Delft University of Technology

Dune erosion prediction methods incorporating effects of wave periods

van Gent, Marcel R. A.; Coeveld, E. Martijn; de Vroeg, Hans; van de Graaff, Jan

DOI
10.1061/40926(239)46

Publication date
2007

Document Version
Final published version

Published in
Coastal Sediments '07

Citation (APA)
van Gent, M. R. A., Coeveld, E. M., de Vroeg, H., & van de Graaff, J. (2007). Dune erosion prediction methods incorporating effects of wave periods. In NC. Kraus, & J. Dean Rosati (Eds.), *Coastal Sediments '07: Proceedings of the sixth international symposium on coastal engineering and science of coastal sediment processes* American Society of Civil Engineers (ASCE). https://doi.org/10.1061/40926(239)46

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright
Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy
Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.

This work is downloaded from Delft University of Technology.
For technical reasons the number of authors shown on this cover page is limited to a maximum of 10.

Green Open Access added to TU Delft Institutional Repository

'You share, we take care!' - Taverne project

https://www.openaccess.nl/en/you-share-we-take-care

Otherwise as indicated in the copyright section: the publisher is the copyright holder of this work and the author uses the Dutch legislation to make this work public.

DUNE EROSION PREDICTION METHODS INCORPORATING EFFECTS OF WAVE PERIODS

Marcel R.A. van Gent[1], E. Martijn Coeveld[1], Hans de Vroeg[1], Jan van de Graaff[2]

1. Delft Hydraulics, Wave Dynamics & Structures Group, P.O. Box 177, 2600 MH Delft, The Netherlands, Marcel.vanGent@wldelft.nl, Martijn.Coeveld@wldelft.nl, Hans.deVroeg@wldelft.nl.
2. Delft University of Technology, Section of Hydraulic Engineering, P.O. Box 5048, 2600 GA Delft, The Netherlands, J.VanDeGraaff@TUDelft.nl.

Abstract: Recently, the influence of wave periods on dune erosion was studied in a series of large-scale physical model tests (Van Gent *et al.,* 2006). In these tests dune erosion was simulated under extreme storm conditions. The aim of the study presented in this paper was to develop dune erosion prediction methods that take effects of wave periods on dune erosion into account. An existing dune erosion prediction method was used as starting point for the development. The obtained prediction method will be used to evaluate the dunes along the Dutch coast, where longer wave periods occur than previously assumed.

1 INTRODUCTION

Dunes in The Netherlands act as primary sea defense for the lowlands behind them. Since this is a densely populated area, it is important to assess their safety against flooding. Therefore, the strength of the dunes needs to be predicted under the hydraulic loads in a normative storm surge. In The Netherlands the normative conditions refer to rather small chances of failure ($\approx 10^{-4}$ to 10^{-5} per year). The strength of the dunes can be determined by predicting the volume of dune erosion during an extreme storm. Failure of the dunes takes place when the rate of dune erosion is so large that flooding of the lowlands behind the dunes occurs. In The Netherlands dune erosion is predicted by using rather simple empirical relations (Vellinga, 1986). These predictions are mainly based on the cross-shore dune profile before a storm, the expected storm surge level, the wave height at deeper water, and characteristics of the sediment.

Recent insights led to the conclusion that wave periods during an extreme storm event along the Dutch coast could be longer than previously assumed. In order to achieve information on possible effects of longer wave periods, large-scale physical model tests were performed in the Delta flume of Delft Hydraulics (Van Gent *et al.,* 2006). These tests indicated that the eroded dune volume increases for longer wave periods (*e.g.* an increase in the wave period of 50% led to an increase in dune erosion volumes of 15% to 25%). However, the method to predict dune erosion that has been applied in The Netherlands does not account for the influence of the wave period. Therefore, the aim of this study is to extend the existing method taking the effects of the wave period into account using the data obtained from the tests.

2 APPROACH

The scope of this study allowed only for an extension of a yet existing method for predicting dune erosion instead of developing an entirely new method. Several concepts of incorporating effects of wave periods into the existing formulations were already developed based on existing data and insights before the recent data from large-scale model tests (Van Gent *et al.*, 2006) became available. These large-scale dune erosion tests were used to verify and to optimize the developed concepts. The dune erosion prediction method that was used as a starting point in this study is described hereafter. A summary of the most important results of the recent large-scale dune erosion tests is also presented in this section.

2.1 Current dune erosion prediction method

In the safety assessment which is presently applied for the Dutch dunes (based on the method described by Vellinga, 1986), use is made of a 2DV description of the dune erosion profile after a very severe storm event with a characteristic significant wave height and water level. With this description of the shape of the dune erosion profile, the location of the dune erosion profile can be obtained by horizontally moving the shape of the dune erosion profile over the initial profile until the total erosion volume is equal to the total accretion volume, see Figure 1. This provides a prediction of the dune erosion volume above storm surge level (*A* in Figure 1). If this volume exceeds the initial volume above storm surge level, flooding occurs. This prediction method will from hereon be referred to as the 'current method'.

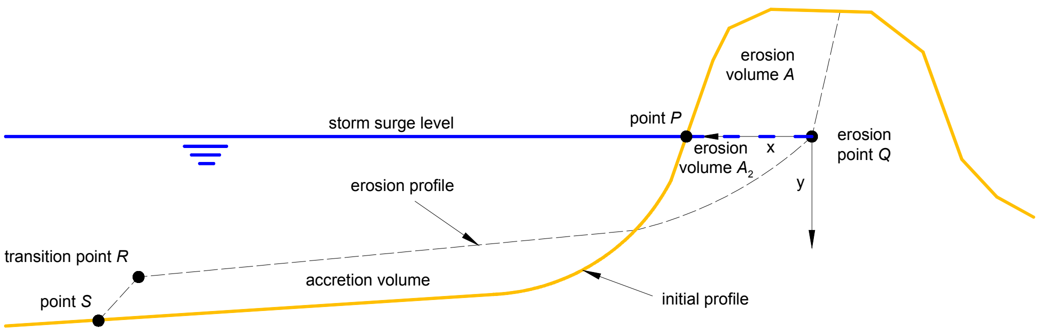

Fig. 1. Definition of characteristic erosion profile, erosion volumes and (erosion) points in a cross-shore profile.

The derived equation for the erosion profile (between point Q and R in Figure 1) is described by Vellinga (1986) and reads:

$$\frac{7.6}{H_{0s}} \cdot y = 0.4714 \left[\left(\frac{7.6}{H_{0s}} \right)^{1.28} \cdot \left(\frac{w}{0.0268} \right)^{0.56} \cdot x + 18 \right]^{0.5} - 2.0 \qquad (1)$$

where H_{0s} = significant wave height at a depth of Datum -20 m (m); w = fall velocity of a grain of sand with diameter $D = D_{50}$ (m/s); y = depth beneath storm surge level (m); and x = horizontal cross-shore distance from point Q (see Figure 1) positive in seaward direction. Point Q is defined at the maximum storm surge level and forms the origin $x = 0, y = 0$ in Equation 1. Equation 1 describes the erosion profile between point Q and transition point R, which is described by:

$$\begin{aligned} x_R &= 250 \cdot \left(\frac{H_{0s}}{7.6} \right)^{1.28} \cdot \left(\frac{0.0268}{w} \right)^{0.56} \\ y_R &= 5.717 \cdot \left(\frac{H_{0s}}{7.6} \right) \end{aligned} \qquad (2)$$

The upward slope on the landward side ($x < 0$ and $y < 0$) is fixed at 1:1. The slope on the seaward edge between the erosion profile and the initial profile (between point R and S in Figure 1) is fixed at 1:12.5.

The equations above were derived on the basis of many experiments including series of large-scale tests for a basic situation with a wave height of H_{0s} = 7.6 m (prototype value) and sediment fall velocity of w = 0.0268 m/s. This basic situation can be clearly recognized as reference values in the equations. The equations were derived for waves with a peak wave period T_p = 12 s, corresponding to a wave steepness of $H_{0s} / L_0 = H_{0s} / 1.56 \cdot T_p^2 = 0.034$. Delft Hydraulics (1982a) states that the method is only valid for situations in which (1) the maximum storm surge level minus 1 m is exceeded for 5 to 6 hours, (2) the grain size diameter is 150 μm < D_{50} < 400 μm, and (3) the wave steepness is larger than H_{0s}/L_0 = 0.02. It is also noted that a post-storm beach profile as measured shortly after the storm will be a little lower than the predicted profile, because of a redistribution of sand after the peak of the storm.

2.2 Results of large-scale dune erosion tests

Large-scale dune erosion tests with different wave periods (Van Gent *et al.,* 2006) were carried out to provide the data necessary to verify the developed concepts. In the tests use was made of the same initial coastal profile (see Figure 2) based on a profile that is considered as characteristic for the Dutch coast. To translate this prototype profile to a model that fits in the flume, use was made of the set of scaling relations derived by Vellinga (1986) that was based on an extensive series of dune erosion tests on different scales and with different sediment diameters (see Section 3.3). In the present tests, geometrically distorted models needed to be applied to properly model the fall velocity of the sediment with respect to the other relevant parameters. The dune erosion tests were carried out with a depth scale of $n_d = 6$. Sediment with a diameter of $D_{50} = 200$ μm was applied in the tests and a wave height of H_{m0} = 1.5 m. The tests used here were performed with a Pierson-Moskowitz spectrum with peak wave periods that varied from T_p = 4.9 s to T_p = 6.12 s to T_p = 7.35 s (model values), denoted with T01, T02 and T03 respectively. This corresponds to peak wave periods of T_p = 12 s, T_p = 15 s and T_p = 18 s in prototype. This means that there is an increase in wave periods (T_p, $T_{m-1,0}$ and T_m) with 50% between conditions T01 and T03. Note that T01 was performed with the same wave period as the condition on which the current method was based.

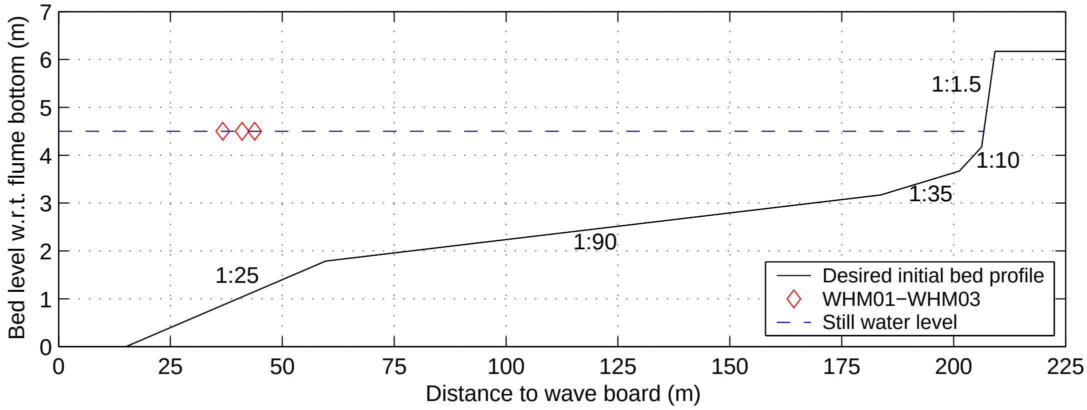

Fig. 2. Initial bed profile (WHM = wave height meter).

During the development of the current dune erosion prediction method (Section 2.1), a characteristic storm duration was defined at maximum storm surge level. This storm duration was 5 hours. At a depth scale of $n_d = 6$, a prototype storm duration of 5 hours corresponds to a test duration of 2.04 hours ($2.04 = 5 / \sqrt{n_d}$). The tests were carried out with a constant water level.

The tests included measurements of the bed profile, wave conditions, flow velocities and sediment concentrations. Furthermore, particle size distributions and fall velocities were determined for several sediment samples.

Figure 3 shows a comparison of the bed profile measurements after 6 hours (model scale) for Tests T01, T02 and T03. This figure shows that the retreat of the dune face (the relative steep part of the bed profile above the still water level) is largest in Test T03 (with the longest wave period) and smallest in Test T01 (with the shortest wave period). The differences in the shape of the bed profile for different wave periods are small, but the changes in dune foot location, slope of the beach profile and the shape of the deposit area for increasing wave periods are consistent. The dune foot is located at the intersection of the relatively steep dune face and the beach just in front of the dune face. It appears that the horizontal position of the dune foot moves more landward for the longest wave period, while the vertical position of the dune foot hardly varies. The slope of the bed profiles around and below the still water level is a bit gentler for the longest wave period. The seaward edge of the deposit area is located farther seaward in Test T03 than in Test T01. Dune erosion volumes were obtained from the bed profile measurements. The volumes were based on the difference between the initial profile and the profile measured after a certain period of time. Tests T01 and T03 have each been repeated. Repetition of the tests led to differences of less than 2.5% in the total eroded volumes after 1, 2 and 6 hours. The differences after 0.1 and 0.3 hour were slightly larger. This indicates that the reproducibility of the results of the tests is good. Hereafter, for Tests T01 and T03 the average of the two test results with equal wave conditions has been used.

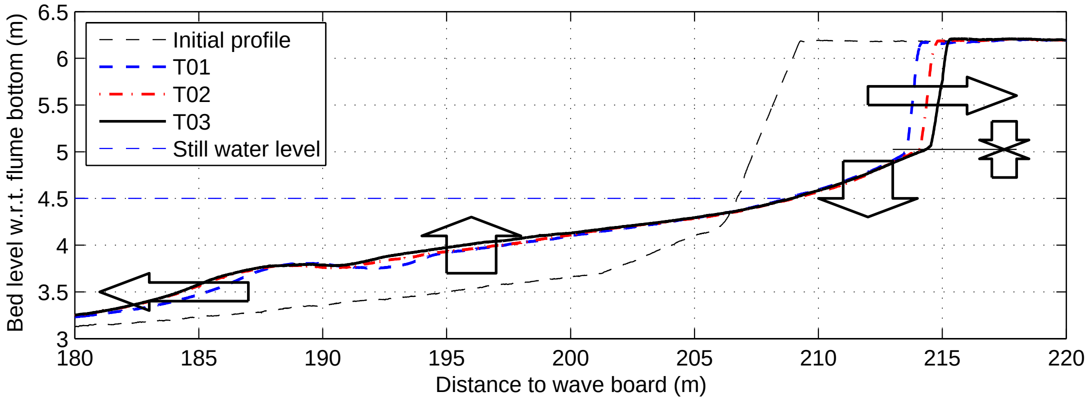

Fig. 3. Comparison of measured bed profiles after 6 hours (model scale) in Tests T01, T02 and T03 and indications of qualitative effects of wave period on erosion profile.

It was found that after 2.04 test duration (*i.e.* 5 hour storm duration in prototype) the dune erosion volume above the still water level increases with 24 % for an increase in wave period with 50% (Figure 4b). It should be noted that an equilibrium situation has not yet been established at that stage, see for example the development of the erosion volume above the still water level with time in Figure 4a.

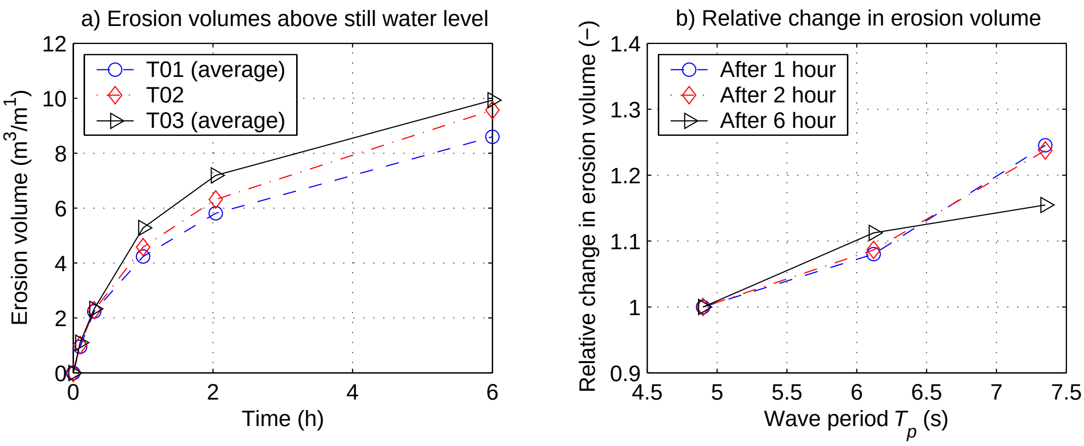

Fig. 4. Development of erosion volume above still water level (a) with time (left) and (b) depending on the wave period (right).

3 NEW DUNE EROSION PREDICTION METHODS

In this section new deterministic dune erosion prediction methods to take effects of the wave period into account will be discussed. These methods have the current method as a starting point. The methods were initially based on data that were already available prior to the execution of the described large-scale tests (Van Gent *et al.,* 2006). With the results of these large-scale tests, the methods were calibrated and evaluated. The methods are subdivided into two categories (1) period-dependent erosion volumes, and (2) period-dependent erosion profiles. In the first category, the shape of the erosion profile as described in Section 2.1 by Equations 1 and 2 remains unchanged and effects of the wave period on dune erosion are taken into account by means of a horizontal translation of the erosion profile based on an additional volume of dune erosion. This volume can be expressed as a function of the wave period (or wave steepness). Methods in this category are discussed in Section 3.1. In the second category, Equations 1 and 2 are extended in order to include effects of the wave period. Methods in this category are discussed in Section 3.2.

3.1 Category 1: Period-dependent erosion volumes

The first method, Method 1, is based on the assessment of a factor P_{extra} for the extra volume of dune erosion (= $P_{extra}\cdot A$) due to effects of an increased wave period compared to the condition for which the current method was derived. This method results in a dune erosion volume of $(1+P_{extra})\cdot A$, in which A is the erosion volume above the water level calculated with the current prediction method, see Section 2.1.

This method can be considered as an extension of earlier methods described in Delft Hydraulics (2006) that were based on a limited number of small-scale tests reported in Delft Hydraulics (1982b). By also using small-scale tests by Coeveld *et al.* (2005) an improved fit could be made, resulting in the following relation between the wave steepness and the dune erosion volume:

$$\begin{cases} \dfrac{H_{0s}}{L_0} < 0.015 & P_{extra} = 0.31 \\ 0.015 \le \dfrac{H_{0s}}{L_0} \le 0.04 & P_{extra} = -16.5\left(\dfrac{H_{0s}}{L_0} - 0.034\right) \\ \dfrac{H_{0s}}{L_0} > 0.04 & P_{extra} = -0.10 \end{cases} \qquad (3)$$

This method was not adjusted based on the large-scale tests, although the large-scale tests showed less dependency on the wave period than Equation 3 (based on small-scale tests) would suggest. With Equation 3 an erosion volume is obtained, but not yet a dune erosion profile. In order to find also a shape of the dune erosion profile with this method it was chosen to deduce information on the erosion profile by letting the newly obtained dune erosion volume be the target volume in a series of iterative dune erosion predictions with the current prediction method. In the iterative predictions the diameter of the sand is reduced until the target volume is obtained.

3.2 Category 2: Period-dependent erosion profiles

In this category two methods are considered, Method 2a and Method 2b. In Method 2a the dune erosion profile beneath storm surge level and the transition between the dune erosion profile and the initial profile are modified. A new equation was derived for the erosion profile using a methodology similar to the one applied in Delft Hydraulics (1982a). In Delft Hydraulics (1982a) the available profiles were all based on tests with a (prototype) peak wave period of about $T_p = 12$ s. Here, data from small-scale tests, including tests with other wave periods, were used for the derivation of Method 2a. Method 2a was not adjusted based on the results from the described large-scale tests. Also similar scaling relationships have been assumed here. This yielded a modified erosion profile beneath storm surge level, with gentler profile slopes for larger wave periods. Method 2a is described by Equation 4:

$$\frac{7.6}{H_{0s}} \cdot y = 0.4714 \cdot \left[\left(\frac{7.6}{H_{0s}} \right)^{1.28} \cdot \left(\frac{w}{0.0268} \right)^{0.56} \cdot x + \frac{\left(T_p + 6\right)^2}{18} \right]^{0.5} - \left(\frac{T_p + 6}{9} \right) \tag{4}$$

This equation gives the same result as Equation 1 for a peak wave period of $T_p = 12$ s, and the location of the dune foot does not shift (in other words: if $y = 0$ then $x = 0$). The slope between point R and S (see Figure 1) is equal to the slope in the current method (1:12.5). The transition point R is located at:

$$\begin{aligned} x_R &= 250 \cdot \left(\frac{H_{0s}}{7.6} \right)^{1.28} \cdot \left(\frac{0.0268}{w} \right)^{0.56} \\ y_R &= \left(\frac{H_{0s}}{7.6} \right) \cdot \left[0.4714 \cdot \left(250 + \frac{\left(T_p + 6\right)^2}{18} \right)^{0.5} - \left(\frac{T_p + 6}{9} \right) \right] \end{aligned} \tag{5}$$

This implies that the horizontal position of the transition point (x_R) relative to the dune foot is equal to the position in the current method. Since the erosion profile between the dune foot and the transition point changed (Equation 4 instead of Equation 1), the vertical position of the transition (y_R) is different.

Similar as for Method 2a, also for Method 2b the dune erosion profile beneath the storm surge level and the transition between the dune erosion profile and the initial profile are modified. The dune erosion profile is modified in a rather straightforward way, viz. by adding a term $(12 / T_p)^{\alpha}$ as indicated in Equation 6. In this way, the term for the wave period is included in a similar way as the wave height and the fall velocity (effect relative to reference value):

$$\frac{7.6}{H_{0s}} \cdot y = 0.4714 \cdot \left[\left(\frac{7.6}{H_{0s}} \right)^{1.28} \cdot \left(\frac{12}{T_p} \right)^{\alpha} \cdot \left(\frac{w}{0.0268} \right)^{0.56} \cdot x + 18 \right]^{0.5} - 2.0 \qquad (6)$$

The exponent α was initially determined with a fitting procedure on data from small-scale tests at α = 0.5. The validation with the large-scale tests led to a small adjustment of this exponent to α = 0.45. For wave periods longer than T_p=12 s, a smaller value for α leads to a smaller landward shift of the dune face and shows a steeper bed profile below the still water level. Equation 6 gives the same result as Equation 1 for a peak wave period of T_p = 12 s, and the location of the dune foot does not shift (in other words, if $y = 0$ then $x = 0$). The slope between point R and S (see Figure 1) is equal to the slope in the current method (1:12.5). The transition point R (see Figure 1) is located at:

$$\begin{aligned} x_R &= 250 \cdot \left(\frac{H_{0s}}{7.6} \right)^{1.28} \cdot \left(\frac{0.0268}{w} \right)^{0.56} \\ y_R &= \left(\frac{H_{0s}}{7.6} \right) \cdot \left[0.4714 \cdot \left(250 \cdot \left(\frac{12}{T_p} \right)^{\alpha} + 18 \right)^{0.5} - 2 \right] \end{aligned} \qquad (7)$$

3.3 Evaluation of prediction methods

The dune erosion prediction methods presented in Sections 3.1 and 3.2 were verified with the measurements of Tests T01, T02 and T03 (see Section 2.2). The validation was carried out by comparing the measured and predicted erosion profiles and erosion volumes above the still water level. For the comparison of the predicted and measured profiles reference is made to Figure 3, which summarizes the qualitative effects of the wave period on the shape of the erosion profile.

Scale relations

Because the prediction methods should be applied for prototype conditions, all measured bed profiles are translated to a prototype situation for this purpose. Use is made of the set of scaling relations described by Vellinga (1986):

$$\begin{aligned} n_l &= n_l \cdot \left(\frac{n_d}{n_w^2} \right)^{0.28} \\ n_H &= n_d \\ n_T &= n_t = n_d^{0.5} \end{aligned} \qquad (8)$$

where n_l = scale factor for horizontal geometrical measures ($n_l = x_{proto} / x_{model}$); n_d = scale factor for vertical geometrical measures; n_w = scale factor for the fall velocity of the sediment; n_H = scale factor for the wave height; n_T = scale factor for the wave period;

and n_t = scale factor for the time. Vellinga (1986) concluded that the hydraulic and morphologic processes need to be scaled with the same time scale factor to appropriately simulate dune erosion on a smaller scale.

The fall velocity scale factor n_w in Equation 8 is obtained by dividing the prototype value of the fall velocity by the model value. For the prototype fall velocity a value of w = 0.0268 m/s is chosen, which was also used in earlier analyses and corresponds with the fall velocity of a grain diameter of D_{50} = 225 µm. To obtain a prototype profile the horizontal dimensions of the model are multiplied with the horizontal length scale factor n_l, and the vertical dimensions (*e.g.*, water depth and wave height) with the depth scale factor n_d. Prototype values for the wave period and the time at which profile measurements were carried out are obtained by multiplying the model values with the square root of the depth scale factor n_d. By multiplying the measured dune erosion volume (per linear meter) with $n_A = n_l \cdot n_d$ the prototype volume is obtained.

Comparison of prediction methods

A comparison between prediction methods is discussed here, primarily focused on the prediction of dune erosion volumes, not on the prediction of dune erosion profiles.

The current method, derived for a wave period of T_p=12 s, over-predicts the erosion volume above still water for this basic condition. This current method is used as starting point for the new methods. The new methods that take into account an extra amount of dune erosion for longer wave period will therefore also over-predict the measured dune erosion volumes, see left panel in Figure 5. Therefore, to obtain better insight into the relative performance of the methods, the erosion volumes have been normalized for T_p = 12 s, see right panel in Figure 5.

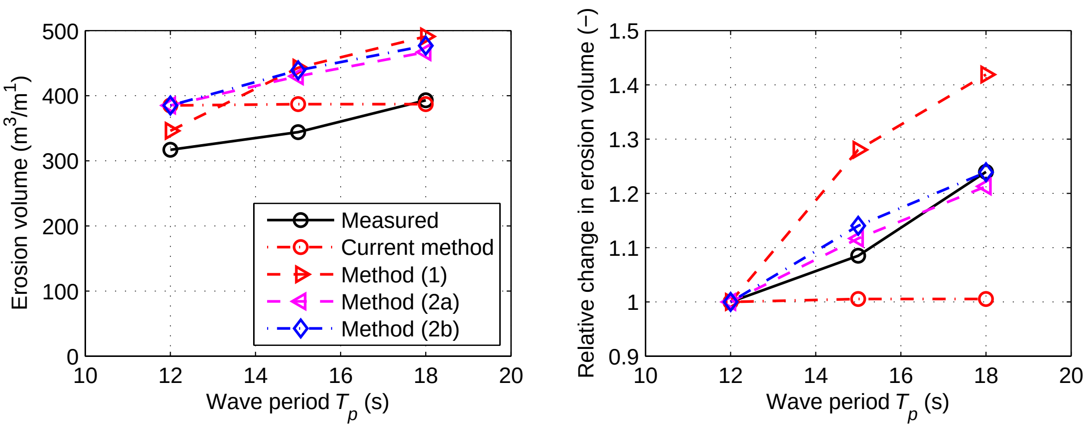

Fig. 5. Measured erosion volumes (translated to prototype) and predicted erosion volumes above still water level and change in erosion volume relative to volume in Test T01 (T_p = 12s)

For all three methods, the predicted erosion volume increases more between T_p = 12 s and T_p = 15 s, than between T_p = 15 s and T_p = 18 s, while for the measurements the opposite applies. Nevertheless, the predicted relative change in erosion volume between T_p = 12 s and T_p = 18 s corresponds best to the measurements when using Method 2a or Method 2b.

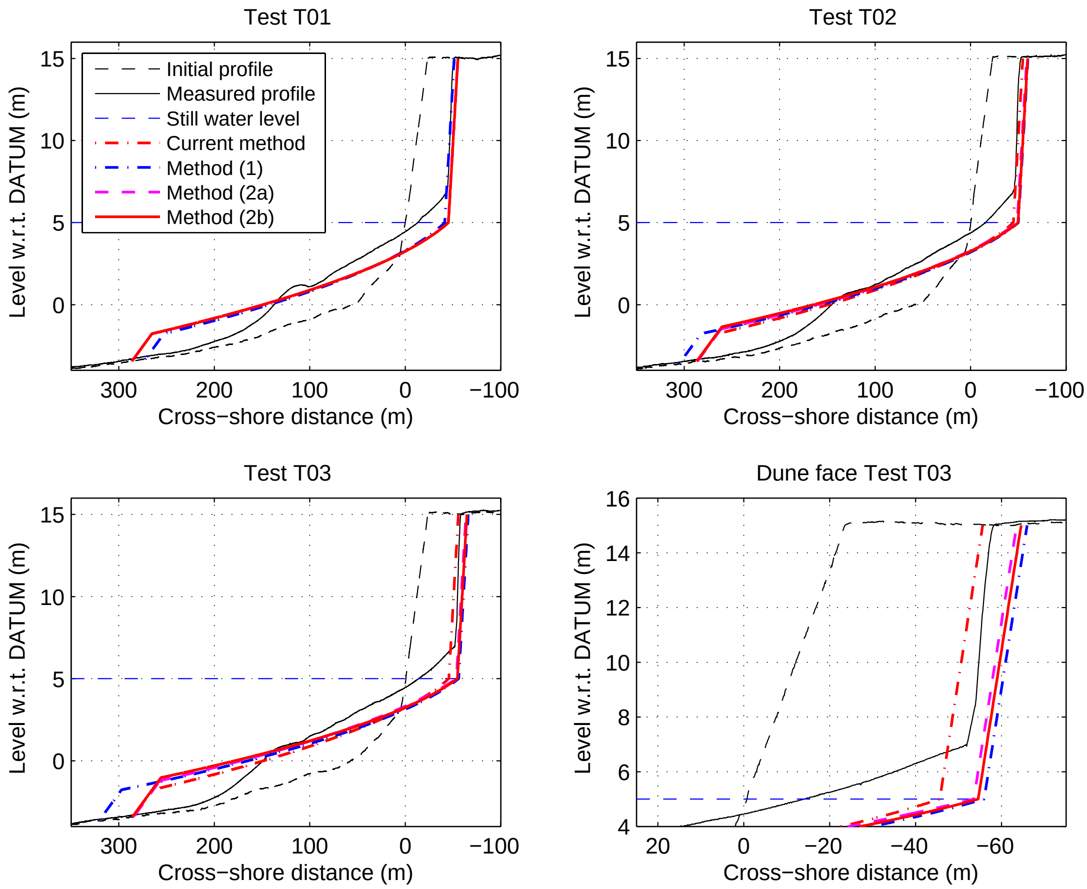

Fig. 6. Measured bed profiles (translated to prototype) and bed profiles predicted with Methods (1), (2a) and (2b) for Tests T01 (T_p = 12 s), T02 (T_p = 15 s) and T03 (T_p = 18 s).

The main goal of the prediction method is to predict the dune erosion volume. Nevertheless, attention is also paid to several aspects of the predicted bed profiles. Figure 6 shows measured and predicted bed profiles for Tests T01, T02 and T03 translated to a prototype situation. The bed profiles predicted with the current method (which is used as a starting point for the other methods) are equal in all tests, because the current method does not take the wave period into account. Furthermore, the following can be observed:

- With the current method the horizontal position of the dune face is predicted more landward than the measured position for Test T01. For Test T03 the opposite applies. By definition, the vertical position of the dune foot predicted with the current method is located at the still water level, while the measured location of the dune foot is well above the still water level. The horizontal position of the dune face predicted with Methods 2a and 2b corresponds reasonably well with the measurements.

- The slope of the predicted profile directly seaward of the dune face is less steep than the measured profile. The correspondence of the bed profile below the still water level predicted with Methods 2a and 2b and the measurements is poor, which is also the case for the current method.
- The predicted deposit area extends significantly more seaward than the measured deposit area. Method 1 shows a larger influence of the wave period on the length of the deposit area, than the predictions of Methods 2a and 2b.

In general, the bed profile predictions do not correspond very well with the measurements irrespective of which prediction method is used. Because this is also the case for the current method, while the current method is used as a starting point for the new methods, no significant improvements can be expected with the new methods with respect to predicted bed profiles. The same is valid for the vertical position of the dune foot.

Influence of wave spectra on dune erosion
Based on dune erosion tests with double-peaked wave energy spectra Van Gent *et al.* (2006) concluded that the influence of wave spectra on dune erosion is more appropriately taken into account using the wave period $T_{m-1,0}$ than using the peak wave period T_p. The wave period $T_{m-1,0}$ can be incorporated in Equations 6 and 7 in the following way:

$$\frac{7.6}{H_{0s}} \cdot y = 0.4714 \cdot \left[\left(\frac{7.6}{H_{0s}} \right)^{1.28} \cdot \left(\frac{10.9}{T_{m-1,0}} \right)^{0.45} \cdot \left(\frac{w}{0.0268} \right)^{0.56} \cdot x + 18 \right]^{0.5} - 2.0 \qquad (9)$$

and

$$x_R = 250 \cdot \left(\frac{H_{0s}}{7.6} \right)^{1.28} \cdot \left(\frac{0.0268}{w} \right)^{0.56}$$
$$y_R = \left(\frac{H_{0s}}{7.6} \right) \cdot \left[0.4714 \cdot \left(250 \cdot \left(\frac{10.9}{T_{m-1,0}} \right)^{0.45} + 18 \right)^{0.5} - 2 \right] \qquad (10)$$

The value 10.9 is based on the fact that the ratio $T_p/T_{m-1,0}$ comes close to a value of $T_p/T_{m-1,0} = 1.1$ for a standard single-peaked spectrum such as the Pierson-Moskowitz spectrum applied in the tests on which Equations 1-7 are based. Figure 7 shows the measured erosion volumes and the volumes predicted with Method 2b based on Equations 9 and 10.

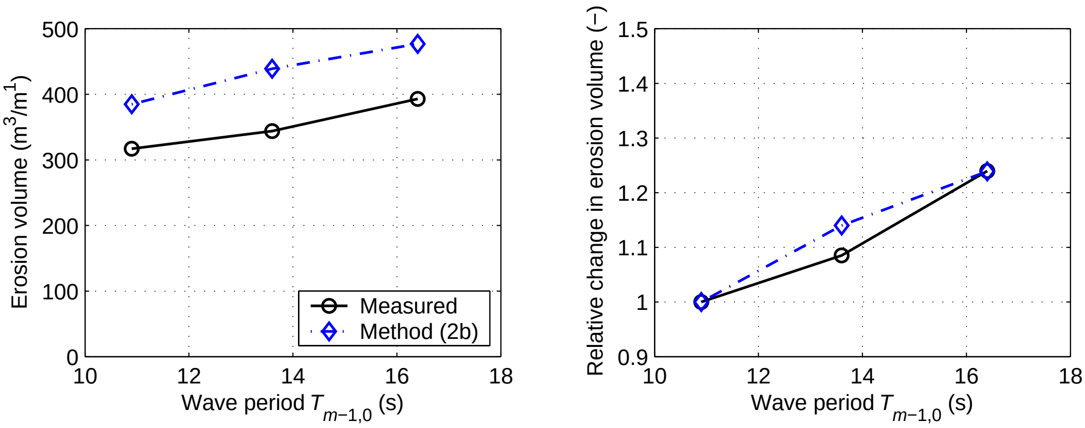

Fig. 7. Measured erosion volumes (prototype) and volumes predicted with Method 2b (Equations 9 and 10) and change in erosion volume relative to Test T01 ($T_{m\text{-}1,0}$ = 10.9 s).

4 DISCUSSION

4.1 Application of selected dune erosion method

Method 2b is selected to replace the current dune erosion prediction method in the safety assessment procedure for the Dutch dunes in the coming years, because of its simplicity.

Figure 8 shows the sensitivity of Method 2b to the input parameters H_s and $T_{m\text{-}1,0}$. A higher wave height leads to a longer deposition area, a more landward located dune face and a larger dune erosion volume. A longer wave period leads to gentler slopes of the bed profile below the still water level, a more landward located dune face and a larger dune erosion volume.

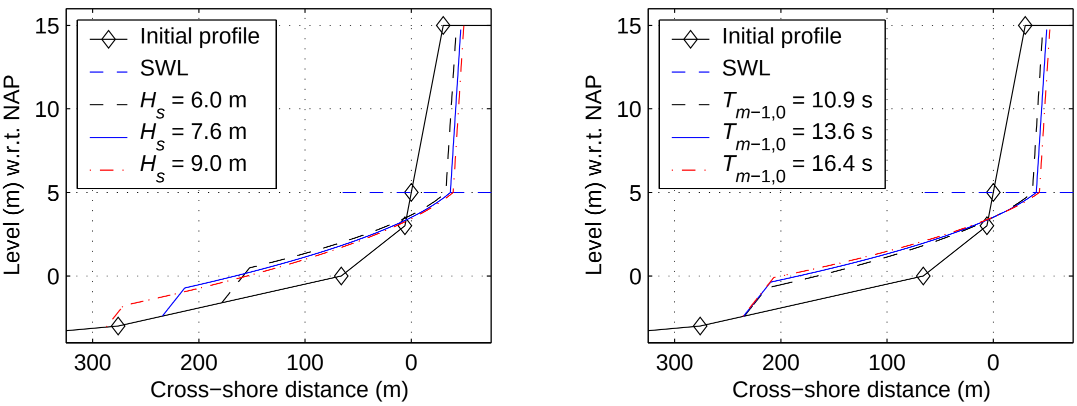

Fig. 8. Sensitivity of Method 2b to input parameters.

An example application of Method 2b is presented in Figure 9. The figure compares the current and the new dune erosion prediction method for a cross-section of an arbitrary Dutch dune for an extreme event. It shows that Method 2b predicts more dune erosion than the current method for the hydraulic conditions indicated in the figure. Obviously, the current method would have predicted the same bed profile for other wave periods.

The increase in erosion volume above the still water level between T_p = 12 s and T_p = 18 s is about 23 %, which agrees well with the observed increase in erosion volume in the physical model tests. It should be noted that the effects of the wave period on dune erosion depend on the initial bed profiles or hydraulic condition if they deviate significantly from the situation in the tests. Different initial profiles may lead to a significantly larger or a significantly smaller dependency on the wave period.

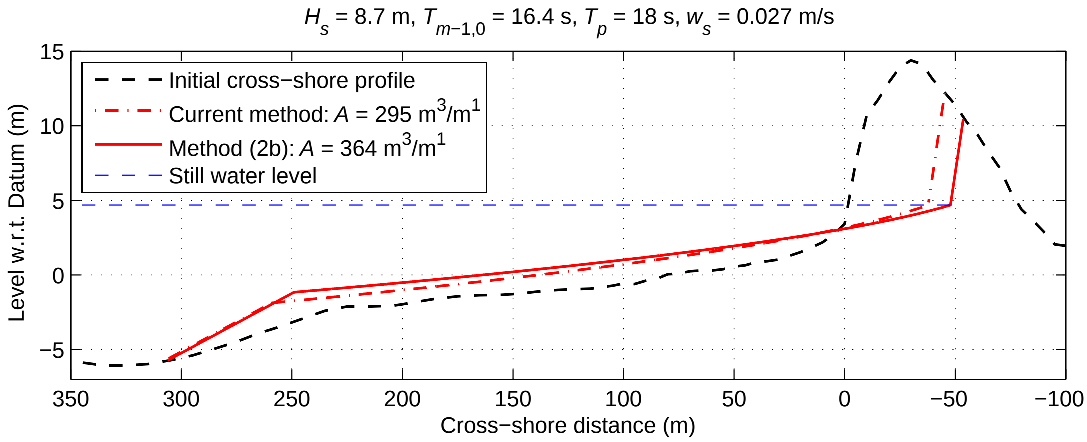

Fig. 9. Example application of current and new dune erosion prediction method for a cross-section of a dune (dashed line = initial bed profile, solid line = predicted erosion profile).

Method 2b has the same range of validity as the current method (see Section 2.1), except that for the wave steepness this method is considered valid for a wider range. Because of the limited amount of data for smaller wave periods, it is recommended to use Method 2b only for conditions with a deep water wave steepness of $0.02 < s_{m-1,0} < 0.063$ (or for standard single-peaked wave energy spectra of $0.017 < s_p < 0.04$).

4.2 Future developments

The method described above provides an indication of dune erosion volumes under extreme storm conditions. Because it is an empirical method, its validity is quite limited. For instance, the development and duration of a storm are strongly schematized, and the influence of the initial cross-shore profile cannot always be correctly reproduced. It is desirable to have methods available that do also account for these effects. Therefore, it is useful to develop a dune erosion prediction method that simulates dune erosion processes rather than an empirical representation of these processes. The large-scale tests will be analyzed to gain more insight into the physical processes underlying dune erosion.

5 CONCLUSIONS

The aim of the study was to develop a dune erosion prediction method that takes effects of the wave period on dune erosion into account. The dune erosion prediction method by Vellinga (1986) was used as a starting point for the new prediction method. Several prediction methods were developed on the basis of existing data and verified with the bed profiles and erosion volumes measured in recent large-scale dune erosion tests.

Based on the comparisons of predictions and measurements of dune erosion, it can be concluded that the relative increase in dune erosion volume for increasing wave periods observed in the tests corresponds well with the predictions of the newly developed methods. The new method can be used to predict dune erosion volumes, including effects of wave period. However, the shape of the bed profile below the still water level is not very well predicted. This is also the case for the current prediction method by Vellinga (1986). The new and current methods are therewith not very suitable to predict the bed profile below the still water level.

ACKNOWLEDGEMENTS

This research was carried out in an assignment of the National Institute for Coastal and Marine Management of the Dutch Ministry of Transport and Public Works. Dr. M. Boers of this institute is acknowledged for his contribution to this research.

REFERENCES

Coeveld, E.M., den Heijer, C., Van de Graaff, J., De Vroeg, J.H., and Steetzel, H.J. (2005). "The effect of the wave period on dune erosion", *ASCE, Proc. of 5th Int. Conf. on Coastal Dynamics 2005*, Barcelona, Spain.

Delft Hydraulics (1982a). "Computational model for the estimation of dune erosion during storm surge", (Rekenmodel voor de verwachting van duinafslag tijdens stormvloed.) Delft Hydraulics report M1263 part IV (in Dutch).

Delft Hydraulics (1982b). "Systematic investigation of parameters relevant for dune erosion", (Systematisch onderzoek naar kenmerkende factoren voor duinafslag.) Delft Hydraulics report M1819 part 1 (in Dutch).

Delft Hydraulics (2006). "Dune erosion, Deterministic dune erosion prediction methods", Delft Hydraulics Report H4357, January 2006, Delft.

Van Gent, M.R.A., Coeveld, E.M., Walstra, D.J.R, Van de Graaff, J., Steetzel, H.J. and Boers, M. (2006). "Dune erosion tests to study the influence of wave periods", *Proc. of 30th ICCE*, San Diego, USA.

Vellinga, P. (1986). "Beach and dune erosion during storm", Ph.D. thesis, Delft University of Technology; see also Delft Hydraulics Communication 372 and Report M1263-IV.

View publication stats