CHAPTER 93

STABILITY CRITERIA FOR TIDAL BASINS

by

Eberhard Renger[1] and Hans-Werner Partenscky[2]

ABSTRACT

The contribution deals with the morphologic examinations and calculations for a deep-water harbour which is to be constructed in the tidal flats of the Elbe estuary near the North Sea islands of Scharhörn and Neuwerk. An attempt is made to examine the stability of tidal channels (gullies)and tidal flats which may be disturbed to a greater or lesser extent by the various proposals for the connecting dike between the industrial area near the harbour and the coastline.

The underlying logic for the determination of the equilibrium of the flats and the quantitative solution for the sand-balance is as follows:

It has been shown in several empirical investigations that the increase of the relative volume of the tidal basin (V/V_{MLW}), referenced to the gully volume for MLW, can be determined as a simple function to the base ($\bar{a}$) logarithm of the geodetic elevation (z^*) between MLW and any higher contour level up to MHW. Furthermore it can be shown that (V_{MLW}) is also a function of the tidal drainage area (E).

The base ($\bar{a}$) has been related to the size of the tidal drainage area (E), because this area is subject to considerable modification by offshore structures such as dikes and causeways.

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[1]Scientific Associate, Franzius-Institute,Hannover, West-Germany

[2]Director of the Franzius-Institute, Technical University of Hannover

A comparison of the volumes of the tidal basins for the situation before and after construction can be made.

This inturn leads to the sand balance which can be applied to the given and expected volumes of the tidal basin, so that the sand removed or added can be predicted.

INTRODUCTION

In case of major man-made constructions in the reach of tidal flats and tidal gully systems, changes in the tidal regime as well as in the morphology of the tidal basins must be expected. However, due to the mutual interaction between tidal currents and velocities and sediment transport a new state of equilibrium will eventually be reached.

Although the coastal engineer in general is mainly interested in the changes of the tidal characteristics (tidal range, current velocities and directions) which will be caused by constructions such as dams, dikes, etc., the modifications in the morphological structure of the tidal basins concerned (erosion and sedimentation) might become an important aspect with respect to navigation. The prediction of the changes to be expected in the cross-sectional area of existing navigation channels as well as the prediction of sand balances is therefore of vital interest in areas where navigation has an important role.

In this contribution an attempt is made to examine the stability behavior of existing tidal basins along the German Bay between the Netherlands and Denmark. The stability criteria obtained by means of a semi-empiric approach are then applied to predict morphologic changes to be expected due to a proposed dam to the deep-water harbor Neuwerk/Scharhörn of the City of Hamburg which is to be constructed in the tidal flats of the ELBE estuary.

STABILITY BEHAVIOR OF TIDAL BASINS

It has been shown by several authors that a relationship exists between the tidal volume, and also the area of the tidal basin (E), and the outflow cross-sectional area (F) on the seaward side. (Bruun, Gerritsen (1958), Hensen (1971) O'Brien (1969), Rodloff (1970), Walther (1972)). However, this two-dimensional approach appears to be somewhat limited for a detailed and, moreover, quantitative description of the actual three-dimensional situation.

In the present study, the usual method for the description of the morphologic state of the tidal basin by means of characteristic vertical cross-sections was therefore abandoned and replaced by an approach in which horizontal layers were used to describe the volume capacity of the tidal gully system (Renger, E. und Partenscky, H.W., 1974).

The contour-enclosed surface area of each layer corresponding to a well-defined geodetic level was evaluated by means of a planimeter by using contour lines of existing sea-charts (1:10000). The characteristic relationships between the contour-enclosed areas of a given tidal basin and the geodetic elevation referred to MLW is shown on figure 1a. Figure 1b shows the typical volume curve of the tidal basin which was obtained by numerical integration from curve a). For the mathematical description the volume values are related to a reference volume of the tidal channel at MLW (figure 1c).

A total of 22 tidal basins on the German Bay (along the North Sea coast) were systematically studied. First, the increase in the horizontal contour-enclosed area open to the sea was determined as a function of increasing contour elevation (see fig. 1a). Then, by stepwise integration, the relative volume of the tidal basin (V/V_{MLW}), referenced to the gully volume for MLW, was calculated (see figure 1c).

The determination of the reference volume (V_{MLW}) as a function of the area of the tidal basin (E) gave for the 22 tidal basins a relation of the form (fig. 2):

$$V_{MLW} = 8 \cdot 10^{-3} E^2 \qquad (1)$$

An appropriate expression may be obtained for the size of the reference area enclosed by the MLW contour (O_{MLW}) by way of the following empirical equation (fig. 3):

$$O_{MLW} = 2.5 \cdot 10^{-2} E^{3/2} \qquad (2)$$

The mathematical approximation to the data for relative volume of the tidal basin (V/V_{MLW}) (See Fig.1c) is given by the logarithmic function

$$z^* = \log_{\bar{a}} (V/V_{MLW}) \qquad (3)$$

where the parameter ($\bar{a}$) is dependent on the size of the tidal area (E) as follows (see fig. 4):

$$\bar{a} = 5 \cdot E^{-0.272} \qquad (4)$$

The parameter ($\bar{a}$) characterizes the volume-distribution of the tidal basin between MLW and any higher contour level up to MHW, i.e. for $z^* \geq 0$.

By means of Eqs. (1) and (4) a relationship for volumes of the tidal basin is established between the area of the tidal basin (E) and the geodetic elevation (z^*) in the following form:

$$V = V_{MLW} (\bar{a})^{z^*} = 8 \cdot 10^{-3} \quad E^2 (5 \; E^{-0.272})^{z^*} = f(z^*, E) \qquad (5)$$

where V = volume of the tidal basin in $10^6 \cdot m^3$
E = area of the tidal basin in km^2
z^* = geodetic elevation referenced to MLW in m.

The relation expressed by Eq. (5) demonstrates clearly that the tidal gully systems of the German Bay exhibit a stability that is readily described.

How much the tidal range and the composition of the bed material may influence the stability of a tidal gully system as expressed in Eq. (5), can not as yet be determined, since the mean tidal range of the tidal basins evaluated falls only between 2,5 m and 3,5 m and the mean grain diameter of the bed material lies between 0,16 mm and 0,20 mm.

APPLICATION OF THE RESULTS OBTAINED TO THE DEEP-WATER HARBOR PROJECT NEUWERK/SCHARHÖRN

1. General layout of the harbor

In the following, the results obtained from the general study on the stability of tidal basins are applied to the project of the planned deep-water harbor Neuwerk/Scharhörn of the city of Hamburg. This harbor is to be constructed in the tidal flats of the Elbe estuary near the North Sea islands of Scharhörn and Neuwerk (fig. 5). An industrial area of about 12 km^2 around the harbor shall be connected with the coast by means of an earthdam. Figure 6 shows the general layout of the planned harbor with different alternatives for the dams in the southern range of the Elbe estuary and the existing morphology of the tidal channel system. (Partenscky, H.W. und Renger, E., 1974).

The project has been studied on a hydraulic fixed-bed model at the FRANZIUS-INSTITUTE of the Technical University of Hannover in order to determine the changes in the tidal characteristics to be expected by the construction of the dams (model boundary on Fig. 5).

The important question as to what extent the stability of the existing tidal basins might be disturbed by the dams could not be answered by the model tests. However, a prediction of the morphological changes was possible by using the results of the general study as outlined above:

In general it is assumed that the existing equilibrium of the tidal basins will more or less be disturbed by the planned dams and shifted to a new equilibrium state.

2. Morphologic changes north of the planned dams

For several reasons, the southern layout of the connecting dam (fig. 6, Alternative C) was finally selected. The areas of the three northern tidal basins Buchtloch, Eitzenbalje and Hundebalje (see Fig.6) shall be enlarged by an area of about 25 km^2, i.e. about 50% of their initial area. This shall consequently lead to an enlargement of the volume of the tidal basin and therefore to erosion. As a result a certain percentage of the eroded sand will be transported by the tidal currents and be deposited outside the seaward boundary of the tidal basins near the important international waterway ELBE - river.

Some secondary dams following the existing watershed were therefore planned to reduce this effect in the northern tidal flats. The danger of sedimentation in the navigation channel could so be kept as small as possible.

3. Morphological changes south of the planned dams

Due to the planned dam (Alternative C, fig. 6), the tidal basin of the TILL is considerably reduced in its area. Fig. 7 shows a simplified sketch of the situation. The area of the tidal basin TILL is shown by the dotted line with different limits for the seaward boundary, labelled by TILL - (11), - (12) and - (13). The pattern of the tidal channels is presented by means of the MLW-contour line.

The total area of the tidal basin TILL shall be reduced in its northern tidal flats and gullies from about 12o km^2 to 90 km^2 (skrashed area on Fig. 8d. A reduction in the drainage area of a tidal basin is usually followed by a shrinking of its volume, i.e. sedimentation in the tidal gullies concerned must be cxpeeted.

The graphs on Fig. 8a to e show on the ordinate thc geodetic elevation z^* referred to the reference levcl at MLW. On the right hand side (fig. 8c), the relative volume of the TILL is shown within the three selected boundaries (11), (12) and (13), whieh were mentioncd above. The eharacteristie parameters ($\bar{a}$) of the logarithmic approximation curve are labelled by the corresponding numbers on Fig. 4 . The points (11), (12) and (13) follow quite well the general tendency even for different limits of the seaward boundary. This rather good agreement makes a relatively independent choice of the seaward boundary possible and keeps the results of the calculations within the gencral tendeneies.

For thc predicted new equilibrium of the TILL with its reduced area of thc tidal basin, a distribution curve of the relative volume was found by means of interpolation between the three eurvcs (11), (12) and (13) (see fig. 8c).The corresponding distribution eurve of the contour-enclosed areas for the predieted eondition of the reduced TILL is shown on fig. 8a. The existing eondition is labelled by (13) on figurc 8a.

In fig. 8b on the right-hand side, the distribution of the contour-enclosed areas ΔO north which had been cut off by the dam from thc tidal basin TILL, is presented. These contour-enclosed areas were added to the northern tidal flats and had to be subtraeted from those of the existing equilibrium. The remaining distribution of the contour-enelosed areas of the rcdueed area of the TILL is given by the curve on the left-hand of figurc 8a, whieh is labclled "existing condition with dam".

The vertical distribution of thc shrinking of the eontour-enclosed arcas is shown on the left-hand side of Fig. 8b (ΔO, south).

This distribution is calculated as the differcnce of the contour-enelosed areas of the "existing condition with dam" and that of the "predicted cquilibrium". The dottcd area (fig. 8a and b) represents a mcasure for the predicted sedimentation in the TILL. Numerically it was found that a volume of about 38 Million m^3 of sand must be expected as sedimentation in thc tidal basin TILL due to the planned construetion of the southern dam.

CONCLUSIONS

A semi-empirical method has been employed to describe the morphologic structure of tidal basins observed in the German Bay/North Sea. The objective of the study was to determine the vertical distribution of the volume of a tidal basin by analytical expressions.

It could be shown that a well defined relationship between the different parameters such as reference area by MLW-contour (O_{MLW}), reference gully-volume V_{MLW}, characteristic parameter ($\bar{a}$) of the relative volume V/V_{MLW} and the area of the tidal basin (E) exists.

The results enable the coastal engineer to predict morphological changes in the tidal basins which must be expected by the construction of greater offshore structures such as dikes and causeways. By comparing the volumes of the tidal basins before and after the construction (new equilibrium), the sand removed or added can be calculated.

The stability criteria obtained by means of the semi-empiric approach were applied to predict morphologic changes to be expected due to a proposed dam to the deep-water harbor Neuwerk/Scharhörn of the city of Hamburg which is to be constructed in the tidal flats of the ELBE estuary.

How much the tidal range and the composition of the bed material may influence the stability of a tidal basin as expressed in equation (5) can not as yet be predicted, since the mean tidal range of the tidal basins evaluated falls only between 2,5 m and 3,5 m and the mean grain diameter of the bed material lies between 0,16 and 0,20 mm.

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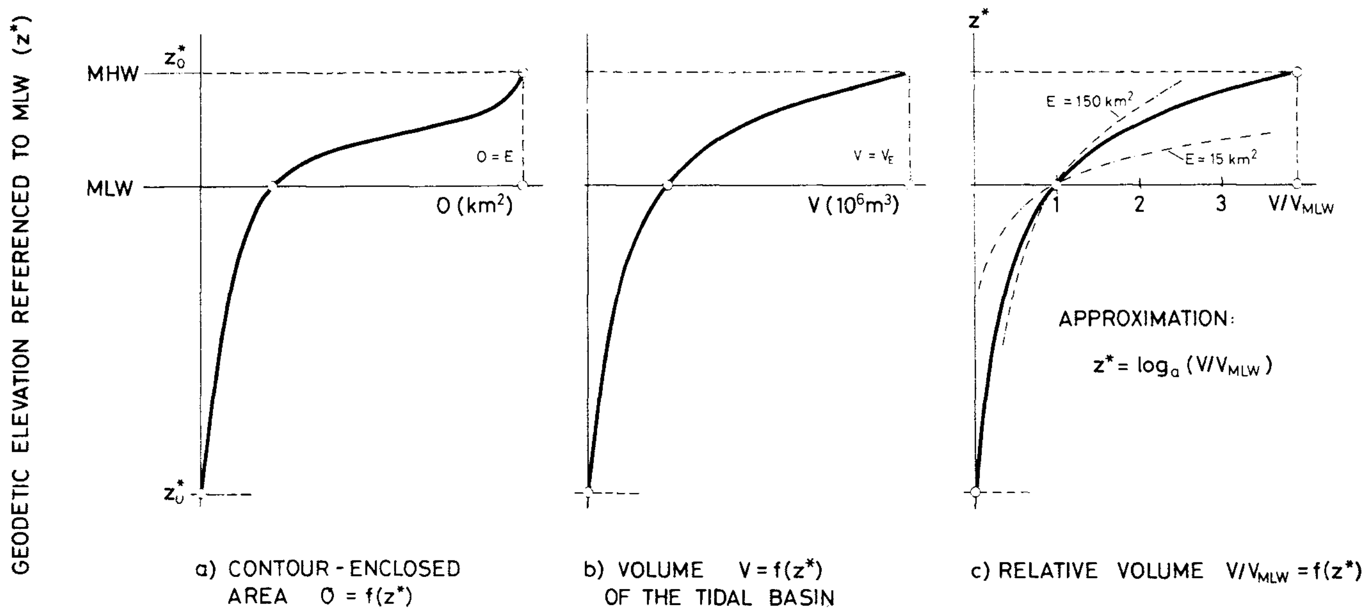
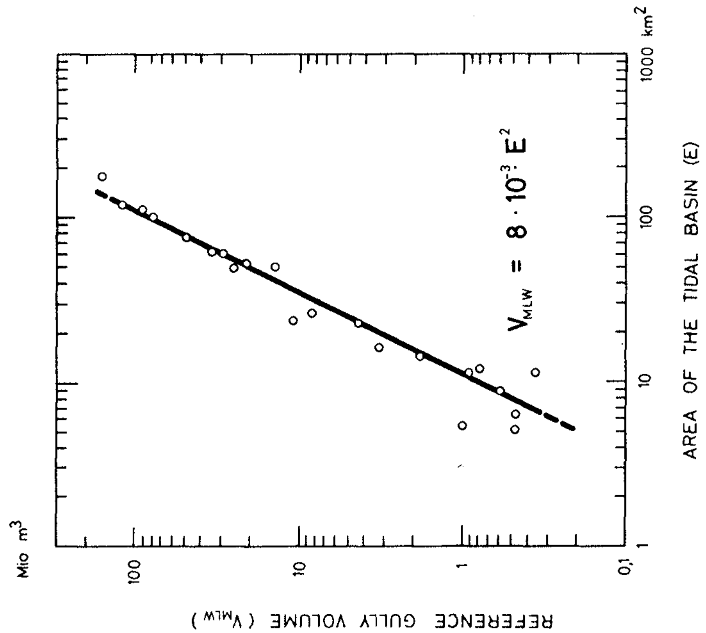
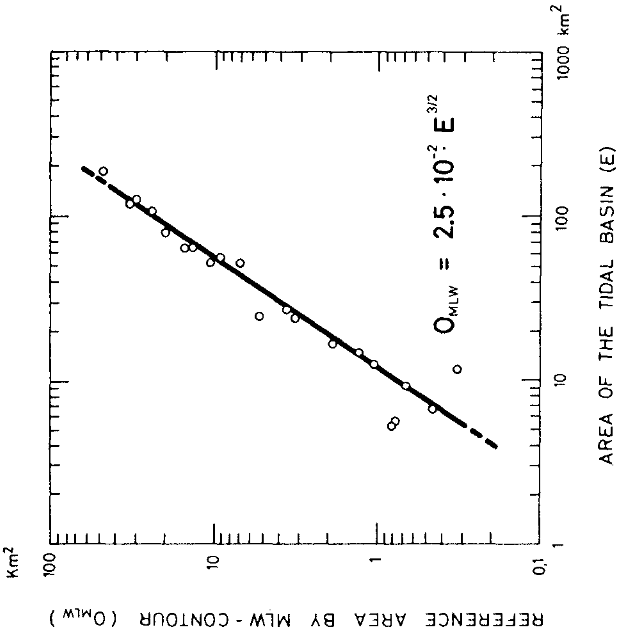


Fig. 1 Typical example of the Morphologic characteristics of a tidal basin in the German Bay/North Sea.



$V_{MLW} = 8 \cdot 10^{-3} \cdot E^2$
REFERENCE GULLY VOLUME (V_{MLW})
Mio m^3
AREA OF THE TIDAL BASIN (E)
km^2
0,1
1
10
100
1000

Fig. 2



$O_{MLW} = 2.5 \cdot 10^{-2} \cdot E^{3/2}$
REFERENCE AREA BY MLW-CONTOUR (O_{MLW})
Km^2
AREA OF THE TIDAL BASIN (E)
km^2
0,1
1
10
100
1000

Fig. 3

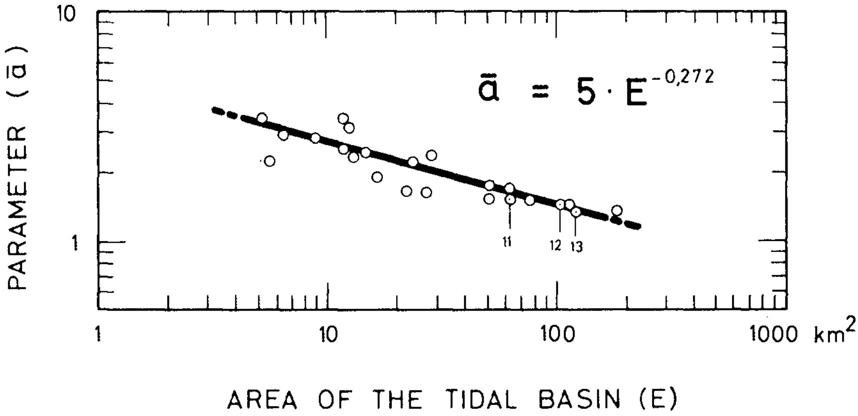


Fig. 4

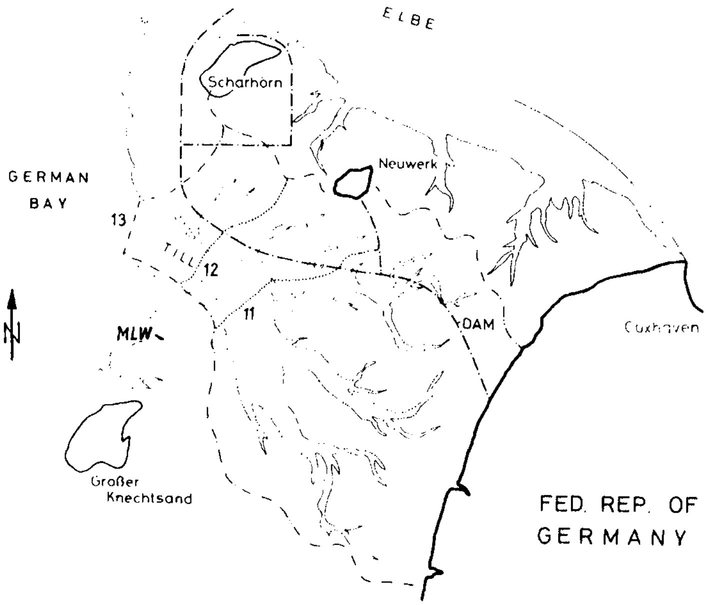


Fig. 7 Simplified sketch of the tidal area Neuwerker Watt (the area of the tidal basin TILL is shown by the dotted line).

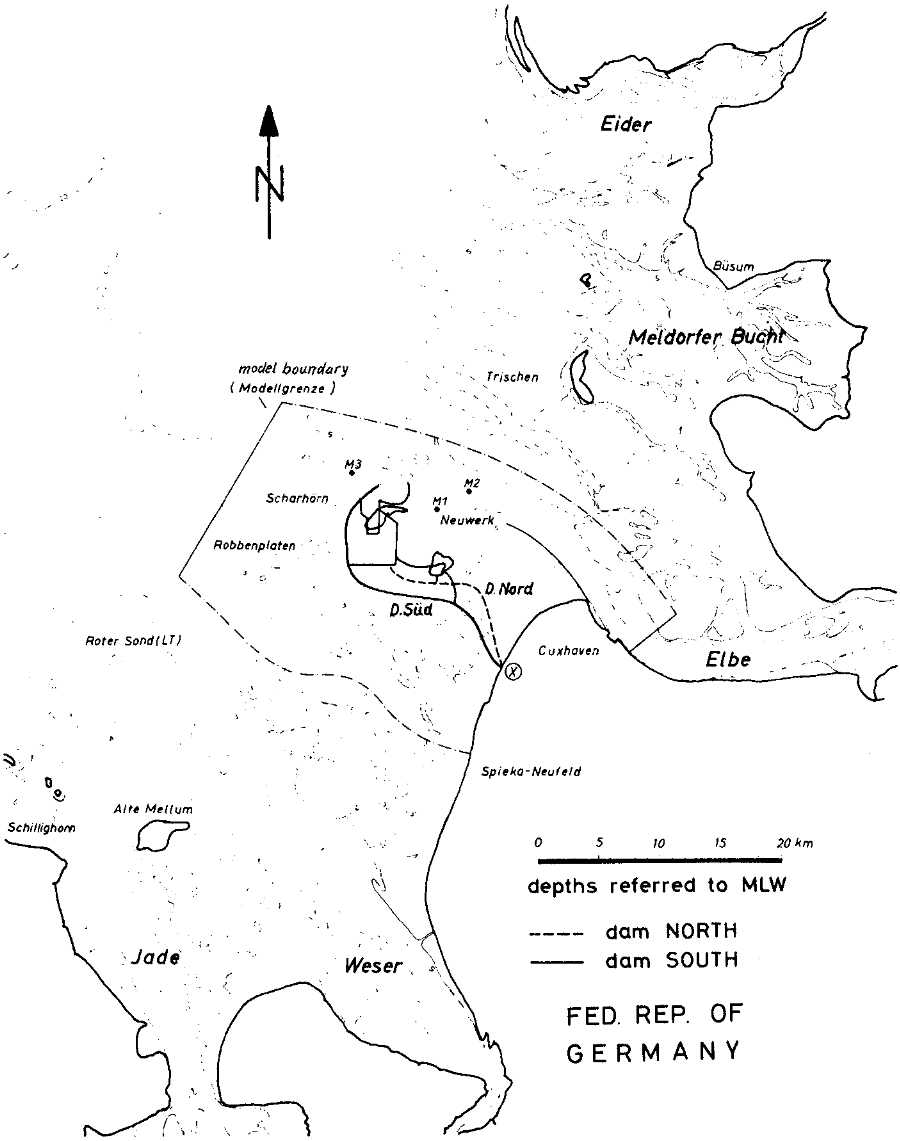


Fig. 5 Tidal basins and tidal channel systems in the German Bay/North Sea. General layout of the deep-water harbor Neuwerk/Scharhörn.

Fig. 6 General layout of the planned deep-water harbor Neuwerk/Scharhörn with different alternatives A,B,C,D for the dams in the southern range of the Elbe estuary and existing morphology of the tidal flats. (Contours referred to MLW).

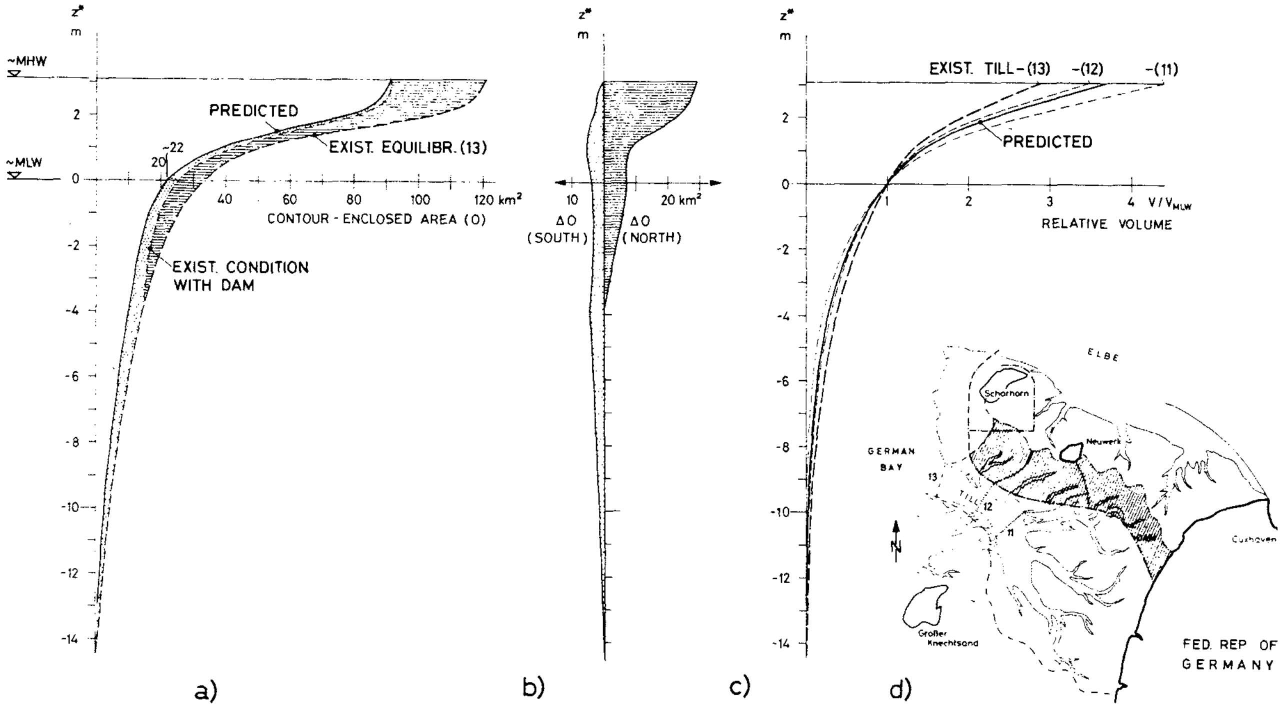


Fig. 8 Results of morphologic calculations for the tidal basin TILL (German Bay/North Sea)