



COMMISSION  
OF THE EUROPEAN  
COMMUNITIES



FP5- EESD

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

## D43 Synthesis and design guidelines

February 2005

J. R. Medina  
J. De Rouck  
M. Figueres  
J. González-Escrivá  
J. Geeraerts



UNIVERSIDAD  
POLITECNICA  
DE VALENCIA



UNIVERSITEIT  
GENT

---

## Table of contents

List of tables

List of figures

List of symbols

0	Preface.....	9
1	Introduction.....	10
2	CLASH methodology to estimate mean overtopping and overtopping risk assessment ..	13
3	CLASH reports.....	19
4	Guidelines .....	23
5	Acknowledgement.....	26
6	References.....	27
7	Appendices.....	29

---

## List of tables

Table 1:	Suggested limits for overtopping mean discharges or peak volumes .....	16
----------	--	----

## List of figures

Figure 1:	CLASH interconnection diagram. ....	12
Figure 2:	Parameters used as input parameters for the CLASH generic prediction method.....	13
Figure 3:	CLASH methodology for the analysis of scale and model effects. ....	15
Figure 4:	Scaling map for wave overtopping results over coastal structures from small-scale model tests. Eq. and Fig. nrs refer to Appendix 1.....	15
Figure 5:	Suggested velocity / depth limits from Ramsbottom <i>et al.</i> (2004). ....	17
Figure 6:	Decision tree for choosing valuation techniques. ....	18

---

**List of symbols**

$A_c$	= height of armour in front of crest element in relation to S.W.L.	[m]
$B$	= berm width, measured horizontally	[m]
$c_i$	= inshore wave celerity	[m/s]
$C_r$	= average reflection coefficient ( $= \sqrt{m_{0,r}} / \sqrt{m_{0,i}}$ )	[%]
CF	= complexity-factor of structure section = 1, 2, 3 or 4	[-]
$h$	= water depth just before the structure (before the structure toe)	[m]
$h_{\text{deep}}$	= water depth in deep water	[m]
$h_t$	= water depth on the toe of the structure	[m]
$h_b$	= berm depth in relation to S.W.L. (negative means berm is above S.W.L.)	[m]
$D_{n50}$	= nominal diameter of rock	[m]
$D_n$	= nominal diameter of concrete armour unit	[m]
$D(f,\theta)$	= directional spreading function, defined as:	[°]
	$(f, \theta) = S(f). D(f,\theta) \text{ met } \int_0^{2\pi} D(f, \theta) d\theta = 0$	
$f$	= frequency	[Hz]
$f_p$	= spectral peak frequency;	
	i.e. frequency at which $S_\eta(f)$ is a maximum	[Hz]
$f_b$	= width of a roughness element (perpendicular to dike axis)	[m]
$f_h$	= height of a roughness element	[m]
$f_L$	= centre-to-centre distance between roughness elements	[m]
$g$	= acceleration due to gravity (= 9,81)	[m/s <sup>2</sup> ]
$G_c$	= width of armour in front of crest element	[m]

---

H	= wave height	[m]
$H_{1/x}$	= average of the highest 1/x th of the wave heights derived from time series	[m]
$H_{x\%}$	= wave height exceeded by x% of all wave heights	[m]
$H_s$	= $H_{1/3}$ = significant wave height	[m]
$H_{m0}$	= estimate of significant wave height based on spectrum = $4\sqrt{m_0}$	[m]
$H_{m0,deep}$	= estimate of significant wave height at deep water	[m]
$H_{m0,toe}$	= estimate of significant wave height at the toe of the structure	[m]
k	= angular wave number (= $2\pi/L$ )	[rad/m]
$L_{berm}$	= horizontal length between two points on slope, $1.0 H_{m0}$ above and $1.0 H_{m0}$ below middle of the berm	[m]
$L_{slope}$	= horizontal length between two points on the slope, $Ru_{2\%}$ above and $1.5 H_{m0}$ below S.W.L.	[m]
L	= wave length measured in the direction of wave propagation	[m]
$L_{0p}$	= peak wave length in deep water = $gT_p^2/2\pi$	[m]
$L_{0m}$	= mean wave length in deep water = $gT_m^2/2\pi$	[m]
$L_0$	= deep water wave length based on $T_{m-1,0} = gT_{m-1,0}^2/2\pi$	[m]
$m_n$	= $\int_{f_1}^{f_2} f^n S(f) df$ = $n^{th}$ moment of spectral density	[m <sup>2</sup> /s <sup>n</sup> ]
	lower integration limit = $f_1 = \min(1/3.f_p, 0.05 \text{ full scale})$	
	upper integration limit = $f_2 = 3.f_p$	
$m_{n,x}$	= $n^{th}$ moment of x spectral density	[m <sup>2</sup> /s <sup>n</sup> ]
	x may be: i for incident spectrum	
	r for reflected spectrum	

---

$N_{ow}$	= number of overtopping waves	[-]
$N_w$	= number of incident waves	[-]
$P(x)$	= probability distribution function	[-]
$p(x)$	= probability density function	[-]
$P_V$	= $P(\underline{V} \geq V)$ = probability of the overtopping volume $\underline{V}$ being larger or equal to $V$	[-]
$P_{ow}$	= probability of overtopping per wave = $N_{ow}/N_w$	[-]
$q$	= mean overtopping discharge per meter structure width	[m <sup>3</sup> /m/s]
$R_c$	= crest freeboard in relation to S.W.L.	[m]
RF	= reliability-factor of test = 1, 2, 3 or 4	[-]
$R_u$	= run-up level, vertical measured with respect to the S.W.L.	[m]
$R_{u2\%}$	= run-up level exceeded by 2% of the incident waves	[m]
$s$	= wave steepness = $H/L$	[-]
$s_{0p}$	= wave steepness with $L_0$ , based on $T_p = H_{m0}/L_{0p} = 2\pi H_{m0}/(gT_p^2)$	[-]
$s_{0m}$	= wave steepness with $L_0$ , based on $T_m = H_{m0}/L_{0m} = 2\pi H_{m0}/(gT_m^2)$	[-]
$s_0$	= wave steepness with $L_0$ , based on $T_{m-1,0} = H_{m0}/L_0 = 2\pi H_{m0}/(gT_{m-1,0}^2)$	[-]
$S_{\eta,i}(f)$	= incident spectral density	[m <sup>2</sup> /Hz]
$S_{\eta,r}(f)$	= reflected spectral density	[m <sup>2</sup> /Hz]
$S(f, \theta)$	= directional spectral density	[(m <sup>2</sup> /Hz)/°]
$t$	= variable of time	[s]
$T$	= wave period = $1/f$	[s]
$T_m$	= average wave period (time-domain)	[s]
$T_p$	= spectral peak wave period = $1/f_p$	[s]
$T_{H1/x}$	= average of the periods of the highest $1/x$ th of wave heights	[s]

---

$T_s$	= $T_{H1/3}$ = significant wave period	[s]
$T_{mi,j}$	= average period calculated from spectral moments, e.g.:	[s]
$T_{m0,1}$	= average period defined by $m_0/m_1$	[s]
$T_{m0,2}$	= average period defined by $\sqrt{m_0/m_2}$	[s]
$T_{m-1,0}$	= average period defined by $m_{-1}/m_0$	[s]
$T_R$	= record length	[s]
$v_z, v_x$	= particle velocities in direction z, and x	[m/s]
$V$	= volume of overtopping wave per unit crest width	[m <sup>3</sup> /m]
$\alpha$	= slope angle	[°]
$\alpha_{wall}$	= angle that steep wall makes with horizontal	[°]
$\alpha_{berm}$	= angle that sloping berm makes with horizontal	[°]
$\beta$	= angle of wave attack with respect to the structure alignment (0° is perpendicular to the structure axis)	[°]
$\eta(t)$	= surface elevation with respect to S.W.L.	[m]
$\gamma_b$	= correction factor for a berm	[-]
$\gamma_f$	= correction factor for the roughness of or on the slope	[-]
$\gamma_\beta$	= correction factor for oblique wave attack	[-]
$\gamma_v$	= correction factor for a vertical wall on the slope	[-]
$\xi_0$	= breaker parameter (= $\tan\alpha/s_0^{1/2}$ )	[-]
$\mu_{(x)}$	= mean of measured parameter x with normal distribution	[..]
$\sigma$	= directional spreading	[°]
$\sigma_{(x)}$	= standard deviation of measured parameter x with normal distribution	[..]
$\theta$	= direction of wave propagation	[°]

---

$\omega$  = angular frequency =  $2\pi f$  [rad/s]



---

## Abstract

The CLASH project (Crest Level Assessment of Coastal Structures by Full Scale Monitoring, Neural Network Prediction and Hazard Analysis on Permissible Wave Overtopping, [www.clash-eu.org](http://www.clash-eu.org)) funded by European Union (EU) through contract no. EVK3-CT-2001-00058, investigated wave overtopping for different structures in prototype and in laboratory (see De Rouck et al., 2002). The main scientific objectives of CLASH were (i) to solve the problem of possible scale effects of wave overtopping and (ii) to produce guidelines for crest height design or assessment, based on overtopping criteria.

This report is a synthesis of the project results. The CLASH methodology to estimate mean overtopping discharges and overtopping risk assessment is based on four elements: (1) the CLASH database (workpackage 2: WP2), (2) the hazard analysis including socio-economic impact (WP6), (3) the scale and model effect analysis (WP7) and (4) the NN generic prediction method (WP8).

For any given specific engineering application, hazard analysis provides the limit of permissible overtopping discharges for different modes of failure or damage (pedestrians, vehicles, property, etc.). Scale and model effect analysis defines the relationship between prototype overtopping and Froude scaled overtopping. Finally, the NN generic prediction method, based on the CLASH database, estimates the overtopping discharges corresponding to the Froude scaled model. The CLASH executable file NN-OVERTOPPING 2.0 is designed for end-users to calculate NN Froude scaled mean overtopping discharges and confidence intervals. In addition prototype mean overtopping estimations, considering scale and model effects are provided. These overtopping estimations can be compared to permissible overtopping for the damage risk assessment (overtopping hazard analysis).

## 0 Preface

CLASH (Crest Level Assessment of Coastal Structures by Full Scale Monitoring, Neural Network Prediction and Hazard Analysis on Permissible Wave Overtopping; contract EVK3-CT-2001-00058) was carried out from January 2002 till December 2004. The project consortium consisted of 13 partners from 7 EU member states, which are listed below:

<b>Partner</b>	<b>Abbreviation</b>	<b>Country</b>
<b>Universiteit Gent (coordinator)</b>	<b>UGent</b>	<b>BE</b>
<b>Flanders Community Coastal Division</b>	<b>FCCD</b>	<b>BE</b>
<b>Flanders Community Flanders Hydraulics</b>	<b>FCFH</b>	<b>BE</b>
<b>Leichtweiss Institut für Wasserbau</b>	<b>LWI</b>	<b>D</b>
<b>Aalborg University</b>	<b>AAU</b>	<b>DK</b>
<b>Universidad Politécnica de Valencia</b>	<b>UPVLC</b>	<b>E</b>
<b>Modimar</b>	<b>MOD</b>	<b>IT</b>
<b>Delft Hydraulics</b>	<b>DH</b>	<b>NL</b>
<b>Infram</b>	<b>INF</b>	<b>NL</b>
<b>Rijkswaterstaat</b>	<b>RIKZ</b>	<b>NL</b>
<b>Manchester Metropolitan University</b>	<b>MMU</b>	<b>UK</b>
<b>University of Edinburgh</b>	<b>UEdin</b>	<b>UK</b>
<b>Hydraulic Research Wallingford</b>	<b>HRW</b>	<b>UK</b>

CLASH was coordinated by Ghent University, in the person of prof. J. De Rouck.  
For more information please contact the coordinator:

**Prof. dr. ir. J. De Rouck**

**Department of Civil Engineering – Ghent University**

**Technologiepark 904**

**9052 Zwijnaarde**

**Belgium**

**[Julien.Derouck@Ugent.be](mailto:Julien.Derouck@Ugent.be)**

---

[Nathalie.Rousseau@Ugent.be](mailto:Nathalie.Rousseau@Ugent.be)

## 1 Introduction

The project has been stimulated by two main issues. The first is the lack of widely applicable and safe prediction methods for structure design. Each coastal structure is different, yet whilst an enormous amount of data on wave overtopping is available at various research institutes and universities, those data have not yet been integrated to give a single design method. The second observation is one of the conclusions of the EU-project OPTICREST which suggests that wave run-up on rubble mound slopes, measured during full-scale storms, was about 20% higher than modelled by selected hydraulic laboratories in small scale test facilities.

The main scientific objectives of CLASH were to:

- a) solve the problem of possible scale / model effects for wave overtopping;
- b) produce a generic prediction method for crest height design or assessment.

The project has used two main approaches. Firstly, wave overtopping events were measured at three coastal sites in Europe. Those storm events were then simulated by laboratory tests and/or by numerical modelling and have been compared with the actual measured events. This has led to a conclusion on scale / model effects and how to deal with it. The second approach was to gather all existing data on overtopping in a homogeneous data base, to supplement that data base with the new full scale measurements and more small scale testing, and to develop a generally applicable design method. This new method used a neural network development and includes the conclusions on scale effects.

To organize all the work to be done, all different tasks were structured in 10 distinct but inter-related WorkPackages (WP). All WPs resulted in clearly defined Deliverables (D). Figure 1 shows the interconnection diagram of the project's Workpackages. Throughout references to specific Deliverables  $D_{nn}$  are made. A list with relevant Deliverables is found at the end of this report (References).

The main objectives of this report are: (1) to synthesise CLASH results so as to draw final conclusions, and (2) to establish a brief guideline for crest level design or assessment based on permissible overtopping.

Furthermore, this report is a synthesis of the project results. The CLASH methodology to estimate mean overtopping discharges and overtopping risk assessment is based on four elements: (1) the CLASH database (WP2), (2) the hazard analysis including socio-economic impact (WP6), (3) the scale and model effect analysis (WP7) and (4) the NN generic prediction method (WP8).

---

Quantifying scale and model effects is mainly done by a comparison of the results of prototype measurements (Zeebrugge (Belgium), Ostia (Italy) and Samphire Hoe (UK)) and reproduced prototype storms in small scale models.

The generic prediction method together with the permissible overtopping as concluded from the hazard analysis in WP6 form the basis for this guideline. The CLASH executable software (NN-OVERTOPPING 2.0) for the generic prediction method is described in D41 and D42 and is also available on the CLASH website. All CLASH reports, including the executable file of the CLASH generic prediction method, are available on the world wide web (<http://www.clash-eu.org>).

The CLASH software and methodology are available to all researchers, consultants and owners of coastal structures for the design, safety assessment of coastal structures, risk assessment of coastal areas, and all projects in which work is carried out where the crest height of coastal structures has a determining role. Guidelines based on the comparison of estimates with permissible overtopping discharges take into account the overtopping risk and vulnerability.

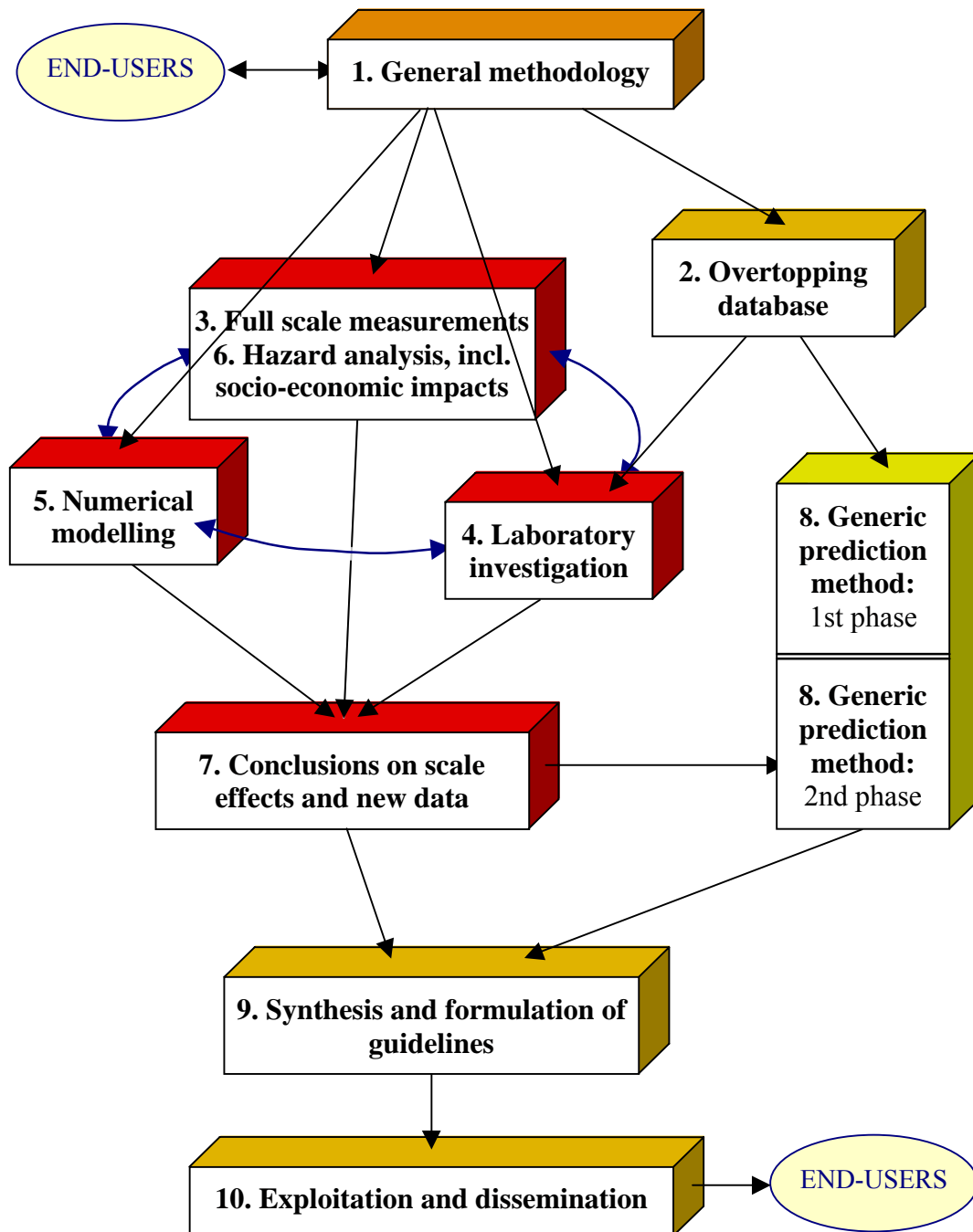


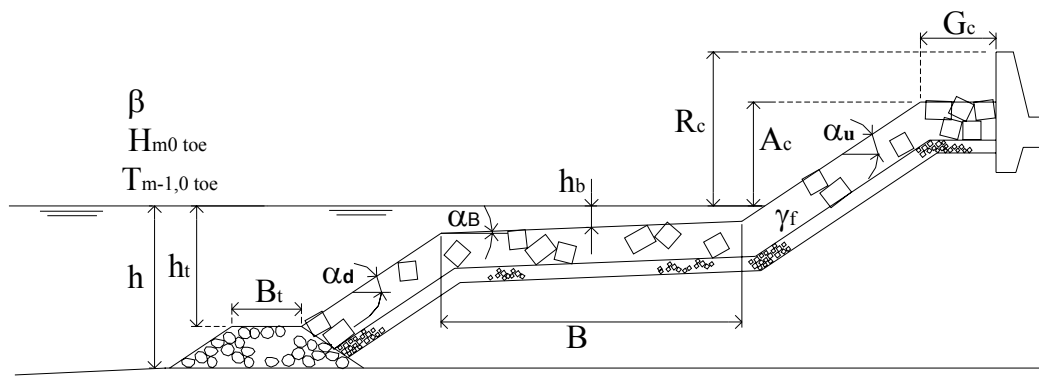
Figure 1: CLASH interconnection diagram.

Section 2 of this report provides the main steps in the CLASH methodology to estimate mean overtopping discharges and overtopping risk assessment with some background. Section 3 provides a description of what work has been performed within the different WPs of CLASH together with the main outcomes. Section 4 gives the different steps to be undertaken in the crest level assessment of a coastal structure.

## 2 CLASH methodology to estimate mean overtopping and overtopping risk assessment

Within the CLASH project, results from more than 10,000 overtopping tests were collected in the CLASH database. There were a wide variety of structural types and hydrodynamic conditions present in the original data set. D28 (CLASH deliverable 28) describes the CLASH database, the quality control and homogenisation procedures employed during CLASH to create the CLASH database, which is the basis of the CLASH generic prediction method. Each overtopping test included in the database was defined by 31 parameters to offer a brief but comprehensive overview of the entire test situation, including a Reliability Factor (RF) and a Complexity Factor (CF), which indicate the reliability of the test and the complexity of the test structure. The CLASH generic prediction method uses only 15 structural and hydraulic parameters as input parameters as specified in D41. The RF and RC were used to build up the NN model described in D42, yet they were not used as input parameters. While the CLASH database was used to formulate the NN generic prediction method, it is also available on the CLASH-website to be utilized directly by end users as explained in D6.

The CLASH generic prediction method (D41) is based on a NN model, which was designed to give an estimation of the mean overtopping rate in addition to an estimated uncertainty for a wide range of structures. D42 describes the input and output parameters and gives examples of the schematisation procedure reported in detail in D6. End users of the CLASH generic prediction method (NN-OVERTOPPING 2.0) should pay special attention to the specific CLASH structural schematisation method to transform breakwater cross sections into NN input vectors. The CLASH schematisation method described in D6 and D42 must be followed when the CLASH generic prediction method is used. Figure 2 illustrates the 15 input parameters.

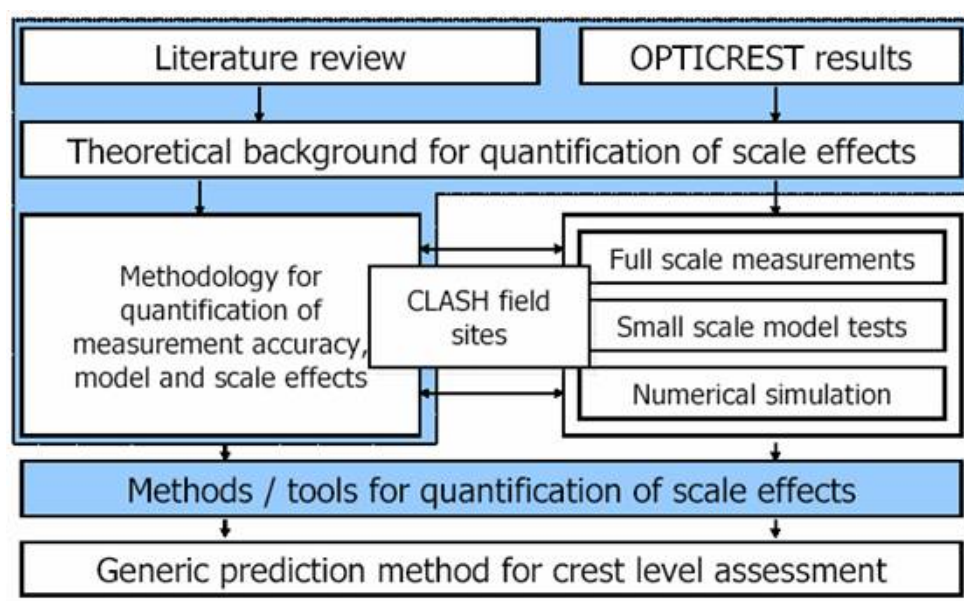


**Figure 2: Parameters used as input parameters for the CLASH generic prediction method.**

$A_c$	= armour crest freeboard of structure	[m]
$B$	= berm width, measured horizontally	[m]
$B_t$	= width of toe of structure	[m]

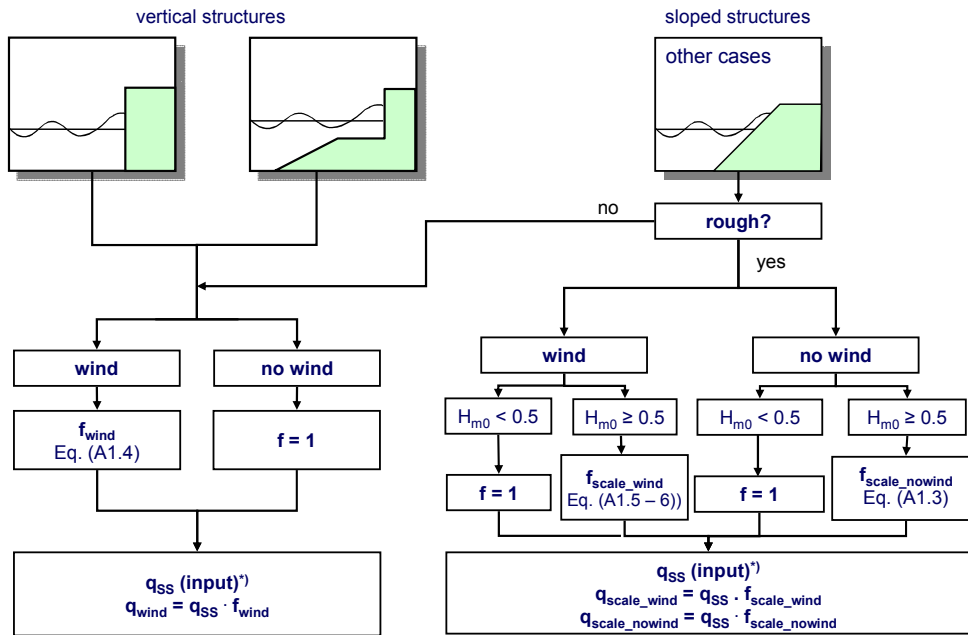
$G_c$	= width of structure crest	[m]
$h$	= water depth at toe of structure	[m]
$h_b$	= water depth on berm (negative means berm is above S.W.L.)	[m]
$h_t$	= water depth on toe of structure	[m]
$H_{m0\ toe}$	= $H_{m0}$ determined at toe of structure	[m]
$R_c$	= crest freeboard of structure	[m]
$T_{m-1,0\ toe}$	= $T_{m-1,0}$ determined at the toe of the structure	[s]
$\alpha_d$	= angle between structure slope downward berm and horizontal	[°]
$\alpha_b$	= angle that sloping berm makes with horizontal	[°]
$\alpha_u$	= angle between structure slope upward berm and horizontal	[°]
$\beta$	= angle of wave attack with respect to the structure alignment ( $0^\circ$ is perpendicular to the structure axis)	[°]
$\gamma_r$	= correction factor for the permeability and roughness of or on the slope	[-]

In addition to the estimation of the mean overtopping rate and the corresponding uncertainty percentiles, the CLASH generic prediction method also provides (when applicable) a corrected estimation considering the scale and model effects with the methodology described in D40. Figure 3 shows a scheme of the general methodology for the analysis of scale and model effects during the CLASH project. The final result is implemented in the executable file of the generic prediction method (NN-OVERTOPPING 2.0) and a brief description is given in Annex 1. The scaling procedure in Annex 1 allows to scale up small scale model results to prototype scale, taking into account possible model and scale effects.



**Figure 3: CLASH methodology for the analysis of scale and model effects.**

Figure 4 provides the scaling map, which is a schematisation of the implemented scaling procedure. This map (and the procedure in Annex 1) can also be used independent from the NN, since it is suited to upscale small scale model results to prototype scale, taking into account model and scale effects. The equation and figure numbers mentioned in Fig. 4 refer to Appendix 1.



<sup>\*)</sup> zero overtopping rates from small-scale model tests can be overcome by the method as described in Fig. A1.4

**Figure 4: Scaling map for wave overtopping results over coastal structures from small-scale model tests. Eq. and Fig. nrs refer to Appendix 1.**

The output of the executable file of the CLASH generic prediction method (NN-OVERTOPPING 2.0) is the mean overtopping discharge  $q$  (and percentiles), considering scale and model effects. In order to use this estimation in overtopping risk assessment, permissible overtopping discharges and socio-economic impact have to be considered. D38 relates the overtopping hazard analysis considering three descriptive variables: (1) mean overtopping discharge  $q$  (litre/s.m), (2) peak overtopping volume  $V_{\max}$  ( $\text{m}^3/\text{m}$ ), and (3) overtopping velocities  $v_x$  and  $v_z$  (m/s). Although overtopping velocities or maximum overtopping volume were more significant for hazards than the mean overtopping discharge, it was the mean overtopping discharge  $q$  ( $\text{m}^3/\text{s.m}$ ) that became the selected variable to describe overtopping because  $q$  was the only variable to describe overtopping in most experiments of the CLASH database. Nevertheless, D38 provides the justification for Table 1, indicating suggested limits for overtopping mean discharge ( $q$  in litre/s.m) in addition to those for maximum overtopping volume ( $V_{\max}$  in litre/m). Table 1 shows the CLASH permissible overtopping to be considered for overtopping hazard assessment.

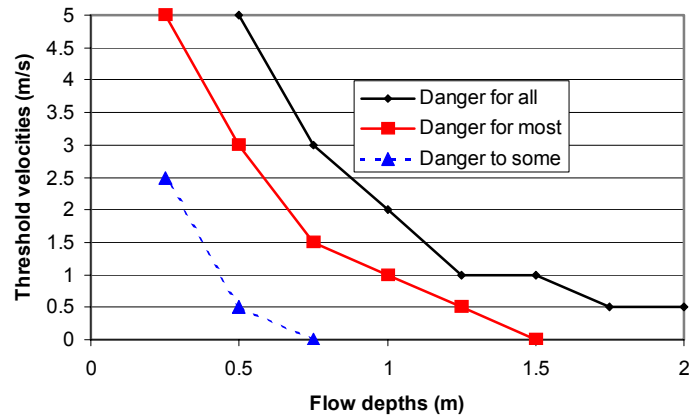


<b>Table 1: Suggested limits for overtopping mean discharges or peak volumes*</b>			
<b>Hazard type / reason</b>	<b>Mean discharge, q</b>	<b>Peak volume, V<sub>max</sub></b>	<b>Comments or other limits</b>
<b>Pedestrians</b>			
Unaware pedestrian, no clear view of the sea, relatively easily upset or frightened, narrow walkway or close proximity to edge	0.03 l/s.m	2-5 l/m at high level or velocity	
Aware pedestrian, clear view of the sea, not easily upset or frightened, able to tolerate getting wet, wider walkway.	0.1 l/s.m	20-50 l/m at high level or velocity	
Trained staff, well shod and protected, expecting to get wet, overtopping flows at lower levels only, no falling jet, low danger of fall from walkway	1-10 l/s.m	500 l/m at low level,	$d.u^2 < 1-5 \text{ m}^3/\text{s}^2.m$
<b>Vehicles</b>			
Driving at moderate or high speed, impulsive overtopping giving falling or high velocity jets	0.01-0.05 l/s.m	5 l/m at high level or velocity	
Driving at low speed, overtopping by pulsating flows at low levels only, no falling jets	10-50 l/s.m	1 m <sup>3</sup> /m	
<b>Property</b>			
Sinking small boats set 5-10m from wall. Damage to larger yachts	q = 10 l/s.m	1 - 10 m <sup>3</sup> /m	Volumes depend on vessel position etc., form of overtopping flow and wave transmission
Significant damage or sinking of larger yachts	q = 50 l/s.m	5 - 50 m <sup>3</sup> /m	

\* Overtopping at "Low level" is overtopping flowing over or close to the promenade. Overtopping at "high level" is overtopping flying through the air.

High or low velocities depending on flow depth, see Fig. 5 for guidance.

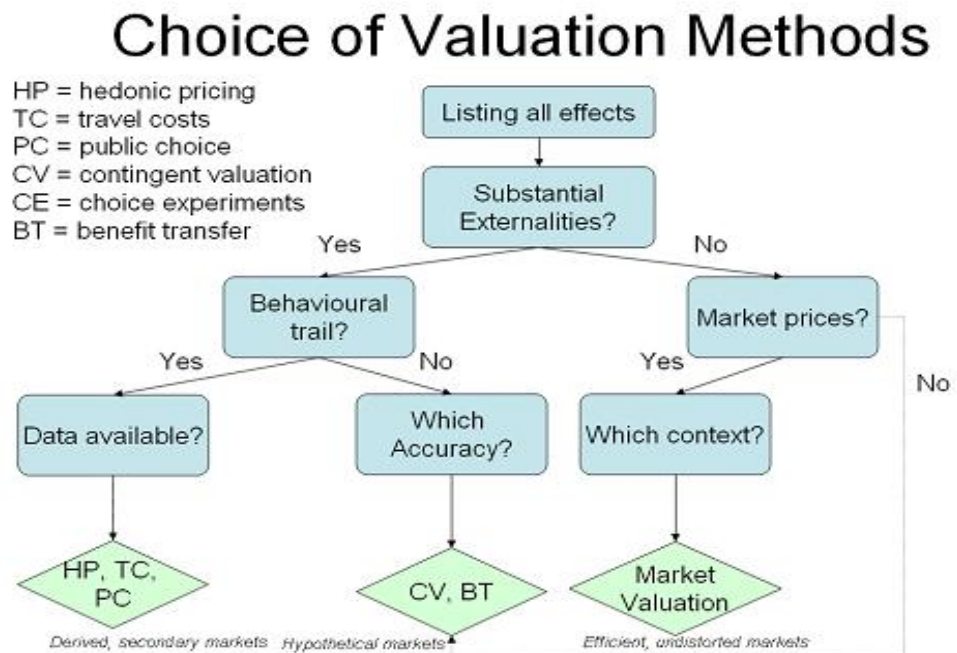
More background on the velocity limits is given in Fig. 5. As these velocity / depth limits were originally derived for relatively steady flows, it would be wise to take a precautionary view of these limits in the derivation of any suggested limits. The middle threshold in Fig. 5 suggests that flow velocities above  $u_z \geq 2.5\text{m/s}$  will be difficult to resist for depths greater than  $d > 0.5\text{m}$ , and  $u_z \geq 5\text{m/s}$  will be difficult to resist for depths greater than  $d > 0.25\text{m}$ .



**Figure 5: Suggested velocity / depth limits from Ramsbottom *et al.* (2004).**

For a rational overtopping hazard analysis of any given situation, the CLASH generic prediction method, including scale and model effects, together with the information in Table 1 provides end users with an estimation of the prototype mean overtopping discharge as well as specific permissible mean overtopping discharges.

D39 presents two case study examples and valuation methods that can be used to calculate economic damage resulting from overtopping events. A decision tree for selecting valuation methods is given below.



**Figure 6: Decision tree for choosing valuation techniques.**

The CLASH methodology summarized above allows end users to obtain:

1. Froude scaled mean estimation and uncertainty of mean overtopping discharge corresponding to a given structural and hydraulic condition (no scale or model effect).
2. Mean overtopping discharge corresponding to a given structural and hydraulic condition, considering scale and model effects.
3. Permissible limits for mean overtopping discharge and maximum overtopping volume.
4. Valuation methods to estimate socio-economic damage due to overtopping.

### 3 CLASH reports

In addition to the CLASH methodology and the generic prediction method implemented in the executable software NN-OVERTOPPING 2.0, a final report D46 has been written to inform interested end users in more detail. In this report reference is made to additional information compiled and other methods developed during the CLASH project.

Following is a list of the summarizing reports of the CLASH work-packages:

**WP1 General Methodology:** D5 describes the CLASH project and methodology as was originally conceived in 2002, two years before the finalization of the project.

**WP2 Overtopping database:** D28 contains the CLASH database with detailed information of more than 10,000 overtopping tests corresponding to a variety of scales, structures and hydraulic conditions. This report describes also the structural schematisation procedure adopted by CLASH and used for training the NN model for the CLASH generic prediction method.

**WP3.1 Full scale measurements - Zeebrugge:** D31 describes the full-scale measurements at the outer Zeebrugge harbour (Belgium). The Zeebrugge field site is located on the NW mound breakwater with an armour layer of 25 ton grooved cubes and crest level at Z+12.40 m. Local tides are characterised by MHWLS=Z+4.62 m and MLWLS= Z+0.32 m. Two cross-sections of the breakwater are instrumented and separated approximately 140 m; a “jetty sec-

tion” with the Measurement Jetty in which most terrestrial instruments are placed and a “tank section” in which the overtopping tank is placed. Different wind, wave and run-up measurement instruments, instrumented dummies and pipeline, and overtopping volumes and velocities are measured at full scale. Nine storms with overtopping measured between 1999 and 2004 are analysed in the report.

**WP3.2: Full scale measurements – Ostia:** D32 describes the prototype overtopping measurement station at the yacht harbour of Rome-Ostia (Italy). The harbour is protected with rubble mound breakwaters varying in depths up to -5.0 m MSL while the crest level of the concrete wall is +4.5 m MSL. The local tide range is 0.5 m, the rock armour seaward slope is 1:3.5. The design armour stones weigh from 3 to 7 tonnes. Seven independent storms with significant overtopping events were recorded during the period October 2003 to February 2004. Observed maximum overtopping volumes  $V_{\max}$  (litre/m) were highly correlated to mean overtopping rate  $q$  (litre/s.m) with a factor of  $10^3$ .

**WP3.3: Full scale measurements – Samphire Hoe:** D33 describes full scale overtopping measurements at the Samphire Hoe recreational reclaimed area immediately to the west of Dover (United Kingdom). The area is enclosed by a vertical seawall with a crest level at +8.22 m ODN and at toe level at -2.42 m ODN. The berm in front of the wall is approximately 3.5 m deep by 10 m wide, having tides characterized by MHWLS = +3.03 m ODN and MLWLS = -2.87 m ODN. The seawall is subject to overtopping by spray approximately 30 days annually and significant wave overtopping is observed regularly. Two storms with significant overtopping were measured in May 2003 and these were analysed showing the influence of wind on the spatial distribution of the overtopping.

**WP3.4: Full scale measurements- Petten:** D37 describes the field measurements (seabed topography, wind, water level, wave and run-up) taken during the 2003-2004 storm season at the Petten Sea Defence station (the Netherlands), which has been operational since 1994. The principal objective of the Petten survey was first to follow wave propagation from deep water through the surf zone to the dike in addition to measuring wave run-up on the dike. This information was used to quantify the reliability of the wave propagation model SWAN and the wave run-up model. Comparisons of the performance of different instruments, the reliability of instruments and the importance of changes in seabed topography are highlighted.

**WP4.1: Laboratory investigation – Zeebrugge:** D34 describes the laboratory research for the Zeebrugge rubble mound breakwater at LWI and UPVLC. Identical tests (i.e. the reproduction of the storms measured at the field site) are carried out in two laboratories in order to check and eliminate any influence, typical for the laboratory measurements (wave generation, measuring device, placement of the armour units, ...) and to allow to identify possible causes of differences. Thus, small scale “prototype-linked” results are double checked. The experimental set-up is very similar to that used for OPTCREST project. During the OPTCREST

---

project, run up and overtopping tests in the UPVLC wind and wave test facility were carried out using a 1:30 scale model of the Zeebrugge breakwater (“jetty section”). During the CLASH project, LWI and UPVLC carried out overtopping experiments with a similar scale model but corresponding to the “tank section” where the prototype overtopping tank was placed. OPTICREST and CLASH results were compared, as were 11 storms between 1999 and 2004 with significant prototype overtopping. Repeatability of tests was analysed and model effects (wind, armour placement, tray position, etc.) were studied; uncertainty of measurements and model effects were assessed.

**WP4.2: Laboratory investigation – Ostia:** D35 describes the laboratory research conducted for the Ostia rubble mound breakwater at UGent and FCFH. To determine the laboratory influence on results, 2D tests (UGent) and 3D tests (FCFH) with the same characteristics were carried out using 1:20 (2D) and 1:40 (3D) scale models of the Ostia breakwater. Several significant overtopping events are described in D32; however, 2D tests reproducing prototype storm conditions measured zero overtopping; only parametric tests with much higher mean water level than prototype generated similar overtopping discharges. Changes in the 2D model tests affecting slope, closing connection, foreshore and permeability of the core were studied to explain the discrepancy between prototype overtopping and 2D Froude scaled overtopping. 3D tests reproducing prototype storm conditions measured some overtopping, but a factor 5 to 10 smaller than in prototype. A comparison of 2D and 3D model results indicates the existence of a 3D effect.

**WP4.3: Laboratory investigation – Samphire Hoe:** D36 describes the laboratory investigations for the Samphire Hoe seawall at UEdin and HRW. These tests include a 2D model (UEdin) in a wave flume and a 3D model (HRW) in a deep-water basin using 1:40 (2D) and 1:20 (3D) Froude scaled models of the Samphire Hoe seawall. Some of the 3D tests were carried out with wind that affects the spatial distribution of overtopping. The two storms described in D33 were reproduced in the two laboratories and testing resulted in a mean overtopping rate in general agreement with the field observations. An analysis of the 3D experiments with wind and the influence of wind on the spatial distribution of overtopped water are given.

**WP4.4: Laboratory investigation – Additional tests:** D24 describes the laboratory research conducted by AAU (Parts A and D), UEdin (Part B) and UGent (Part C) to cover the white spots in the CLASH database. 3D tests performed in the AAU shallow water basin were designed to give additional information on the influence of wave direction and directional spreading on wave overtopping (Part A). 2D experiments carried out in the UEdin wave flume were designed to analyse the influence of armour unit types (Part B). 2D experiments performed in the UGent wave flume were designed to examine the influence of wave steepness on the wave overtopping at smooth dikes (Part C). Finally, 2D tests performed in the AAU wave flume were designed to give additional information on the overtopping as well as

data on the front and rear stability of reshaping breakwaters (Part D). The parametric tests of AAU (part A) involved the following: two armour unit types (rocks and cubes), three directional spreadings, four crest freeboards and five angles of attack (from 0° to 60°) in different wave conditions. The parametric tests of UEdin (Part B) covered ten armour unit types (slope 1:1.5) and several water levels and wave conditions; for rock and cubes two slopes 1:1.5 and 1:2 are tested. The tests performed in UGent (Part C) dealt with three different geometries and two different foreshores. The tests performed in the AAU wave flume (Part D) examined four crest freeboards and four crest widths.

**WP5: Numerical modelling:** D27 describes the AMAZON-SC code developed by MMU. This code provides a numerical wave flume in which the flow equations are solved both in the air and in the water. Also included is a description of the LVOF code developed by UGent for the simulation of overtopping in a numerical wave tank. The AMAZON-SC code was applied in the examination of a selected overtopping event in Samphire Hoe as well as in the study of scale effects of wave overtopping. The LVOF code was also used for numerical simulations on the Ostia porous breakwater to study scale effects of wave overtopping.

**WP6: Hazard Analysis including socio-economic impacts:** D38 and D39 respectively describe the hazard analysis and socio-economic impacts of wave overtopping. D38 analyses the hazards to pedestrians, vehicles, etc. close behind the coastal defence, covering the gap of knowledge on the limits to overtopping volumes, mean discharges and velocities that might be accepted. Laboratory and field observations of overtopping hazards have been recorded at selected sites and new limits are suggested for overtopping mean discharges and peak volumes. D39 presents an overview of valuation literature relevant to the estimation of damage caused by overtopping, as well as a guide to the valuation of damages. The report also contains details regarding two case studies, corresponding to a beach nourishment project on the Belgian coast (De Haan) and a recreational port in Italy (Rapallo).

**WP7: Conclusion on scale effects:** D40 analyses the differences between prototype and laboratory observations of overtopping through a detailed description of the causes for the measurement effects, the model effects and the scale effects. A statistical quantification of measurement effects is given as well as a quantification of the model effects (wind, foreshore, etc.). The CLASH prototype measurements were compared with CLASH small-scale results. Numerical simulations were also conducted to give information for the quantification of the scale effects. A method to account for scale / model effects is presented.

**WP8: Generic prediction method:** D41 and D42 describe the NN method and the CLASH generic prediction method. D42 describes the CLASH NN methodology including limits of applicability and confidence intervals of the NN estimations based on the Froude similarity law and the CLASH database. D41 includes the user's manual for the software NN-OVERTOPPING 2.0 that implements the CLASH generic prediction method, including NN

---

model and scale effect corrections. D41 also describes in detail the input and output variables and provides illustrative examples to use the software NN-OVERTOPPING 2.0.

Finally, the present report D43 (WP9) aims to briefly synthesise the results of CLASH and to guide end users on crest level design or assessment based on permissible overtopping. As the reader may verify, D43 includes a synthesis of WP7 (measurement, model and scale effects) together with an example of an application of the CLASH generic prediction method to justify overtopping warning limits for the Northern motorway of Valencia and its coastal defence. To have a more detailed overview of the work performed in this project and obtained results, the authors refer to D46, the CLASH final report.

## 4 Guidelines

When considering the CLASH methodology to make an assessment of the crest level of a coastal structure, it is suggested to go step-wise through the procedure.

Three main possibilities are seen:

1. No measurements at any scale are available: Use the CLASH NN ; Start at Step 1
2. Small scale model tests are available: Go to Step 3
3. Prototype measurements of an existing structure are available: Go to Step 3

- 1. Waves and MWL at toe of the structure:** CLASH executable file NN-OVERTOPPING 2.0 requires the incident wave conditions and mean water level (MWL) at the toe of the structure. The use of a wave propagation model may be necessary to transform deep water wave characteristics into incident wave conditions at the toe of the structure, if the conditions at the toe are not known. The necessary wave conditions are summed and clarified in the NN-manual (available on the CLASH-website in the same ZIP-folder as this document).



2. **Structure cross section:** the CLASH executable file NN-OVERTOPPING 2.0 requires a parametric schematization of the structure, following the CLASH methodology. Real structures have to be transformed in CLASH schematic cross sections. If the schematic section differs significantly from the real section, CLASH overtopping predictions are not reliable. The schematisation procedure is explained in NN-manual (available on the CLASH-website in the same ZIP-folder as this document).
- 2a. **“Out of range”:** the CLASH methodology is based on the CLASH database with more than 10,000 overtopping tests. However, not all possible structural and wave conditions are represented in the database and CLASH overtopping predictions are not reliable for those conditions. NN-OVERTOPPING 2.0 gives “out of range” messages.
- 2b. **Input and output format:** NN-OVERTOPPING 2.0 requires a specific format for input files and gives the predictions in a specific output format. For specific information on this, reference is made to D41 – the NN manual (available on the clash-website in the same ZIP-file as this document [www.clash-eu.org](http://www.clash-eu.org)) .
3. **Average value (and uncertainty):** When using the NN model, the 1<sup>st</sup> and 3<sup>rd</sup> to 9<sup>th</sup> columns of the output file show overtopping estimations assuming Froude similarity. The first column shows the average value and the other seven columns show the percentiles 2.5%, 5%, 25%, 50%, 75%, 95% and 97.5% respectively. The percentiles give a measure of the uncertainty of the CLASH overtopping prediction method.

However overtopping rate can also be based on small scale model tests or prototype measurements. In the latter cases, no uncertainties are available. In the case q results from small scale model tests, go to step 4. In the case q results from prototype measurements, immediately go to Step 6.

4. **Scale and model effect correction factor:** In case the NN-model has been used, the REMARK (11<sup>th</sup>) column of the output file shows, if applicable, automatic remarks and the average overtopping estimation (1<sup>st</sup> column) corrected by estimated scale/model effects.

In case the q results from small scale model tests, the correction factor, to be used on the upscaled q value can be determined using the procedure in Appendix 1.

5. **Overtopping estimator:** This step is only relevant in case the NN has been used. The use of NN-OVERTOPPING 2.0 to assess overtopping hazards may require the selection of one of the upper overtopping percentiles (columns 6<sup>th</sup> to 8<sup>th</sup>) as the appropriate overtopping estimator.
6. **Overtopping hazard:** The overtopping hazard assessment of a given case usually requires the comparison of quantitative overtopping discharges and permissible overtopping limits. CLASH suggested overtopping limits are based on objective field measurements and subjective criteria. However, overtopping risk assessment requires the use of valuation procedures and the consideration of social and legal aspects which may have to be adapted to the specific local and regional environment. The obtained q value at prototype scale can be compared to the permissible levels in table 1.

The CLASH methodology is founded in four basic elements (database, NN method, scale/model effects and overtopping limits); in the future, improvements may be expected in each of the four basic elements. Therefore, CLASH methodology may be the first of a line of continuously improving methodologies for overtopping risk assessment.

To illustrate the applicability of the CLASH methodology, Appendix 2 describes a case study referred to the establishment of an overtopping warning system for a motorway coastal defence.

## **5 Acknowledgement**

CLASH was a EU 5<sup>th</sup> framework research project, funded by EU under contract number EVK3-CT-2001-00058. The financial support of the EU is very much acknowledged.

Furthermore our EC-scientific officers Mr. H. Barth and previously Mr. C. Fragakis are very much acknowledged for their understanding cooperation during the whole project duration.

The authors also want to thank all CLASH-partners for the fruitful cooperation.

---

## 6 References

(all references / reports can be downloaded at the CLASH-homepage: [www.clash-eu.org](http://www.clash-eu.org))

- D5** (WP1): Boone, C., Geeraerts, J., De Rouck, J. (2002). General Methodology Report.
- D24-Part A** (WP4.4): Andersen, T.L., Burcharth, H. (2004). Additional Tests – Effect of obliqueness, short-crested waves and directional spreading.
- D24-Part B** (WP4.4): Pearson, J., Bruce, T., Franco, L., van der Meer, J., Falzacappa, M., Molino, R., (2004). Additional Tests - Roughness factor.
- D24-Part C** (WP4.4): Geeraerts, J. (2004). Additional Tests – Influence of low wave steepness.
- D24-Part D** (WP4.4): Andersen, T.L., Burcharth, H. (2004). Additional Tests – Reshaping breakwater tests.
- D27** (WP5): Ingram, D., Causon, D., Gao, F., Mingham, C., Troch, P., Li, T., De Rouck, J. (2004). Final Report on numerical modelling.
- D28** (WP2): van der Meer, J., Verhaeghe, H., Steendam, G.J. (2004). Overtopping Database.
- D31** (WP3.1): Geeraerts, J., Boone, C. (2004). Report on full scale measurements – Zeebrugge.
- D32** (WP3.2): Franco, L., Briganti, R., Bellotti, G. (2004). Report on full scale measurements – Ostia.
- D33** (WP3.3): Pullen, T. (2004). Report on full scale measurements – Samphire Hoe.
- D34** (WP4.1): Kortenhaus, A., Medina, J., Garrido, J., Gonzalez-Escrivera, J. (2004). Final report on laboratory measurements – Zeebrugge.
- D35** (WP4.2): Geeraerts, J., Willems, M. (2004). Final report on laboratory measurements – Ostia.
- D36** (WP4.3): Pullen, T. (2004). Final report on laboratory measurements – Samphire Hoe.
- D37** (WP3.4): Hordijk, D. (2004). Report on full scale measurements – Petten
- D38** (WP6): Allsop, W. (2004). Report on hazard analysis.
- D39** (WP6): Bouma, J.J., Schram, A., François, D. (2004). Report on socio-economic impacts.
- D40** (WP7): Kortenhaus, A., van der Meer, J., Burcharth, H., Geeraerts, J., Pullen, T., Ingram, D., Troch, P. (2005). Report on conclusion of scale effects.
- D41** (WP8): Pozueta, B., Van Gent, M., van den Boogaard, H. (2004). Neural Network.

**D42** (WP8): Van Gent, M., Pozueta, B., van den Boogaard, H., Medina, J. (2004). Final Report on generic prediction method.

**D43** (WP9): Medina, J., De Rouck, J., Figueres, M., Gonzalez-Escriva, J., Geeraerts, J., (2005). Guidelines.

**D46**. De Rouck, J., Geeraerts, J. (2005). Final Report, full scientific and technical report.

## 7 Appendices

### Appendix 1. Model and scale effects

#### *A1.1 Method to account for scale / model effects*

A number of possible reasons for differences between prototype and model scale has been listed in D40. It has been shown that all measurement uncertainties and model effects may have a considerable effect on wave overtopping so that most data points fall within the differences of one standard deviation of the result. Therefore, scale effects are very difficult to observe since differences in the resulting plots may be all due to model effects only.

##### **A1.1.a Requirements for scale effects**

The theoretical investigations and review of the available literature in D40 has shown that differences in wave run-up heights for rough slopes (both permeable and impermeable) have been observed in many cases. Therefore, the wave run-up height should be included in any guidance on how to scale wave overtopping. The following requirements may be derived from the literature and observations in the model and prototype tests:

- scaling effects have only been observed for sloped structures but not for vertical ones;
- the scaling factor must be higher for lower overtopping rates; it even has to work for ‘no overtopping’ measurements in the flume so that some overtopping is measured in prototype;
- roughness of the slope has to be included; critical Reynolds numbers can be defined;
- the core permeability needs to be included where lower permeability in the core creates more run-up on the slope and more overtopping
- wind effects should be included since wind seems to increase wave overtopping rates considerably;

##### **A1.1.b Factor resulting from scale effects on wave run-up**

The second and third requirement may be fulfilled by a simple approach which is described in the following. Schulz (1992) and others have indicated that the increase of run-up heights from small-scale to large-scale models are in the range of 15%. If this is introduced as an additional ‘roughness’ factor (to be treated in the same way as a traditional roughness factor) to a standard wave overtopping formula it gives:

$$\frac{q_{\text{red}}}{\sqrt{g \cdot H_{m0}^3}} = q_0 \cdot \exp\left(b \frac{R_c}{H_{m0}} \cdot \frac{1}{\gamma_f} \cdot \frac{1}{\gamma_s}\right) \quad (\text{A1.1})$$

where  $\gamma_s$  is the scaling reduction due to scale effects on the seaward slope ( $\gamma_s = 1,15$  here). Eq. (A1.1) differs from the standard wave overtopping formula by a factor  $1/\gamma_s$  only so that  $q_{\text{red}}$  can be calculated as  $q_{\text{red}} = q^{(1/\gamma_s)}$ . The relative scaling factor  $f_{s,q} = q_{\text{red}}/q$  can then be calculated as:

$$f_{s,q} = \frac{q_{\text{red}}}{q} = \frac{q^{1/\gamma_s}}{q} \quad (\text{A1.2})$$

where  $q_{\text{red}}$  is the theoretically reduced overtopping rate as given by Eq. (A1.1). In Figure A1.1 the factor given by Eq. (A1.2) is plotted against the wave overtopping discharge using the Zeebrugge parametric tests at LWI from the first test phase. The latter have been scaled up to prototype conditions using Froude law. Each data point is then achieved by performing the following steps:

- derive  $q$  for specified tests from measurements;
- scale  $q$  up to prototype using Froude law (if  $q$  is from model tests);
- calculate the reduced overtopping rate using Eq. (A1.1);
- calculate  $f_{s,q}$  for each data point using Eq. (A1.2)

Furthermore, an additional formula for a factor  $f_{\text{scale\_nowind}}$  has been plotted which shows a similar behaviour than Eq. (A2.3) but is closer to the data. This curve can be described by the following equation:

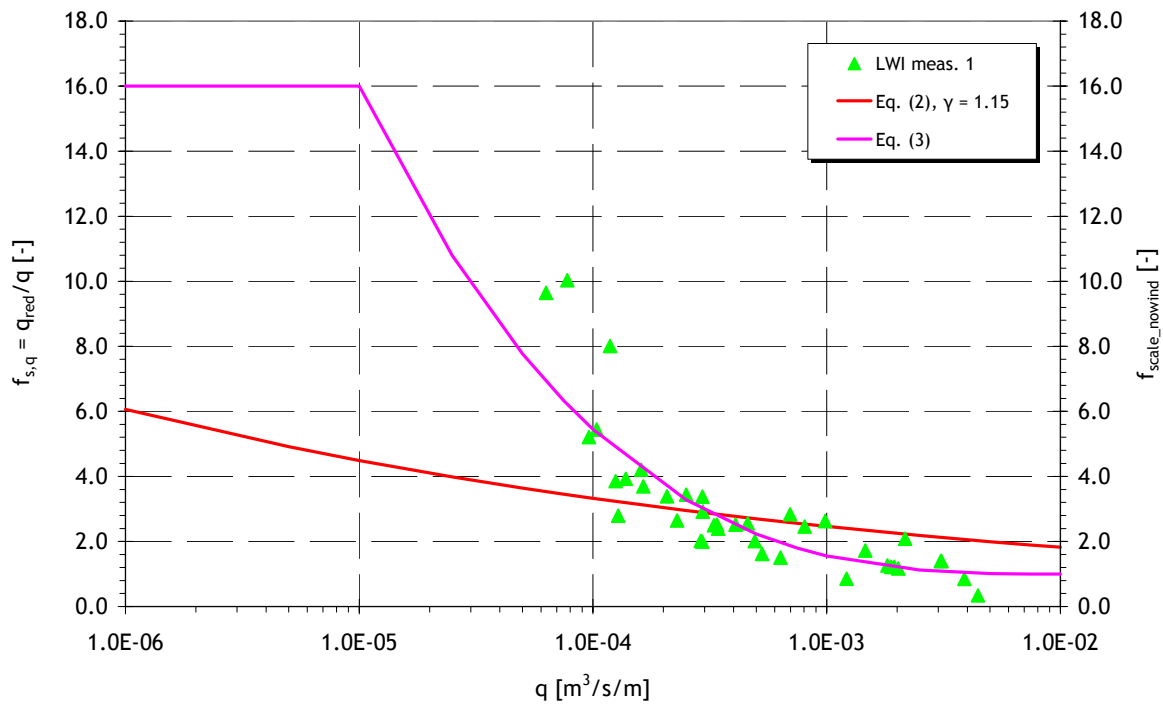
$$f_{\text{scale\_nowind}} = \begin{cases} f_{\text{scale\_nw}} & \text{for } \gamma_f \leq 0.7 \\ 5 \cdot (1 - f_{\text{scale\_nw}}) \cdot \gamma_f + (f_{\text{scale\_nw}} - 1) \cdot 4.5 + 1 & \text{for } 0.7 < \gamma_f < 0.9 \end{cases} \quad (\text{A1.3a})$$

where

$$f_{\text{scale\_nw}} = \begin{cases} 16.0 & \text{for } q_{\text{SS}} < 1 \cdot 10^{-5} \text{ m}^3 / \text{s} \cdot \text{m} \\ 1.0 + 15 \cdot \left( \frac{-\log q_{\text{SS}} - 2}{3} \right)^3 & \text{for } q_{\text{SS}} < 1 \cdot 10^{-2} \text{ m}^3 / \text{s} \cdot \text{m} \\ 1.0 & \text{for } q_{\text{SS}} \geq 1 \cdot 10^{-2} \text{ m}^3 / \text{s} \cdot \text{m} \end{cases} \quad (\text{A1.3b})$$

It should be noted that  $q_{\text{SS}}$  is a value resulting from small scale tests, already upscaled to prototype scale by means of Froude scaling law.

Eq. (A1.3b) delivers a scaling factor for really rough structures when  $\gamma_f \leq 0.7$ . When  $\gamma_f \geq 0.9$  the structure is smooth and the scaling factor will be  $f_{\text{scale\_nw}} = 1.0$ . In between both values a linear interpolation can be assumed.



*Figure A1.1: Reduction of wave overtopping due to reduction of wave run-up on the seaward slope for the Zeebrugge storm data*

It can be seen from Figure A1.1 that factors may easily go up to one order of magnitude for lower overtopping rates whereas they are still in the same range as without run-up reduction for higher overtopping rates. Since data from comparison between small-scale and large-scale model do not support regions of overtopping ratios lower than  $1 \cdot 10^{-5} \text{ m}^3/\text{s}\cdot\text{m}$  the formula will not go up to higher values than a factor of 16.0.

Eq. (A1.2) is determined for a scaling factor which is only valid for rough slopes and no wind effects. The latter can be assumed since comparisons between large-scale and small-scale tests are always referring to tests in either the GWK in Hannover or the Delta flume in De Voorst which both do not include any wind.

Therefore, a method needs to be found which summarises the various influences of scale and wind effects. This method will be discussed in the subsequent section. Since the magnitude of the influence of scaling the core material is not known up to date this influence will be ignored in the following.

### **A2.1.c Factor resulting from wind effect on vertical structures**

It is possible to examine the results of de De Waal et al. (1996), Davey (2004) and Pullen & Allsop (2004), as described in Kortenhaus et al. (2005). By examining the data it is possible to ascribe the following formula to the scaling factor for wind  $f_{\text{Wind}}$ :



$$f_{\text{wind}} = \begin{cases} 4.0 & \text{for } q_{\text{SS}} < 1 \cdot 10^{-5} \text{ m}^3 / \text{s} \cdot \text{m} \\ 1.0 + 3 \cdot \left( \frac{-\log q_{\text{SS}} - 2}{3} \right)^3 & \text{for } q_{\text{SS}} < 1 \cdot 10^{-2} \text{ m}^3 / \text{s} \cdot \text{m} \\ 1.0 & \text{for } q_{\text{SS}} \geq 1 \cdot 10^{-2} \text{ m}^3 / \text{s} \cdot \text{m} \end{cases} \quad (\text{A1.4})$$

In this instance the factor 4.0 is not a scaling factor as previously described, but it can be used to make an allowance for the effects of the wind, and also has the advantage of not using a separate technique. It is especially important to make this distinction, because it has been demonstrated by Pullen & Allsop (2004), that there are no scaling effects for vertical and composite vertical structures. Figure A1.2 shows that a factor of 4.0 provides a conservative estimate of the effect of the wind with respect to the overtopping discharge rate  $q$ .

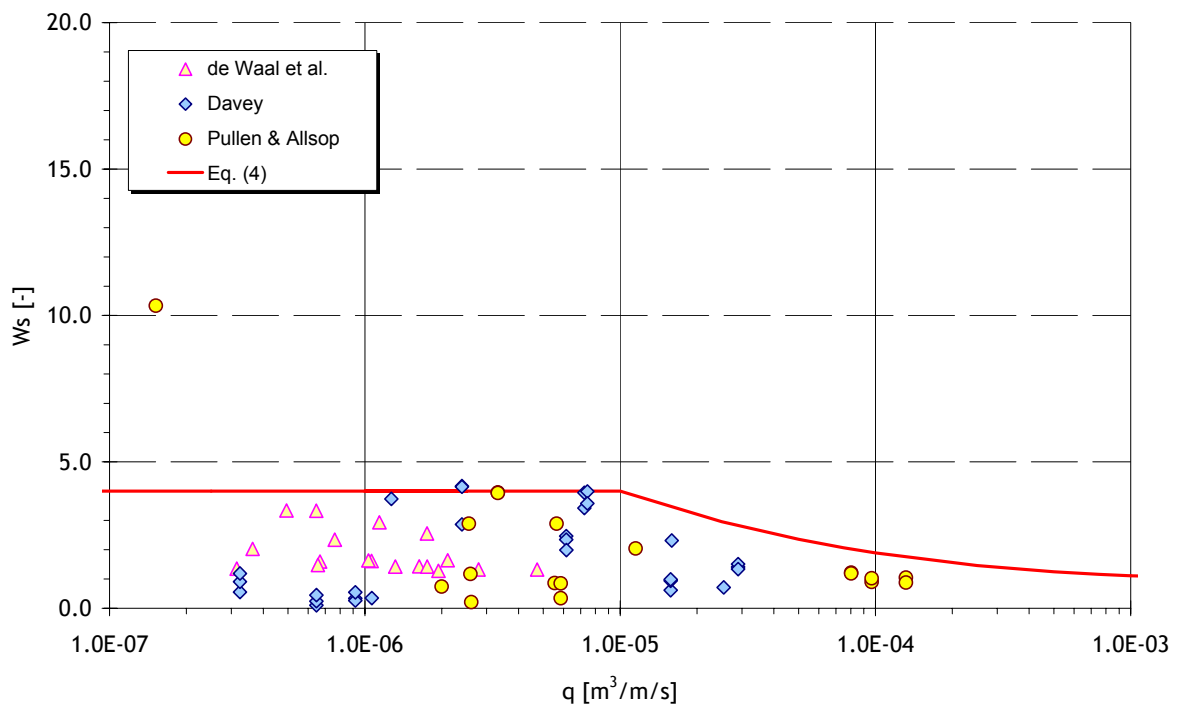


Figure A1.2: Discharge rates and the effect of the transport factor  $W_s$

#### A1.1.d Overall procedure

##### A2.1.d.1 Input

The final procedure to account for scale effects starts with a mean overtopping rate predicted small-scale model tests  $q_{\text{SS}}$  as input.

Besides the  $q_{\text{SS}}$  the following parameters are required:

- wave height  $H_{m0}$  at the toe of the structure (output scale<sup>1</sup>),
- roughness coefficient  $\gamma_f$  for the seaward side of the structure,
- width of the seaward berm  $B$  of the structure,
- water depth over the horizontal berm  $d_h$ ,
- slope of the structure below the berm  $\cot\alpha_d$ ,
- slope of the structure above the berm  $\cot\alpha_u$

For a more detailed description of these parameters see Verhaeghe et al. (2003). The wave height  $H_{m0}$  is needed to distinguish between model scale, full-scale or any other scale in between. The roughness coefficient  $\gamma_f$  is needed to distinguish between a smooth and a rough structure whereas all other parameters are needed to select vertical structures or sloped structures.

#### **A2.1.d.2**      *Output*

There are three possible outputs of the procedure which are:

- mean overtopping rate with possible wind effect  $q_{wind}$ : wind may play a role for all vertical structures and all smooth (sloping) structures which are believed to have no scale effects
- mean overtopping rate with possible scale and wind effects on rough structures  $q_{scale\_wind}$ : this output will only be relevant for rough structures and includes both possible scale and wind effects.
- mean overtopping rate with scale effects on rough structures without wind  $q_{scale\_nowind}$ : this output will only be relevant for rough structures and includes only scale effects. The main interest is to predict wave overtopping rates for large-scale tests without wind.

The prediction method gives all these four mean overtopping discharges  $q_{ss}$ ,  $q_{wind}$ ,  $q_{scale\_wind}$  and  $q_{scale\_nowind}$ . Differences between these values may give the user a good idea what kind of effect could play a role in his given situation.

#### **A2.1.d.3**      *Step 1: vertical structure?*

Step 1 checks whether the structure is rough sloping or not (Fig. A1.3). If the structure is vertical or almost vertical continue with 'If there is no wind it needs to be decided under which scale the procedure is applied. Therefore, a distinction will be made with respect to the wave height  $H_{m0}$ . For wave heights at output scale  $H_{m0} < 0.5$  m the factor for scaling is  $f_{scale}=1.0$ . For all other cases the calculation of  $f_{scale\_nowind}$  can be performed using Eq. (A1.A1.3b). Go to A2.1.d.7      Step 5: Final calculation of mean wave overtopping *rate* to finalise the procedure.

---

<sup>1</sup> ,output scale' means that  $H_{m0}$  needs to be given in the scale where the final result with respect to wave overtopping rates are needed

**A2.1.d.6 Step 4: Procedure wind effect'** If this is not the case go to 'A2.1.d.4 Step 2: rough structure?'

*Note:* To help distinguishing between vertical and non-vertical structures there are two configurations using the input parameters of the CLASH database which indicate a vertical structure. These are:

- if  $\cot \alpha_u < 1$  and  $\cot \alpha_d < 1$  the structure is vertical or almost vertical.
- if  $\cot \alpha_u < 1$  and  $B > 0$  and  $h_b > 0$  there is most probably a berm below swl and a vertical structure on top of the berm.

Please note that this parameter distinction cannot be used when parapets are used with the structure. Furthermore, for some complex structures the simple distinction proposed here may fail to give the correct answer.

**A2.1.d.4 Step 2: rough structure?**

Step 2 checks whether the structure is rough or smooth. If the structure is rough, continue with **Fout! Ongeldige bladwijzerverwijzing**, if the structure is smooth continue with 'If there is no wind it needs to be decided under which scale the procedure is applied. Therefore, a distinction will be made with respect to the wave height  $H_{m0}$ . For wave heights at output scale  $H_{m0} < 0.5$  m the factor for scaling is  $f_{scale}=1.0$ . For all other cases the calculation of  $f_{scale\_nowind}$  can be performed using Eq. (A1.A1.3b). Go to A2.1.d.7 Step 5: Final calculation of mean wave overtopping *rate* to finalise the procedure.

**A2.1.d.6 Step 4: Procedure wind effect'**

*Note:* The roughness of a structure may be distinguished from the roughness coefficient  $\gamma_f$  of the CLASH database. If  $\gamma_f$  is smaller than 0.9 the structure is considered to be a rough sloping structure otherwise the structure is smooth.

**A2.1.d.5 Step 3: rough sloping structure**

Within this step the first decision to be made is whether to consider the influence of wind or not. If yes, the factor for scale and wind effects  $f_{scale\_wind\_max}$  can be calculated as follows:

$$f_{scale\_wind\_max} = \begin{cases} 24.0 & \text{for } q_{SS} < 1 \cdot 10^{-5} \text{ m}^3 / \text{s} \cdot \text{m} \\ 1.0 + 23 \cdot \left( \frac{-\log q_{SS} - 2}{3} \right)^3 & \text{for } q_{SS} < 1 \cdot 10^{-2} \text{ m}^3 / \text{s} \cdot \text{m} \\ 1.0 & \text{for } q_{SS} \geq 1 \cdot 10^{-2} \text{ m}^3 / \text{s} \cdot \text{m} \end{cases} \quad (\text{A1.5})$$

It should be noted that this factor includes both the influence of scale and wind effects, the latter being a model rather than a scale effect. Furthermore, Eq. (A1.3) suggested a maximum factor of 16.0 for scale effects without any wind. Assuming that factors for scale and wind effects should be multiplied to achieve an overall factor, a theoretical factor for wind of 1.5 would be obtained. This is lower than indicated in Eq. (A1.4) for vertical walls, which is be-

lied to be due to the effect of wind for vertical structures being larger than for rough sloping structures.

Eq. (A1.5) delivers a scaling factor for really rough structures when  $\gamma_f \leq 0.7$ . When  $\gamma_f \geq 0.9$  the structure is smooth and the scaling factor will be  $f_{\text{scale}} = 1.0$ . In between both values a linear interpolation can be assumed so that the scaling factor for rough slopes  $f_{\text{scale\_wind}}$  can be determined by:

$$f_{\text{scale\_wind}} = \begin{cases} f_{\text{scale\_wind\_max}} & \text{for } \gamma_f \leq 0.7 \\ 5 \cdot (1 - f_{\text{scale\_wind\_max}}) \cdot \gamma_f + (f_{\text{scale\_wind\_max}} - 1) \cdot 4.5 + 1 & \text{for } 0.7 < \gamma_f < 0.9 \end{cases} \quad (\text{A1.6})$$

If there is no wind it needs to be decided under which scale the procedure is applied. Therefore, a distinction will be made with respect to the wave height  $H_{m0}$ . For wave heights at output scale  $H_{m0} < 0.5$  m the factor for scaling is  $f_{\text{scale}} = 1.0$ . For all other cases the calculation of  $f_{\text{scale\_nowind}}$  can be performed using Eq. (A1.A1.3b). Go to A2.1.d.7 Step 5: Final calculation of mean wave overtopping *rate* to finalise the procedure.

#### **A2.1.d.6 Step 4: Procedure wind effect**

For structures other than rough structures there might be a wind effect. First a decision has to be made whether wind effects are to be considered or not. If not, the factor for the wind-influence is set to  $f_{\text{wind}} = 1$ . If wind effects have to be considered, they can be calculated using Eq. (A1.4).

Finally the factor for wind effects can be applied to the overtopping rate  $q_{\text{SS}}$  which is performed in “A2.1.d.7 Step 5: Final calculation of mean wave overtopping *rate*”.

#### **A2.1.d.7 Step 5: Final calculation of mean wave overtopping rate**

The final calculation of mean wave overtopping rates should include both a calculation for wind effects and smooth structures and a calculation for scale and wind effects and rough structures as follows:

$$q_{\text{wind}} = q_{\text{SS}} \cdot f_{\text{wind}} \quad (f_{\text{wind}} \text{ (eq. (A1.4))}) \quad (\text{A1.7})$$

$$q_{\text{scale\_wind}} = q_{\text{SS}} \cdot f_{\text{scale\_wind}} \quad (f_{\text{scale\_wind}} \text{ (eq. A1.5-6)}) \quad (\text{A1.8})$$

$$q_{\text{scale\_nowind}} = q_{\text{SS}} \cdot f_{\text{scale\_nowind}} \quad (f_{\text{scale\_nowind}} \text{ (eq. (A1.3))}) \quad (\text{A1.9})$$

#### **A2.1.d.8 Step 6: Scaling map for coastal structures**

The procedure described above is summarised in a simple scaling map for wave overtopping over coastal structures obtained from small-scale model tests (Figure A1.3). This map is only needed when

- wave heights  $H_{m0}$  for the structure the user is interested in are higher than 0.5 m;
- the user starts from model scale with wave heights  $H_{m0} < 0.5$  m

Furthermore, the distinction between vertical and sloped structures as given by the parameters used in Figure A1.3 are only valid for structures which do not have parapets or overhanging elements.

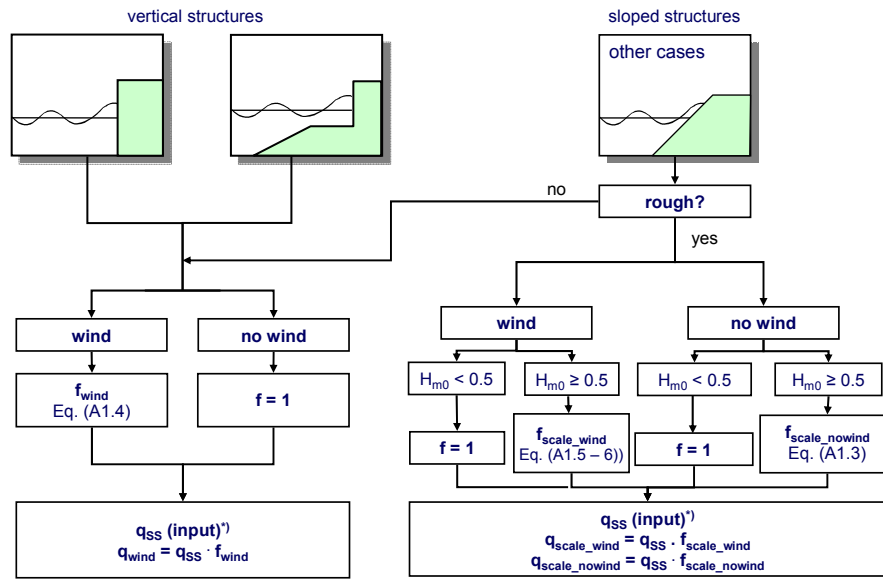


Figure A1.3: Scaling map for wave overtopping results over coastal structures from small-scale model tests

**Procedure for zero measurements in small scale model tests**

Fig. A1.4 illustrates how to deal with zero measurements in small scale models. As can be seen from the figure, 2D tests give zero overtopping for dimensionless crest freeboards larger than 1.50. Prototype measurements result in measured overtopping different from zero, for dimensionless crest freeboards of about 1.80.

To deal with this, a procedure is illustrated in Fig. A1.4. This procedure consists of determining the best fit through the non-zero small scale results (in this case, this fit is characterized by the line  $\gamma_r = 0.37$ ). The next step is to vertically project the zero data on this best fit line, as is indicated by the vertical arrows in the figure.

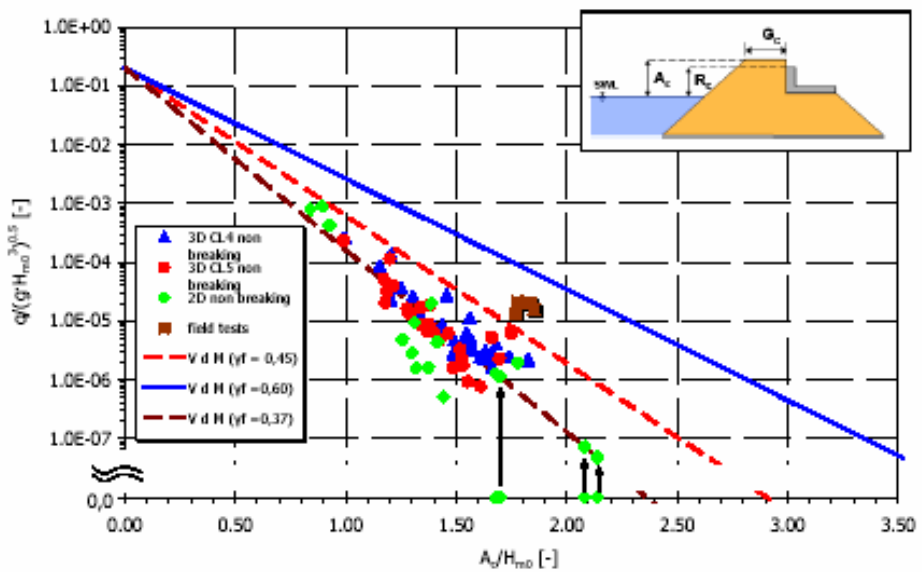


Figure A1.4 : Example on how to deal with zero overtopping in small scale models.

## Appendix 2. Case study

In order to illustrate the utility of the CLASH methodology to solve practical problems involving overtopping hazards, Appendix 1 describes the problem of defining warning levels for the coastal defence of the Northern motorway (N-221) of Valencia (Spain), which is almost parallel to the coastal defence for 4 km. During the past decade, this motorway experienced the effects of several intense overtopping events, which interrupted the South-to-North traffic (i.e. during the storm of November 2001), and damaged the coastal defence itself. After the 2001 storm, the coastal defence was rebuilt.

A typical application of the CLASH methodology is presented to investigate the overtopping hazard of existing structures for establishing a warning system for users (people, vehicles, etc) and civil protection authorities. Sea waves and water level are routinely forecasted in many countries and CLASH methodology can be used to determine the appropriate warning levels in the neighbourhood of breakwaters and sea defences. In this case, Spanish *Puertos del Estado* routinely provides a 48-hours forecast of sea waves and water levels along the Spanish coast, which can be used to estimate the overtopping discharges and corresponding hazards. The goal of this case study is to use the forecasted sea waves and water levels of the Spanish Mediterranean coast and the CLASH methodology to define a warning system and a protocol for the sea defence of the Northern motorway of Valencia.

### A2.1 Introduction

The Northern motorway of Valencia (800,000 inhabitants) is a key transportation infrastructure of the city. Figure A3.1 shows the location of the case study in the Mediterranean coast.

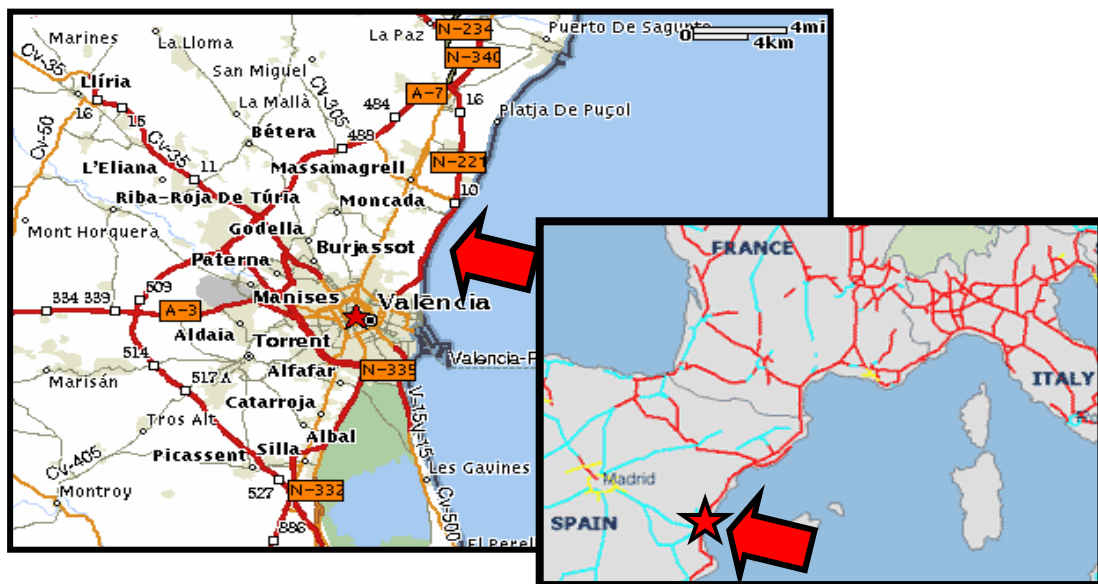


Figure A2.1. Location of the Northern motorway of Valencia and coastal defence.

Some overtopping events during the past two decades temporally caused the partial closure of some lanes of the motorway (South to North direction) and damage the coastal defence. During November 2001, an intense storm attacked the Spanish Mediterranean coast which results in littoral flooding and damages to a number of port and coastal structures, including the coastal defence of the Northern motorway of Valencia. Figures A1.2 and A1.3 show the motorway near the coastal defence and the overtopping discharges observed before 2002.

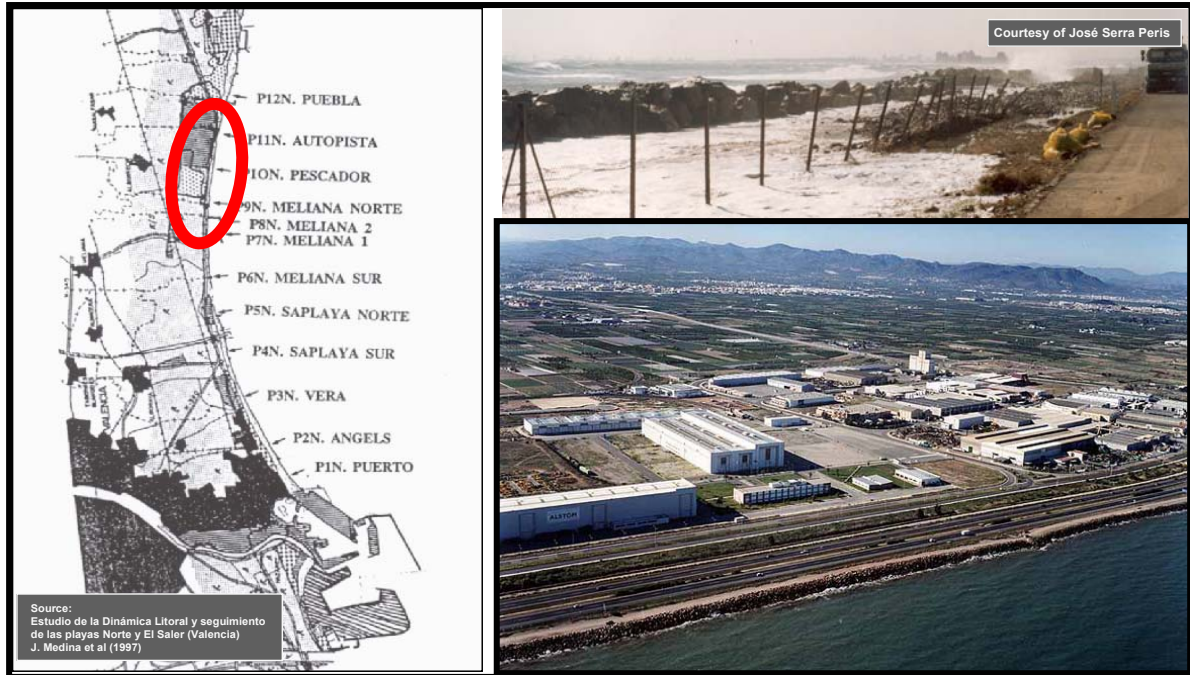


Figure A2.2. Plan, aerial view and overtopping discharges of the motorway coastal defence.



Figure A2.3. Damages on the motorway coastal defence.



Figure A1.4 shows the new coastal defence reconstructed during 2002. Crest freeboard was increased as well as the corresponding visual impact.



*Figure A2.4. New motorway coastal defence.*

The overtopping hazards of the new motorway coastal defence can be referred to pedestrians and pleasure fishermen on the rocks of the revetment, and to vehicles on the unpaved service road and on the motorway. Finally, damages to the coastal defence and erosion of the unpaved service road can also be produced with massive overtopping.

Taking into consideration the 48-hours forecast of sea waves and water levels along the Spanish coast, CLASH methodology can be used to estimate in advance the overtopping discharges and the corresponding overtopping hazards of the Northern motorway of Valencia and new coastal defence. The goal is to define an overtopping warning system to guide public intervention and prevent serious injuries to users (pedestrians and drivers) of the motorway, service road and coastal defence.

## ***A2.2 Overtopping forecast and overtopping hazard assesment***

The CLASH executable software NN-OVERTOPPING 2.0 requires specific inputs describing the wave attack at the toe of the structure:  $H_{m0,toe}$ ,  $T_{-1,0,toe}$  and  $b$ . Additionally, two structural parameter inputs ( $h_t$  and  $R_c$ ) are related to the mean water level (MWL) during the storm. Therefore, to use the CLASH generic prediction method it is required first to define the wave characteristics at the toe of the structure and the corresponding water levels. In this case, sea wave characteristics, astronomical tide and storm surge are routinely predicted. Figure A1.5 shows the forecasting WAM grid of the Mediterranean Spanish coast and Figure A1.6 shows the significant wave height, peak period and mean sea level forecasted at the Valencia wave measurement station during the intense storm of November 2001.

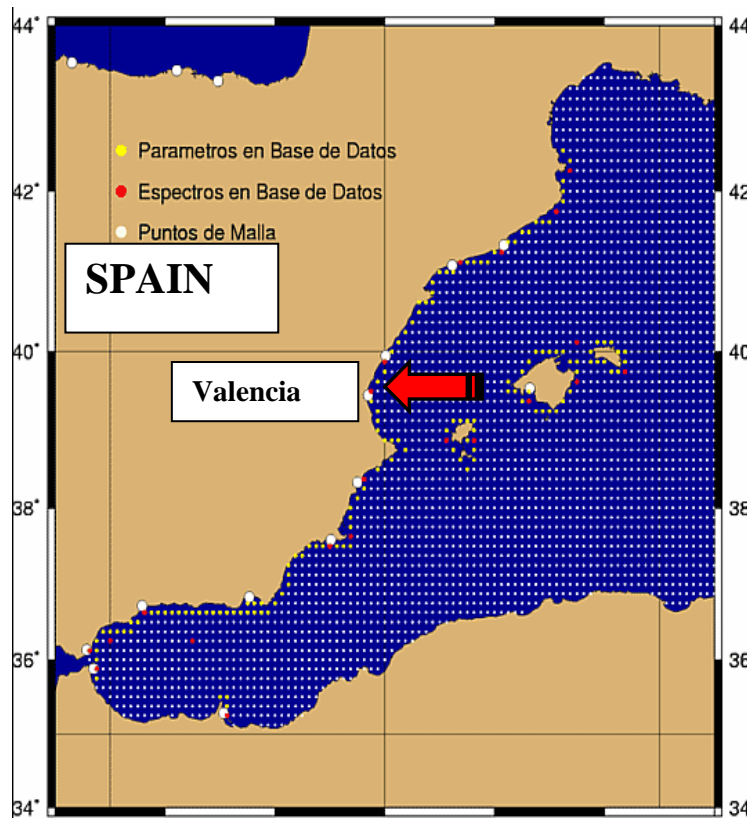


Figure A2.5. Forecast WAM model grid of the Spanish Mediterranean coast.

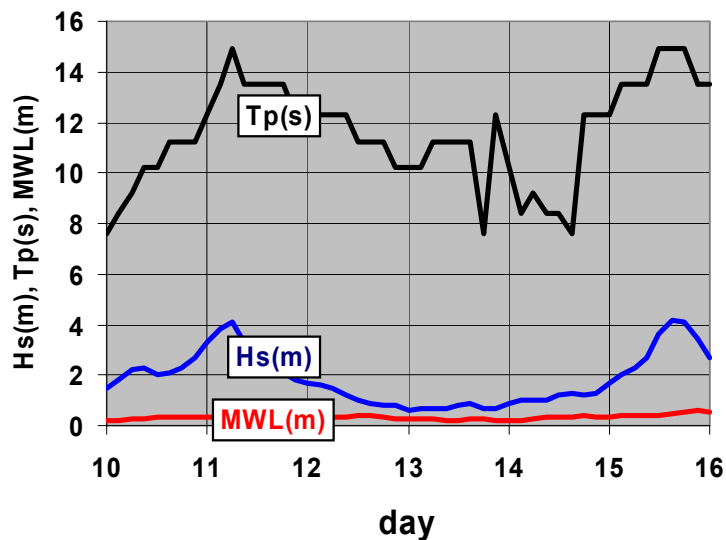


Figure A2.6. Sea waves and MSL forecast (November 2001).

SWAN (1D) model is used here to transform deep water wave characteristics to wave attack characteristics at the toe of the structure using a simplified cross section and beach profile along the coast (propagation perpendicular to the coastline is assumed). Figure A1.7 shows the schematization of cross section and beach profile of the coastal defence used for the propagation model and overtopping calculations. The objective is to transform forecasted sea waves and mean sea levels into overtopping discharges and hazards. The goal is to provide an overtopping warning system to prevent damages associated to the overtopping hazard of the

coastal defence. In the following, a five-step procedure is given to provide the appropriate overtopping warning messages.

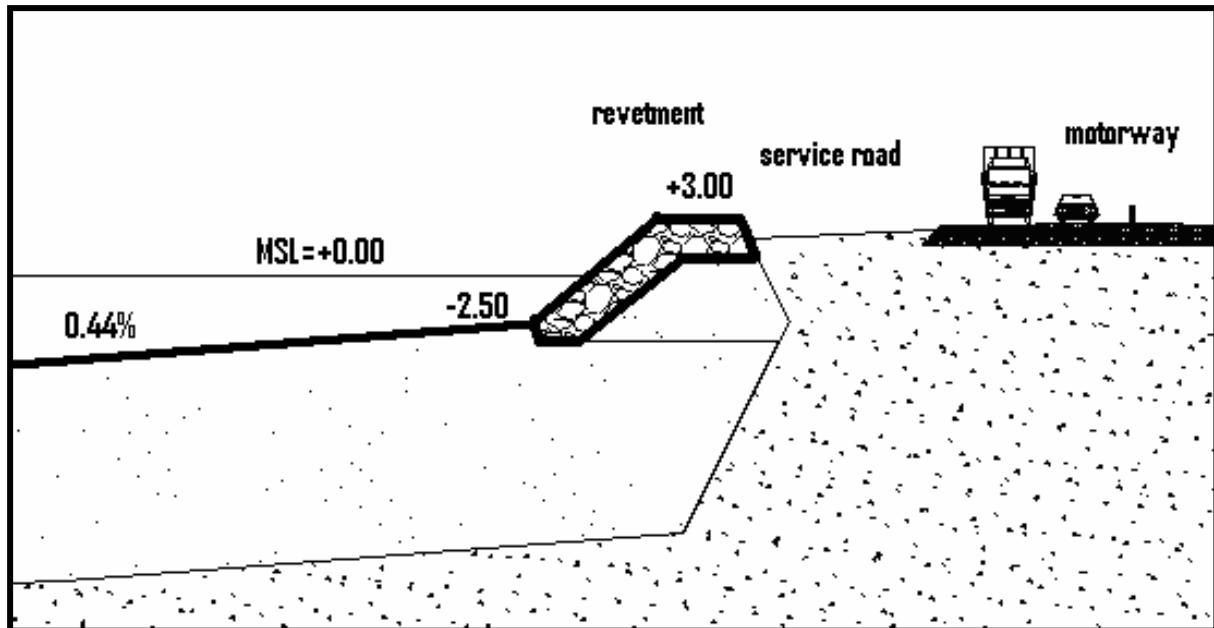


Figure A2.7. Schematized cross section and beach profile.

The first step is to define the possible wave climate and water level scenarios in deep water conditions (significant wave height, mean period, etc.). For simplicity, in this case study only the mean sea level (MSL) and wave characteristics described in Table A1.1 are considered. Table A1.1 covers a few typical mean sea levels and wave characteristics of the coast of Valencia.

Hs(deep) [m]	Tp(deep) [m]
0.50	4.67
1.00	6.60
1.50	8.08
2.00	9.33
2.50	10.44
3.00	11.43
3.50	12.35
4.00	13.20

(a)

MSL [m]
0.0
0.2
0.4
0.6
0.8

(b)

Table A2.1. (a) Deep water wave characteristics and (b)MSL.

The second step is to transform the deep water wave climate scenarios into estimated MSL and wave characteristics at the toe of the structure. In this case study, the breaking process in shallow water is conditioning the waves attacking the structure and forecasted MSL have an important effect on both wave propagation and crest freeboard. Table A1.2 shows the incident wave characteristics at the toe of the structure corresponding to the MSL and deep water wave characteristics described in Table A1.1. Because of  $T_{-1,0,toe}$  is a required input to run NN-OVERTOPPING 2.0 and the forecasting system provides only the peak period  $T_p$ , it has

been assumed  $T_{-1,0,toe} = T_p/1.1$  and  $T_{01} = T_p/1.2$  to calculate  $T_{-1,0,toe}$  from  $T_{01toe}$  after wave propagation.

Deep water		Hst(m)	T01t(s)	Hst(m)	T01t(s)	Hst(m)	T01t(s)	Hst(m)	T01t(s)	Hst(m)	T01t(s)
Hs(m)	Tp(s)	MSL=0.0 m		MSL=0.2 m		MSL=0.4 m		MSL=0.6 m		MSL=0.8 m	
0.5	4.7	0.44	3.86	0.44	3.85	0.44	3.84	0.44	3.83	0.44	3.81
1.0	6.6	0.96	5.74	0.96	5.72	0.95	5.70	0.94	5.68	0.93	5.66
1.5	8.1	1.32	7.31	1.40	7.26	1.44	7.23	1.48	7.20	1.50	7.17
2.0	9.3	1.43	8.54	1.52	8.51	1.60	8.48	1.68	8.46	1.75	8.43
2.5	10.4	1.48	9.53	1.58	9.50	1.68	9.48	1.77	9.46	1.86	9.43
3.0	11.4	1.52	10.40	1.62	10.38	1.72	10.36	1.82	10.34	1.92	10.32
3.5	12.3	1.56	11.31	1.66	11.30	1.76	11.29	1.86	11.27	1.96	11.25
4.0	13.2	1.59	12.00	1.69	11.98	1.79	11.97	1.89	11.96	1.99	11.94

Table A2.2. Wave characteristics at the toe of the coastal defence.

The third step is to prepare the input file for the CLASH executable software NN-OVERTOPPING 2.0. Figure A2.8 shows the input file (.xls format) corresponding to the structure cross section given in Figure A2.7a and the water level and wave conditions at the toe of the structure described by Table A2.2. The format (.xls) must be transformed to the appropriate format before feeding the executable software NN-OVERTOPPING 2.0.

Nr.Pat.	$\beta$	h	$H_{m0\ toe}$	$T_{m-1,0\ toe}$	$h_t$	$B_t$	$\gamma_f$	$cota_d$	$cota_u$	$R_c$	B	$h_b$	$tana_B$	$A_c$	$G_c$
	degr	m	m	s	m	m				m	m	m		m	m
1	0	2.50	0.44	4.21	2.50	0	0.7	1.2	1.2	3.00	0	2.50	0	3.00	4
2	0	2.70	0.44	4.20	2.70	0	0.7	1.2	1.2	2.80	0	2.70	0	2.80	4
3	0	2.90	0.44	4.19	2.90	0	0.7	1.2	1.2	2.60	0	2.90	0	2.60	4
4	0	3.10	0.44	4.17	3.10	0	0.7	1.2	1.2	2.40	0	3.10	0	2.40	4
5	0	3.30	0.44	4.16	3.30	0	0.7	1.2	1.2	2.20	0	3.30	0	2.20	4
6	0	2.49	0.96	6.26	2.49	0	0.7	1.2	1.2	3.01	0	2.49	0	3.01	4
7	0	2.69	0.96	6.24	2.69	0	0.7	1.2	1.2	2.81	0	2.69	0	2.81	4
8	0	2.89	0.95	6.22	2.89	0	0.7	1.2	1.2	2.61	0	2.89	0	2.61	4
9	0	3.09	0.94	6.19	3.09	0	0.7	1.2	1.2	2.41	0	3.09	0	2.41	4
10	0	3.29	0.93	6.17	3.29	0	0.7	1.2	1.2	2.21	0	3.29	0	2.21	4
11	0	2.50	1.32	7.97	2.50	0	0.7	1.2	1.2	3.00	0	2.50	0	3.00	4
12	0	2.69	1.40	7.92	2.69	0	0.7	1.2	1.2	2.81	0	2.69	0	2.81	4
13	0	2.89	1.44	7.89	2.89	0	0.7	1.2	1.2	2.61	0	2.89	0	2.61	4
14	0	3.09	1.48	7.86	3.09	0	0.7	1.2	1.2	2.41	0	3.09	0	2.41	4
15	0	3.29	1.50	7.83	3.29	0	0.7	1.2	1.2	2.21	0	3.29	0	2.21	4
16	0	2.53	1.43	9.31	2.53	0	0.7	1.2	1.2	2.97	0	2.53	0	2.97	4
17	0	2.72	1.52	9.28	2.72	0	0.7	1.2	1.2	2.78	0	2.72	0	2.78	4
18	0	2.91	1.60	9.25	2.91	0	0.7	1.2	1.2	2.59	0	2.91	0	2.59	4
19	0	3.11	1.68	9.23	3.11	0	0.7	1.2	1.2	2.39	0	3.11	0	2.39	4
20	0	3.30	1.75	9.20	3.30	0	0.7	1.2	1.2	2.20	0	3.30	0	2.20	4
21	0	2.56	1.48	10.39	2.56	0	0.7	1.2	1.2	2.94	0	2.56	0	2.94	4
22	0	2.75	1.58	10.37	2.75	0	0.7	1.2	1.2	2.75	0	2.75	0	2.75	4
23	0	2.94	1.68	10.34	2.94	0	0.7	1.2	1.2	2.56	0	2.94	0	2.56	4
24	0	3.13	1.77	10.32	3.13	0	0.7	1.2	1.2	2.37	0	3.13	0	2.37	4
25	0	3.32	1.86	10.29	3.32	0	0.7	1.2	1.2	2.18	0	3.32	0	2.18	4
26	0	2.59	1.52	11.34	2.59	0	0.7	1.2	1.2	2.91	0	2.59	0	2.91	4
27	0	2.78	1.62	11.32	2.78	0	0.7	1.2	1.2	2.72	0	2.78	0	2.72	4
28	0	2.97	1.72	11.30	2.97	0	0.7	1.2	1.2	2.53	0	2.97	0	2.53	4
29	0	3.16	1.82	11.28	3.16	0	0.7	1.2	1.2	2.34	0	3.16	0	2.34	4
30	0	3.36	1.92	11.26	3.36	0	0.7	1.2	1.2	2.14	0	3.36	0	2.14	4
31	0	2.63	1.56	12.34	2.63	0	0.7	1.2	1.2	2.87	0	2.63	0	2.87	4
32	0	2.82	1.66	12.33	2.82	0	0.7	1.2	1.2	2.68	0	2.82	0	2.68	4
33	0	3.01	1.76	12.31	3.01	0	0.7	1.2	1.2	2.49	0	3.01	0	2.49	4
34	0	3.20	1.86	12.29	3.20	0	0.7	1.2	1.2	2.30	0	3.20	0	2.30	4
35	0	3.39	1.96	12.28	3.39	0	0.7	1.2	1.2	2.11	0	3.39	0	2.11	4
36	0	2.66	1.59	13.09	2.66	0	0.7	1.2	1.2	2.84	0	2.66	0	2.84	4
37	0	2.85	1.69	13.07	2.85	0	0.7	1.2	1.2	2.65	0	2.85	0	2.65	4
38	0	3.04	1.79	13.06	3.04	0	0.7	1.2	1.2	2.46	0	3.04	0	2.46	4
39	0	3.23	1.89	13.04	3.23	0	0.7	1.2	1.2	2.27	0	3.23	0	2.27	4
40	0	3.42	1.99	13.03	3.42	0	0.7	1.2	1.2	2.08	0	3.42	0	2.08	4
Nr.Pat.	$\beta$	h	$H_{m0\ toe}$	$T_{m-1,0\ toe}$	$h_t$	$B_t$	$\gamma_f$	$cota_d$	$cota_u$	$R_c$	B	$h_b$	$tana_B$	$A_c$	$G_c$
	degr	m	m	s	m	m				m	m	m		m	m

Figure A2.8. Input file for NN-OVERTOPPING 2.0.

The fourth step is to run the executable file NN-OVERTOPPING 2.0. Figure A2.9 shows the output file (.xls format) corresponding to the input file shown in Figure A2.8. Table A2.3 shows the corrected mean overtopping discharges (considering scale and model effects) and the 75% percentile corresponding to the MSL and deep water characteristics described in Table A2.1.

Nr.Pat.	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%]	REMARK	q <sub>corrected</sub>
1	-1	-1	-1	-1	-1	-1	-1	-1	1	-1
2	-1	-1	-1	-1	-1	-1	-1	-1	1	-1
3	-1	-1	-1	-1	-1	-1	-1	-1	1	-1
4	-1	-1	-1	-1	-1	-1	-1	-1	1	-1
5	-1	-1	-1	-1	-1	-1	-1	-1	1	-1
6	7.1E-5	3.8E-7	8.4E-7	1.3E-5	7.6E-5	4.1E-4	4.4E-3	8.1E-3	4	3.1E-4
7	8.7E-5	3.5E-7	1.0E-6	1.5E-5	1.0E-4	4.9E-4	5.3E-3	1.2E-2	4	3.4E-4
8	1.0E-4	4.1E-7	1.1E-6	1.6E-5	1.2E-4	5.9E-4	6.5E-3	1.2E-2	4	3.7E-4
9	1.2E-4	4.2E-7	1.3E-6	1.9E-5	1.3E-4	7.4E-4	8.6E-3	1.9E-2	4	4.0E-4
10	1.4E-4	4.1E-7	1.3E-6	2.3E-5	1.4E-4	9.1E-4	1.1E-2	3.5E-2	4	4.4E-4
11	4.9E-4	6.1E-6	1.2E-5	1.1E-4	5.0E-4	2.0E-3	1.5E-2	3.9E-2	4	8.6E-4
12	8.8E-4	1.2E-5	2.2E-5	2.2E-4	9.0E-4	3.7E-3	2.8E-2	6.5E-2	4	1.2E-3
13	1.4E-3	1.9E-5	3.7E-5	3.3E-4	1.4E-3	5.8E-3	4.6E-2	1.2E-1	4	1.7E-3
14	2.2E-3	2.9E-5	6.6E-5	5.1E-4	2.1E-3	9.6E-3	7.0E-2	1.8E-1	4	2.4E-3
15	3.2E-3	4.5E-5	9.5E-5	7.3E-4	3.0E-3	1.4E-2	1.2E-1	2.9E-1	4	3.3E-3
16	1.2E-3	2.0E-5	4.0E-5	2.7E-4	1.2E-3	5.0E-3	4.6E-2	8.5E-2	4	1.5E-3
17	2.4E-3	3.2E-5	7.5E-5	5.9E-4	2.5E-3	9.8E-3	8.3E-2	1.6E-1	4	2.6E-3
18	4.4E-3	6.8E-5	1.3E-4	1.1E-3	4.7E-3	1.8E-2	1.4E-1	3.6E-1	4	4.4E-3
19	8.1E-3	1.3E-4	2.7E-4	2.0E-3	8.7E-3	3.3E-2	2.2E-1	6.0E-1	4	8.1E-3
20	1.4E-2	2.5E-4	6.4E-4	3.6E-3	1.5E-2	5.2E-2	3.6E-1	9.6E-1	4	1.4E-2
21	2.2E-3	3.2E-5	6.4E-5	5.2E-4	2.3E-3	8.9E-3	9.1E-2	1.5E-1	4	2.4E-3
22	4.4E-3	6.1E-5	1.2E-4	1.2E-3	4.6E-3	1.7E-2	1.5E-1	3.4E-1	4	4.5E-3
23	8.7E-3	1.4E-4	2.8E-4	2.2E-3	9.6E-3	3.1E-2	2.3E-1	6.8E-1	4	8.7E-3
24	1.6E-2	2.7E-4	5.6E-4	4.3E-3	1.7E-2	6.1E-2	4.0E-1	1.1E+0	4	1.6E-2
25	3.0E-2	6.0E-4	1.3E-3	8.0E-3	3.0E-2	1.1E-1	7.6E-1	1.8E+0	4	3.0E-2
26	3.5E-3	4.0E-5	9.4E-5	8.6E-4	3.6E-3	1.4E-2	1.2E-1	3.2E-1	4	3.6E-3
27	7.0E-3	1.0E-4	1.7E-4	1.8E-3	7.3E-3	2.8E-2	1.9E-1	4.9E-1	4	7.0E-3
28	1.4E-2	2.2E-4	4.3E-4	3.6E-3	1.4E-2	5.4E-2	3.4E-1	8.6E-1	4	1.4E-2
29	2.6E-2	3.5E-4	1.0E-3	7.3E-3	2.5E-2	1.0E-1	6.5E-1	1.8E+0	4	2.6E-2
30	4.9E-2	8.3E-4	2.0E-3	1.4E-2	4.7E-2	1.8E-1	1.3E+0	2.7E+0	4	4.9E-2
31	5.5E-3	7.1E-5	1.4E-4	1.4E-3	5.8E-3	2.3E-2	1.9E-1	4.4E-1	4	5.6E-3
32	1.1E-2	1.5E-4	2.5E-4	2.9E-3	1.2E-2	4.6E-2	3.0E-1	8.9E-1	4	1.1E-2
33	2.1E-2	2.8E-4	5.9E-4	5.8E-3	2.1E-2	8.7E-2	6.1E-1	1.4E+0	4	2.1E-2
34	4.0E-2	5.4E-4	1.4E-3	1.1E-2	4.0E-2	1.6E-1	1.1E+0	2.3E+0	4	4.0E-2
35	7.3E-2	9.9E-4	2.8E-3	2.1E-2	7.3E-2	2.6E-1	2.0E+0	4.4E+0	4	7.3E-2
36	7.7E-3	9.6E-5	1.8E-4	1.9E-3	8.2E-3	3.4E-2	2.9E-1	7.0E-1	4	7.7E-3
37	1.5E-2	1.8E-4	3.5E-4	4.1E-3	1.5E-2	6.5E-2	4.6E-1	1.3E+0	4	1.5E-2
38	2.9E-2	3.5E-4	7.9E-4	7.5E-3	3.0E-2	1.2E-1	8.5E-1	2.2E+0	4	2.9E-2
39	5.4E-2	6.8E-4	1.8E-3	1.4E-2	5.6E-2	2.1E-1	1.6E+0	3.0E+0	4	5.4E-2
40	9.5E-2	1.3E-3	3.0E-3	2.5E-2	1.0E-1	3.7E-1	2.9E+0	5.5E+0	4	9.5E-2
Nr.Pat.	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%]	REMARK	q <sub>corrected</sub>

Figure A2.9. Output file of the software NN-OVERTOPPING 2.0.

Fifth step is to compare estimated overtopping discharges with permissible overtopping limits. To calculate the estimated overtopping in this case study, the 75% percentile ( $q_{75\%}$ ) and the scale and model effects correction factor ( $q_{corrected}/q$ ) are used

$$q_{75\%corrected} = q_{75\%} \left[ \frac{q_{corrected}}{q} \right]$$

This overtopping estimator takes into account possible scale and model effects and also the uncertainty of the neural network estimation. Quantitative overtopping discharges shown in Table A2.3 are transformed in overtopping hazard assessments which are synthesized later into Table A2.4, showing the overtopping warning messages.

Deep water		q <sub>75%corrected</sub>				
Hs(m)	Tp(s)	MSL=0.0m	MSL=0.2m	MSL=0.4m	MSL=0.6m	MSL=0.8m
0.5	4.7	Out of range	Out of range	Out of range	Out of range	Out of range
1.0	6.6	1.7	1.9	2.2	2.5	2.8
1.5	8.1	3.6	5.1	7.1	10.6	14.8
2.0	9.3	6.3	10.6	18.4	32.6	52.3
2.5	10.4	9.8	16.9	31.3	60.5	106.6
3.0	11.4	14.5	28.1	54.4	101.5	184.6
3.5	12.3	22.8	46.4	86.7	157.3	260.7
4.0	13.2	34.3	65.2	119.5	212.3	365.9

Table A2.3. Corrected 75% percentile for mean overtopping discharges (in litre/s.m).

Deep water		q <sub>75%corrected</sub>				
Hs(m)	Tp(s)	MSL=0.0m	MSL=0.2m	MSL=0.4m	MSL=0.6m	MSL=0.8m
0.5	4.7	0	0	0	0	0
1.0	6.6	1	1	1	1	1
1.5	8.1	2	2	2	2	2
2.0	9.3	2	2	2	3	3
2.5	10.4	2	2	3	4	4
3.0	11.4	2	3	3	4	5
3.5	12.3	3	3	4	5	5
4.0	13.2	3	4	4	5	5

0=	no hazard
1=	≈1 l/s.m "unpleasant for pedestrians"
2=	≈10 l/s.m "dangerous for pedestrians and low speed vehicles (road)"
3=	≈30 l/s.m "dangerous for low speed vehicles driving on the service road"
4=	≈100 l/s.m "possible damages on the service road (unpaved)"
5=	≈200 l/s.m "damages on the service road + possible affection to motorway"

Table A2.4. Warning overtopping messages.

### A2.3 An overtopping warning system

For a given forecasted wave climate scenario, it is possible to obtain a prediction of the overtopping discharges (and corresponding warning messages) comparing this scenario with the previously calculated scenarios or following the calculation procedure described in the previous section. The transportation authority and potential users of the coastal revetment, service road and motorway may be warned in advance when predictions are higher than overtopping limits. In this case study, warning messages "0" and "1" would not require public intervention different from general education about the overtopping hazards. Warning message "2" would

alert the coastal and transportation authorities for overtopping hazards on the coastal defence and unpaved service road. Warning message “3” would require a direct public intervention closing the service road to pedestrians and non emergency vehicles. Warning message “4” would alert the transportation authority for possible damages to the service road and possible affection to the motorway. Warning message “5” would require real-time monitoring of the overtopping problems on the motorway and to be ready for a temporal closure of some of the motorway lanes. Warning messages “3” to “5” could be directly informed to drivers on the motorway via the electronic motorway information panels.

Because of the structural variables of the case study are not “out of range”, only wave climate variables can generate “out of range” dimensionless inputs, with too low or too high overtopping discharge and makes the NN prediction method unreliable. However, these extreme cases are relatively easy to detect by experts and to transform it in a reliable “overtopping warning message”. For simplicity, this case study has assumed 1D propagation, straight coastline, single cross section and beach profile, wave direction perpendicular to the shoreline and constant wave steepness. Large wave and water level intervals have been considered to make more readable Tables A2.1 to A2.4. A more realistic warning system would require the consideration of a 2D bathymetry and a 2D wave propagation model, several cross sections to refer overtopping hazards, various deep water mean wave directions and spreading and multiple combinations of  $\{MSL, H_{m0}$  and  $T_{-1,0}\}$ . All this calculations can be completed in advance to provide multivariable tables similar to the two-dimensional Tables A2.3 and A2.4 shown in this Appendix. These multivariate tables could be used in real-time (by non experts) as the core element of an overtopping warning system applicable to the coastal defence of the Northern motorway of Valencia.

Figure A2.10 schematizes the simplified overtopping warning system for the coastal defence, system described in this Appendix. The procedure described in Figure A2.10 fails if the software NN-OVERTOPPING 2.0 does not provide a quantitative estimation of overtopping discharges but an “out of range” warning message. Figure A2.9 showed some “out of range” cases which corresponded to very low overtopping discharges; however, not all “out of range” cases corresponds to a very low overtopping situation. Real-time use of NN-OVERTOPPING 2.0 by non-experts are not recommended but, as was done in this case study, NN-OVERTOPPING 2.0 can be run by experts to estimate overtopping discharges in all imaginable situations. Non experts can easily select similar cases and obtain the appropriate “warning message” by comparison with cases previously analyzed by experts.

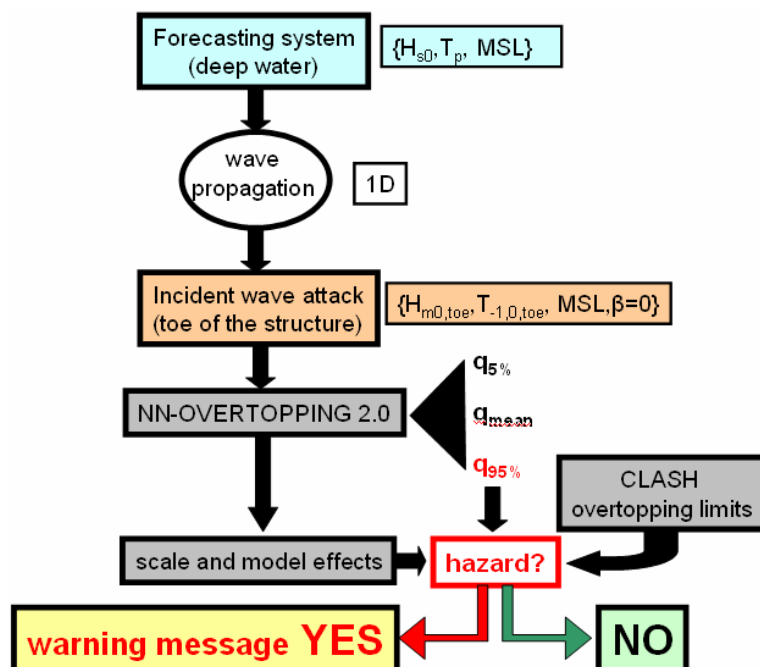


Figure A2.10. Scheme of the simplified version of the overtopping warning system.

The complete overtopping warning system for the coastal defence would be similar to the simplified system schematized in Figure A2.10 but considering 2D information and a much more number of possible forecasted storm conditions.

In the following, a simulation of the application of the simplified overtopping warning system (Figure A2.10) is given, taking as deep water wave conditions the data obtained during the storm of November 2001 (Figure A2.6). Figure A2.11 shows the input file and Figure A2.12 shows and output file and corresponding warning messages. Figure A2.13 represents graphically the output variables and the warning messages

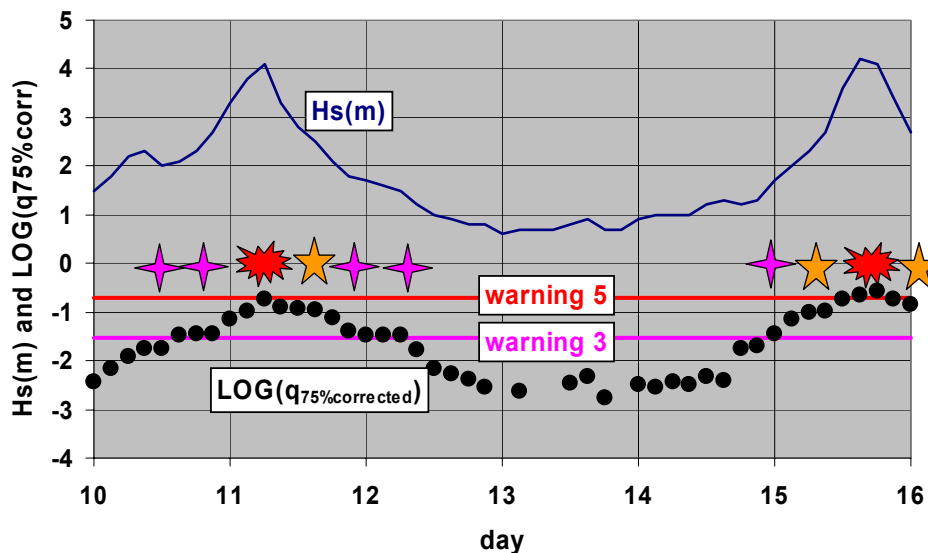
Nr.Pat.	$\beta$ degr	h m	$H_{m0\ toe}$ m	$T_{m-1,0\ toe}$ s	$h_t$ m	$B_t$ m	$\gamma_f$	$cota_d$	$cota_u$	$R_c$ m	B m	$h_b$ m	$tana_B$	$A_c$ m	$G_c$ m
1	0	2.66	1.34	7.35	2.66	0	0.7	1.2	1.2	2.84	0	2.66	0	2.84	4
2	0	2.72	1.46	8.25	2.72	0	0.7	1.2	1.2	2.78	0	2.72	0	2.78	4
3	0	2.77	1.55	9.18	2.77	0	0.7	1.2	1.2	2.73	0	2.77	0	2.73	4
4	0	2.78	1.59	10.05	2.78	0	0.7	1.2	1.2	2.72	0	2.78	0	2.72	4
5	0	2.82	1.59	9.99	2.82	0	0.7	1.2	1.2	2.68	0	2.82	0	2.68	4
6	0	2.87	1.66	11.00	2.87	0	0.7	1.2	1.2	2.63	0	2.87	0	2.63	4
7	0	2.89	1.67	11.04	2.89	0	0.7	1.2	1.2	2.61	0	2.89	0	2.61	4
8	0	2.88	1.67	11.11	2.88	0	0.7	1.2	1.2	2.62	0	2.88	0	2.62	4
9	0	2.93	1.72	12.24	2.93	0	0.7	1.2	1.2	2.57	0	2.93	0	2.57	4
10	0	2.99	1.77	13.27	2.99	0	0.7	1.2	1.2	2.51	0	2.99	0	2.51	4
11	0	3.05	1.82	14.70	3.05	0	0.7	1.2	1.2	2.45	0	3.05	0	2.45	4
12	0	3.02	1.80	13.20	3.02	0	0.7	1.2	1.2	2.48	0	3.02	0	2.48	4
13	0	3.03	1.79	13.15	3.03	0	0.7	1.2	1.2	2.47	0	3.03	0	2.47	4
14	0	3.01	1.78	13.11	3.01	0	0.7	1.2	1.2	2.49	0	3.01	0	2.49	4
15	0	2.93	1.71	13.06	2.93	0	0.7	1.2	1.2	2.57	0	2.93	0	2.57	4
16	0	2.84	1.63	12.02	2.84	0	0.7	1.2	1.2	2.66	0	2.84	0	2.66	4
17	0	2.80	1.60	12.00	2.80	0	0.7	1.2	1.2	2.70	0	2.80	0	2.70	4
18	0	2.84	1.59	11.99	2.84	0	0.7	1.2	1.2	2.66	0	2.84	0	2.66	4
19	0	2.84	1.58	11.95	2.84	0	0.7	1.2	1.2	2.66	0	2.84	0	2.66	4
20	0	2.85	1.41	11.92	2.85	0	0.7	1.2	1.2	2.65	0	2.85	0	2.65	4
21	0	2.87	1.20	10.83	2.87	0	0.7	1.2	1.2	2.63	0	2.87	0	2.63	4
22	0	2.89	1.09	10.83	2.89	0	0.7	1.2	1.2	2.61	0	2.89	0	2.61	4
23	0	2.84	0.97	10.83	2.84	0	0.7	1.2	1.2	2.66	0	2.84	0	2.66	4
24	0	2.79	0.92	9.81	2.79	0	0.7	1.2	1.2	2.71	0	2.79	0	2.71	4
25	0	2.78	0.69	9.81	2.78	0	0.7	1.2	1.2	2.72	0	2.78	0	2.72	4
26	0	2.77	0.80	9.81	2.77	0	0.7	1.2	1.2	2.73	0	2.77	0	2.73	4
27	0	2.73	0.86	10.83	2.73	0	0.7	1.2	1.2	2.77	0	2.73	0	2.77	4
28	0	2.67	0.86	10.84	2.67	0	0.7	1.2	1.2	2.83	0	2.67	0	2.83	4
29	0	2.72	0.98	10.84	2.72	0	0.7	1.2	1.2	2.78	0	2.72	0	2.78	4
30	0	2.76	1.09	10.83	2.76	0	0.7	1.2	1.2	2.74	0	2.76	0	2.74	4
31	0	2.77	0.71	7.23	2.77	0	0.7	1.2	1.2	2.73	0	2.77	0	2.73	4
32	0	2.68	0.87	11.90	2.68	0	0.7	1.2	1.2	2.82	0	2.68	0	2.82	4
33	0	2.66	1.04	9.83	2.66	0	0.7	1.2	1.2	2.84	0	2.66	0	2.84	4
34	0	2.71	1.08	8.08	2.71	0	0.7	1.2	1.2	2.79	0	2.71	0	2.79	4
35	0	2.77	1.12	8.94	2.77	0	0.7	1.2	1.2	2.73	0	2.77	0	2.73	4
36	0	2.80	1.08	8.07	2.80	0	0.7	1.2	1.2	2.70	0	2.80	0	2.70	4
37	0	2.82	1.26	8.10	2.82	0	0.7	1.2	1.2	2.68	0	2.82	0	2.68	4
38	0	2.82	1.27	7.28	2.82	0	0.7	1.2	1.2	2.68	0	2.82	0	2.68	4
39	0	2.86	1.41	11.92	2.86	0	0.7	1.2	1.2	2.64	0	2.86	0	2.64	4
40	0	2.81	1.47	11.93	2.81	0	0.7	1.2	1.2	2.69	0	2.81	0	2.69	4
41	0	2.83	1.61	12.00	2.83	0	0.7	1.2	1.2	2.67	0	2.83	0	2.67	4
42	0	2.89	1.71	13.03	2.89	0	0.7	1.2	1.2	2.61	0	2.89	0	2.61	4
43	0	2.9663	1.74547	13.0817	2.9663	0	0.7	1.2	1.2	2.5337	0	2.9663	0	2.5337	4
44	0	2.9905	1.77299	13.1377	2.9905	0	0.7	1.2	1.2	2.5095	0	2.9905	0	2.5095	4
45	0	3.0366	1.82242	14.6412	3.0366	0	0.7	1.2	1.2	2.4634	0	3.0366	0	2.4634	4
46	0	3.1109	1.85642	14.7016	3.1109	0	0.7	1.2	1.2	2.3891	0	3.1109	0	2.3891	4
47	0	3.1716	1.88983	14.6873	3.1716	0	0.7	1.2	1.2	2.3284	0	3.1716	0	2.3284	4
48	0	3.176	1.88007	13.2038	3.176	0	0.7	1.2	1.2	2.324	0	3.176	0	2.324	4
49	0	3.0861	1.82116	13.1288	3.0861	0	0.7	1.2	1.2	2.4139	0	3.0861	0	2.4139	4
Nr.Pat.	$\beta$ degr	h m	$H_{m0\ toe}$ m	$T_{m-1,0\ toe}$ s	$h_t$ m	$B_t$ m	$\gamma_f$	$cota_d$	$cota_u$	$R_c$ m	B m	$h_b$ m	$tana_B$	$A_c$ m	$G_c$ m



Figure A2.11. Input file of 2001 storm conditions.

Nr.Pat.	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%]	REMARK	q <sub>corrected</sub>	q <sub>75%corrected</sub>	warning
1	5.5E-4	5.9E-6	1.3E-5	1.3E-4	5.7E-4	2.2E-3	1.7E-2	4.1E-2	4	9.2E-4	3.7	1
2	1.3E-3	2.0E-5	3.4E-5	3.1E-4	1.3E-3	5.7E-3	4.0E-2	1.0E-1	4	1.6E-3	7.0	2
3	2.8E-3	4.1E-5	9.1E-5	7.0E-4	2.9E-3	1.2E-2	9.0E-2	2.2E-1	4	3.0E-3	12.3	2
4	4.4E-3	6.4E-5	1.3E-4	1.1E-3	4.7E-3	1.7E-2	1.5E-1	3.6E-1	4	4.4E-3	17.5	2
5	4.6E-3	6.9E-5	1.3E-4	1.2E-3	5.1E-3	1.8E-2	1.5E-1	4.1E-1	4	4.6E-3	17.8	2
6	8.6E-3	1.4E-4	2.5E-4	2.2E-3	9.1E-3	3.3E-2	2.3E-1	5.3E-1	4	8.6E-3	33.1	3
7	9.4E-3	1.4E-4	2.7E-4	2.4E-3	9.9E-3	3.6E-2	2.5E-1	5.7E-1	4	9.4E-3	35.8	3
8	9.4E-3	1.4E-4	2.8E-4	2.4E-3	1.0E-2	3.7E-2	2.4E-1	5.8E-1	4	9.4E-3	36.7	3
9	1.6E-2	2.1E-4	4.0E-4	4.2E-3	1.6E-2	7.0E-2	4.4E-1	1.1E+0	4	1.6E-2	70.2	4
10	2.6E-2	3.3E-4	7.0E-4	6.6E-3	2.6E-2	1.1E-1	8.0E-1	2.1E+0	4	2.6E-2	107.3	4
11	4.3E-2	4.6E-4	1.2E-3	1.0E-2	4.4E-2	1.9E-1	1.3E+0	3.0E+0	4	4.3E-2	187.7	5
12	3.0E-2	3.8E-4	8.6E-4	7.7E-3	3.1E-2	1.2E-1	9.0E-1	2.2E+0	4	3.0E-2	123.1	4
13	2.9E-2	3.6E-4	8.3E-4	7.5E-3	3.0E-2	1.2E-1	8.7E-1	2.2E+0	4	2.9E-2	120.2	4
14	2.7E-2	3.3E-4	7.6E-4	6.9E-3	2.8E-2	1.1E-1	8.0E-1	2.1E+0	4	2.7E-2	111.6	4
15	1.8E-2	2.3E-4	4.4E-4	4.9E-3	1.8E-2	7.8E-2	5.3E-1	1.5E+0	4	1.8E-2	77.9	4
16	9.4E-3	1.3E-4	2.2E-4	2.4E-3	1.0E-2	4.0E-2	2.8E-1	7.8E-1	4	9.4E-3	40.2	3
17	7.8E-3	1.1E-4	1.8E-4	1.9E-3	8.4E-3	3.4E-2	2.4E-1	6.8E-1	4	7.8E-3	33.6	3
18	8.0E-3	1.1E-4	1.8E-4	2.0E-3	8.5E-3	3.4E-2	2.6E-1	7.1E-1	4	8.0E-3	34.4	3
19	7.6E-3	9.8E-5	1.7E-4	1.9E-3	8.1E-3	3.2E-2	2.6E-1	6.8E-1	4	7.6E-3	32.5	3
20	3.8E-3	2.9E-5	6.8E-5	8.9E-4	4.2E-3	1.7E-2	1.7E-1	4.8E-1	4	3.9E-3	17.2	2
21	1.1E-3	6.6E-6	1.8E-5	2.2E-4	1.1E-3	5.3E-3	6.7E-2	1.8E-1	4	1.4E-3	6.9	2
22	6.5E-4	3.5E-6	7.7E-6	1.2E-4	6.5E-4	3.4E-3	5.0E-2	1.0E-1	4	1.0E-3	5.3	2
23	3.2E-4	1.3E-6	3.5E-6	5.7E-5	3.3E-4	2.0E-3	2.9E-2	6.0E-2	4	6.8E-4	4.1	2
24	1.8E-4	8.3E-7	2.3E-6	3.3E-5	2.0E-4	1.0E-3	1.4E-2	3.9E-2	4	5.0E-4	2.8	1
25	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	1	-1.0E+0		0
26	9.5E-5	3.0E-7	8.0E-7	1.4E-5	9.9E-5	6.3E-4	9.5E-3	3.4E-2	4	3.6E-4	2.4	1
27	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	1	-1.0E+0		0
28	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	1	-1.0E+0		0
29	2.9E-4	1.2E-6	3.6E-6	5.4E-5	2.8E-4	1.5E-3	2.6E-2	5.2E-2	4	6.4E-4	3.4	2
30	5.4E-4	3.1E-6	7.7E-6	1.1E-4	5.7E-4	2.9E-3	4.0E-2	8.3E-2	4	9.1E-4	4.8	2
31	3.8E-5	7.6E-8	2.3E-7	5.4E-6	3.8E-5	3.0E-4	3.9E-3	7.4E-3	4	2.2E-4	1.7	1
32	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	-1.0E+0	1	-1.0E+0		0
33	2.8E-4	1.8E-6	4.5E-6	5.2E-5	2.8E-4	1.4E-3	1.7E-2	4.7E-2	4	6.3E-4	3.2	2
34	2.3E-4	1.4E-6	3.5E-6	5.3E-5	2.4E-4	1.2E-3	1.1E-2	2.6E-2	4	5.7E-4	2.9	2
35	3.8E-4	2.5E-6	7.1E-6	7.5E-5	4.1E-4	1.9E-3	1.9E-2	3.9E-2	4	7.4E-4	3.7	2
36	2.6E-4	1.6E-6	3.5E-6	5.7E-5	2.7E-4	1.4E-3	1.3E-2	3.0E-2	4	6.0E-4	3.2	2
37	6.0E-4	6.2E-6	9.8E-6	1.4E-4	6.4E-4	2.9E-3	2.7E-2	5.7E-2	4	9.7E-4	4.7	2
38	4.9E-4	4.6E-6	7.8E-6	1.1E-4	5.0E-4	2.2E-3	1.9E-2	4.4E-2	4	8.6E-4	3.9	2
39	3.9E-3	2.9E-5	6.8E-5	9.0E-4	4.3E-3	1.7E-2	1.8E-1	4.9E-1	4	3.9E-3	17.2	2
40	4.6E-3	4.6E-5	9.2E-5	1.1E-3	5.0E-3	2.0E-2	1.8E-1	4.6E-1	4	4.7E-3	20.0	2
41	8.5E-3	1.2E-4	2.0E-4	2.2E-3	9.1E-3	3.7E-2	2.6E-1	7.3E-1	4	8.5E-3	36.6	3
42	1.7E-2	2.1E-4	4.1E-4	4.6E-3	1.7E-2	7.1E-2	5.1E-1	1.5E+0	4	1.7E-2	71.5	4
43	2.2E-2	2.8E-4	5.6E-4	5.7E-3	2.2E-2	9.5E-2	6.5E-1	1.7E+0	4	2.2E-2	95.0	4
44	2.6E-2	3.2E-4	7.1E-4	6.6E-3	2.6E-2	1.1E-1	7.7E-1	2.0E+0	4	2.6E-2	105.7	4
45	4.2E-2	4.6E-4	1.1E-3	1.0E-2	4.3E-2	1.8E-1	1.2E+0	2.9E+0	4	4.2E-2	180.4	5
46	5.3E-2	5.9E-4	1.6E-3	1.3E-2	5.5E-2	2.3E-1	1.6E+0	3.5E+0	4	5.3E-2	225.1	5
47	6.4E-2	7.4E-4	1.9E-3	1.6E-2	6.9E-2	2.6E-1	1.8E+0	3.8E+0	4	6.4E-2	264.6	5
48	5.0E-2	6.2E-4	1.6E-3	1.3E-2	5.1E-2	1.9E-1	1.4E+0	3.1E+0	4	5.0E-2	189.4	5
49	3.5E-2	4.3E-4	1.0E-3	9.1E-3	3.6E-2	1.4E-1	1.0E+0	2.5E+0	4	3.5E-2	141.7	4

Figure A2.12. Output file and warning messages for the 2001 storm conditions.



*Figure A2.13.  $H_s(m)$ , mean overtopping and “3” to “5” warning levels for the 2001 storm.*

## ***A2.4 Summary and conclusions***

This Appendix describes a typical application of the CLASH methodology and the CLASH generic prediction method implemented in the CLASH executable file NN-OVERTOPPING 2.0. The application refers to the adoption of an overtopping warning system for the coastal defence of the Northern motorway of Valencia (Spain) which has been affected by several overtopping events during the past decades.

A simplified method to propose the overtopping warning system is described here, including input and output files for the executable NN-OVERTOPPING 2.0 and the corresponding interpretation of results. This example of application illustrates how CLASH methodology works in solving engineering problems; in this case, preventing damages to people and vehicles by assessing future overtopping hazards and giving appropriate overtopping warning messages.