CHAPTER 204

HOW TO ANALYSE BEACH PROFILE MEASUREMENTS ?

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1 INTRODUCTION

A manager of a sandy coastal area is by virtue of his or her profession interested in the behaviour of that coastal area. Is the coast eroding, accreting or, by chance, stable? And, if the coast is not stable: what are the erosion or accreting rates?
It is almost trivial to mention that the basic information can be acquired with a measuring program.

In collecting data almost always a more or less 'natural' evolution can be noticed. One starts often collecting data which can be simply acquired. E.g. aerial photographs or surveys of the position of the waterline only.

A next step in a 'natural' evolution consists often of more extended measurements. E.g. entire cross-sections are measured on a regular basis. These extended measurements are often necessary to really understand what happens with the coast. That doesn't mean, however, that the former, simple, measurements become useless. A special treatment is necessary to 'couple' the results of the simple measurements to the results of the extended measurements. If that is possible indeed, mostly a data set holding over a longer period can be acquired.

If, after a couple of years, a series of measurements is available, the question arises: how to analyse the data in order to get a clear insight in the behaviour of the coast?
In this contribution mainly two topics are discussed:

- analysis of entire beach profiles
- coupling procedures of 'simple' measurements to 'extended' measurements.

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2 BEHAVIOUR OF A STRETCH OF COAST

Fig. 1 shows in plan view a piece of a sandy coast. The coastal zone manager likes to know 'the' behaviour of stretch AB of the coast. Many coastal zone managers pay their attention often mainly to the behaviour as a function of time of the position of the waterline or line DD'. Line DD' is the so-called dune foot line; generally the transition between the beach and the mainland. Fig. 2 shows schematically what can occur as a function of time with the position of point P (see Fig. 1) with respect to an arbitrary reference line. The three possibilities, accreting, stable and eroding can simply be discerned.
We will confine ourselves further (mainly) to the eroding case.
To quantify reliably the rate of the average yearly retreat (that is in the simplified case of Fig. 2 the slope of the fitted line through the measuring points), is just a very important topic. These erosion-numbers are important, for instance, to predict the position of the coastline in near future.

Often a coastal zone manager is almost forced (e.g. by 'society') to combat the erosion. Counter-measures have to be taken to stop the erosion or to overcome the detrimental effects of the erosion. Planning and designing the appropriate counter-measures is only possible if one 'understands' what the real reasons are of the underlying erosion problem. It is self-evident that sediment transports are the basic reason of any coastal erosion problem.

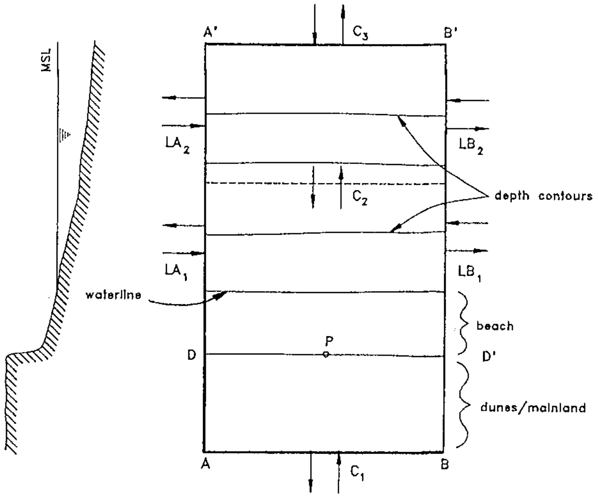

Fig. 1 Coastal processes in stretch of coast

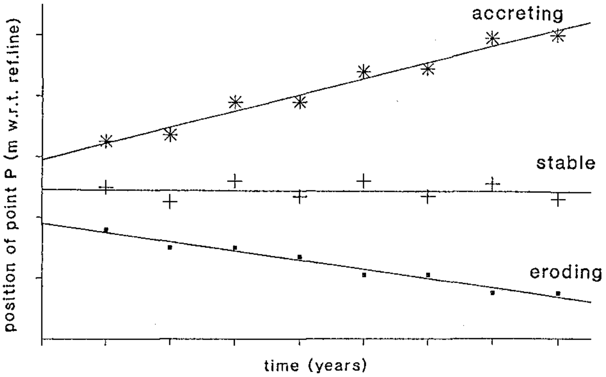

Fig. 2 Behaviour of coast as a function of time

In Fig. 1 some sediment transport vectors have been indicated; the magnitude of these vectors 'steer' the sand volume in the area AA' B' BA. A decrease of the volume of sand in that area is in principle the real reason of the erosion problem. So generally (gradients in) longshore transports and/or cross-shore sediment transports are the reason of the erosion problem.

In Fig. 1 the longshore transports have been split up in two components (LA_1 and LA_2 through section AA'; through section BB' similar). If desired, a further splitting up of the longshore transport in more vectors can be considered. (Or only one vector can be taken into account.)

Let us consider a time period of one year. In order to quantify the variation of the volume of sand in that year in the area AA' B' BA one has to calculate the yearly net transport of the contributions LA_1, LA_2, C_3, LB_2, LB_1 and C_1. However, due to very inaccurate sediment transport formulae and due to the often highly varying boundary conditions (like wave height, wave direction and tidal current velocities), it is in fact almost impossible to quantify the several yearly contributions properly.

In some classes of coastal erosion problems this calculation-first-method is in fact the only possibility to tackle the problem. In many other classes of problems, however, the 'field' shows already clearly the coastal behaviour (often an unacceptable erosion). A proper analysis of that behaviour may yield 'true' volume variation figures. Sediment transport calculations can be carried out next. If these calculations yield eventually similar results as the 'true' volume variations, the sediment transport calculation method can be used to predict (or better: to estimate) the behaviour of the coast in (near) future. E.g. changes in the coastline position due to expected changing boundary conditions can be estimated in this manner. Or, in cases without changing boundary conditions, the results of sediment transport calculations can be used as a more or less sophisticated extrapolation method. Most likely the calculated sediment transport rates depend for example on the actual position of the coastline; changing positions yield so different transports.

Artificial beach nourishments are nowadays increasingly considered and increasingly used as a fair method to solve erosion problems. [See e.g. Manual on Artificial Beach Nourishment (1987).] Also for the design of an artificial beach nourishment scheme a proper insight in the actual loss of sand out of the problem area is desired.

In conclusion it can be stated that it is essential to quantify the sediment volume (and its variation with time) in areas like area AA′B′BA in Fig. 1. In the next Section it will turn out that the selection of the proper boundaries of area AA′B′BA is in fact a difficult and also tricky task.

3 QUANTIFICATION OF VOLUME VARIATIONS

Whether a certain stretch of coast is considered or only a single cross-section, is not principally different. In the latter case the stretch of coast has (accidentally) a length of 1 m only!

Let us next consider a set of yearly measured cross-shore beach profiles. Let us assume that a set of 20 yearly measurements is available. Fig. 3 shows, as an example, the shape of the cross-sections for three distinct profiles from the series; the 17 other profiles have been left out to avoid confusion.

The aim of the analysis is to quantify (the trends in) the variations in the volume of sand in the cross-section. Cross-shore profiles can, however, be extended indefinitely. As well from a practical point of view as from a coastal morphological point of view, the length of cross-shore profile measurements must, however, be limited. A requirement for the length, covered by measurements, is that the so-called closure-points (depths) are included by the measurements.

In a beach profile in fact two closure-points can be discerned; a landward- and a seaward closure-point. The landward (seaward) closure-point in the profile is the position in the beach profile where landward (seaward) of that position apparently no systematic profile variations do occur. All systematic profile variations (losses and gains) take place consequently between the landward- and seaward closure-points (the so-called control area).

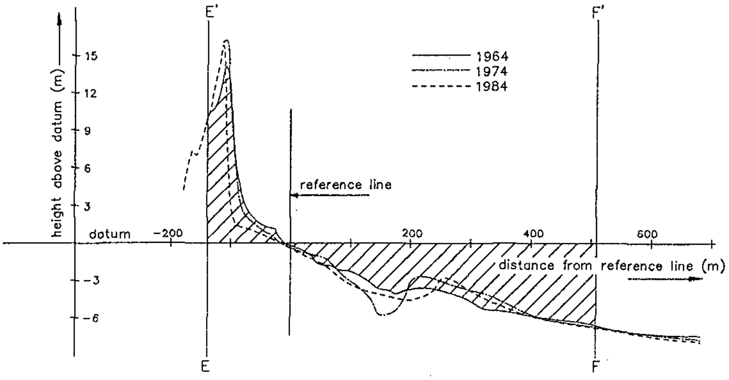

Fig. 3 Beach profile measurements in several years

Although this definition seems sound, in practice the relevant time- and length scales of the problem have also to be taken into consideration.
The loss of sand out of the control area through a chosen landward closure-position of say 1 m^3/(m year) due to landward directed winds, might be very important if the formation of dunes on a geological time-scale is considered. If, in contrast, the erosion problem in the lee-area of a newly built harbour is considered, the same loss of 1 m^3/(m year) plays most likely a minor role only.

In the present paper only classes of problems are considered where losses or gains (if any) out of the control area of orders of magnitude of 1 m^3/(m year) are negligible small.

If the series of profiles (represented by Fig. 3) are analysed, the choice of the landward closure-position is next relatively simple to make. By visual inspection the selection of line E' E seems to be a good choice. All profile fluctuations take apparently place seaward from line E' E.

The choice of the seaward closure-position (F' F) is far more difficult. In the example case of Fig. 3 the measurements have been extended over a distance of almost 1000 m. That seems rather long. However, even a visiual inspection yet of the measured profiles, points already to noticable fluctuations at the very seaward end of the profiles. That complicates much the selection of a reliable (so covering all relevant volume fluctuations) seaward closure-position.

Requirements for the selection of a single standard point as the seaward closure-position cannot be given. A procedure is, however, proposed which meets the proper selection problem to some extent. The analysis of the results of the proposed procedure will furthermore enlarge the insight in the morphological processes which apparently take place.

In the procedure as proposed the position of the seaward closure-position (in Fig. 3 the line F' F) is systematically varied. With the selected (fixed) landward- and (varied) seaward closure-position, the 'volume' of sand in the profile as has been indicated in Fig. 3, is calculated for each profile of the long-continued series of yearly measurements. In Fig. 3 the 'datum' level (e. g. mean sea level; MSL) is selected as reference level. The volume per running m of 'sand' above datum is considered as positive; the volume of 'water' below datum as negative.

In Fig. 4 the thus calculated volumes per running m have been plotted as a function of time. (Fig. 4 holds for the case that the position of F' F is selected at 510 m from the reference line; see Fig. 3.)

Although some scatter does occur, a distinct trend can be noticed in Fig. 4. If a linear trend line is fitted through the calculated volumes from the profile measurements (e. g. with a least square method), apparently an average yearly loss of sand occurs between the limits E' E and F' F of approximately 25 m^3/m. [According to Fig. 4 the resulting 'wet' volume (so negative values) of the profiles increases, so a loss of sand is found indeed; on an average of 25 m^3/(m year).]

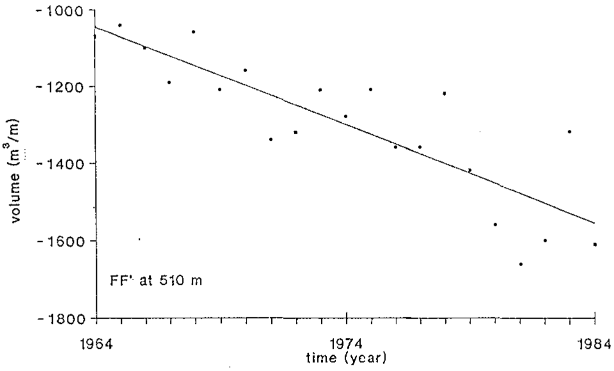

Fig. 4 Volume as a function of time

The standard deviation of the differences of the individual points of Fig. 4 with the fitted line is about 100 m^3/m. Real fluctuations in the volume of sand in the profile, but also measuring errors, contribute to that seemingly rather high value. A standard deviation in the volume of 100 m^3/m over 650 m of the profile (distance between E' E and F' F) yields a standard deviation per measuring point of about 0.15 m. That value is, however, a quite usual figure for the standard deviation of even the measuring errors only of this type of profile measurements. So 100 m^3/m is not unacceptable large.

Whether it is allowed to represent the results like in Fig. 4 by a simple straight line, has to be investigated from case to case. In some cases for example also periodic fluctuations with a period of several years can be discerned.

The result of Fig. 4 [loss of 25 $m^3/(m\ year)$] holds for the selected position of F' F. By varying the position of F' F different yearly losses (or gains) are found. Next a plot of the average yearly variation as a function of the position of F' F can be made. Fig. 5 shows four typical results of real Dutch cases. Fig. 6 shows the locations along the Dutch coast. All results are based on at least 20 yearly profile measurements (period: 1964 - present).

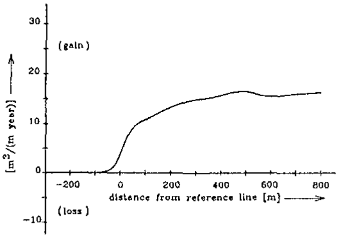

Fig. 5a Case 5a

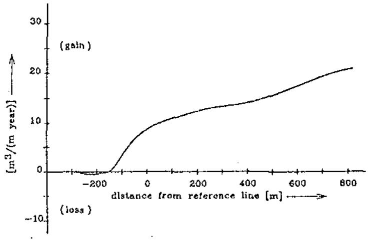

Fig. 5b Case 5b

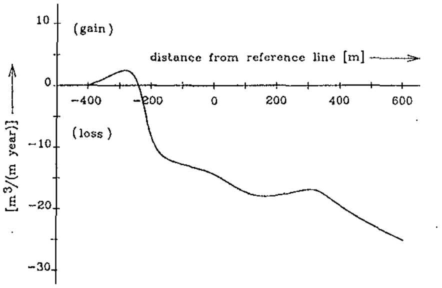

Fig. 5c Case 5c

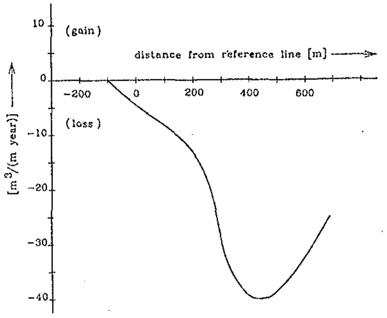

Fig. 5d Case 5d

Fig. 5a (an accreting case) is the easiest one to handle. It is apparently possible to select a proper (according to the definition) seaward closure-point. The horizontal course of the line seaward of say 500 m from the reference line means that from that position no additional losses or gains do occur. A slightly wrong selected seaward closure-position will not yield fundamentally different results. From Fig. 5a an indeed total gain of about 15 m^3/(m year) can be determined.

Fig. 5b (also an accreting case) is more difficult to handle. Apparently seaward from say 500 m from the reference line, still relatively large profile flucuations do occur; resulting in an ever increasing yearly accreting volume for the profile the farther the seaward 'closure-position' is selected. In fact a real closure-position is not yet reached with the present length of the profile measurements. Consequently the total (in this case) gain of sand in the profile cannot be determined. The description of 'the' behaviour of the beach profile as a function of time remains still open.

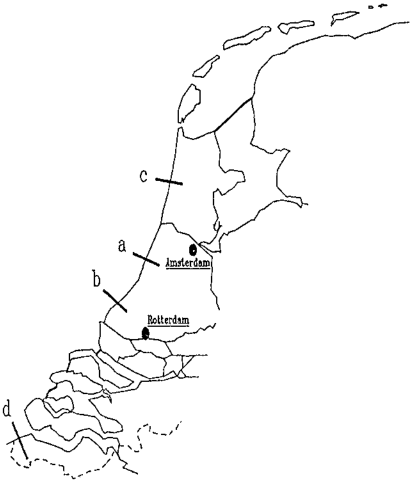

Fig. 6 Location of profiles along coast

Fig. 5c (an overall eroding case) shows a remarkable pattern. Starting from the landward closure-position (-400 m) and looking in seaward direction, first a small gain is noticed. (Apparently some sand is accumulated in the dunes seaward of the landward closure-position.) Further seaward an ever increasing erosion appears. Between -150 m and 300 m from the reference line the yearly rate of erosion does not change very much; however, seaward of 300 m the total average yearly erosion is ever increasing. Apparently due to additional losses in that area. Also in this case a description of 'the' behaviour of the beach profile is in fact impossible.

In Fig. 5d an ever increasing yearly erosion takes place up to 450 m from the reference line (average yearly erosion 40 m^3/m). Seaward of 450 m accumulation of sand does occur, resulting in an ever decreasing erosion figure. At the end of the measurements (approximately at 700 m from the reference line) the total erosion yields still yet approximately 23 $m^3/(m\ year)$.
Also in the case of Fig. 5d 'the' behaviour of the profile depends largely on the distance over which the profile fluctuations are considered.

4 DISCUSSION QUANTIFICATION OF VOLUME VARIATIONS

About 2000 cross-shore profiles are measured along the Dutch coast yearly. In most of these cases it is rather easy to find a reliable seaward closure-position; in many cases directly; in some other cases by some acceptable slight extrapolation. The cases of Fig. 5a up to 5d are in this respect by no means fully representative to the total Dutch situation. There remain, however, many cases where it is, notwithstanding the distance of often 800 m from the waterline over which profile measurements have been carried out, very difficult to determine the behaviour of the profile properly.

The question arises whether that is a real problem or in fact some kind of an artificial problem. If for instance in all cases a distance of up to say 600 m seaward of the reference line is considered, the gains or losses in just that zone can be calculated and can be taken as a basis for further considerations. It is of course next possible to calculate transport vectors holding especially for that part of the profile. In that case, however, an essential contribution to the sand-volume balance is then due to cross-shore transports through the vertical at 600 m from the reference line. (Cf. vector C_3 in Fig. 1.) Since the reliable computation of cross-shore sediment transports is often considered as far more difficult than the computation of longshore transports [see Van de Graaff (1988)], extra complicating elements are introduced in the entire analysis of the coastal behaviour. To analyse cases where real seaward closure-points are found, is far easier. Also in these cases cross-shore transports play their role in the behaviour of the coast, but they can, at least in first instance, be considered as a redistribution factor only. By cross-shore sediment transport processes, volumes of sand are redistributed over the active part of the profile; the real gains or losses are then mainly due to (gradients) in longshore sediment transport rates.

In conclusion it can be stated that seaward closure-points are extremely important in coastal morphology studies. Along the Dutch coast these seaward closure-points are sometimes apparently situated beyond the limits of the standard yearly measurements. (Sometimes beyond approximately 800 m from the position of the waterline.)
If 'new' standard measuring programmes are planned, it is recommended to extend the measurements beyond the seaward closure-point.

5 MEASUREMENTS OF CHARACTERISTIC DEPTH CONTOURS

Often series of measurements of only some characteristic depth contours are longer lasting than series of regularly measured entire beach profiles.

In the Netherlands, for instance, over approximately 140 years results are available of yearly measurements of the position of the MLW -, the MHW - and the Dune Foot line for each kilometer of the Dutch coastline. (Systematic entire profile measurements for each 200 - 250 m along the coast are available in the Netherlands over 'only' 25 years; for some portions of the coast longer lasting series.)
This long lasting series can in principle serve as a very valuable data base.

A plot of e.g. the MHW -line in a cross-section as a function of time, shows often a lot of scatter (in the Netherlands these plots are therefore often indicated with 'lightening-plots'). With filter-techniques often clear trends can be derived of such long series of measurements; sometimes even clear long-periodic fluctuations can be noticed in the plots.

For many phenomenological studies these measurements are very valuable. The coastline behaviour from the past to present can be described with the help of these measurements. The measurements can also be fruitfully used to predict the position of the coastline in (near) future. (Some extrapolation is probably allowed.)
From the results even time-average yearly erosion - or accreting rates can be derived. However, these rates are expressed in m/year.

As has been discussed in Section 2 the real reason of coastline development with time is due to variations of sediment transports along the coast and sediment transports in the cross-shore direction. And to understand what really happens, insight in these actual sediment transports is necessary. A time-average coastline recession rate of say x m/year is in reality associated with a loss of sand out of the beach profile of y m^3/(m year). The latter value is next directly associated with (gradients in) sediment transport rates. [Also eventually expressed in m^3/(m year).]

Consequently the use of long lasting series of measurements of the position of a few depth contours only in sediment transport studies, calls for conversion factors. (E.g. what is the relationship between x and y as mentioned in the preceding paragraph?)

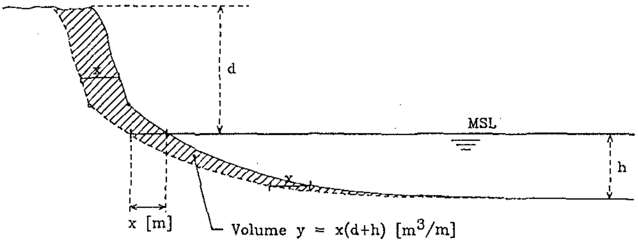

Fig. 7 Eroding beach profile behaviour

Fig. 7 shows a rather simple model to derive a conversion factor. In the sketch of Fig. 7 it is assumed that the shape of the active profile remains constant. A yearly retreat of the 'coastline' with x m means that all depth contours in the active part of the profile will retreat with the same x m. If this model is true y and x are related as follows:

$$y = x\ (d + h) \qquad (1)$$

where: y : average yearly loss/gain of volume of sand in the beach profile [m^3/(m year)]
x : average yearly erosion/accretion of the 'coastline' (e.g. average position of MLW- and MHW line) [m /year]
d : height of dunes/mainland above MSL [m]
h : depth of seaward closure-point below MSL [m]

An arbitrary selection of 23 cases has been made, more or less regularly divided along the Dutch coast. Only 14 cases have been ultimately used in the further analysis. In these 14 cases the time-averaged yearly losses or gains exceed 10 m^3/(m year). (If the yearly losses or gains are too small the accuracy of the conversion factors to be derived, becomes too low.)

The series of measurements of entire beach profiles have been used (more than 20 yearly measurements). Of these profiles also the average position of the MLW- and MHW line (so say the coastline) has been determined.

Two methods to check Eq. (1) have been used.
In Method I plots have been made of the average position of the MLW- and MHW line in every year versus the volume of sand in every year. (To determine the volume of sand in the beach profiles the entire measured profiles have been used. According to Fig. 5 it is not quite sure that the relevant volume is covered entirely in all cases.) The trend line through the more than 20 yearly measurements has next been calculated. The slope of that trend line yields an estimate of the ratio y/x, so an estimate of a proper conversion factor. In Fig. 8a that conversion factor is compared with the height (d + h). [The magnitude (d + h) has been measured from profile measurements.]
It is remarkable that the conversion factor as calculated with Method I is in all cases smaller than (d + h). The 4 cases with time-average yearly losses/gains which are larger than 30 m^3/(m year) score relatively better than the other cases.
In 4 cases it was clear (from figures like Fig. 5) that the real control area is not covered by the measurements and that y is consequently underestimated. That could be a reason of the low conversion factors as derived in comparison with the height (d + h) in these cases. (In 8 cases of Fig. 8a the proper control area was covered by the measurements.)

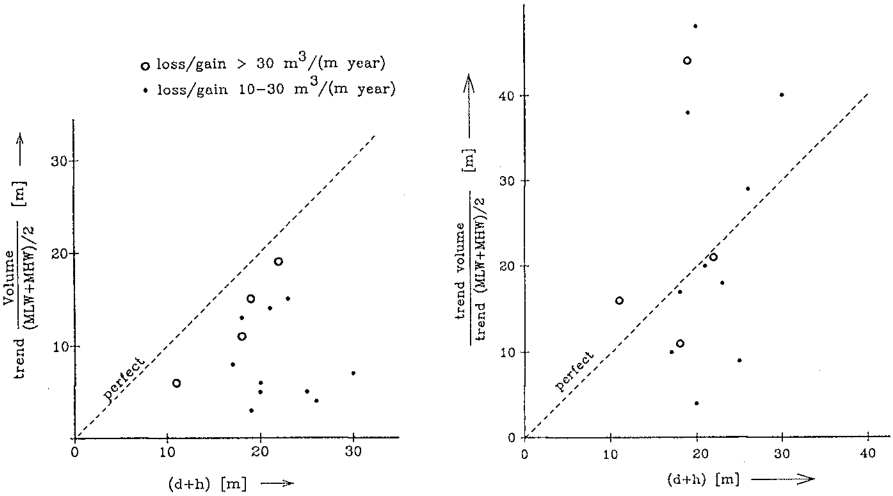

Fig. 8a **Conversion factor versus (d + h)** **Fig. 8b**

In Method II first linear trend lines have been determined in plots showing the volume as a function of time as well as in plots showing the average position of the MLW- and MHW lines. Next the two resulting trends have been divided, yielding an other estimate for a conversion factor. Fig. 8b shows the comparison between this conversion factor and the height (d + h). A great deal of scatter can be noticed. Under-estimations as well as over-predictions can be observed in this comparison.

6 DISCUSSION MEASUREMENTS CHARACTERISTIC DEPTH CONTOURS

The Method I and Method II to calculate a conversion factor, yield different results. (Method I is felt to be slightly 'better' than Method II.) In both cases, however, large differences do exist from the simple model according to Fig. 7. That means in fact that, based on the results of this research, a single simple conversion factor does not exist. So it is still difficult to couple series of measurements of a few characteristic depth contours to series of measurements of entire profiles. It is not excluded, however, that with longer joint series (longer than say 20 - 25 years) a more conclusive result will be obtained.

If the results of Fig. 8a are considered as 'true', the basic idea of Fig. 7 (a constant shape of the profile) does apparently not hold. Due to the general under-estimation two hypotheses can be considered to 'explain' the behaviour, viz.:

a) systematic flattening of the entire profile
b) (temporarily) steepening of the profile

Re a)
If the beach profile flattens systematically the (e.g.) regression of the MLW- and MHW lines is faster than the deeper depth contours. The associated volume loss out of the profile is consequently less than expected from Fig. 7.

Re b)
In a structural eroding beach profile the erosion of the dunes or mainland occurs mostly more or less shock-wise. Under usual conditions the erosion of the beach and foreshore takes already gradually place, but the dunes or mainland are not reached by the water and waves. The erosion of the dunes 'waits' for rather rare more severe conditions. The profile adjustments in the dunes 'necessary' according to the model of Fig. 7, can only occur during a storm (surge). Especially if rather short series are considered (however, is 20 - 25 years short ?), it is not excluded that the necessary adaptations in the dunes or mainland have not yet been finished due to lack

of stormy weather. Due to the storm (surge) the volume of sand in the profile will not change in principle, but the position of the MLW- and MHW lines will do.

7 CONCLUSIONS

- Systematic measurements of entire beach profiles are indispensable in analysing the behaviour of coasts (coastlines).
- Insight in systematic volume changes in profiles (losses/gains) is an important analysing goal of profile measurements.
- Even very good (rather long lasting) series of entire profile measurements (like in the Netherlands) cannot always analysed straightforwardly.
- The length over which the measurements extend in seaward direction calls for special attention (often too short).
- 'New' series of systematic measurements should be analysed as soon as possible in order to check whether the measurements fulfil the requirements. (The set-up of the measurements have to be adapted possibly.)
- With a restricted number of arbitrary selected beach profiles along the Dutch coast as basis, it turned out to be very difficult to determine a simple conversion factor to couple series of measurements of a few characteristic depth contours and series of measurements of entire beach profiles.

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