CREST LEVEL ASSESSMENT OF
COASTAL STRUCTURES BY
FULL-SCALE MONITORING,
NEURAL NETWORK PREDICTION
AND HAZARD ANALYSIS
ON PERMISSIBLE WAVE OVERTOPPING

CLASH

EVK3-CT-2001-00058

R E P O R T

Neural Network

Manual NN_OVERTOPPING 2

Clash: Workpackage 8

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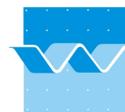
wL | delft hydraulics

Contents

1   Introduction

1.1   General

In this manual, the use of the program **NN_OVERTOPPING 2** is described. The purpose of this document is to provide guidance on the use and handling of the prediction tool developed for the estimation of mean overtopping discharges at various types of coastal structures. Details of the methodology followed for the development of the prediction tool are described in Pozueta *et al.* (2004) and Van Gent *et al.* (2004). The output of this program tool includes the Neural Network prediction of the mean overtopping discharge at a coastal structure and several other parameters indicating the uncertainty of the prediction.

The program **NN_OVERTOPPING** was developed by DELFT HYDRAULICS. The study on which this tool is based was co-sponsored by the Commission of the European Communities within the framework of the CLASH project ('Crest Level Assessment of Coastal Structures by full scale monitoring, neural network prediction and Hazard analysis on permissible wave overtopping', contract EVK3-2001-00058).

The predictions based on the Neural Network can be used for the conceptual design of coastal structures; they may not be used in the final design stage, since the results should be verified based on dedicated physical model tests for the particular wave conditions and structure geometry of the structure to be built. The predictions are based on a data-set based on small-scale physical model tests; the predictions are to some extent affected by model effects, scale effects (see deliverable D40 from the CLASH project), limited accuracy of measurement equipment, limited accuracy of wave generation techniques (compared to nowadays state-of-the-art techniques), inconsistencies in the data-set, and lack of data in certain fields of application. Although reliability levels are given in addition to the predictions, these reliability levels do not account for most of these influences. Therefore, the Neural Network predictions may only be used as first estimates of mean overtopping discharges.

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Because programs are inherently complex and may not be completely free of errors, the user shall validate his work. The user shall satisfy himself that the software provides satisfactory solutions.

1.2   Background

For the prediction of the mean overtopping discharge a Neural Network model is used in **NN_OVERTOPPING 2**. This model was derived by DELFT HYDRAULICS from 8372 input-output

combinations obtained from measurements performed in hydraulic scale models at several institutes (Aalborg University, Denmark; Danish Hydraulic Institute, Denmark; DELFT HYDRAULICS, The Netherlands; Hydraulic Research Wallingford, UK; Leichtweiss Institute für Wasserbau, WKS+GWK, Germany; Modimar, Italy; University of Edinburgh, United Kingdom; Universidad Politécnica de Valencia, Spain; and others in Iceland, Japan, Norway and U.S.A).

1.3   Outline

Following this general introduction, Chapter 2 provides the structure of the program and the description of the parameters involved in the prediction tool. Then, Chapter 3 provides an explanation of the estimation and schematisation of the hydraulic and structure parameters. Finally, Chapter 4 describes the use of **NN_OVERTOPPING 2,** including:

i.   a description of the contents and organisation of the input file that must be prepared for **NN_OVERTOPPING 2,** (see Section 4.3).

ii.   a description of the contents and organisation of the output file that will be produced by **NN_OVERTOPPING 2,** (see Section 4.4).

iii.   and the guidelines to run **NN_OVERTOPPING 2**, i.e. the procedure that must be followed to obtain the output file of (ii) given an appropriately generated input file in (i), (see Section 4.5).

2   Structure of the program

2.1   File structure

This section briefly describes the structure of the program. The complete system **NN_OVERTOPPING 2** consists of three files, **NN_OVERTOPPING.EXE, NN_OVERTOPPING. NTD** and **NN_OVERTOPPING. LIC**. These three files will become available to the user once the setup procedure is performed. A brief description of these files is given below. The details of the setup procedure are given in Section 4.1.

Nevertheless, in order to execute the program, an input file, **NN_OVERTOPPING.INP,** must be prepared and placed in the directory where the program will be executed. The first time the model is run, the output file **NN_OVERTOPPING.LIS** will be created. For subsequent runs, the old version will be destroyed and again created for the present application. While the model is running, an error file, **NN_OVERTOPPING.ERR**, will also be created. In case no errors occur during the execution, the error file will be automatically erased before the application is finished. A more detailed description of the input, output an error files is given in Sections 4.3, 4.4 and 4.5.

NN_OVERTOPPING.EXE :   An executable to predict the mean overtopping discharge at coastal structures given user-supplied input parameters that characterise the geometry of the structure together with geometric sea-related conditions in front of that structure, and parameters describing the wave field.

NN_OVERTOPPING. NTD :   A configuration file used by **NN_OVERTOPPING.EXE**. This configuration file must be in the same directory as **NN_OVERTOPPING.EXE**. If this binary file is removed, renamed, changed, or corrupted, **NN_OVERTOPPING.EXE** will be aborted immediately.

NN_OVERTOPPING. LIC :   A license file used by **NN_OVERTOPPING.EXE**. This license allows the use of the tool **NN_OVERTOPPING**. This file must be in the same directory as **NN_OVERTOPPING.EXE**.
If this file is removed, renamed, changed, or corrupted, **NN_OVERTOPPING.EXE** will be aborted immediately.

NN_OVERTOPPING 2 can be applied on personal computers (Windows XP) using MS-DOS as operating system. The minimum hardware and software specifications for proper use of the software are:
- Microsoft Windows 98 / 2000 / XP / NT environment
- INTEL Pentium 1 GHz processor or similar
- 128 Mb internal memory
- 10 Gb available hard disk memory

2.2   Required input information

An input pattern consists of the following 15 parameters. A more detailed description of these parameters is given in Section 3.

β : direction of wave attack w.r.t. to the normal of the structure [°]
h : water depth in front of the structure [m]
$H_{m0,toe}$: significant wave height at the toe of the structure obtained from spectral analysis, $H_{m0,toe} = 4\sqrt{m_0}$ [m]
$T_{m-1,0\,toe}$: mean wave period at the toe of the structure obtained from spectral analysis, $T_{m-1,0\,toe} = m_{-1}/m_0$ [s]
h_t : water depth on the toe of the structure [m]
B_t : width of the toe of the structure [m]
γ_f : roughness/permeability of the structure [-]
$cot\ \alpha_d$: slope of the structure downward of the berm [-]
$cot\ \alpha_u$: slope of the structure upward of the berm [-]
R_c : crest freeboard of the structure [m]
B : width of the berm [m]
h_b : water depth on the berm [m]
$tan\ \alpha_B$: slope of the berm [-]
A_c : armour crest freeboard of the structure [m]
G_c : crest width of the structure [m]

Figure 1 shows a graphical illustration of the meaning of the fifteen parameters used as input to the program.
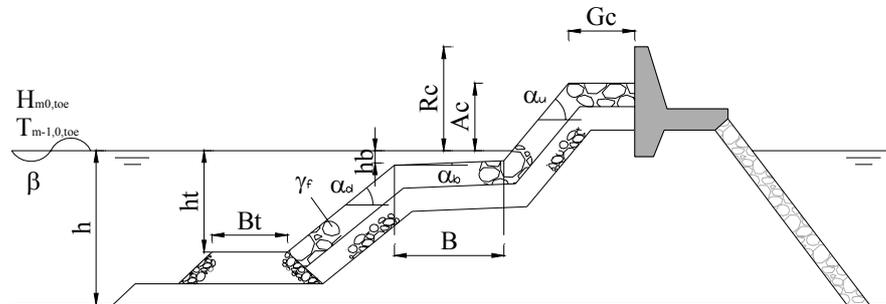
Figure 1 Parameters used for the NN modelling of wave overtopping discharge at coastal structures

For each user-supplied set of input parameters [H_{m0}, $T_{m-1,0}$, β, h, h_t, B_t, γ_f, $cot\ \alpha_d$, $cot\ \alpha_u$, B, h_b, $tan\ \alpha_b$, R_c, A_c, G_c], the output of the prediction tool **NN_OVERTOPPING 2** includes the mean overtopping discharge (q), and 7 other output values indicating the quantiles of several orders, $q_{2,5\%}$, $q_{5\%}$, $q_{25\%}$, $q_{50\%}$, $q_{75\%}$, $q_{95\%}$ and $q_{97,5\%}$.. The 95% confidence interval is, for instance, given by the quantiles $q_{2.5\%}$ and $q_{97.5\%}$.

3   Determination of parameters

This section briefly describes how to estimate some of the hydraulic parameters required by the program when these are not available, and how to determine the required structure parameters for any arbitrary structure and for rather complicated coastal structures. A more extensive description can be found in Appendix A.

3.1   Determination of hydraulic parameters

Often some of the hydraulic parameters might not be directly available. In these cases, the following estimations or calculations can be applied:

- If only the deep water wave characteristics are available and not the wave characteristics at the toe of the structure, the calculation of the wave characteristics at the toe of the structure can be performed with the model 'SWAN'.

- If only the wave height from time domain analysis, H_s, is available, the wave height from spectral domain analysis, H_{m0}, can be determined with Battjes and Groenendijk (2000).

- If only the wave period from time domain analysis is available, the estimation of the wave period from spectral analysis can be made by means of empirically determined proportions of wave periods available in literature, such as the following (Goda and Nagai, 1974; Goda, 1985), which can be used for single-peaked wave energy spectra with a spectral shape similar to Jonswap spectra.

$$T_p \approx 1.05 \ T_{1/3}$$
$$T_p = 1.2 \ T_m$$
$$T_{m-1,0} \approx T_p \ / \ 1.1$$

3.2   Determination of structure parameters

Most coastal structures can be relatively well schematised by means of the 12 structure parameters presented in Section 2. For the correct use of this prediction tool it is important that all parameters are determined in the same way. In the following, a brief description indicating how to determine these 12 structure parameters for an arbitrary structure is given.

3.2.1   Toe, berm and crest of the structure

Three parts can be distinguished in an average coastal structure, the lower part (or **toe**), the centre part (eventually with a **berm),** and the upper part (or **crest)**. The separation of these three parts of the structure is not always that clear and depends on the hydraulic conditions and structure shape. In this way, the same structure could have a different schematisation for a different water level and different wave attack. Figure 2 shows the three parts of a typical coastal structure, where the Centre part corresponds to the area within the vertical distance

1.5*$H_{m0,toe}$ above and below the sea water level, and the Upper and Lower parts correspond to the areas above and below the Centre part, respectively.
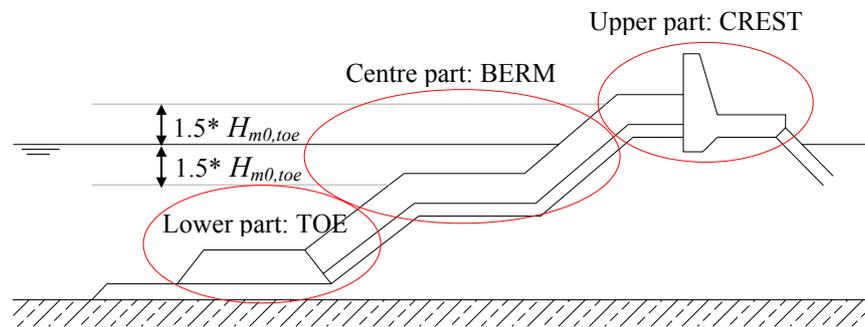
Figure 2 Parts of a coastal structure

The toe of the structure is normally situated in the lower area of the structure. Nevertheless, in some cases the toe can also be located at the centre part of the structure (e.g. structure with quite large toe situated in relatively shallow water). In this case, the toe can be taken into account as a berm, as shown in Figure 3.

A berm is always located in the centre area of the structure. If the 'berm' is situated lower, then it is considered as a toe (as shown in Figure 3), while if it is situated higher, then it is considered as a crest. Some further restrictions exist regarding the definition of a berm. These are described in TAW (2002).
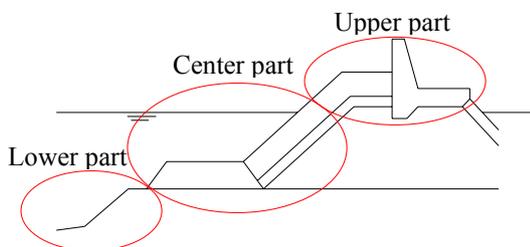
Figure 3 Toe schematised as a berm   Figure 4 Berm schematised as a toe
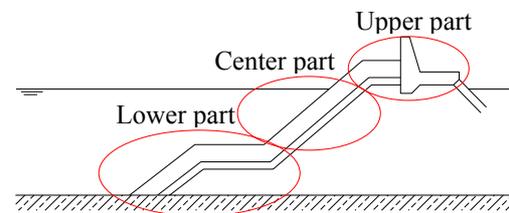
A crest of a structure is situated normally in the upper area of a structure. However, there are also exceptions in this case (e.g. in very low structures the crest can be a part of the centre area).

3.2.2 Structure parameters

In the following, a detailed explanation regarding the determination of each of the 12 structure parameters is given.

− h [m]: This is the water depth at the toe of the structure, more precisely the water depth just before the structure.

- h_t [m], B_t [m]: These are the water depth on the toe and the width of the toe. The width of the toe is measured on top of the toe. If there is no toe, the value of the water depth on the toe is the same as the water depth in front of the structure $h_t = h$. In this case the width of the berm B_t is equal to zero.

- B [m], h_b [m], $tan\ \alpha_B$ [-]: These parameters describe the berm of the structure. B is the berm width, measured horizontally. h_b is the water depth on the berm, measured in the middle of the berm. If the berm is situated above swl, h_b is negative. $Tan\ \alpha_B$ is the tangent of the slope of the berm. If the berm is horizontally, $tan\ \alpha_B = 0$.

- R_c [m], A_c [m], G_c [m]: These parameters describe the upper part of the structure. R_c is the crest freeboard of the structure; that is, the distance, measured vertically from the still water level (swl) to the highest impermeable point of the structure. This means that at this point, waves are stopped by the structure. A_c is the armour crest freeboard of the structure; that is, the distance, measured vertically from the swl to the highest point of the armour on the structure. G_c is the crest width. In the case that a crest is constructed on the structure, G_c is the width of the armour in front of the crest element.

- $cot\ \alpha_d$ [-], $cot\ \alpha_u$ [-]: These parameters are used to describe the slope(s) of the structure. The toe and the crest of the structure are already described in other parameters, therefore they are not included in these two parameters. $cot\ \alpha_d$ and $cot\ \alpha_u$ are the cotangents of the mean slopes in the centre area of the structure under (cot α_{down}) and above (cot α_{up}) the berm respectively. The upper slope α_u can be determined by taking the point of the structure at a level of $1.5*H_{m0\ toe}$ above the swl and connecting it with the point of the berm farthest from the sea. If the crest of the structure is situated in the centre area of the structure (at a distance less than $1.5*H_{m0\ toe}$ above swl), then the point of the crest nearest to the sea has to be used to determine α_u. The lower slope α_d can be determined by taking the point of the structure at a level of $1.5*H_{m0\ toe}$ under the swl and connecting it with the point of the berm nearest to the sea. If the toe of the structure is situated in the centre area of the structure (at a distance less than $1.5*H_{m0\ to}$ under swl), then the point of the toe farthest of the sea has to be used to determine α_d.

- γ_f [-]: This parameter gives an indication of the roughness and the permeability of the structure. The rougher and more permeable a structure is, the lower the overtopping will be since more energy is dissipated on a rough surface and more energy will disappear into a permeable structure. The factor γ_f was originally introduced as a reduction factor for the roughness and permeability for run-up on a structure. Values of γ_f for run-up on dikes with different top-layers are given in TAW (2002). Overtopping structures are often constructed of rubble mound, artificial armour units or a combination of both. As no extensive research has been performed before regarding the roughness of different armour units, some assumptions can be made. Table 1 gives some suggestions for the roughness-factors of the most common armour layers.

Type of armour layer	γ_f
Smooth impermeable surface	1
Rocks	0.5
Cubes (2 layers, random)	0.5
Cubes (1 layer, random)	0.52
Antifers	0.5
Accropods	0.49
X-blocks	0.49
Core-locs	0.47
HARO's	0.47
Tetrapods	0.4
Bermbreakwater (reshaping)	0.45
Dolosse	0.43
Icelandic bermbreakwater (not reshaping)	0.4
Seabeas	0.5

Table 1 Roughness/permeability of common armour layers

3.2.3 Schematisation of complex structures

In some cases, it is not possible to describe very complicated coastal structures with the above-mentioned parameters. For these cases, it is then required to make rough schematisations to come to an approximate description of the section with these parameters. Often, several possibilities exist to make such approximations; therefore it is the task of the user to choose the best solution for the schematisation of the structure. In the following, some examples of the schematisation of several structures are given.

Example 1: Structure with several slopes

In the case that a structure consists of more than two slopes (e.g. lower, mid and upper slopes), it should be taken into account that a mid-slope of 1:5 is too steep to be a berm. This slope should be therefore included in the slope of the structure downward of the berm (parameter *cot α_d*). A possible schematisation could be to consider the lower slope as the toe of the structure with toe width $B_t = 0$, the mid-slope as the slope downward the berm (*cot α_d*), the upper slope as the slope upward the berm (*cot α_u*) and the intersection between the last slopes as a berm with berm width $B = 0$.
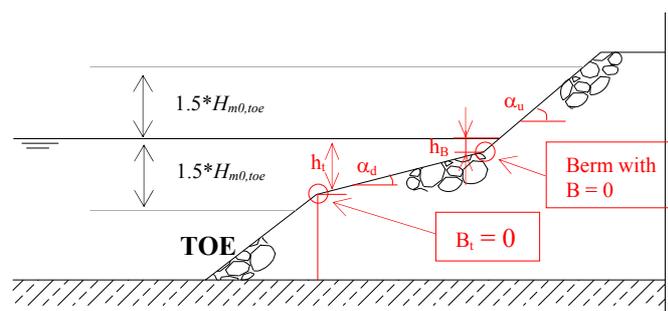
Figure 5 Example 1: Structure with several slopes

Example 2: Structure with more than one berm

In the case that a structure consists of several sloping and horizontal parts (e.g. two horizontal parts or horizontal berms with not a too big difference in level between both berms), a rougher schematisation is required. The schematisation advised in this case is to combine the two horizontal berms in one mean berm at the average level of both berms. The berm width can be determined here by lengthen the upper and lower slope up to the level of the mean berm.

If the width of the two berms is very different, a weighted average level of the mean berm is preferable (so the berm with the largest width has most influence on the level of the mean berm).
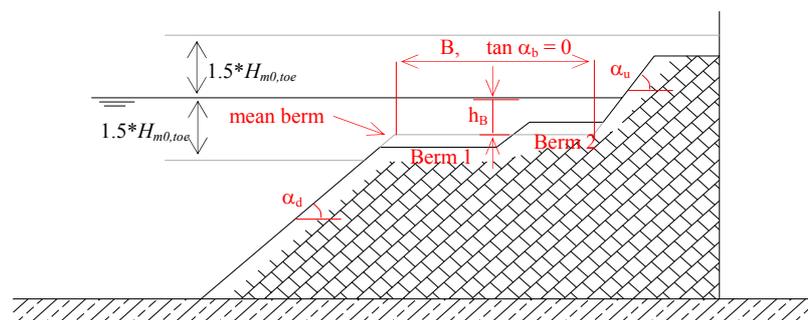
Figure 6 Example 2: Structure with more than one berm

Example 3: Sloping crest

The schematisation advised in the case that the crest of the structure is a sloping crest, is to consider the crest as a horizontal crest at a level corresponding to the middle point of the crest. The value of the crest width, G_c, in this case results from extending the slope of the structure up to the level of the horizontal crest.
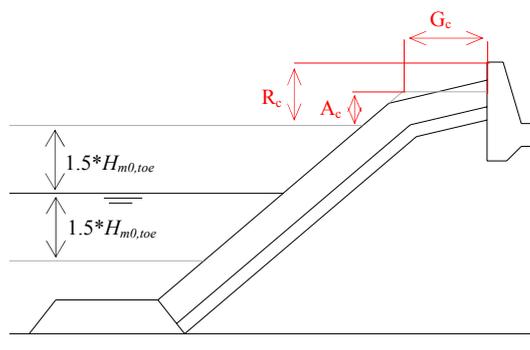
Figure 7 Example 3: Sloping crest

4   How to use the NN tool

4.1   Setup procedure

In order to run the program **NN_OVERTOPPING 2,** the user must go through the Setup procedure (**Setup_NN_Overtopping.exe**). This procedure generates the **NN_OVERTOPPING 2** environment in the directory the user selects or in the default directory,

C:\Program Files\Delft-Chess\ **NN_OVERTOPPING 2**

Once the setup is finished, the three system files described in Section 2.1, **NN_OVERTOPPING.EXE, NN_OVERTOPPING.NTD** and **NN_OVERTOPPING.LIC**, will be available to the user. In addition, the executable **Unwise.exe** will also be available, in case the user needs to uninstall the software.

4.2   Range of applicability of the NN tool

It should be taken into account that the NN-tool was constructed on the basis of a database in which each of the input parameters had a certain range of values. Additionally, this database was not uniformly distributed within the ranges of the input parameters. Consequently, the applicability of the program **NN_OVERTOPPING 2** is, to some extent, limited by the ranges of the input parameters used in its configuration.

Table 2 gives the ranges of validity of each of the input parameters required for the use of the **NN_OVERTOPPING 2** tool, referred to a significant wave height H_{m0} = 1 m. If the program **NN_OVERTOPPING 2** is used for input patterns out of these ranges of applicability, the program will not give a prediction in this case and will report a warning message to the output file. The program will automatically start calculating the prediction of the next input pattern (see Section 4.5.1).

Parameter	Maximum	Minimum
H_{m0} (m)	1.0	1.0
$s_{m-1,0}$	0.005	0.07
β	80.0	0.0
h (m)	20.0	0.9
h_t (m)	20.0	0.5
B_t (m)	10.0	0.0
γ_f	1.0	0.3
$cot\ \alpha_d$	10.0	0.0
$cot\ \alpha_u$	10.0	-1.0
B (m)	15.0	0.0
h_b (m)	5.0	-1.0
$tan\ \alpha_b$	0.1	0.0
R_c (m)	5.0	0.5
A_c (m)	5.0	0.0
G_c (m)	10.0	0.0

Table 2 Range of possible input parameters for the use of NN_OVERTOPPING (referred to a significant wave height, H_{m0}=1 m).

4.3   Description of the input file

For the application of **NN_OVERTOPPING.EXE,** an input file must be prepared with one or more sets of input parameters (input patterns). Each input pattern consists of 15 (numerical, free-format) values representing the 15 input parameters described in Section 2. Each of these input patterns must be entered in one line, with the following order and dimensions:

[β (°) h (m) $H_{m0,toe}$ (m) $T_{m-1,0,\ toe}$ (s) h (m) h_t (m) B_t (m) γ_f $cot\alpha_d$ $cot\alpha_u$ R_c (m) B (m) h_b (m) $tan\ \alpha_B$ A_c (m) G_c (m)]

The input parameters must be separated by blanks or single commas. No tabs should be used for separation of successive input values. Subsequent input patterns can be separated by an arbitrary number of comment records, if desired. Comment records are defined by '!' or '*' as leading character. Comments can also be placed at the end of records and must be preceded by '!' or '*' as well. The name of the input file with the user-supplied input patterns must be **NN_OVERTOPPING.INP**. There is no limit on the number of patterns (set of input parameters) that are provided in the user-supplied input file.

It should be noted that the prediction tool requires the input of 15 parameters. If one of these parameters is not provided in the input file, the program will report an error to the standard

(monitor) output device and the program will automatically be aborted (see Section 4.5.1). The program will also create an error file, **NN_OVERTOPPING.ERR**, where the error message will be reported.

Figure 8 provides an example of an admissible input file, **NN_OVERTOPPING_1.INP,** for **NN_OVERTOPPING 2** which contains 6 input patterns.

A second example of an input file, **NN_OVERTOPPING_2.INP,** can be derived from the one of the preceding example by removing all the comments. This example is shown in Figure 9.

For the application of the prediction tool **NN_OVERTOPPING.EXE** the two input files **NN_OVERTOPPING_1.INP** and **NN_OVERTOPPING_2.INP** are equivalent.

```
!----------------------------------------------------------------------------
! Begin input file
! NN_OVERTOPPING_1.INP
! This is a comment record
! =============================
! COLUMN#01  Angle of Wave attack
! COLUMN#02  Water depth in front of structure
! COLUMN#03  Significant Wave Height at the toe of structure
! COLUMN#04  Wave period
! COLUMN#05  Water depth at the toe of structure
! COLUMN#06  Width of toe
! COLUMN#07  Roughness coefficient
! COLUMN#08  Angle of down slope
! COLUMN#09  Angle of upper slope
! COLUMN#10  Crest Freeboard in relation to SWL
! COLUMN#11  Berm Width
! COLUMN#12  Water depth at the berm of the structure
! COLUMN#13  Berm slope
! COLUMN#14  Armour Freeboard in relation to SWL
! COLUMN#15  Armour Width
! =============================
! and this is another comment record
* as well as this one, and the next five ones
!----------------------------------------------------------------------------
!0 1   02      03      04      05      06      07     08      09     10      11      12      13     14     15
!b     h       Hm0     Tm-1,0  ht      Bt      gf     cotad   cotau  Rc      B       hb      tanaB  Ac     Gc
!degr  m       toe(m)  toe(s)  m       m                             m       m       m              m      m
!----------------------------------------------------------------------------
!
0     0.085   0.063   1.968   0.085   0.000   1.00   0.00    0.00   0.025   0.000   0.000   0.00   0.009  0.432
0     0.179   0.097   1.161   0.103   0.173   0.49   1.50    1.50   0.192   0.000   0.000   0.00   0.214  0.094
45    0.197   0.094   1.138   0.127   0.161   0.49   1.50    1.50   0.148   0.000   0.000   0.00   0.169  0.365
0     0.148   0.096   2.123   0.108   0.000   0.50   1.50    1.50   0.148   0.000   0.000   0.00   0.072  0.616
14    3.633   2.189   6.634   1.383   8.000   1.00   0.00    0.00   7.008   0.000   0.000   0.00   2.988  1.000
0     0.700   0.073   4.584   0.700   0.000   1.00   6.00    6.00   0.100   0.000   0.000   0.00   0.100  0.000
!
! The columns do not need to be aligned
! End of input file NN_OVERTOPPING_1.INP
```

Figure 8 Example of input file NN_OVERTOPPING_1.INP for NN_OVERTOPPING.EXE

```
0     0.085    0.063    1.968    0.085    0.000    1.00    0.00    0.00    0.025    0.000    0.000    0.00    0.009    0.432
0     0.179    0.097    1.161    0.103    0.173    0.49    1.50    1.50    0.192    0.000    0.000    0.00    0.214    0.094
45    0.197    0.094    1.138    0.127    0.161    0.49    1.50    1.50    0.148    0.000    0.000    0.00    0.169    0.365
0     0.148    0.096    2.123    0.108    0.000    0.50    1.50    1.50    0.148    0.000    0.000    0.00    0.072    0.616
14    3.633    2.189    6.634    1.383    8.000    1.00    0.00    0.00    7.008    0.000    0.000    0.00    2.988    1.000
0     0.700    0.073    4.584    0.700    0.000    1.00    6.00    6.00    0.100    0.000    0.000    0.00    0.100    0.000
```

Figure 9 Example of input file NN_OVERTOPPING_2.INP for NN_OVERTOPPING.EXE

4.4   Description of the output file

The mean overtopping discharge q [m^3/s/m] predicted by **NN_OVERTOPPING 2** and the rest of the output parameters indicating the uncertainty of the prediction of this discharge are saved in an output file (in standard ASCII-organisation) with the name **NN_OVERTOPPING.LIS**. The first part of the output file corresponds to the numeric output of the model (the prediction and its uncertainties); the second part of the output file reports different remarks and warnings derived from the application of the model to the selected input patterns.

In this output file the first record is a legend describing the contents of the columns that follow. Next, **NN_OVERTOPPING 2** generates one record for every input pattern that was read.

4.4.1   Numerical output

As described in previous sections, the first part of the output file gives in the first column the mean overtopping discharge (q) predicted by the NN model, and in columns 2 to 8 the quantiles $q_{2,5\%}$, $q_{5\%}$, $q_{25\%}$, $q_{50\%}$, $q_{75\%}$, $q_{95\%}$ and $q_{97,5\%}$. Finally, column 9 gives the number of the input pattern. In Figure 10, the response of **NN_OVERTOPPING 2** to the input file of the first example (**NN_OVERTOPPING_1.INP**) of Section 4.3 is given as an example of the first part (numerical output) of the output file generated by the model.

4.4.2   Remarks and Warnings

The second part of the output file gives in Column 11 a concise description of the different remarks and warnings necessary for a good interpretation of the results of the model.

The remark (REMARK I) in Column 10 gives a number between 0 and 7 to express the following:

–   **1**: 'WARNING> Parameter in column 5 out of range of validity. No prediction is given'

    This warning indicates that because the parameter in column 5 (the water depth at the toe of structure, h_t) is out of the range of validity of the NN model, no prediction is given. This warning can appear for any of the input parameters, in relation with the values indicated in Table 2.

–   **2**: 'WARNING> For $10^{-6} < Q < 10^{-5}$, the NN prediction is less reliable (indicative)'

    This remark indicates that the dimensionless value of the mean overtopping discharge predicted by the NN lies in the region $10^{-6} < Q < 10^{-5}$, (with Q = dimensionless overtopping discharge, $Q = q / \sqrt{gH_s^{\,3}}$), and therefore, the NN prediction should be considered as less reliable, or indicative.

–   **3**: 'WARNING> For $Q < 10^{-6}$, no prediction is given'

This remark indicates that the dimensionless value of the mean overtopping discharge predicted by the NN is in the region $Q < 10^{-6}$ (with Q = dimensionless overtopping discharge, $Q = q/\sqrt{gH_s^{\,3}}$), and therefore, the NN prediction does not give any prediction. The default value given in this case is -1.

– **4**: 'REMARK > For prototype, rough-sloping structures, a correction factor is applied: q = '

With this remark the user is given the possibility of choosing between the direct output of the NN model or a corrected value to account for model effects, scale effects and wind effects in prototype situations, for rough-sloping structures ($\gamma_f < 0.9$ and cot $\alpha >$ 1).

– **5**: 'REMARK > For prototype, rough-sloping structures, a correction factor is applied: q =   , Since $10^{-6} < Q < 10^{-5}$, the NN prediction is less reliable (indicative)'

With this remark the user is given the possibility of choosing between the direct output of the NN model or a corrected value to account for model effects, scale effects and wind effects in prototype situations, for rough-sloping structures ($\gamma_f < 0.9$ and cot $\alpha >$ 1). The user is also warned that the dimensionless value of the mean overtopping discharge predicted by the NN before the correction is applied lies in the region $10^{-6} < Q < 10^{-5}$, and therefore the NN prediction should be considered as less reliable, or indicative.

– **6**: 'REMARK > For prototype, smooth vertical structures, a correction factor is applied: q = '

With this remark the user is given the possibility of choosing between the direct output of the NN model or a corrected value to account for wind effects in prototype situations, for smooth ($\gamma_f \geq 0.9$) and vertical structures (cot $\alpha \leq 1$).

– **7**: 'REMARK > For prototype, smooth vertical structures, a correction factor is applied: q =   , Since $10^{-6} < Q < 10^{-5}$, the NN prediction is less reliable (indicative)'

With this remark the user is given the possibility of choosing between the direct output of the NN model or a corrected value to account for wind effects in prototype situations, for smooth ($\gamma_f \geq 0.9$) and vertical structures (cot $\alpha \leq 1$). The user is also warned that the dimensionless value of the mean overtopping discharge predicted by the NN before the correction is applied lies in the region $10^{-6} < Q < 10^{-5}$, and therefore the NN prediction should be considered as less reliable, or indicative.

– **0**: In this case, no remarks or warnings are given.

In Figure 11, the different remarks and/or warning messages corresponding to the input file of the first example of Section 4.3 are given as an example of the second part of the output file generated by the model.

```
 *
 * Col 01            02            03            04            05            06            07            08            09      …
 *  q (m3/s/m)   q[ 2.50%]     q[ 5.00%]     q[25.00%]     q[50.00%]     q[75.00%]     q[95.00%]     q[97.50%]     Nr.Pat. …
    0.1233E-02    0.5115E-04    0.9205E-04    0.3848E-03    0.1187E-02    0.3608E-02    0.1931E-01    0.3967E-01       1      …
    0.5549E-06    0.1914E-06    0.2281E-06    0.3771E-06    0.5390E-06    0.8041E-06    0.1488E-05    0.1682E-05       2      …
   -1.000        -1.000        -1.000        -1.000        -1.000        -1.000        -1.000        -1.000           3      …
    0.8478E-05    0.9678E-06    0.1395E-05    0.3819E-05    0.8811E-05    0.1892E-04    0.5100E-04    0.7061E-04       4      …
    0.5590E-03    0.1507E-03    0.1978E-03    0.3658E-03    0.5760E-03    0.8539E-03    0.1633E-02    0.1953E-02       5      …
   -1.000        -1.000        -1.000        -1.000        -1.000        -1.000        -1.000        -1.000           6      …
```

Figure 10 Example of first part of output file NN_OVERTOPPING_1.LIS for NN_OVERTOPPING.EXE

```
 *
 * …    09            10
 * …   Nr.Pat.      REMARK I
   …     1            0       |
   …     2            2       |WARNING> For 10^-6 < Q < 10^-5, the NN prediction is less reliable (indicative)
   …     3            3       |WARNING> For Q < 10^-6, no prediction is given
   …     4            0       |
   …     5            6       |REMARK > For prototype, smooth vertical structures, a correction factor is applied: q =   0.6810E-03
   …     6            1       |WARNING> Wave steepness out of range of validity. No prediction is given
```

Figure 11 Example of second part of output file NN_OVERTOPPING_1.LIS for NN_OVERTOPPING.EXE

4.5   How to run the NN-tool

After preparation of an input file (**NN_OVERTOPPING.INP)** with one or more input patterns according to the prescriptions of Section 4.3, **NN_OVERTOPPING 2** can be run by entering the command **NN_OVERTOPPING.EXE** to the standard (monitor) console input. The program will automatically read the supplied input file, perform the desired predictions and write the results to the supplied output file following the organisation described in Section 4.4. This can be followed on the screen with the following messages:

```
Reading NN-configuration and ensembles from file        : NN_OVERTOPPING.NTD

Reading user supplied input pattern(s) from file        : NN_OVERTOPPING.INP
and writing NN-overtopping predictions to file          : NN_OVERTOPPING.LIS
```

The 'progress' of **NN_OVERTOPPING.EXE** can be monitored from the standard output device according to messages of the form:

```
Number of input patterns processed so far               : 1
Number of input patterns processed so far               : 100
Number of input patterns processed so far               : 200
.................................................................
                    *** Normal End of Program ***
```

etc., until the last input pattern has been processed.

The first time the model is run, if the output file does not exist it will be created. For subsequent runs, the old version will be destroyed and again created for the present application.

4.5.1 Error messages

In case that a non-admissible input pattern is found in the user-supplied input file **NN_OVERTOPPING.EXE** will report an error to the standard (monitor) output device and the program will be aborted. The program will also create an error file, **NN_OVERTOPPING.ERR**, where this message will be reported. This will e.g. happen if an input pattern is of a non-numeric format.

Figure 12 and Figure 13 show an example of an invalid input file and the corresponding error file. An error will be found while reading the value of $H_{m0,toe}$ for the second pattern. Since

NN_OVERTOPPING 2 will be aborted immediately (rather than resume reading the next records of the input file), the output file will contain the predictions for the overtopping discharge and uncertainties only for the first input pattern.

```
!------------------------------------------------------------------------------------------
!   NN_OVERTOPPING_4.INP
! =============================
! COLUMN#01  Angle of Wave attack
! COLUMN#02  Water depth in front of structure
! COLUMN#03  Significant Wave Height at the toe of structure
! COLUMN#04  Wave period
! COLUMN#05  Roughness coefficient
! COLUMN#06  Angle of down slope
! COLUMN#07  Angle of upper slope
! COLUMN#08  Crest Freeboard in relation to SWL
! COLUMN#09  Berm Width
! COLUMN#10  Water depth at the berm of the structure
! COLUMN#11  Berm slope
! COLUMN#12  Armour Freeboard in relation to SWL
! COLUMN#13  Armour Width
! =============================
!------------------------------------------------------------------------------------------
! 01    02      03      04      05     06     07     08      09      10      11      12      13      14      15
!b      h       Hm0     Tm-1,0  ht     Bt     gf     cotad   cotau   Rc      B       hb      tanaB   Ac      Gc
!degr   m       toe(m)  toe(s)  m      m                             m       m       m               m       m
!------------------------------------------------------------------------------------------
!
10     0.121   0.064   1.580   0.121  0.000  1.00   1.00    0.00    0.411   0.400   0.009   0.00    0.210   0.050
0      0.085   abcde   1.968   0.085  0.000  1.00   0.00    0.00    0.025   0.000   0.000   0.00    0.009   0.432
!
! End of input file NN_OVERTOPPING_4.INP
!
```

Figure 12 Example of input file NN_OVERTOPPING_4.INP for NN_OVERTOPPING.EXE

```
*
ERROR> File NN_OVERTOPPING.inp
      > Error detected in file at record  number         31
      > while reading NN/MLP input pattern number         2
      > Non-numeric input "abcde"
      > found for input component number                  3
```

Figure 13 Example of error file NN_OVERTOPPING_4.ERR for NN_OVERTOPPING.EXE

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A   Determination of structure parameters

In Section 3.1 the determination of the 3 hydraulic input parameters is described and in Section 3.2 the 12 input parameters concerning the structure. Since the description in Section 3.2 is fairly briefly, a more extensive description is given in this appendix. The text below is extracted from the detailed report on the extensive database on wave overtopping at coastal structures (Van der Meer *et al.*, 2004). For more background information is referred to this original report. As the prediction tool is developed on the basis of this database, only a good prediction can be obtained if the input parameters of new input patterns are determined according to their definition as given to it during the setup of the database.

The importance of determining the structure parameters in the same way as during setup of the database should be stressed here. In the following paragraphs the schematisation procedure for a new overtopping case is given.

A.1   General schematisation of the structure; crest, berm and toe

A first schematisation step consists of splitting up the overtopping structure into three main parts (see Figure A.2). The area marked off by the value of $1.5H_{m0toe}$ above and $1.5H_{m0toe}$ below swl is called the '**centre area**' of the structure. The area below the centre area is called then the '**lower area**' of the structure and the area above the centre area is called the '**upper area**' of the structure. Depending on the wave height and the water level, the upper or lower area may be lacking.

It is defined that a structure berm is most likely situated in the centre area of the structure. If the 'berm' ('berm' refers here to the name assigned to it by the designer of the structure) is situated lower, it is more likely to be felt by the waves as a toe. If the 'berm' is situated higher, it is more likely to be felt as a crest. In connection with the position of the berm, a toe is defined as most likely to appear in the lower area of the structure (= lower than $1.5H_{m0toe}$ below swl) and a crest in the upper area of the structure (= higher than $1.5H_{m0toe}$ above swl).

Consequently it may happen that what is called a 'berm' by the designer, should be called a 'toe' or 'crest' regarding the schematisation for the prediction method, although the above described levels of toe, berm and crest are not binding. Tests e.g. with very small wave heights $H_{m0\ toe}$ [m], leading to a very restricted centre area, are often schematised with a berm which is not situated in the centre area of the structure. Structure types with quite large toes, situated in relatively shallow water, can be referred to as structures which do not fulfil this most likely position of a toe. Also low crested structures of which the upper point of the structure has a level within $1.5H_{m0\ toe}$ above swl can be referred to as structures which do not fulfil this most likely position of a berm.

In Figure A.2 a typical rubble mound structure is shown. The centre area, defined by the value of the wave height $H_{m0\ toe}$ [m], contains a slightly sloping berm. The crest is situated in the upper area, the toe is situated in the lower area. This example corresponds with the most common position of the mentioned three structure parts.
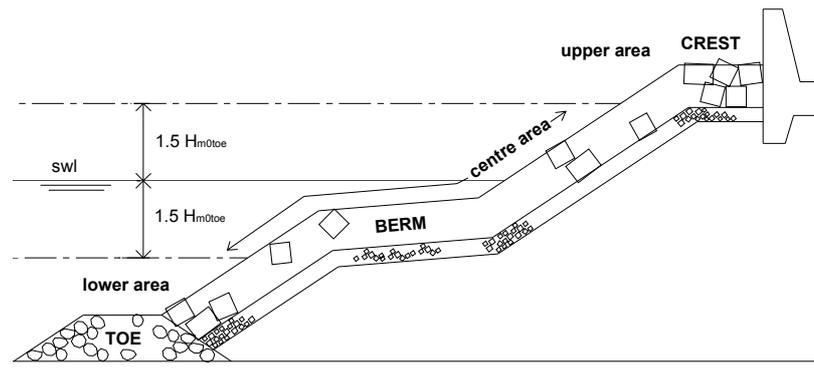
Figure A.2 Typical position of berm, crest and toe

Figure A.3 gives an example of a structure with a high situated toe. The different structure materials contribute to the preference of schematising the lower part of the structure here as a large toe.
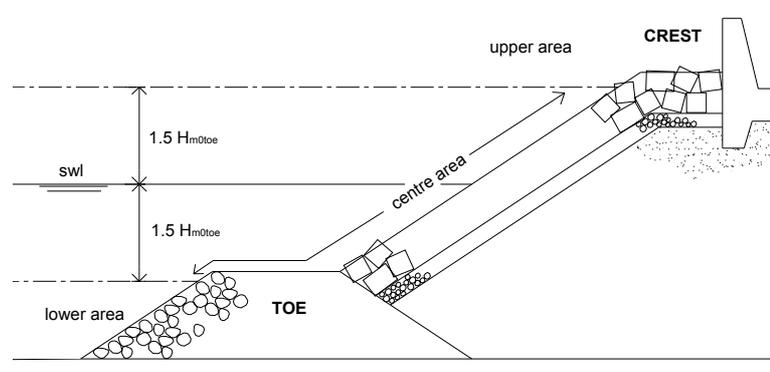
Figure A.3 Structure type with large toe

Figure A.4 shows a structure for which the small value of the wave height at the toe of the structure, $H_{m0\,toe}$ [m], leads to a situation in which the berm is situated in the lower part of the structure. It is quite logic in this case that it concerns a berm here and not a toe.
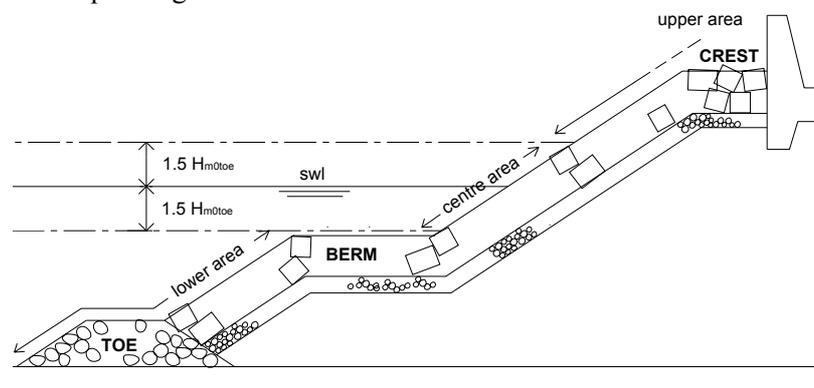
Figure A.4 Structure type with low situated berm

In Figure A.5 at last an example is given of a structure with a low situated crest. Because of the high water level, the entire structure is situated lower than the $1.5H_{m0\,toe}$ -line above swl.
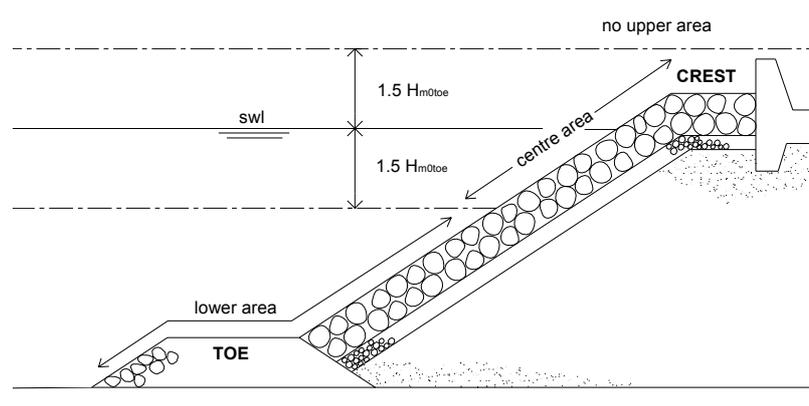
Figure A.5 Structure type with low situated crest

It may be clear that it is not always straight-forward how to schematise a horizontal or slightly sloping part of a structure. In some cases more than one schematisation possibility exists.

Additionally to the levels of the berm, crest and toe of a structure, some restrictions regarding the slope and the length of a berm are made in the schematisation for the database:

Slope of a berm:
Slopes less steep than 1:15 are preferred for a berm, although slopes up to 1:10 are allowed. Slopes steeper than 1:10 should be considered as a normal sloping structure part.
Length of a berm:
A berm length up to one wave length is allowed, although berm lengths smaller than $0.25L_0$ are preferred. If the berm is longer than L_0, it should be considered as a foreshore. Consequently in this last case the part of the structure lower than the 'berm' also should be considered as a part of the foreshore.

A.2   Structure parameters

In a second step, the structure parameters can be determined one by one. This section explains how to determine these parameters for a rather easy-to-schematise overtopping structure. In Section A.3 some examples of possible schematisations of more complex sections are given.

A.2.1   h [m]

The value of h [m] refers to the water depth just in front of the structure. This parameter is also referred to as the water depth 'at' the toe of the structure. In Figure A.6 the value of h is indicated.

A.2.2 h_t [m], B_t [m]

These are the water depth on the toe respectively the width of the toe. The value of h_t [m] is measured in the middle of the toe. The value of B_t [m] is measured on top of the toe. This is also illustrated in Figure A.6.
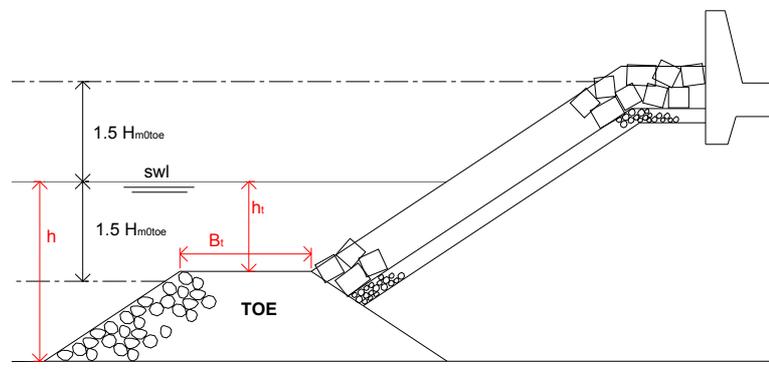
Figure A.6 Determination of h [m] , h_t [m] and B_t [m]

If the structure has no toe, the value of the water depth on the toe h_t [m] equals the value of the water depth at the toe of the structure h [m]. In this case the width of the toe B_t [m] is equal to zero. Figure A.7 gives an example of such situation.
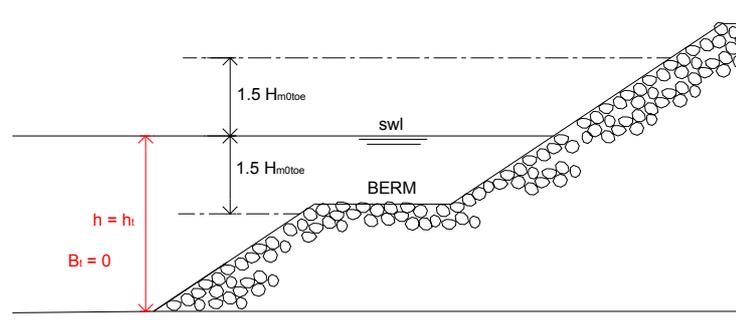
Figure A.7 Determination of h, h_t [m] and B_t [m] in case of no toe

A.2.3   B [m], h_b [m], $\tan\alpha_B$ [-]

These are three parameters to describe the berm of an overtopping structure.
The value of B [m] represents the berm width and is measured horizontally.
h_b [m] is the water depth on the berm, measured in the middle of the berm. If the berm is situated above swl, the value of h_b [m] is negative.
$\tan\alpha_B$ [-] is the tangent of the slope of the berm. If the berm is horizontally, $\tan\alpha_B$ [-] = 0.
If the structure has no berm, the values of B [m], $\tan\alpha_B$ [-] and h_b [m] are all equal to zero.
In Figure A.8 the berm parameters are clarified.
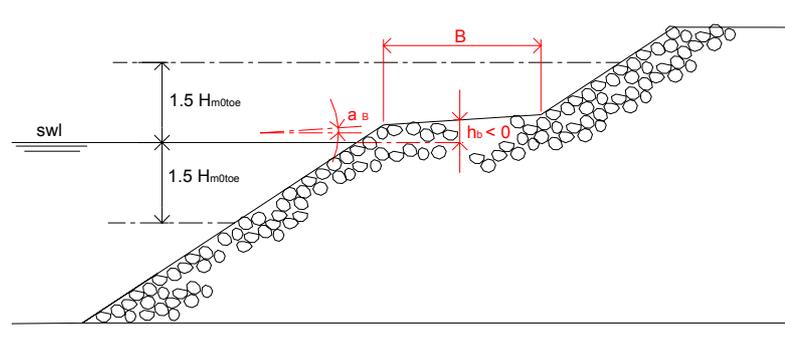
Figure A.8 Determination of B [m], $\tan\alpha_B$ [-] and h_b [m]

A.2.4 R_c [m], A_c [m], G_c [m]

These parameters describe the upper part of an overtopping structure.
R_c [m] is the crest freeboard of the structure. It is the distance, measured vertically, from swl to the highest impermeable point of the structure. This means that at this point, waves are returned by the structure. This is not always the highest point of the structure (see Figure A.9 (d)).
A_c [m] is the armour crest freeboard of the structure. It is the distance, measured vertically from swl to the upper limit of the armour layer. In a lot of cases, A_c [m] = R_c [m].
G_c [m] represents the crest width.

Figure A.9 gives several examples of crest structures with an indication of the corresponding parameters. As can be seen on the different figures, R_c [m] can adopt a value larger, smaller or equal to A_c [m].

(a)
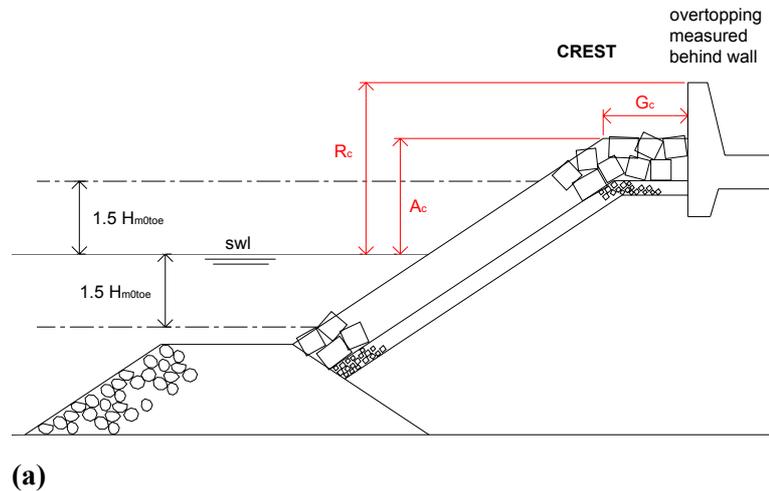
Figure A.9 Determination of R_c [m], A_c [m] and G_c [m]
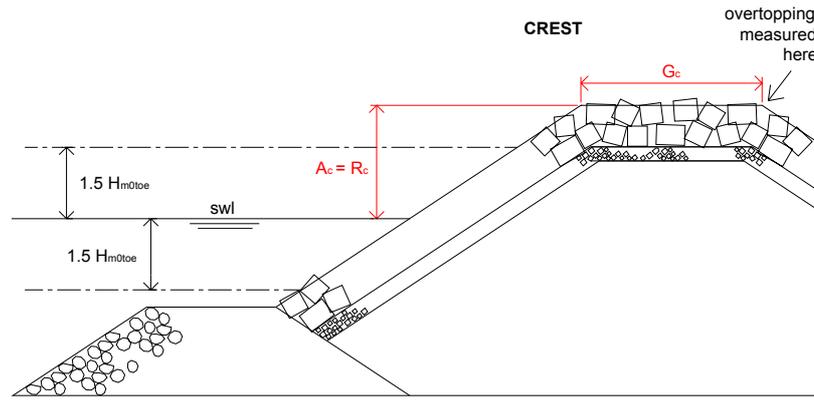
(b)
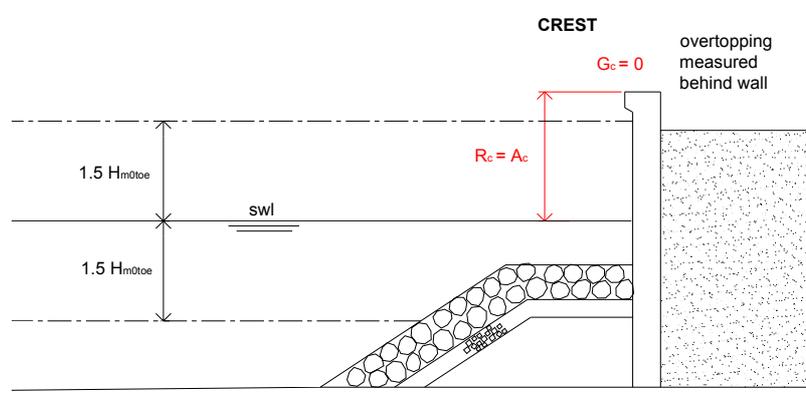
(c)
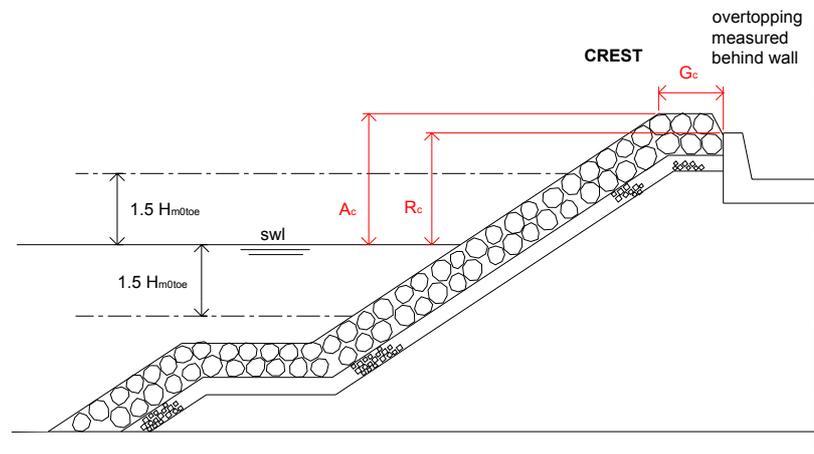
(d)

Figure A.9 (continued) Determination of R_c [m], A_c [m] and G_c [m]

It has to be mentioned that the parameter G_c [m] only includes the permeable horizontal part of the crest, as it is assumed that overtopping water just passes an impermeable surface if it reaches it. An example can be seen in Figure A.10(a): as the crest consists of a horizontal impermeable surface, the value of G_c [m] is equal to zero. Logically, if the crest consists of

an impermeable horizontal road, and the overtopping discharge is measured behind a wall located at the landside of the road, the crest width G_c [m] will be equal to the width of the road, as only the water which passes the wall itself will be measured. An example can be seen in Figure A.10(b).

(a)

(b)
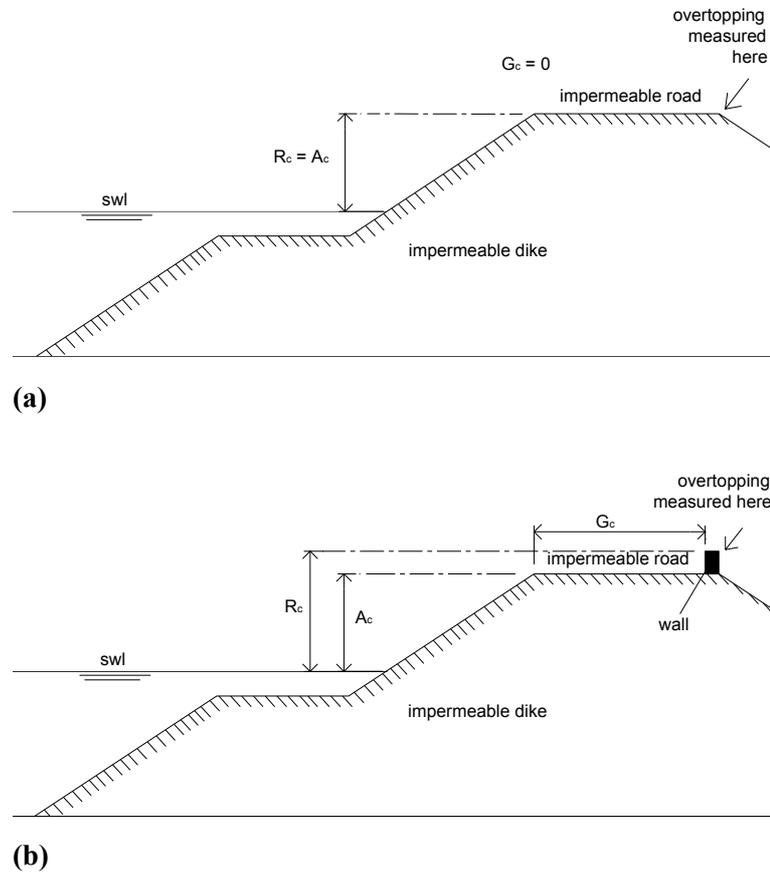
Figure A.10 Determination of G_c [m]

A.2.5   cotα_d [-], cotα_u [-]

These parameters describe the slope(s) of the overtopping structure. It has to be stressed that the toe and the crest of the structure are not included in this slope parameters, as these are already described by separate parameters.

cotα_d [-] and cotα_u [-] are the cotangents of the mean slopes in the centre area of the structure, below (cotα_{down}) and above (cotα_{up}) the berm respectively.

The upper slope of the structure α_u is the slope upward the berm. It is determined by taking the point of the structure at a level of $1.5H_{m0\ toe}$ above swl and connecting it with the leeside endpoint of the berm. If the crest of the structure is situated in the centre area of the structure (this implicates that the crest is situated less than $1.5H_{m0\ toe}$ above swl), then the starting point of the crest has to be used instead of the point at level $1.5H_{m0\ toe}$ above swl to determine α_u.

The lower slope of the structure α_d is the slope downward the berm. It is determined by taking the point of the structure at a level of $1.5H_{m0\ toe}$ below swl and connecting it with the

seaside endpoint of the berm. If the toe of the structure is situated in the centre area of the structure (this implicates that the toe is situated less than $1.5H_{m0\ toe}$ below swl), then the starting point of the toe has to be used instead of the point at level $1.5H_{m0\ toe}$ below swl to determine α_d.

In Figure A.11 the slope angles are indicated, in graph (a) for a rubble mound structure without berm, in graph (b) for a rubble mound structure with a horizontal berm and in graph (c) for a vertical wall with a rubble mound protection in front of it.

(a)

(b)

(c)
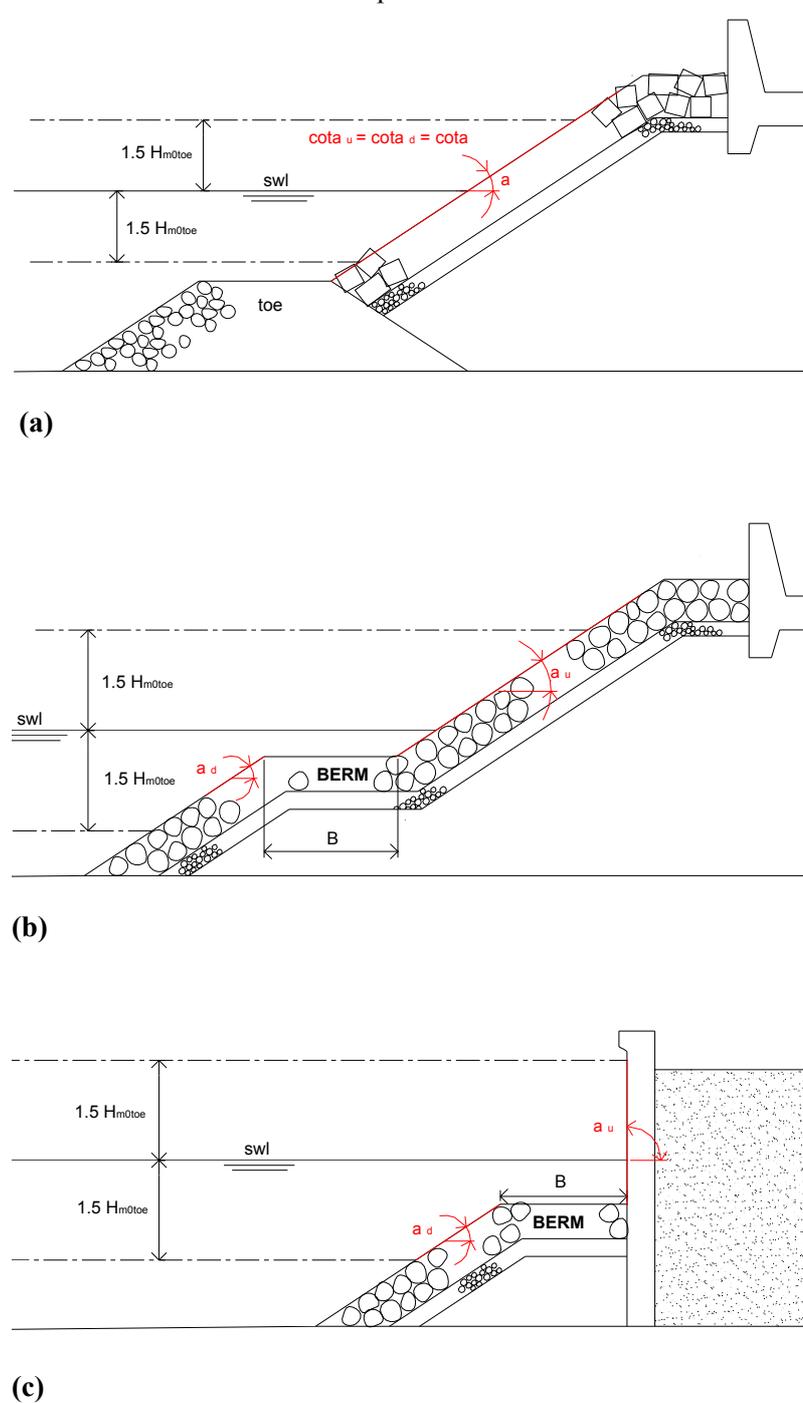
Figure A.11 Determination of the structures slope parameters

In Figure A.12 two extra examples regarding the determination of the structure slope parameters are given. In Figure A.12(a) the toe is situated in the centre area of the structure. As can be seen on the Figure A.the starting point of the toe is used to determine α_d instead of the point at level $1.5H_{m0\,toe}$ below swl. In Figure A.(b) the crest is situated in the centre area of the structure. Analogous the starting point of the crest is used to determine α_u here instead of the point at level $1.5H_{m0\,toe}$ above swl.

(a)

(b)
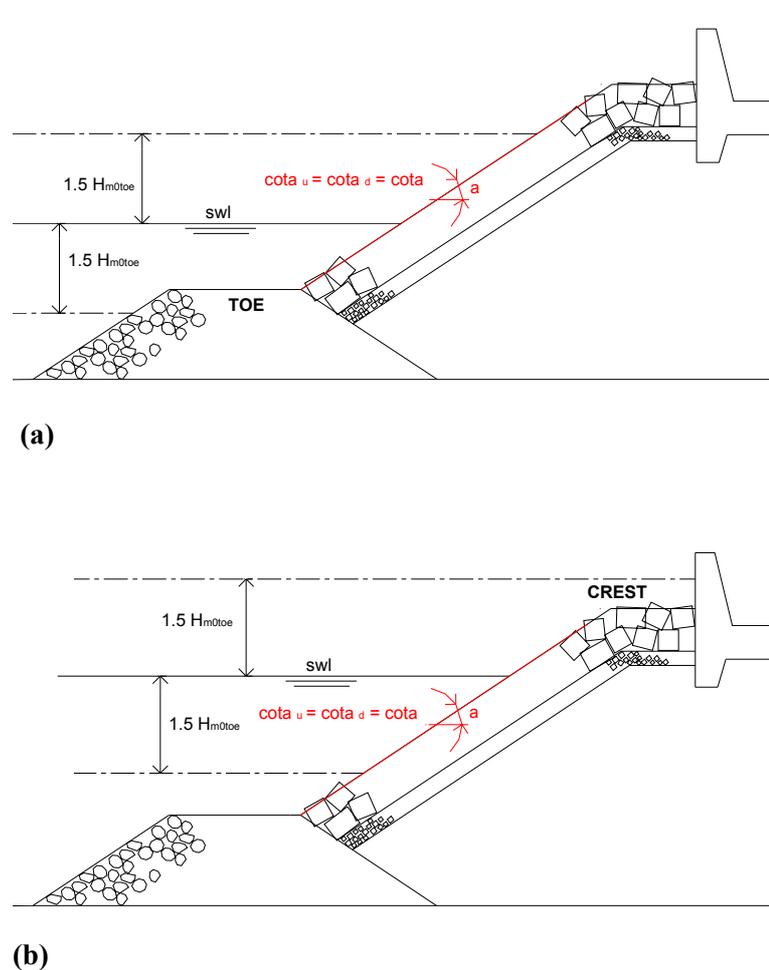
**Figure A.12 Determination of the structures slope parameters,
extra examples**

The use of the two slope parameters $\cot\alpha_u$ [-] and $\cot\alpha_d$ [-] also allows to schematise structures consisting of subsequent different slopes (without a horizontal part in between) very well. By defining the transition point as a berm with width B [m] = 0, a good schematisation is obtained.

Figure A.13 shows a structure consisting of 2 different slopes. By defining a berm with width B [m] = 0 at the transition point, the structure is schematised correct.
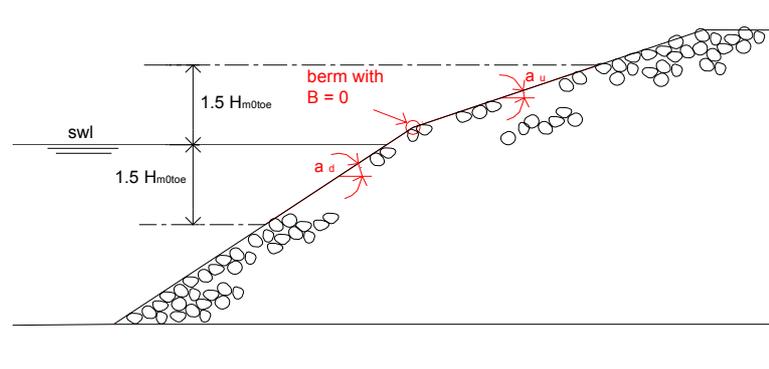
Figure A.13 Schematisation of 2 subsequent slopes

In the special case of a structure type with an overhanging part, a negative value can be assigned to the parameter $\cot\alpha_u$ [-]. Figure A.14 gives an example. It concerns a large (recurved) wave return wall, which is schematised by introducing a berm at a certain point with B [m] = 0, in combination with a well chosen value for the upper and down slope. The berm level is chosen rather arbitrary, providing upper and down slope with a good fitting to the structure. The upper slope leans back seaward introducing a negative value for the cotangent of it.

Also structures such as vertical walls with an overhanging upper part (seaward), should be schematised with a negative value of $\cot\alpha_u$ [-].
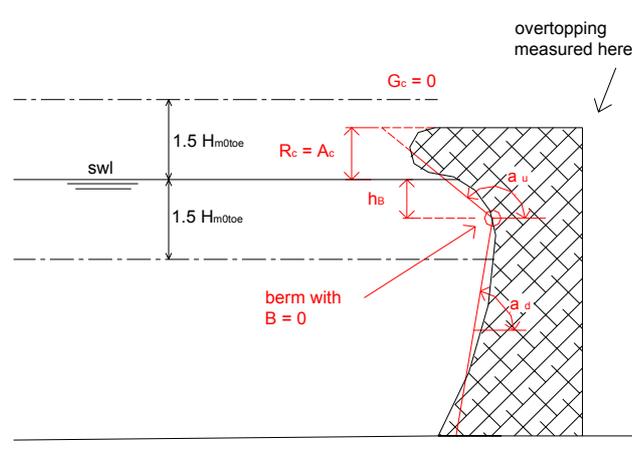
Figure A.14 Schematisation of a large recurved wave return wall

A.2.6 γ_f [-]

The value of the parameter γ_f [-] is determined by the roughness and the permeability of the structure on the one hand, and the presence of a (small) recurved wave return wall on the other hand. 'Small' refers here to recurved wave return walls which are not dominating the entire structure lay-out, as e.g. in Figure A.14. These 'large' recurved wave return walls should be schematised by means of a negative upper slope as already stated. In general, a lower value of γ_f [-] refers to more energy which is dissipated, leading to less overtopping.

To determine the correct value of γ_f [-] for the prediction method, one should act in two steps:
- Step 1:
Determine the value of γ_f [-] corresponding with the roughness/permeability of the structure. This interim value is referred to as $\gamma_{f\,armour}$ [-].
- Step 2:
Eventually determine an adapted (reduced) value to account for a (small) recurved wave return wall.
The final value of this parameter is referred to as γ_f [-].

In a **first step** the value of $\gamma_{f\,armour}$ [-] should determined. This is the value according to the roughness/permeability of the structure. The rougher and more permeable a structure, the lower the value of $\gamma_{f\,armour}$ [-] is.
Table 1 gives a summary of the $\gamma_{f\,armour}$ [-] values which were used in the datasets on which the network was trained. For this reason, these and only these values should be used for corresponding new input in the prediction method.

Table 1 Values for the roughness/ permeability factor $\gamma_{f\,armour}$ [-]

Type of armour layer	$\gamma_{f\ armour}$
Smooth impermeable surface	1
Rocks	0.5
Cubes (2 layers, random)	0.5
Cubes (1 layer, random)	0.52
Antifers	0.5
Accropods	0.49
X-blocks	0.49
Core-locs	0.47
HARO's	0.47
Tetrapods	0.4
Bermbreakwater (reshaping)	0.45
Dolosse	0.43
Icelandic bermbreakwater (not reshaping)	0.4
Seabeas	0.5

For overtopping structures consisting of an armour layer with other elements than the ones mentioned in table one, an estimate of the user is needed. This estimate should be based on the present values in table1, e.g. if the roughness/permeability of an armour layer is estimated to be in between the roughness/permeability of tetrapods and cubes, an estimation of $\gamma_{f\,armour}$ [-] = 0.45 could be made.

For composite structures such as vertical walls with a rubble mound protection, an 'average' value has to be determined for $\gamma_{f\,armour}$ [-]. This should be done by **only considering the structure part which is situated above swl**. This implicates that in case of a vertical wall with a rubble mound protection situated entirely below swl, a value of $\gamma_{f\,armour}$ [-] = 1 should be assigned to the structure.
In case two different roughnesses/permeabilities appear above swl, a weighted average should be taken for the $\gamma_{f\,armour}$ [-] value over the height of $1.5H_{m0\,toe}$ above swl, taking into account the width of the eventually present berm.

In a **second step**, an eventually extra reduction to the value of $\gamma_{f\,armour}$ [-] should be applied to account for the effect of a small recurved wave return wall. Distinction is made between rough and smooth structure types. Equations (1) and (2) give the reduction.

In case of a rough structure, i.e. $\gamma_{f\,armour} < 0.9$:

$$\left|\begin{array}{ll} \textbf{for } R_c / H_{m0\,toe} \geq 0.5 & : \gamma_f = \gamma_{f\,armour} - 0.05 \\[2mm] \textbf{for } R_c / H_{m0\,toe} < 0.5 & : \gamma_f = \gamma_{f\,armour} \end{array}\right. \qquad \textbf{(1)}$$

In case of a smooth structure, i.e. $\gamma_{f\,armour} \geq 0.9$:

$$\left|\begin{array}{ll} \textbf{for } R_c / H_{m0\,toe} > 1 & : \gamma_f = \gamma_{f\,armour} - 0.3 \\[2mm] \textbf{for } R_c / H_{m0\,toe} \leq 0.5 & : \gamma_f = \gamma_{f\,armour} \\[2mm] \textbf{for } 0.5 < R_c / H_{m0\,toe} \leq 1 & : \textbf{ interpolation} \end{array}\right. \qquad \textbf{(2)}$$

In Figure A.11(c) the recurved wave return wall is schematised by means of a reduction of the $\gamma_{f\,armour}$ - value. As the structure part which is situated above swl concerns a smooth wall, $\gamma_{f\,armour} = 1$. The structure crest freeboard R_c is larger than $H_{m0\,toe}$, resulting in a reduction of $\gamma_{f\,armour}$ of 0.3 to account for the effect of the recurved part. The final γ_f -value for this structure is 1 - 0.3 = 0.7.

A.3   Examples of 'difficult' overtopping sections

In some cases it is quite difficult to schematise a complex overtopping structure by means of these 12 structure parameters. Often more than one solution exists to come to an acceptable structure schematisation. It is up to the user to come to the best schematisation.

Example 1: Structure with horizontal part with width > L₀ [m], (Figure A.14)

Within a structure section, a horizontal (or slightly sloping) part with a length of more than one wave length L_0 can not be considered as a berm. The structure part is preferably considered as a part of the foreshore in these cases. The consequence is that the toe of the structure moves to the right (see Figure A.14) and calculations are needed to determine the wave characteristics at that location.
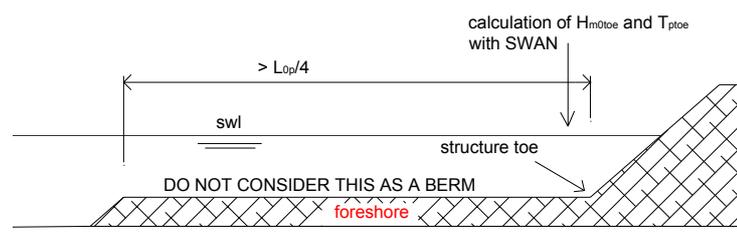
Figure A.14 Example 1

Example 2: Structure consisting of more than 2 subsequent slopes (Figure A.15)

Figure A.15 shows a structure section consisting of three subsequent sloping parts. The slope 1:5 is too steep to be considered as a berm. The problem can be solved in this example by including this part as the lower structure slope. The lowest transition point is included in the schematisation by considering the part of the structure below it as a structure toe with toe width B_t [m] = 0. The upper transition point is considered as a berm with width B [m] = 0. The schematisation parameters are marked in the figure.
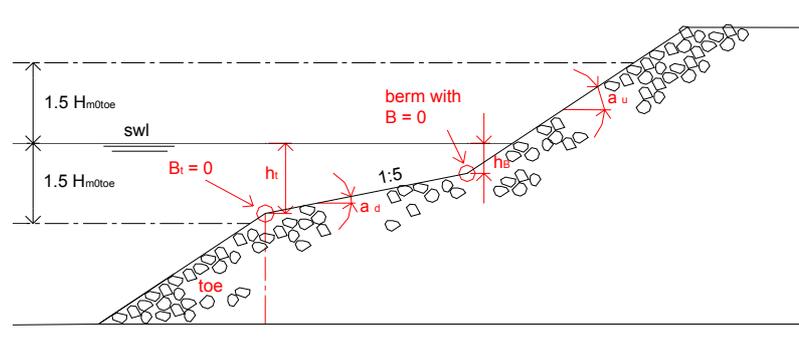
Figure A.15 Example 2

Example 3: Structure with more than one berm (Figure A.16)

The possibility exists that a structure is composed of several slightly sloping and horizontal parts. Figure A.16 shows a structure consisting of two horizontal parts (two 'berms'), together with a possible schematisation.
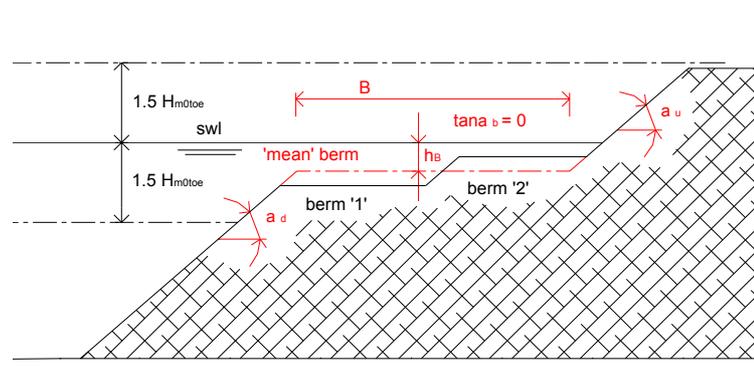
Figure A.16 Example 3

As the difference in level between the two berms is quite small, the two horizontal parts can be schematised by means of one larger berm, with an average berm level.
The berm width is determined here by lengthening the upper and lower slope up to the level of the mean berm.
If the width of the two berms was very different of each other (in this example they are almost equal), a weighted average level for the mean berm (according to the length of the berms) can be taken.

Example 4: Sloping crest (Figure A.17)

Figure A.17 shows a structure containing a sloping crest configuration. As the sloping part is situated in the upper part of the structure, it has to be schematised as a part of the crest.
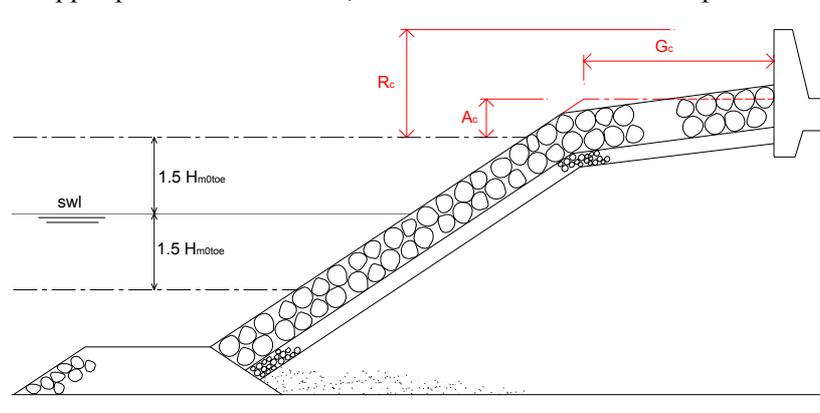
Figure A.17 Example 6

The upper sloping part is schematised horizontal by drawing a horizontal line trough the middle of the crest. Extending the slope of the structure results in the value for G_c [m].