CHAPTER 103

Coastal engineering studies for inshore mining of diamonds at
Oranjemund

J P Möller*, K C Owen** and D H Swart*

ABSTRACT

This paper describes a diamond mining operation on the west coast
of Africa in Namibia (South West Africa, see Figures 1a and 1b), where
a sea-wall of normal beach sand has been built out to a distance of
more than 300 m seawards of the original coastline. The wall which
runs alongshore is maintained in the high energy environment, which is
characterized by northbound longshore transport rates, by means of
artificial suppletion at a rate of up to and more than 300 000 m^3/
month. Before embarking on the project the company had to be assured
of the sand on the sand-wall; to allow completion of the project free
of severe damage by wave action. This implied being able to predict
the erosion rate of the sea-wall by the waves. The data set used con-
sisted of wave measurements by Waverider and wave observations obtained
from voluntary observing ships; aerial photographs at monthly inter-
vals of the waterline in the study area; and soundings of the beach,
sea-wall and nearshore topography by using a helicopter as a platform.
Various methods of prediction and projection were used to quantify
sediment movement

1.   BACKGROUND

     The diamonds have been deposited in a number of beaches on a
narrow wave cut bedrock shelf. This series of beaches, itself formed
by alternating transgressions and regressions of the sea, is covered by
varying depths (up to 20 m) of marine sand overburden. The diamond
deposits are continuous seawards and this paper addresses particularly
the coastal engineering aspects of the mining methods used in this area
adjoining the sea. In the 1970's various types of beach protection
against wave attack were used to make mining of the beach area in the
dry possible. These included interlocking concrete blocks and sheet-
piles. Due to economic constraints and the requirement only being for
temporary protection attention turned to using the sand overburden,
which has to be excavated and dumped to expose the diamond gravels, to
build the sea-wall. This structure has a crest width of 25 m, about
10 m above MSL and is progressively developed seawards.

*   Sediment Dynamics Division, Coastal Engineering and Hydraulics,
    National Research Institute for Oceanology, CSIR, P.O. Box 320,
    Stellenbosch, 7600, Republic of South Africa.
** Assistant General Manager, Consolidated Diamond Mines (Pty) Ltd,
    P.O. Box 35, Oranjemund, 9000, Namibia.

The mining sequence becomes rather critical in as far as it relates to the distance over which excavated material is to be transported, this being one of the major expense items in the project. This implies that the area to be excavated and the length of sea-wall to be constructed or maintained should always be in close proximity.

The increase in beach slope causes increased offshore losses of material and the stability and construction of such a structure require close monitoring to ensure the safety of personnel and equipment and to make such a capital-intensive undertaking economical. An extensive monitoring programme which includes inshore bathymetric surveys, aerial photography, the analysis of sea-wall volumes and regular site visits by personnel and consultants was incorporated at an early stage.

At present the mine is at its maximum planned offshore limit and the mining programme is now even more strictly governed by the effect of the harsh littoral processes in the area. The regular monitoring of progress and changes in the nearshore coastal area ensures that the project proceeds optimally.

2.   OVERVIEW OF AVAILABLE DATA

Wave Data

Oranjemund lies on a desolate part of the coast far from any major harbours and wave data from the area, before the project was started, were rather sparse. A Waverider station was set up in 1978 in 17 m of water depth to gather information for the design of a piled jetty in the surf zone in the mining area. In 1981 the station was moved to a water depth of 106 m and the CSIR has analysed the data from this station by standard methods.

As the Waverider does not record wave direction use had to be made of available Voluntary Observing Ship's (VOS) records that were collected between 1960 and 1979. Figure 1a shows the $1^{\circ} \times 1^{\circ}$ squares in which the VOS data available along the Southern African coast were grouped for the analysis. In Swart and Serdyn (1981) annual, seasonal and monthly analyses are shown for height, period and direction combinations. It was also possible to collect raw VOS data during the project by utilizing Cape Town based coasters that operated on the west coast.

The aim was to use Waverider and VOS data collected during a specific period and correlate these with the beach behaviour during the corresponding period.

Figure 2 contains a wave-height exceedance curve for the 106 m Waverider station at Oranjemund. It can be seen that the wave climate is fairly severe, with a once/year significant wave height of 5,6 m. Figures 3 and 4 show the wave height and period histograms for all data. On the basis of the VOS wave data a swell rose was compiled, as shown in Figure 5. The swell waves exhibit a strong south-easterly tendency, whereas the local wind field is more predominantly south-east (see Figure 6), which is alongshore.
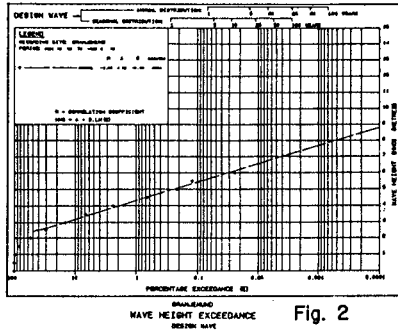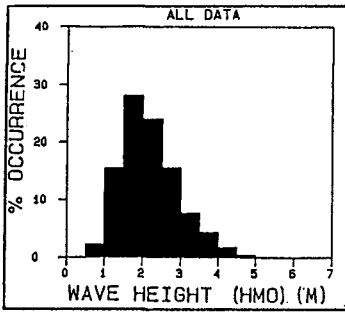
Fig.Ia

Fig.Ib Oranjemund mining layout

BRANJEMUND
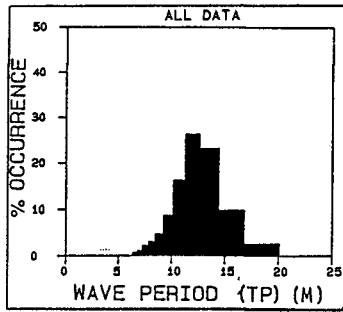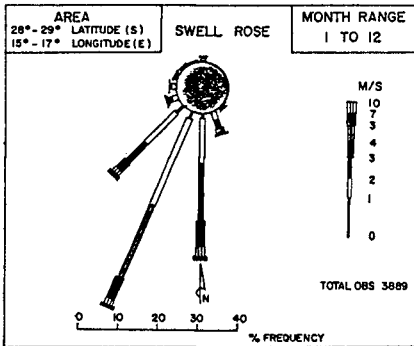WAVE HEIGHT EXCEEDANCE   **Fig. 2**
DESIGN WAVE
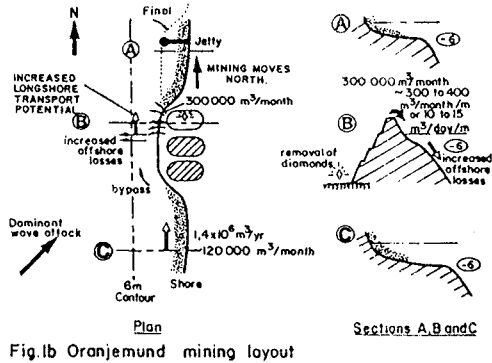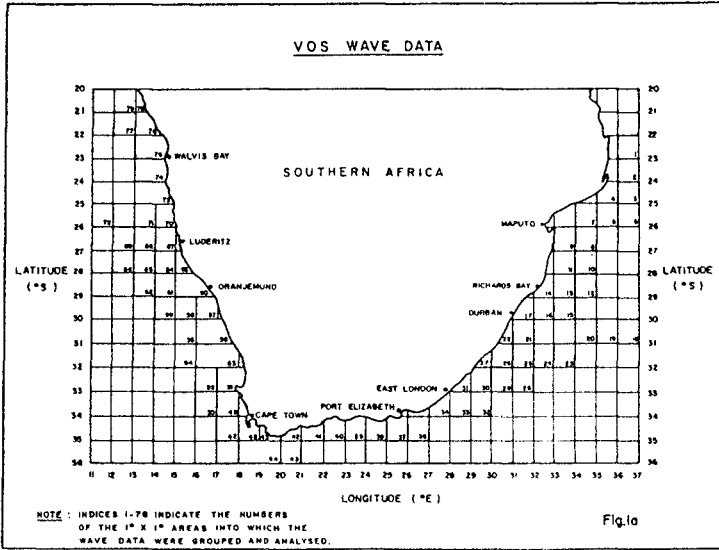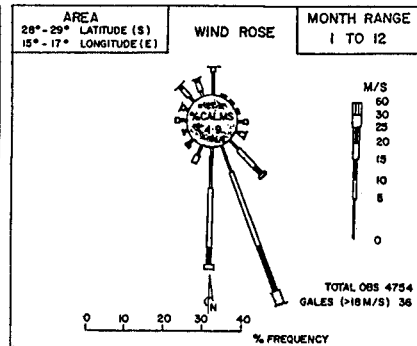

Fig.3

Fig.4

Fig.5

Fig.6

Surveys

The highly dynamic littoral zone along the mining area requires close topographical monitoring, especially in front of the sea-wall where substantial offshore losses could occur during stormy events.

A helicopter is used for the surveying, which is done with a lead-line and 3 theodolites. Beach and nearshore surveys have been carried out routinely at 3-monthly intervals for 10 years. Each survey, which includes a set of 7 lines for which records are available since the beginning of the project, consists of 23 lines that extend from the top of the sea-wall to $\pm$ 15 m below MSL.

Profiles, contour maps (Figure 7a) and difference maps (Figure 7b), which relate each survey to the preceding survey, are drawn for each survey. The difference maps clearly show areas of erosion or accretion between surveys which is of great help when trends in the coastal processes are to be studied.

Aerial Photography

Aerial photo mosaics are taken monthly and display beach form characteristics and operational features of importance to the design. The photography is done from a helicopter and a set of ground beacons is used for proper alignment while the camera is horizontal. This allows fairly accurate measurements to be made on the mosaics. Figure 8 shows, for example, the northward advance of the leading edge of the sea-wall in time.
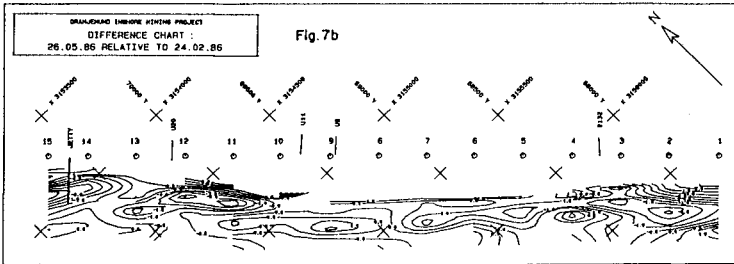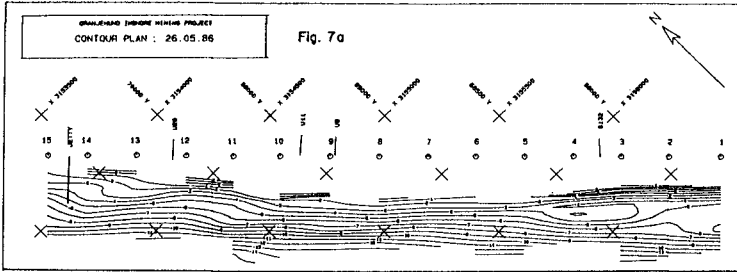
Sand Samples

For the calculation of on/offshore and longshore transport capacities knowledge of the grain size distribution of the beach material is required. Initial sampling along the coastline over 35 km during 1979 indicated that the median grain size decreases towards the north. The median grain size typically varied from about 600 microns at the Orange River in the south to 350 microns 35 km north of the Orange River (see Figure 9). This has been verified by subsequent annual re-sampling.

Artificially Dumped Volumes

Up to 5 million cubic metres of overburden are excavated annually for sea-wall construction and maintenance. Diesel-driven dozers and scrapers are used for this work. It is essential that the schedule at which material is required for the construction and maintenance of the sea-wall matches the scheduled programme for overburden stripping. Figure 10 gives as an example the dumped volume during a 19-month period in 1985/86. During this period the average monthly dump rate was 300 000 m^3, which amounts to nearly 3 times the average northbound drift rate.

It is specifically relevant that due cognizance be taken of the fact that the natural net longshore transport capacity in the area is about 1,3 million cubic metres per year towards the north (see Chapter 3 below). The mining procedure is therefore directed to benefit

Fig. 7a

GRAHLEHANG INSHORE MINING PROJECT
CONTOUR PLAN : 26.05.86

Fig. 7b

GRAHLEHANG INSHORE MINING PROJECT
DIFFERENCE CHART :
26.05.86 RELATIVE TO 24.02.86

A POINT 80N SEAWARDS OF LINE OF BEACONS IS TAKEN AS REFERENCE

Fig. 8   BEACH BUILDING NORTHWARDS OF THE SEAWALL

VARIATION OF GRAIN SIZE FROM THE
ORANGE RIVER NORTHWARDS

D_{50}
(MICRON)
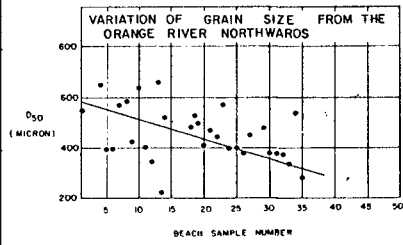
BEACH SAMPLE NUMBER
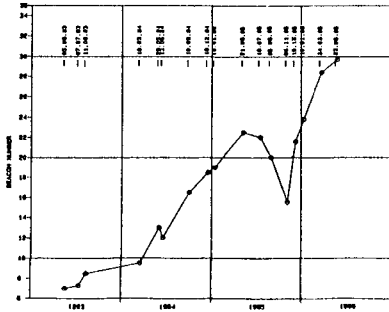
Fig. 9

VOLUME DUMPED ONTO SEAWALL FOR BUILDING AND
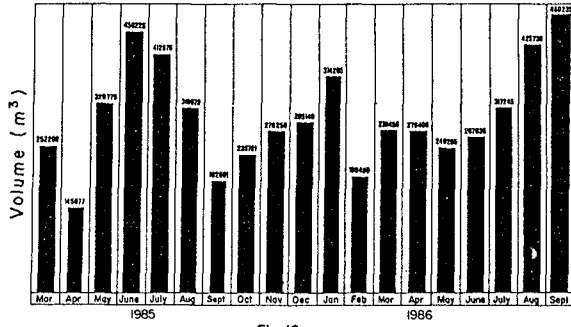MAINTENANCE MONTHLY DURING 1985/86

Fig. 10

Fig. 12

Fig. 11

SAND BALANCE
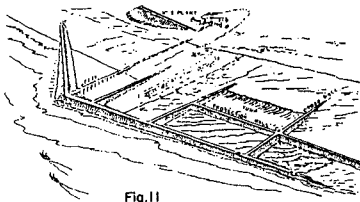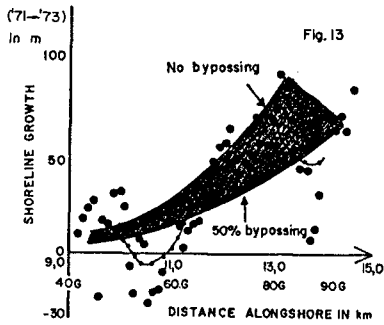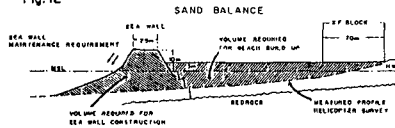
Fig. 13

maximally from this natural mechanism of moving material.

3.   INTERPRETATION OF PHYSICAL PROCESSES OPERATIVE IN THE COASTAL AREA

     In order to assess the behaviour of a sea-wall such as that shown
schematically in Figures 11, 12 and 1b, it is necessary to quantify the
littoral processes in three different areas, namely,

* the area to the south of the sea-wall proper, which will be shown
  below to be the updrift area;
* the area in front of the sea-wall proper, and
* the area to the north (downdrift) of the sea-wall proper.

Updrift Area

     The available wave data for the area clearly show a strong pre-
dominance of waves with a high angle of incidence from the south-
southwesterly sector. As a result the littoral drift in the area is
predominantly northbound. Swart in CSIR (1979) found on the basis of
predictions with the SPM littoral drift predictor (SPM, 1973) that the
gross longshore transport in the area is about 1,9 million cubic metres
per year, with a net of 1,3 million cubic metres per year northbound.
These extremely high values, which are the result of the high angles of
incidence referred to above, have been verified by comparison with the
rate of updrift infill at the first sea-wall, which was constructed in
1971. Figure 13 shows this verification in the form of a comparison
between actual shoreline changes and the shoreline changes predicted
with the assumption of a littoral drift rate as given above.

     Figure 13 indicates that up to 50 per cent of the littoral drift
arriving from the south bypasses into the area in front of the sea-wall
proper. Obviously the magnitude (percentage) of the bypassed quantity
depends on the degree of build-out of the sea-wall relative to the ori-
ginal waterline and the degree of change in the coastline orientation.

Area Seawards of Sea-wall

     Prior to the initiation of inshore mining the sea-bed in the sea-
wall area was characterized by a typically concave beach profile which
shelved out at 6 m below mean sea level (MSL). The 6 m contour typi-
cally was situated about 300 to 400 m seawards of the mean waterline.
Swart in CSIR (1979) showed that the plateau referred to here can be
physically explained as the lower limit of the active profile develop-
ment in the area where combined bed-load and suspended load takes place
(Swart, 1974). Between the 6 m and 16 m contours the underwater slope
was relatively steep at 1 in 30.

     The foregoing means that any plans to build out a sea-wall into
the nearshore area would be bounded on the seaward side by the sharp
change in profile. In practice this meant that the maximum distance
over which the mean water line could be shifted seawards was of the
order of 200 to 300 m, just by considering the geometry of typical
beach profiles found in the area. Obviously this would only be possi-
ble if artificial nourishment were to be added at the top of the pro-
file to compensate for additional wave-driven seaward losses due to the

steepening of the beach profile. The studies described in this paper
were aimed largely at quantifying these processes and determining prac-
tical limits for the beach build-out.

Figures 14 and 15 show examples of hydrographic profiles taken
over a 4-year period across the beach in front of the sea-wall. Figu-
re 14 was taken in the southern section of the sea-wall while it was
still being built out to its maximum protrusion. Figure 15 depicts
profiles in the area of maximum protrusion. The dramatic recent build-
up of 180 m can be seen clearly. Prior to 1982 about 10 m of build-up
had already taken place in this area, making the total build-up of the
order of 300 m. As a reference Figure 16 contains beach profiles about
8 km north (downdrift) of any inshore mining activities. Reference to
Figure 12 shows schematically how the sand balance is made up.
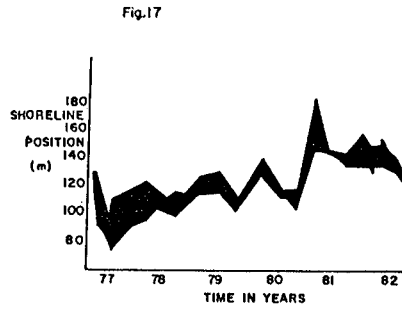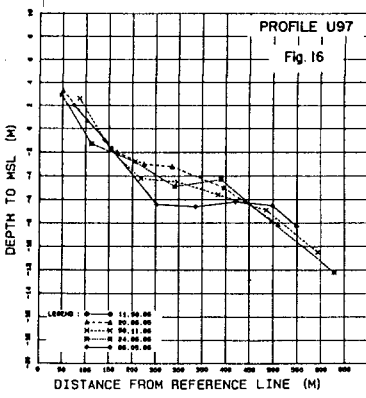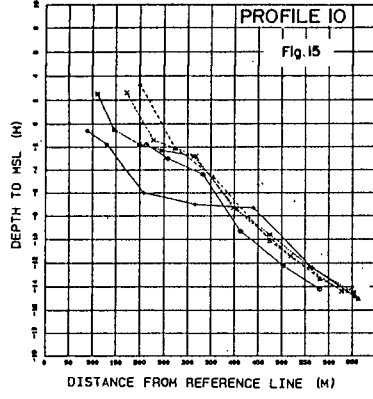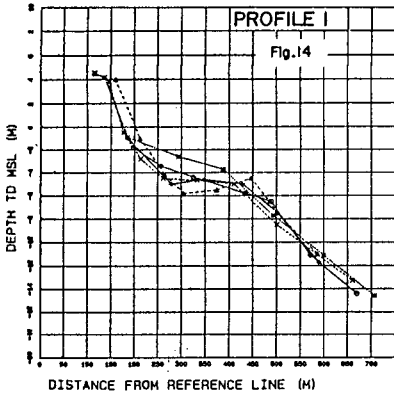
Downdrift Area

In the classical case of an obstruction to longshore drift one
would expect downdrift erosion. However, in the case of the sea-wall,
the processes operative in the area are completely different and merits
special discussion. As a result of the artificial nourishment in the
area of the sea-wall proper the magnitude of the northbound longshore
drift is increased sharply in relation to the initial pre-sea-wall con-
dition. Swart showed in CSIR (1979) that the extent of the increase in
the longshore transport rate is a function of the degree of build-out
from the original waterline, which is logical. For an offshore build-
out of 200 m relative to the already partially built-out shoreline he
predicted an increase in the amount of longshore transport of 250 per
cent, which sounds very high.

Because the longshore drift potential returns to normal towards
the north, as the effects of the inshore mining activities become less,
it means that the excess material arriving from the sea-wall area in
the south will deposit, thereby creating an area of substantial accre-
tion to the north (downdrift) of the sea-wall proper. Figure 17 con-
tains an example of the seaward growth in the shoreline during 1977 to
1982 at a location about 3 to 5 km to the north of the sea-wall posi-
tion at that time. Simulations of downdrift shoreline change, perfor-
med with the one-line shoreline model of Pelnard-Considère (1954),
modified to include longshore variations in wave height and beach pro-
file and location, verified the longshore transport increase by 250 per
cent, which was quoted above.

The sedimentation to the north of the sea-wall proper takes place
in the form of a low washover fan at the level of a maximum wave run-
up, which typically is about 2 to 4 m above MSL. One of the main out-
comes of the study reported in this paper was to optimize the northward
sea-wall advance such that the sedimentation to the north of the sea-
wall can be used to maximum benefit as a platform for the building out
of the sea-wall in that area.

4.   MINING SEQUENCE AS RELATED TO COASTAL PROCESSES

On the basis of a detailed modelling of the physical coastal pro-
cesses in the area, it was possible to optimize various aspects related

PROFILE I

Fig.14

DEPTH TO MSL (M)

DISTANCE FROM REFERENCE LINE (M)

PROFILE IO

Fig.15

DEPTH TO MSL (M)

DISTANCE FROM REFERENCE LINE (M)

PROFILE U97

Fig. 16

DEPTH TO MSL (M)

DISTANCE FROM REFERENCE LINE (M)

Fig.17

SHORELINE
POSITION
(m)

180
160
140
120
100
80

77   78   79   80   81   82
TIME IN YEARS

to the sea-wall (CSIR, 1983).

Mathematical models based on the onshore-offshore model developed by Swart (1974), the shoreline evolution theory of Pelnard-Considère (1954) and topographical changes have been and are still being used to predict the littoral response.   The model on topographical changes referred to is similar to that developed by Perlin and Dean (1983) but it uses the Swart (1974) method for the prediction of onshore-offshore transport, which is well tried.   The wealth of survey data allows for the easy calibration of the above-mentioned mathematical models and also supplies a unique data set showing how very steep and very much flatter beach profiles in close proximity react to the same incident waves.

Calculations were made to determine the extent of maintenance feeding which would be required for different sea-wall offset distances from the original shore.   It was concluded that it would be possible to maintain a sea-wall in a position more than 300 m seawards of the original shoreline.

Typical components of a mining sequence strategy developed on the basis of the research are the following:

•   the sea-wall should be actively maintained over a 600 m length, which is advanced northwards at 800 m per year;

•   the volume of material required annually for sea-wall building and maintenance was theoretically predicted to have a minimum value of 2,7 million cubic metres, which contains 2 million for sea-wall building alone.   The maximum predicted sea-wall maintenance is much higher than the minimum value of 0,7 million cubic metres and could be as high as 3 million cubic metres, making the total volume required 5 million cubic metres per year.   Actual dumped figures to date fall within these bracketing values.

•   The sea-wall is particularly vulnerable during spring high-tide and arrangements must be made to cope with an increased maintenance load during periods of spring tide.

5.   SUMMARY AND CONCLUSIONS

In summary, it can be stated that a sea-wall which is maintained at Oranjemund at a distance of more than 300 m seawards of the original waterline, causes updrift accretion of between 50 and 100 per cent of the strong, net littoral drift of about 1,3 million cubic metres per year, which arrives from the south.   In front of the sea-wall a beach profile steeper than the initial one is maintained by artificial nourishment.   As a result the longshore drift rate in this area is increased more than twofold by the increased suspended load in the water column.   To the north (downdrift) of the sea-wall proper the reduction of the drift rate back to normal leads to an area of sedimentation advancing northwards with the sea-wall.

On the basis of the understanding of the processes involved and the mathematical modelling of these processes an optimum mining strate-

gy was developed.

Apart from recommendations regarding the broad strategy for in-shore mining, this ongoing study has regularly supplied inputs on the basis of the gathered data and model results which allowed an essen-tially non-marine project team to optimize their activities to cope with changes in the littoral environment.

In addition, the project can serve as a one-to-one scale beachfill test and could prove extremely useful to evaluate techniques for the design of beachfills.

REFERENCES

CSIR (1979). Oranjemund beach study. CSIR Report C/SEA 7935, Stellen-bosch, RSA.

CSIR (1983). Oranjemund sea mining project. CSIR Report C/SEA 8379, Stellenbosch, RSA.

PELNARD-CONSIDèRE, R. (1954). "Essai de théorie de l'évolution des formes di rivages en plages de sable et de galets". Quatriéme Jour-nèes de l'Hydraulique, Paris, 13-15 Juin 1954.

PERLIN, M. and DEAN, R.G. (1983). A numerical model to simulate sedi-ment transport in the vicinity of coastal structures. Miscellaneous Report No. 83-10, US Army Corps of Engineers.

SPM (1973). Shore Protection Manual, US Army Corps of Engineers.

SWART, D.H. (1974). Offshore sediment transport and equilibrium beach profiles. Doctoral thesis, Technische Hogeschool, Delft, 302 pp.

SWART, D.H. and SERDYN, J.de V. (1981). Statistical analysis of visually observed wave data from voluntary observing ships for South African coast. Unpublished CSIR Report, 80 volumes, Stellenbosch, RSA.