

CHAPTER 46

SAND TRANSPORT DURING CLOSURE OF TIDAL CHANNELS

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Abstract

A method is presented for estimating the dredger capacity required for closing tidal gaps with sand as the only building material.

The method is based essentially on a relation between parameters describing the flow of the water and the resulting sand transport.

Empirically determined coefficients are used to approximate the effects of the non-stationary flow in the gap and the supply of suspended material at the dumping site.

The experiences gained at a number of closure operations are discussed and compared with the computations.

Introduction

The choice of the construction to be applied during the last phase of a closure operation of dams in tidal waters depends largely on the current velocities occurring in the remaining gap.

The material to be used should have either sufficient weight to resist erosion or be supplied in such large quantities so that the main portion is not carried away by the currents. In the latter case sand or gravel are possible materials.

If currents velocities in the closing gap reach high values (order 3 m/sec or more) large scale methods are necessary (caissons, concrete blocks, etc.). Due to the high velocities costly bottom protection works are required.

If the currents are of moderate magnitude (order 2.5 m/sec or less) local sand may be used. A part of this material will be

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lost in the closing operation. However, the costs of the expensive bottom protection are saved. Therefore, the losses of sand may well be accepted in the overall economics of the works.

Recently a number of tidal channels both in The Netherlands and in Germany were closed successfully by pumping sand into the gap. This was mainly possible because of the increased capacity of the modern suction dredgers.

This paper describes a method with which the required capacity of the dredgers can be estimated for a given closure operation. The method can be used to determine the most economical scheme of an operation. The effect of a temporary decrease or interruption of the sand supply can also be evaluated.

Method of calculation

The method is essentially based on the computation of the suspended sediment load. The suspension transport is considered only because relatively fine sands (diameter 0.120 to 0.250 mm) were used in the closure operations realised until now. Then the bed load may be neglected compared with the suspension load. When coarser sands are used, however, the bed load should also be considered.

The suspended sediment load can be calculated using the relations presented by LANE AND KALINSKE, further elaborated by MORRA and summarized by DRONKERS (1970).

The equations describing the suspended sediment load apply to steady flow in a condition of equilibrium between erosion and sedimentation.

The first condition is not satisfied in a tidal area. MORRA, however, proved that acceptable results can be obtained if the current velocity curve during the tide is schematized by a number of time intervals with constant current velocities.

The second condition, equilibrium of erosion and sedimentation is also not satisfied, because of the acceleration and deceleration of the water flow in the area of the closure gap.

The closure gap may be divided into two areas: the sloping

head of the sandfill where the sand is supplied and the area outside this head which is only affected by the accelerated water flow. In both areas there is an increase in sand transport capacity (q_{cap}) which is the quantity of transported sand under equilibrium conditions, calculated with the above mentioned formulae.

The increase in sand transport capacity (q_{cap}) along the streamlines of the gap will result in a certain amount of erosion. However, a certain distance is necessary for the erosion of an additional amount of sand from the bed to distribute it over the vertical and so create a new equilibrium. Usually this distance is larger than the zone of accelerated flow.

Therefore the transport of eroded sediment (q_{LE}) in the closure gap outside the head of the fill is smaller than the sand transport capacity q_{cap} .

The proportionality factor (A) between q_{LE} and q_{cap} may be estimated afterwards from the comparison of the observed quantities of erosion and calculated q_{cap} in closure gaps. This factor cannot be determined precisely enough. The amount of erosion which cannot be computed very accurately from soundings is related to the period between the soundings. In practice, however, the current measurements are limited to one tidal cycle only within such a period. It is doubtful whether the results of these measurements are representative for the whole period, because the closure operations proceed further.

It was found that the factor A varies between 0.05 and 0.6 while its mean value is about 0.1. In the computations realised until now the factor A was estimated to be 0.25.

At the head of the fill in front of the discharge pipes all sand is supplied in suspension flowing down along the submerged slope of the head. The quantity of sand in the water far exceeds the sand transport capacity (q_{cap}) in this area. Some time is required for the settling of this sand. As a result a certain part of it is transported by the currents and settles outside the base of the closure dam.

The loss of sand in this part of the gap (q_{LD}) was assumed

to be $q_{LD} = B \cdot q_{cap}$, with $B = 2$ for sand with a mean diameter of 0.120 to 0.250 mm. The total loss of sand per unit of time is $q_{LD} + q_{LE}$, both being computed from q_{cap} using above mentioned factors A and B.

The variables necessary for the calculation of q_{cap} (see Dronkers, op.cit.) are the average current velocity over the vertical, the waterdepth, the Chézy coefficient, the mean diameter of both the sand that will be supplied and that of the bed material in the gap.

The current velocities during the successive phases of the closure operation can be derived from model tests or from tidal computations.

The Chézy coefficient is determined from prototype measurements; q_{cap} is expressed by $m^3/m'/unit\ of\ time$.

In order to calculate q_{cap} over the entire longitudinal section of the gap during one tide the following procedure may be applied.

The longitudinal section of the gap should be schematized into parts. In each of these parts, both the depth and the current conditions are supposed to be constant within a time interval Δt (figure 1).

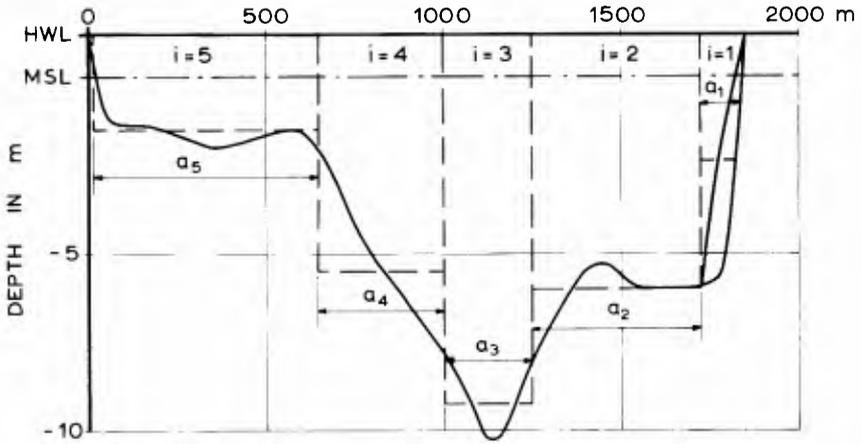
When a_i is the length of part i in meters, then the sand transport capacity per unit of time in part i is: $a_i \cdot q_{cap\ i}$, varying during the tidal cycle.

The time intervals are usually chosen either $\frac{1}{2}$ or 1 hour. (There is a diurnal tide along the Dutch coast).

The total sand transport capacity q_i for part i over the total tidal cycle is computed by summation.

The sand loss per tide over the longitudinal section (q_{LT}) can now be evaluated taking into account that the sand loss over the dumping site is $2 q_i$ and in the rest of the section $0,25 q_i$.

The same procedure should be repeated for the successive stages of narrowing the closure gap.



LONGITUDINAL SECTION OF A CLOSURE GAP
Fig. 1



Fig. 2

Experiences

With the procedure outlined above an optimization of the closure operations can be set up. If the time of the entire closure operation has been fixed the necessary dredger capacity can be estimated.

On the other hand if the dredger capacity has been fixed the time of the closure operation can be determined.

The method was applied to the closure of the following tidal channels in The Netherlands (figure 2), Brielse Gat (1966), Zuidwal, Lauwerszee (1968), Noord Pampus, Haringvliet (1968), Springersdiep, Brouwershavense Gat (1969) and Geul, Oosterschelde (1972, in execution), figure 3. Some data of these channels are presented in table 1.

The following experiences were obtained. Obviously the actual closure of the channels was realised with a minimum width of the primary dam in order to finish the enclosure in a short time and to reduce the loss of sand. In practice a crest width is determined by the number of discharge pipelines and was chosen at 50 to 100 m. The height of these dams is determined by accepted risks for destruction of the pipelines and was chosen between 2 and 3 m above M.S.L.

The final dam of larger dimensions was realised after the closure operation of the primary dam. It appears that a large part of the quantity of sand transported from the closure gap settles within the cross-section of the final dam. The computed loss of sand during the closure operation should consequently not be considered to be the loss in the overall work. It determines the duration of the operation and is the base for the choice of the total capacity of the dredgers.

The total economy of a project, however, is determined by the losses of sand outside the base of the final dam.

In order to evaluate the accuracy of the computations, observed losses were compared with both the predicted and the calculated losses.

The observed sand loss is the difference between the dredger production and the sedimentation within the designed cross-

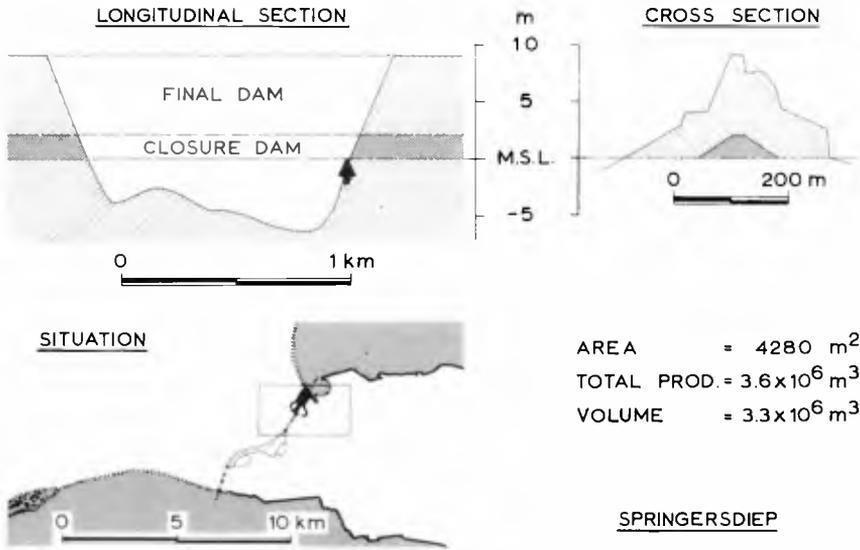


Fig 3^a EXAMPLE OF MODERATE DEEP CLOSURE GAP

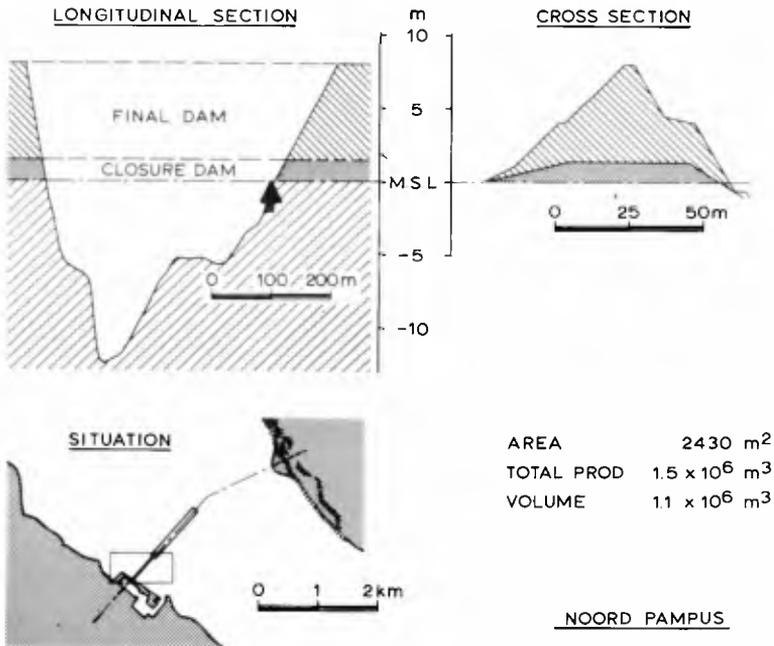


Fig 3^b EXAMPLE OF DEEP CLOSURE GAP

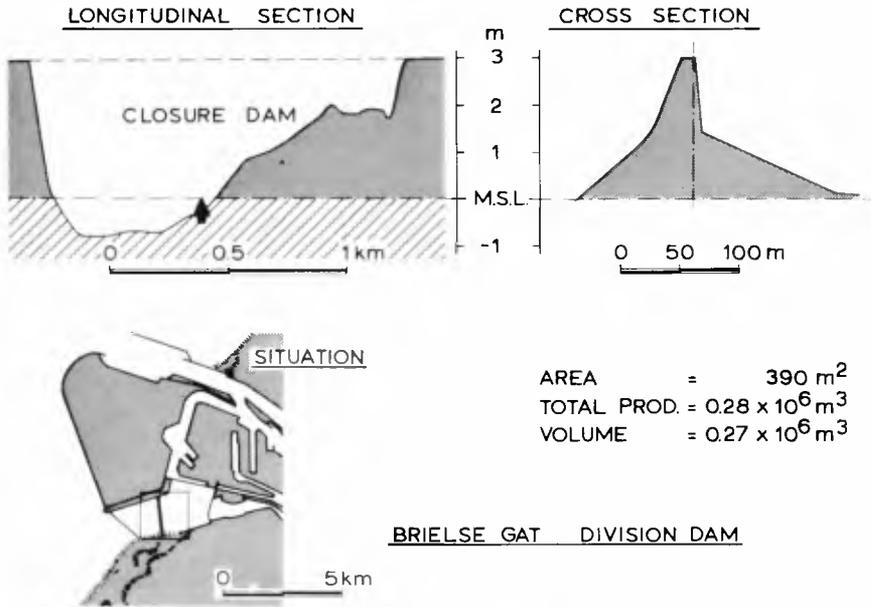


Fig. 3^c EXAMPLE OF SHALLOW CLOSURE GAP

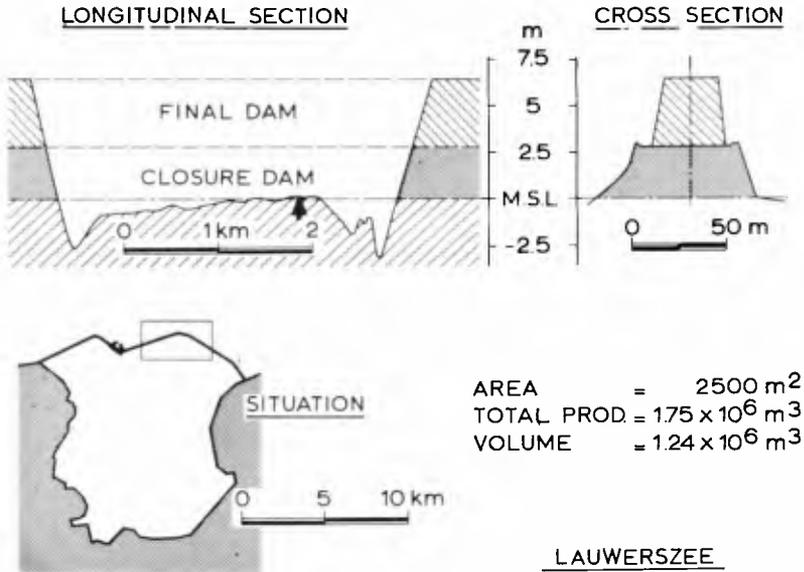


Fig. 3^d EXAMPLE OF SHALLOW CLOSURE GAP

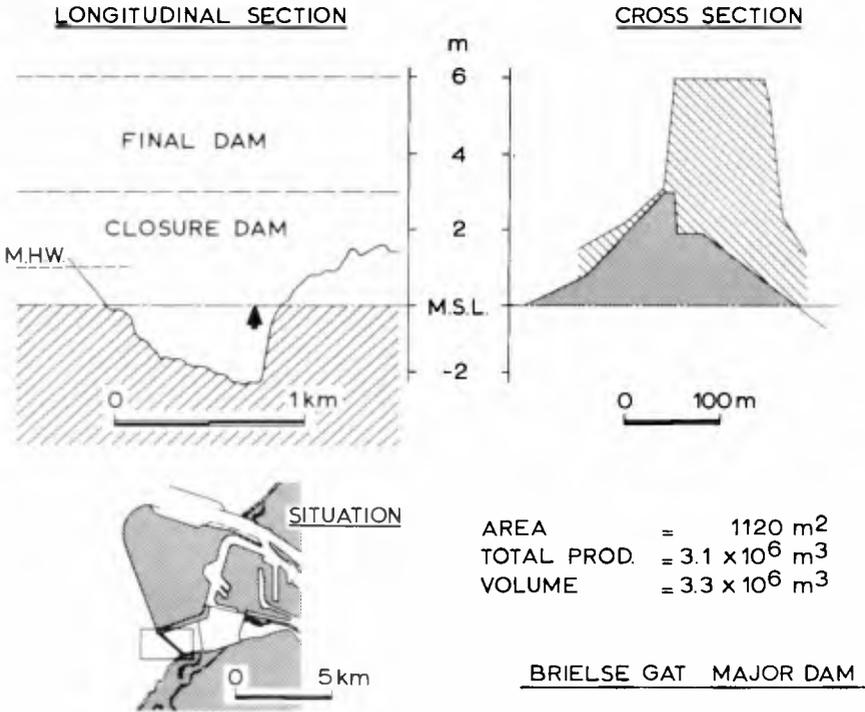


Fig. 3^e EXAMPLE OF SHALLOW CLOSURE GAP

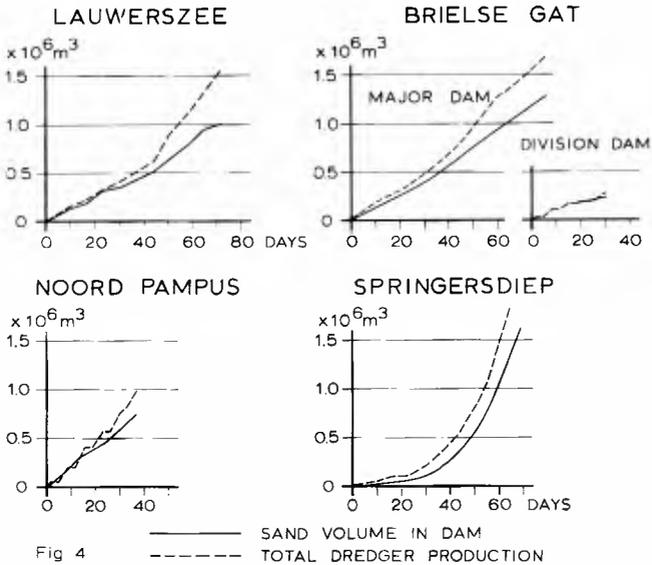


Fig 4

	Lauwerszee Zuidwal	Brielse Gat Division Dam	Brielse Gat Major Dam	Noord Pampus	Springers- diep
Mean tidal range	m	2.2	2.2	1.85	2.60
Length of closure gap	m	3351	1820	400	1000
Area of closure gap	m ²	4280	390	2450	4280
Volume of closure dam	10 ⁶ m ³	1.04	0.22	0.75	1.62
Volume of final dam	10 ⁶ m ³	1.24	0.23	1.10	3.54
Total production of dredgers during closure	10 ⁶ m ³	1.56	0.27	0.97	1.87
Total production of dredgers in overall work	10 ⁶ m ³	1.75	0.28	1.50	3.60
Total observed loss of sand during closure	10 ⁶ m ³	0.52	0.06	0.22	0.25
Total observed loss of sand in overall work	10 ⁶ m ³	0.51	0.05	0.40	0.26
Time of closure operations	days	70	36	63	66
Maximum number of dredgers		3	1	2	3
Maximum production per tide	10 ³ m ³	16	10,5	20	25
Maximum predicted loss of sand per tide	10 ³ m ³	1.48	6	12	7.8
Number of sides of sand fill		2	1	2	1
Mean grain size of supplied sand	microns	130	-	-	200

Table 1. Data of closure gaps and dredging operations

section of the final dam. It may be noted that the actual side slopes of the sand dam may deviate from the designed ones. If there is any wave action, almost an equilibrium beach profile is developing during the operation. The material eventually deposited outside the design cross-section contributes to this equilibrium profile and therefore should not be considered as lost to the volume of the dam. Moreover, the dredger production is measured as volume of spoil, consisting of sand and mud. The mud, however, is hardly found in the sand dam. So a part of the observed sand loss consists of the mud suspended in the spoil.

The predicted sand loss is that which has been calculated before the works started. The data are estimates, derived from tidal computations or model experiments. These data may deviate from the actual ones, operating during the closure procedure. Furthermore the outline of the closure procedure may deviate from the planning and the data introduced in the calculation of the predicted sand loss are no longer reliable. Moreover, variations in weather conditions cannot be included in the computation.

Therefore, the calculated sand loss was introduced. This is the sand loss computed from data derived from actual measurements made during the closure operation (hindcast).

The discrepancies between calculated and observed sand losses are then mainly due to the inaccuracy of the method or that of the current measurements.

From some closure operations there were enough acceptable data to compare the predicted, the calculated and the observed sand losses. Table 2 gives the results. In figure 4 the dredger production and losses are illustrated.

It may be concluded that in most cases the calculated and observed sand losses are of the same order of magnitude. The predicted sand losses deviate in most cases considerably from the observed losses. This indicates that much care should be given to the data on which the prediction is based.

From table 1 it can be learned that successful operations were executed when the maximum dredger production per tide was at least four times the predicted maximum losses of sand per tide.

	Lauwerszee	Brielse Gat Division Dam	Brielse Gat Major Dam	Noord Pampus	Springers- diep
Total dredger productions (D) (10^6 m^3)	1.56	0.27	1.72	0.97	1.87
Observed losses of sand (O) (10^6 m^3)	0.52	0.06	0.53	0.22	0.25
Predicted losses of sand (P) (10^6 m^3)	0.90	*	*	0.20	0.70
Calculated losses of sand during closure operation (C) (10^6 m^3)	0.45	0.10		0.06	0.35
Percentage O ÷ D	33	22	31	25	15
Percentage P ÷ D	60			20	42
Percentage C ÷ D	29	37		6	21
$\frac{P - O}{P}$	0.43			- 0.20	0.64

* Execution of closure operation deviated very much from planning; predicted losses of sand unreliable

Table 2. Dredger productions and losses of sand

Some illustrations of the optimalization of the closure operations can be presented here.

It appeared that in most cases an increase in dredger capacity results in a reduction of the sand losses during closing. This is indicated in table 3.

Assumed dredger productions m^3/week	Time of closure operation weeks	Calculated loss of sand 10^6 m^3
230,000	5	0.50
300,000	$3\frac{1}{2}$	0.35
350,000	$2\frac{1}{2}$	0.25

Table 3. Calculated loss of sand. Dam through Springersdiep for several dredger productions.

Furthermore the computations may show at which stages of the closing the largest sand losses are to be expected (figure 5). It may be wise to reach this stage during neap tide conditions.

This determines the beginning time of the operation. The difference in sand loss during spring and neap tide is illustrated in figure 6 for the closure of a gap from one side. It can be seen that during the ten weeks closure operation the actual losses vary with the tidal range.

Also the computations may indicate the most feasible way of operations viz. closing from one side to the other, or the reverse or from both sides together. There can be a great difference in current pattern and velocities in the closing gap for different ways of operations.

Table 4 shows for example that in the North Pampus channel the calculated sand losses are much higher when proceeding the dam from N to S than from S to N.

	Loss of sand in 10^6 m^3
Operation from S to N	0.10
Operation from N to S	0.19

Table 4. Calculated loss of sand, Dam through Noord Pampus.

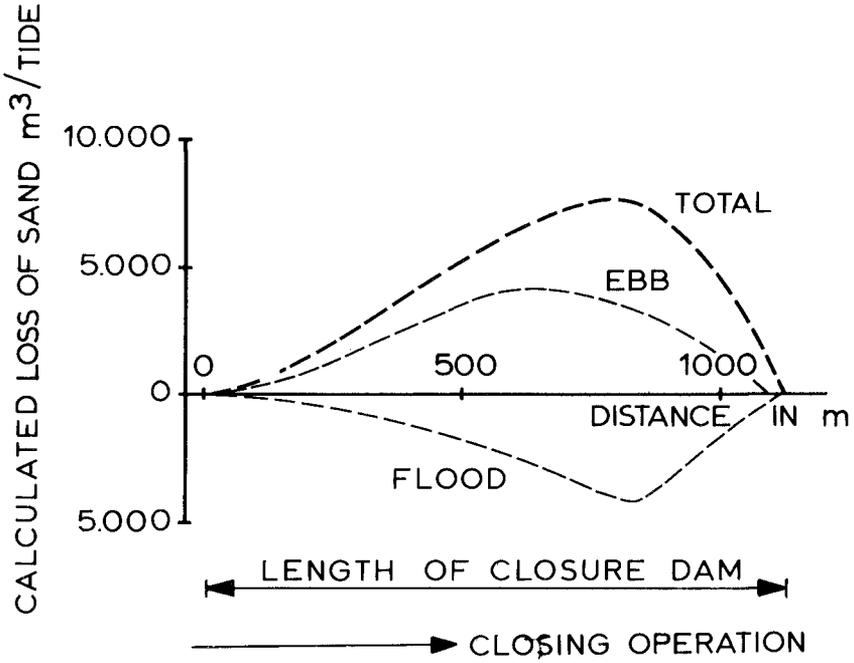


Fig. 5

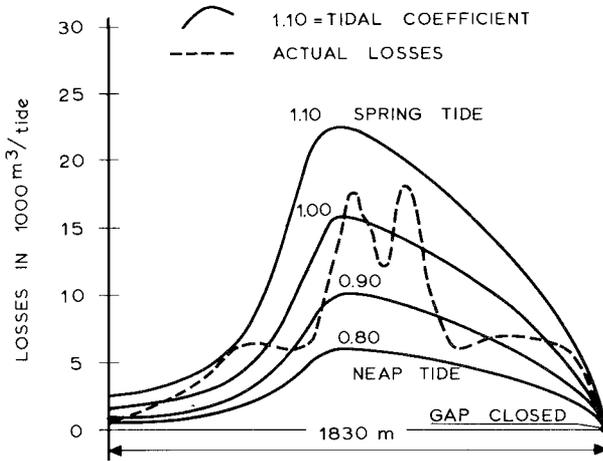


Fig. 6 CALCULATED LOSSES DURING THE CLOSURE OF A GAP

The representative grain size, which may be introduced into the computations may be established as follows. From samples of borings of the winning pit the variation of grain size with depth can be found (figure 7) and schematized. The schematized data of several borings can be put together in order to obtain an overall indication of the variation of the grain sizes with depth. Then an overall grain size distribution of all the material can be determined.

For each grain size fraction the sand transport capacity per unit of time can be calculated taking into account the percentage material present in that particular fraction. The cumulative distribution of the transport capacities of all fractions gives the total sand transport for that grain size distribution ($q_{\text{cap } f}$) (figure 8).

Furthermore the sand transport capacity can also be calculated for each fraction assuming a uniform grain diameter $q_{\text{cap } u}$. (So in every fraction there is 100% of material). The representative diameter is that one for which $q_{\text{cap } u} = q_{\text{cap } f}$ (figure 8).

Finally it was observed that the submerged slopes of the dumping site were 1 : 15 to 1 : 20 for grain sizes of .15 to .20 mm, whereas the emerged slopes were about 1 : 30.

From experience and calculations it appeared that usually the most favourable location of the final gap of the sand dam is a shallow part of the cross-section. This is due to the fact that the current velocities in the final gap situated in a shallow area are lower compared with those in a deep final gap. Moreover, the length of the sloping fill head is less and consequently also the losses of sand.

Furthermore the sand volume needed for the final stage of the closure operation is lower. Altogether, shorter time is needed with the final stage in a shallow area. Then both the amount of erosion in the gap and the losses out of the base of the dam are reduced while the current velocities reach their maximum values.

Success of the operation also depends on the working method, the layout of the pipelines, the sand-water ratio of the spoil

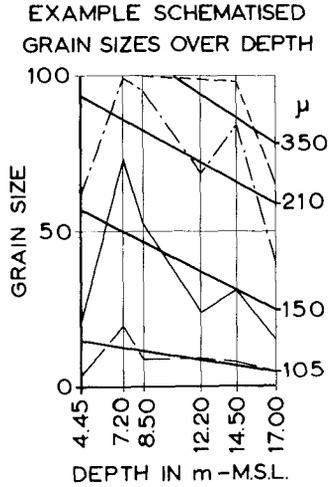


Fig. 7

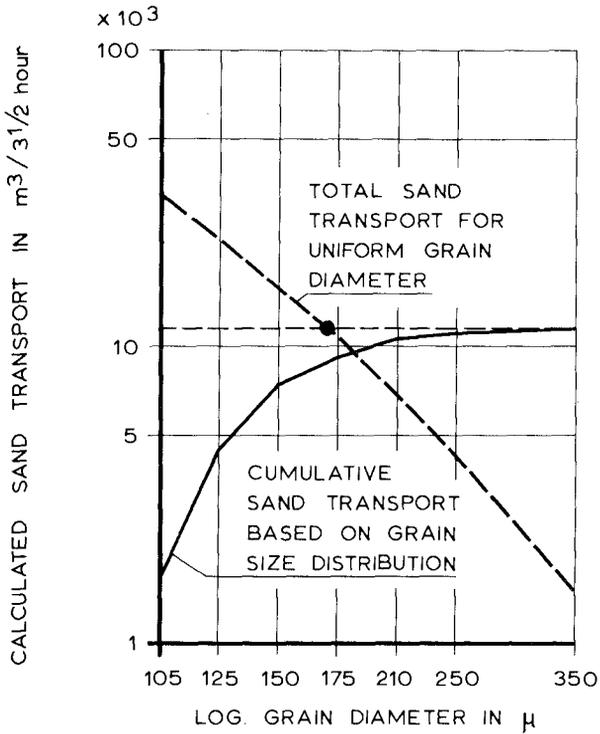


Fig. 8

and the working time of the dredgers.

In the final gap, bulldozers and draglines should operate on the fill to control the sand deposition above the water level (see photo 1).

A special problem is to control the supplied water eroding channels while running down the fill, especially when dredgers with large discharge capacities are used. Normally these channels are rapidly filled when the tide is rising.

The method of computation presented above can be of great help to determine the feasibility of the closing of a tidal channel by means of a sand dam. Further it gives reliable data on the optimum dredger capacity and the time involved in the closure operation. Finally it can contribute to the choice of the best operational scheme.

Reference:

- Dronkers, J.J., 1970. Research for the coastal area of the Delta region of the Netherlands.
XIIth Conf. on Coastal Engineering, Washington D.C.



Photo 1. Final gap. Bulldozers and draglines operating on the fill