Discussion.

Sir CYRIL KIRKPATRICK, Past-President, regretted that unforeseen circumstances had prevented him from giving to the Paper that attention which it deserved, so that his remarks would only be of a general character. He knew Holland fairly well. All the waterways in the neighbourhood of the North Sea canal, which ran from Ymuiden to Amsterdam, were at a much lower level than the canal. The Author, however, had given interesting examples of districts in the eastern portion of Holland, where the drainage water-levels were much higher than the canals. Sir Cyril Kirkpatrick.

In reading the Paper, two points in particular had interested him. The first was that models were employed to a very much greater extent in Holland and on the Continent generally than was the case in England. The Paper gave examples of extensive alterations which had had to be made in the design of structures as the result of model-experiments. Continental engineers were perhaps more theoretically inclined than English ones; nevertheless, the Delft laboratory often carried out elaborate model-tests, of which much more use was made in Holland than in England, and he thought that their results had been materially helpful. The second main point brought out in the Paper was the very large amount of drainage-water which had to be taken off in the canals described. Engineers in England did not have very much experience of navigation-canals and drainage-canals combined, but it was rather surprising to learn from the Paper that the widening of the Ymuiden canal was due, not to the requirements of navigation, but to the necessity of taking off a large amount of drainage. It was now a wide canal, and the figures given on p. 223 of the amounts which had to be drained at the Zuyder Zee and the North Sea ends were very large indeed. It was stated that the velocity in the Amsterdam canal sometimes reached as much as 1 knot (0·5 metre per second). With a

Sir Cyril Kirkpatrick. light vessel coming down with that current, he was not surprised that difficulties arose, especially when the wind was astern.

There were many other features of the Paper that would be particularly interesting to engineers concerned with navigation and drainage canals—for example, in India and in Egypt; he hoped that engineers who had had experience in the subject in those countries would give The Institution the benefit of their opinions.

Mr. Saner. Mr. J. A. SANER remarked that the Paper would be of great use to those who were engaged in canal work; he did not, however, entirely agree with some of the statements contained in it. Firstly, although there were no ship-canals in England which were also used for irrigation or drainage, there were canalized rivers whose floods had to be dealt with; his own experience of the Weaver navigation was that there was no real difficulty in navigating with or against the flood until its velocity became 2 or 2½ miles per hour. The Author mentioned on p. 223 the figure of 0·5 metre per second (which was only 1·12 mile per hour) as a strong current. With large vessels when light and with a slight wind there would be some difficulty in navigating, even with that current, because the wind would take hold of the vessel and would probably blow her across the stream. On the river Weaver the ratio of the cross-section of the vessels to that of the waterway was 1 to 4, whereas on the Amsterdam canal it was 1 to 7.

There were certain points in connection with the Manchester Ship Canal that might be of interest in the present discussion. The Manchester Ship Canal had originally been made with large tidal openings or weirs over which the tide had flowed when it had risen above the 14-foot mark at Liverpool. Those tidal openings had been found to cause a great deal of trouble; they had brought in ice and debris of all kinds, and the Canal Company had gone to Parliament in 1896 for powers to close them. He mentioned the question in connection with the Author's statement on p. 228 that the calculations necessary in designing canals were not simple. With that he quite agreed, because in 1896 the question had arisen as to what the current-velocity would be when the tidal openings were closed, so that all the water would have to come in at the Eastham locks. The late Mr. W. H. Hunter, M. Inst. C.E., then the Chief Engineer, had predicted that on certain tides the maximum velocities would be increased; he, as a witness for the opponents, had had to say whether Mr. Hunter's figures were correct or not. The canal was 36 miles long, and the first 20 miles from Eastham to Latchford was subject to tidal influence. At that time a tide of 20 feet 3 inches was computed to bring in 7,000,000 cubic yards of water, all of which entered the locks at Eastham excepting the land water, which was estimated at 1,000,000 cubic yards; it all came in between an hour before and half-an-hour after high water. The level of the water at Eastham rose by 5 feet 6 inches, and that at Latchford (owing to the tidal momentum) by 8 feet 10 inches. Before alterations, a 19-foot tide had produced a velocity in the canal of 2·6 miles per hour, and a 21-foot 6-inch tide had produced 2·7 miles an hour—only, of course, for short periods. It had been predicted that those velocities would be increased to 3·74 and 5·13 miles per hour. The works had been sanctioned and had been carried out, and it was interesting to note that the resulting velocities had proved to be 4·1 and 4·9 miles per hour respectively. There were one or two places, where the cross-section of the canal changed, where the maximum velocity exceeded 4·9 miles per hour. Those velocities had been of much greater duration than the original velocities, and they had caused so much trouble to navigation that the Company had obtained powers to raise the permanent level of the canal and to exclude some of the tides, thus reducing the amount of water that had to come in at high tide. Neither the barges (whose cross-section had a ratio of about 1 to 25 to that of the canal) nor the larger vessels (which had a cross-section ratio of about 1 to 5) had been pulled up by the original velocities of 2·6 and 2·7 miles per hour; but the barges, when they had had to face a current of nearly 5 miles per hour, had been pulled up entirely, and the larger vessels had been detained at Eastham locks until the water had settled. Those particulars were interesting in comparison with what was stated in the Paper. **Mr. Saner.**

On p. 230 the Author gave a very interesting description of how he dealt with the incoming streams. The only comparable case of which he himself knew was one where he had had to advise as to the discharge of about 9,000 cubic feet per minute into the Weston canal, which was about 1,200 square feet in section. The small, narrow canal boats had, however, to pass close to the opening where the water was coming out; in order to lessen its exit velocity, he had adopted a system which was practically the same as that shown on pp. 238 and 239, and it had proved very successful.

Mr. Oscar Borer observed that canals were not used a great deal in England for drainage purposes, presumably because the conditions in England were so different from those in Holland, in so far as England was a country with numerous hills and valleys, so that the drainage came down by a number of relatively small rivers discharging directly to the sea. Trouble, however, was experienced when canal systems cut across the catchment-areas of the various **Mr. Borer.**

Mr. Borer. rivers, and serious difficulties might arise with the drainage authority, as the canals naturally followed the contours of the hills and, in so far as they followed those contours, they acted as catch-waters. As long as the intercepted water could be used for locking purposes, all was well; but in the winter surplus water had to be discharged by sluices from the canals into the rivers below, which had been practically dried-up on account of the interception of their supplies during the summer, and flooding was experienced in consequence.

In making the general statement that English canals were not usually concerned with drainage, he had to make the great exception of all the area which had been reclaimed by the Bedford Level Corporation, namely, the fen area drained by the Ouse, the Nene and the Welland. In that connection, although it might not at first be realized, very many of those rivers which were now shown on the map were really artificial. The Drainage Boards met with considerable difficulties on account of the navigation. They were under statute throughout their South Level area, where they had 80 miles of river which belonged to the South Level Navigation, and they had to hold the water to the level of + 6 O.D.; in the Middle Level area also they were under obligation to hold the water in their drainage-canals to a statutory level. The consequent difficulty was that in the winter, when it would be useful to lower the water-level in order to anticipate any flooding, they were compelled to keep it to the statutory level for navigation. Further trouble also arose from the requirements of irrigation. Throughout the summer the Middle Level and the South Level were supplying all the fen areas with water from canals, and practically no water passed down to the sea. It became particularly serious in the Middle Level, because the amount of water available for irrigation purposes became inadequate during the summer with a fall in water-level, and water had to be let in from the tidal Ouse to raise the water-level for navigation, which was at its heaviest during the autumn on account of the sugar-beet campaign. That tidal water carried a good deal of silt in suspension, and deposited it in the various canals; the Middle Level was thus faced with the very serious problem of how that silt was to be dredged out, the receipts from navigation being far below the cost of maintaining the canals in order to carry what barge traffic there was. Unfortunately, the Ministry of Transport had ruled that those canals had to be kept open for barges, and the position was at present at a deadlock.

Comparing the conditions in the Fens with those described in the Paper, on p. 223, the Author referred to a pumping plant discharging

3,000,000 cubic metres in 24 hours. The Middle Level pumps had Mr. Borer. been running for the first time in February, 1936, and their maximum discharge had been of the order of 2,000 tons per minute, which was exactly 3,000,000 cubic metres in 24 hours. At that discharge the current-velocities in the Middle Level had been from 1·25 to 1·5 foot per second. In the South Level, the maximum discharge under flood conditions had been at the rate of 8,500,000 cubic metres in 24 hours. That discharge could not be maintained continuously, owing to tidal conditions, and so the average discharge in 24 hours would probably be of the order of 4,000,000 cubic metres. The velocities in the canalized rivers, instead of being only ½ foot per second as in normal conditions, had increased to 1·9 foot per second, and the surface gradient had risen to 4½ inches per mile. The embanking of rivers in order to prevent flood-water spreading over the land, to which the Author referred as adding to his difficulties because of the additional water brought in to the system, was also causing trouble in the case of the Great Ouse Catchment Board.

It was interesting to compare the designs of the Bolksbeek and the Zutphen sluices with the design of aprons which had been recently fitted at St. Ives, which was the last staunch on the main river Ouse before it came down into the tidal section. The maximum discharge at St. Ives was about 3,000 cubic feet per second, and the design of the apron had been investigated by means of models, which had enabled the engineers to ascertain, by running a series of experiments, the difference of level between head-water and tail-water that would give the maximum amount of scour which had to be legislated for. In the particular case the flow was 3,000 cubic feet per second, and they had found that levels of + 18·5 O.D. and + 15 O.D. respectively gave the worst conditions under the present circumstances. They had finally devised a new type of sill which had been put in at a level of + 11 O.D., and had worked very satisfactorily indeed. They had not only to consider the present conditions of the river, but also to anticipate the effect of a future lowering of the tail-water due to proposed river-improvements. The design of the sill had been based entirely on the model-experiments; a good deal was found to depend on the velocity of approach of the water, the quantity of water being dealt with, and the amount of cushioning that could be obtained. In ordinary practice a water-cushion might be obtained by allowing the bed to be scoured away to some extent, but he appreciated that conditions in Holland could not be dealt with in the same way, because it had to be remembered that everything in Holland was founded on sand; every precaution had therefore to be taken to see that any structure which was built was entirely self-

Mr. Borer. contained and could not give rise to any damage once it had been constructed. In that connection he had been rather surprised to find that the apron-length in the Bolksbeek design was only 7 metres. Admittedly a fairly high sill had been constructed on the downstream side, and he supposed that the Author's decision to put in such a short apron had been due to structural considerations; the result was that a hydraulic jump took place, necessitating the provision of mattress-work. Such mattresses were standard Dutch practice, and a certain number of them were now being put on the Ouse and on other rivers in England; they provided a simple and satisfactory way of protecting the bed of a river. Could the Author give further particulars of the hexagonal concrete blocks which had been put in on the upstream side of the sluices at Zutphen, and which, he believed, had been used in place of much more expensive hexagonal granite blocks from Germany?

The design of the Zutphen lock was especially interesting. He did not remember having seen models of it at the Delft laboratories, but any such problems in Holland were generally referred to them; Mr. Thijsse, who was in charge there, was doing excellent work, and the laboratories were most fascinating to visit. Engineers in Holland were very progressive, and they, as well as the German engineers, were always willing to give every assistance that they could in connection with their model-investigations. An interesting point in connection with the weir at Bolksbeek was the slope of 0·45 metre (about 18 inches) along the length of the sill. Such an amount of cross fall was unusual, but knowing the great care which was taken at Delft in investigating matters, he had no doubt whatever that that fall was essential. He was also much impressed by the care taken by the Dutch engineers in the design of the small inlets, which, even though they only had to discharge 2 cubic metres per second, seemed to have been very carefully thought out. He felt that it would be useful to try to follow up some of the suggestions arising from the Paper, which should be of considerable assistance, and gave much food for thought.

Mr. Wilson. Mr. C. A. WILSON remarked that the Grand Union canal was sometimes inconvenienced by the flood waters which flowed into it. The river Tove had long been a cause of trouble in winter, when it discharged its excess flow into the canal. Although the relationships of the canal companies with the Catchment Boards were very happy, he was afraid they could never see quite eye to eye with them in regard to preparing their levels to meet the floods which the Boards passed on to them. They did try in every way they could to release the water as quickly as it came to them without definitely lowering their levels, because they did find that navigation was hindered, and sometimes held up for several days, when they got exceptional floods; it was in everybody's interest to get rid of the water as expeditiously as possible. Mr. Wilson.

In the Paper there were one or two points which were of even greater interest from the point of view of navigation than from that of drainage. The Author mentioned a section-ratio of 7 to 1, but later on referred to less advantageous ratios; in the list of canals which he gave on p. 225 he mentioned cross-sections which compared closely with the London section of the Grand Union canal, which had a cross-section of 278 square feet (25·8 square metres). The side slopes were given as 1 to 2; the navigation speed was not stated, but reference was made elsewhere to 5 kilometres per hour—approximately 3 miles per hour, which was rather a slow speed—and it would be interesting to know whether the banks of those canals suffered from erosion or whether the canal adopted a semi-elliptical or saucer shape due to the wave-action of the traffic. Some years ago Mr. Wilson had carried out certain tests on the Grand Union canal, and had found that where the ratio of a section had been increased, by dredging, from 5·1 up to 8 to 1, the speed of barges had been increased by 69 per cent., from 2·73 to 4·61 miles per hour; he was afraid, however, that the erosion due to wave-action had increased by an equal or greater proportion, and that the engineers of the smaller canals would have to consider how far they should restrict traffic by limiting the speed, perhaps by restricting the size and speed of the propeller, which seemed to be the simplest method.

He had also been interested in the Author's assumption of a tug-pull of 1 kilogram per net ton at a speed through the water of 5 kilometres per hour. The Author did not say how he had estimated that pull, but in connection with the tests which he himself had carried out he had tried to deduce the pulls, and had found that they varied very considerably, ranging from 1 lb. per ton up to 10 or 12 lbs. per ton. He had looked up some experiments in that connection which had been made many years ago on the Grand Junction canal, and he had found that although the loads towed had ranged from 50 tons to 170 tons the pull ranged between 12 and 4 lbs. per ton at speeds of $4\frac{1}{2}$ to $2\frac{1}{2}$ miles per hour.

He was interested to note that the models had in fact been used only to ascertain the relative merits of various designs, and not to make the design itself. It was sometimes difficult for an engineer to decide how far he was justified in spending money on model-tests, and it would be interesting to know what were the costs of the tests mentioned, as percentages of the costs of the works. He

Mr. Wilson. would also like to ask the Author whether, in the tests he had carried out, any allowance had been made for the silt-content, whether that had had any effect on the design of settling-basins, and whether it had proved anything in regard to their efficiency.

Mr. Griffiths. Mr. G. J. GRIFFITHS remarked that the shipping and navigation interest and the drainage interest were hard to reconcile one with the other. The use of a navigation-canal also as a drainage-channel undoubtedly interfered very materially with navigation, and in his opinion engineers should try to separate the two, because the inflow of drainage into the main navigation, at whatever angle it was arranged, would, he thought, always cause trouble.

The Paper showed that great care had been taken to try to stop suspended matter from settling in the navigation-channels. He had previously remarked that when the Thames at Teddington was bank-high, about 1,100 tons of suspended matter passed over the weir in 24 hours. In a restricted channel such as a canal, suspended matter might settle—and it generally did—somewhere near the junction of two streams; he had experienced such difficulties on the Wey navigation. In some cases where he had short-circuited, or altered the point where the river joined the canal, shoaling had taken place and would continue to do so; in fact, that had been more or less foreseen, and an understanding had been reached between the authorities concerned with regard to the removal of such shoals when they formed. Shoaling might take place either above or below such a junction, much depending upon the velocity of the stream and the angle at which entry took place. The engineers concerned were still learning and would go on learning; that was especially so with regard to the use of models. He himself used his own works where he could to test his ideas in that way; it was wonderful how much experience could thus be obtained. In connection with Mr. Borer's remarks, he would cite the case of the new weir at Molesey. It had not been definitely known at what state of the river that weir ought to be drawn. It had therefore been tried with tail-water at a certain level, and such a troublesome standing wave had arisen below the weir that it had had to be shut within a quarter of an hour. The tail-water had then been allowed to rise a little higher, but the opening of the weir had still produced that standing wave, and in about 48 hours the river-bed below the apron was scoured to a maximum depth of 6 feet over an area approximately 75 feet wide by 50 feet long. That had taught them not to do it in that way! Their experience had been such that, even after putting down a concrete-block apron about 200 feet in length, they still found it advisable to allow the tail-water to rise to a certain level. Mr. Griffiths.

With regard to the Manchester Ship Canal, one interesting point arose out of Mr. Saner's remarks. A certain section above Eastham had slopes of 2 in 1, and at Mount Manisty the slopes were 6 in 1. If he remembered rightly, the water at the entrance to the narrows was "humped up," and there was a definite rise in the water-level. The navigation at times was considerably hampered by the narrows. The water-level was higher in the channel in the narrows than it was in the wider section; at the other end the level fell again; a ship going upstream with the tide was speeded up in the narrows, and directly she got out she seemed to have a still further increased velocity relative to the water, appearing to dive downwards. There was always a very great deal of settlement of silt near the tidal openings mentioned by Mr. Saner, and he remembered that it had been a very costly matter to keep the canal clear.

Mr. W. J. E. BINNIE, referring to p. 225, remarked that it would add to the interest of the Paper if the Author would give further information on the experiments he had made in order to ascertain the maximum permissible velocity of the current so as to allow of the maintenance of the slopes and the bottom of the canal. Most engineers were now making model-experiments when they had to deal with the flow of water, as it was impossible to arrive at the facts by calculation. If water were flowing around a bend in a channel, and it were required to have a uniform velocity at the exit, that object could be attained if the bottom of the channel were shaped in a certain manner. The engineers had been faced with such a problem in connection with the approach to a channel at the Burnhope reservoir, where there was a large bell-mouth overflow at the end, and it had been essential that the filaments of water approaching that bell-mouth should not have too large an asymmetric tangential velocity on the two sides of the bell-mouth. The original design had been hopeless, and it had not been until they had tilted the floors one way or another—which could only be tried by means of the model—that they had been able to solve the problem. There had been a very heavy flood since the reservoir had been constructed—about 60 per cent. of the maximum calculated flood, according to the Flood Committee's report—and he was glad to say that the overflow had acted exactly as the model had predicted. Mr. Binnie.

The PRESIDENT supported what Mr. Binnie had said about the value of models; his own firm invariably made a model when they were dealing with the flow of water, and he was quite certain that the The President.

The President. expense was justified. Models cost very little, and their results often saved many thousands of pounds. He knew of one instance where a model which had cost £10,000 had saved £2,000,000; the model had shown that proposed works, which were to have cost £2,000,000, would have been perfectly useless.

⁂ The Author's reply to the Discussion, together with the Correspondence (see footnote †, p. 221), will be published in the Institution Journal for October, 1937.—SEC. INST. C.E.