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THE NEW DELTA FLUME FOR LARGE-SCALE TESTING

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The new Delta Flume in Delft was constructed to facilitate large-scale physical model testing. The new Delta Flume has a length of about 300m, a width of 5m and a height of 9.5m. The maximum significant wave height that can be generated is about H_s = 2.2m and maximum individual wave heights in the range between H_{max} = 4m and 4.5m. This unique facility enables physical modelling at prototype-scale or at close-to-prototype scale. Preventing or diminishing scale-effects is especially important for coastal structures in which sand, clay, grass or other natural construction material is being applied. Besides projects with dikes and dunes, structures such as breakwaters, bed protections, monopiles, offshore wind farms, and storm surge barriers are scheduled to be tested. Along with new facilities also new measurement techniques have been developed, both for the new Delta Flume and for the other wave facilities (*e.g.* wave basins). The new Delta Flume completes a set of wave facilities for physical model testing consisting of small and large-scale test facilities and 2D (wave flumes) and 3D (wave basins) facilities.

Introduction

To determine the response of coastal structures such as dikes, dunes, dune-revetments, breakwaters, cobble & gravel beaches, intake & outfall structures, offshore windfarms and bed protections, under loading of waves and/or currents physical model testing is an essential part of the design and evaluation process of such structures. Some aspects require modelling at a large scale since the materials and/or physical processes cannot be modelled properly on a small scale using Froude's scaling law. Examples of materials that cannot be modelled properly at a small-scale are sand, clay, grass or natural construction material (*e.g.* brushwood). Physical processes that cannot be modelled properly at a small-scale are often related to flow characteristics that do not scale according to Froude's scaling law, *e.g.* for structures in which laminar (porous) flow plays an important role results may be affected by scale-effects. Nevertheless, tests at small-scale can provide valuable indicative results although for accurate quantitative results large scale models are still

Figure 1 - Examples of projects in the Delta Flume

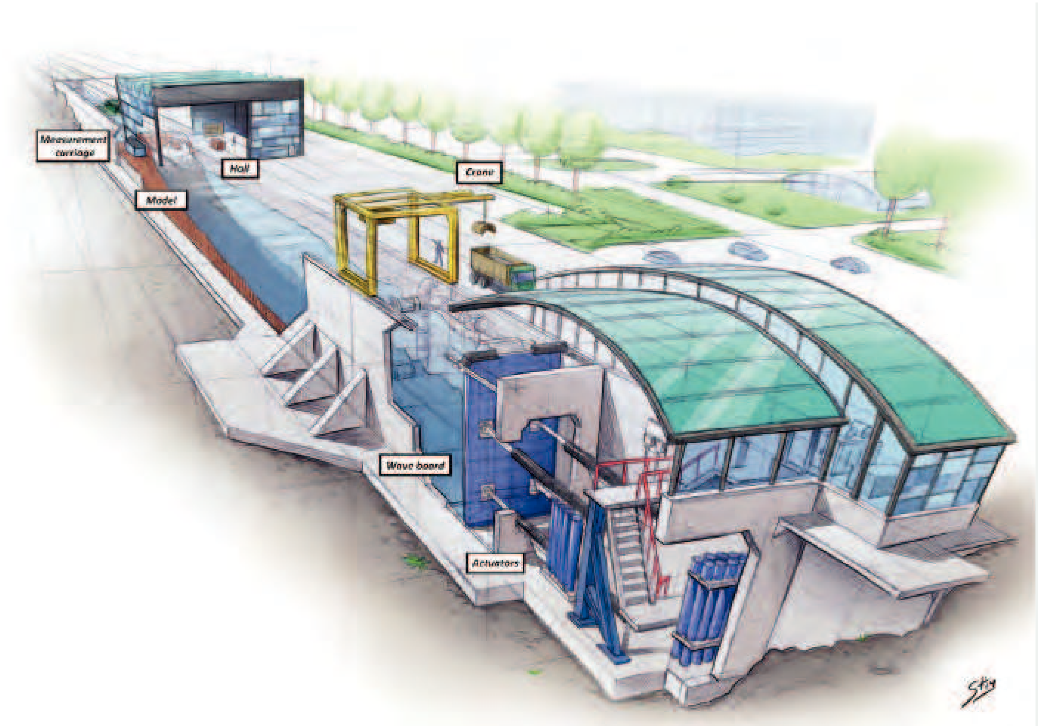

Figure 2 - Impression of the new Delta Flume (courtecy mr Stephan Timmers)

required. Many types of coastal structures can be modelled sufficiently accurate at small scales, e.g. most rubble mound breakwaters.

Besides the scale of models it is important to determine whether the structures can be modelled in a 2D model (wave flumes) or need to be modelled in a 3D model (wave basins). Often combinations of 2D and 3D models are applied, e.g. where cross-sections of structures are optimized in a wave flume, while 3D aspects are studied afterwards in a separate 3D model. Also the combination of small-scale tests and large-scale tests may be an efficient way to determine the performance of coastal structures for those structures in which some of the characteristics would be affected by scale-effects in smaller models. Therefore, it is essential to have a set of small-scale and large-scale facilities available, as well as 2D (wave flumes) and 3D facilities (wave basins). Not only the facilities are important, also the measurement equipment and experienced staff are key factors of the success of physical model tests. In Van Gent (2014) an overview of projects in the various physical model facilities is given.

Projects In The Old Delta Flume

In the old Delta Flume (240m*5m*7m) a large number of projects has been performed in the last 35 years. In these projects the choice for this facility has been based mainly on the need to limit or avoid scale-effects in physical model tests. The new Delta Flume in Delft (300m*5m*9.5m) has been constructed to facilitate measurements at an even larger scale. Figure 1 shows examples of projects performed in the old Delta Flume: Wave impacts on vertical walls, wave overtopping at dikes with grass, the dynamic behaviour of cobble beaches, the stability of placed-block revetments, the residual strength of clay-dikes, breakwater stability, dune erosion, and wave damping by brushwood mattresses. Other typical studies in the Delta Flume are related to for instance the validation of numerical models, testing and calibration of field measurement equipment, and the stability of pipeline covers.

Besides consultancy projects many research projects in the Delta Flume have been performed and resulted in information on the performance of coastal structures, for instance:

■ Placed-block revetments ■ Grass slopes under wave attack ■ Residual strength of dikes ■ Dune erosion ■ Gravel and cobble beaches ■ Wave impacts on vertical walls ■ Geotubes and geocontainers.

The New Delta Flume

The main characteristics of the new Delta Flume compared to the old Delta Flume are that the maximum wave height that can be generated is higher, the length is increased, tidal water level variations can be generated, and the new Delta Flume is close to the other wave facilities in Delft. One of the main advantages of the new Delta Flume over the old Delta Flume is that scale-effects are further reduced; a larger portion of the projects can be performed at (close-to) prototype scale. Figure 2 provides an impression of the new Delta Flume.

Flume dimensions The flume has a total length of about 300m. The size was determined based on tests that have been performed in the old Delta Flume. The modelling area has a total depth of 9.5m for a length of 183m, and an extra 75m section of 7m deep. The deep part has a length that is sufficient to model structures such as dikes while the combination with a shallower section allows for modelling of gentle foreshores over a length of about 250m in combination with for instance dunes. For the majority of the projects the water depth at the wave board will be between 2.5m and 8m. The flume is 5m wide.

Wave conditions The maximum wave heights that can be generated are about H_{m0} = 2.2m and maximum individual wave heights in the range between H_{max} = 4m and 4.5m. The optimal water depth at the wave board for reaching the highest significant wave height for which also the wave height distribution is modelled accurately, is estimated at 6.9m. Spectral significant wave heights larger than H_{m0} = 2.2m can be generated but these will cause some side wall overtopping. Irregular and regular waves, as well as some more special wave conditions can be generated (*e.g.* for

Tsunami modelling and focussed waves). It is expected that irregular wave conditions with standard spectral shapes (*e.g.* Jonswap) will be generated in the majority of experiments, so that during the design of the wave generator emphasis was put on precise specification of this type of wave conditions. Increasing wave height, wave period and water depth require more wave generating power, more wave board stroke and larger flume depths. In Hofland et al (2013) the percentage of water defences in The Netherlands that can be modelled at full scale is discussed. It is estimated that the new Delta Flume is capable of generating sufficiently large wave heights to cover about 85% of the Dutch sea dikes at prototype scale under design conditions. This means an increase in number of Dutch dike sections that can be tested at full scale of about 50% compared to the old Delta Flume.

To generate the large wave heights (*e.g.* $H_{m0} = 2.2$m) with the corresponding wave periods (e.g. $T_p = 9.4$s), a certain wave board stroke is needed. However, waves will reflect from the structures in the wave flume. To absorb these reflected waves with our active reflection compensation system (ARC, see also Wenneker *et al*, 2010), also a part of the wave board stroke is needed. The stroke of the new wave board is 7m, allowing for the mentioned significant wave height in combination with space to absorb waves that are reflected by structures in the flume.

Wave generator To generate the waves that are required a piston-type wave board was selected because of its good performance for coastal applications. The wave board is of the dry-back type. A hydraulic system was opted for. Four actuators are applied to better distribute the forces that the board will experience. The wave generator utilizes Degree of Freedom (DOF) control on the four actuators to accurately control the linear motion of the board while zeroing out unwanted board deflections such as twisting or bending due to hydrodynamic forces and board compliance. The length of an actuator is 24.5m when fully extended. A novelty in the new Delta Flume is that a tidal variation in the water level is possible by filling and emptying the flume during an experiment. The maximum filling discharge is 1 m^3/s.

Measurements Various measurement techniques are acquired and developed to extract data from the experiments in the flume (Hofland *et al*, 2012). Besides classic point measurements, also synoptic measurement techniques (i.e. high resolution measurements of time-varying spatial fields) have been developed. For the measurements of waves (at the wall) the proven resistance-type wave probes are used. Radars will be used to obtain wave height measurements at any location. In addition, the use of laser scanners and stereo matching of video images can be used to obtain spatially distributed information of waves and/or (deformed) structures. Also good visual observation of the tests is ensured using for instance a central video observation system and many (flush) cavities in the wall near the location of most models to install instruments.

Marcel R.A. van Gent **is a specialist in the field of coastal engineering, in particular coastal structures, wave modelling, dikes and dunes. He obtained his PhD at the Delft University of Technology in 1995 on the modelling of reshaping rubble mound coastal structures and gravel beaches. Dr Marcel van Gent is now head of the department 'Coastal Structures & Waves' at Deltares, Delft. His is leading a group that consists of about 35 scientists and assistants for performing physical model tests in wave flumes and wave basins, developing numerical wave models, and providing specialist consultancy services. Since 1991 Marcel van Gent participated in various research projects, including projects for the European Union, for the Dutch Government, and in co-operation with Universities, Consultancy firms, and Contractors. Dr Marcel van Gent published about 100 international scientific papers on coastal structures, wave modelling and dune erosion.**

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(a)


(b)


(c)

(a) hydraulic power units for wave generator
(b) crane above flume to construct structures to be tested
(c) blue wave paddle