CHAPTER 19

SCALE EFFECTS IN MODELS WITH LITTORAL SAND-DRIFT

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INTRODUCTION

In the "De Voorst" Laboratory of the Hydraulics Laboratory, Delft, a model investigation has been carried out concerning the problems which present themselves around the Thyborøn Channel on the west coast of Denmark. This investigation was commissioned by the Danish Board of Maritime Works, who also supplied the necessary data and information. In this model a scale effect very clearly presented itself with regard to the littoral drift caused by waves, which led to phenomena in the model which deviated considerably from those in the prototype. As this scale effect is likely to occur in some degree in most of the models with littoral drift caused by waves, the publication of the phenomenon observed seems justified.

DESCRIPTION OF PROTOTYPE

The Jutland Peninsula, the mainland of Denmark, is divided into two by the Limfiord, which connects the Cattegat with the North Sea (figure 1). The western approach to the Limfiord is the Thyborøn Channel, which is actually a breach through the barrier separating the Limfiord from the North Sea, which occurred in 1862. In previous years this barrier had repeatedly been burst during heavy storms from the west, but in course of time the channels formed in this way sanded up again.

Ever since the existence of the Thyborøn Channel much sand has been introduced into the Limfiord, where an extensive sandbank area was formed. This sand comes from the parts of the coast on either side of the entrance to the channel, each about 10 km in length. For the period from 1912 to 1943 about 0.77 million cubic metres of sand a year were calculated to be deposited in the Limfiord.

The recession of the coast-line during the first years after the development of the Thyborøn Channel was enormous, especially near the entrance to the channel. The first information about this dates from 1874, that is 12 years after the breach (figure 2). The average recession between 1874 and 1890 of the coast-line of 20 km was about 10 m a year.

In order to reduce coastal erosion, and to protect, for the benefit of navigation, the channel against sanding up many groynes were built along the coast, most of them between 1885 and 1905. The first groynes reached to only small depths, some no further than to about the low-water contour. The construction of the groynes was such that the position of their heads could not be maintained when the coast-line further receded.

2. After the building of the groynes the erosion of the bar and the scouring of the channel was too heavy. This was the result of the alteration of the scale for the littoral drift owing to the groynes. So the transport capacity of the current velocities in the channel and on the bar after the construction of the groynes was too great. This could be corrected in a simple way by reducing the current velocities to such an extent that the scale for the material movement in the channel and on the bar was again equal to that of the littoral drift.

CONCLUSION

The most important conclusion is that in small-scale models in which problems concerning littoral drift are studied, a considerable scale effect may occur in the transport distribution in a line perpendicular to the coast. At the same time it appears that this may result in phenomena in the model which greatly deviate from the prototype.

Now by visual observations the impression is created that in other coastal models in the Hydraulics Laboratory "De Voorst" where sand with d_m = 200 - 250 μ is used as transport material this scale effect occurs to a far lesser degree. From this it might be concluded that in similar models this sand is preferable to ground bakelite, which was used in the Thyborøn model. On the other hand, however, the critical velocity for the initial movement of the sand is higher than for ground bakelite. If an inlet is present, and sand is used, the current velocities in this inlet will often have to be exaggerated in order to obtain sufficient transport. In that case the condition $n_v = n_c = \sqrt{n_h}$ is no longer satisfied, which results in a deviating refraction pattern of the waves, and thus to an incorrect transport of solids. In future a transport material may have to be found which already starts moving at relatively low velocities, and for which the transport distribution by waves in a line perpendicular to the coast corresponds with the situation in nature. For this purpose, however, more data about the transport distribution in the prototype must be available than has been the case so far.

Experience has taught, however, that if the various factors which influence the littoral drift are taken into due account, and if, moreover, sufficient data are known of the changes in the bottom configuration during the past in the prototype, a very workable model can be designed (figure 5). If the model results are handled with caution, which in the majority of investigations is imperative in any case, a coastal model, too, will be an important aid in solving various problems.

that at the point of time mentioned the groynes reached to a depth of 8 cm on an average, so that the waves broke on the landward side of the line connecting the groyne heads. A further increase in the distance between the heads of the groynes and the coast-line only little influenced the littoral drift.

From the figures 3A and 3B a relation can be found between the points of time at which the recession of the coast-lines in prototype and model since 1874 were equal. This relation is shown in figure 4A, in which the years for the prototype on the horizontal axis are plotted against the hours for the model on the vertical axis. The relation over the period from 1874 to 1890 as well as after 1920, appears to be linear. Now the gradient is a measure for the time-scale of the coastal erosion, which is represented in figure 4B. For the period from 1874 to 1890 one year prototype corresponds with 1/2 hour model, after 1920 one year prototype corresponds with 2 hours model.

This change in the time-scale for the coastal erosion is caused by the fact that in the model the transport distribution in a line perpendicular to the coast deviates from that in the prototype. In the model relatively too much material migrates along the coast in the breaker zone. Consequently the groynes in the model exert a much greater influence on the littoral drift than in the prototype. In the prototype the ratio between the recession of the coast-line before 1890 and after 1920 is 4.5 : 1; in the model this ratio is 18 : 1.

The incorrect transport distribution in the model resulted in a number of phenomena which deviated from those in the prototype.

1. Before the groynes had been built the coast near the channel entrance in the model showed a tendency to accretion, in contrast with the prototype where at this place the coast eroded. In this area the wave motion near the coast was relatively slight, as the waves were breaking further seaward on the bar where, at the time, the depths were small. Hence the transport capacity of the waves was here less than at a greater distance from the channel entrance. Now in the prototype the reduced transport by the waves was compensated by higher current velocities near the channel entrance.

   As in the model the littoral drift was far more concentrated in the breaker zone the transport of solids close to the coast by the waves near the channel entrance was far more reduced than in the prototype. The current velocities, which were adjusted in such a way that the depths on the bar and in the channel were correctly represented, now appeared to be only partly capable of compensating the reduced transport capacity of the waves near the coast.

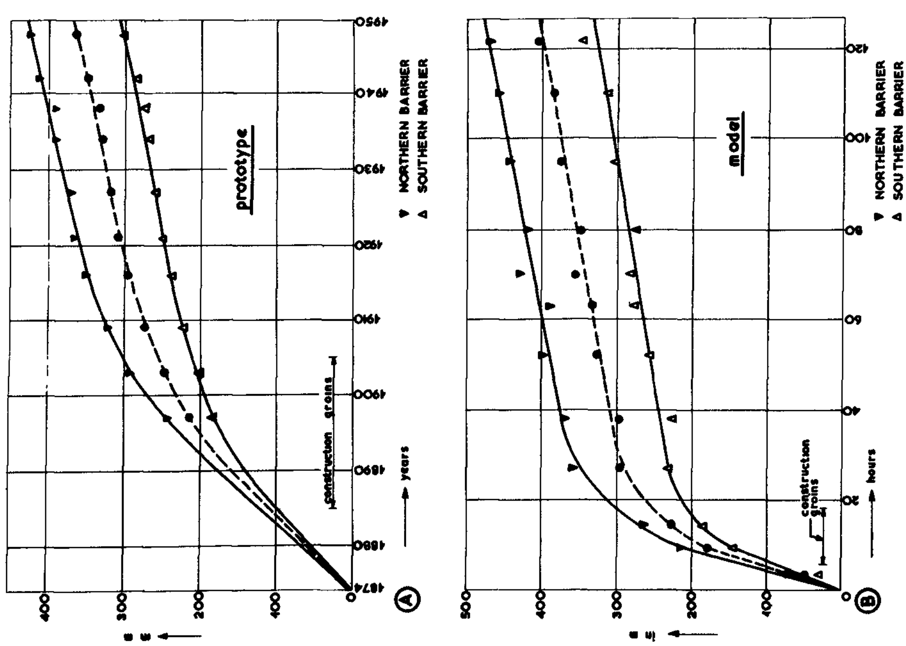

Fig. 3. Recession of the shore line.

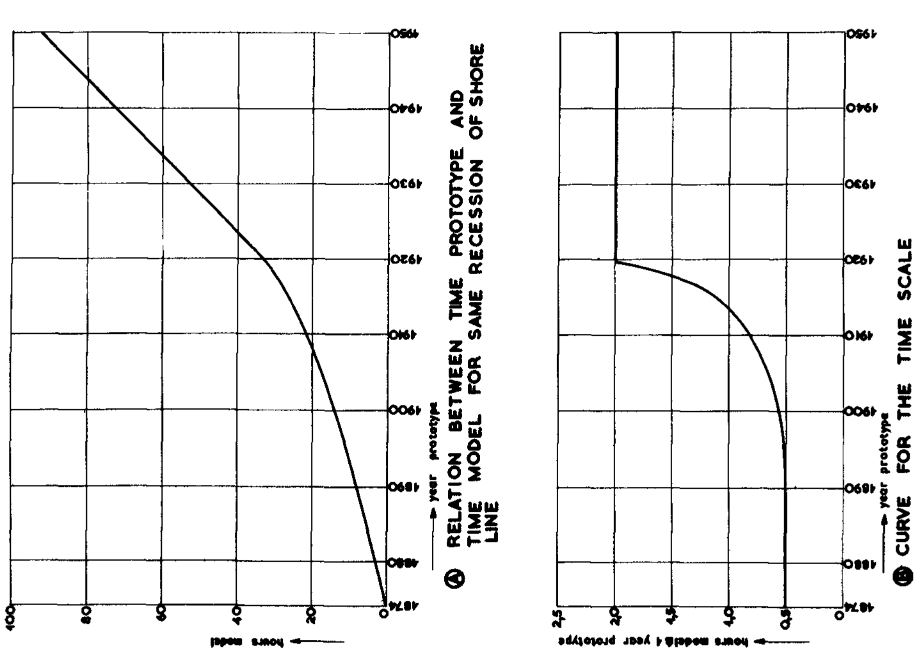

Fig. 4. Time scale for recession shore line.

The boundary conditions to be adjusted with regard to the currents and waves were determined by reproducing the changes of the bottom topography in the prototype since 1874 in the model. For this purpose the wave motion and the littoral current were provisionally determined, so that the coastal erosion was simulated with reasonable accuracy. The current velocities and the tidal periods in the channel were adapted to this, the depths on the bar and in the channel corresponding with those in the prototype. Owing to the refraction of the waves caused by the tidal currents which occurred on the bar, the current velocities had to fulfil certain requirements. In order to obtain a correct representation of the refraction of the waves resulting from the sloping-up of the bottom the condition $n_c = \sqrt{n_h}$ must be applicable, and for a correct representation of the wave refraction caused by the currents $n_v = n_c$. Hence $n_v = \sqrt{n_h}$. In the model the wave period was T = 1.3 sec and the wave height H = 5 cm, which compared with prototype T = 8 sec, and H = 2 m.

For the judgment of the model results the following magnitudes for prototype and model have in the first place been compared:

a. The recession of the coast-line;
b. The erosion of the bar;
c. The scouring of the channel.

The recession of the coast-line since 1874 in prototype, both north and south of the channel has been represented in figure 3A. Between 1874 and 1890 the recession averaged 10 m a year. Owing to the presence of the groynes the annual recession between 1890 and 1920 became less. After 1920 the recession has been practically oonstant at 2.2 m a year. The reasons for this are the following:

a. Since 1920 the groynes reach, for most of the waves, beyond the breaker zone, and thus the greater part of the littoral drift has been checked. On the seaward side of the breaker zone the transport of solids per unit of width is little, and a further extension of the distance between the groyne heads and the coast-line has, after 1920, not much influence on the coastal erosion.
b. Moreover, the groynes in the prototype show some abrasion, so that the annual increase in the distance between the heads and the beach-line is even less than 2.2 m a year.

In the model a similar phenomenon was observable as in the prototype. After the building of the groynes, here, too, the coastal erosion became less, but much more so than in the prototype (figure 3B). It may be observed here that in the model the groynes were built at those points of time at which the position of the coast-line corresponded with that in the prototype. Most of them were built from 5,5 to 18 hours after the initial point of time. After operation of the model for 33 hours the position of the coast-line corresponded with that in the prototype in the year 1920. It is noteworthy that since that time the recession of the coast in the model had also a constant value. It appears

Hence the effect of the groynes on the coastal erosion was slight. By applying a heavier construction and by carrying out much maintenance work, the position of the groyne heads over the last dozens of years has been ensured with reasonable success. The recession of the coast-line has thus been reduced considerably and since 1920 it averages 2.2 m a year.

By the building of the groynes the sand transport to the channel entrance was greatly diminished. This resulted in serious erosion of the bar before the entrance to the channel and in scouring of the channel.

LAY-OUT OF THE MODEL

The model represents the Thyborøn Channel, a small part of the Limfiord and the stretches of coast on either side of the entrance to the channel, each 10 km in length. The horizontal scale of the model $n_L = 250$, the vertical scale $n_h = 40$. The distortion of the model has been chosen in such a way that the slopes of the coast in the model correspond with those in the prototype. Ground bakelite with $d_m = 1.8$ mm and a density $\rho = 1350$ kg/m^3 was decided upon as transport material. The model is further fitted with a wave generator with a total length of 80 m. At sea in the model a north-going and a south-going current can be adjusted, combined with both an incoming and an outgoing current in the channel.

MODEL INVESTIGATION

Before the investigation on the measures proposed to improve the situation could be started, the transport of solids in the model had to be verified with that in the model. A further item of importance was the determination of the time-scale for the transport of solids.

According to the nature of the transport of solids three areas can be distinguished:

a. the coast, where the transport of solids is caused by the motion of the waves and the weak littoral current.
b. the bar and the channel entrance, where the waves and the strong tidal currents cause the transport of solids.
c. the channel, where the transport of solids is caused almost exclusively by the tidal currents.

There is a close connection between the phenomena which occur in these three areas. The rate of the coastal erosion for example, and consequently the movement of material to the channel entrance will influence the depths over the bar and in the channel. From this it follows directly that the currents and the waves in the model must be selected in such a way that the scale ratios for the transport of solids in the three areas mentioned must be equal so that there is one time-scale for the events.

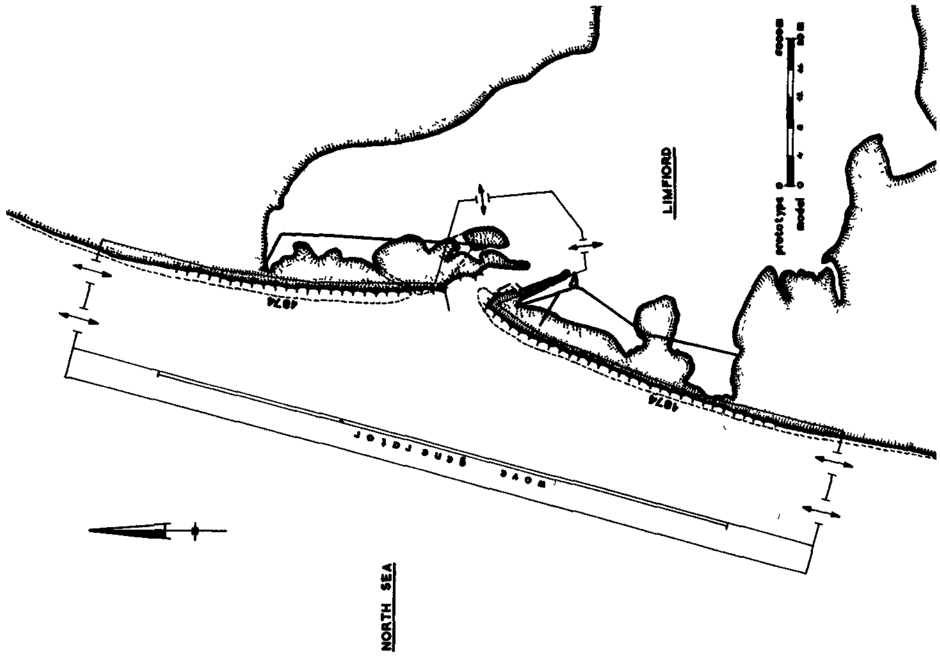

Fig. 2. Thyborøn channel.

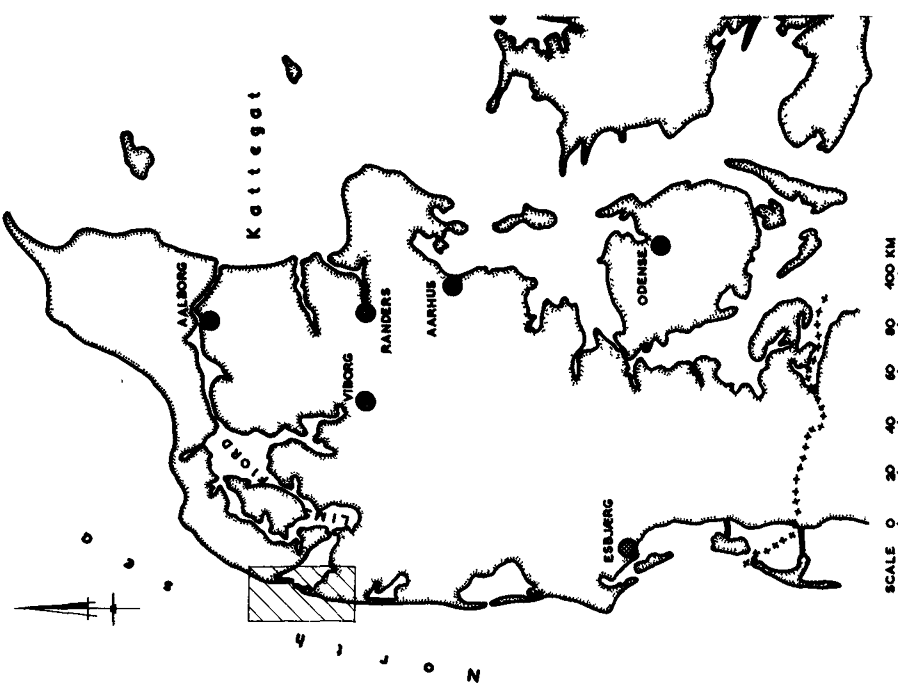

Fig. 1. Denmark.

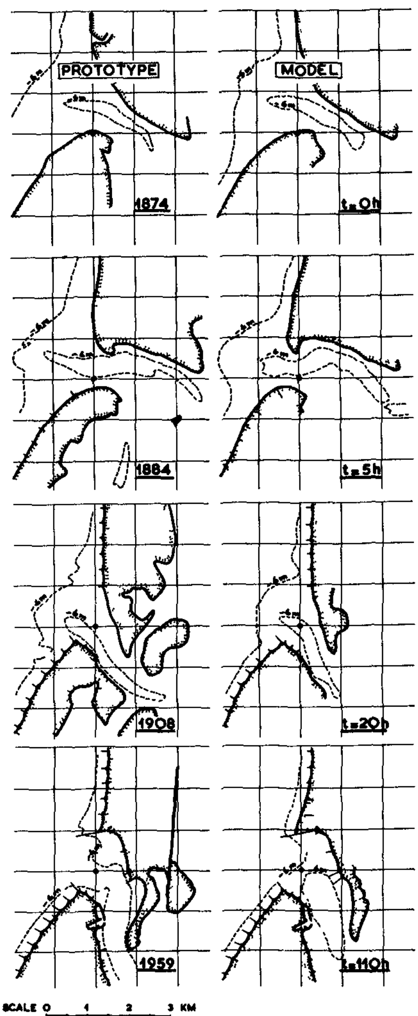

Fig. 5. Development Thyborøn channel.

ACKNOWLEDGMENTS

The author wishes to express his tanks to Mr A. Lehnfelt, Director of the Danish Board of Maritime Works for his permission to publish the above model results.

He also likes to express his most grateful thanks to Mr K. Otterstrøm, Civil Engineer of the Danish Board of Maritime Works for the valuable information which he has given concerning the development of the situation in the prototype. Without his help it would have been impossible to conduct this investigation satisfactorily.

He is further grateful for the assistance which he received from Mr E.W. Bijker, Head of the "De Voorst" Laboratory during the model investigation and the composition of this paper.