CHAPTER 108

HARBOUR INLETS ON TIDAL ESTUARIES

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Two important points should be considered if a harbour mouth is planned on a river:

1. The traffic conditions especially the navigation must be considered (i.e. large width of the mouth)
2. The sedimentation should be small (i.e. small width of the mouth)

These conditions are contradictory. Harbour mouthes are lateral enlargements. The current doesn't follow these enlargements, a separation sheet forms which is characterized by eddies. A more or less great mass of water is in movement in the enlargement. These rotating movements are called "vortices". One distinguishes "primary vortices", "secondary vortices" etc. depending on the initiating current (Fig. 1).

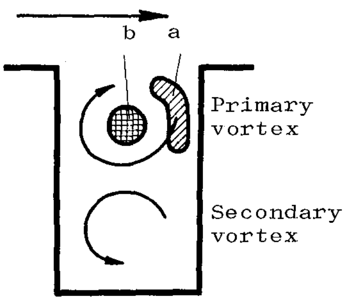

Fig. 1

The deposition of sediment in lateral enlargements depends on the characteristics of the vortices, because the exchange of liquid material has interacted with the exchange of transported material. Normally the coarse material deposits in area a and the fine material in area b (Fig. 1).

Generally one can define the reasons for sedimentation as follows (Fig. 2).

1. Current effect (vortex in the harbour mouth caused by energy exchange)
2. Tide effect (fill up of the harbour basin during the flood tide)
3. Density effect (density current caused by different salinity in the estuary and the harbour entrance)

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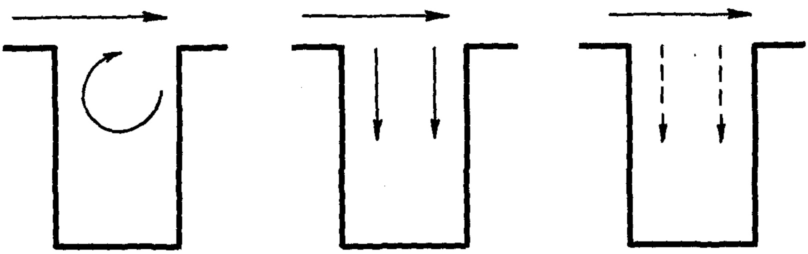


a. Current effect b. Tide effect c. Density effect

Fig. 2

The current effect is dominant for the sedimentation in harbour mouthes situated on rivers with one-directional flow. If it is possible to influence the primary vortex the sedimentation will be smaller. Fig. 3 shows possible ways to displace or to diminish the primary vortex.

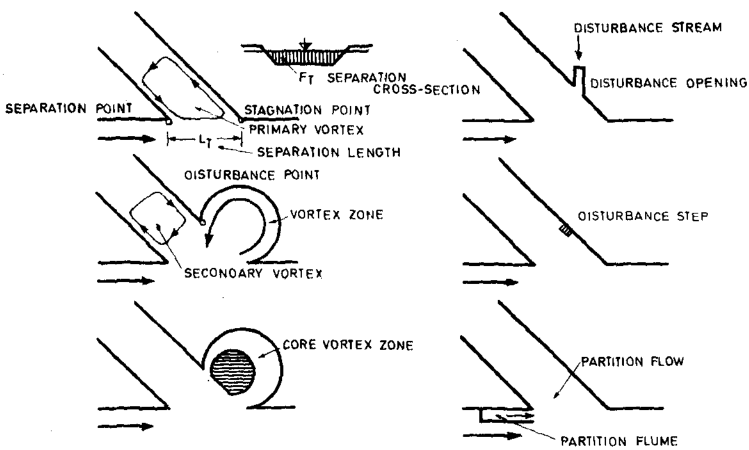


Fig. 3

There is the "vortex zone", the "vortex zone" restricted on the border current (core vortex zone), a so-called "disturbance opening" and a "disturbance step". These methodes are based on an alteration of the downstream geometry of the harbour mouth.

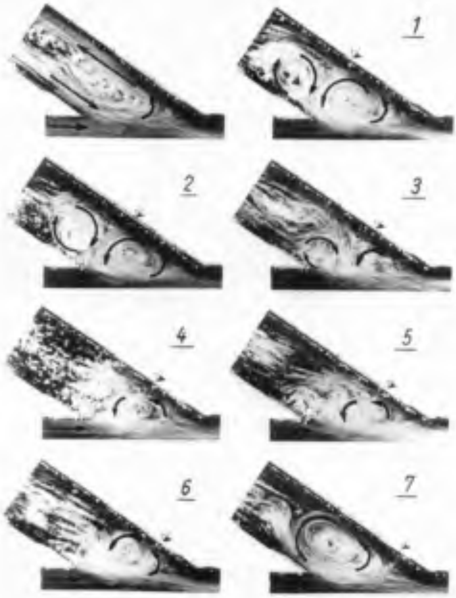


Fig. 4

Fig. 5

It is possible to influence the separation zone i.e. the velocity gradient between the river flow and the vortex area with a so-called "partition flow". The "partition flow" is directly taken from the river flow, but only the upper layer with smaller sediment load.

The influence of the primary vortex with the "disturbance step" may be seen on Fig. 4. The practical use of a "vortex zone" is demonstrated on a harbour at the Rhine River. Above one can see the situation before the alteration of the mouth and below there is the new entrance. Now the deposition zone has been located downstream (Fig. 5).

In estuaries it is very difficult to find a satisfying solution because the current direction changes rhythmically. Neglecting the density effect, the following happens (Fig.6): During the flood tide, the current effect and tide effect superpose mutually, i.e. the current intensity is very great starting on the stagnation point. During the ebb tide the two effects work against one another. Because vortices are movements with no much energy small currents can destroy the development of a vortex.

These general considerations were used for a case study in the Ems-Estuary-Model at the Bundesanstalt für Wasserbau in Hamburg.

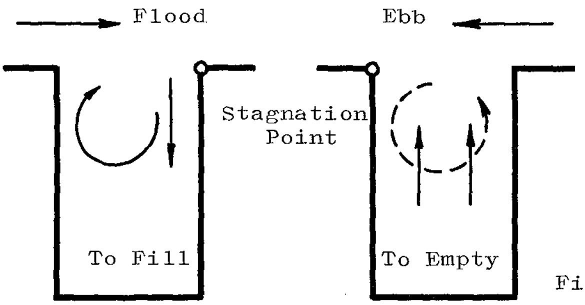


Fig. 6

The model includes the River Ems and has been built as a fixed bed model, with the possibility to also investigate sections with movable bed. The horizontal scale is 1:500, the vertical is 1:100. Since the Ems is a boundary river between the Netherlands and the Federal Republic of Germany a number of problems also arose for the Dutch authorities. The new entrance of the Delfzijl harbour was one of these problems (Fig. 7).

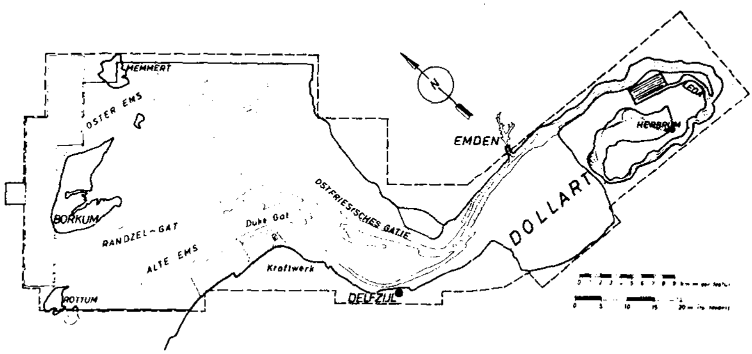


Fig. 7

The general situation of the Delfzijl harbour is shown in Fig. 8. 20 years ago the harbour was only the basin on the left, the bight of Watum was the acces channel. Because the sedimentation in the bight of Watum increased, it was necessary to dredge a new acces from the main channel Borkum - Emden. The industrial development and the sedimentation in the near field zone of the old entrance led to the enlargement of the basin and the construction of the new entrance. The old entrance will be closed later on. Contrary to usual harbours with vertical development to the river the Delfzijl harbour is practically only a parallel channel under tidal influence. It could be expected that very bad current conditions would appear if the old entrance was closed. Therefore the model investigations were concentrated to improving the current situation in the new entrance.

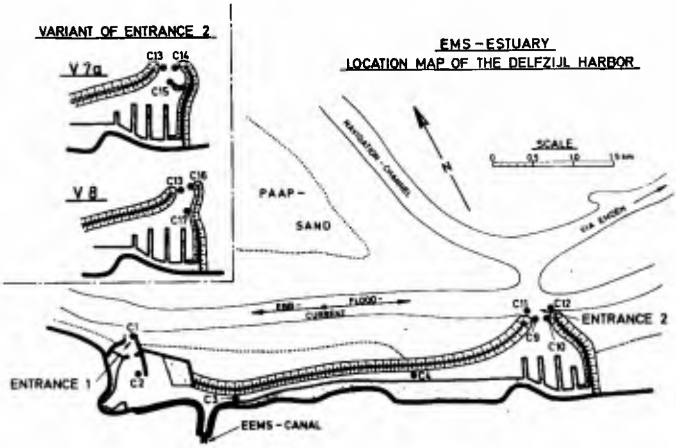


Fig. 8

The estimation of the different investigated variations has been carried out with the aid of the surface current visualised with photographed scraps of paper and with the aid of velocity measurements in a medium water depth at certain points.

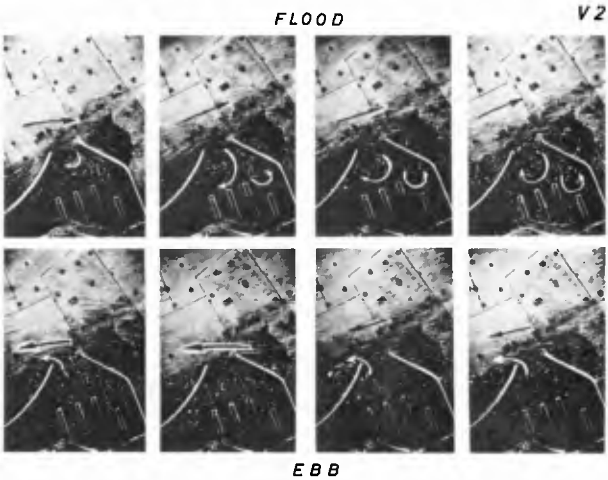


Fig. 9

The current situation for V2 (new entrance open, old entrance closed) can be gathered from Fig. 9. During the flood tide there is a velocity concentration on the right jetty which produces a large vortex in the main basin. The current effect and tide effect are superposed upon one another. During the ebb tide the tide effect i.e. the outflow from the basin dominants the current effect. There is no rotating flow in the entrance zone. In this case the current effect is especially small caused by the diversion of the upstream jetty.

Fig. 10 shows clearly that using a "vortex zone" there is no possibility to avoid the primary vortex in the harbour mouth. Only in the first flood phase one can see a relativly good velocity distribution in the entrance cross section. Subsequently, large vortices appear.

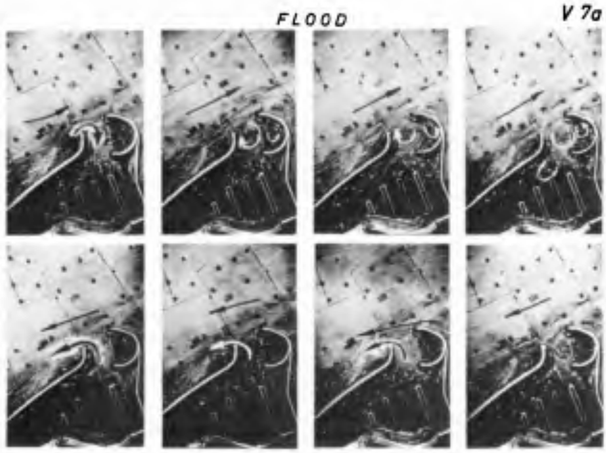


Fig. 10

Geometrical alterations were not sufficient to suppress the overlapping of current and tide effect. Finally the only possibility was to renounce the closure of the seaside entrance and to produce a stream against the tide and current effect in the new entrance. For this reason a systematic investigation has been started with different widths (100, 65, 50, 40 m) of the old entrance. The development of the surface current for an inlet width of 100, 65 and 40 m is demonstrated by the following photos. The results of the investigation with three various inlet width are

a) 100 m(Fig. 11): The energy slope is sufficient to prevent the inflow on the upstream jetty. In the first flood phase there is practically no movement. Later, a uniform outflow appears in the harbour mouth. During the ebb tide the current enters the harbours on the downstream jetty, a small vortex now turns in the large basin.

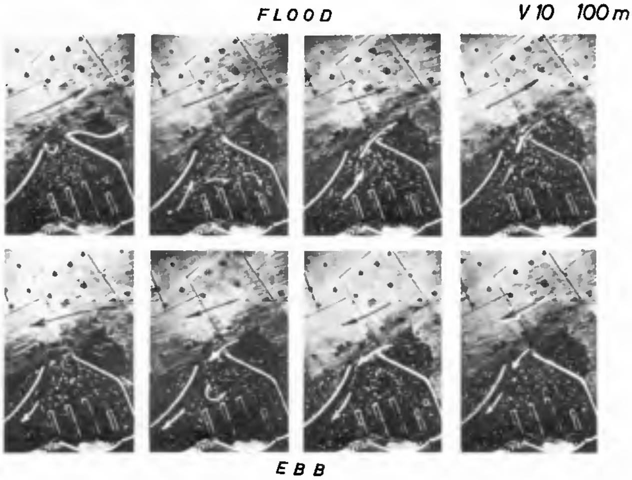


Fig. 11

b) 65 m (Fig. 12): For an opening width of 65 m one can see nearly the same surface current distribution.

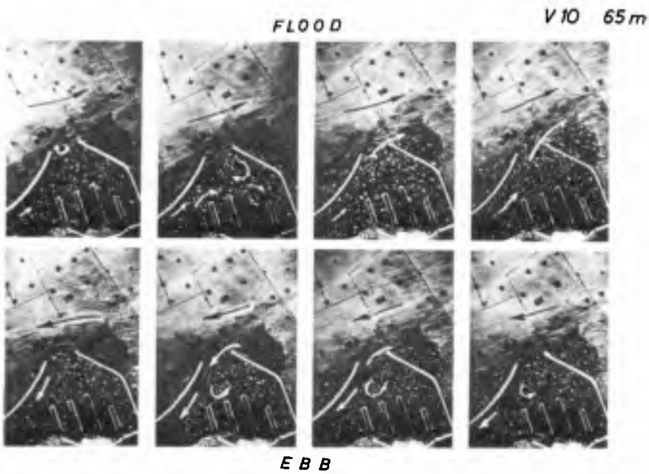


Fig. 12

c) 40 m (Fig. 13): This width is not sufficient to avoid the inflow on the upstream jetty in the first flood phases. Only in phase 4 an outflow occurs.

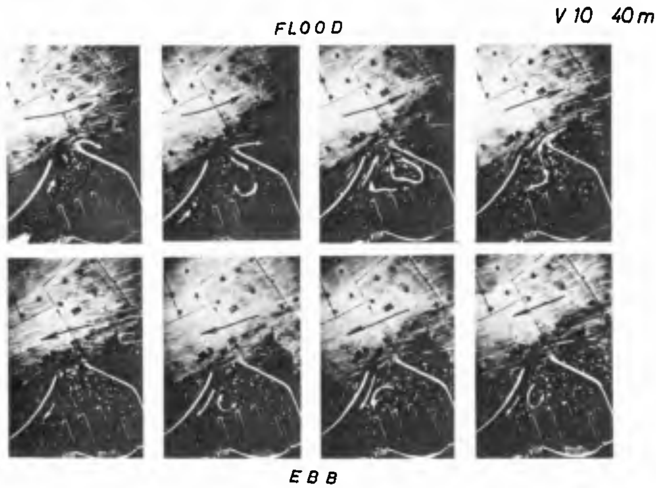
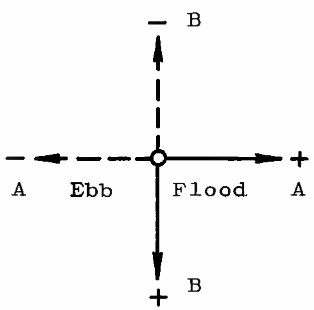


Fig. 13

During the ebb tide the current distribution is nearly the same for all opening widths.

To help confirm the observations of the surface currents, velocity measurements were carried out in medium water depth in certain points. Fig. 8 shows these measuring points. The velocity has been measured either in flood/ebb direction or vertically to it. Fig. 14 may help explain.



A: 3, 4, 11, 12

B: 1, 2, 9, 10 (13-17)

Fig. 14

At the velocities for V 7a und V 8, there are high inflow rates in C 14 and also in C 16. The oscillations in C 15 depend on the position of the current meter. The outflow distribution in C 13 has the same characteristic for V 7a and V 8 (Fig. 15).

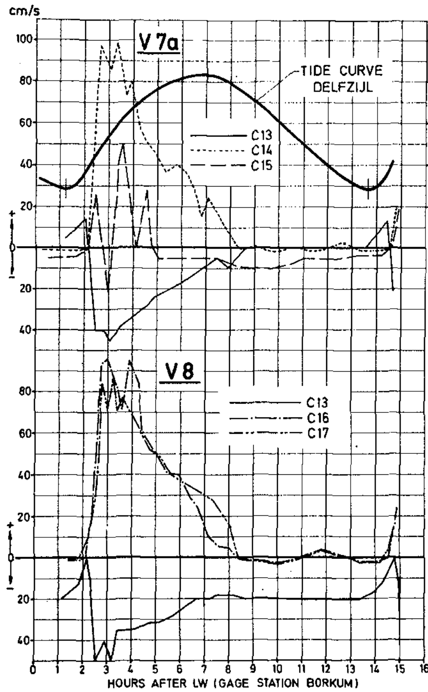


Fig. 15

Fig. 16 to Fig. 19 demonstrate the results of the test series V 10 in comparison with V 1 (old harbour without the new entrance) and V 2 (new harbour, old entrance closed). In C 1 one can see clearly the increase of velocity depending on the width of the old entrance. The decrease of velocity in C 2 in relation to the increased width depends on the situation of C 2 because this point is influenced by the jet-stream (Fig. 16 and Fig. 8).

In the harbour channel the velocity relationship is clear. With decreasing width the velocity also decreases. This clearly appears during the ebb tide in C 4 (Fig. 17).

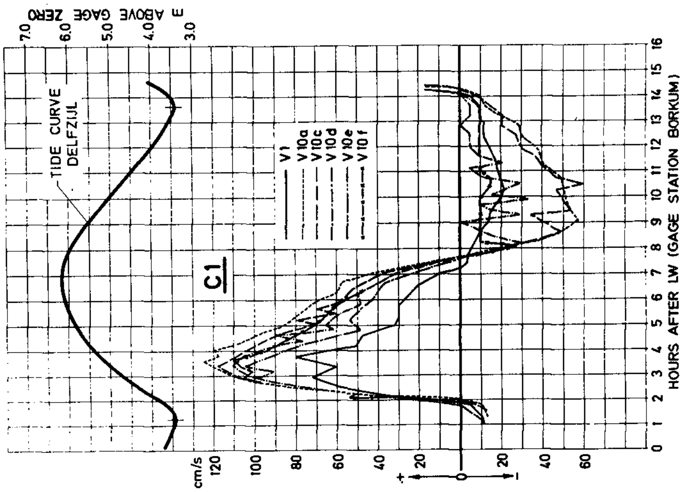


Fig. 16a

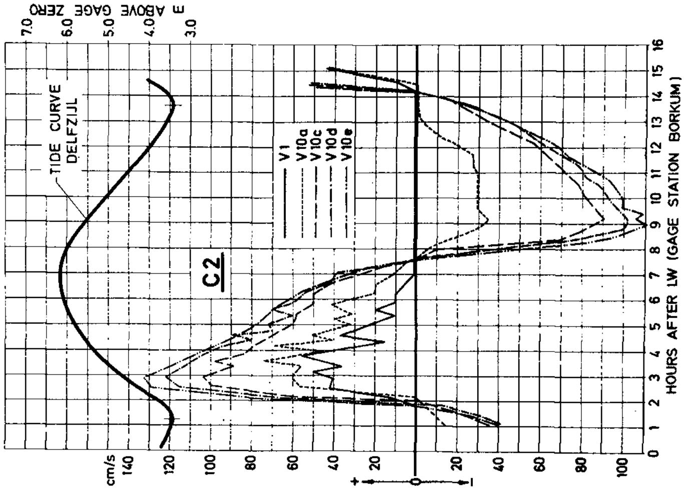


Fig. 16b

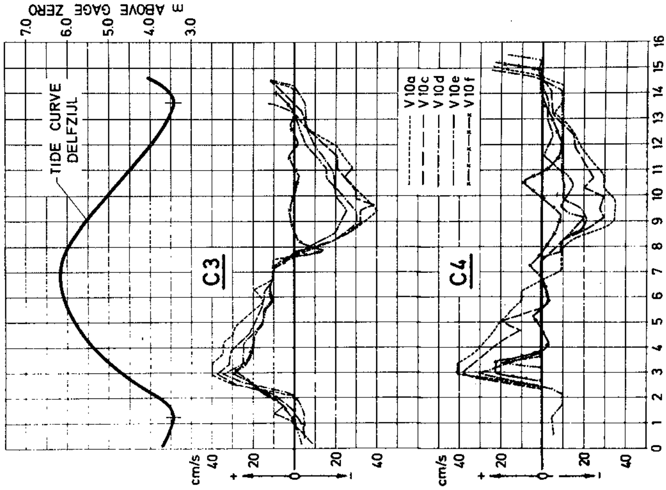

TIDE CURVE DELFZIJL
m ABOVE GAGE ZERO
cm/s
C3
C4
V10a
V10c
V10d
V10e
V10f
HOURS AFTER LW (GAGE STATION BORKUM)

Fig. 17

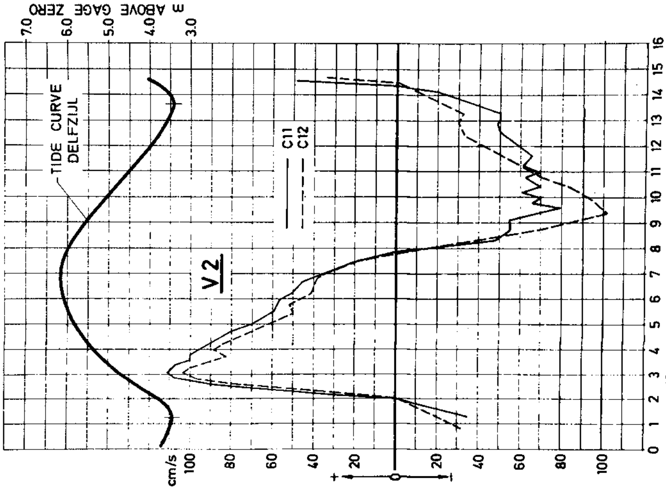

TIDE CURVE DELFZIJL
m ABOVE GAGE ZERO
cm/s
V2
C11
C12
HOURS AFTER LW (GAGE STATION BORKUM)

Fig. 18

The points C 11 and C 12 are situated in the main current in front of the new entrance. The distribution is typical for a tide flow. The smaller and oscillating ebb velocities in C 11 are influenced by the upstream jetty and the outflow from the harbour basin (Fig. 18).

In C 10 the difference of the current situation between closed and opened old entrance is clearly recognizible. There is a very high inflow during the flood tide and a small outflow in the ebb tide. In C 9, one can notice a permanent outflow during the whole tide. (flood: vortex in the harbour mouth; ebb: emptying of the harbour) (Fig. 19).

In the test series V 10 the graduation between as well flood and ebb as the width of the old entrance is very good. For V 10f an ebb inflow is not possible because for this test the old entrance has been closed during the ebb.

Following the model tests it was proposed not to close the old entrance and to observe the situation. After finishing the construction in nature a number of velocity measurements were made in the two entrances and in the harbour channel. Up to now the results are not completely analysed.

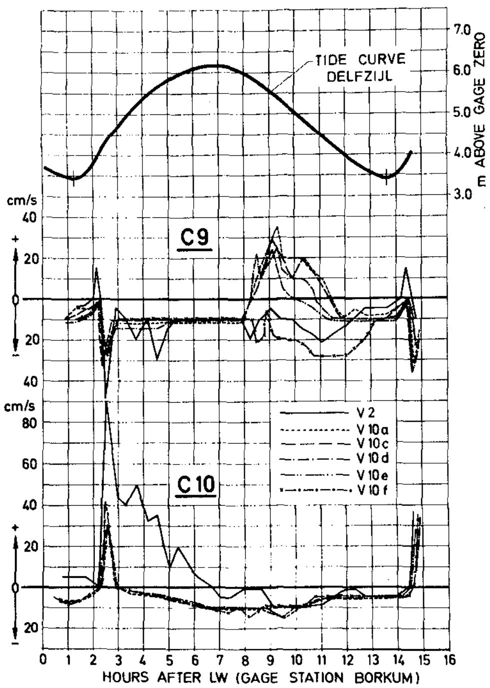


Fig. 19

In general one can say the following:

The model results are in a fair agreement with the nature. But concerning the vertical distribution of velocity there are phenomenon which need special investigations to explain it.

In contrariety to a vortex which is produced by an one-directional flow and which shows a good agreement between surface and bottom current, one observes different rotating systems in lateral enlargements under tidal influence.

Measurements in the entrance to the Kiel-Kanal may explain this phenomenon (Fig. 20). Certainly in this case the density effect is of great importance. In Fig. 21 and 22 the normal velocity distribution during the tide has been measured in the Elbe River in front of the entrance. One can recognize also the displacement of the slack-water. Fig. 21 shows the first flood phase. In the surface area there is a fillstream in the entrance and near the bottom the water flows out. During the ebb tide the distribution of surface and bottom current is also quite different, which is demonstrated by Fig. 22.

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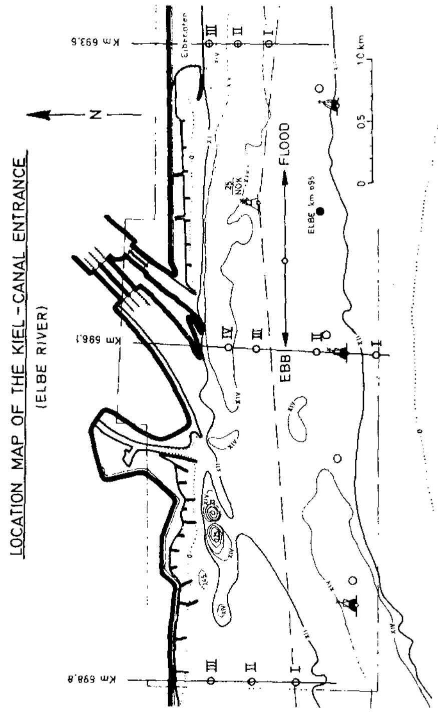

Fig. 20

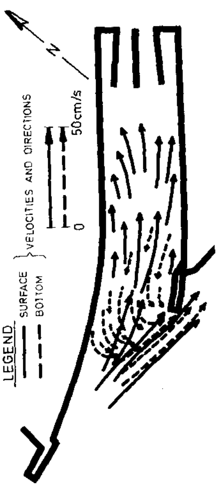

Fig. 21

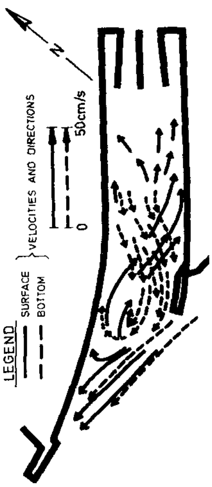

Fig. 22