DEPARTMENT for ENVIRONMENT, FOOD and RURAL AFFAIRS

Research and Development

Final Project Report

(Not to be used for LINK projects)

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Project title	Coastal Flooding Hazard by Wave Overtopping (Phase 2)
DEFRA project code	**FD 2412**
Contractor organisation and location	HR Wallingford Group Ltd Howbery Park Wallingford Oxfordshire OX10 8BA
Total DEFRA project costs	£ 139,840
Project start date	01/01/02
Project end date	30/06/05

Executive summary (maximum 2 sides A4)

This FD2412 project provided matching funds for the CLASH project (Crest Level Assessment of Coastal Structures by Full Scale Monitoring, Neural Network Prediction and Hazard Analysis on Permissible Wave Overtopping) contract no. EVK3-CT-2001-00058 funded by the European Union (EU). CLASH investigated wave overtopping for different structures in prototype and in the laboratory. All references to CLASH in this report will be assumed to be referring to FD2412 Coastal Flooding Hazard by Wave Overtopping (Phase 2). 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 NNOVERTOPPING 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).

Scientific report (maximum 20 sides A4)

Introduction

Project No: FD 2412 Coastal Flooding Hazard by Wave Overtopping (Phase 2), known here as CLASH, provided matching funds for the CLASH project (Crest Level Assessment of Coastal Structures by Full Scale Monitoring, Neural Network Prediction and Hazard Analysis on Permissible Wave Overtopping) contract no. EVK3-CT-2001-00058 funded by the European Union (EU). The project was 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 suggested that wave run-up on rubble mound slopes, measured during prototype 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 lead to a conclusion on scale and model effects and how to deal with them. The second approach was to gather all existing data on overtopping in a homogeneous database, to supplement that database 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 (NN) 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 interrelated WorkPackages (WP). All WPs resulted in clearly defined Deliverables (Dnn). A list with relevant Deliverables is found at the end of this report (References). Each of the 10 WPs are discussed in detail below.

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 (NNOVERTOPPING 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 at 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.

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.

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 CF 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 (NNOVERTOPPING 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.

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. The final result is implemented in the executable file of the generic prediction method (NNOVERTOPPING 2.0) and a brief description is given in D40. The scaling procedure in D40 allows to scale up small scale model results to prototype scale, taking into account possible model and scale effects.

The output of the executable file of the CLASH generic prediction method (NNOVERTOPPING 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} (m^3/m), and
(3) overtopping velocities v_x and v_z (m/s*).*

Although overtopping velocities or peak overtopping volume were more significant for hazards than the mean overtopping discharge, it was the mean overtopping discharge q (m^3/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. The suggested limits for overtopping mean discharge (q in litre/s.m) are in D38, in addition to those for peak overtopping volume (V_{max} in litre/m).

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 D38, 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.

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.

The WorkPackages

In addition to the CLASH methodology and the generic prediction method implemented in the executable software NNOVERTOPPING 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. The following list also summarises the reports of the CLASH WorkPackages:

WP1 General Methodology: D5 describes the CLASH project and methodology as was originally conceived in 2002, two years before the finalisation 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+12.40m. Local tides are characterised by MHWLS=Z+4.62m and MLWLS= Z+0.32m. Two cross sections of the breakwater are instrumented and separated by approximately 140m; a “jetty section” 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 -5.0m MSL while the crest level of the concrete wall is +4.5m MSL. The local tide range is 0.5m, 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 +8.22mODN and at toe level at -2.42mODN. The berm in front of the wall is approximately 3.5m deep by 10m wide, having tides characterized by MHWLS = +3.03mODN and MLWLS = -2.87mODN. 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) were 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, *et cetera*) 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 OPTICREST project. During the OPTICREST 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, *et cetera*.) 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 affecting 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 is 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 spreading, four crest freeboards and five angles of attack (from 0º to 60º) 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 and a recreational port in Italy.

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 and 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 users' manual for the software NNOVERTOPPING 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 NNOVERTOPPING 2.0.

WP9/10: Guidelines and Dissemination: D46 is the full scientific report detailing all the work under CLASH and giving a detailed discussion of the results, the overtopping database, the Neural Network, application of the scaling effects and all the guidelines. These various elements that make up D46 and the work done under each of the WorkPackages, have been presented comprehensively at all the major Coastal Engineering conferences since 2002, and are due to be presented at ICCE in 2006.

References

All the references and reports will be available to download from the CLASH-homepage (www.clash-eu.org) from December 2005 (or contact Dr. Tim Pullen t.pullen@hrwallingford.co.uk):

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-Escriva, 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.