have been considered only very vaguely in the model.

On p. 28 the final decisions were mentioned. The Rangoon Port Commissioners apparently accepted the advice of Sir Alexander Gibb and Partners and did not carry out any dredging, and they were wise in so doing, but it was rather doubtful whether there was any necessity for them to announce that in future Rangoon would be only a second-class port, because from what Mr. Guthrie Brown had said it would appear that the conditions were now much better there than they had been. It was unwise for the Commissioners to say that they could not take any vessels drawing more than 28 feet of water. At that time—1935—Rangoon was only a port for Burma, but in view of the war in China it was now a port for western China also, and might be of greater importance in the future than it had been in the past.

**Mr. John McClure** observed that it would be of interest if Mr. Elsdon could explain what provision had been made in the tidal mechanism for

producing the natural period of rest, varying from, say, 20 to 30 minutes at high and low water, as such periods of rest had an important effect on the deposition of the silt. The peaks of the model tidal waves in the diagrams shown in Figs. 8, Plate 1, seemed somewhat sharp, and would indicate a lack of still-water periods.

After 3 years of model-investigation, the final decision reached had been to permit present conditions to remain and to limit the future draft of vessels using the port, which seemed somewhat disappointing; in that connexion it would be of interest to know whether any model-experiment had been made with the proposed dredged channel shown in Fig. 9, Plate 1, using half-tide banks to form a funnel entrance to the cut. Clay seemed to be available for the purpose, and the advantage of using clay was that if, shortly after the commencement of the cut, it were found that no good purpose was being served, it would be quite easy to dredge it up again, whilst if the effect of the channel were really satisfactory it could be made more permanent. In a similar case of a long dredge and curved entrance-channel with which he had been concerned, such a hard clay funnel-mouth bank had been formed, with very good results in the maintenance of the channel, and afterwards it had been improved with rubble on the channel side to render it more permanent.

Referring to Mr. Allen's Paper, he wondered whether any experiments under scheme E had been made, especially on ebb tides, by actually forming a channel. Had any experiment been made by drawing the sand aside and inducing the channel to avail itself of the ebb flow which was referred to? If in the model any advantage had been found from that experiment, it seemed to him that it would not be very difficult, with a big sand-dredger depositing sand from that channel (not the full depth at once), to introduce it, with the proviso that the sand which was dredged from the cut had to be introduced under water-level at the banks, and not above water-level. If that were done, it would be found that the sand would stay there, and would probably not be readily carried away by the currents.

**Mr. J. L. Matheson** remarked that the great complexity of the regime in the Rangoon estuary and the various points which had been taken into consideration, such as silt and coast-erosion, contrasted with the comparative simplicity of the Dee estuary, which was almost free of silt, so that it was not necessary to introduce it into the model.

That contrast between the two models was reflected in the tide-curves. The Rangoon tide-curves showed a slight divergence between those of the model and those actually obtained in the estuary, no doubt due to the great variety of influences which affected the Rangoon tide. On the other hand, the tide-curves of the Dee showed an almost exact agreement between the tide in the model and the tide in the estuary.

Turning to the question of the Dee, he showed two lantern-slides which illustrated the regime in that river. A survey of the Dee in 1732, which had been made by the opponents of the scheme of training walls, showed

that the deep-water channel clung to the north shore of the estuary. The training walls had been constructed about 1750 and deflected the channel to the south shore, but seaward of the walls the channel reverted to the north shore near Parkgate (*Figs. 1, p. 31*), which at that time was a port of some importance. That tendency of the river was shown exactly by the model itself, and it was interesting that every attempt which was made to restrain it on the south side met with considerable opposition from the river itself, which tended to revert to its old course along the north bank. It was also particularly interesting to notice how the S-bend in the river near Parkgate, which had been shown on some of Mr. Allen's lantern-slides, was developed in the model with remarkable accuracy.

Mr. Ll. E. Williams, Assoc. M. Inst. C.E., had found the speed of the bore in the river between Connah's Quay and Chester to be 8 miles per hour. The speed in the model, when converted to full-scale units, was 7.94 miles per hour.

Mr. G. A. Maunsell had taken part in a preliminary investigation into the problem of the Rangoon Outer bar. That investigation had comprised both a study of old records and an examination of the actual conditions near Rangoon, where he spent several weeks in 1929. As a result of that investigation the conclusion had been reached that training banks offered very little prospect of success within reasonable limits of cost. He was, therefore, very interested to see that the third stage of the model-experiments described by Mr. Elsdon—namely, the attempts to see the effect of training banks in a model—showed that the conclusions reached from the preliminary investigations were sound.

Mr. Elsdon also mentioned the very interesting fact that the mouth of the old Rangoon river might possibly have followed quite a different course about 200 years ago. That was the conclusion that had been reached as a result of the examination of old records. Such a change in course was not inherently unlikely in that neighbourhood, because the whole district was a vast natural laboratory where great changes in the river regime were going on at an extremely rapid rate; for example, in the Sittang river, a little higher up the Gulf of Martaban, there was a pronounced bore, and within living memory a big cut-off had occurred whereby a 40-mile length of fairly wide estuary had been eliminated.

Mr. Elsdon found that it was impossible to find a material which would produce the effect of erosion in the model, and he described how, at intervals during the experiment, he used to pare away by hand banks which were eroding in practice, whereas the model by itself was capable automatically of producing the silting effect by accretion. Mr. Allen, on the other hand, was able to produce the effect of erosion as well as of accretion in his model, and it had been mentioned that the model of the Dee was a very much simpler problem on account of its being just a matter of a fresh-water discharge combined with and the flux and reflux of tides over a large sandy estuary, whereas in the Rangoon model there were two different kinds of accretion going on, the accretion of sandbanks rolling

down the river-bed and accumulating just at the mouth of the river, and the accretion due to siltation. To what extent in the reproduction of the natural accretion in the Rangoon model was it possible to discriminate between the accretion due to sandbank formation and the accretion due to silting? Was it possible in the model to produce both sandbanks and mudbanks? The bar itself, which extended about 6 or 7 miles out to sea, consisted of a huge flat expanse of very soft mud. Just outside the mouth of the Rangoon river, where the river channel was itself very deep (that was to say, nearer inshore than the great mud bar mentioned above), the river had piled up enormous banks of sand on either side of its channels. Those sandbanks were of a firm compact description, and great expanses of them were exposed at low tide. The bottom of the river-channel in the Rangoon river itself were almost everywhere composed of sand or gravel. There were deposits of fine silt in backwaters of the channel and the banks of the channel were mudbanks which had been cut through by the river and which were being eroded in many places. The bottoms of the active channels were, however, almost invariably covered with sand. Mr. Maunsell therefore came to the conclusion that there were two totally independent sources of accretion, the one being sand which was rolling or drifting down the bed of the river and which was ultimately finding a resting place in the sandbanks formed near or just outside the mouth of the river, and the other being a very fine argillaceous silt which was being deposited everywhere over the whole bottom of the Gulf of Martaban wherever the movement of the current was sufficiently sluggish to permit deposition to take place. For many miles off shore the water in the Gulf of Martaban had the appearance of very thin pea soup, caused by the presence in the water of that impalpable silt, brought down partly by the Rangoon and Sittang rivers but mainly by the great rivers draining from the central Asian mountain plateau, namely the Irrawaddy and the Salween.

The problem of the Outer bar at Rangoon was quite evidently a case of silt-deposit from the silt-laden waters of the gulf, and he assumed that Mr. Elsdén's model-experiments were mainly directed to reproducing that silt-deposit. However, the fact should not be lost sight of that the other deposit of sandbanks, just inside and just outside the mouth of the river itself, was quite a separate phenomenon which was going on all the time, and which probably exercised a determining influence upon the direction of the channels at the mouth of the river and to a large extent regulated the erosion in the banks of the river at Elephant Point and elsewhere. Had an attempt been made in the model to reproduce that sand phenomena simultaneously with the reproduction of the silting phenomena upon the Outer bar?

Mr. Maunsell wondered if Mr. Elsdén wished to qualify his statement that the model-experiments were based upon empirical formulas originally devised by Professor Osborne Reynolds. It appeared that the use of the word "empirical" might give the impression that there was no basis in mathematical first principles for model-experiments.

Did Mr. Elsdon consider that it would be possible to make model-experiments reversible? That was to say, starting with present-day conditions in the tidal estuary, would it be possible to devise tidal movements which would in effect run backwards in time, and which would reproduce conditions of erosion and accretion in the reverse order so as to finish up with the state of the estuary such as it did in fact occupy in time past?

**Mr. W. E. Doran** said that both the Papers gave very interesting accounts of model-experiments, but that as time was limited he proposed to confine his remarks to Mr. Allen's Paper on the Dee. It was of interest to note that when the North wall was extended, the scour only extended a short distance beyond the toe of the wall, and that material was in fact carried upstream rather than the reverse. Mr. Allen's statement with regard to the same result being obtained with three different bed-materials related to what appeared to be a fundamental point in investigations of that kind, namely, the selection of the bed-material. The Author had not mentioned that any special investigations were made in that connexion, but no doubt such an investigation had been carried out. It had been found in model-experiments generally that the rate of scour depended chiefly on the grain-size and the specific gravity of the material, and that the model time-scale could not therefore be applied to the rate of movement of bed-material. From results which had been obtained with models in the past it seemed that in many cases, even when special precautions had not been taken in the selection of bed-material, the models did reproduce their prototypes quite closely, and he felt somewhat puzzled why that should be so, because it appeared to him that unless the rate of movement of the bed per tide in the model corresponded to the rate of movement per tide in nature, a cumulative error was bound to take place, which, in a relatively short time, would change the channels, and hence alter the direction of the currents and therefore the tide-curve.

Obviously the rate of scour for powdered pumice and for somewhat coarse sand would be quite different, and again the critical velocity at which movement began and ceased would also be different; apparently, however, the results in the same number of tides were very much the same, and no cumulative error appeared to take place. He would be very glad if Mr. Allen could explain that apparent contradiction.

He felt that the question of bed-material was of very great importance, because unless its behaviour could be relied upon the validity of the conclusions as a whole would have to be questioned. In the present case it apparently had not been possible to prove the fidelity of reproduction of the model by selecting a known state in nature, or, rather, two known states separated by a time-interval, and then running the model in a corresponding manner, in order to see whether the second state in the model corresponded to the second state in nature. In the absence of such evidence of the accuracy of the model-predictions, the results depended essentially on the question of bed-material movement.

He noticed that the model showed a satisfactory stability over 9.64 years after the conclusion of the works, and he presumed that although the depth of water at low water spring tides was only 3 feet at the end of the training walls, the stability of the channel could be relied upon. Was there reasonable certainty that storms and other factors which could not be provided for in the model would not cause the channel to alter, and thus perhaps invalidate the effect of the training walls? In other words, did the model reproduce all the really important factors which governed the changing of the channels?

With regard to the experiment on the barrage, if the barrage were shut it cut off the very important ebb flow of the tide, which would be bound eventually to cause siltation of the estuary, and he wondered whether any experiments had been tried of keeping the sluices open up to the maximum flood tide and then closing them for an interval. In that way the ebb flow of the portion of the river above the sluices would still take place and the necessary increased velocity would have been obtained in the ebb flow; that increased velocity might possibly have prevented siltation below the sluices.

In conclusion, he thought that Mr. Allen's Paper illustrated in a most admirable manner the very great value of model-investigations in regard to a tidal estuary. It was only necessary to consider the five projects shown in *Figs. 7* (pp. 42, 43), and numerous others which were bound to have been tried. Without the help of a model it would have been impossible to have assessed with any degree of accuracy the precise effect of each project. Again, in the case of the barrage it had been thought that a channel 6 feet below ordnance datum could have been scoured out, but the model was able to show that such would not have been the case. In view of the directness of the results and the ease with which variations could be tested in a model, he thought that no engineer could be justified in failing to test his theories in that way before putting them into practice.

\* \* **Mr. M. F.-G. Wilson**, Vice-President, thought that everyone would be impressed by the great care and forethought with which every factor affecting the question had been considered, and every imaginable contingency provided for, when working out the details of the Rangoon model, more so perhaps than was often the case. Local conditions were also very difficult to provide for, the difference in the flow between the dry-season flow and times of heavy floods being practically in the proportion of 1 to 25. A first impression might be that the model had been worked out in almost too elaborate detail, and that time and cost could have been saved by adopting a less complicated apparatus, but closer consideration corrected that impression. It was, he thought, often difficult to appreciate the great proportional difference in the real size of a model of the kind in question as compared with nature, as the idea of size was governed by the horizontal scale of so many feet to the inch. In the present case if the

\* \* This contribution was submitted in writing.—SEC. INST. C.E.

three scales were multiplied together it would be found that the volume of the model was only about one twelve-thousand-millionth of nature. Where such great disproportions were involved it was obvious that too much care could not be taken in regard to any detail affecting the construction and working of the model, even if that should involve considerable expense, for without such care the valuable and reliable results so often obtained from models, and which quickly repaid their cost, could not possibly be attained. That as a result of the experiments the Rangoon Port Commissioners were enabled to come to the important conclusions referred to on p. 28 was ample proof of the value of the experiments and the reliability that could be attached to them.

The accuracy with which the actual tides were reproduced was clearly indicated by the close similarity between the curves of the natural and model-waves, as shown in Figs. 8, Plate 1; in the case of the Severn Barrage model there was an even more striking check on the accuracy of models: floats put into the river near Avonmouth about the time of low water were carried up by the flood, some of them grounding on the river bank when the tide turned. Similar floats put into the model were carried up to, and grounded at, almost the corresponding places.

Nevertheless it seemed to Mr. Wilson that, in spite of the good results obtainable from a carefully made model, they should always, at any rate in certain directions, be treated with caution. The general indications might no doubt be accepted with very considerable confidence; for example, if the model showed that in certain places or over certain areas deposition and shoaling occurred it might be assumed with great confidence that changes of a similar character would take place in nature. Further, the indications given by the model regarding whether the observed changes would be slow or rapid might no doubt be relied upon. The extent of those changes, as affecting the actual depth of the channel at any given spot or over any particular area, should not, however, be accepted with certainty. He had on several occasions noted a marked difference between the precise indications of the model in that respect and the actual results in nature. Those discrepancies might perhaps be accounted for, at any rate to some extent, by the great difference in the proportionate size of the sand-particles in the model as compared with nature.

It was stated that the wind fans were regulated to produce waves of the correct height from crest to trough, "a factor considered to be of more importance in this case than length or speed." It would be of interest if the particular reason for that opinion in connexion with Rangoon were given. At Colombo the height of the long heavy south-west monsoon waves seldom exceeded about 15 feet, yet they struck the breakwater with such force that on one occasion while the works were still under construction the whole outer end of the structure, consisting of 32-ton concrete blocks, was slewed bodily inwards due to the weight of the wave-stroke.

The Dee model was built to a considerably larger scale than the Rangoon

model ; that could be easily and advantageously done because of the much smaller area to be dealt with. What was particularly interesting to note in the Dee model was the difference in the direction of the main conclusions drawn from it as compared with those drawn from the model of the adjoining river Mersey, although the physical conditions obtaining in the two cases were naturally very different. There was a large reservoir of tidal water in the Upper Mersey, the filling and emptying of which was shown by the Mersey model to produce sufficient scour to render high training walls unnecessary ; in fact a trial of such walls in the model proved them to be completely unsatisfactory, and even harmful. There was practically no upper reservoir in the Dee, however, and the experiments with the model showed that training walls, reaching, over a considerable proportion of their length, to high-water level, were necessary.

**Mr. Elsdén**, in reply, pointed out that the materials used to represent alluvial silt in the Rangoon model were commercial clays, chosen after exhaustive tests to determine whether or not they would settle through water at the correct scale rate.

The coagulation-effect mentioned by Mr. Borer had been definitely obtained in the Rangoon model. In that respect, the model was behaving in a manner entirely true to real conditions : the coagulation-effect was, in real estuaries, an important factor in producing silty deposits where fresh-water rivers entered the salty waters of the sea, and it was essential that the model should reproduce that phenomenon.

Mr. Elsdén could say definitely that the model had reproduced both sandbanks and mudbanks in the mouth of the river, and in answer to Mr. Maunsell's question, he would say that the silt- and sandbanks could readily be distinguished when the model was being surveyed. As mentioned on p. 22, the travel of the silt was traced by means of a series of chemical tests. That process entailed the taking of a large number of bed-samples at the close of each run of the model ; those samples showed at once whether a shoal was formed of sand or of silt.

He considered that coastal erosion was far more difficult to reproduce in a model than was the local erosion which was bound to accompany the movements of the various shoals in the bed of an estuary. The latter type of erosion had appeared in the model, but Mr. Elsdén had found extreme difficulty in reproducing the coastal erosion between Bassein creek and Elephant Point ; that was to say, that along the west bank of the river. In that case the natural side slope was very steep, and became sensibly vertical when modelled to the exaggerated vertical scale adopted. To save time in further preliminary experimental work, Mr. Elsdén adopted the procedure explained on p. 21. When that had been done, the sandbanks to which Mr. Maunsell referred developed in the model in a manner similar to that followed by the actual shoals.

Mr. Elsdén did not intend to deny the existence of a mathematical basis for hydraulic models, but tidal models were, he understood, usually proportioned on an experimentally-determined relation (due to Osborne

Reynolds) between the range of the tide in question and the scale exaggeration of the model.

He did not consider that the development of an estuary was a reversible process, though it might easily be cyclical, and the regime might revert to an earlier phase. A "reversed" model could, of course, be constructed, but in Mr. Elsdén's opinion it would merely show what would happen if the direction of flow of the rivers and tidal streams were reversed. He did not consider that models could be used for historical research.

No special means had been adopted to produce slack-water periods in the model tides. The curves given in Figs. 8, Plate 1, showed that the model-tides were rather flatter than the actual curves at high-water spring tides; the reverse was the case at neap tides.

He agreed that a closer agreement could have been obtained between model- and actual tides by prolonging the experimental adjustment of the tide-engine. The number of actual tide-curves obtained from Rangoon had, however, to be severely limited owing to the difficulty of taking long series of readings at such stations as Elephant Point and China Bakir. As the actual tides were subject to considerable meteorological variations, it was not considered that further refinements in the model-tides, to make them agree in detail with a particular set of actual curves, would be warranted, particularly as the model-results were only to be accepted after they had been exhaustively proved over a long period of past history.

In answer to Mr. McClure's second question, no scheme of half-tide walls had been tried in connexion with the dredged channels. The actual material dredged would not be suitable for the construction of such walls, and they would not otherwise be an economic possibility.

Mr. Elsdén agreed with Mr. Stuart that, as things turned out, the scope of the model could have been limited to the region below the Pegu entrance. When planning the model, however, it had been considered best to include the whole of the inner harbour, in case it should be desired to investigate further problems in that area. The coast-lines in the upper part of the Gulf of Martaban were only very vaguely known in actual fact, and the earlier charts from which the experiments had been started were very vague indeed. Had more definite data been available, those coast-lines would have been reproduced in greater detail.

Mr. Elsdén agreed with Mr. Wilson's view that model-results should be accepted at any rate with some caution. He felt that it was not yet possible to make accurate predictions of channel-depths.

The reason for adopting height as the criterion for model-waves was that, in a model constructed to the scales adopted in the Rangoon experiments, it was the only practical criterion to adopt. Waves of the correct length, even if considerations of surface-tension allowed them to be modelled, would be so small as to have no effect on the bed-materials. Waves of the correct speed, or with correct energy, would be impracticable for similar reasons.

**Mr. Allen**, in reply, said that, in regard to the width of the channel between the training walls, various widths had in fact been investigated; the results obtained with the model had been such as to indicate that the widths given in the Paper would be the most successful.

With regard to the barrage, as tried in the model no tide water passed the sluices on the flood tide above the site of the barrage, but river water which accumulated above the site of the barrage during the time that the gates were closed was discharged on the ebb. The possible variation of admitting a certain amount of flood water through the sluices and using that for scour on the ebb tide had not actually been tried, but he did not think, from the general run of the experiments, that there was much possibility of obtaining anything but a local improvement by means of any possible arrangement of barrage.

The bed-material had been mentioned. A sand the diameter of which was about 0.007 inch had been used, and the ratio of that to the sand of the natural estuary of the Dee would be about 3 : 4, or about the same as in the case of the Rangoon model; certain vital tests had, however, been tried with other bed-materials—a coarser sand, of about 0.009 inch diameter, and a powdered pumice, much coarser in size but much lighter—and the results had been sensibly the same. Two very different model-scales had also been tried, as detailed in the Paper, and the results obtained had been sensibly in agreement on all issues. The time taken for the model-investigation of the Dee was about 15 months.

The practical consideration of the construction of any such scheme of walls in the actual estuary had been referred to, but that was a problem which was outside the scope of the Paper. The object of the investigation, in his view, was to study scientifically (or so, at least, he hoped) the hydraulic advantages of various possible schemes. Constructional difficulties, as apart from hydraulic effects, had not been dealt with in the Paper, but it might be mentioned that the opinion of river-training engineers had been sought on that question, and the opinion had been expressed that it would be practicable to construct such a scheme of walls, using dredged sand for the core of the walls, with a pitching of stones and the principle of the mattress.

It was especially gratifying to have the opinion of **Mr. Griffiths** that it would be incorrect to try to keep the controlled channel too near to the Flintshire coast. Regarding the possible programmes of extending the walls, it might be of interest to state that since the Paper was written an alternative suggestion had been investigated; namely, the construction of the walls of scheme E by commencing at the seaward end with the North wall, and bringing that gradually upstream for some distance before carrying out operations on the raising and extending of the existing walls. Further, in the final arrangement the South wall was not continued downstream beyond section 11, thus saving approximately 2 miles of wall as compared with the scheme as shown in Fig. 8, Plate 2. On the whole, that arrangement had not proved as satisfactory as the

original scheme E: there had been a movement of material from the Bagillt bank into the channel seaward of section 11, and consequently an increased volume of dredging had been required to maintain as good a channel. Moreover, the beginning of the flood tide at Connah's Quay had proved to be quicker, and the latter part of the ebb slower, than if the South wall, as well as the North wall, were extended to the neighbourhood of section 15.

Whilst it had been pointed out that the intrinsic constructional problems involved in such works were not within the scope of the model-investigation, it was appropriate to point out that a model might be of some assistance in that respect: for example, the model of the Dee indicated that extra protection of the back of the North wall would be desirable in the region between sections 10 and 11, to withstand the impact of the flood current proceeding along the old channel. An effect of that kind, as also any cross currents likely to cause difficulty either in the construction of the walls or in navigation between them, was demonstrated very clearly in such a model.

Concerning Mr. McClure's query, the model did not lend support to the conclusion that a dredged channel would be adequately maintained without training walls.

Mr. Wilson's reference to the different conclusions that were naturally derived from the model of the Dee and one previously constructed at Manchester of the Mersey, in respect to the desirable height of the training walls, was certainly significant in support of the contention that every river presented peculiar features, and, if major works were contemplated, deserved its own model-investigation. It was equally true, as Mr. Wilson observed, that model-results were to be interpreted with caution, and Mr. Allen was of opinion that it was important to carry out pairs of tests, starting from the same initial condition, with and without proposed works, in order to obtain a direct comparison.

Mr. Borer and Mr. Doran had raised the important question of bed-materials. It was true that in the Dee investigation no test had been carried out to compare the behaviour of the models over a period of time corresponding to two surveys in the natural estuary. On the other hand, the method of comparative tests, with and without proposed schemes, had been used, and two models of very different scales had been employed as an indication of possible "scale-effect."

The general subject of "calibration tests" from the state of an old chart to present-day conditions deserved consideration. Certainly in more than one investigation, the reliability of a model had been thoroughly proved by such tests, but there was no rational cause for anticipating that, having moulded the bed to some previous state—say 50 years past—and running the tides up to date, the model would show, in any given case, the present configuration of the estuary, unless the information was available, and the mechanical devices were practicable, to reproduce gales and other such "spasmodic" occurrences as might give rise to some

alterations in nature. A model would only show the general effect of normal tidal action, although a reasonable attempt might often be made to reproduce abnormally high or low tides, or flood or drought conditions of the rivers, if the necessary data for the estuary itself were provided.

If, as in the upper estuary of the Severn, the currents themselves were very strong, it was proved by experiment that close agreement with nature over a long period of time was obtained. In general, however, a model might be expected to show the probable results of proposed works in conjunction with normal tidal action, and a qualitative estimate of gale-effects might be made by visual observation of the model, which might indicate, for instance, that gales from a certain probable direction would carry bed-material over the walls and into the trained channel of some suggested scheme.

The question of rate of movement of the bed had to be considered in relation to the duration of the experiments. In non-tidal work on the scour at the toes of dams, it had been found by Messrs. R. V. Burns and C. M. White\* that, whilst the rate of scour with various materials was quite different, the final condition reached was almost identical (within limits of grain-size). Accordingly, if the test were run sufficiently long for the establishment of approximate stability, similar conclusions would be reached. In tidal work, however, the alternating effect of flood and ebb greatly assisted in making the rate of change of the bed approximately the same for materials of different kinds (within limits). Thus, in an extreme case, if a certain material were moved equally up and downstream by flood and ebb respectively, the final result would be identical with that obtained if the bed-material had not been moved at all.

Mr. Allen would invite the attention of those interested in the theoretical and experimental subject of the effect of grain-size, shape, and density, to Professor A. H. Gibson's Severn Model Reports, Sections IV and V and Appendix D †, and to pp. 708-713 of his Vernon-Harcourt Lecture ‡; and again, concerning the matter of silt in suspension and its disposition in a model, to his Severn Reports, Section XIV\*.

In conclusion, he would like to endorse the view that both Mr. Elsdon and himself had been very fortunate in being students of Professor Gibson, to whom they owed a great deal.

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\* \* The Correspondence on the foregoing Papers will be published in the Institution Journal for October, 1939.—SEC. INST. C.E.

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\* "The Protection of Dams, Weirs, and Sluices against Scour." Journal Inst. C.E., vol. 10 (1938-39), p. 23. (November 1938.)

† "Construction and Operation of a Tidal Model of the Severn Estuary." H.M. Stationery Office, London, 1933.

‡ "Tidal and River Models." Journal Inst. C.E., vol. 3 (1935-36). (October Supplement, 1936.)