CHAPTER ONE HUNDRED TWENTY TWO

Shore Approach at the Danish North Sea Coast, Monitoring of Sedimentation in a Dredged Trench

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1. Introduction

The Danish Natural Gas and Oil Transmission system included the landing of a 30' Gas pipeline and a 20' Oil pipeline in a common shore approach at the Danish North Sea Coast. The location of the site is shown in Figure 1.1.

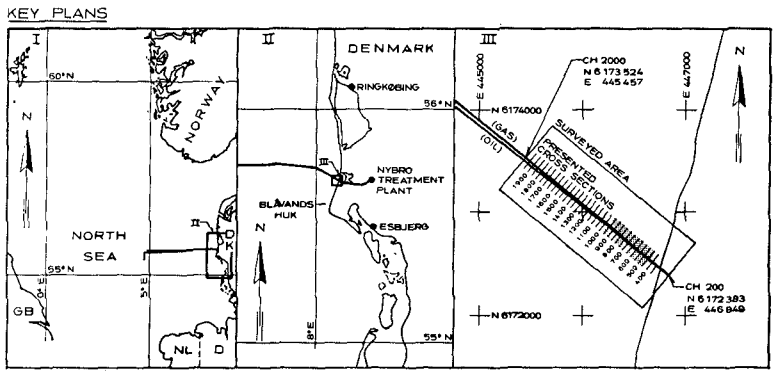

Figure 1.1 Key plans of the North Sea Shore Approach Site.

The two pipes were pulled ashore in a common pre-dredged trench into a sheet piled cofferdam across the beach. The trench was 1600 m long and had a volume of about 600,000 m^3. The dredging and the backfilling were monitored closely together with wind, wave, and current conditions over the four months dredging and installation period. After termination of the pulls and backlaying the trench was left for natural backfilling. The backfilling was monitored for one year together with the environmental conditions.

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The monitoring during the construction period was performed by the contractor Saipem/Volker Stevin and by the client, Danish Oil and Natural Gas Company, (D.O.N.G. A/S) with assistance from the Danish Coast Authority (KI). The monitoring activities, which continued after the final check of the backfilling within the construction contract, were initiated by DHI and partly financed by the Danish Council for Industrial and Scientific Research (STVF). The monitoring was performed in co-operation between D.O.N.G. A/S, KI and DHI.

All data from the monitoring program are presented in the report:

North Sea Shore Approach
Monitoring of Sedimentation in a Dredged Trench
August 1984
Prepared by DHI for STVF.

2. General Description of the Site

2.1 Site Conditions

The sandy coastal area at the shore approach site appears as follows: Backland with heather covered dunes, foredunes being parly covered with beach grass, a 150 m wide sand beach and a 1200 m wide breaker zone with three bars.

This appearance together with geological and historical evidence shows that the beach at the landfall site has accreted and is now largely in dynamic equilibrium with long term rates of supply and loss and sediments being equal.

During severe storms the coast profile will be smoothed resulting in beach erosion and seawards movements of the bars. After the storm the coast profile will normally restore again after some time.

The project exploited ten years of yearly coast profiling every kilometre performed by the Danish Coast Authority. Combining 10 x 10 profiles located symmetrically around the pipeline using the foot of the dunes as the common reference point, the low envelope was established. As the profiles represent calm weather conditions a storm erosion of 1,2 m and the required wall time cover of 1,0 m was added to the low envelope in order to obtain the top of pipe profile, see Figure 2.1.

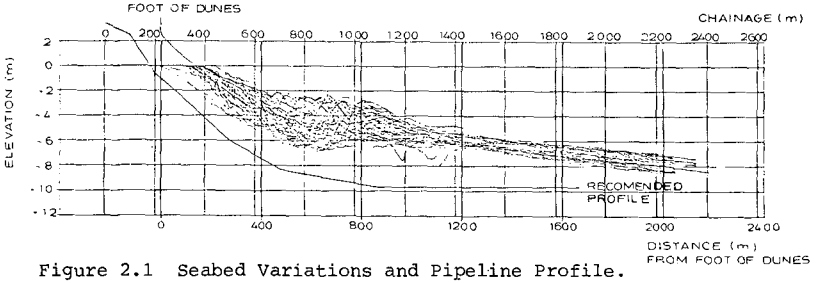

Figure 2.1 Seabed Variations and Pipeline Profile.

The required minimum distance between the gas pipe and the oil pipe was 5 m out to chainage 800, whereafter the minimum distance increased 1 m per 100 being 17 m at chainage 2000 at the end of the trench. The gas pipeline is located towards north with a straight alignment in the direction 310°. The normal to the coast is 285°, thus the trench formed an angle of 65° with the coast.

2.2 Environmental Conditions

The Shore Approach site is fully exposed to the North Sea environment. Because of the extremely high longshore sediment transport in the area the Shore Approach was considered one of the major challenges of the entire Danish Natural Gas and Oil Transmission system.

The gross longshore sediment transport in the area has been evaluated at approximately 1.5 mio. m^3 per year, with an average during the spring and summer months of approx. 100,000 m^3 per month. The net longshore transport is southgoing. Variations with factors of 2-3 should not be considered as unnormal. During the worst day a transport exceeding 100,000 m^3 may be expected.

On basis of the environmental conditions the construction period for the sea bound Shore Approach works were selected to March through June.

3. Collected Data

The collected data consists of bathymetric surveys, bottom samples, wind, wave and water level data. A summary of the data collection programme is presented in Table 3.1.

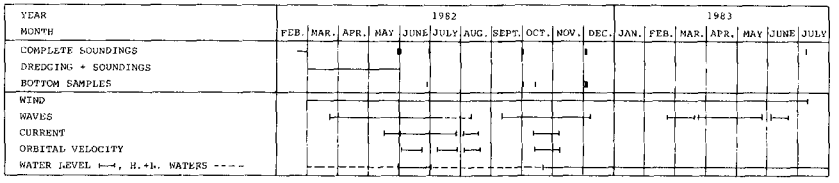

Table 3.1 Summary of the data collection programme.

3.1 Soundings

All soundings were performed by echo sounder combined with various types of electronic positioning systems.

The complete sounding campaigns of the dredged area have consisted of three longitudinal profiles, one in the gas pipe centre line and one on each side spaced 2-300 m. Moreover cross-sections perpendicular to the gas pipe alignment with a distance of 25 to 50 m and a length of 3-400 m on each side of the centre line were performed.

Beyond above-mentioned complete sounding campaigns the Contractor performed soundings currently during the dredging period March through June 2, 1982.

On basis of the described sounding campaigns, sounding plans have been prepared at a scale of 1:1000. On the basis of the sounding plans cross-sections for every 50 m have been prepared. These cross-sections have formed the basis for the calculations of the sedimentation, which is described in Section 4.

3.2 Bottom Samples

Bottom samples have been collected before the dredging of the trench. After the dredging of the trench samples have been collected in and off the trench in connection with some of the mentioned surveys, see the summary in Table 3.1. All bottom samples were collected by a grap sampler which penetrates 10-15 cm into the bottom.

The sea bed soils consist of alternating layers of fine and medium to coarse sand covering sandy gravel.

Fine sand: Mean Grain Size : d_{50} = 0.14-0.21 mm
Uniformity Ratio : d_{60}/d_{10} = 1.27-1.47

Medium to coarse sand: Mean Grain Size : d_{50} = 0.28-0,80 mm
Uniformity Ratio : d_{60}/d_{10} = 2.17-2.78

The samples taken in the trench are of two different categories:

Category 1 : Dark greyish green MUD with varying contents of fine sand and silt and shell fragments.
Mean Grain Size : d_{50} = 0.02 to 0.1 mm
Organic Content : 3 - 14%.

Category 2 : SAND, fine to medium, grey, varying small contents of mud.
Mean Grain Size : d_{50} = 0.14-0.23 mm

Category 1 is found at the bottom of the trench in areas where practically no backfilling has taken place. Category 2 is found at the bottom and to the sides in areas which have experienced considerable backfilling. It is assumed that the trench finally was filled completely with Category 2 varying with thin layers of Category 1.

3.3 Wind measurements

Wind measurements from the nearby Blåvandshuk Light House have been collected for the total monitoring period.

3.4 Wave Measurements

Waves were measured from March 13, 1982 to June 20, 1983 at 12 m water depth about 2 km north of the Shore Approach site. The measurements were performed by a Datawell Waverider buoy. In periods where wave records are missing, see Table 3.1, the wave heights have been estimated from the wind data using correlations between H_s and the wind speed for various direction intervals. The correlations were established from the periods with simultaneous recordings of waves and wind.

The wind direction was used as offshore wave direction. Refraction calculations was performed using the DHI wave refraction model - SPECFRAC - in order to obtain wave conditions at breaking, $H_{s,b}$, θ_b. The breaking criteria $H_{s,b} = 0.8\ h_b$ was used, where h_b is the water depth at the breaking point.

The distribution of the breaking waves in the six periods in which backfilling has been measured, ref. Section 4, are presented in Figure 3.1.

22.3 - 15.4.82

ABSCISSA: Direction (degrees)
ORDINATE: Hs (m)

intv	262.5	267.5	272.5	277.5	282.5	287.5	292.5	297.5	302.5	total	pct	accpct
5.75										0	0.0	0.0
5.25										0	0.0	0.0
4.75							1			1	0.7	0.7
4.25						1		1		2	1.3	2.0
3.75					4	1				5	3.3	5.2
3.25					5	3				8	5.2	10.5
2.75					5	2				7	4.6	15.0
2.25		1	1		1	9	2	1		15	9.8	24.8
1.75		1					1			2	1.3	26.1
1.25				3	2		2	1		8	5.2	31.4
0.75		2		7	27	6	6	10		66	43.1	74.5
0.25		2	9	4	8	2	3	9		39	25.5	100.0
total	0	6	10	14	52	23	15	30	3	153		
pct	0.0	3.9	6.5	9.2	34.0	15.0	9.8	19.6	2.0		100.0	
accpct	100.0	100.0	97.4	90.8	80.4	54.2	30.3	25.5	2.0			

22.4 - 5.5.82

ABSCISSA: Direction (degrees)
ORDINATE: Hs (m)

intv	262.5	267.5	272.5	277.5	282.5	287.5	292.5	297.5	302.5	total	pct	accpct
5.75										0	0.0	0.0
5.25										0	0.0	0.0
4.75										0	0.0	0.0
4.25									1	1	1.1	1.1
3.75						3				3	3.3	4.3
3.25										1	1.1	5.4
2.75					5	1	1			7	8.7	13.0
2.25		2			4		2	3	2	14	15.2	28.3
1.75	1	8	1	5	1	3	3	4	5	31	33.7	62.0
1.25		5	6	1	1	3	5	3		21	22.8	84.8
0.75		2			1		1	9		14	15.2	100.0
0.25										0	0.0	100.0
total	1	17	7	6	12	7	12	19	10	92		
pct	1.1	18.5	7.6	6.5	13.0	7.6	13.0	20.7	10.9		100.0	
accpct	100.0	98.9	80.4	72.8	66.3	53.3	45.6	32.6	10.9			

1.6 -29.6.82

ABSCISSA: Direction (degrees)
ORDINATE: Hs (m)

intv	262.5	267.5	272.5	277.5	282.5	287.5	292.5	297.5	302.5	total	pct	accpct
5.75										0	0.0	0.0
5.25										0	0.0	0.0
4.75										0	0.0	0.0
4.25										0	0.0	0.0
3.75										0	0.0	0.0
3.25										0	0.0	0.0
2.75										0	0.0	0.0
2.25						1	2			3	2.3	2.3
1.75					4	6	8	5	3	26	19.5	21.8
1.25					2	14	9	2		27	20.3	42.1
0.75				2	3	11	10	21	1	48	36.1	78.2
0.25			9	2	1	1	1	5		29	21.8	100.0
total	0	0	9	4	10	33	30	33	4	133		
pct	0.0	0.0	6.8	3.0	7.5	24.8	22.6	24.8	3.0		100.0	
accpct	100.0	100.0	93.2	86.5	75.9	51.1	26.3	3.0	3.0			

29.6 - 1.10.82

ABSCISSA: Direction (degrees)
ORDINATE: Hs (m)

intv	262.5	267.5	272.5	277.5	282.5	287.5	292.5	297.5	302.5	total	pct	accpct
5.75										0	0.0	0.0
5.25										0	0.0	0.0
4.75										0	0.0	0.0
4.25										0	0.0	0.0
3.75										0	0.0	0.0
3.25										0	0.0	0.0
2.75				4						4	0.8	0.8
2.25	1	1	1	20	7	1	1	1		33	6.2	7.0
1.75	1	3	13	6	2	6	13	4		48	9.1	16.1
1.25		1	27	55	20	21	28	4		176	33.1	49.1
0.75		28	4	26	27	29	20	33	1	168	31.8	80.9
0.25		35	44	2	7	5	3	1		101	19.1	100.0
total	2	68	93	113	63	62	65	43	1	529		
pct	0.4	12.9	17.6	21.4	11.9	11.7	12.3	8.1	0.2		100.0	
accpct	100.0	99.6	86.6	69.0	47.6	35.7	24.0	11.7	0.2			

1.10 - 4.12.82

ABSCISSA: Direction (degrees)
ORDINATE: Hs (m)

intv	262.5	267.5	272.5	277.5	282.5	287.5	292.5	297.5	302.5	total	pct	accpct
5.75										0	0.0	0.0
5.25		2								2	0.0	0.0
4.75			3							3	1.0	0.1
4.25			2							2	0.8	0.9
3.75	1		3							4	1.7	2.6
3.25			4	11	1	1				17	2.9	7.5
2.75	3	1	6	1	4	1				16	6.6	14.1
2.25	4	6	3	2	2	2	1			20	8.3	22.4
1.75	5	18	9	9	4	4	1			50	20.7	43.2
1.25		8	10	11	13	4	6			52	21.6	64.7
0.75		21	6	2	6	9	3	14	3	64	26.6	91.3
0.25		8	11			2				21	8.7	100.0
total	13	64	57	36	30	23	11	14	3	241		
pct	5.4	26.6	23.7	10.8	12.4	9.5	4.6	5.8	1.2		100.0	
accpct	100.0	94.6	68.0	44.4	33.6	21.2	11.5	7.7	1.2			

4.12.82 - 8.7.83

ABSCISSA: Direction (degrees)
ORDINATE: Hs (m)

intv	262.5	267.5	272.5	277.5	282.5	287.5	292.5	297.5	302.5	total	pct	accpct
5.75		1								1	0.1	0.1
5.25										0	0.0	0.1
4.75	1			1			1			3	0.3	0.4
4.25	2		1	1						4	0.4	0.7
3.75					3					4	0.4	1.1
3.25		4	8	1	1	1	3			18	1.6	2.7
2.75				29	12	3	1	3		50	4.5	7.2
2.25	13	9	21	28	17	7	15	6		116	10.5	17.8
1.75	7	15	27	13	4	5	13	9		93	8.4	26.2
1.25		20	57	77	47	40	18	3		262	23.7	49.9
0.75		44	19	45	33	38	28	80		287	26.0	75.9
0.25		98	105	8	10	15	7	23		266	24.1	100.0
total	23	191	234	203	127	109	86	124	6	1104		
pct	2.1	17.3	21.2	18.4	11.5	9.9	7.7	11.2	0.5		100.0	
accpct	100.0	97.9	80.5	59.4	40.9	29.3	20.0	12.1	0.5			

Figure 3.1 Distribution of breaking waves in six periods.

3.5 Current and Wave Induced Orbital Velocity

Current and wave induced orbital velocities have been measured by an electromagnetic current recorder of the type Marsh McBirney. The recorder was mounted in a rack which was placed at the sea bed at the same position as the wave recorder. The sensor of the Marsh McBirney recorder was situated 1.5 m above the sea bed.

Because of combination of financial, technical and weather-caused difficulties the wanted continuous time series of above-mentioned parameters were not obtained. The periods of data coverage are presented in Table 3.1. It was originally planned that the direction of the orbital velocities should be used as the wave direction at 12 m water depth, however, for above-mentioned reasons the wave directions were established by the refraction calculations.

The current outside the breaking zone has two main components: tidal and storm surge currents. The main directions of the tidal currents are directed N-S and the maximum tidal currents at mean spring are approx. 0.2 m/s. The storm surge currents are also directed N-S with the north-going being the dominating. The following exceedance frequences have been estimated.

Exceedance percentage	Storm surge current
1%	0.25 m/s
5%	0.17 m/s
50%	0.07 m/s

3.6 Water Level Conditions

The tide is semi-diurnal with a mean tidal range of approx. 1.0 m.

The following relation between the storm surge and the wind speed for westerly winds may be used as a good first estimate: storm surge $\approx 7 \times U_{wind}$, the wind speed U_{wind} in m/s gives the surge in cm.

4. Measured Sedimentation

Sedimentation or backfilling in the trench during a certain period has been calculated by multiplying the backfilling area for a cross-section A_3, by the distance between the cross-sections, see Fig. 4.1. By this method the sedimentation distribution along the trench, i.e. approximately perpendicular to the coast, has been calculated.

The sedimentation and other profile characteristics have been calculated according to the sketch presented in Figure 4.1.

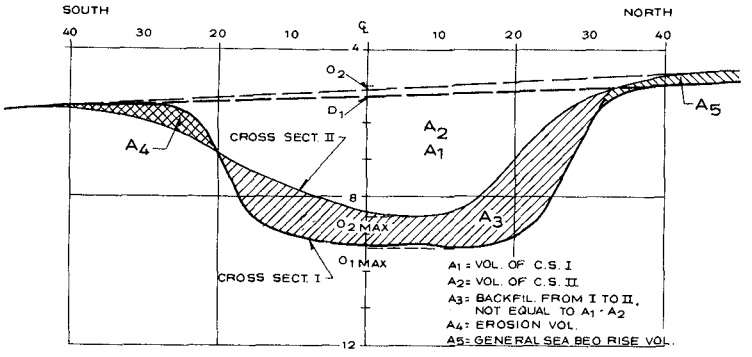

Figure 4.1 Definition of Cross-Section Characteristics.

Cross-sections of some characteristic areas for the available periods are presented in the Figures 4.2, 4.3 and 4.4, see summary Table 4.1.

Period	Charac. Area Chainage	2nd bar 700	Trough 2nd to 3rd bar 1000	3rd bar 1150-1200	Offshore 3rd bar 1700
22.3 to 15.4.82		Not dredged	Partly dredged	Fig. 4.2	Fig. 4.2
22.4 to 05.5.82		Not dredged	Not dredged	Fig. 4.3	Fig. 4.3
01.6 to 29.6.82 29.6 to 1.10.82 1.10 to 3.12.82 3.12.82 to 8.7.83		Fig. 4.4	Fig. 4.4	Fig. 4.4	Fig. 4.4

Table 4.1 Summary over presented cross-sections.

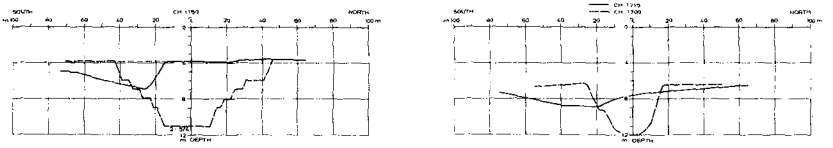

Figure 4.2 Cross-sections from 3rd and offshore 3rd bar, period 23.3 to 15.4.82.

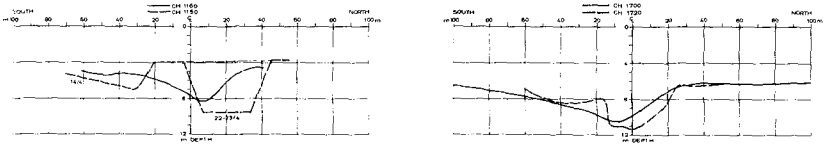

Figure 4.3 Cross-sections from 3rd and offshore 3rd bar, period 22.4 to 5.5.82.

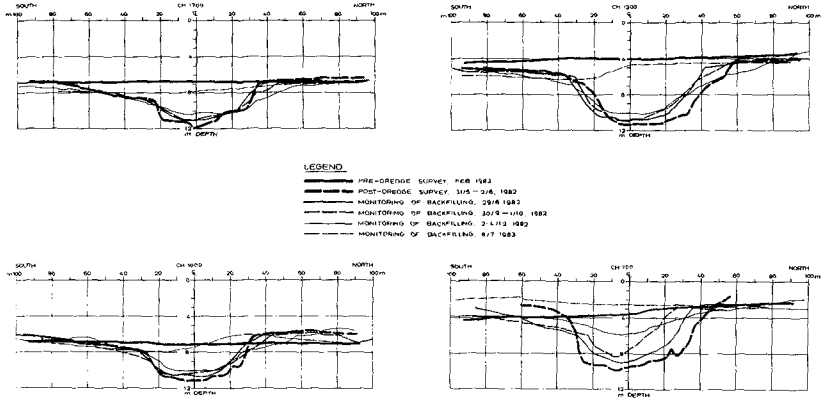

Figure 4.4 Cross-sections from 2nd bar, trough between 2nd and 3rd bar, 3rd bar and offshore 3rd bar, four periods.

The mean sea bed profile, the profiles of the trench in the beginning and the end of the periods, the distribution of the trench volume at the beginning of the periods and the distribution of the measured backfilling during the periods are presented in Figure 4.5.

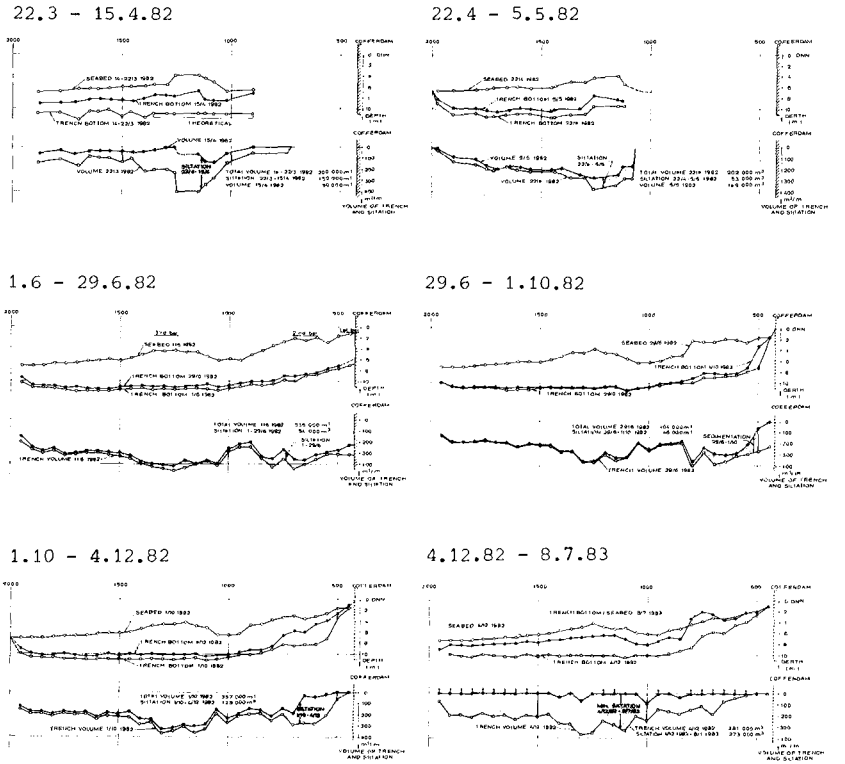

Figure 4.5 Seabed and trench bottom profiles and distributions of trench volume and siltation for six periods.

The backfilling distribution in the profiles is varying considerably because of variations of the wave conditions in the backfilling period. The backfilling is concentrated in the bar areas, in rough weather at the outer bar, see f.ex. the distribution in the period 23.3 to 15.4.82 in Figures Nos. 4.2 and 4.5, in mild periods at the two minor bars, see f.ex. the distribution in the period 29.6 to 1.10.82 in Figures Nos. 4.4 and 4.5.

5. Calculated Longshore Transport by CERC-Formula

The gross longshore transport in the backfilling periods have been calculated inserting the three hourly breaking wave parameters ($H_{s,b}$, α_b), see in Figure 3.1, in the CERC-formula:

$$Q = 1228\ H_{s,b}^{5/2} \sin 2\alpha_b$$

$H_{s,b}$ in m gives Q in m^3/3 h.

By assuming the bulk of the transport in the profile taking place between the depths 0.7 h_b and 1.3 h_b a simplified theoretical distribution of the longshore transport in the profiles has been evaluated. This distribution fits reasonably well with the measured distributions of backfilling. By subtracting the transport which takes place in areas with no trench from the calculated gross transports, one obtain corrected transport amounts, which should be directly comparable with the total measured backfilling amounts. It has been assumed that all longshore transport are trapped in areas with an intact or partly filled trench.

The corrected longshore transport is presented as function of the measured backfilling in Figure 5.1.

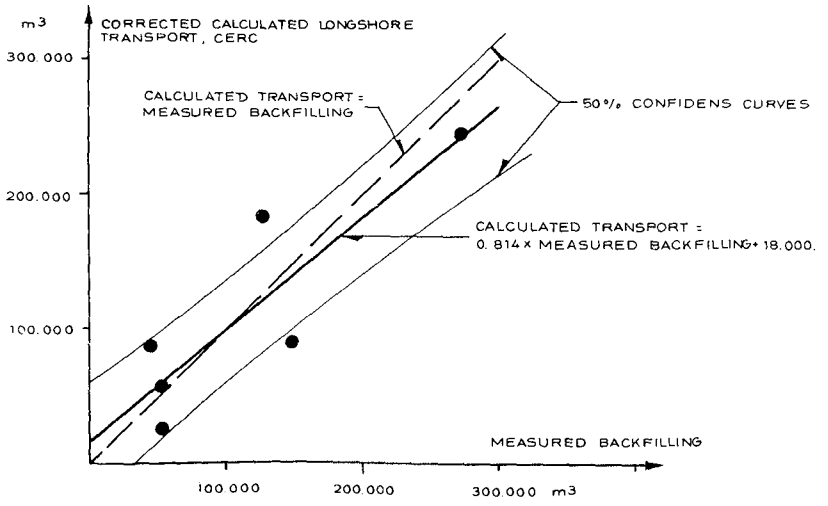

Figure 5.1 Calculated Longshore Transport (CERC) versus Measured Backfilling.

6. Improved Calculation of Longshore Transport

Finally the measured backfilling rate for the period March 22, 1982 to April 15, 1982 has been compared to the gross longshore sediment transport for the same period calculated by a method recently presented by J. Fredsøe, /1/. This method enables the calculation of the sediment transport - bed load as well as suspended load - in the combined flow field of a steady current superimposed by waves. Briefly the method considers the wave boundary layer at the flow bed as it grows up and collapses cyclically with the wave motion in the combined flow. By application of the momentum equation to the boundary layer and a few additional simple principles the temporal variation of the layer is calculated and subsequently the temporal variation in the bed shear stress and eddy viscosity distribution over the depth. The bed load transport rate is immediately related to the bed shear stress as is the concentration of suspended load at the bed and both respond with zero time lag to the variations in the bed shear stress. The concentration distribution over the depth is assumed to be described by the one-dimensional diffusion equation with the sediment diffusivity equal to the eddy viscosity. This equation is solved numerically with depth and time yielding the cyclic variation of the suspended load concentration at any particular depth. The corresponding instantaneous suspended load transport rate is the product of flow velocity and suspended load concentration integrated over the flow depth and is thus cyclic as well. The instantaneous transport rates - bed load as well as suspended load - are averaged over a wave cycle and added to yield what is termed the sediment transport rate. All calculations are carried out by automatic computer. For further details reference is made to /1/.

The steady current is the longshore current which is assumed to be exclusively wave generated. As an approximation it is calculated as proposed by Longuet-Higgins, /3/, for a coast with no bars but with the following modifications :

- The reference velocity V_o is determined as for a coast with no bars but with the coastal slope equal to the bed slope at the point of breaking
- The velocity distribution across the surf zone is calculated as for a coast with slope 1:130 and no bars, see Fig. 6.1.b.
- Only the outermost breaking line is taken into account, even though wave breaking may occur up to three times before reaching the coastline.

After breaking at wave height H_B the wave height H is assumed to be modified with the distance Δx from the breaking lines as,

$$H/H_B = 0.35 + 0.65 \exp(- 0.12 \Delta x/H_B)$$

see e.g. /2/. As the decayed wave runs up the front slope of the following bar the wave height increases again with diminishing depth and breaking occurs once again and so forth until the coastline is reached.

In this way the steady current as well as the wave agitation are calculated at a number of points across the surf zone for the wave conditions occurring during the period 22.3 - 15.4.82.

The sediment transport rate at each point is calculated corresponding to each significant wave height and angle of incidence at breaking as depicted on Fig. 3.1 using that the normal to the coast has the direction 285° and assuming the sediment grain size to be 0.2 mm and the water temperature 5°C. With the duration of each wave condition as shown on Fig. 3.1 the gross transport rate has been calculated for each point. The results are shown on Fig. 6.1.a and compared to the measured backfilling during the same period. The calculated longshore transport comes out in volume solid material during the period whereas the backfill is measured as volume of material in deposit. It has been converted to volume solid material by assuming a porosity of 40%. It is noted that the measured backfill is about 2 times the calculated gross transport. In this connection it should be mentioned that:

- The measured backfill has not been reduced by the volume originating solely from the deformation of the trench and is therefore not equal to the gross longshore transport.
- Longshore currents from other sources than obliquely incident breaking waves have been ignored and may not be so, especially during and after a stormy period as occurred within the period considered.

With this in mind the discrepancy between the calculations and the measurements is not really that discouraging. Efforts continue to improve the method of calculations, primarily by improving the method of calculating the longshore currents.

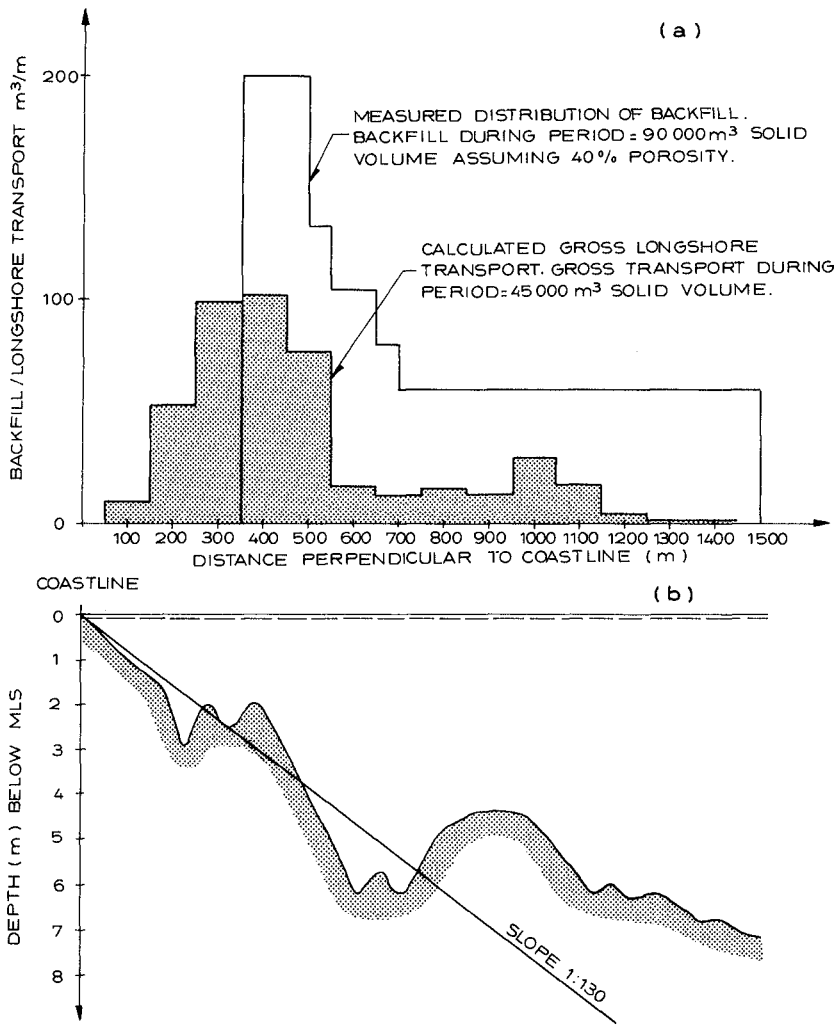

Fig. 6.1 (a) Longshore transport for period 22.3-15.4, 1982 by J. Fredsøe's model /1/ and natural backfill during the same period.

(b) Coast profile as observed during same period.

References

/1/ J. Fredsøe : 'Sediment Transport in Current and Waves'.
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