CHAPTER 43

MEASURING SAND DISCHARGE NEAR THE SEA-BOTTOM

Dieter WENZEL

Dipl.-Ing., Amt für Land- und Wasserwirtschaft

D-2250 Husum, Fed. Rep. of Germany

Abstract

The direct and continuous measurement of the littoral drift is an essential problem with investigations on erosion of sandy coasts, as for instance at the island of Sylt. The measuring conditions require equipment of very particular features.

Recent measurements have supplied informations about the conditions of sound propagation in sediment loaded water, leading to the conception of a sand discharge measuring device. It will consist in a combination of a current meter and a sand concentration meter.

A convenient equipment is actually being developed. It is to supply an idea about the magnitude of the instantaneous sand discharge, the approximate remaining sediment transport vector, the phases of maximum and minimum sediment load, and so on. Consequently it will help to obtain a reliable statement about erosion processes, indispensable information for successful coastal engineering work.

1. Introduction

The island of Sylt (Northern Germany) continuously loses material of its western coast by erosion. The beach consisting of sand is exposed to the surf of the open North Sea. The coast of the central part yields in the mean by 1 m a year. At the northern and southern ends the mean loss runs up even to 4 m a year.

Coastal engineering work in this area has to maintain the shore line in order to protect considerable material values (fig. 2). But so far no efficient shore protection method has been found. The most recent action, a beach nourishment at Westerland in 1972, is still being under study (ref. 3).

As in other places, the actual relationships between wind data, wave characteristics, surf currents, tidal currents, and coast erosion are not yet well known. The links between hydrological forces and results of morphological processes are to be detected. This aim requires to make up the energy balance on the one hand, and to measure the morphological process itself, i.e. the sand transport, on the other.

An idea about the intensity of sediment transport on the west coast of Sylt is given by the effects of storms: Dunes and cliffs may lose 6 m

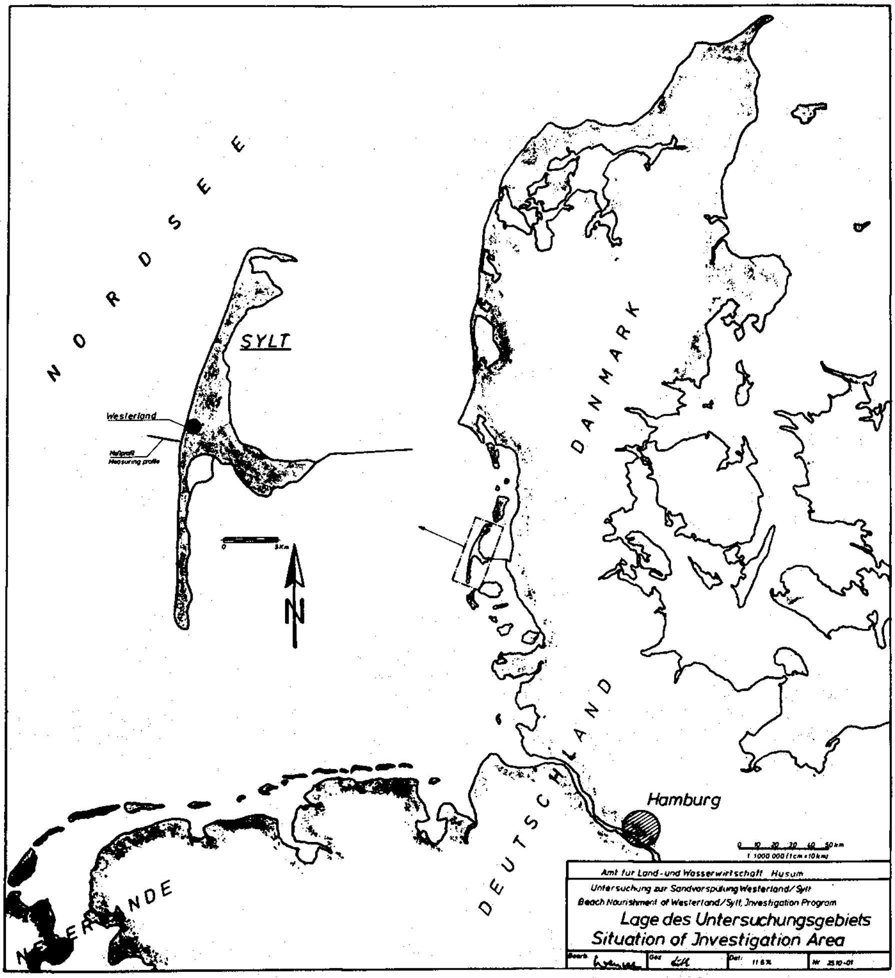


Fig. 1. The situation of the investigation area

Fig. 2. Aerial view of the town of Westerland (to the east)

Fig. 3. COMEX electromagnetic current-meter, mounted on its support

of depth during 3 hours, and the beach level may change by 2 m in 6 hours.

2. Requirements

As weather and waves may change frequently and rapidly, continuous measuring facility is necessary, and that with high resolution in time during periods of hours and with low resolution in time during periods of months. The measuring equipment has to be independent of water colour and turbidity which are variable. Moreover, it is the scope of this study to measure not only the suspended sediment, but above all the sediment coarser than that normally in suspension within the Stokes ranges, i.e. up to about 2 mm Ø. For the above reasons, no sand trap or turbidity (light absorption) device can be used.

The measuring conditions in this area are difficult because of the shallow water (max. depth 10 m), mobile sea-bottom (sand) and considerable wave heights (maximum measured during storm in November 1973: 6,8 m). Installation and inspection of submarine units is possible only during about six weeks a year (June and September) due to the atmospheric conditions.

An equipment adapted to these conditions must present particular features such as:

- permanent installation on the sea-bottom, but possibility of being moved to another measuring place
- strong mechanical resistance to high orbital movement by a construction without moving parts
- continuous operation and reliability for at least eight months
- a marine cable link for power and data transmission
- data transmission unaffected by variable electrical resistances in the cable and transitions
- indicating and recording data ashore.

3. Present Measuring Devices and Results

In accordance with the above-mentioned features, some measuring devices have been installed and operated (fig. 4).

3.1. Current-Meters (S1, S2)

Data about current velocities in the Sylt site have been gathered so far by means of electromagnetic current-meters: An electric tension is induced by the water passing through an alternating electromagnetic field. These current-meters allow the measurement of orbital movement with a resolution of 0,1 s as well as the measurement of tidal currents, projected onto two horizontal axes. The distance sensor - sea-bottom varies from 0 to 1 m, depending on the level of the sea-bottom (fig. 3).

The results show that the mean longshore component changes its direction in the tidal rhythm and reaches about 0,6 m/s (fig. 5). The mean component perpendicular to the shore varies very little and runs up to 0,3 m/s.

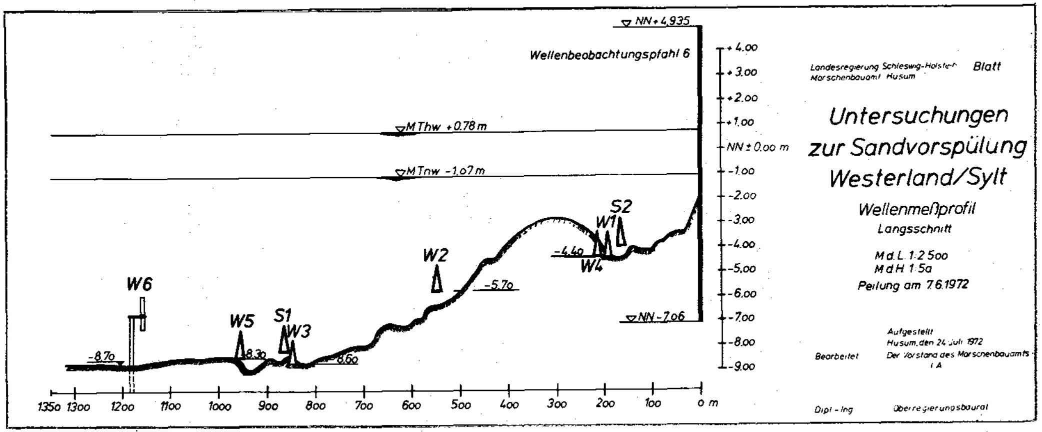


Fig. 4. The measuring profile near Westerland, looking to the north.

MThw = mean tide high water level
MTnw = mean tide low water level

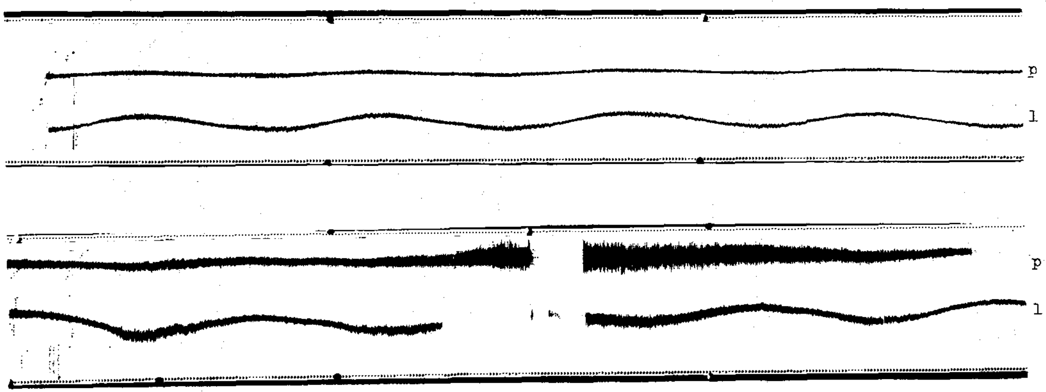


Fig. 5. Current recordings.

calm weather, low waves

p = component perpendicular to shore
l = longshore component

passage of a wind field with increasing and decreasing waves

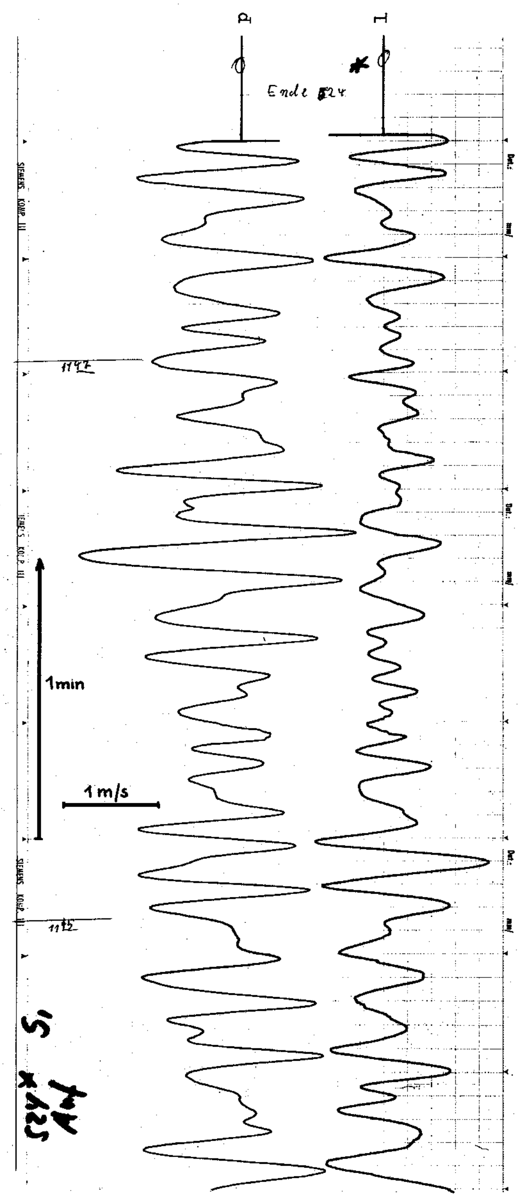


Fig. 6. Orbital currents during storm. Max. wave height about 6 m
p = component perpendicular to shore
l = longshore component

They are superimposed by the orbital movements caused by waves. The amplitude of the orbital velocities comes up to 2,9 m/s in one axis, depending on wave height and direction (fig. 6). Hence the considerable sediment transport in the site can be explained: the orbital movement causes the sand to be whirled up. Consequently the tidal and surf currents are enabled to transport sediment grains of a far greater diameter than corresponding to their mean velocity (ref. 6).

3.2. Wave Gauges (W1 - W3, W6)

Recent measurements with ultrasonic wave gauges have demonstrated the intensity of sound absorption in sediment loaded water. These wave gauges work exactly like reversed echo-sounders, installed on the sea-bottom (fig. 7). They are emitting pulse-trains at a rate of 8 pulses p.s. and a sound frequency of about 100 kHz. The emitted sound energy is in the order of 60 W. The distance sensor - sea-bottom varies from 0 to 1 m, depending on the level of the sea-bottom. It can be evaluated ashore by the appearance of multiple echos on the oscilloscope (fig. 8).

It turned out that no echo was received from the sea-surface during periods of high waves. On the oscilloscope, variable layers of concentrated intermediate reflectors (sand grains) could be observed. They passed the sound beam like clouds, their passage taking generally some minutes (fig. 9). With very high waves, absence of surface echos was recorded even for hours. This effect is more marked on the measuring stations near the beach, where the surf energy is liberated and takes action on erosion.

The station W6 is equipped with a sound velocity measuring device. The output is a frequency proportional to the sound velocity. This device has run so far for one day only, but proves able to give useful data. The short term variation is only 0,25 ... 0,35 m/s $\hat{=}$ 1,8 ... 2,5 x 10^{-4}, which seems to be due to the inherent limits of the device.

4. Intended Realization

4.1. Object to Be Measured

Sand discharge, Q_{sed}, is defined as the volume of sand transported per time unit through a definite area, A. L (load or sand concentration) be the ratio between a certain volume of sediment and the total volume of water-sediment-mixture, in which it is contained:

$$L = \frac{V_{sed}}{V_{tot}} , \qquad 0 \leqq L \leqq 1$$

L is one variable magnitude to be measured continuously as an average value in the measuring area: $L = f(t)$.

The discharge of water-sediment-mixture can be obtained by measuring the current velocity in a definite area: $Q_{tot} = v \cdot A$. v is another variable magnitude to be measured continuously: $v = f(t)$.

Consequently, sand discharge is obtained as

$$Q_{sed} = L \cdot Q_{tot} = L \cdot v \cdot A,$$

i.e. by continuous multiplying the current velocity by the sand concentration.

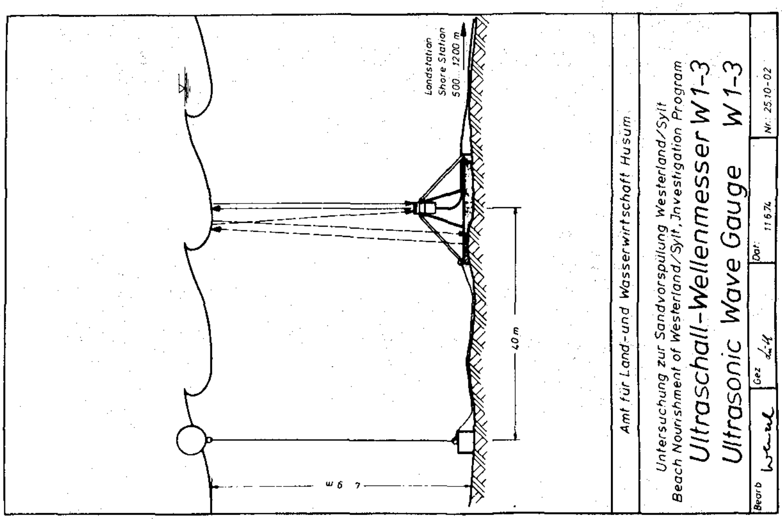


Fig. 7. Ultrasonic wave gauges W1 - W3

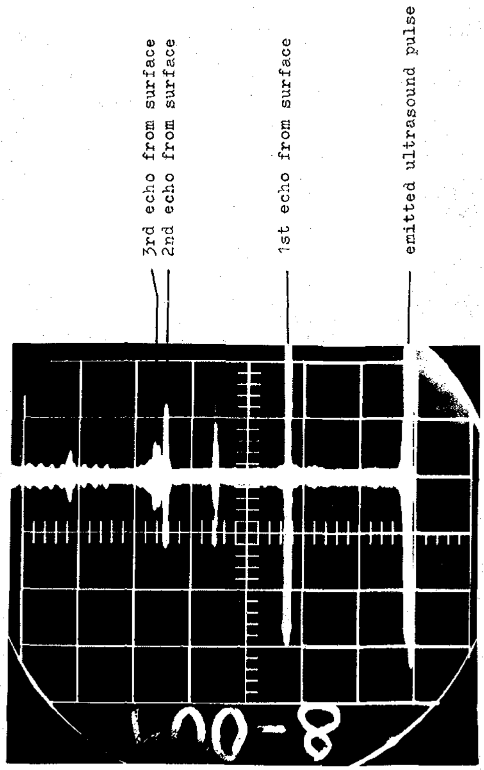


Fig. 8. Oscillogramme of wave gauge, low waves

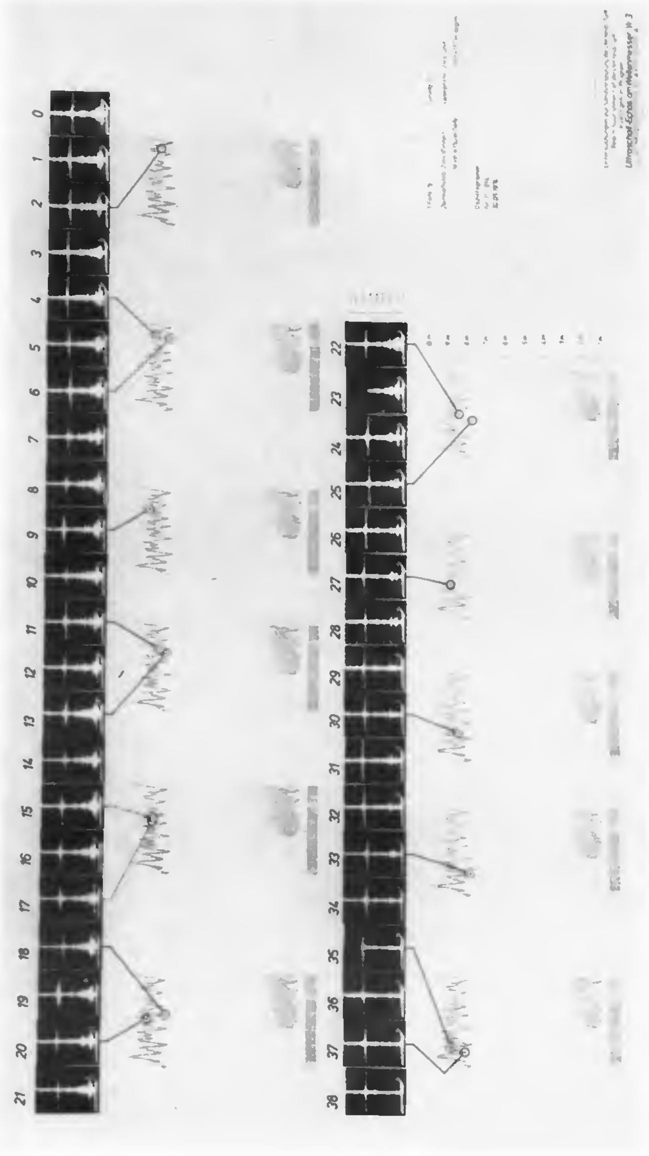


Fig. 9. Comparison of wave record and consecutive oscillogrammes (rate 1 photo/s).
Max. wave height about 1,5 m. From photo no 0 to no 24, a "sand cloud" is passing (visible in the lower part of the wave record).

The area A is a constant, defined by the construction of the sensor. It has to be constant for any direction of v.

As the main quantity of sediment is moved near the bottom, this area is to be placed here in a way giving the average of a certain layer (ref. 4).

The parameter L can be measured by three acoustic phenomena: sound reflection, sound absorption, and variation of sound velocity in sediment loaded water. The sound reflection method seems to be more difficult in gauging than using sound absorption. As to sound absorption, refer to 3.2., where it is shown empirically that there is a distinct correlation between load and absorption. It is to be noted, that the effect appearing here as absorption is due mainly to a scattered reflection by fine particles.

Sound velocity in sea water is given by the classical LAPLACE-formula

$$c = \sqrt{\frac{\mathcal{X}}{\varrho \cdot \varkappa}},$$

signifying that it depends on temperature, salinity, and pressure:

$$c = f(T, S, P) \qquad \text{(ref. 1, 5)}$$

Among these parameters temperature has the greatest influence.

Approximate calculation is possible for instance by (ref. 1):

$$c = 1445{,}5 + 4{,}62T - 0{,}0452T^2 + (1{,}32 - 0{,}007T)x(S - 35)$$

with c [m/s]
T = temperature [°C]
S = salinity [°/oo]

These formulas do not take into account the presence of sediment in the water. This is done by a formula by URICK/BERGMANN (ref. 1):

$$c_o^2 = \frac{1}{[\varrho_2\alpha + \varrho_1(1-\alpha)] \cdot [\beta_2\alpha + \beta_1(1-\alpha)]}$$

with c_o = sound velocity in a suspension
ϱ_1 = density of pure liquid
ϱ_2 = density of suspended material
β_1 = compressibility of pure liquid
β_2 = compressibility of suspended material
α = part of volume of suspended material in the suspension
c_1 = sound velocity of pure liquid

Analysis proves that $\frac{c_1}{c_o} = f(\alpha)$ is a parabolic curve (ref. 1). That means that sound velocity depends well on sediment load, but in a certain range any value of measured sound velocity may belong to two values of sediment load. The function is ambiguous in a certain range. A combination of sound velocity measurement with sound absorption measurement will be useful.

4.2. Measuring Device

An equipment for the measurement of both parameters, the current velocity v and the sand concentration L, is actually being developed. The physical principle applied for both is ultrasound (fig. 10, 11).

The current-meter measures the velocity vector projected on two orthogonal horizontal axes by comparing the relative sound speeds upstream and downstream. An optional feature, computing and taking into account the true

Fig. 10.
Sand discharge measuring device, planned construction

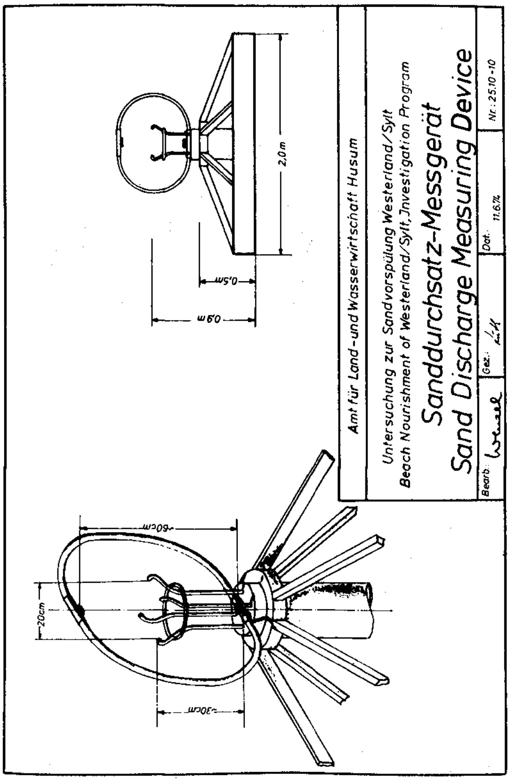
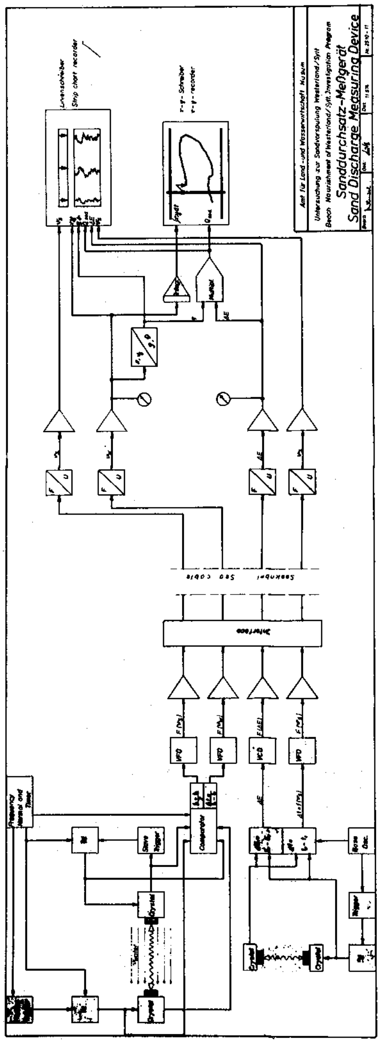


Fig. 11.
Sand discharge measuring device, block diagram



sound velocity, allows to increase the accuracy of computed current velocity. Moreover, output and recording of the sound velocity will be very useful for getting data about sand concentration. A convenient equipment is designed and manufactured by an industrial company.

It will be combined with a sand concentration measuring device. The sand concentration in the water is obtained by measuring the sound absorption in a vertical axis. It is arranged in this sense in order to minimize the disturbance of the horizontal currents and to get the average of a certain layer (0,6 m). At the same time, this device, too, will compute and output the sound velocity.

It is essential that the sand concentration is measured in exactly the same point as the current velocity: the three measuring axes form a cross of axes each of which being perpendicular to the others.

The shore station of the equipment has to compute magnitude and direction of current velocities, sand concentration, sand discharge, and to record data, including continuous recording of the sound velocity in order to increase the redundance.

5. Problems to Be Resolved

The accurate calibration of the sand concentration meter presents certain difficulties as it is to be done full-scale. The influence of granulometry is to be examined during gauging work. The respective effects of sand grains and enclosed air bubbles are to be discerned. This can be done by means of the existing ultrasound wave gauges.

Some more experience is needed to find the best mechanical construction for the submarine unit, as to good hydrodynamic shape, sufficient resistance against damage, minimum affection by fouling etc.

6. Future Investigations

The sand discharge measuring device actually under development is expected to supply continuous data any time and at any weather condition (as to storm and wave heights), particularly in autumn and winter, the seasons of heaviest attacks to the shore. The actual object is to obtain one operational equipment, giving information about direction and magnitude of sediment transport during all tidal phases.

Integration of the x,y-components of the current vectors over the time (e.g. entire tides) and recording by a x-y-recorder will produce approximately the course of a fictive water particle (fig. 12), supposing that a uniform velocity field surrounds the measuring point. The vector from the beginning to the end of such a recording over an entire tide is considered as the remaining current vector. In the same way the sand discharge vectors may be recorded. The recording will supply an idea about the approximate remaining sediment transport vector, a very important information for shore protection work.

Another useful presentation of measured data will be the immediate display of the current velocity vector integrated over the time as before, directly correlated point by point to the correspondent sand concentration (fig. 13). This plotting allows to recognize at which tidal phases the maxima and minima of sediment load arise. It seems to be able to facilitate the comprehension of the mechanism of sediment transport.

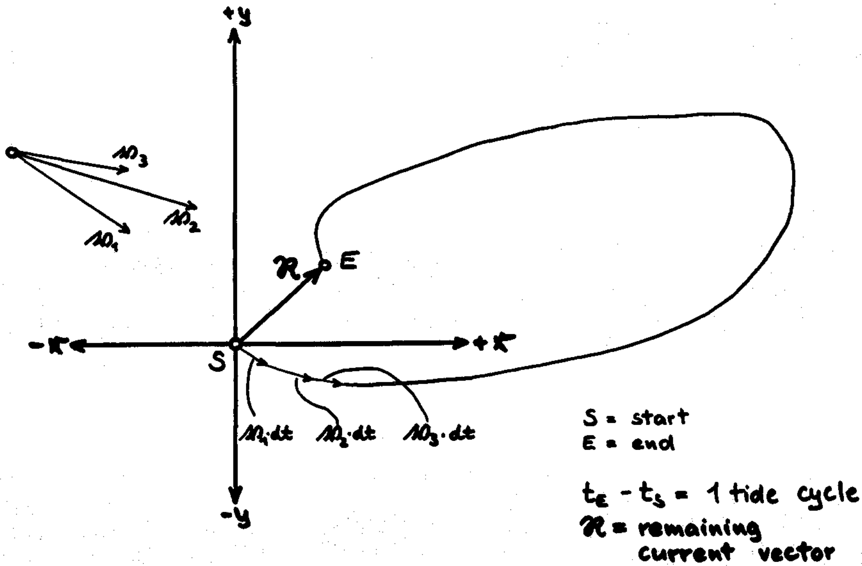


Fig. 12. Display of the remaining current vector.
v_1, v_2, v_3 = instantaneous current vectors

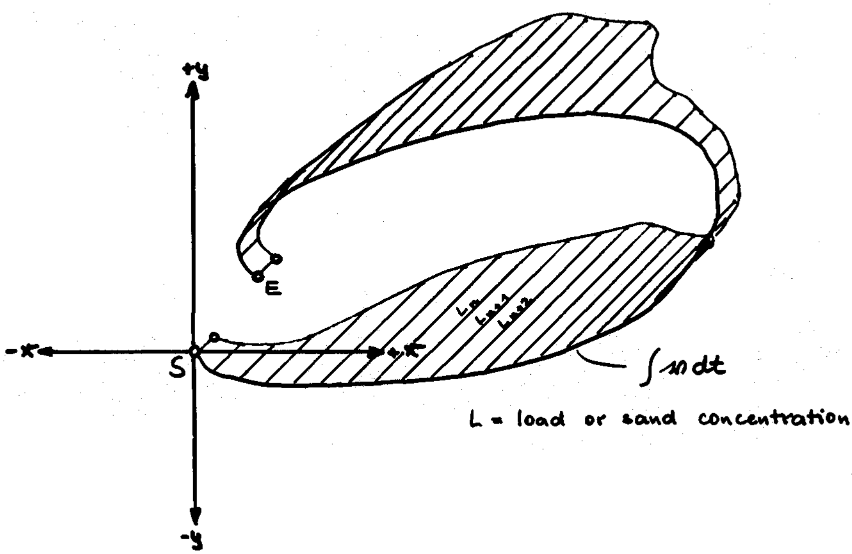


Fig. 13. Simultaneous display of current vectors and sand concentration

Formerly tracer measurements have been executed using radioactive and fluorescent tracers to study the sediment transport. They permit "static" measuring only of the sediment transport, as the tracer distribution is recorded at determined moments with rather long intervals. The processes between measuring moments are not stated. In order to obtain current information about sediment transport, "dynamic" measuring as by sand discharge measuring is necessary. For this purpose the aim is to install a series of equal stations supplying a reliable statement about erosion processes, when combined with energy balance considerations and tracer measurements.

7. Conclusions

Successful coastal engineering work at sand coasts subject to an important surf requires the knowledge of the erosion process. One way of investigational approach to this problem is the measurement of sand discharge in situ, at any time, particularly at heavy storm surges. An equipment for this purpose must be fit for severe environmental conditions. Using ultrasonic devices will allow to combine continuous current metering and continuous metering of sand concentration in the water. The arithmetical product of both will give the sand discharge through a definite area presented as a vector.

The feasibility of applying this method is demonstrated by the use of ultrasonic wave gauges, operated during periods of high waves. The sediment load in the water caused variable sound absorption. A first sand discharge measuring device is actually being developed. The principal problem to be resolved is to gauge accurately the sand concentration meter. The device is to be installed at the west coast of the island of Sylt (Germany).

8. Acknowledgements

The investigations leading to the conception of the sand discharge measuring device form part of the investigation program accompanying the beach nourishment of Westerland/Sylt.

This program as well as the beach nourishment were executed by the Land Schleswig-Holstein, Amt für Land- und Wasserwirtschaft Husum (formerly Marschenbauamt Husum) and financed by the Federal Republic of Germany and the Land Schleswig-Holstein, Ministries of Food and Agriculture.

REFERENCES

1. Bergmann, L.: Der Ultraschall. 6th ed., Stuttgart, S. Hirzel Verlag, 1954

2. Dietrich, G. and Kalle, K.: Allgemeine Meereskunde. 2nd ed., Berlin, Gebr. Borntraeger, 1965

3. Führböter, A., Köster, R., Kramer, J., Schwitters, J., and Sindern, J.: Sandbuhne vor Sylt zur Stranderhaltung. Die Küste, Heide, no 23, 1972, p. 1-62

4. Glover, J.R., Bhattacharya, P.K., and Kennedy, J.F.: An electrooptical system for measurement of mean and statistical properties of sediment suspensions. IIHR Report no 120, Iowa City, 1969

5. Kroebel, W. and Mahrt, K.-H.: Direct Precision Measurements of Sound Velocity and Discussion of Resulting Differences to Values Calculated from Salinity, Temperature and Pressure, Using the Wilson-Formula. Proceedings of Interocean '73, Düsseldorf, Vol. 2, Paper IO 73 - 655, 1973

6. Yalin, S.: Die theoretische Analyse der Mechanik der Geschiebebewegung. Mitteilungsblatt der Bundesanstalt für Wasserbau, Karlsruhe, no 8, 1957