

# TRAINING OF FULTA JAMES AND MARY REACH OF HOOGHLY

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Fulta James and Mary Reach

## PREFACE

The maintenance of 100 mile long approaches to the port of Calcutta has engaged the attention of the Port Authorities since the middle of the 19th century. Consequent on the increase of size of the vessels and their draughts, the problem of improving the navigability of the river Hooghly became more acute than in olden days. Port Commissioners sought the advice of various recognised experts. They were generally of the opinion that the James and Mary Reach was a bottleneck in the way of navigation. In 1947, Sir Claude Inglis, whom the Port Commissioners consulted, advised them to investigate the measures for improving the navigability of the river Hooghly by hydraulic model studies. The problem was, therefore, referred to the Central Water & Power Research Station in May 1947.

The memorandum gives a resume of model studies conducted to evolve an optimum solution for the improvement of the Fulta James and Mary Reach. These investigations were conducted on a hydraulic model of the Hooghly extending from the Sand Heads to Bansbaria at the field laboratory of the CWPRS.

The authors gratefully acknowledge the help of Shri A S Maik, B Sc, in conducting the model tests.

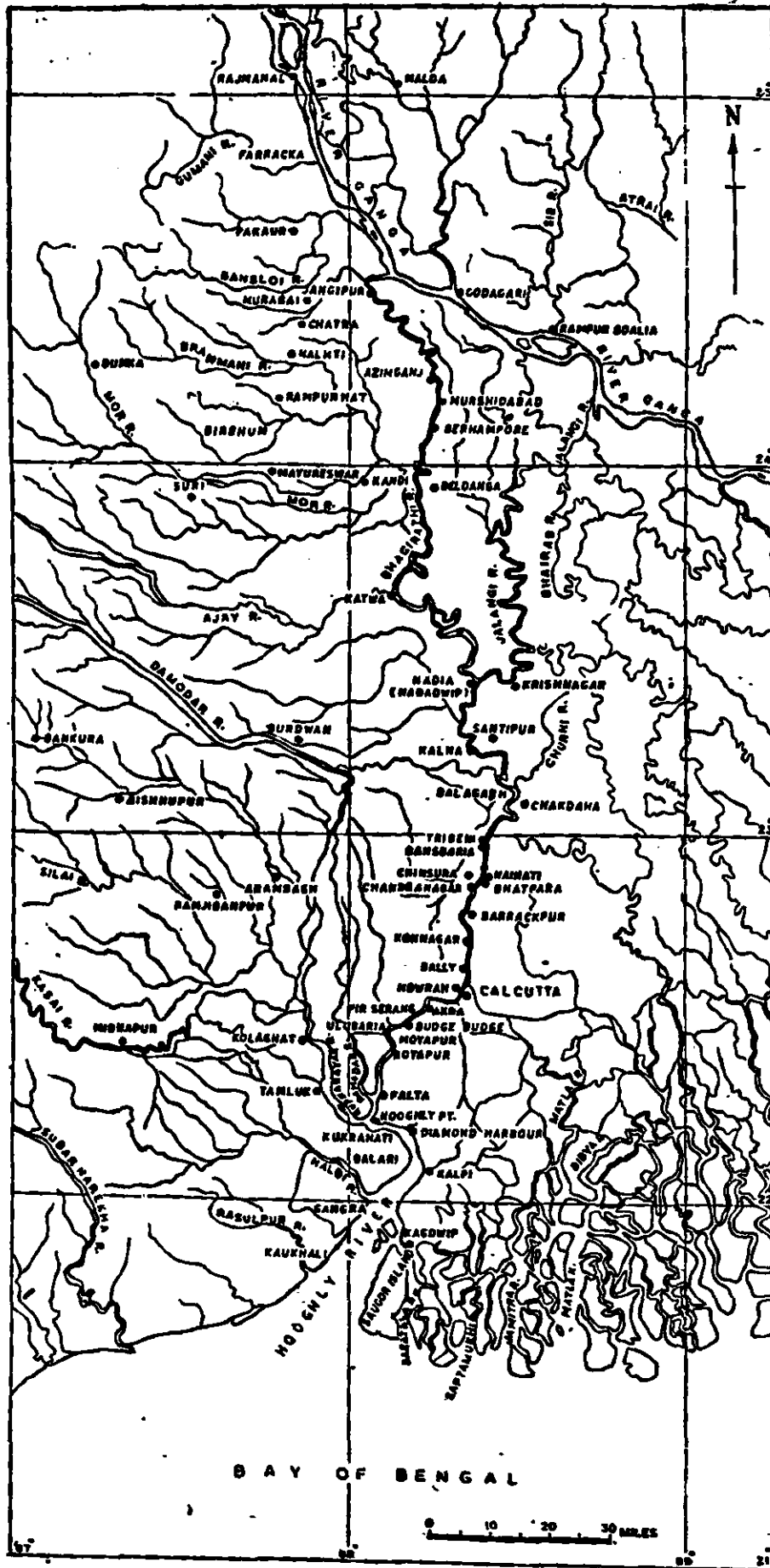


Fig 1 : Index Plan

## TRAINING OF FULTA JAMES AND MARY REACH OF HOOGLHY

### 1. HOOGLHY RIVER SYSTEM

The River Hooghly is formed by the confluence of the Bhagirathi and the Bhairab-Jalangi at Nabadwip about 138.40 km(75 N miles) above Calcutta(fig 1). Churni, the third feeder river joins the Hooghly 66.4 km(36 N miles) further down. Of these three spill channels of the parent river Ganga, only the Bhagirathi drains about 6700 sq miles of catchment on its western bank covering a large part of Birbhum district and the Santhal parganas with an average rainfall of 53 inches, through the tributaries Ajoy, Mor, Bansloi, Pagla, Babla etc.

Until 1893, the Damodar, one of the major tributaries of the Hooghly, had its outfall at Kalna 103.3 km(56 N miles) above Calcutta. However, due to changes in its course, the outfall shifted to a point about 57 km(31 N miles) downstream of Calcutta off Fulta. The Damodar river spills bulk of its freshet volume on its right bank into the Rupnarain which meets the Hooghly at Hooghly Point 7.40 km(4 N miles) south of the Damodar outfall. Two more smaller tributaries, the Haldia and the Rasulpur meet the Hooghly further down on its right bank 104 and 131 km(56.5 and 77 N miles) south of Calcutta.

### 2. APPROACHES TO PORT

The port of Calcutta is situated 184 km(100 N miles) inland. The outer bar, Beaumonts gut is 24 km(13 N miles) south of Saugor the Southern most gauge-site in the estuary. From Saugor to Diamond Harbour 67.4 km(36.5 N miles) further north, the estuary converges from

24 km (13 N miles) to 3.04 km (1.65 N miles) at an average rate of 0.31 km per km.

In the 62.7 km (34 N miles) stretch from Hooghly Point to Calcutta the river width decreases from 1.9 km to 0.5 km. The river course in this stretch is much more tortuous than further south, with the meanders gradually increasing in length. On account of the tortuosity, secondary currents develop and at every contraflexure of curvature a crossing appears. Also, on account of the peculiar geography of certain reaches like Sankrail and Ninan, bars form due to the divergence of the axes of the ebb and flood currents. During the freshets ebb currents predominate, to which the crossings tend to align. In the dry season when the flood tide dominates the crossings tend to align to the flood flow. The seasonal shift of the crossings is a source of trouble for day-to-day navigation. This behaviour of the crossings generally persists in the stretch down to Hooghly Point.

Further downstream to Diamond Harbour the river is very deep due to ebb of the Rupnarain which draws nearly 50 percent of the tidal influx at Hooghly Point. In this stretch there is only one crossing from below Luff Point. Between Diamond Harbour and Saugor in a distance of nearly 67.4 km (36 N miles) there are only two bars viz the Balari and Auckland. Below Diamond Harbour the channels are flood maintained and they do not exhibit the seasonal shifts of alignment of crossings as in the upper river.

South of Saugor the position of the bar depends on the entrance channel. There are three of them viz the Eastern channel with the Lower Long Sand on its west, the middle branch of the Western Channel running immediately along the Western face of Lower Long Sand and

the Far Western channel with its head off the Rasulpur outfall.

Prior to 1937 the Eastern channel was being navigated when the outer bar was Middleton about 8.9 km (4.8 N miles) below Saugor. Later on it deteriorated and the middle branch of the Western Channel opened when the outer bar was Beaumonts gut 24 km (13 N miles) south of Saugor. Round about 1768 the far Western Channel was navigated.

The cyclic changes of the entrance channel and its repercussions on the navigation channel in the Diamond Harbour-Gangra stretch form a problem by themselves.

### 3. NAVIGATION TO AND FROM CALCUTTA

An inbound vessel can be navigated with the rising tide to reach Calcutta in about 10 hours. An outbound vessel, however, has to anchor enroute. Ships of moderate draft negotiate the five low water crossings between Garden Reach and Ulubaria on the ebb to arrive at Moyapur on the next rising tide. Deep draft vessels negotiate these crossings on the night rising tide to anchor at Ulubaria before making of the ebb and proceed further on the next flood to cross the Eastern gut near about high water. Further down they may anchor at Kalpi to reach the open sea navigating against the next tide.

Though every bar or crossing is an impediment in the way of navigation, yet James and Mary reach of Hooghly Point had been the biggest one on account of its quick changing nature. As much as 1.67 m (5 ft) siltation in a day or two of spring tides is not unusual. Consequently it was the weakest link in the chain of bars at the time.

Since the introduction of steamers in place of sailing vessels, heavier and larger ships have naturally been put in the trade. While in the 19th century the port used to cater for comparatively low

draught vessels, in recent times 26 ft draught vessels are quite common (fig 2). Added to this, is the deterioration of the river channels. Both the factors contribute to restrictions on navigation. Since 1853 the Port Commissioners consulted recognised experts to study the question of the river condition and advise about measures for improving its navigability. There was no unanimity on the aspect of deterioration but various training works were suggested for improving the navigability (fig 3). In addition to the experts, Mr Webster, Chief Engineer of the Port Commissioners revived the suggestion of a ship canal joining the deep channel at Diamond Harbour to Kidderpore and King George Docks.

In 1947 the Port Commissioners consulted Sir Claude Inglis regarding improving the navigability of the river Hooghly. In his report the latter advocated hydraulic model tests for evolving suitable training works. Accordingly, the problem of improving the navigability of the Hooghly was entrusted to the Central Water and Power Research Station, Poona.

#### 4. THE FULTA-JAMES and MARY REACH

The typical geography of the Fulda-James and Mary reach with the outfalls of Damodar and Rupnarain at its ends and incidental complex flow pattern with strong secondary currents, render it the most hazardous as compared to other reaches. This reach was, therefore, taken up for studies first.

The reach consists of concave eastern bank above and below the projection of the Fulda Point. On the western bank the Damodar meets the Hooghly. At its lower end the river takes a right angled bend to the east at Hooghly Point; while the Rupnarain meets it on



the western bank opposite Hooghly Point.

During the freshets the dominating ebb follows the concave Fulta bight above the Fulta Point projection. Below the projection it naturally swings towards the Bungalow Point on the western bank with consequent slack velocities in the Ninan-Nurpur reach. Further down, due to the effect of the Rupnarain ebb which masks the ebb in the western gut, the ebb tends to be deflected to the Eastern gut. This improves the Eastern gut but deteriorates the Ninan-Nurpur reach.

In the following dry season the flood tide dominates and reshapes the channel configuration. It makes along the Western gut and is directed a few degrees east of north. It thus sets on to the Ninan bar and scours out the freshet season deposit, thereby improving the Ninan bar. However, due to secondary currents at the Hooghly Point, the bed load is drawn by the Eastern gut which deteriorates. Thus during the year either Ninan or Eastern gut is bad.

Since Eastern gut is a high water crossing, out-bound vessels have to negotiate the Fulta Point about 20 minutes to half an hour before high water. At this phase of the tide, in the dry season above the Fulta Point in the lee of the projection there is an ebb eddy in the channel(photo 1). At the point itself the set of the flood is due north. Thus when the bow of a vessel gets in the flooding region the stern is still in the slack and she gets a shear on to the Fulta sands. Similar eddy also appears at the Hooghly Point rendering navigation difficult.

##### 5. THE ESTUARY MODEL

The model covers a 249 km(135 N miles) reach from Reefs 113.76km (105 N miles) south of Calcutta to Bansbaria 55.36 km(30 N miles)

north of it(photo 2); the 87.65 km( $47\frac{1}{2}$  N miles) tidal reach above Bansbaria being incorporated in a labyrinth to absorb the tide. Rupnarain, the major tributary of the Hooghly in the tidal zone is reproduced as far as Baxi 52.6 km(28.5 N miles) above the outfall at Hooghly Point. The other minor tributaries viz Damodar, Haldia and Rasulpur are reproduced for a length of about 14.76 km( 8 N miles) beyond which suitable labyrinths have been provided to absorb the tide. The scale ratios adopted are

Horizontal	1/2000	Velocity	1/12.65
Vertical	1/160	Time	1/158

The design of model scale ratios was based on J Allen's criterion for movement of bed material(see appendix I). The mean diameter of the bed material chosen viz Ninan Sand was .094 mm which was about 75 percent of the mean grade of sand in the river.

#### 6. TIDE REPRODUCING ARRANGEMENT

Though electronically operated system for tide reproduction was thought of, yet considering the time and personnel required to develop such an arrangement, it was decided to use a manually operated arrangement for the purpose initially. The design of the equipment used is shown in fig 4. Since salinity reproduction was thought of, recirculation system was adopted.

The design consisted of a main sump fed by gravity supply from the Lake Fife. Water from the sump could be passed into the entrance channel either by gravity or by pumping when recirculation was required. The entrance channel fed the desired discharge directly into the tide chamber. From the tidal chamber surplus discharge in excess of that required by the tidal phase could be escaped out of the model to flow

into the Mutha Right Bank canal or back into the sump in case of recirculation by adjusting the radial gate opening.

### 7. SIMULATION OF TIDES

The curves for southern limit were statistically computed and adjusted in the light of initial observations so as to get as close a reproduction of gauges at Saugor and other places as possible. Fig 5 shows typical neaps and springs as obtained in model. A scrutiny of the various curves will show that the gauges at Saugor, Balari and Garden Reach were reproduced fairly satisfactorily.

### 8. TIME LAG BETWEEN GAUGES

Correct reproduction of time lag in a model means satisfactory tide propagation and right adjustment of desired friction coefficients. Observations of this aspect with comparative prototype figures are given in Table 1.

TABLE 1

Site	Time lag in model		Model values reduced to prototype dimensions:				Prototype time lag			
	Neap	Spring	Neap	Spring	Neap	Spring	Neap	Spring		
	Sec	Sec	hr	min	hr	min	hr	min	hr	min
Southern limit to Saugor	27	27	1	11	1	11	1	10	1	10
Saugor to Balari	35	60	1	32	2	38	1	35	2	40
Balari to Garden Reach	76	82	3	20	3	36	3	22	3	38

Comparison of columns 3 and 4 shows that the reproduction of time-lag and hence the velocity of propagation of the tidal wave was satisfactory.

## 9. FLOOD AND EBB CONDITIONS OF FLOW

In nature the flood arrives earlier by about 15 minutes along the Channel Creek and runs along the eastern side of Saugor island. The model observations showed that the flood of the creek channel arrived 5.6 seconds earlier which is equivalent to 14.45 minutes. The reproduction was considered satisfactory.

**HOOGLY POINT:** At the Hooghly Point, first of the flood passed into the Hooghly along the Western Gut while at the Eastern Gut there was a return eddy. After the high water slack the ebb first made along the Eastern Gut. As the phase advanced greater and greater width of the section began to ebb. When it went about half way, a return eddy began to make its appearance in the Western Gut; because some of the extreme left bank filaments of Rupnarain ebb made their way into the Hooghly. This return eddy went on elongating as the ebb proceeded up to Bungalow Point to merge into the first of the next flood(photo 3).

**FULTA POINT:** On the first of the flood the flow fanned out past the Fulta Point as below a gorge. Thus there was general initial flooding all across the section above Fulta Point. The fanning out effect reduced as the water level rose and a dead water region occurred near Date Station. This developed into a return eddy which gradually elongated with rise of water level. Just before high water slack, the clockwise return eddy extended from below near 29 Station down to M S 36 Station, finally to merge into the following ebb.

**SANKRAIL REACH:** Between Hangman's Point at the upper end and Akra Column at the lower one both the banks belly out. The river section in the reach, therefore, is wider than either upstream or downstream of it. In this reach the ebb followed the right bank but the flood tended

to make straight through the shoal away from the right bank with dead water at Sankrail which was just according to prototype observations.

First of the ebb at Akra made along the right bank where the channel was deep with almost a dead water region on the left bank. As the water level fell the slack water region developed into a counter clockwise return eddy which gradually elongated along the left bank. These flood and ebb flood conditions were confirmed by the officers of the Port Commissioners.

#### 10. BORE TIDE

The formation of bore tide is a phenomenon peculiar to the Hooghly river. Its neighbouring estuary, of the "MATLA", does not exhibit this characteristic. It is a wave front about 5 to 6 feet high, which travels upstream. It first shows at Brul and travels with a high velocity of about 17.5 knots. This sudden impulse causes considerable damage to property such as jetties, wharves, etc, dislocation of traffic and considerable silt movement in the upstream direction.

In the model this phenomenon was reproduced to a remarkable extent. The model bore travelled with a velocity 2.15 feet per second which works out to 16.35 nautical miles per hour. This was considered satisfactory.

#### 11. SIMULATION OF BED CHANGES

Initially quite a number of difficulties had to be overcome in respect of bed movement. Though the model was designed for bed movement according to the experimental results of Dr Jack Allen, it was noted that there was excessive movement in the upper reaches above Moyapur. From Moyapur to Diamond Harbour the movement was satisfactory while

below Diamond Harbour there was practically no bed movement. In the upper relatively narrow reaches, on account of vertical exaggeration, it was not possible to reproduce bed contours and they had to be laid in lean sand cement mix. So far as Fulta-James and Mary reach under investigation was concerned, the estuary below Diamond Harbour served as entry length. With injection and the satisfactory bed movement in the investigation reach fairly qualitative results were expected.

Another difficulty to be surmounted was of algae growth on the sandy model bed. When under water for about a week, the growth formed a film on the sand surface, prevented bed movement and defeated the very purpose of experiment. A series of tests were conducted for eradication of the growth. The choice of chemicals for treatment was limited by the fact that the discharge escaped from the model was required to be dropped into the Mutha Right bank canal which supplies drinking water to Poona city. A series of tests were conducted in the Chemistry Division. The final practicable solution of the problem consisted in treating the sand initially with a dose of copper sulphate as weak as 1 part in million and cutting off sun's rays by providing a cover to the model.

In nature sediment transport takes place by rolling on the bed, sal-tation and suspension while in the model only the first and partially the second aspect are present. Consequently accretion by suspended load had to be reproduced by injection of suitable material. In these experiments injection of treated saw dust was found to be satisfactory. The injected material moved freely with the currents and did not cause unnatural deposition at the site of injection. Pumice stone powder or gilsonite were also suitable but on account of availability and cost, saw dust was preferred for injection.

The adjustment of the rate of injection at the upstream and downstream end on the ebb and flood tides respectively was the next point to be determined. This depended on the tide cycle reproduced and the number of repetitions required for getting the desired bed changes. These adjustments were done by trial and error process. It was found that 360 repetitions of dry season spring tide were enough to give the bed changes with injection of saw dust.

With the various adjustments determined in preliminary runs, the model was laid to post-freshet conditions(fig 6a) and dry season spring tide operated. The model contours obtained at the end of 360 repetitions of the tide are shown in fig 6b while the corresponding prototype survey is shown in fig 6c. It will be observed that the formation of Eastern gut bar, improvement of Ninan bar and shrinking of the Fulta bight as indicated by the eastwardly shift of the 12 ft contour were fairly reproduced. The model performance was, therefore, considered satisfactory for evaluating the comparative effect of different training measures.

## 12. EXPERTS' PROPOSALS

As mentioned earlier various experts had suggested means to improve the Fulta-James and Mary Reach. Instead of spending time on detailed observations of each proposal, it was considered desirable to test the proposals in preliminary runs and concentrate only on the ones which gave promising results. The criteria for judging the performance were

- i. improvement of flow conditions and bars in the navigation channel
- ii. implementation of the proposal without affecting day-to-day navigation.

### 13. BROOKS' PROPOSAL

The proposal provided a cut from Nurpur across the land to opposite Luff Point and a small groyne at Shipgunj Column to direct the ebb into the cut. It was noted that the ebb bed load tended to enter the cut. The ebb velocities in the cut were slacker than in the main river. The groyne was ineffective in diverting ebb into the cut.

On the flood a return eddy formed on the leeward side of the groyne. Due to the meeting of the flood from the cut and the main river the flow pattern at the junction was complex. It was felt that unless the river below the cut was completely dammed, the cut would not function as desired.

Later experiments with a similar cut with the river below dammed showed that due to relatively greater energy of the tide on account of short cutting the length and avoiding loss at the right angled bend at Hooghly Point, there was a tendency to higher bores. Generally, conditions with the proposal were not considered satisfactory.

### 14. LEONARDS AND VERNON HARCOURT'S PROPOSALS

Both the proposals aimed at diverting the ebb into the Western gut. A longitudinal guide bund was envisaged. Leonard proposed to terminate it off Nurpur point with reclamation at Dhaja point above Damodar outfall and a groyne at Fort Mornington to induce greater influx in the Hooghly by reducing it from Rupnarain. On the other hand Vernon Harcourt proposed to continue the embankment down to Hooghly Point (fig 3).

Both the proposals when tested on the model showed that the ebb was not deflected to the Western gut. It always tended to flow down to the Eastern gut. An additional test was also conducted to test the effect of changing the concavity of the bank between Fulta & Hooghly



Point into a convexity with the Western bank suitably aligned(fig 7). The configuration thus smoothened out the bend at Hooghly Point to an extent.

The model showed that the ebb could not be drawn into the Western gut. It crossed over to the Eastern gut with sand separating it from the Western gut. Rupnarain ebb was noted to mask the ebb in the Western gut which got deflected into the Eastern gut.

#### 15. SIR CHARLES HARTLEY'S PROPOSAL

This consisted of a half tide mid river training wall on Muckrapatty sand. This proposal also did not work. A series of tests conducted on the lines of this proposal will be discussed later.

#### 16. LINDON BATES' PROPOSAL

The proposal envisaged getting rid of the double concavity by cutting off the projection at Fulta, with reclamation works above and below Damodar outfall. This was expected to improve Ninan and the Eastern gut. In the model the proposal was observed to give satisfactory conditions of flow in the Fulta-James and Mary reach. However, at Brul the tendency was to increase flood currents on the sand at the cost of the bight.

Of the various proposals tested, this appeared to be on the right lines in as much as it did not aim at reversing natural tendency of the ebb to follow the Eastern bank at Hooghly Point.

#### 17. SHIP CANAL SCHEME

This proposal was made by Mr Webster, Chief Engineer, Calcutta Port Commissioners. It consisted of connecting the Kidderpore and King George Docks to the deep bight at Diamond Harbour by a ship canal with necessary locks. Such a proposal would naturally obviate the need of navigating

the tortuous route along the river with its various bars and crossings and also their costly dredging.

To test this idea the model was run with freshet season followed by dry season for an equivalent period of seven years. Results showed that the tidal ranges at Bansbaria reduced first and then as the experiment proceeded the same effect was observed at Garden Reach. This effect gradually proceeded downstream. The low waters rose <sup>indicating</sup> and the likely deterioration in the channel retarding the tidal propagation. It was apprehended that in the long run this deteriorative trend would affect the lower reaches as well. The proposal was, therefore, dropped.

#### 18. FURTHER INVESTIGATIONS

Dry season runs showed that the Eastern gut deteriorated due to the secondary currents developing on account of curved flow at the Hooghly Point bend. It was thought that if the flood could be redistributed so that Eastern gut could draw greater volume than under existing conditions, the sand carried by the secondary currents might travel further up instead of depositing in the gut and improve it thereby. A number of vanes and groynes of different lengths, and top levels were tried in preliminary runs. Finally a half tide flood repelling groyne at Durgapur was found to be promising as judged by initial flow conditions.

The effect of the groyne was, therefore, further investigated in the model. The tests showed that with the Durgapur groyne a narrow gut through the bar deeper than 18 ft could be obtained. However, since the bed load entering the gut travelled further up and the Eastern gut drew more flood at the cost of Western gut, the Ninan bar was adversely affected.

With the flood tide an eddy developed off Shipgunj point thereby

reducing the sectional area for the forward flow. This effect together with the constriction at Fulta caused the flood to set on due north on to the Dhaja bank. Realigning the bank at Shipgunj effected better flow distribution across the section at Fulta Point but did not materially help the Fulta bight where at later phases slack water developed(photo 4).

To improve Ninan during freshet conditions recession of the Fulta projection in stages of 152.4 m(500 ft) was tested in combination with Durgapur groyne. The results were not satisfactory. The Durgapur groyne was ineffective to influence conditions at Ninan. Recession of the projection by 304.8 m(1000 ft) gave promising results which improved markedly when reclamation bunds were put at Dhaja. With these improvement works at Fulta, further tests to improve the Eastern gut in the dry season were conducted.

Since in the dry season bed sand from the back of the Hooghly drifts into the gut, submerged vanes to deflect the bed load away from the Eastern gut were evolved by trial in preliminary runs. It was noted that with these vanes a mid-river training wall on Muckrapatty wand was essential in order to prevent the deflected drift of sand coming up via Western gut into the channel along eastern bank. This device was subjected to detailed studies. Though flood bed load was effectively diverted from the Eastern gut, flow conditions on the flood and ebb were quite unsatisfactory as the experiment progressed (photos 5 to 9). The unsatisfactory aspects were:

- a. tendency of the flood to hug along the eastern face of the mid river training wall
- b. return eddy at the Hooghly Point during flooding
- c. concentration of ebb along the eastern face of the mid river training wall

- d. the sharp angle between the Rupnarain and the Eastern gut ebb
- e. eddy formation at the tail of the mid river training wall and also off Luff Point.

The model bed survey(fig 8) was also unsatisfactory as the channel on the east of the mid river wall developed a sharp kink. The diversion of bed load away from its natural course thus did not prove satisfactory. Consequently various shapes and lengths of mid river wall only were tested.

A mid river training wall with a bell-mouth shape was tested. A 12 ft bar appeared and the channel tended to hug the lower half of the training wall(fig 9). Curving the mid river wall also did not help. A mid river training wall with a bell-mouth in combination with a curved vane from Hooghly Point curving round to end of Durgapur was tested. Fig 10 shows the bed survey. The eastern 12 ft contour encroached on the channel and a bar shallower than 12 ft developed. Channel condition was obviously unsatisfactory.

The tests showed that it was not advisable to artificially enforce conditions against the natural secondary currents at the Hooghly Point. The channel tended to hug the training wall which was unsafe from the point of view of navigation under the flow conditions obtaining.

#### 19. TRAINING THE EBB

As the methods of training the flood at Hooghly Point were not successful, efforts were made to train and strengthen the Eastern gut ebb with a view to counteract the siltation obtained by secondary currents on the flood. Effect of recession of the projection along with reclamation off the Dhaja bank was further studied. It was noted that mere recession of the projection was not enough to improve the

flood set in the Fulda bight. With the reclamation bunds at the Dhaja flat and off Shipgunj above and below the Damodar outfall, flow conditions markedly improved. Effect of slicing off the projection in small bits with reclamation above and below Damodar outfall was tested in preliminary runs. It was noted that 152.4 m(500 ft) recession was not enough in improving the Fulda bight. 304.8 m(1000 ft) recession showed promising conditions, while with recession of 548.64 m(1800 ft) or more the flood velocities over the Brul sand further upstream increased with development of dead water in the bight. 365.76 m(1200 ft) was about the optimum recession. The effects of 304.8 m(1000 ft) and 365.76 m (1200 ft) recessions of the projection were, therefore, studied further.

The model was laid to post freshet survey of 1945 and tested under dry season conditions. Figs 11 to 13 show comparative model survey under existing conditions (fig 11), with 304.8 m(1000 ft) recession (fig 12) and with 365.76 m(1200 ft) recession (fig 13). Comparison of figs 11 and 12 shows reduction in the length of the bar, while fig 13 shows a narrow channel though its direction is slightly altered.

In the Fulda bight, under existing conditions, the upper and lower 5.49 m(18 ft) contours were separated from each other with a shallower gap off lower Fulda Mark with an isolated pocket (photo 10). On the other hand, with 365.76 m(1200 ft) recession, the shallow stretch was deepened giving a through channel along the bight (photo 11).

## 20. VELOCITIES

Figs 14(A) and 14(B) show velocities during a complete tidal cycle at various points in the reach from Brul down to Hooghly Point. Inset of fig 14(A) shows location of the points. Table 2 shows the mean and maximum velocities at the points.

TABLE 2 : Model Velocities in ft/sec

A = Experiment with existing conditions

M = Model

B = Experiment with 1200 ft recession

P = Prototype

Point of observation (see fig 14A)		Mean Velocity				Maximum Velocity			
		Flood		Ebb		Flood		Ebb	
		M	P	M	P	M	P	M	P
Eastern Gut Point 39 (0'N 2'W)	A	.49	6.20	.28	3.54	.71	8.98	.42	5.31
	B	.44	5.57	.33	4.17	.71	8.98	.56	7.08
Point 35 (1'N 1.25'W)	A	—	nil	.32	4.05	nil		.50	6.33
	B		nil	.35	4.43	nil		.50	6.33
Point 33 (2'N 0.50'W)	A		nil	.35	4.43	nil		.56	7.08
	B		nil	.46	5.82	nil		.63	7.97
Western Gut Point 28 (3'N 2'W)	A	.42	5.31	.33	4.17	.63	7.97	.50	6.33
	B	.45	5.69	.18	2.28	.63	7.97	.28	3.54
Fulta-Ninan Reach Point 24 (7'N 2'E)	A	.28	3.54	.43	5.44	.50	6.33	.56	7.08
	B	.15	1.90	.50	6.33	.31	3.92	.36	7.97
Point 17 (12'N 3'E)	A	.08	1.01	.36	4.55	.19	2.40	.56	7.08
	B	.32	4.05	.41	5.19	.50	6.33	.63	7.97
Point 13 (14'N 4.5'E)	A	.11	1.39	.40	5.06	.23	2.91	.56	7.08
	B	.19	2.40	.42	5.31	.36	4.55	.63	7.97
Brul Reach Point 6 (27.25'N 2.33'E)	A	.13	1.64	.40	5.06	.48	4.81	.59	7.46
	B	.12	1.52	.40	5.06	.36	4.55	.56	7.08

Reference to points 39, 35 and 33 in the Eastern gut shows that at point 39 the ebb velocities considerably increased during the latter half of the tide with the recessed Fulta Bank. This was because of the strengthening and better canalisation of the ebb with consequent checking of the flood eddy abreast Hooghly Point. Points 35 and 33 fall in the region of ebb eddy and as such the flood velocities at these points were not affected by the recession. During ebb, however, the velocities improved much especially on the last of the ebb.

In the Western Gut, at point 28, it was observed that the flood velocities were little affected but the ebb velocities decreased by the recession of Fulta bank, at the cost of corresponding increase of ebb velocities in the Eastern gut which is a good feature.

Fig 14(B) shows the velocities in the Ninan Reach, Fulta bight and the Brul reach. Ninan bar forms during freshets but improves during dry season. Hence, freshet velocities in the vicinity of this bar with and without recession were observed and are shown in fig 14(B) at point 24. It will be seen that the ebb velocities considerably increased and consequently a better channel in the Ninan reach was obtained. The flood velocities were seen to have reduced with the recession.

At both the points 17 and 13 in the Fulta bight the flood velocities markedly increased. This was due to the removal of the projection, as a result of which forward flow was ensured in the bight. This indicated that the deterioration of Fulta reach during the dry season under existing conditions will be checked by recession. During ebb tide, the velocities were not much affected as expected.

At point 6 in the channel opposite Brul Column, the average flood velocity was unaltered which indicates that the 1200 ft recession would

not affect the Brul reach adversely. The average ebb velocities were were also not appreciably changed.

## 21. FLOW PATTERN

Observations of flow pattern with recessed Fulta bank were made photographically by means of confetti. For comparison corresponding photographs under existing conditions are also reproduced.

Photo 12 shows the dry season flood flow under existing conditions and 13 with 365.76 m(1200 ft) recession of Fulta bank and corresponding reclamation. It will be observed that with existing conditions ebb eddies appeared at the Hooghly Point, Shipgunj Point and in the Fulta bight. The eddy at Shipgunj restricted the waterway of forward flow thus adding to the gorge effect above Fulta Point. This resulted in the flood flow tending to set towards Dhaja bank with an eddy in the Fulta bight.

With the recession and reclamation(photo 13) the eddy at Hooghly Point shifted its tail slightly further upstream. The general pattern of flood flow at the point was otherwise similar to that in photo 12. Further upstream the flood flow improved considerably; the gorge effect above Fulta Point disappeared and flow conditions improved with forward flow in the Fulta bight.

As the work of recession of the projection was likely to be difficult an attempt was made to see if training works alone on the western bank above and below Damodar outfall would give equally good conditions. Accordingly, to cause as little contraction of the existing section as possible, half tide permeable groynes were tested above and below the Damodar outfall without recession of the point.

Photo 14 shows flow conditions after 4 hours making of flood at



Hooghly Point. These were not satisfactory. The eddies in the Fulta bight as also the flood set off the point were unchanged. Dredging of the flat in front of the Fulta Point in addition to the half tide groynes above and below Damodar outfall worsened the conditions (photos 15 to 18).

Of all the tests, satisfactory results were obtained with a 365.76 m (1200 ft) recession of the Fulta Point and corresponding reclamation above and below Damodar outfall.

## 22. EFFECT OF FULTA POINT SCHEME ON BRUL REACH

The effect of the Fulta Point Scheme on the Brul Reach was tested on the model laid in treated saw dust. After preliminary runs for selection of tide cycle and evaluation of time scale, comparative tests with existing conditions and with 365.76 m (1200 ft) recession and corresponding reclamation were conducted. Results showed that compared to existing conditions there was no deteriorative trend of depths or velocities in the Brul and Royapur Channels due to the recession of the Fulta Point.

## 23. PHASING OF WORK INVOLVED IN FULTA POINT RECESSION

The complete scheme of training the Fulta James and Mary reach consisted of the following works:

- i. Reclamation above the Damodar outfall
- ii. Reclamation below the Damodar outfall
- iii. Removal of the flat in front of the Fulta bank
- (and iv. Recession of the projection

Of these, (i) and (ii) pertaining to reclamation were away from the navigation channel and could be executed without interference with day-to-day navigation.

Works for (iii) and (iv) were along the navigation channel. It was necessary to phase the programme of work in a manner not to create undesirable conditions and hamper day-to-day navigation.

To draw out a programme of work consistent with above requirements two series of experiments were conducted with the model bed laid mobile to post freshet conditions and the dry season spring tide simulated.

First series without reclamation on the Eastern bank was run to show the following phases of work(fig 15):

- a. The outer spit dredged to 20 ft to about the datum line abreast of the point with the inner dredged line running about North and South of the western most point of the Fulta projection.
- b. Bund to admit dredger over a width of 400 ft and the area inside the bund removed in stages of
  - i.  $\frac{1}{8}$ th dredged
  - ii.  $\frac{1}{2}$  dredged
  - iii.  $\frac{7}{8}$ th dredged
  - iv. inside bund completely dredged to 20 ft
- c. Dredging outside bund completed except for the spit to the northward.
- d. The removal of the bund starting at the north end block by block for 6 blocks starting 1200 ft from the recession line.

The second series was run in exactly the same way as the first except that the reclamation bunds were in position.

The removal of the outside strip in the first series did not adversely affect the navigational conditions and if anything, showed slight improvement in eddies above Fulta Point and a tendency to concentrate the flow in Ninan slightly eastward of normal condition. In the second series on the ebb tide, the flow still followed the east bank above the point but tended more to the eastward at Ninan. On the flood tide, the flow across the Fulta sand appeared to be more concentrated to the east. There was the normal slow reverse eddy along the east bank, on the last of the flood tide.

In neither series did the cutting of the bund over a width of 121.92 m(400 ft) at a position 365.76 m(1200 ft) to 487.68 m(1600 ft) from the recession line have any effect on the navigable channel.

The result of dredging inside the bund was the same in both series. There was a slight increase in the eddies at the entrance as the dredging progressed but these did not extend outside the bund and though there was a slow rotary current inside the dredged area, it did not appear to be of sufficient strength to interfere with the operation.

Up to this point the operation cannot be said to have affected the navigation of ships except possibly by the presence of the dredger and its anchor cables. The conditions were if anything slightly improved as the work progressed and the existence of the reclamation work in anything showed further improvement. It appeared possible that if the lower part of Fulta sand showed any tendency to encroach on the channel, prior dredging to widen the channel in this area might be an advantage. At Ninan the slight swing of the flow of the ebb eastwards caused by the removal of the outer strip and increased by the reclamation works might require the services of a dredger.

The completion of the removal of the outer strip had the same effect in both series namely the swing of flood and ebb currents eastward in Ninan and a concentration of the flood above Fulta Point over the eastern area of Fulta Sand. These tendencies were emphasized by the reclamation on the west bank. At this stage there appeared to be definite advantages in the existence of the reclaimed area.

The removal of the bund, however, created critical conditions both for the navigable channel and the dredger. These reached a peak when 543.64m (1800 ft) of bund had been removed from the north end and continued till the 5th block had been removed after which conditions improved. By the time the 6th block had been removed, the channel was practically unaffected.

During this operation, there appeared to be no doubt that the existence of the reclamation area was an advantage to the shipping but made the work of the dredger more difficult by increasing the intensity of the eddies in the vicinity of the bund. There was an indication that shipping would be restricted during this period though it may be permitted for half an hour either side of High Water. The restricted period may be expected not to exceed about one month.

During the second series, the removal of the lower part of the outer spit was not done until over one half of the bund had been removed and it appeared that the existence of this strip was advantageous to the dredger without interfering with navigation. This would appear to provide a means of obtaining flexibility in the dredging programme.

As a result of model tests the provisional dredging programme was recommended as under:

- a. October 1958 to February-March 1959  
Outer strip part. Stage IA & IB
- b. February-March to September 1959  
inside bund. Stage II
- c. October 1959 to January 1960 complete  
outer strip. Stage IV
- d. January-February 1960  
demolish bund. Stage III
- e. March 1960 complete  
cleaning up and upper spit. Stage V.

The construction of the reclamation work is advantageous from the time the outer spit is removed but need not be completed till the area inside the bund has been dredged in September 1959. The important part is that the construction of the nose of the upstream reclamation should be strong enough to withstand the attack of the flood tide.

The demolition of the centre of the bund should preferably take place during weak tides of December-January-February and preferably during

the neap tides.

It appears desirable to phase the progress of the reclamation work to start as soon as possible and to complete it by December 1959. It is likely that the maintenance dredging programme will depend on this progress up to the time of the removal of the bund, when the full effect of the operations will be felt in the navigable channel.

#### 24. CONCLUSIONS

The tests brought out the following points:

1. Though Western gut is the natural flood channel it does not draw sufficient ebb flow. On the other hand Eastern gut is the natural ebb channel which deteriorates in the dry season due to secondary flood currents.
2. With the pattern of flow conditions imposed by the Rupnarain ebb, it is not possible to develop a navigable channel to the Western gut. Any works aiming at this would oppose nature rather than aid it.
3. If the river were left to itself without any dredging or training works, serious deterioration may result in the long run.
4. Training works designed to deflect flood into the Eastern gut are undesirable since they result in channel and flow conditions detrimental to navigation.
5. Training the ebb to the Eastern gut is by far the best solution of the problem.
6. Recession of the projection by 1200 ft would benefit the Fulda bight as well as Ninan Eastern gut reach.
7. Since the optimum alignment of bank line at Fulda may erode and upset the desired regime it is necessary to hold the bank by suitable pitching.
8. Programme of work should be so phased that there is least trouble in navigation during the transition period. By the time the recession is complete - the reclamation above and below Damodar outfall may be completed.
9. The programme of works evolved if adhered to would give the least interference with day-to-day navigation.

The recommendation of the CWPRS namely recession of the Fulda Point projection by 365.76 m(1200 ft) and reclamation above and below Damodar outfall was communicated to the Commissioners for the Port of Calcutta

who accepted it for implementation. The reclamation works are planned to be done departmentally while for the recession work world tenders were invited.

The recession work consisting of dredging 4.59 m cubic metres (6.01 m cubic yards) of hard blue clay and some sand, was allotted to the Dutch Firm AMSTERDAMSCHER BALLAST MAATSCHAPPIJ, AMSTERDAM.

Reclamation works were planned to be done departmentally. At the time of writing this report the works above the Damodar outfall have been completed. Permeable groynes consisting of 1,33 m distant piles in two rows 1 metre apart with split bamboo fastened across served their purpose very well.

The implementation of the entire scheme is scheduled to be completed by 1961.

## APPENDIX I

### Design of scale ratios of the Model of Hooghly River from Bansbaria to Reefs 25 miles below Saugor

The model of the Hooghly Estuary covers a reach of 115 N miles from Bansbaria down to Reefs 15 miles below the Saugor Light House. The object of model experiments is to investigate the means of improving the navigability of the river.

Length scale ratio: Considering the area available immediately, the length scale of 1/2000 suggested by Sir Claude Inglis is suitable and is adopted.

Depth scale ratio: Sir Claude Inglis had proposed a depth scale of 1/160; presumably this was based on Lacey's formula which gives

$$\text{depth scale} = (\text{length scale ratio})^{2/3} = 1/158$$

However, it was expedient to examine the choice of depth scale ratio from the view point of bed movement, turbulence etc.

Table 3 gives the computations for Allen's criterion for different depth scales at various sections along the river from Saugor to Calcutta. First row gives 'h', the depth; second computed velocity; and the third the Reynold's number. Computed velocity was worked out by Dr Jack Allen's formula

$$V = 1.3(F - F')^{.27} L^{.27} M^{-.27} h^{.23}$$

where

- V = velocity in ft/sec
- F = specific gravity of sand used in the model
- F' = specific gravity of water assumed unity in this case
- L = length of the side of a cube having the same weight as the average grain (inches)
- M = uniformity modulus of material
- h = depth of water in inches

The average grain size was taken to be the weighted mean diameter of the Ninan sand viz .094 mm with which the model bed was proposed to be moulded. Fig 16 shows the sand distribution graph from which the modulus of uniformity of Ninan sand was worked out to be .483.

Comparison of prototype and model values for 1/160 scale shows that bed movement may be expected in the model with this depth scale. It was noted that considering the high computed threshold velocities it may be necessary to go in for a higher exaggeration or material of lower specific gravity, unless on account of curvature effect and consequent velocity distribution satisfactory bed movement was possible. Further considering the availability of discharge it was considered better to work with the depth scale of 1/160 at the outset.

From the tabulated values of Reynold's number it will be seen that in each case turbulent flow in the model was satisfactorily ensured.

Table 4 shows the computations for Reynolds' criterion. It will be seen that except in the case of the depth scale of 1/80 Gibson's criterion of  $h^3 \sqrt{H/30} \geq 0.09$  was not satisfied. However, in the light of experience of other tidal models it was likely that the depth scale of 1/160 may give satisfactory results.



TABLE 3

		: Prototype	: Model values for depth scale			
		: values for	:	:	:	:
		: maximum	: 1/80	: 1/120	: 1/160	: 1/200
		: flood	:	:	:	:
SAUGOR	h	25' 0"	3.756"	2.496"	1.884"	1.500"
	V (ft/sec)	5.2	.513	.467	.443	.416
	*R x 10 <sup>-5</sup>	130.0	.1666	.0971	.0695	.0520
GANGRA	h	26' 1"	3.912"	2.616"	1.956"	1.572"
	V (ft/sec)	7.41	.520	.472	.442	.420
	R x 10 <sup>-5</sup>	193.29	.1695	.1092	.0720	.0550
BALARI	h	25' 0"	3.756"	2.496"	1.884"	1.500"
	V (ft/sec)	5.4	.513	.467	.443	.416
	R x 10 <sup>-5</sup>	135.0	.1606	.0971	.0695	.0520
HOOGHLY POINT	h	27' 4"	4.116"	2.748"	2.064"	1.644"
	V (ft/sec)	7.5	.524	.478	.447	.424
	R x 10 <sup>-5</sup>	205.0	.1707	.1095	.0769	.0581
KING GEORGE DOCKS	h	35' 0"	5.250"	3.492"	2.628"	2.100"
	V (ft/sec)	10.7	.554	.505	.473	.449
	R x 10 <sup>-5</sup>	374.5	.2426	.1469	.1036	.0786

\* Reynold's number

TABLE 4

Depth: h	≡	:	:	:	: Verti-	: Max	: Q in	: Time	: Model
scale: 16.33 ft:	:	:	:	:	: cal	: flood:	model	: scale	: Tidal
: below	: 100h <sup>3</sup> :	e	: h <sup>3</sup> e <sup>√H/30</sup> :	Velor	: in	: =	: ratio	: period	:
: Saugor	:	:	:	: city	: model:	50x10 <sup>6</sup> :	:	: 12 hrs	:
: (ft)	:	:	:	: ratio	: 10 <sup>6</sup> :	cfs	:	: 18 min	:
:	:	:	:	: L/d	: 10 <sup>6</sup> :	:	:	: min	:
1/80	.204	.85	25.00	.157	2.80	1/1.43	35.00	1/223	3.30
1/120	.136	.25	16.67	.0307	1.52	1/2.63	19.00	1/183	4.03
1/160	.102	.11	12.50	.0101	.988	1/4.05	12.35	1/158	4.66
1/200	.082	.06	10.00	.00442	.706	1/5.66	8.82	1/141	5.24

\*  $\sqrt{H/30} = 0.737$

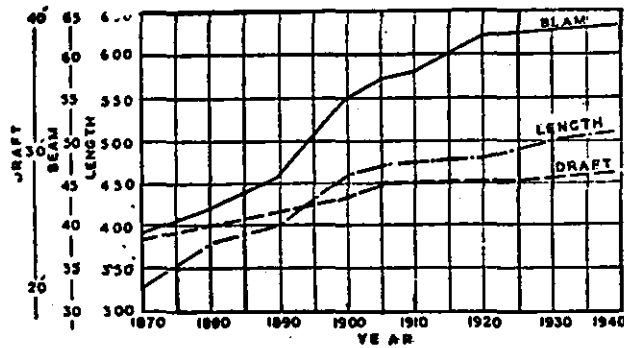


Fig 2: The increase in size of vessels trading with the Port of Calcutta worked out from average of the ten largest ships.

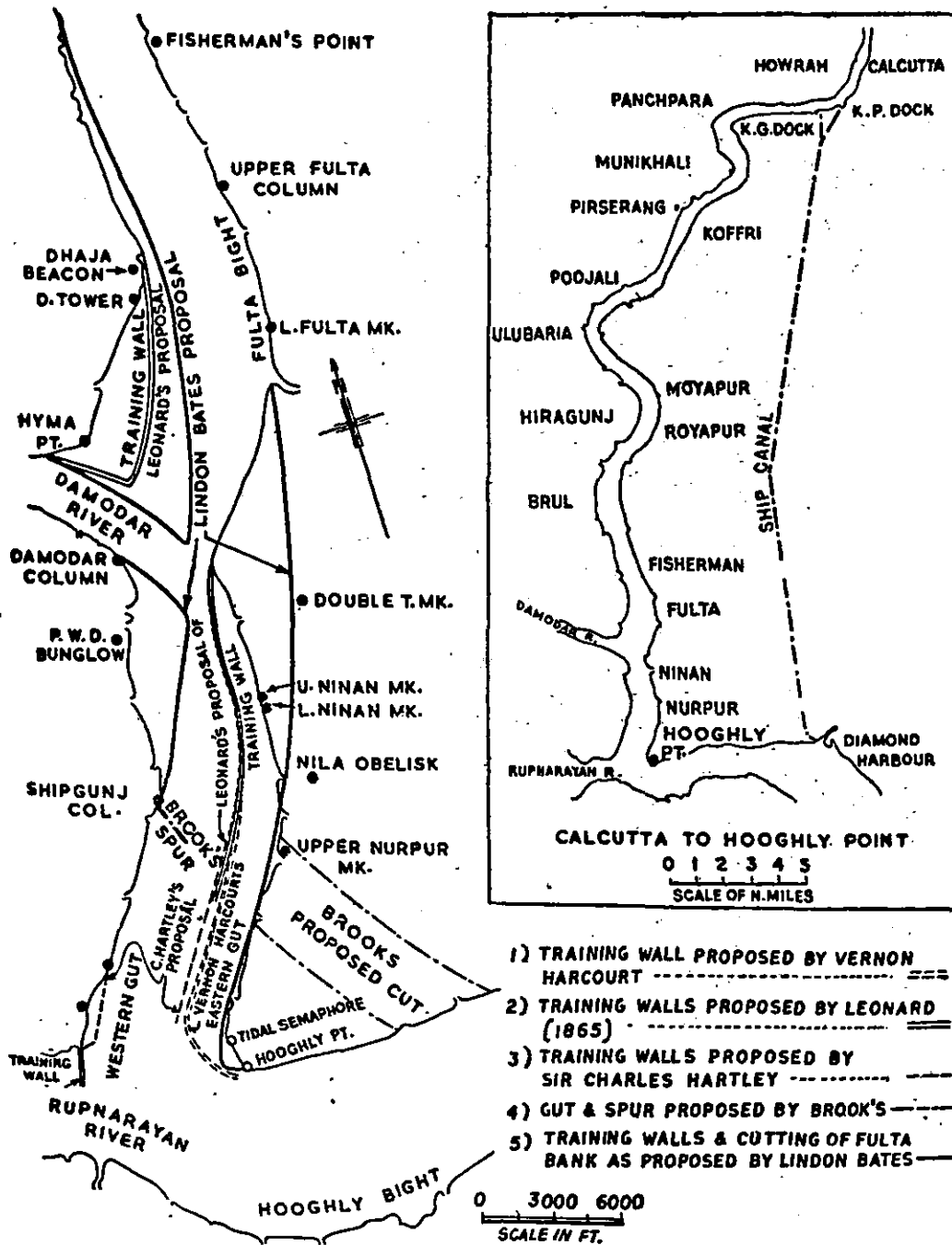


Fig 3: 1/2000 : 1/160 model of the Hooghly estuary showing proposals of experiment in the Fulta Reach.

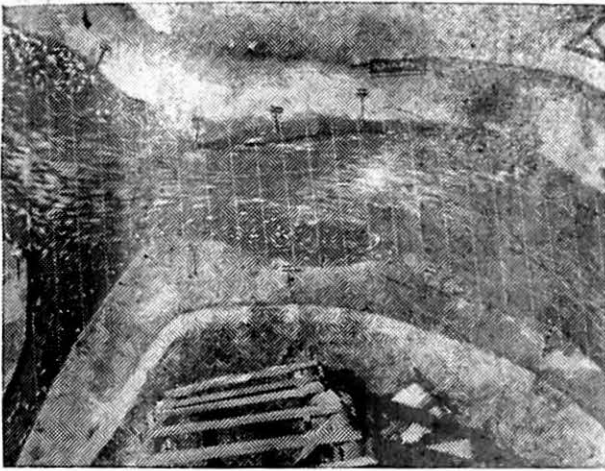


Photo 1 : Flood flow pattern on the last of the flood



Photo 3 : Flood eddy between Fort Mornington and Bungalow point

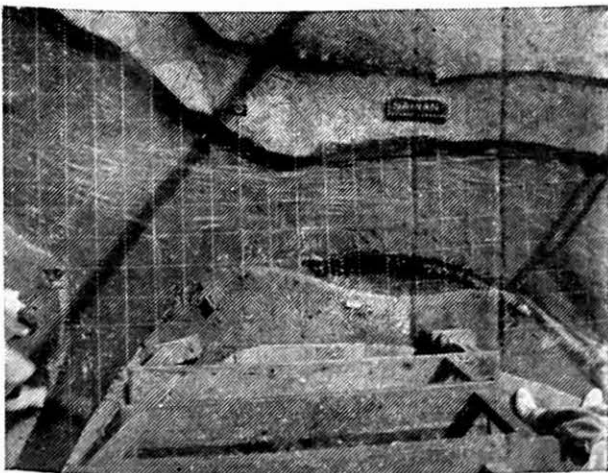


Photo 4 : Effect of realigning bank at Shipgunj

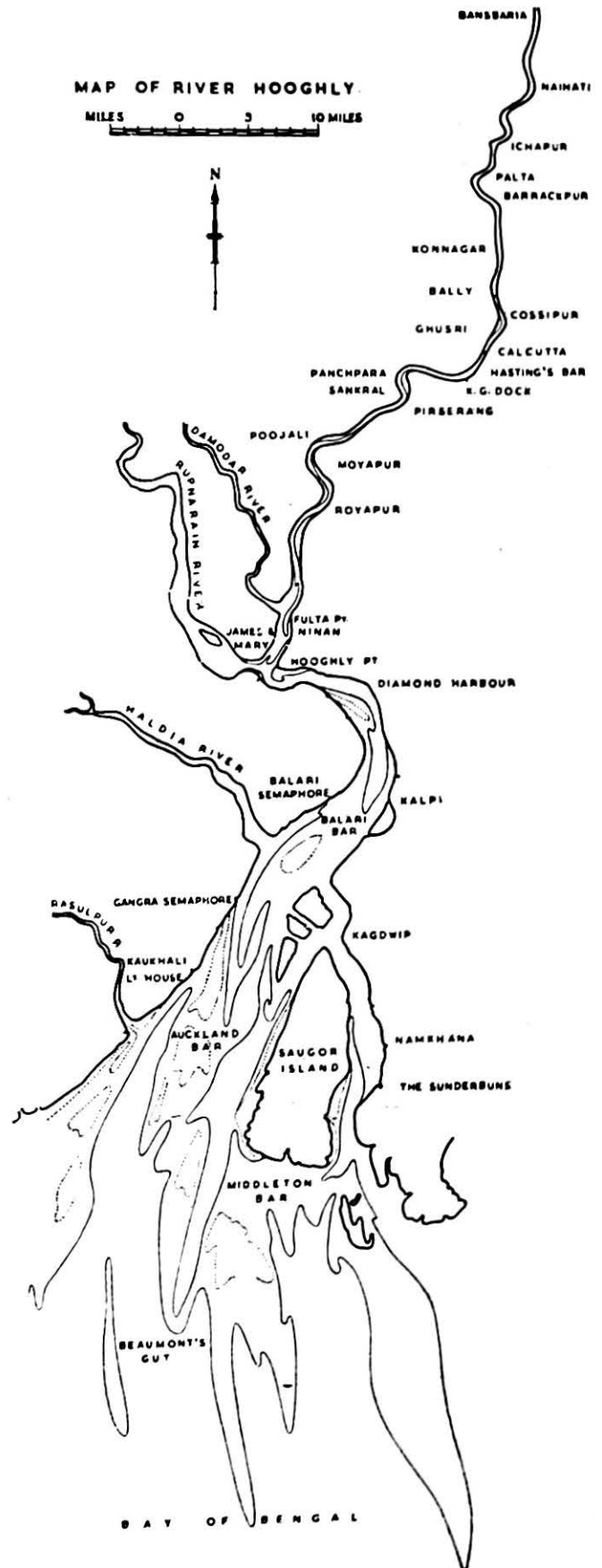


Photo 2 : The reach reproduced in the model

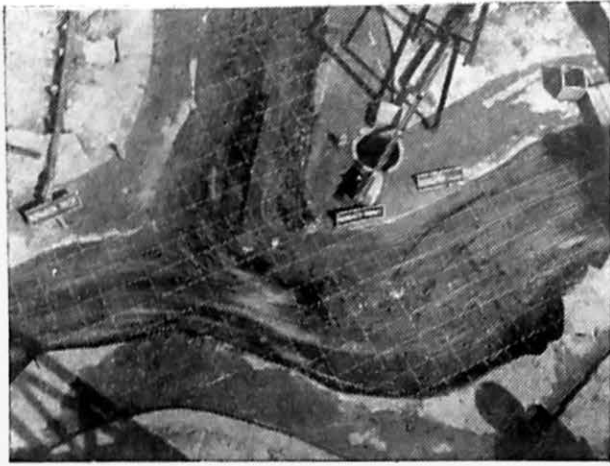


Photo 5: Flood flow pattern 40 seconds (1 hr 45 mts) after making of flood

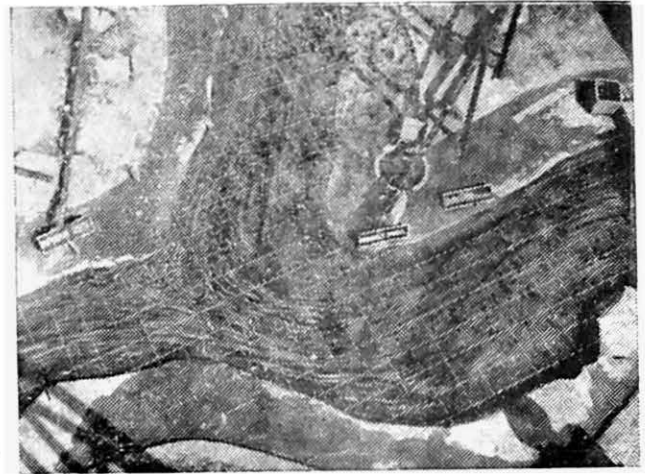


Photo 6: Flood flow pattern 1 m (2 hrs 38 mts) after making of flood



Photo 7: Ebb flow pattern 20 seconds (52 mts) after making of ebb



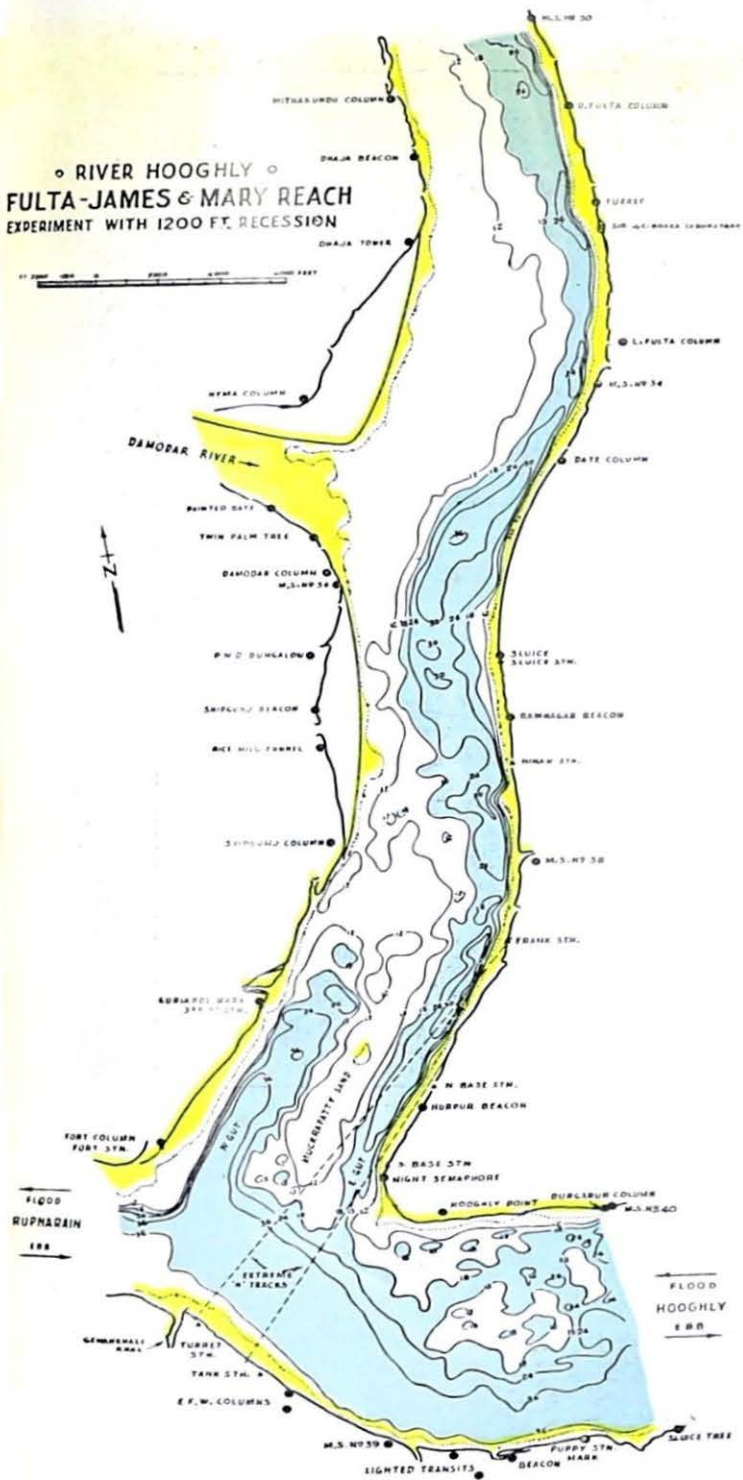
Photo 8: Ebb flow pattern 1 m (2 hrs 38 mts) after making of ebb



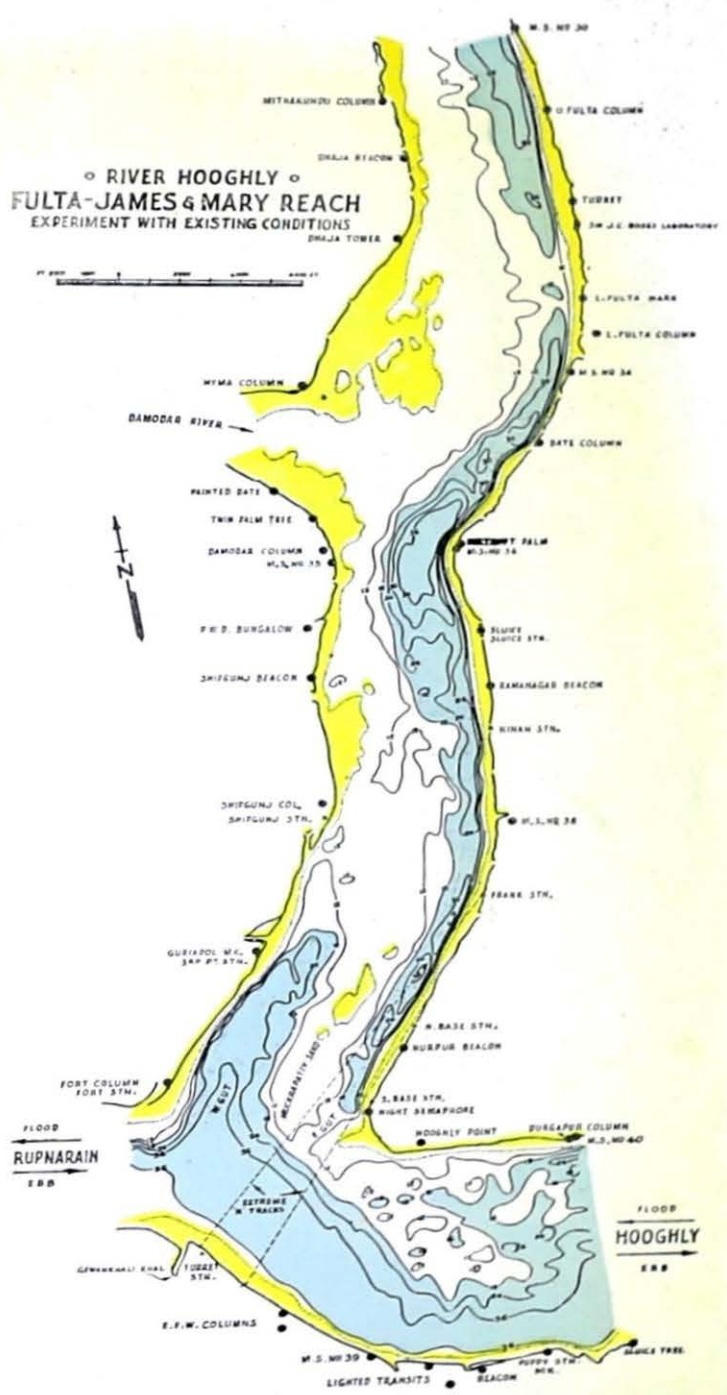
Photo 9: Ebb flow pattern 2 mts and 20 seconds (6 hrs 8 mts) after making of ebb



◦ RIVER HOOGHLY ◦  
**FULTA-JAMES & MARY REACH**  
 EXPERIMENT WITH 1200 FT. RECESSION



◦ RIVER HOOGHLY ◦  
**FULTA-JAMES & MARY REACH**  
 EXPERIMENT WITH EXISTING CONDITIONS



Photos 10 & 11

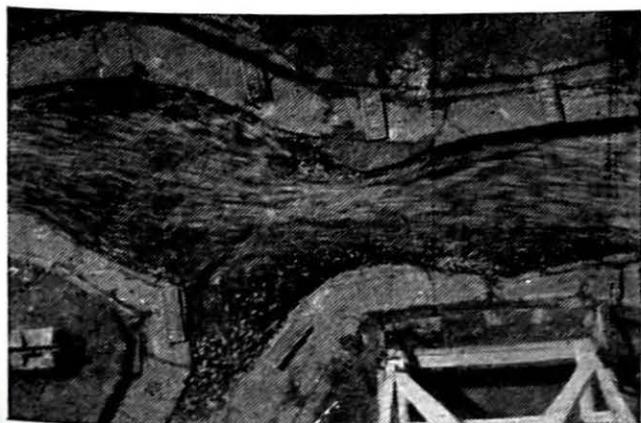


Photo 14 : Flood flow pattern with only half tide groynes above and below Damodar outfall



Photo 12 : Flood flow pattern with existing conditions  
3 hrs after L W

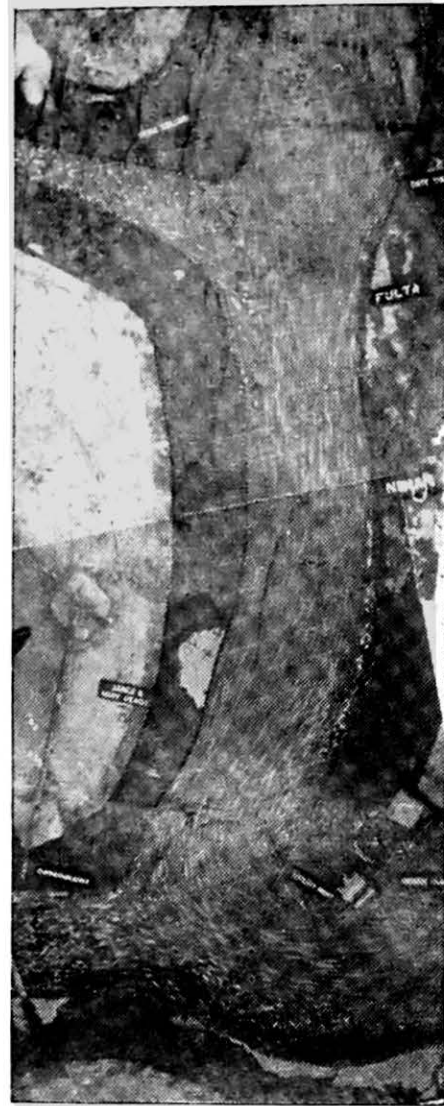


Photo 13 : Flood flow pattern with 1200 ft recessio  
and reclamations, 3 hrs after L W



Photo 15 : Flood flow pattern 47.4 mts after L W



Photo 16 : Flood flow pattern 1 hr 27 mts  
after L W



Photo 17 : Flood flow pattern 2 hrs 19.7 mt  
after L W



Photo 18 : Flood flow pattern 3 hrs 15 mts  
after L W

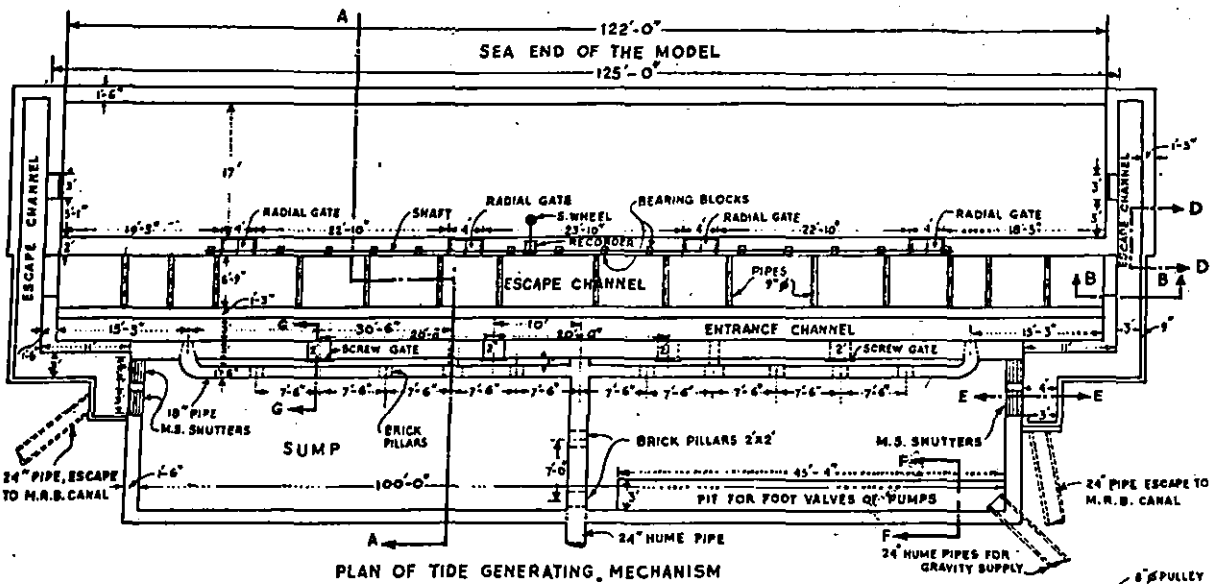
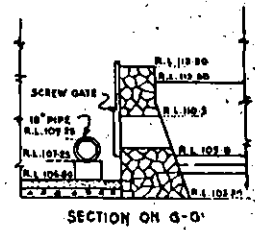
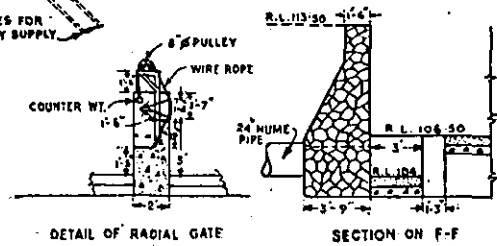
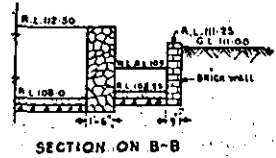
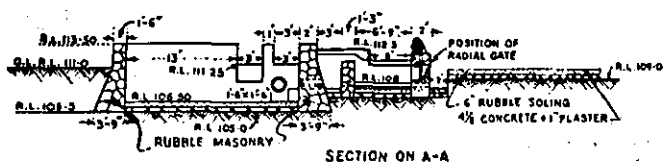
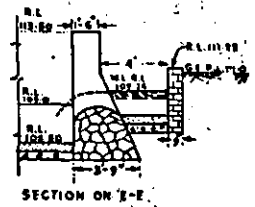
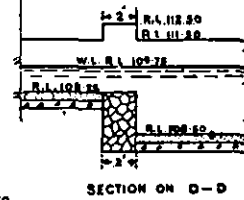


FIG. 4.  
TIDE MECHANISM OF  
HOOGHLY MODEL

0 6 12 FOR PLAN  
0 3 6 FOR SECTIONS  
SCALE IN FEET





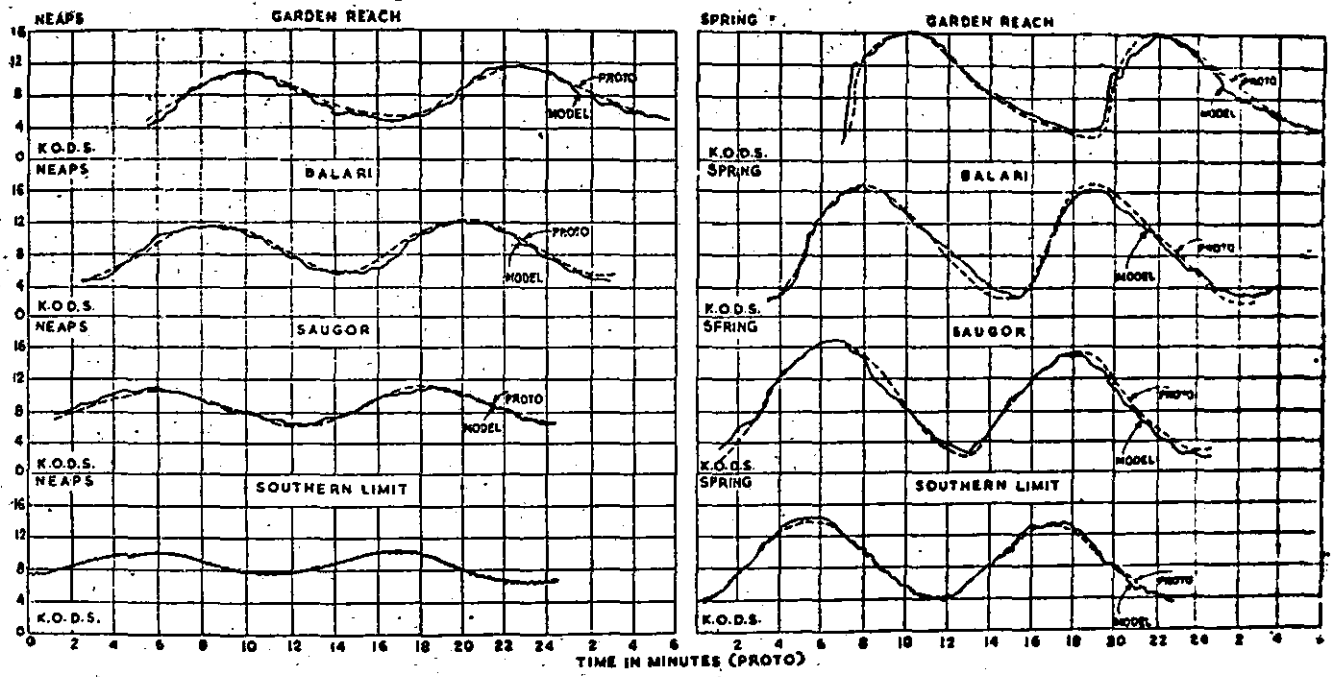


Fig 5: Tides obtained in the model. Semilunation chosen 5th to 19th Feb 1939

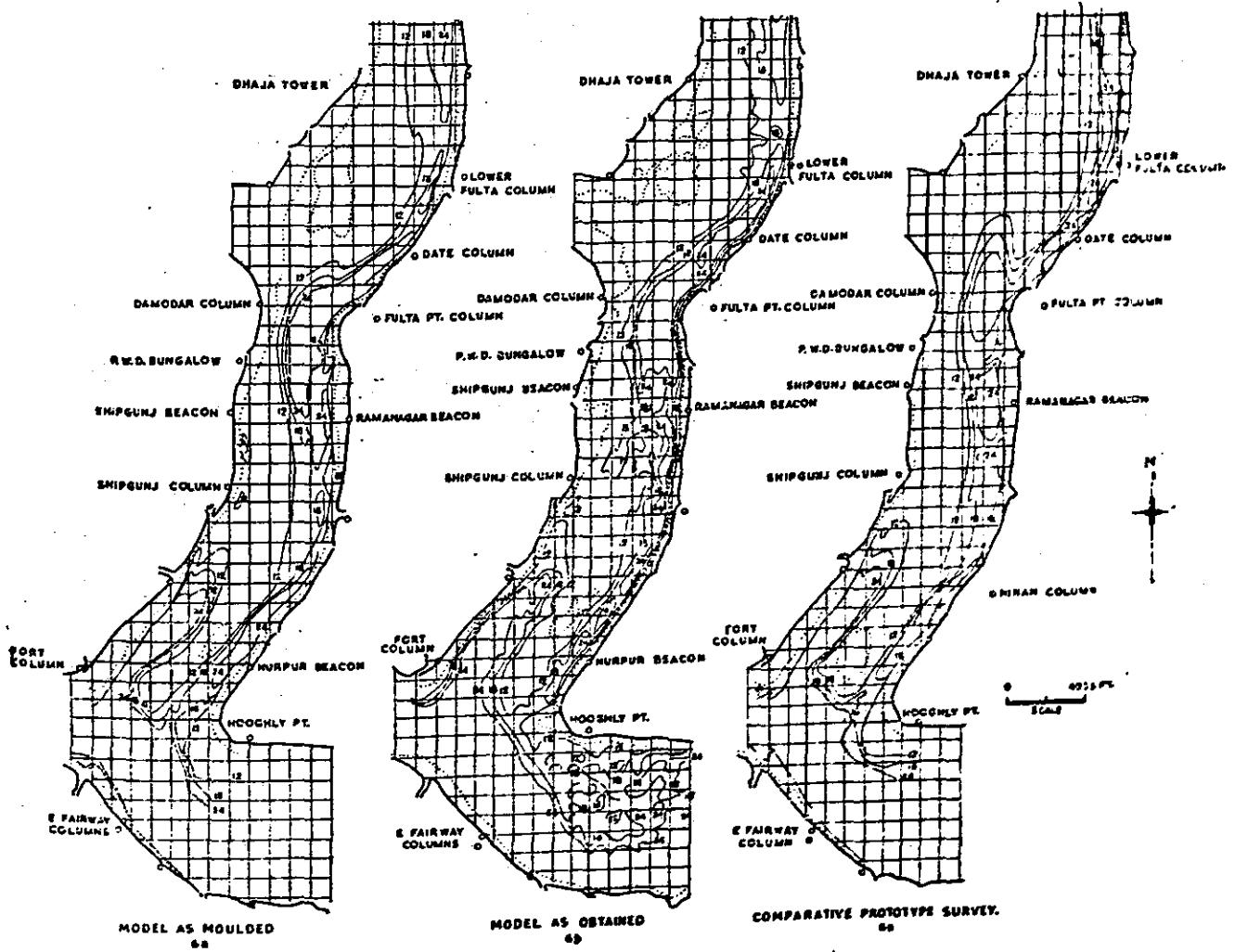
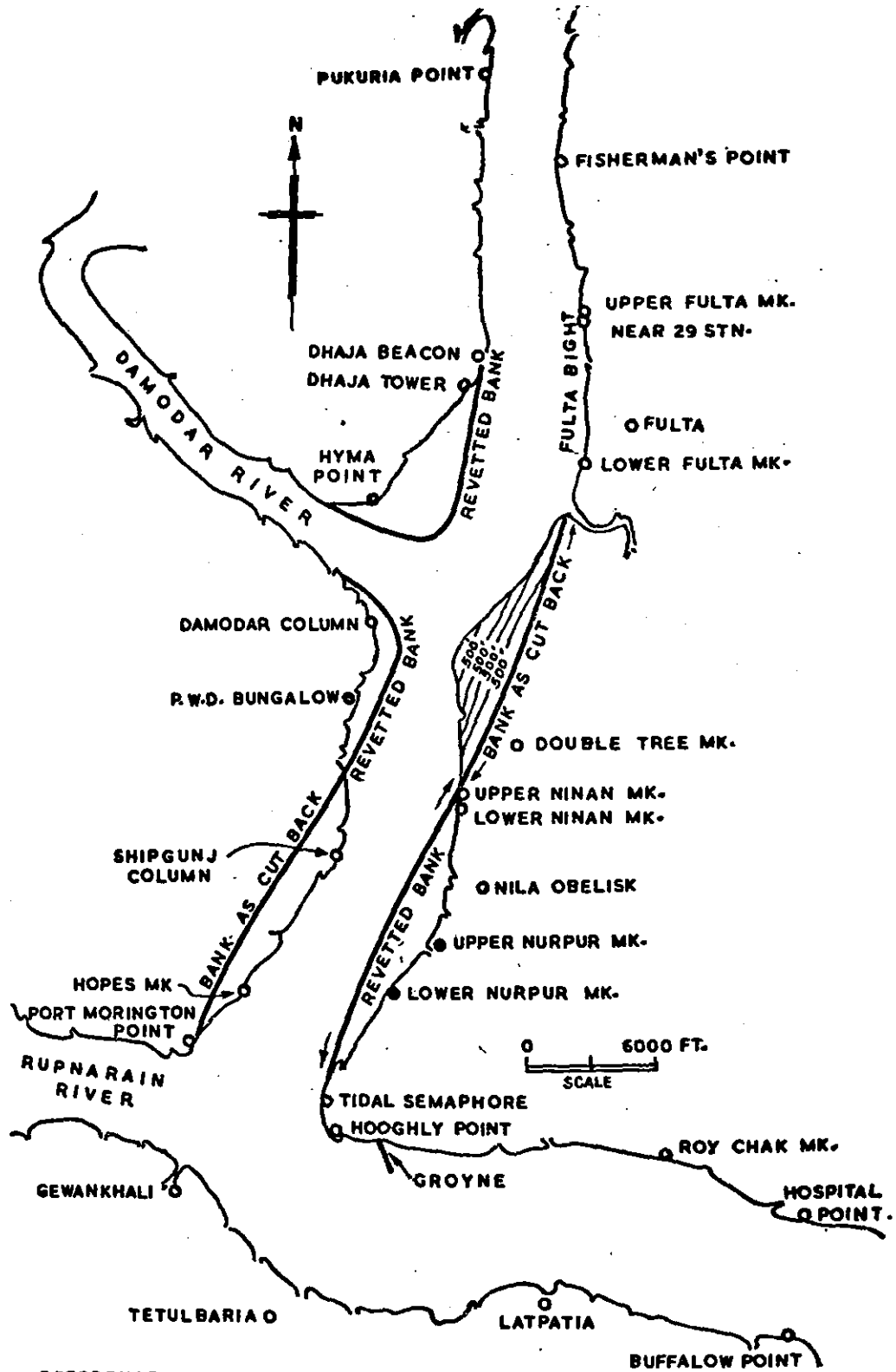


Fig 6 (a, b, c): Comparative model and prototype bed changes



REFERENCE :-

PROPOSED PARTIAL RECESSION OF FULTA BANK IN STAGES & GROUYNE

RECESSION OF FULTA POINT WITH CONVEX LEFT BANK BELOW NINAN & CORRESPONDING CONCAVE TO RIGHT BANK

FIG. 7-

1/2000 : 1/160 MODEL OF THE HOUGHLY ESTUARY SHOWING PROPOSALS OF EXPERIMENTS

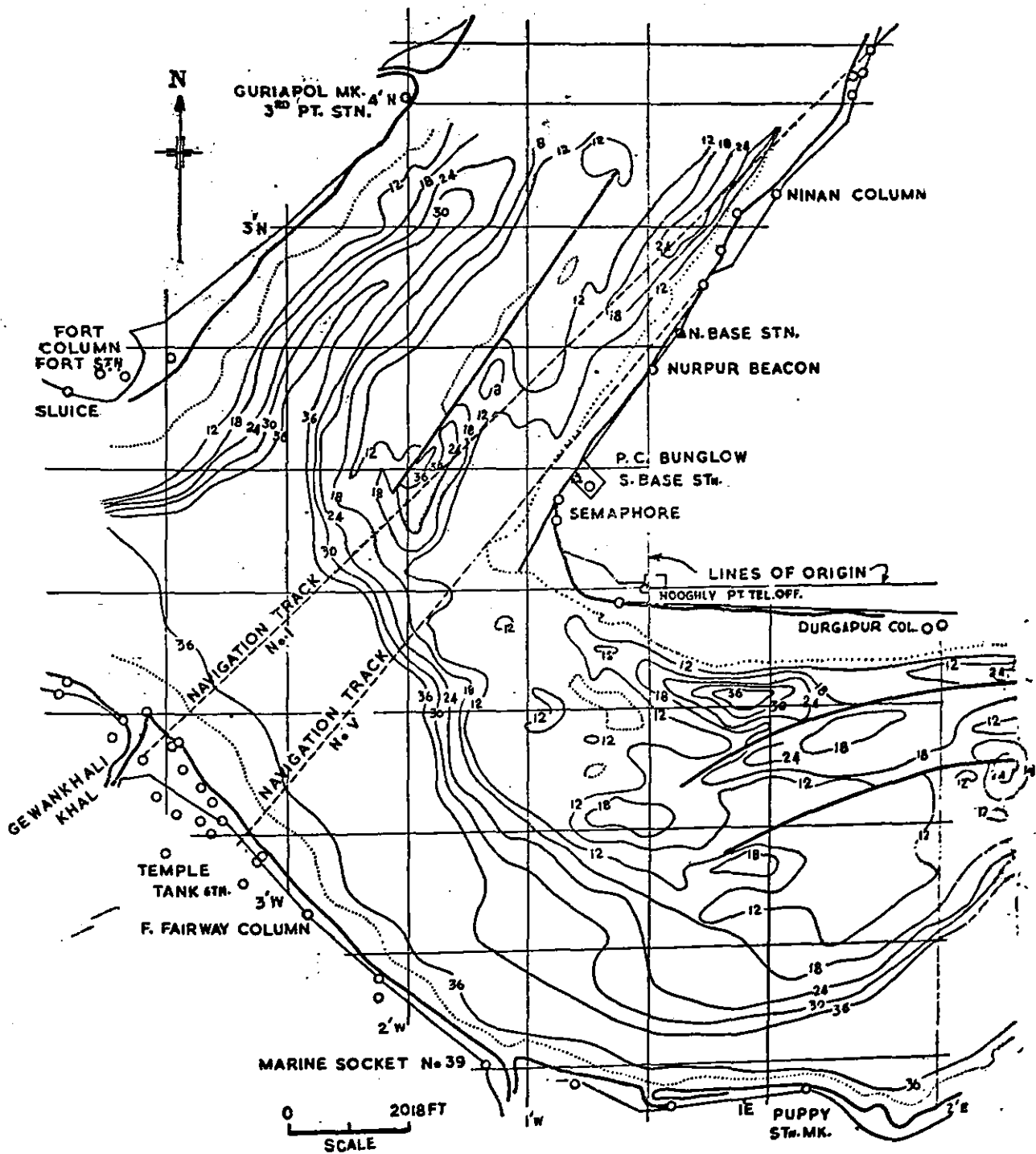


Fig 8 : Experiment with mid-river training wall on the Muckrapatty sand, two curved submerged vanes on the Hooghly shoal, 1000 ft recession of Fulta Point. A short extension of the left bank near Hooghly Pt and are as above and below the outfall of Damodar reclaimed.

The model bed laid to 1945 (Nov-Dec) survey and dry season spring tides run. Contours after running 367 D. S. Spring tides. Datum for contours = KODS

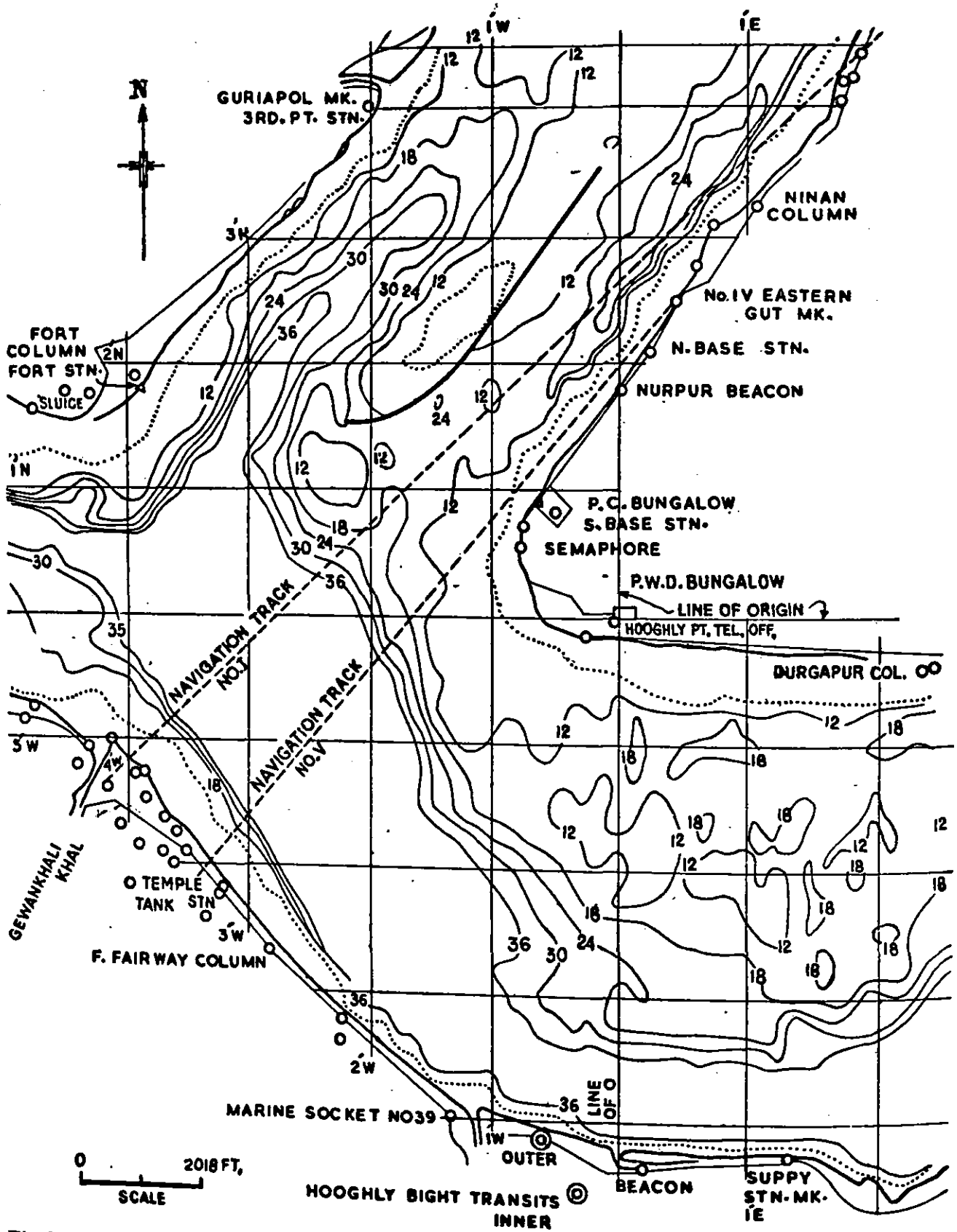


Fig 9 : Experiment with a bell-mouthed training wall on the Muckrapatty sand, 1000 ft recession of Fulta Point and areas above and below outfall of Damodar reclaimed. The model bed laid to Nov-Dec 1945 Survey. Contours taken after running 368 D. S. Spring tides. Datum for contours = KODS

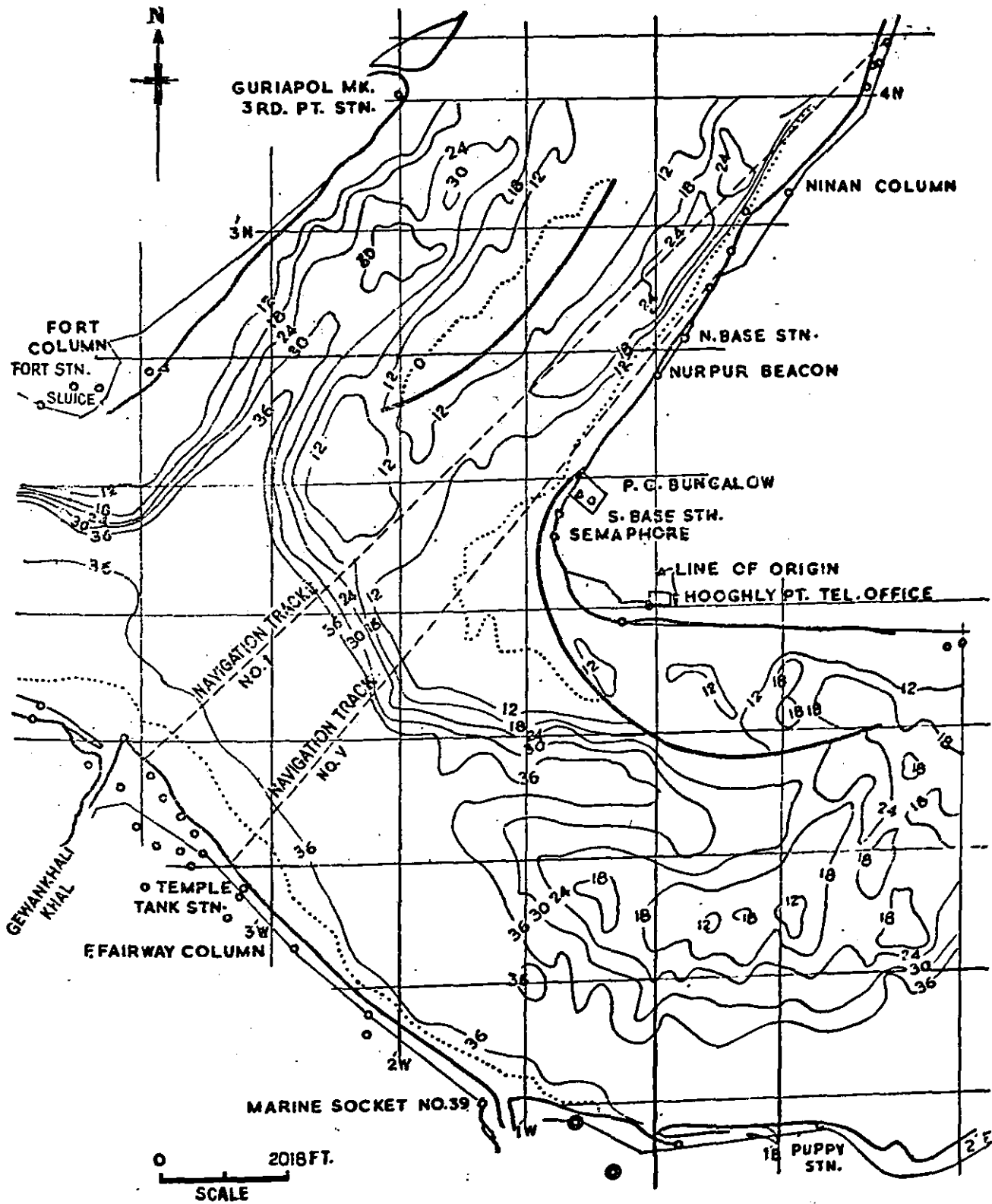


Fig 10 : Experiment with bell-mouthed training wall on the Muckrapatty sand, a curved embankment near Hooghly Point corner as shown in the figure.

1000 ft recession of Fulda Point and areas above and below outfall of Damodar reclaimed.

The model bed laid to Nov-Dec 1945 survey and dry season spring tides run. Contours after running 370 D S Spring tides. Datum for contours = KODS

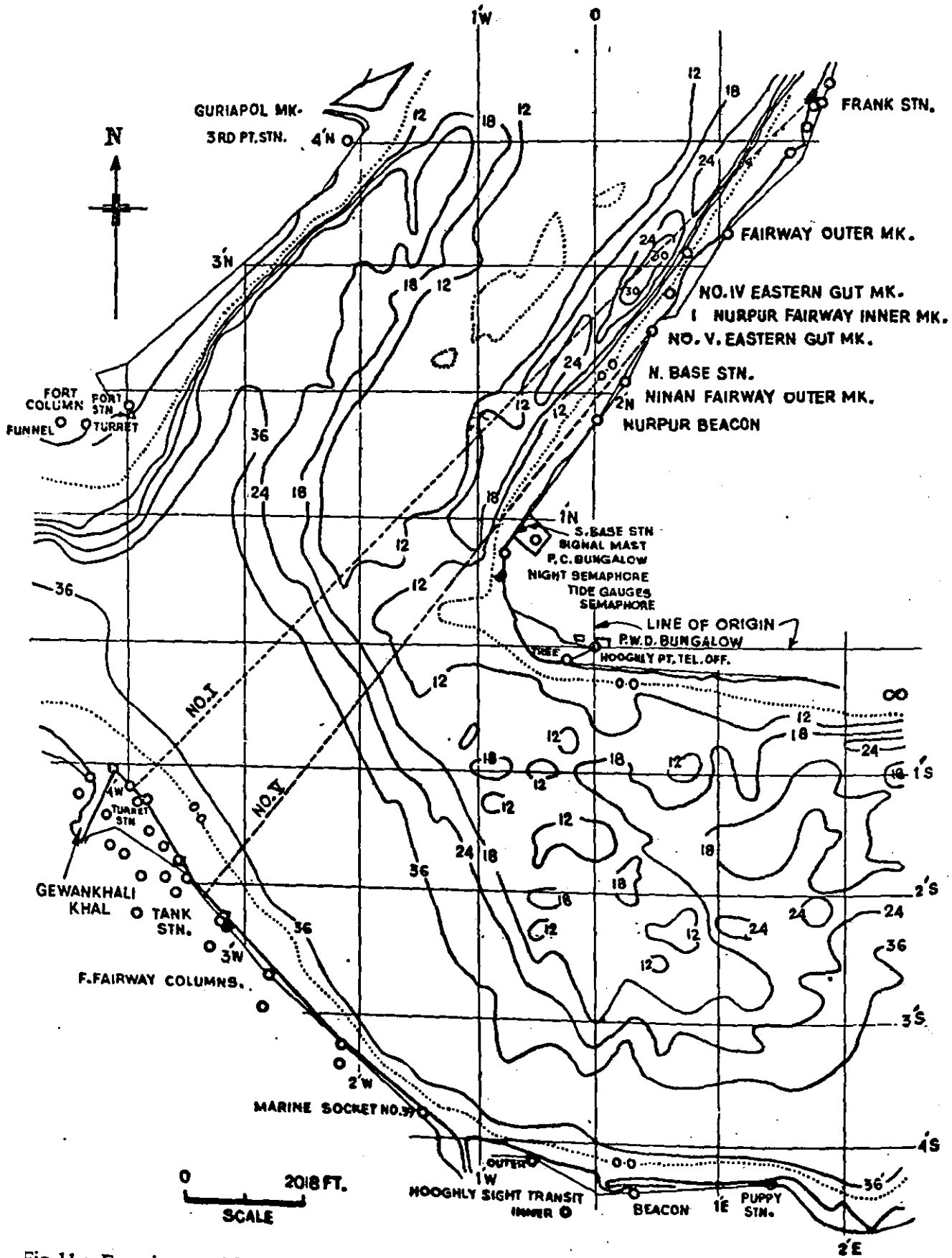
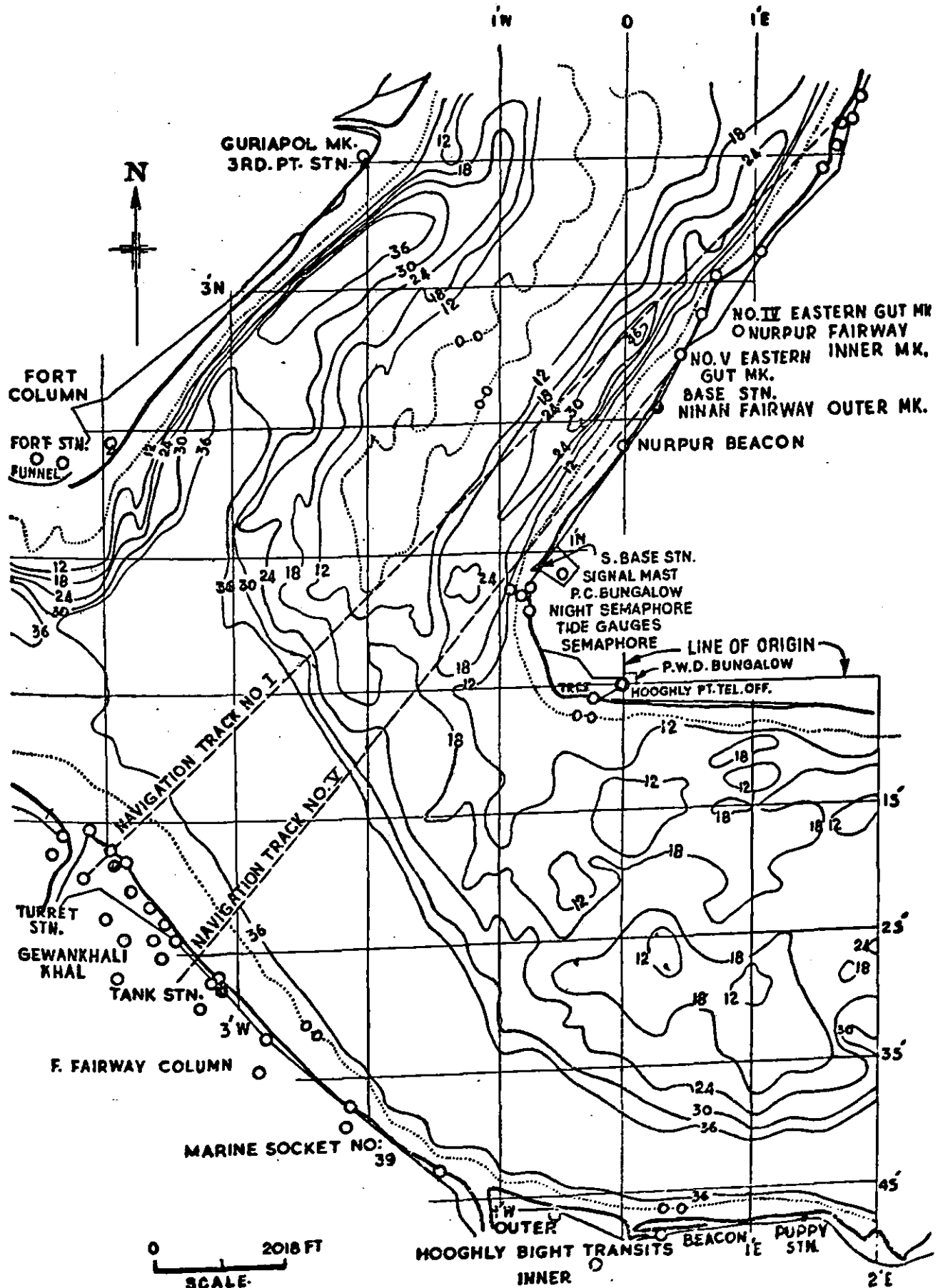
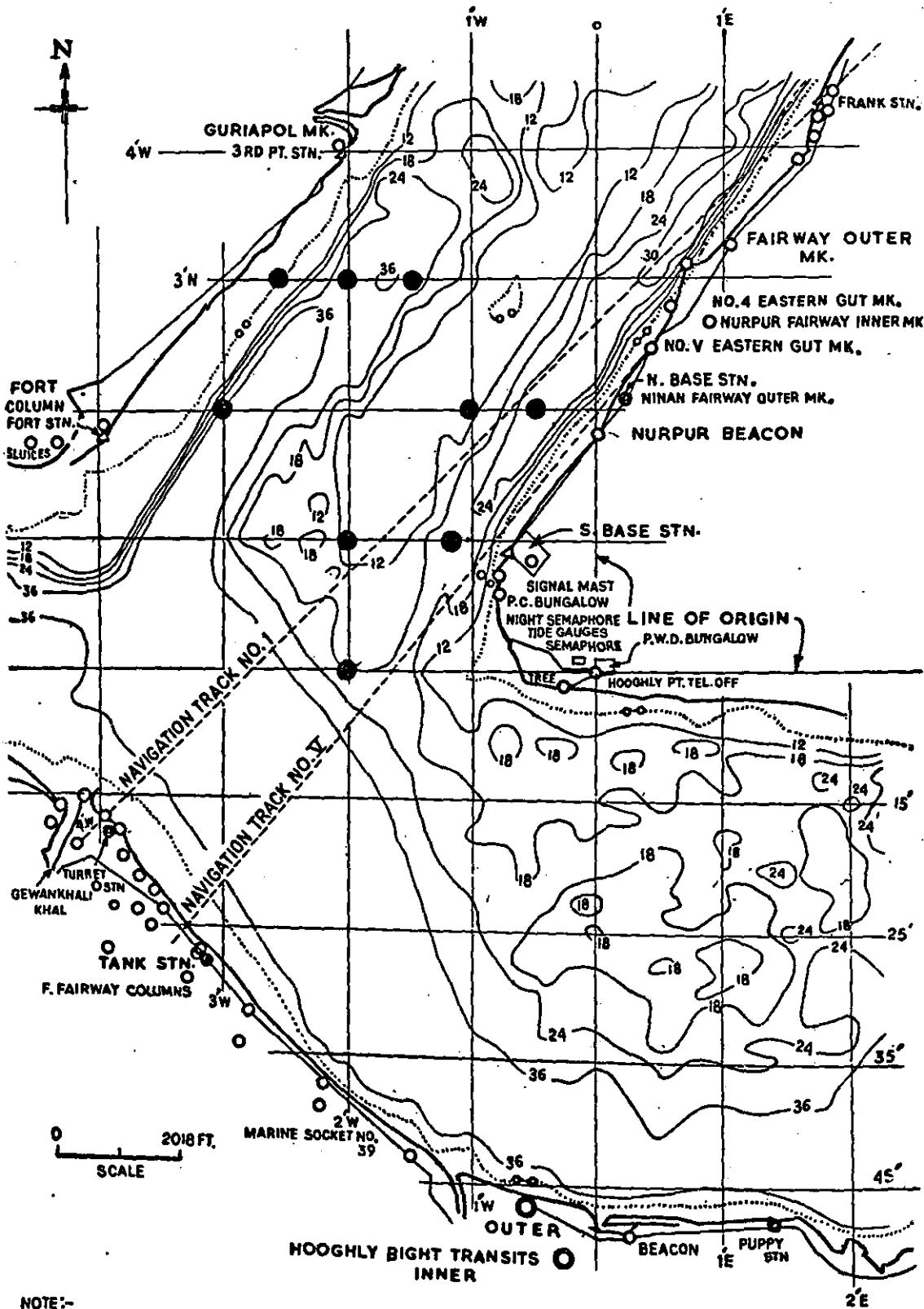


Fig 11 : Experiment with existing conditions. Contours at the end of model dry season. Datum for contours = KODS



Note: Experiment with 1000 ft recession of Fulda Point and areas above and below outfall of Damodar reclaimed. Datum for contours = KODS  
 Fig 12: Contours after running 367 dry season spring tides



NOTE:-  
 EXPERIMENT WITH 1200' RECESSION OF FULTA POINT  
 AND AREAS ABOVE & BELOW.  
 OUTFALL OF DAMODAR RECLAIMED.  
 VELOCITY OBSERVATION POINTS — ●  
 Datum for contours = K.O.D.S.

FIG.13.  
 FULTA JAMES & MARY REACH.  
 SHOWING CONTOURS TAKEN AFTER  
 RUNNING 367 DRY SEASON SPRING  
 TIDE.



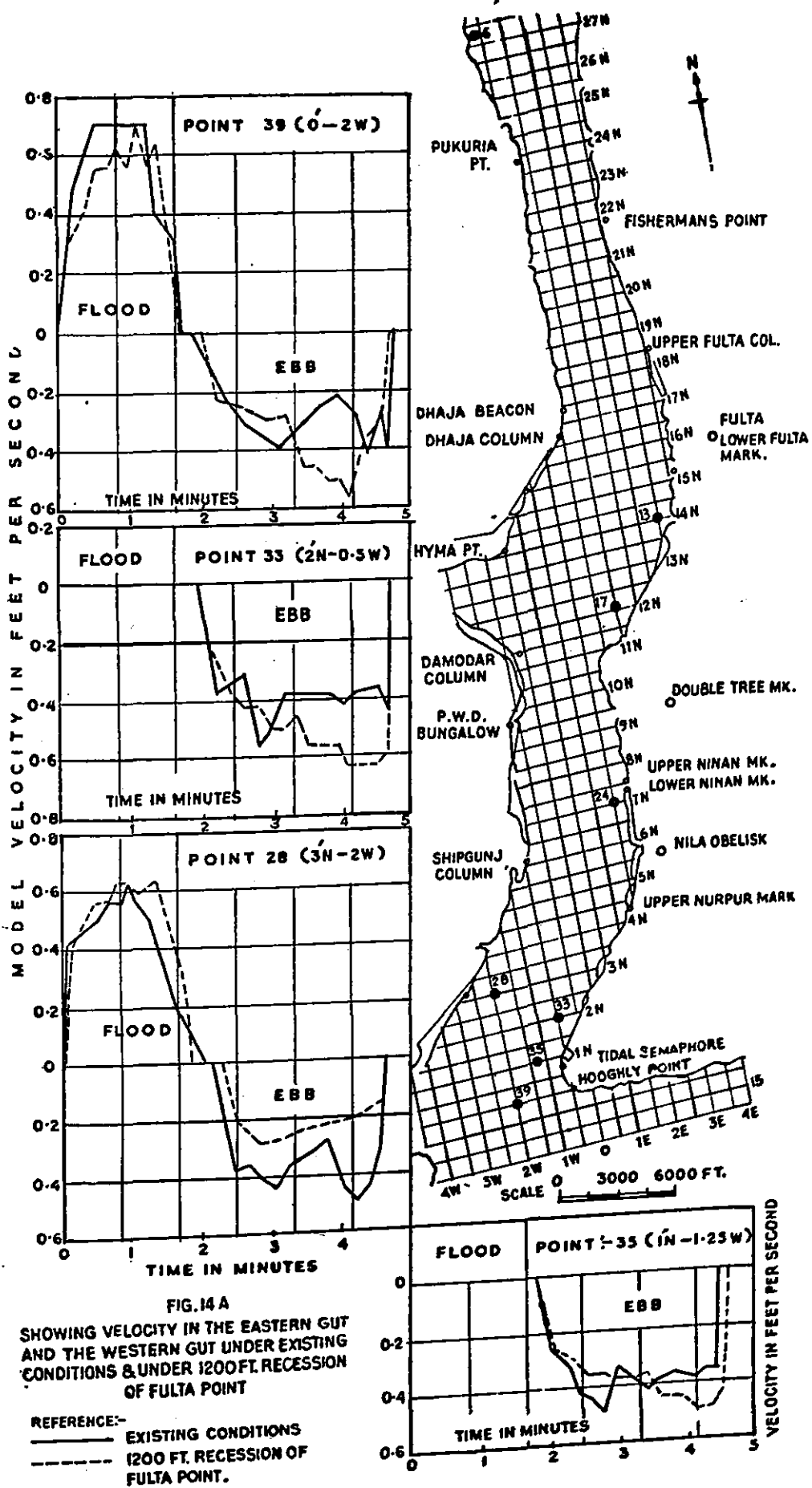


FIG. 14 A  
 SHOWING VELOCITY IN THE EASTERN GUT  
 AND THE WESTERN GUT UNDER EXISTING  
 CONDITIONS & UNDER 1200 FT. RECESSION  
 OF FULTA POINT

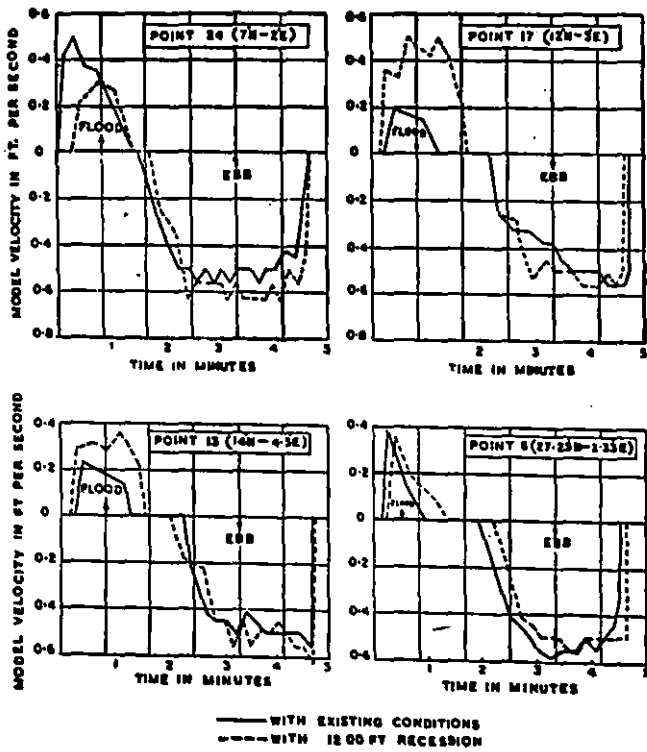


Fig 14 B : Velocities in the Ninan Reach and Fulda Bight under existing conditions and under 1200 ft recession of Fulda Point

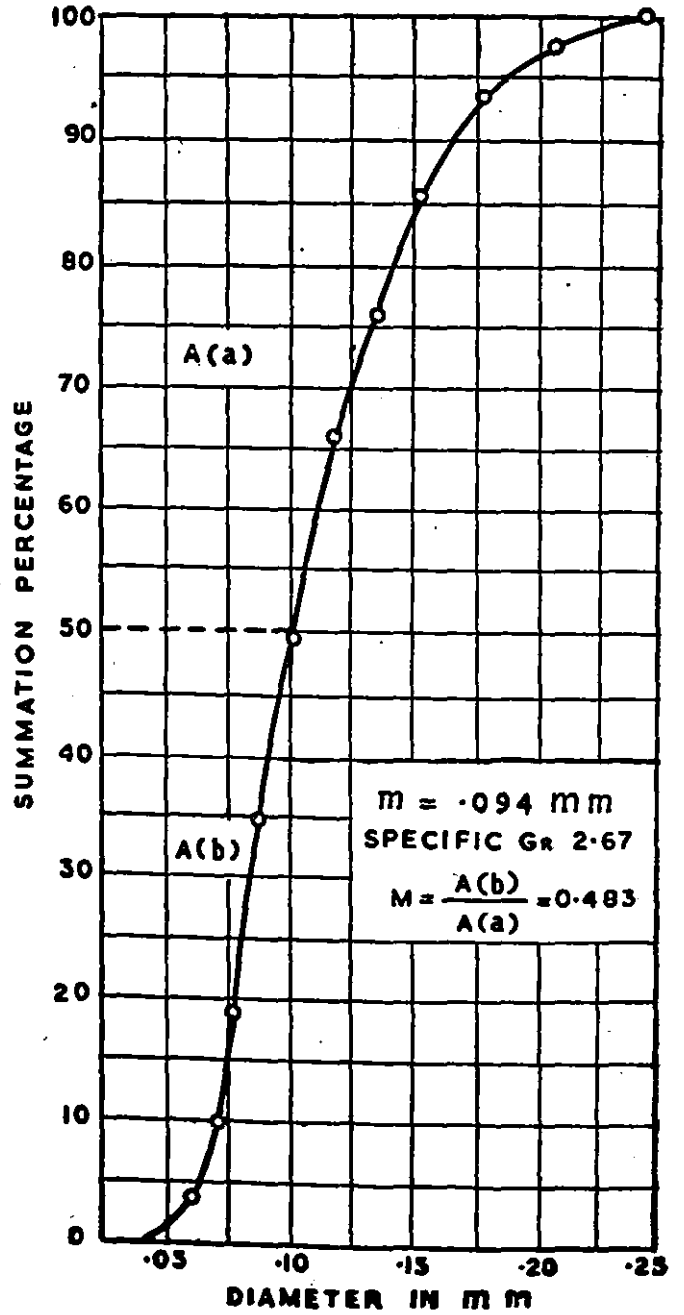


Fig 16 : Summation curve of Ninan sand for computing uniformity modulus

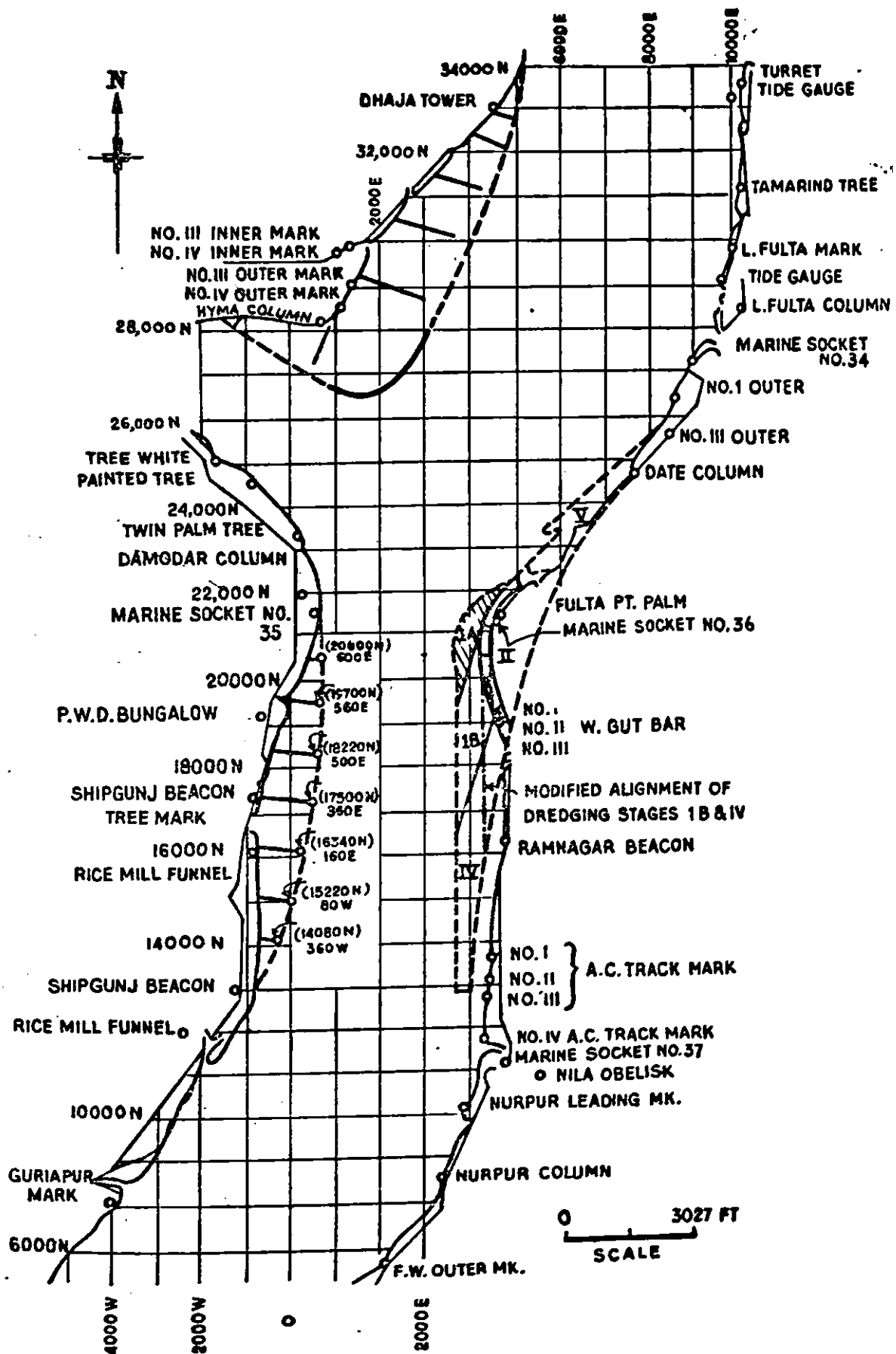


Fig 15 : Different stages of Fulta Pt scheme and the permeable spurs above and below Damodar outfall

# CWPRS TECHNICAL MEMORANDUMS

## SUBJECT CLASSIFICATION

Subject	Symbol
Water studies & Hydrology	HLO
Rainfall & Runoff	
Regeneration & Losses	
Quantity of Water	
Fluid Mechanics	FLM
Design of Hydraulic Structures	HYD
River Training & Flood Control	HYR
Irrigation, Drainage & Reclamation	IRD
Surface & subsurface irrigation	
Water requirements of crops	
Soil survey and crop pattern	
Drainage	
Reclamation	
Navigation	NAV
Ports, Harbours & Estuaries	
Inland Navigation	
Coastal Erosion	
Ships & Navigation Crafts	
Structural Design	STD
Soil Mechanics & Foundation Engineering	SFE
Investigations	
Stability, deformations & displacements of earth structures	
Foundation studies including geophysical	
Construction Materials & Practices	CMP
Concrete Technology	
Building & other Materials	
Instrumentation	IST
Model and Prototype comparisons	MPC
Other miscellaneous	MIS

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