CHAPTER 56

TRACER TESTS IN THE MIDDLE NORTH SEA

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INTRODUCTION

Tracing of sediment transport has so far mostly been concentrated in rivers and particularly in estuaries and in shallow coastal waters with main interest on navigational, erosional and some pollutionary aspects. With the ever increasing oil activites in the North Sea, knowledge on bottom sediment movements at large water depths is becoming more and more important. Little tracing has been undertaken on the offshore sea bottom at depths exceeding 20 - 30 meters.



This paper describes tests using fluorescent tracers carried out at the Phillips Petroleum Company's production platform, "GULF TIDE", located at the Ekofisk site in the middle of the North Sea.

The water depth in the area is 70 meters. See Figs. 1 and 2.



FIG. 2 GULF TIDE

EXPERIMENTAL PROCEDURES.



200 lbs of blue fluorescent tracer were placed 9 m from one of the platform legs on March 15. 1973. The tracer reproduced the actual grain size distribution at the site with a D_{50} of about 0.12 mm and was placed in a half circle around 50 cm in radius and in a 5 cm layer. An idealized layout of the bottom installations and the positioning of the tracer is shown in Fig. 3.

FIG. 3 IDEALIZED BOTTOM INSTALLATIONS AND TRACER POSITIONING

COASTAL ENGINEERING

DATE OF	SAMPLING AT DISTANCES (m)							SAMPLING	
SAMPLING	1.5	3.0	4.5	7.5	15	30	60	PROCEDURE	
MAY 3.1973	х	х						PLATES	
JUNE 10. "		х	х					UT	
JULY 12. "	х	Х	х	х				11	
AUG. 20. "			х	х				11	
OCT. 10. "				х	х			11	
JUNE 20.1974					х	х	х	GRAB	

Table 1: DATA ON SAMPLING

The samples taken are shown in Table 1.

Introductory all samples were taken by divers forcing a 30 by 30 cm plastic plate covered with grease down into the sea bottom. Except from this sampling the divers were only swimming over the sampling area at approximately ten feet above the sea bed every fourteen days to inspect the bases of the platform legs.



FIG.4 SAMPLING SCHEME

The latest set of samples on June 20. 1974 were taken by a simple self-releasing grab-type sampler lowered from a boat. Samples were taken in 8 different directions as shown in Fig. 4, for distances 15, 30 and 60m. Samples nearer the tracer source were taken in the same directions.

WIND, WAVES AND CURRENTS.

Long-term distributions of wind and wave observations from weather ship "Famita" positioned about 100 km north of the Ekofisk area are shown in Figs. 5 and 6. The wind velocity is the 10 min. average. Wave heights were observed visually and corresponds reasonably well to the significant wave height.



FIG. 5 WIND FREQUENCY AS A FUNCTION OF DIRECTION. (1959-69). REF. (1).



FIG. 6 WAVE HEIGHT FREQUENCY AS A FUNCTION OF DIRECTION, VISUALLY OBSERVED WAVES (1959-69). REF. (1).

For a one year period the wind observations were distributed as shown in Fig. 7. Wind was calm with undeterminable direction in 2.9% of the time.

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FIG. 7 WIND DISTRIBUTION ON DIRECTIONS MARCH 1973 - MARCH 1974

The predominant wind directions are NW, W to SW. Comparing to Fig. 5 it is noted that the highest value of wind velocity could be expected from NW or SE. Comparison of wind and wave directions indicates that they are quite close and Fig. 7 should therefore give a fairly correct impression of wave directions in the area during the one year period.

Figs. 8 and 9 give the distribution of wave heights and wave periods observed at the Gulf Tide over a one year period.



FIG. 8 DISTRIBUTION OF WAVE HEIGHTS FEBR. 1973 - FEBR. 1974



FIG. 9 DISTRIBUTION OF WAVE PERIODS FEBR. 1973 -FEBR. 1974

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Three current meters were installed on the Gulf Tide at 9, 27 and 58 m water depth. Unfortunately the meters have been out of order part of the time. For the 27 and 58 m depth the results of 137 days of recordings from February -August 1973 are shown in Table 2.

Table	2:	CURRENT OBSERVATIONS.
		137 DAYS RECORDINGS FEBRAUG. 1973.

	27 m WATER DEPTH				58 m WATER DEPTH				
CURRENT DIRECTION	PERCENT OF TIME WITH CURRENT SPEED (KNOTS)				PERCENT OF TIME WITH CURRENT SPEED (KNOTS)				
	0-1/4	1/4-1/2	1/2-3/4	Σ=	0-1/4	1/4-1/2	¹ ₂ -3/4	Σ=	
N					0.1	0.1		0.2	
NE	4.0	4.4	1.3	9.7	0.9	1.7		2.6	
Е	36.5	43.4	0.4	80.3	8.0	9.7	0.1	17.8	
SE	2.5	7.1	0.4	10.0	11.5	20.7	29.4	61.6	
S					4.2	4.1	8.6	16.9	
SW					0.5	0.1	0.1	0.7	
W						0.1		0.1	
NW						0.1		0.1	
Σ=	43.0	54.9	2.1		25.2	36.6	38.2		

This table show a clockwise turning of the predominant current direction with increasing depth, perhaps indicating the effect of the earth's rotation. Unfortunately no current recordings closer to the bottom were obtained.

The observation of currents at 9 m depth unfortunately were inadequate. Surface currents needless to say shift continually with the wind. The effect in deeper water may be seen as an integrated result combined with tidal currents running mainly E-W and possibly density current phenomena by which slightly higher salinity and temperature water flowing north is balanced by slightly higher density water flowing south.

TRACER RESULTS

The result of the samplings in TABLE 1 are shown in Figs. 10 - 14 where concentrations are given in tracers per cm^2 , while Fig. 15 gives the concentration in tracer grains per cm^3 .

The concentrations found by the plastic plate sampling procedure could be influenced by arbitrary conditions at the sampling point. Still most of the samles seem to give reasonable results. The results e.g. show an expected tendency to decreasing concentration with increased distance and time.





FIG. 11 SAMPLING JUNE 10, 1973

FIG. 10 SAMPLING MAY 3, 1973



FIG. 12 SAMPLING JULY 12, 1973



FIG. 14 SAMPLING OCT. 10. 1973



IG. 15 SAMPLING JUNE 20. 1974 (GRAB-SAMPLING)

DISCUSSION.

The results of the tracing on the Ekofisk site clearly showed that the bottom sediments are moving. The fine sand has a critical velocity for incipient motion well below the actual water particle velocities at the bottom during a moderate to heavy storm. A wave of 10 sec. period and 6 m height would according to first order theory give water particle velocities at 70 m water depth of about 0.22 m/s, while the critical velocity for incipient motion of the fine sand probably is around 0.15 m/s. The effect of waves in the transportation of sediment is negligible. Fluid displacement due to wave action can, however, be important when coupled with a stronger or weaker current at the sea bed. At the 58 m water depth the current exceeded ½ knot (0.25 m/sec) during 38 percent of the time. (Table 2).

Indications are that the current and wave actions at the Ekofisk site should be able to move the fine bottom sediments at the site. This has been verified by the tracer tests. Fig. 15 shows the result of the sampling carried out in June 1974, demonstrating the movement which took place over an extended period of time. This included some extraordinarily severe winter storms in November and January. The latter storms caused several shipwrecks including one platform, The TRANSOCEAN 61, which broke up and sank. These storms were typical SW to NW storms but of an intensity which caused waves of up to about 20 meters at the Ekofisk site.

The distribution of tracers may be interpreted as follows:

The 15 m and 60 m distributions are not far from being symmetrical N-S as well as E-W the latter being more predominant then the former. This may be seen as a result of the scattering by waves coming from SW to NW causing the coarsest particles to tend to move towards the E, perhaps with a southward tendency due to current action (as also revealed by the earlier samplings). It will be a tendency for relatively finer particles to move in the opposite direction i.e. W. This tendency will predominate when ripple marks have been found and the relatively rapid forward movement of water particles over the rippled bottom causes the development of small eddies downstream of the steep slope of the ripple marks. These eddies contain some particles which, by the relatively slower backward movement of water particles, wash up as independent elements above the ripple marks where the total water movement may easily be in the direction opposite to the direction of wave propagation.

The distribution for 30 m distance shows a definite NE-SW trend, mainly due to one particular strong concentration towards SW (to S). This could be accidental, resulting from the limitations of the sampling technique by which a coverup of tracer particles below sampling level is still possible.

The possibility of movement in any one of the eight directions where samples were taken is given by the concentration (number of tracer grains) found in sampling points in this direction. If one grain moved in all directions in a relative magnitude given by the ratio between the concentrations in these directions, the integrated resulting movement is obtained by adding concentrations times travel distances in length and direction as vectors.

The resulting mass movements are obtained by multiplication of the resulting concentration and the length of migration. This is done in Fig. 16. Assuming that the concentrations at e.g. 30 m distance represent conditions between 23 m and 45 m and similarly for the 15 m and 60 m distance, one would then know the development within an area limited by an inner circle of 7.5 m and an outer circle of 75 m., covering an area of about 17.500 m². According to Fig. 16 the resultant direction of drift within the said area is towards SSW. The magnitude of drift of tracer grains was 800 grains/cm³. m.



FIG. 16 RESULTING MASS MOVEMENT

In order to quantify this number one has to know the depth of movement. The sampling penetrated about 4 cm down in the bottom and the concentration refers to that depth. It is not very likely that movement penetrated deeper in an unobstructed bottom. One therefore arrives at the fact that the resultant movement

 $= \frac{0.04 \cdot 800 \cdot 1 \cdot 1 \cdot 1}{30.000} \text{ m}^4 = \frac{4 \cdot 800 \cdot 10^6}{30.000} \text{ cm}^4 = 10^5 \text{ cm}^3 \cdot \text{cm} = 0.001 \text{ m}^3 \cdot \text{m}$ which in practical terms may be visualised as 1 mm layer of the bottom i.e. a layer of about 8 grains, moving averagely 1 m during the period of record of about 15 months ≈ 450 days.

This is a very small quantity. In this respect it should, however, be borne in mind that seen on the geological time scale this quantity would be detrimental to existing bottom topography and depth if it were a continous trend extending over larger bottom areas. The result would be deep erosion in some areas and considerable accumulation in others. The fact that the sea exists and in its present shape has existed for some thousand of years proves that the <u>resultant</u> bottom movements must be very small.

SUMMARY AND CONCLUSION.

(1) It is apparent that at about 70 m depth forces by waves and/or currents are strong enough at any time of the year to move the fine bottom sand at the EKOFISK site.

(2) The movements recorded must be a result of combined current and wave action. The importance of wave action under moderate wave conditions apparently is that the oscillating water movement breaks the sand particles loose from the bottom after which currents carry the material with them. During periods of heavier wave action, i.e. waves from SW to NW during fall and winter storms, the asymmetrical water motion (waves in heavy storms are shallow water waves!) moves the material in the direction of wave propagation - and probably also in the opposite direction as the bottom is horizontal and bottom-creep material and suspended materials behave differently. The bottom current apparently were predominant towards S still makes its influence felt mainly on the suspended particles. The combined result of current and wave motion would, in this case, be a resulting movement towards SSW-SW-as actually found by averaging the movements found. The direction of propagation of sand waves indicated in Fig. 1 shows for area five a direction of travel which does not deviate too much from the resulting direction found by the tracer experiments.

(3) An attempt was made to quantify the results based on assumptions which may be open to discussion - but a resulting movement of 1 mm times 1 meter in 450 days seems - at least - to have the right dimension. The movement during single storms is not known, but the maximum surface concentration recorded has been of the order of 100 grains/cm². If it is assumed that this layer extends 10 mm down this would correspond to a concentration of about 1 in 60 or to an average movement of ab. 0.2 millimeter or two grains' thickness. This still assumes that the bottom is entirely unobstructed.

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