

CHAPTER 39

USE OF MODEL EXPERIMENTS IN SOLVING QUESTIONS OF NAVIGATION WITH SPECIAL REFERENCE TO THE ENTRANCE OF ST. ANNA BAY, CURACAO, NETHERLANDS ANTILLES

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GENERAL

For a great many years model experiments with ships have been carried out in towing tanks in order to ascertain the reactive movements of ships under different wave and current conditions. Such experiment do not only pertain to the stability of the ships but also to forces brought to bear on the hulls of the ships.

A recent development in the coastal engineering field includes the use of ship models in questions of navigation.

The reason why such experiments are undertaken is that numerous accidents, such as collisions and run-agsrounds, occur when ships enter harbors and inlets. Very often such accidents are caused by adverse wave and current conditions.

In the laboratory it is possible to duplicate the actual wave and current conditions and studies can be made by using models of ships of the influence of waves and currents on the navigation of ships approaching or passing through the harbor.

The importance of these studies is obvious. First, it is possible for pilots to study the problems in detail and thereby gain more experience about how to navigate under certain conditions, and next, recommendations for improvements to the entrance of the harbor can be made.

The following is a description of the conditions found in the harbor at Curacao, Netherlands, Antilles, and a description of corrective measures taken, including the use of model experiments.

SITUATION

Curacao, the largest island of the Netherlands Antilles, has one of the busiest harbors in the world (Fig. 1). In 1954, 7600 ships put into the harbor, among which were 5400 tankers.

The ports are situated on the Schottegat, a big inland lake, and on St. Anna Bay, the connection of the Schottegat with the sea. On the Schottegat are situated the landing-stages of the CPIM (Shell Oil) refineries and a new commercial port. Along St. Anna Bay we find the older quays of the shipping companies which transport both passengers and goods.

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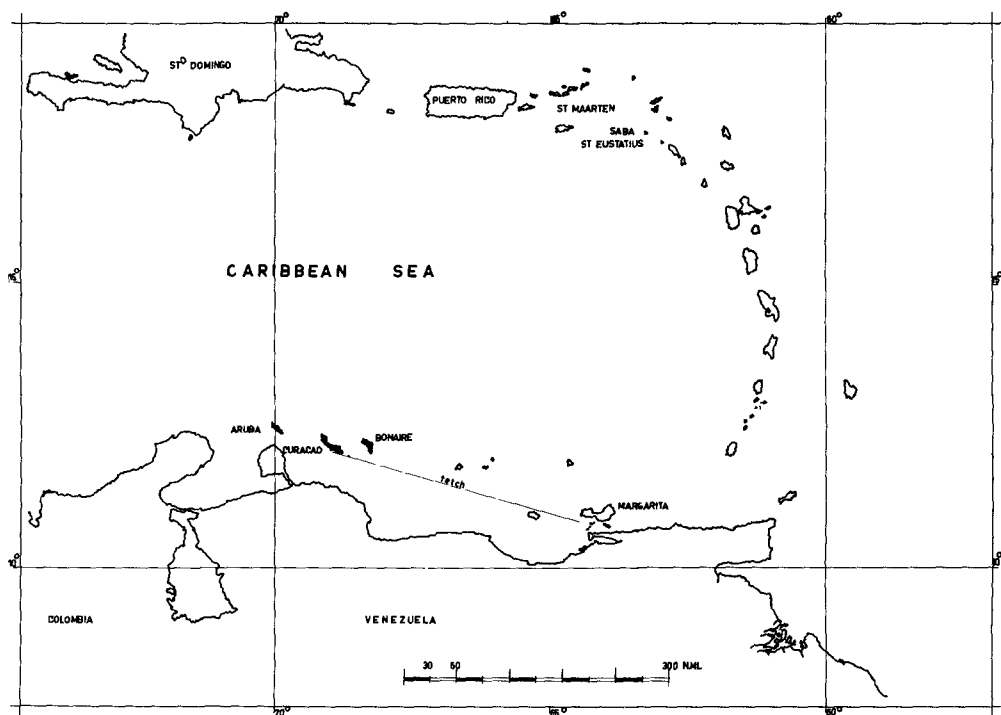


Fig. 1. Netherlands Antilles

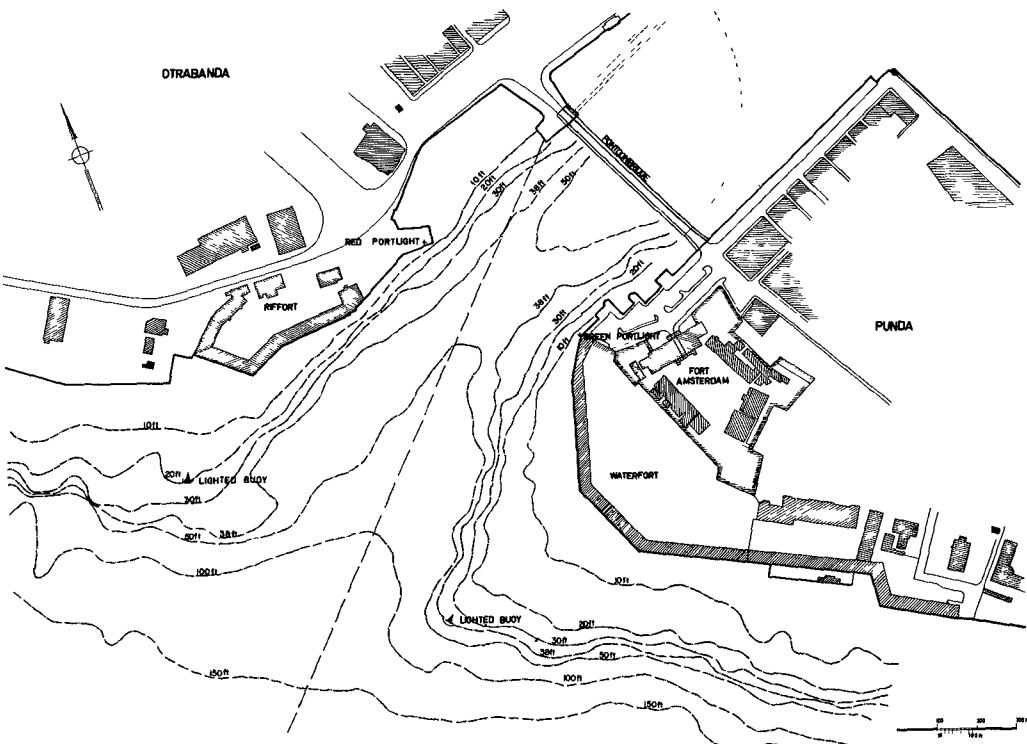


Fig. 2. Entrance St. Anna Bay. Present situation.

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Fig. 3. Survey St. Anna Bay. In the foreground, the harbor entrance, on the right-hand side of the entrance Waterfort, on the left-hand side Riffort.



Fig. 4. Entrance St. Anna Bay. The bulkhead of the bridge which runs far into the entrance channel is clearly visible. On the left top the Shell refineries.

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The entrance to the harbor, the mouth of St. Anna Bay, lies in the center of Willemstad, the capital of Curacao. This narrow entrance is bounded by two old fortresses (Waterfort and Riffort). Over a range of 800 ft. the entrance channel narrows from 650 to 300 ft. near the portlights (measured between the drop lines of 30 ft. below low water) (Figs. 2, 3, 4). The underwater slopes of the channel are very steep.

At about 400 ft. inwards from the portlights there is a pontoon bridge which opens in a westerly direction, and which then has a navigable passage of 380 ft.

The mouth of the channel is bounded on either side by coral reefs. From the coast line the surface of those reefs slopes gently down to a 30 ft. depth. Then the slope grows rapidly steeper, and the surface inclines to great depths at an angle of 45° .

The fairway is not only marked by the portlights at the narrowest spot, but also by two buoys at sea.

At the harbor mouth there is, in general, an easterly littoral current. This west-going current is mostly weak, but occasionally it can reach a considerable velocity for a short time. Several times velocities of 4 ft./sec. have been measured near the easterly buoy.

An easterly trade wind blows in Curacao. No data are available concerning the wind at the mouth of St. Anna Bay but only as to the wind on the north side of the island where the airport is situated. From a short series of comparative measurements it has been proved that in the daytime the wind at the airport has reversed itself as compared with the wind near the buoys at sea at the harbor mouth. It also has been proved that the wind velocities are greater near the airport than at the harbor mouth. During the periods of drought an average wind velocity of 14 knots is normal. In contrast to the wind forces near the buoys at sea there is but little wind between the high walls of the fortresses.

The difference between the water lines at low tide and at high tide amounts to approximately 1 ft. The tidal currents in St. Anna Bay are not strong -- the maximal steepness of the local tidal diagram $\frac{dz}{dt}$ appears to be $2 \cdot 10^{-5}$ m/sec.

DIFFICULTIES WHEN PUTTING INTO THE HARBOR

When putting into the harbor ships meet with difficulties when there is a strong easterly littoral current.

These difficulties arise when the ships pass from the sea current into the relatively smooth water in the harbor mouth where there is insufficient space for correction after possible sheering.

In most cases, when a maneuver has failed, the ship turns to starboard when passing the easterly buoy as a result of the pressure of the

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current on the stern. Then the ship threatens to run aground near the green portlight or a little farther on.

In some cases the tendency of running aground can be successfully checked by carrying out a correcting rudder and machine maneuver. Then however, the ship has a tendency to turn to the port side, which cannot be checked. The ship then runs the risk of going aground on the west side near the Otrabanda bridge head.

Finally, there are a number of cases in which the ship, either owing to excessive correction of the expected turning to starboard, or because of too little speed, turns to the port side and is in danger of running aground under Riffort or at the Otrabanda bridge head, or of running into that bridge head.

The risk of sustaining damage is considerably increased by the presence of the pontoon-bridge and of cables lying in the fairway.

In case the pontoon-bridge should be damaged, the vehicular traffic that is using the bridge (8,000 vehicles per day) has to be diverted over a distance of about 16 kms. Pedestrians are transported by ferry. Up to now it has always been possible to repair the damage caused to the bridge within a few weeks because spare parts and pontoons are available in Curacao.

The difficulties presented themselves especially just before the Second World War and have continued since that time. This is due to the greater intensity of the shipping traffic; the fact that the ships are getting bigger and bigger; and to the fact that some post-war types of tankers, which frequently put into port, steer badly.

Whether a change in the staffing of the pilotage service could exert any influence cannot easily be traced.

SURVEY OF THE ADVICE GIVEN AND THE MEASURES TAKEN IN 1954

In 1948 the Hydraulic Laboratory at Delft was charged with the investigation of the possibility of shifting the current farther outside the mouth.

A model was built on a scale of 1 to 144. From the investigation carried out in this model it proved to be possible to shift the current about 250 ft. seaward by building a breakwater about 350 ft. long in the sea. In view of the outlay in money involved, however, there was some doubt as to the question whether the construction of such a breakwater would serve any purpose. Consequently it was decided not to proceed with the building of this breakwater.

In 1951 the entrance channel was broadened by means of dredging the advice of Dr. ir Ringers, ex-Engineer-in-Chief, Director of the Ministry of Transport and Works, Waterstaat, and ex-Minister of Trans

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and Waterstaat in the Netherlands. It is remarkable that in his report Dr. Ringers points to the influence of the wind. When coming between the fortress walls a ship comes into an area where there is but a faint current and to a certain extent, this is also the case with the wind.

Owing to a series of difficulties that arose during a highly critical period of strong currents at the harbor mouth in the middle of 1953, during which period there were many collisions, the harbor-master, who is also head of the Pilotage Service, ordered the old 3,000 ton tanker "Susane" to be stationed at about 200 ft. east of the easterly buoy to serve as a temporary breakwater.

By means of this temporary breakwater the current was diverted to a point outside the harbor. According to the pilots this improved the situation. After some weeks the tanker had to be removed because postponement would render salvage impossible.

After the installation of the temporary breakwater the Council of Curacao appointed a technical commission, whose personnel included the Harbor-master, the Director of Public Works and the Marine Superintendent of the C.P.I.M.

The advice given by the commission was practically the same as that of ir J. B. Schijf, Engineer-in-Chief of the Research Division of the Ministry of Transport and Waterstaat, who had in the meantime been appointed adviser, and who had come over from the Netherlands to Curacao in order to give advice.

IMPROVEMENTS PROPOSED BY IR J. B. SCHIJF IN JANUARY 1954

An illustration of the proposed improvements is shown in Fig. 5.

THE CONSTRUCTION OF A BREAKWATER

As has been mentioned before, the difficulties are caused by the transition of the sea current into the relatively smooth water in the harbor mouth. Therefore it is obvious that the situation would be improved by shifting this sudden change in the strengths of the currents as far outside the harbor mouth as possible, which has also been demonstrated in practice by means of the test with the tanker "Susane". Once more the Hydraulic Laboratory was charged with the investigation of the situation in the harbor mouth, as regards the currents, after a breakwater would have been built.

THE EXECUTION OF DREDGING WORK BEFORE RIFFORT

On the west side, the entrance channel can still be broadened considerably, which would facilitate maneuvering.

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THE INSTALLATION OF A CURRENT METER

As the velocity of the current at the harbor mouth can increase considerably within a short period, a permanently installed current meter, provided with an indicator and a recorder, was recommended.

Then the indicated strength of the current would always be visible at sea.

THE BROADENING AND DEEPENING OF THE NARROW CROSS-SECTION BETWEEN THE PORTLIGHTS

In order to facilitate steering the ships it was recommended to make the narrow cross-section between the portlights broader and deeper.

THE REMOVAL OF CABLES LYING IN THE FAIRWAY

Between the two banks, near the pontoon-bridge, there are the pulling-cable of the pontoon-bridge, and several electric and telepho cables, which give much trouble if an anchor has to be used. The cables are lying there at the risk of their owners. It was recommended to remove these cables.

THE SHIFTING OR ENLARGING OF THE NAVIGABLE PASSAGE OF THE PONTOON-BRIDGE

The Public Works Service has investigated the possibility of moving the bridge farther inward.

This proved to be possible, though only at high expense, but it certainly meant no improvement for the traffic by land. By lengthening the bridge, and by shortening the land-abutment, however, the navigable passage can be broadened by 50 ft.

INVESTIGATIONS CARRIED OUT IN THE MODEL

These investigations have been effected by the Hydraulic Laboratory in an open-air model in the Northeast Polder of the Netherlands, in fulfillment of the advice given.

Experiments have been carried out to determine the aspect of the currents in different situations. Further experiments have been made with sailing models of ships, in order to study the entering into the harbor of different types of tankers.

As it was also necessary to carry out sailing tests, a scale has been chosen of 1 to 64. So the scale of the velocities of the current is $V_{64} = 8$. To get enough space to sail with the ship models it was necessary to put sufficiently far out to sea.

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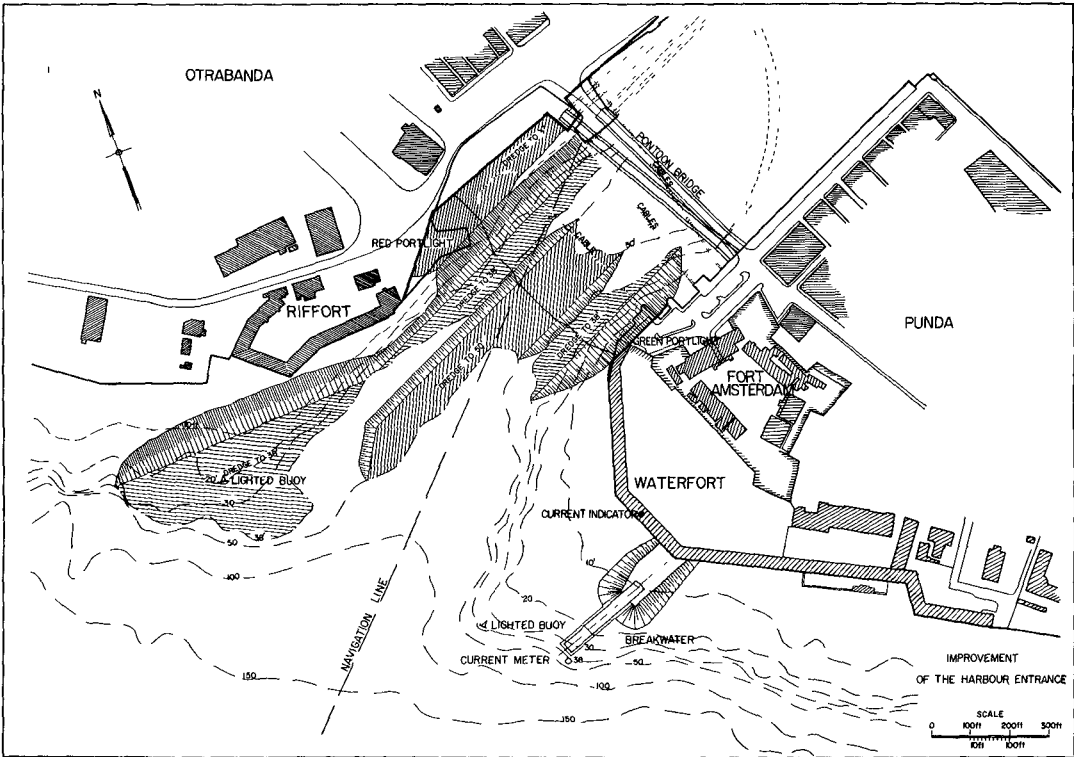


Fig. 5. Improved harbor entrance.

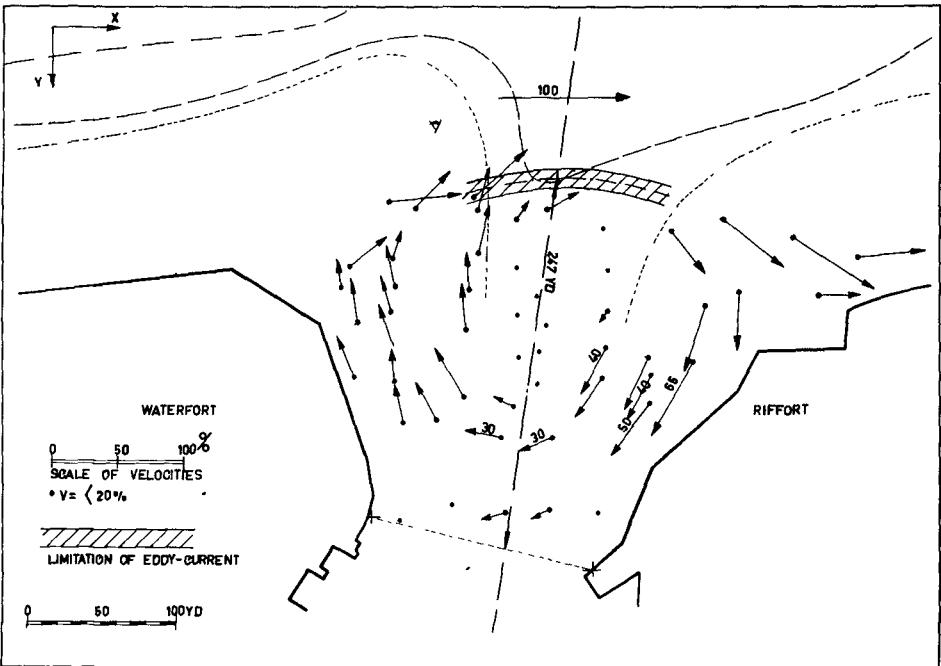


Fig. 6. Aspect of currents in the harbor mouth in the present situation.

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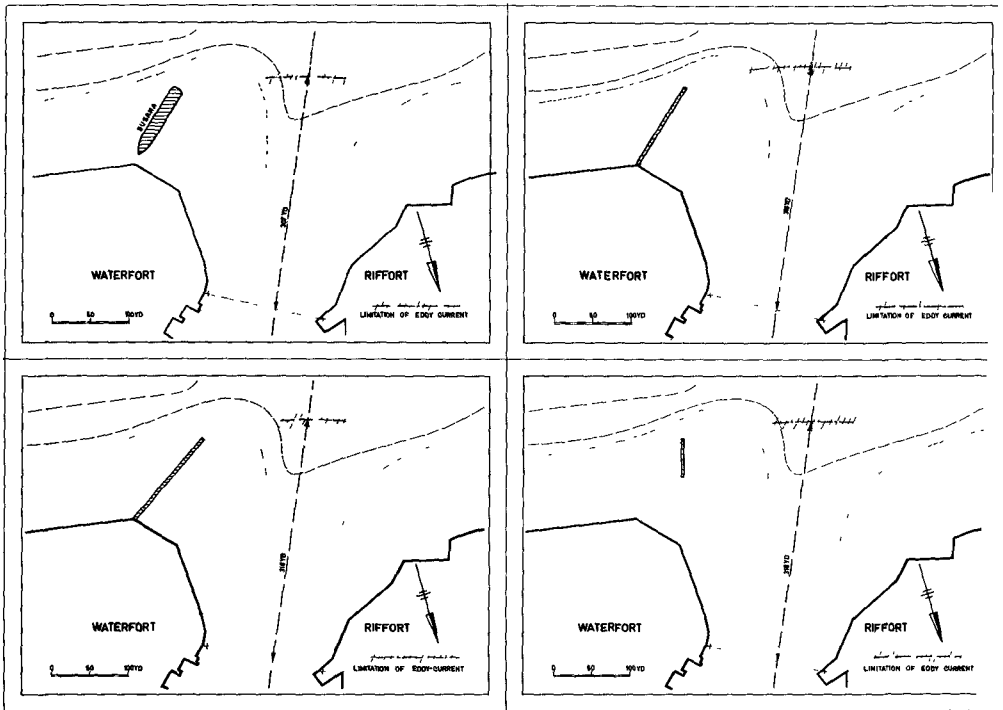


Fig. 7. Limitation of eddy-current with different ground plans of the breakwater.

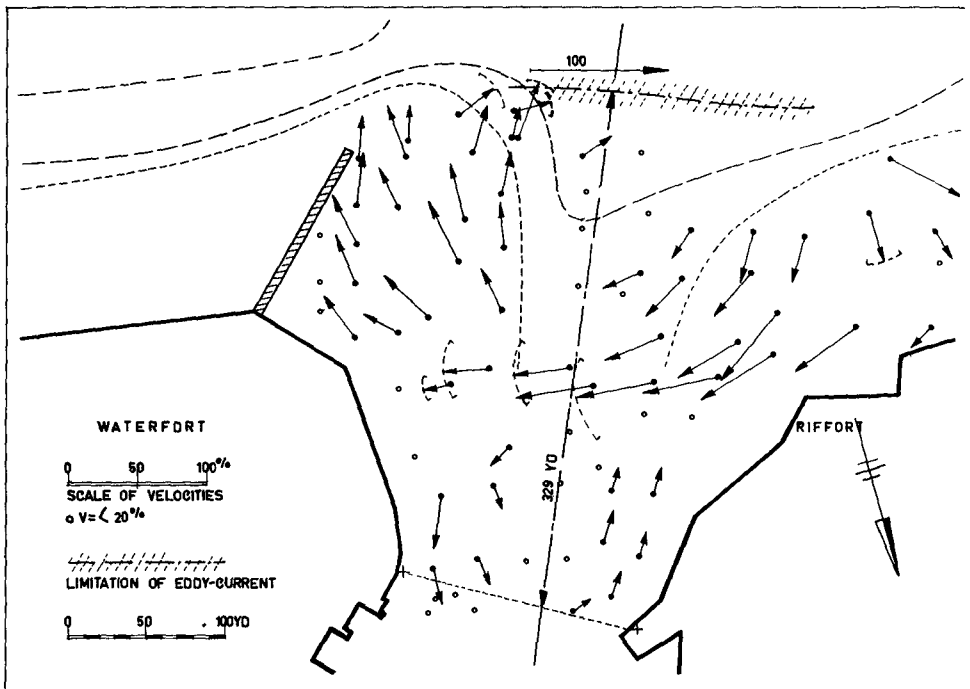


Fig. 8. Aspects of currents in the harbor mouth after the breakwater has been constructed.

USE OF MODEL EXPERIMENTS IN SOLVING QUESTIONS OF NAVIGATION WITH SPECIAL REFERENCE TO THE ENTRANCE OF ST. ANNA BAY, CURACAO, NETHERLANDS ANTILLES THE PRESENT SITUATION

In order to make it possible to study the present situation, the model has been brought into agreement with the measurements carried out on the spot. This has been done with regard to the directions of the currents as well as with regard to the interrelations of their velocities in the various places, in so far as it was possible to reconstruct the aspect of the currents from the observation material. Of importance is the great velocity-gradient between the main current and the slowly turning eddy current. This transition is not stable and is characterized by small whirling currents between the main current and the eddy, which flow in the direction of the main current.

The result of the detailed measurements of the currents in a model of the present situation is shown in Fig. 6. The influence of the tidal current in St. Anna Bay, near the limits of the eddy current, has also been studied but proved to be imperceptible.

INVESTIGATION OF POSSIBLE IMPROVEMENTS IN THE MODEL

As mentioned in the foregoing, an old tanker was used as a breakwater in 1953. On carrying out measurements with the tanker in the model, the limit of the eddy current was found to be at about the same spot as had been found in reality during the measurements carried out by means of a float (150 ft. seaward from the limits of the eddy in Fig. 6).

Further, various ground-plans of the breakwater have been investigated in the model. The head of the breakwater was always placed at the edge of the reef at a depth of 40 ft., as this head can hardly be placed farther away owing to the steep underwater slope.

The ground-plans shown in Fig. 7 always proved to have the limits of the eddy lying at about 180 or 200 ft. seaward from the limits of the eddy in Fig. 6. Since the ground-plan of the breakwater does not appear to exert any appreciable influence, the recommended plan has been taken as a basis, and has been subjected to a more detailed examination, a survey of which is given in Fig. 8. The currents have also been investigated at various depths in the harbor mouth.

With this ground-plan of the breakwater it appears that the current over the reef head has not become appreciably stronger. Further, it appears that a secondary eddy current has been formed. The return current of the eddy is situated at about 400 ft. outside the connecting line of the portlights, and amounts to 40% to 60% of the main current. This is 30% to 50% more than the return current in the present situation (Fig. 6), but a favorable circumstance is that this return current lies 200 ft. farther seaward so that there is a greater opportunity of regaining the correct course. The cause of the greater intensity of the return current should be sought in the fact that the main current drives the eddy on over a larger surface.

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Further, it has been investigated whether there is a possibility of weakening the return current by making an aperture in the breakwater, and by dredging a channel into the reef. This proved indeed to be possible in the model, but not in reality, as the channel would have to be dredged very accurately under cross-section, which is not feasible in practice. Besides, frequent dredging work at sea would be very expensive because there is no dredger available in Curacao which can be used at sea.

The dredging work carried out at Riffort appears to exert no influence on the limits of the eddy. Nor does it entail an appreciable change in the current system in the harbor mouth.

SAILING TESTS CARRIED OUT IN THE MODEL WITH AND WITHOUT BREAKWATER

A model was made on a scale of 1 to 64 of three current types of tankers.

Type	Number of Screws	Measurements			Measurements		
		Overall length	beam	draught	Overall length	beam	draught
T2 tanker	1	523'6"	68'0"	39'3"	98"	12½"	7½"
G2 tanker	2	405'10"	62'6"	21'6"	76"	12"	4"
Supertanker	1	610'0"	80'6"	45'0"	115"	15"	8½"

The ship models are driven by an electromotor and are electrical steered. The velocity of the rudder movement has been brought into agreement with that of the tankers. The contact between the shore and the ship consists of a composite cable which, by means of a fishing reel, is held in such a position that no tensile stress is exerted on the vessel.

The time that is needed for the switching over from full speed ahead to full speed astern is different for each ship. If it is 1 minute in reality, it is 8 seconds in the model since it is possible to switch over more quickly in the model. The reaction time of the crew on the bridge, and that of the controller of the model are equal. Consequently one has to react 8 times more quickly in the model. Therefore the controller only succeeds in sailing with the models by practice.

As the model had been placed in the open air, the sailing tests had to be carried out when there was very little wind. Wind-screens were put up around the model. Sailing tests were carried out with a

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of the models of the three types of tankers, during which tests the model was brought into agreement with the present situation in the Curacao harbor.

The behavior of the model tankers and the difficulties in controlling these tankers appeared to correspond very well with reality, since the failing of the maneuvers led to the same consequences.

Further tests were made in the situation where there is a breakwater, and where the dredging work at Riffort has been performed. Some random trial trips of the maneuvers have been recorded in Figs. 9 and 10.

It was of very great importance that the harbor-master and some other navigation experts attended the sailing with the models.

After having carried out the sailing tests the following conclusions have been drawn.

(1) In the present situation the best way of putting into the harbor is to sail dead slow against the stream, parallel to the coast at about a quarter of a mile from it. Just before the leading lights are seen in a line the helm should be put a little to port, and one has to steer direct for the buoy. When the ship has come at about a ship's length from the buoy, the helm must be put entirely to port, so that the stern is pushed against the stream. With supertankers full speed ahead is required for it. When the stern is out of the main current, the helm should be righted.

(2) The presence of the breakwater does not facilitate in itself the maneuvers to put the T2 and G2 tankers into the harbor. It is important, however, that in case the maneuver fails, the tanker grounds further outside the harbor, so that the risk of damage is considerably reduced.

The advantage is most marked, however, when supertankers are concerned. In the present situation full speed ahead has always been necessary, when maneuvering, in order to put into port allright. When there is a breakwater ships can also enter dead slow, which is a great advantage in view of the dangers attendant on the increase in velocity of most of these tankers.

(3) The dredging away of the reef at Riffort is recommended since, in case of successful maneuvers with supertankers, there is risk of running aground on the westerly reef with the stern. With every type of tanker the advantage is that when the ship drifts off to the westerly reef during a failed maneuver, there is a greater possibility of casting anchor in time.

(4) The present leading line is of little use when maneuvering. It is not a matter of keeping a certain course but rather of carrying out a certain maneuver at the proper moment.

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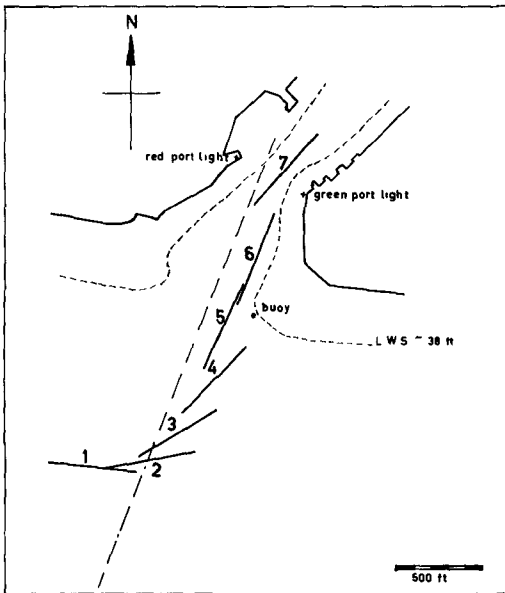


Fig. 9a

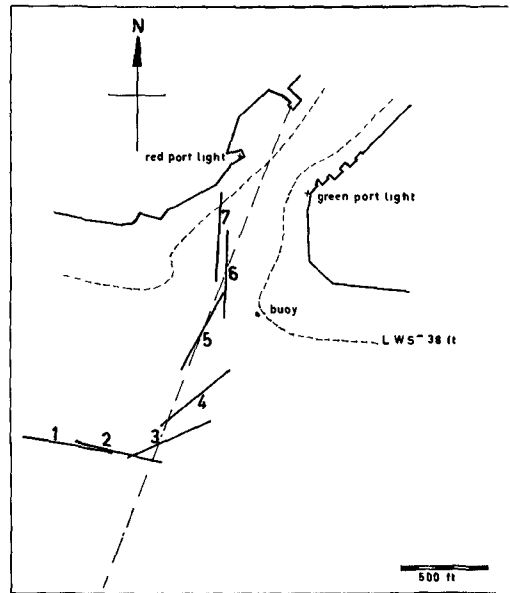


Fig. 9b

Fig. 9a Maneuver T2 Tanker

With the helm turned a little to port and the screw dead slow, the ship makes straight for the buoy, against the stream, at a quarter of a mile's distance from the shore. In position 3 the helm is turned completely to port, and kept so during positions 4 and 5. Then the helm is gradually turned into its former position, in such a manner that it is righted in position 7. During the whole maneuver the screw works dead slow.

Fig. 9b Maneuver T2 Tanker

The ship threatens to pass the buoy on the wrong side. Therefore the helm is already put entirely to port in position 3. Screw is kept dead slow. In position 6, however, the helm is still entirely put to port. This is incorrect. In spite of helm being turned to starboard, and screw full speed ahead, the ship runs into the westerly reef near the red port-light position 7. After position 5 the helm should have been righted gradually.

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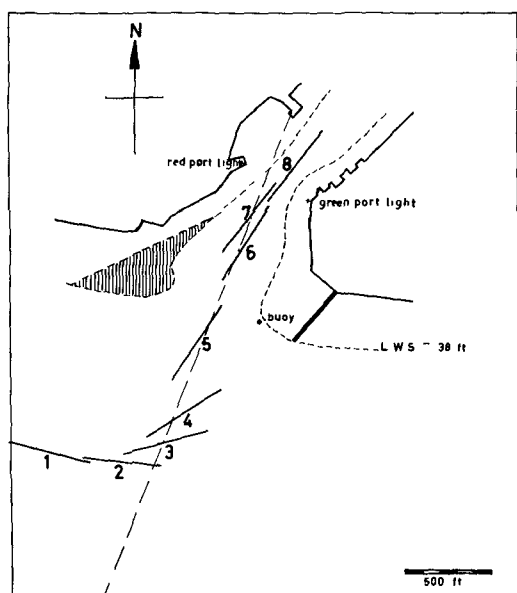


Fig. 9c

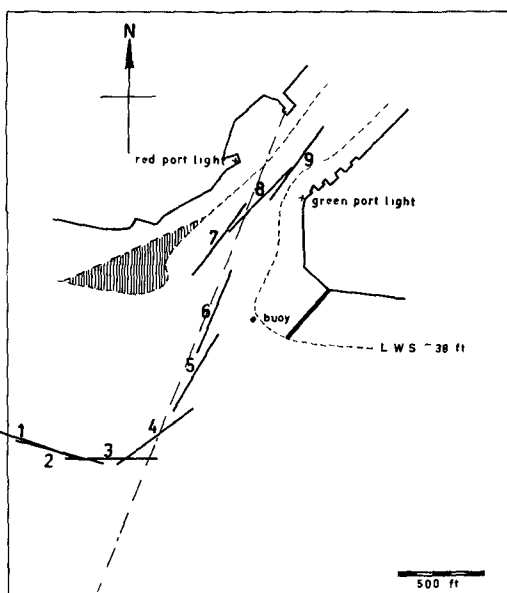


Fig. 9d

Fig. 9c Maneuver T2 Tanker

The tanker sails dead slow against the stream at a quarter of a mile's distance from the shore. During the whole maneuver screw dead slow. In position 2 the helm is turned slowly to port in positions 5 and 6 it is kept entirely to port. Bow does not turn to starboard. In position 7 the helm is righted again. The tanker arrives correctly between the heads of the bridge.

Fig. 9d Maneuver T2 Tanker

At about a quarter of a mile's distance from the shore the tanker sails dead slow against the west going current. During the whole maneuver the screw is kept dead slow. In position 3 helm slowly to port. In position 5, when the ship comes into smooth water, helm entirely to port. Also in position 6 the helm is kept completely to port. Then it is righted and in position 7 put a little to starboard. In positions 8 and 9 the helm is righted, after which the tanker arrives correctly between the heads of the bridge.

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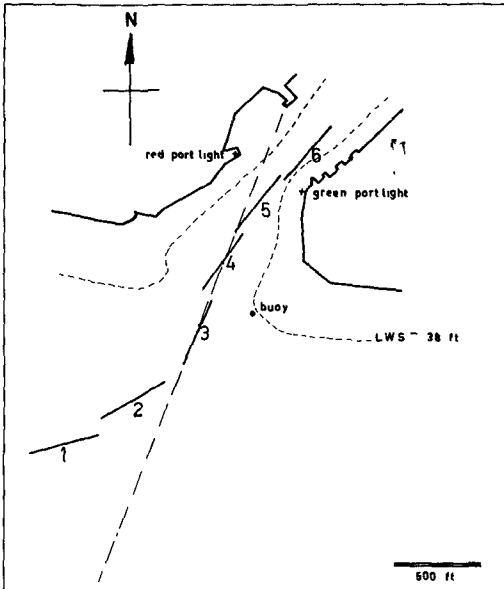


Fig. 10a

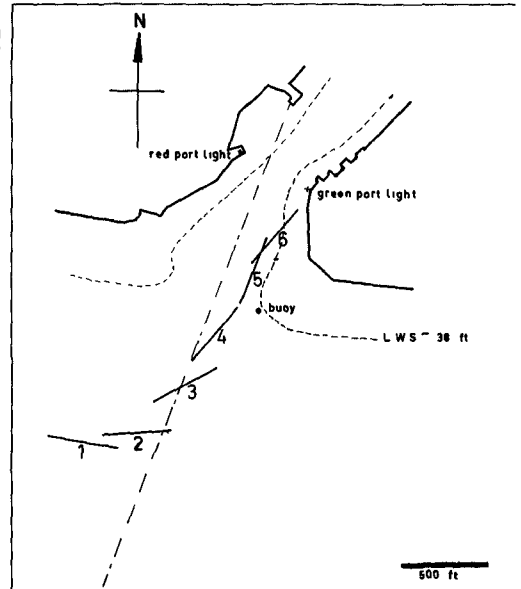


Fig. 10b

Fig. 10a Maneuver G2 Tanker

With helm a little to port the tanker makes straight for the buoy. In position 3 helm completely to port. The bow threatens to turn a little to starboard. This is obviated by sailing full speed ahead between positions 3 and 4, for a short moment. The port screw keeps revolving dead slow ahead. In position 4 both screws again dead slow ahead. The helm is still kept entirely to port. In positions 5 and 6 helm righted.

Fig. 10b Maneuver G2 Tanker

Tanker correctly makes straight for the buoy. Both screws revolve dead slow ahead. In position 1 helm a little to port, in position 4 helm completely to port. Then, before the stern has come into smooth water the helm has already been righted, so that the bow turns to starboard and the tanker runs ashore near the green portlight. In position 5 the helm should still have been put entirely to port, only after position 5 should it have been righted slowly.

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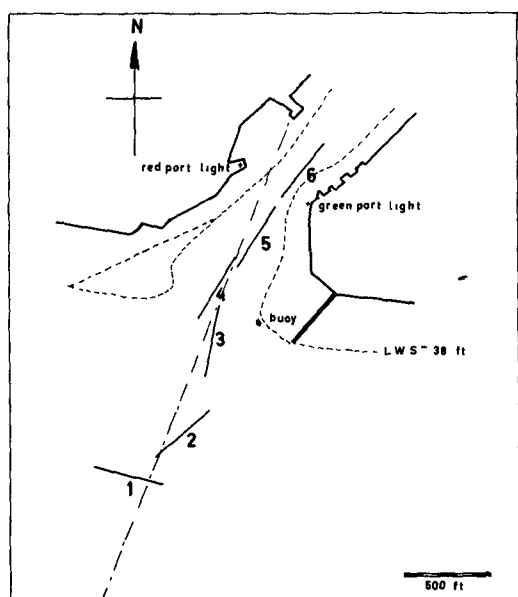


Fig. 10c

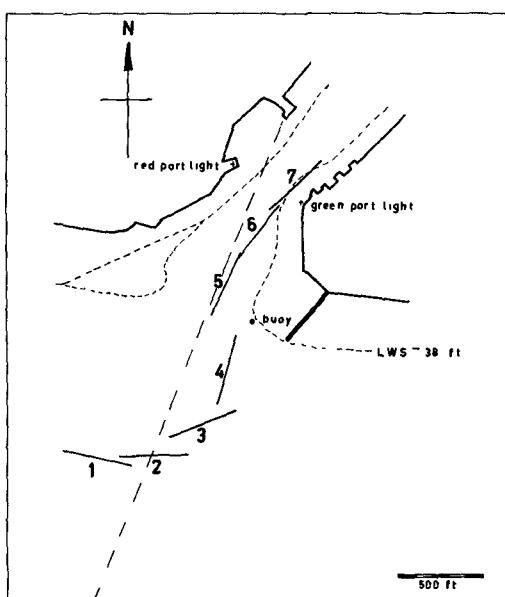


Fig. 10d

Fig. 10c Maneuver G2 Tanker

Tanker sails dead slow against the stream and the helm is put a little to port in position 1. In position 2 the helm is turned further to port. In position 3 the helm is turned entirely to port. In position 4 the whole tanker, including the stern, has come into smooth water the helm is righted. During the whole maneuver both screws revolve dead slow ahead.

Fig. 10d Maneuver G2 Tanker

Tanker threatens to pass the buoy on the wrong side. Both screws dead slow ahead. Already in position 3 rudder entirely to port in order to get the buoy on starboard. Between positions 4 and 5 the bow threatens to turn to starboard. Therefore maneuvers are carried out with the screws. Starboard screw full speed ahead and port screw full speed astern. In this way running ashore on the easterly reef is successfully avoided. Maneuvers by means of screws cause loss of time. In position 5 again both screws dead slow ahead. The helm is still kept a little to port. The tanker puts into port a little too near the green portlight.

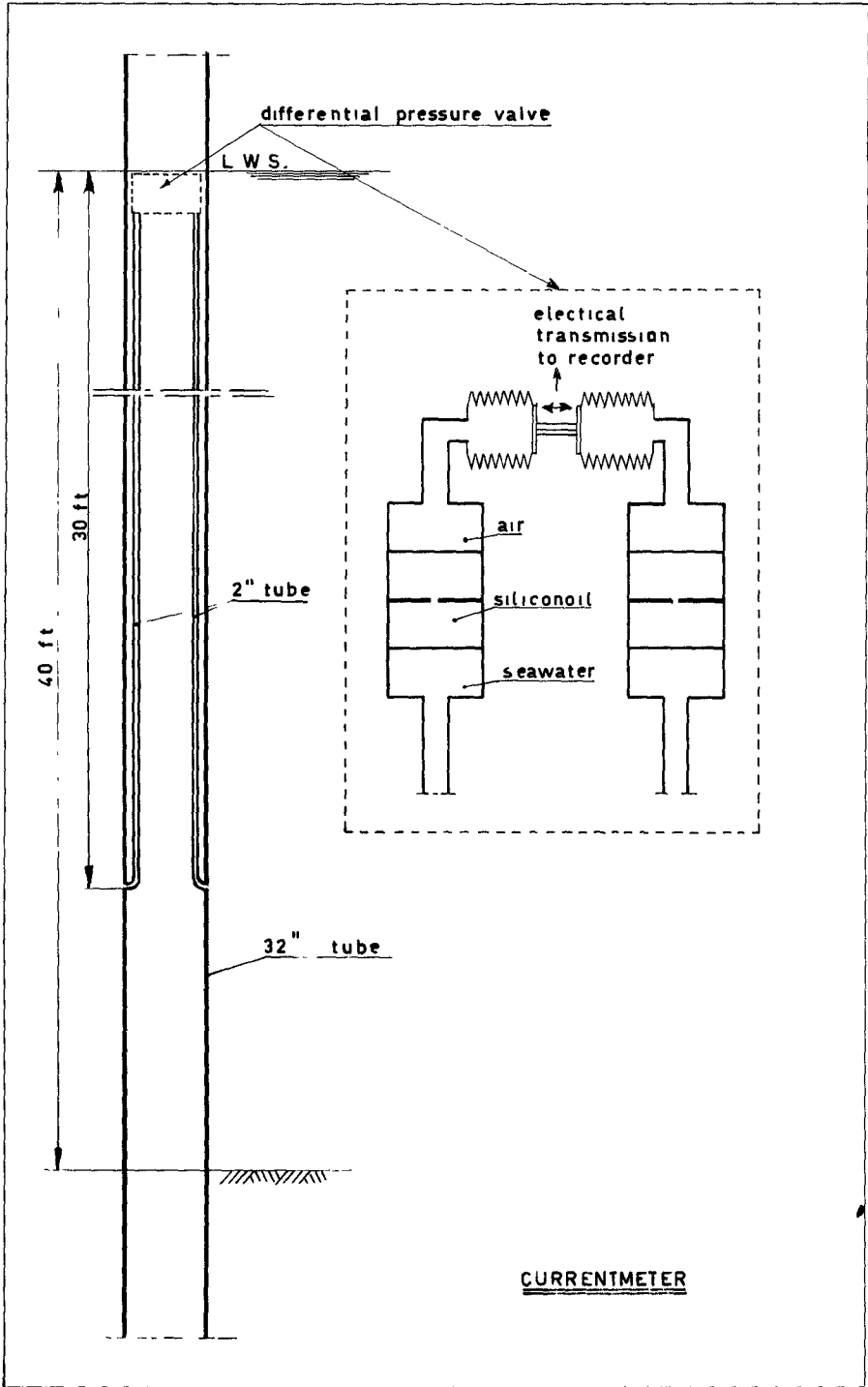


Fig. 11

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The sailing tests taken are of very great value. It can be shown how the improvements projected will work in practice; besides, these tests are very instructive for the pilotage staff. Each pilot has his own way of piloting a ship into port. It is impossible to give instructions for the piloting into port of ships. It can only be useful for every pilot to try his way of entering into port in a model.

The small number of ship accidents since the middle of 1955 is due, in large part, to a better insight into the behavior of ships when putting into port as a result of the investigations carried out in the model.

EXECUTION OF THE IMPROVEMENTS PROPOSED

Of the improvements proposed only the current-meter and widening of the narrow cross-section have been realized up to now, whereas a start has been made with the preparations for the construction of a breakwater.

A temporary current-meter, projected as a result of the combined efforts of several Netherlands laboratories, has been put up about 200 ft. east of the easterly buoy, at a spot where the water is 40 ft. deep. This current-meter consists of a 32 ft. tube which has been driven into the ground. At a depth of 30 ft. there are 2 holes, diametrically opposed to each other, and lying in the direction of the current. The velocity of the current can be obtained by measuring the difference in pressure between the two holes. In order to cause the current to detach itself always from the wall at the same spots, two angle sections have been welded on either side of the tube, across the direction of the current.

In order to prevent the wave motion from influencing the results, columns of air and silicon oil have been applied between the points of pressure and the pressure gauge. In the column of silicon oil a plate has been fixed, provided with a narrow hole, which plate acts as a resistor. This resistor serves to eliminate the influence of the differences in pressure caused by the waves. Silicon oil is used because it is chemically inert. Fig. 11 gives a schematic outline of the operation. The measurements are transmitted electrically to the shore and recorded. Signal lamps indicate the velocity of the current at sea and are visible at sea at all times.

No decision has yet been made as to the manner in which the breakwater will be constructed. Since the breakwater has to be built as far seaward as possible it will be necessary that the end of the breakwater be constructed with vertical walls.

Information about waves was not available at the time of research on this paper. At the present time a wave recorder is installed near the harbor entrance to obtain basic information for design.