THE INTERNATIONAL DATABASE ON WAVE OVERTOPPING

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One of the main objectives within the EU-project CLASH (www.clash-eu.org) was to create a generic prediction method for wave overtopping at coastal structures by means of the Neural Network technique. An extensive and homogeneous database on wave overtopping was set up within CLASH, mainly with the aim to be used for the training process of the Neural Network (NN). A total number of 10,532 tests from 163 independent test series were screened and included in the database. The final database consists of far more information than needed for the training of the NN: 31 parameters are included to describe each overtopping test of which only 17 are used for the NN development. This explains the possible use of the overtopping database on its own. Plotting various parameters of the database together in graphs gives a clear view on the contents of the database. Also the ranges covered by the parameters can be detected in this way. The creation of the database, the analysis of the database, and the possible use of the database on its own are described in this paper.

1. Introduction

Within the CLASH-project (Crest Level Assessment of Coastal Structures by full scale monitoring, neural network prediction and Hazard Analysis on permissible wave overtopping) one of the main objective was to create a generic prediction method on wave overtopping (De Rouck et al. 2002). This paper considers the basis of the NN, which provides this generic prediction: the international homogeneous database on wave overtopping. Besides the use for the NN prediction method, the database consists of a huge amount of information on its own right and can be considered as a valuable inventory of overtopping information. The database will be available for free in 2005 on the internet at the end of the CLASH project.

2. The international database on wave overtopping

2.1. *Setup of a homogeneous database*

The database is created within Excel. Each overtopping test is included by means of 31 parameters, which form the 31 columns within the spreadsheet. The Excel format makes it easy for users to perform every analysis wanted or needed; 10,532 tests from 163 independent test series are included. About 80% of the data included in the database are originating from CLASH partners. Various institutes from Japan, USA, Canada, Denmark, Iceland, Norway and others outside the CLASH project contributed to the remaining 20% of the test results.

A whole range of data is included in the database: basic research as well as site specific confidential tests, small scale tests from 2D and 3D models as well as prototype (field) data, and simple geometries as well as very complex situations contribute to the database.

For each tests detailed information was gathered in order to determine whether a test was performed in such conditions that overtopping rates could be related to the hydraulic conditions of the test and the structural parameters of the overtopping structure. In this context information was gathered about the wave characteristics, the test structure, the overtopping measurements, the test facility and the processing of the data. A summary is given in Table 1.

In addition to the investigation of all data as described in Table 1, every test series of the database has been screened by means of plotting the data in a typical overtopping graph. The data were graphically compared with existing formulae for dikes (TAW 2002), vertical structures (Franco et al. 1994), (Allsop et al. 1995) and sloping structures with roughness (TAW 2002, $\gamma_f = 0.5$). The aim was here to track wrong data although outliers were only revised on correctness but not excluded from the database.

Table 1. Information gathered for each test in the database

Wave characteristics	**Structure**	**Overtopping**	**Facilities**	**Data processing**
Regular / irregular waves	Structure type	Overtopping volume / percentage of waves resulting in overtopping	Wave flume / wave basin	Time domain analysis / spectral domain analysis
Characteristic wave heights and characteristic wave periods	Geometrical parameters		2-dimenional tests / 3-dimensional tests	Separation of incident and reflected waves / total waves considered
Incident wave angle	Composing materials		Reflection compensation / no reflection compensation	Methodology to determine incident waves
			active / passive wave absorption	
long crested / short crested waves	Characteristics of the foreshore		Model scale	

An example is given in Figure 1. This example of a breakwater with antifer cubes shows that almost all measured data are situated below the line of TAW 2002 with a roughness factor γ_f of 0.5. This corresponds well with expected values since antifer cubes are supposed to have a roughness factor γ_f of about 0.47.

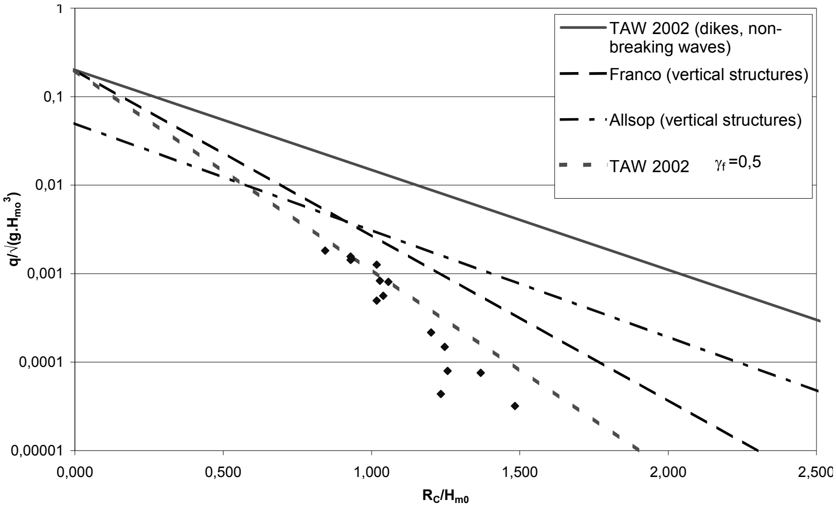

Figure 1. Example screening by comparing to different formulae.

Sometimes not all 31 parameters were available for an overtopping test. Additional calculations or assumptions had to be made then in order to complete the dataset, especially for use in the development of the NN prediction method. In cases where only deep water conditions were known, calculations were made with the SWAN model (Booij et al. 1999) to get the wave conditions at the toe of the structure. In other cases only time domain analysis of wave conditions was performed where spectral parameters were preferred for the database. To transpose the time domain parameter $H_{1/3,\ toe}$ to the spectral parameter $H_{m0,toe,}$ generalised empirical wave height distributions on shallow foreshores were used (Battjes en Groenendijk, 2000). A third case in which estimations were needed, emerged when not all of the three characteristic wave period parameters included in the database ($T_{m,}$, T_p and $T_{m-1,0}$, see next paragraph) were available. In these cases fixed relationships between the parameters were used to estimate the missing parameter (Goda 1985, Goda and Nagai 1974, TAW 2002).

2.2. *Contents of the database*

As mentioned each test is described and included in the database by means of 31 parameters. The parameters can be divided in three groups: general parameters, hydraulic parameters (releated tot incident waves) and structural parameters. They are listed per group in Table 2 (general parameters), Table 3 (Hydraulic parameters) and Table 4 (structural parameters). For detailed information on each of these parameters is referred to Verhaeghe et al. 2004. For each parameter the range which is included in the database is given. In Figure 2 the hydraulic and structural parameters from the database used in the NN are shown.

Table 2.General and hydraulic parameters included in the database

no	parameter	min.	max.	description
General parameters				
1	Name			This parameter assigns a unique name to each test. It is just meant to recognise each test but has no further meaning.
2	RF [-]	1	4	The 'Reliability Factor' gives an indication of the reliability of the test. It can adopt the values 1, 2, 3 or 4. Detailed information about this factor can be found in (CLASH WP2: Verhaeghe et al., 2004).
3	CF [-]	1	4	This parameter, called the 'Complexity Factor' gives an indication of the complexity of the test structure. It can adopt the values 1, 2, 3 or 4. Detailed information about this factor can be found in (CLASH WP2: Verhaeghe et al., 2004).

Table 3. Hydraulic parameters included in the database

Hydraulic parameters				
4	$H_{m0\ deep}$ [m]	0.003	5.920	Significant wave height from spectral analysis $= 4\sqrt{m_0}$, determined at deep water
5	$T_{p\ deep}$ [s]	0.545	15.000	Peak period from spectral analysis at deep water
6	$T_{m\ deep}$ [s]	0.454	12.5	Mean period either from spectral analysis $=m_2/m_0$ or from time domain analysis (zero-downcrossing) at deep water
7	$T_{m\ -1,0\ deep}$ [s]	0.495	13.6	Mean period from spectral analysis at deep water $= m_{-1}/m_0$
8	β [°]	0	80	Angle of wave attack relative to the normal on the structure
9	$H_{m0\ toe}$ [m]	0.003	3.8	Significant wave height from spectral analysis = $4\sqrt{m_0}$ at the toe of the structure
10	$T_{p\ toe}$ [s]	0.545	16.4	Peak period from spectral analysis at the toe of the structure
11	$T_{m\ toe}$ [s]	0.454	11.8	Mean period either from spectral analysis $=m_2/m_0$ or from time domain analysis (zero-downcrossing) at the toe of the structure
12	$T_{m\ -1,0\ toe}$ [s]	0.495	10.6	Mean period from spectral analysis at the toe of the structure $= m_{-1}/m_0$
13	q [m^3/s.m]	0	$1.65*10^{-1}$	Overtopping discharge per second per meter width
14	P_{ow} [-]	0	81	Percentage of the waves resulting in overtopping

Table 4. Structural parameters included in the database

no	**parameter**	**min.**	**max.**	**description**
Structural parameters				
15	h_{deep} [m]	0	100	Water depth at deep water
16	m [-]	6.0	1000	Slope of the foreshore
17	h [m]	0.029	9.32	Water depth at the toe of the structure
18	h_t [m]	0.025	7.78	Water depth on the toe of the structure
19	B_t [m]	0.00	10.00	Width of the toe of the structure
20	γ_f [-]	0.35	1.00	Roughness/permeability factor for the structure
21	$\cot\alpha_d$ [-]	0	7.0	Cotangent of the slope of the structure downward of the berm
22	$\cot\alpha_u$ [-]	-5.0	9.7	Cotangent of the slope of the structure upward of the berm
23	$\cot\alpha_{excl}$ [-]	-1.5	8.1	Mean cotangent of the slope of the structure, without contribution of the berm
24	$\cot\alpha_{incl}$ [-]	-1.5	12.8	Mean cotangent of the slope of the structure, with contribution of the berm
25	R_c [m]	0	8.3	Crest freeboard of the structure
26	B [m]	0	8.00	Width of the berm
27	h_b [m]	-0.208	1.175	Water depth on the berm
28	$\tan\alpha_B$ [-]	0	0.125	Tangent of the slope of the berm
29	B_h [m]	0	8.00	Width of the horizontally schematised berm
30	A_c [m]	0	7.87	Armour crest freeboard of the structure
31	G_c [m]	0	5.60	Width of the structure crest

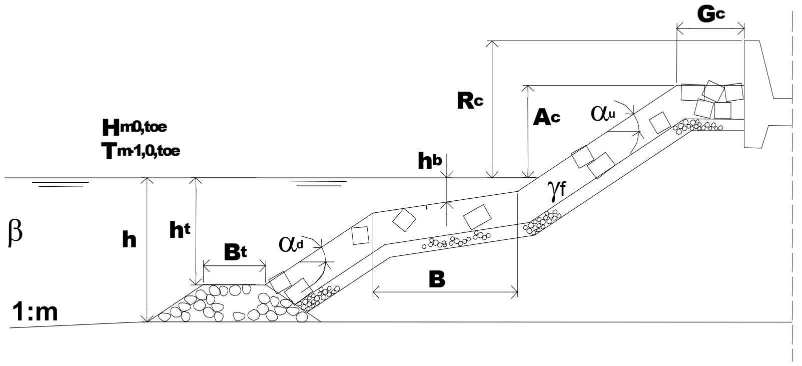

Figure 2. Parameters in the homogeneous database on wave overtopping used in NN

The above described structural parameters were chosen in such a way that a lot of test structures for overtopping can be described in a relative good way by these and only these parameters. More detailed information on the determination of the structural parameters is given in Verhaeghe et al., 2003.

2.3. *Analysis of the database*

As the database is far more extensive than needed for the input for the NN (Pozueta et al., 2004), the database contains a lot of information to be used at its own right. As mentioned in section 2.1 all data is screened before entering the database. Depending on the outcome of this screening phase, each overtopping test was assigned a reliability factor RF and complexity factor CF to (see Table 2). Data with a reliability and/or complexity factor of 4 (not reliable or too complex) had to be excluded from further investigations, e.g. the NN prediction, as these data are not well represented by the 31 parameters, or as the parameters are unreliable. About 1000 data have to be excluded in this way.

Compared with the first database (Verhaeghe et al., 2003), the final database is extended with more than 4000 additional tests, and improvements of some parameter definitions and values were made. The additional tests originate from "white spot" tests, field measurements and small scale simulations of the field measurements, performed within the CLASH project, but also new data from outside CLASH were gathered during this second phase.

After analysing the first database it was found that some regions in the ranges of parameters were not present or under represented. Therefore parametric tests, called 'white spot' tests, were conducted to fill up these gaps. In this context about 700 tests were performed in 3D test facilities to cover a full range of tests with oblique wave attack on rock and cube armoured slopes. Also the need for establishing good values of the roughness factors for different types of armour units was recognised. By performing additional tests on all kind of armour units, specific roughness coefficients (γ_f) were established depending on the type of armour unit. These validated roughness coefficients were put into the database (replacing estimated values in the first database). Other additional tests concerned overtopping tests on berm breakwaters.

The field measurements and corresponding small scale simulations within CLASH originate from three test sites: Samphire Hoe (UK), Ostia (Italy) and Zeebrugge (Belgium).

Furthermore, additional data from outside the project were received and added to the database.

Figure 3 gives an overall view of measured (dimensionless) overtopping discharge as a function of the relative crest freeboard for all tests in the database. In this figure it is shown that the area between 10^{-6} and 10^{-1} (dimensionless q) is well covered. The dimensionless relative crest freeboard (R_c/H_{m0}) is well covered in the range between 0.3 up to 3.5.

Some outliers can be identified. For example the points indicated by the circles give unexpected large overtopping. It was found that these tests were performed with a very shallow foreshore, where very heavy breaking occurred, introducing effects of surfbeat. The broken wave height at the toe of the structure was only 2 cm, in combination with a value of $T_{m-1,0\ toe}$ of 10 s, resulting in a wave steepness s_0 of only 0.00013.

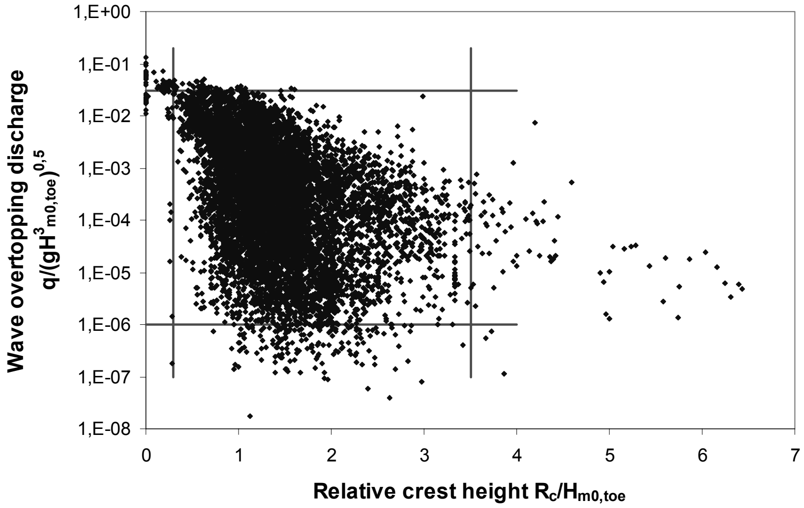

Figure 3. Relative crest height against dimensionless overtopping all tests

Most of the points with a freeboard of over 3 or 4 wave heights belong to tests on vertical walls on a steep foreshore or on a berm, e.g. VOWS-data (www.vows.ac.uk) where overtopping was generated by impacting waves. It is noticed that in such test situations, relative high overtopping values are measured.

At the left side of Figure 3 (indicated by boxes) outliers are identified, giving low overtopping for very low relative freeboards. It was found that a fairly high and wide rubble mound armour crest (A_c and G_c) was present here, which reduces the amount of overtopping considerable. The measurement location of the overtopping was situated lower than the armour elevation in these cases ($R_c < A_c$).

In Tables 2 and 3 an overview was given of the parameter ranges of each parameter included in the database. As the tests included in the database contain small and large scale laboratory tests as well as field measurements, the minimum (dimensional) values correspond in most cases with small scale model tests and the maximum (dimensional) values with prototype measurements.

The small scale tests were carried out in various laboratories around Europe and other parts of the world. The large scale tests were performed at the Delta flume from Delft Hydraulics, The Netherlands, or the Groβen Wellen Kanal at Hannover, Germany. The majority of the included field measurements are collected within the CLASH-project, although also some Japanese field measurements are included. Figure 4 gives the wave steepness as a function of the wave height for all tests.

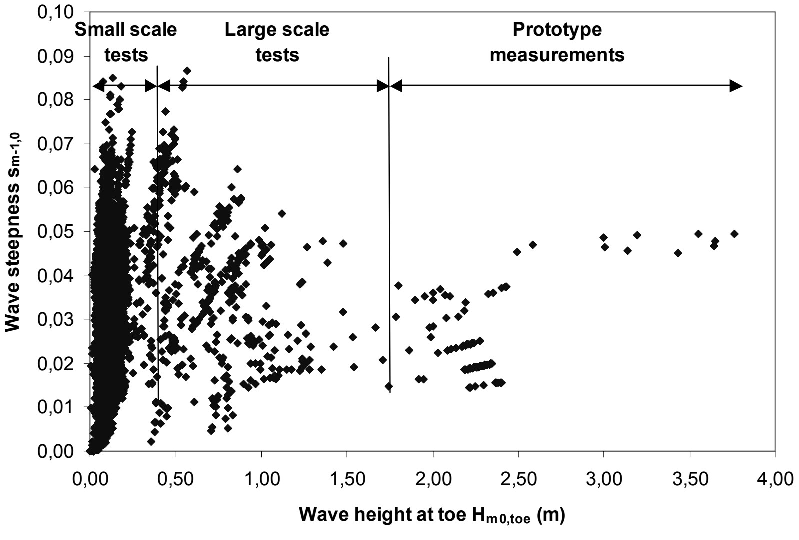

Figure 4 Small scale, large scale and prototype data; wave steepness versus wave height

Figure 5 shows only wave steepness' values for small scale tests and is a subset of Figure 4. A wave steepness of over 0.07 is physically not possible as the waves break on steepness. Therefore the data above the 0.07-line are considered as less reliable. Also wave steepness' lower than 0.005 are difficult to generate. Very small waves i.e. under 0.03 m are also considered less reliable.

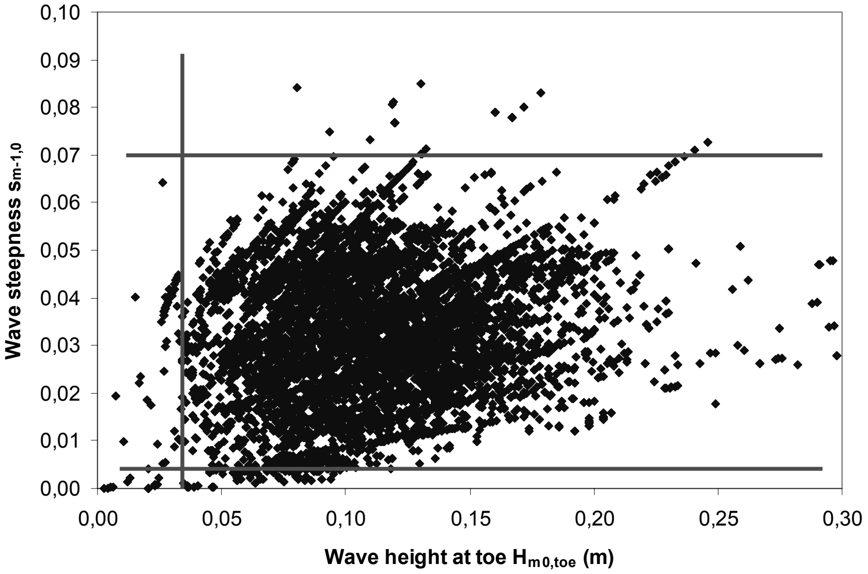

Figure 5 Wave steepness as function of wave height for small scale tests

Figure 6 gives combinations of upper and down slopes, with or without a berm. As can be seen in the graph, for a lot of tests both parameters are equal to each other, corresponding to uniform sloping structures with or without berm.

The upper slope in some cases has a negative value. This corresponds to test structures with a large wave return wall. The large wave return wall is schematised by means of a negative upper slope. Data points on the vertical axis correspond to structures with a vertical down slope and a sloping upper part. Data points with a value of $\cot\alpha_{up} = 0$ correspond to structures with a vertical upper part and a sloping lower part. As can be seen for non-equal values of $\cot\alpha_{up}$ and $\cot\alpha_{down}$, most structures are composed of a flatter lower slope with a steeper upper slope.

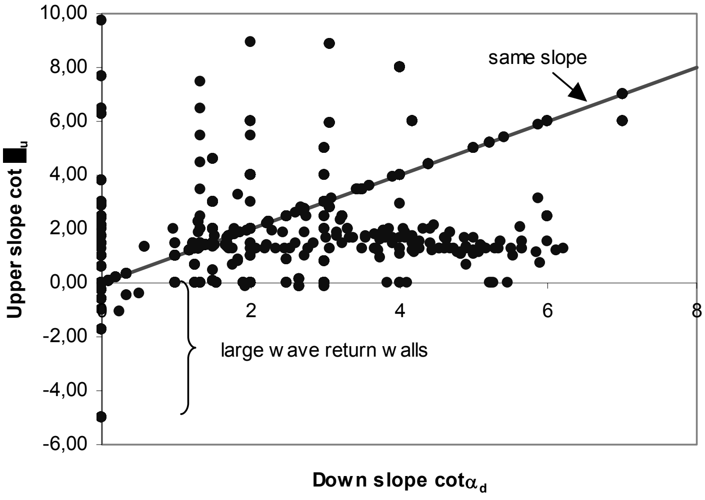

Figure 6. Combinations of upper and down slope

Structures generally have a toe (width B_t and depth h_t), a berm (width B and depth h_b), a crest (width G_c and height A_c) or a combination of these features. In Figure 7 the relative depth and width of each of these structure parts is given for all data. The width of toe, berm or crest can reach up to 10 or more wave heights. These large relative widths are often caused by very low wave heights. The figure shows clearly that in general the crest level is located higher than the berm level, which on its turn is located higher than the toe level.

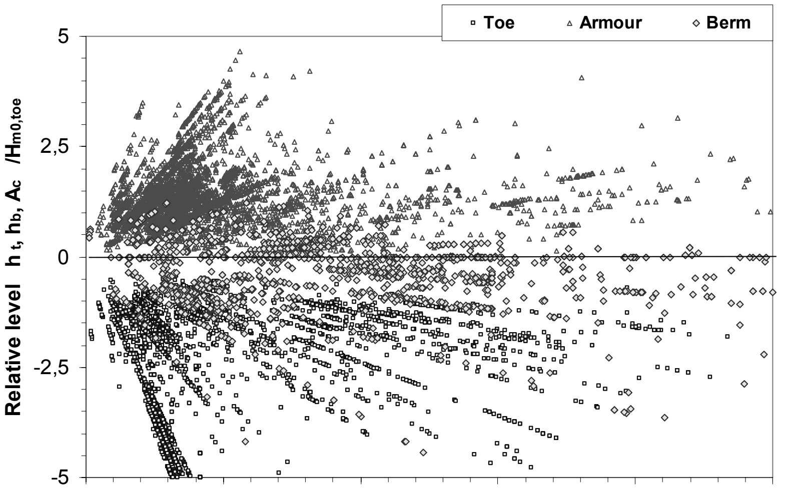

Figure 7. Relative depth and width of toe, berm and crest armour

Points on a straight line represent often tests from one test series in which only the water level and wave characteristics are changed. The relative depth and width changes in these cases. The majority of data points lies within the range of -5 < level/$H_{m0\ toe}$ < +5 and 0 < width/$H_{m0\ toe}$ < 10.

3. Application example

In addition to the neural network application, extra information can be extracted from the database. For users who want to evaluate for example a specific structure type, it is possible to look into the database and find similar cases with corresponding measured overtopping rates. All tests found can then be considered in depth. In this section an example is given of a specific application to use the information in the database.

Suppose a user has a vertical wall ($\cot\alpha_u = 0$) with a rock berm ($\gamma_f = 0.4$, B>0) around still water level ($-0.5H_{m0,toe} < h_b < 0.5H_{m0,toe}$). The water depth in front of the structure should be larger than 3 times $H_{m0,toe}$ ($h > 3\ H_{m0,toe}$) and the user only wants to consider very reliable tests (RF = 1 and 2). Giving these restrictions to corresponding columns in the Excel spreadsheet results in the wanted data. From the database it can be found that only one test series complies with above restrictions. In Figure 7 the selected data are shown.

A more detailed analysis divides the tests into groups depending on the width of the berm (B) related to the offshore wave length (L_0). The figure shows that, as expected, the rate of overtopping is dependent on this width of the berm in front of the structure. Figure 7 shows clearly that if the berm is wider less overtopping occurs.

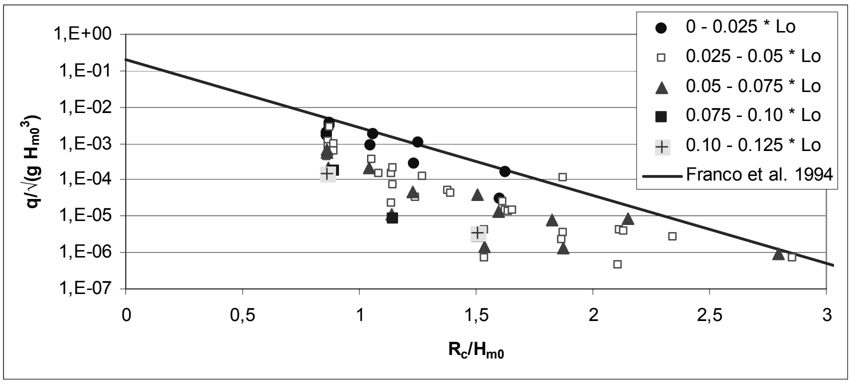

Figure 8. Dimensionless overtopping at a vertical wall with a berm in front

It is noted that the rate of overtopping is influenced by the exact level of the berm. In this case the berm level is chosen between + and – 0.5 $H_{m0,toe}$. There will be a slight difference in the rate of overtopping if the height is –0.5 H_{m0} or + 0.5 H_{m0}.

In a similar way as given in this example all kind of structures can be extracted from the database and considered more in detail. A user should know, however, what the meaning of each parameter is, what the possible ranges mean in physical terms and how these conditions can be given as a constraint to the database. Furthermore, very often the constraints have to be given in dimensionless form. For example a range of B/H_{m0} should be considered for a berm width and not directly B, as this value is depending on the scale of the tests.

4. Conclusions

An extensive homogeneous database on wave overtopping has been created within the EU-project of CLASH. The database will be available to the public for free in 2005. In this database over 10,000 tests are gathered from test facilities around Europe and outside Europe. Beside model tests, also prototype data is put into the database. Distinction can be made between confidential and non-confidential data. For the last group of tests, a reference list will be available describing the origin of the tests.

The database has been used for the development of a Neural Network prediction method for wave overtopping (Pozueta et al. 2004). This Neural Network is the core of the new developed generic prediction method. With this prediction method the user is able to estimate the rate of overtopping for each type of coastal structure.

The database consists of far more information than needed for the NN, which allows the user to select tests from the database with similar features as the structure the user wants to investigate. The data found in this way directly correspond to measured overtopping discharges at similar structure types and are not a prediction. Whenever data is compared it is stressed that the physics involved should be considered and understood properly.

5. Acknowledgement

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