TABLE XX.

	Clay from borrow-pit on reservoir bank upstream.			Clay from river flat downstream.		
Water-content: per cent.	20	23	30	20	23	30
Void-ratio	0·78	0·89	1·68	0·78	0·89	1·68
Vertical pressure (Terzaghi test): kilogrammes per square centimetre	10·0	6·8	2·9	6·8	5·0	2·7
Height of bank equivalent to this pressure: feet	164	110	48	110	82	44
Permeability $\times 10^{-9}$	0·6	1·0	2·9	0·8	1·1	2·0
ϕ	4° 30′	2° 30′	1° 30′	2° 30′	1° 30′	1° 00′
Cohesion: lb. per square inch	22	8	1·2	33	20	4·8
Stability measurement:— Horizontal pressures in lb. per square inch:—						
For vertical pressure = 42·6 lb. per square inch (50 foot bank)	5	24	35	—	13	35
For vertical pressure = 85·2 lb. per square inch (100-foot bank)	40	70	78	24	50	74

Paper No. 5110.

"An Experimental Investigation of the Effect of Bridge-Piers and other Obstructions on the Tidal Levels in an Estuary." †

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Correspondence.

Mr. Herbert Addison, of Giza, Egypt, had found it interesting to construct diagrams showing the longitudinal profile of the water-surface in the models. One of them was based on the tide-curves reproduced in *Figs. 6* (pp. 220 § and 221 §); since in all the curves the same datum for time and the same datum for levels were used, it was easy to plot the surface-profiles at various periods before and after high water. Only points relating to the unobstructed estuary were chosen: at Avonmouth,

† Journal Inst. C.E., vol. 8 (1937–38), p. 210 (March 1938).

§ Page numbers so marked refer to the Paper. (Footnote (†) above.)—SEC. INST. C.E.

above Beachley, and at Sharpness. The profiles appeared (*Fig. 9*) to be normal in form, and they showed graphically how the inertia forces accelerating or retarding the water affected the levels at the head of the estuary.

The profiles relating to the symmetrical-estuary model, based on *Figs. 7* and *8* (pp. 223 § and 224 §), and concerning points A, C, and D (open estuary) were more difficult to understand (*Fig. 10*). The remarkable thing about them was that in every profile except the one taken at 2 seconds after low water, the water-level at the head of the estuary (point D) was higher than the level at the mouth (point A). That was contrary to what would be imagined would happen in ideal conditions,

Fig. 9.

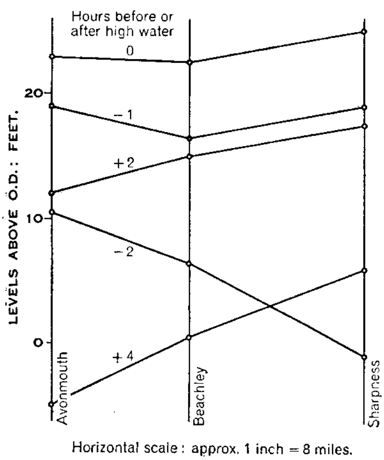
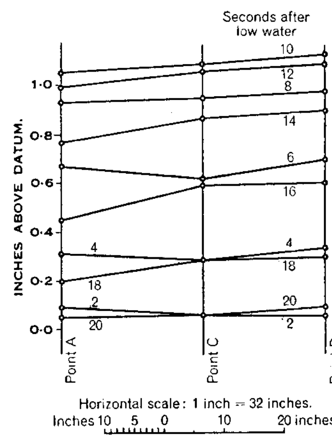


Fig. 10.



where the level at the head would be above the level at the mouth of the estuary at the end of the flood and at the beginning of the ebb, whilst at the end of the ebb and at the beginning of the flood the level at the head of the estuary would be below the level at the mouth. It would be very helpful to have the Author's comments on that point.

Could the Author give any figures for the afflux produced by the various kinds of obstruction? What, for example, was the maximum estimated afflux, for the full scale, produced by the piers of the proposed bridge over the river Severn which gave an 8 per cent. obstruction of the channel?

Mr. R. F. Hindmarsh observed that a record of actual tidal observations taken on the river Tyne might be a useful addition to the results given in the Paper and the conclusions reached.

At the present time there were in all eight bridges between the north

§ *Ibid.*

and south banks of the river at or above Newcastle, which was 9 miles from the sea, the bridge farthest from the sea being Newburn bridge at a distance of 18 miles. All the bridges except the latest—the Tyne bridge—had piers in the river, the greatest obstruction being at the Swing bridge at Newcastle, where it amounted to about 25 per cent. The Tyne Improvement Commission, whilst safeguarding the interests of navigation, had never offered objection to the erection of the bridge-piers at present in the river.

Automatic tide-gauges were in use at the river entrance and at Newcastle, and actual tide-observations were taken daily at Newburn bridge and at Ryton, about 1 mile above Newburn bridge. The following was a record obtained by averaging a number of observations taken in August 1930 and in December 1937.

	North and south piers, Tyne entrance.				Swing bridge, Newcastle.				Ryton and Newburn bridge.			
	Time: hours.	mins.	Height: feet.	inches.	Time: hours.	mins.	Height: feet.	inches.	Time: hours.	mins.	Height: feet.	inches.
					Tide-observations, August 1930.							
H.W.O.S.T. .	8	12	13	2½	8	15	13	10	8	16	14	1
L.W.O.S.T. .	8	22	2	11½	8	36	3	2	8	45	3	2
					Tide-Observations, December 1937.							
H.W.O.S.T. .	4	8	13	7	4	0	14	5	4	25	14	11½
L.W.O.S.T. .	10	5	2	6	10	2	3	0	10	31	2	6

In the vicinity of several of the bridges the level of the bed of the river was below the level of the bed above and below the bridge. There was no change in the river between the years 1930 and 1937 so far as obstructions or clearance of obstructions to tidal flow was concerned.

Mr. G. A. Maunsell observed that the Author's experiments went to prove that the amplitude of the tidal wave at the head of an estuary was not necessarily lowered by placing a partial obstruction across the estuary lower down, a conclusion which was to some extent contrary to what might have been anticipated according to pre-conceived ideas.

A few years ago he had studied movements which had occurred in the estuary of the Sittang river over a period of the preceding 30 years, and some of the movements in question appeared to have distinct bearing upon the subject of the Paper, and if not to corroborate, at any rate to parallel the Author's conclusions.

The Sittang estuary, situated at the head of the Gulf of Martaban in Burma, was probably the place where tidal and estuarian phenomena occurred on the grandest and most bizarre scale of anywhere in the world.

It might, indeed, be regarded as a natural laboratory where the most astounding changes were continually in progress.

At the head of the estuary, where the waterway was only about $\frac{1}{3}$ mile wide, was situated the Burma Railways bridge, having eleven spans of 150 feet. On the east bank 10 miles below the bridge there was a village called Kyaikkatha, and to an observer there the channel of the Sittang in 1930 had the appearance of an estuary 3 miles wide, bordered at low water by great expanses of mudbank with extensive shoals of sand exposed in the waterway. The water between the sand-shoals was spread out in wide shallow sheets, through which, during the period of low water (which lasted for 6 or 7 hours), the ebb flow went on continuously but without much apparent lowering of water-level.

Over those expanses of mud, sand, and water the incoming tide advanced suddenly. There was no preliminary backing up of the water-level before the turn, and no period of slack water. The crest of the advancing tidal wave appeared running over the top of the ebbing water, over-riding the banks of mud and sand and accompanied by noise and commotion, and bringing in its wake an immediate reversal of flow. Following the reversal the current flowed upstream at high speed, the whole channel became filled with swirling turbid water and the water-level rose, and continued to rise rapidly until in the course of 1 or 2 hours the whole estuary was running brimful between its banks. There followed a period of slackness at high water, and after that a rapid outflow of the tide and a falling away of the level until the normal low-water conditions were restored. Some idea of the size and shallowness of the estuary could be obtained by considering the fact that 50 miles seawards, on a line drawn across the Gulf of Martaban between the outlet of the Rangoon river on the west bank and that of the Salween river on the east bank, the width of the estuary was about 50 miles, but the general level of the bottom, still largely of a sandy character, was only about 15 feet below mean sea-level. The upper part of the estuary had never been charted. The rise of spring tide in the Gulf of Martaban was only about 8 feet above mean sea-level, whereas the rise in the river-channel beneath the Sittang bridge was between 20 and 40 feet. Those were conditions which gave rise to the famous Sittang tidal bore.

Between 1905 and 1928 a great change had occurred in the course of the estuary between the village of Kyaikkatha and the Sittang railway-bridge. Before 1905 the tidal channel between the bridge and the village had a course 50 miles in length, whereas it was now 10 miles. The change had come about through the short-circuiting of a great loop by a cut-off at the neck of the loop, called the Alok Cut. The Alok Cut had been a mere trickle when it had first appeared in 1905. It had attained a width of 500 feet with a depth of 30 feet in 1910, and in 1923 it had grown to $\frac{1}{2}$ mile in width, whilst in 1928 it had become 3 miles wide.

There was reason to believe that the short new channel was somewhat deeper than the old winding channel used to be, and there had certainly been a definite scouring action deepening the channel beneath the bridge, whilst in addition the level of the water at the bridge was lower than it used to be at corresponding states of the tide and fresh-water outflow.

Owing to the remoteness of the Sittang estuary from civilization there had unfortunately been no close and accurate records kept by reliable observers of what actually happened from year to year, and it had been necessary to piece together fragments of local information and records obtained from various sources, both European and native. The occurrence of the bore beneath the bridge being a somewhat spectacular affair, it had naturally left its mark in the memories of the local residents to a greater extent than changes in water-level and changes in position, and it had therefore been possible to gather fairly reliable information regarding the bore. There was no doubt that the bore used to appear underneath the bridge on spring tides between the years 1900 and 1913; that was to say, both before the formation of the Alok Cut and also during the early years before the Alok Cut had grown large enough to exercise an important influence. The bore did not appear in 1914 and 1915, but it reappeared in 1916. It became violent in 1924, running on one occasion beneath the bridge as a solid wall of water at least 10 feet high, and the action of the bore was observed to extend 8 miles upstream of the bridge in 1926. In 1928, the Alok Cut being fully established, the downstream mouth of the old channel had become entirely silted up and the bore beneath the bridge was not very noticeable. In 1930, however, it was again observed to be running more strongly, and on some occasions a bore-wave about 6 feet high was then observed beneath the bridge. What was so interesting from the evidence of the case was that before the Alok Cut formed, and in spite of the higher level of fresh water then obtaining under the bridge, the tidal wave used to be able to make its way up the long winding channel and to appear as a bore-wave beneath the Sittang bridge just as it did at the present time. The size of the bore-wave was not perhaps so large then as now, but the actual level of the crest above mean sea-level was very nearly the same.

The observations were not conclusive evidence of the importance of any particular factor, but they tended to indicate that a long tortuous channel was capable of transmitting a tidal wave of the same amplitude that a much shorter and more direct channel could transmit, a conclusion which ran parallel to Professor Gibson's theory that a 40-per-cent. restriction across a tidal channel might produce very little damping-out effect upon the tidal wave.

The Author, in reply, pointed out that if in *Fig. 9* (p. 496) additional points had been plotted showing the levels at the upper end of the Severn model—at Gloucester—the completed profiles would have shown the same phenomenon as in that of the symmetrical estuary, namely that in every profile except one the water-level at the head of the estuary was higher than at the mouth. If, however, similar profiles were plotted for the symmetrical model modified by the presence of a 60-per-cent. obstruction, they were essentially different from those from the unobstructed estuary, those on the flood showing lower levels at the top of the estuary than at the mouth and those on the ebb showing the reverse. The form of the profiles was bound to depend essentially on the form and length of the estuary, and on the relationship of its period of free oscillation to the tidal period.

It would be difficult to estimate the effect of the presence of bridge-piers on the volume of afflux with any great accuracy, but in the case of the proposed bridge over the Severn with its 8-per-cent. obstruction of the channel, the effect on the tidal levels was so extremely small—only a small fraction of an inch—that the effect on the volume passing would be almost infinitesimally small. In the case of a 40-per cent. obstruction it would only amount to some 2 or 3 per cent. of the normal inflow and outflow.

The information regarding the tidal observations on the river Tyne was interesting as showing that, in spite of the obstructions afforded by the piers of the many bridges between the sea and Ryton, the level of high water at the latter place was appreciably higher than at the sea, whilst the level of low water was sensibly the same at both points. It would be of great interest if corresponding figures could be given for the river before the bridges were built.

The description of the tidal phenomena in the Sittang estuary, and of the changes accompanying a straightening and shortening of the channel, would tend to confirm the conclusions drawn from the Authors' experiments, namely, that improving, from an engineering point of view, an estuary, did not necessarily give an increased inflow and outflow to the upper estuary, but might actually have the opposite effect.