2. THE IMPORTANCE OF EXPERIMENTS FOR MARINE ENGINEERING DESIGN PRACTICE

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Introduction

Being invited to be a speaker on “The importance of experiments for marine engineering design practice”, I will utilise the opportunity to summarise my professional life since been graduated from the Technical University of Denmark in summer 1970.

My master study included an experiment with sediment transport in a diffusive flow and my latest work has included model tests on dynamic forces from waves and ice to offshore wind turbine foundations.

Naturally, the examples I show in the power point presentation will be dominated by my point of view, which is mainly based on Danish experience and Danish examples. The examples include many significant contributions from several other Danish scientists and engineers.

2.1 Irregular waves and breakwaters

This includes 2-D-irregular/reproduced waves acting on vertical face, cylindrical and rubble mound breakwaters. The development of the vertical/cylindrical breakwater was in Denmark initiated with professor Lundgren’s work on Hanstholm breakwater. It was tested in Delft Hydraulics wind-wave flume in late 60-ties. This project led to the design of Brighton Marina (my first larger job in 1972), where new procedures for generating irregular waves in a short wave flume to generate shock pressures was developed. Examples of design for composite breakwaters include an alternative to the Sines breakwater (Portugal) and a breakwater at Sagunto (Spain). Important new model techniques include a cylindrical breakwater model of araldite with strain gauges.

In mid 70-ties many model tests were carried out for rubble mound breakwaters using various armour units leading to the first modern design basis for breakwaters exposed to irregular waves. Important aspects like breakwaters on a steep slope causing extreme high breaking waves (relative to the water depth) and effect of core permeability was described in these years. Further it now became possible to utilise the model test as a mean for detailed optimisation with examples including optimised design based on detailed quarry information, minimised amount of artificial unit in cross section through optimised use of natural rock, and detailed optimisation of berm and toe structures.

2.2 Harbour disturbance

The examples illustrate some first model tests with irregular waves. They include model tests on Thorlakshöfn port in Iceland (been exposed to an intensive study of potential harbour layouts) and Maceio (island breakwater in Brasil), where our first analysis of wave group effects from irregular waves and associated long waves was carried out. This led to the...
analysis of how a long period energy is increased at shallow waters until finally release during breaking. This understanding is vital for design of harbours for large vessels.

The complexity of optimisation of a port with many factors and important parameters is illustrated by an interaction diagrammed from 1978 showing that for example all the following parameters need to be considered: Harbour layout, harbour entrance, type of quay, angle of quay, fender stiffness and mooring stiffness.

It has also been experienced that there is a risk for generating excessive long period energy in a disturbance model test.

In some case the disturbance tests may be combined with ship propeller scour tests (like for Elsingore port)

### 2.3 3-D waves

Our studies started in 1976 with a field test where the surface elevation was measured in one point but where the 2-D wave velocity field was measured in 3 points. This represented improved information compared with the previous tilting recordings in a 3-D wave field made approximately 15 years earlier. First experimental set-up (3-D shallow water waves) from 1977 at Technical University of Denmark (DTU) is illustrated. The improved 3-D wave generation technique was later implemented in the 3-D wave basin on Danish Hydraulic Institute (DHI). Most recent development include hybrid modelling, where the physical limitations in the test facility is exchanged by mathematical boundary models for example to moorings or risers.

Examples with floating production structures and a moored semi sub show the importance of been able to describe the 3-D effect to obtain realistic estimates. Field measurements show freak waves and freak group waves, where improvements are still required as design is still too uncertain.

### 2.4 Marine pipelines

The examples illustrate the development from 1975 to now, where accurate design procedures exist for many of the problems related to marine pipelines such as hydrodynamic forces, pipe friction, 3-D wave effect, floatation, ship forces to pipelines, backfill of trench, backfill of dredged channel (in connection with shore approach), scour creating spans, and protection against grounding vessels. Spanning includes interesting tests with a short piece of pipe, where the most difficult is to model the correct current boundary layer. A circular flume has given a good description on erosion in cohesive materials. Improved tests on soils have been important.

### 2.5 Bridge piers

Ship impact modelling is based on scale crushing test (calibrated by the few accurate field data), non-linear soil tests and non-linear finite element models. Dynamic ice model tests with artificial ice acting on elastic suspended structural elements may provide forces and response data. Consequences of open bottom valves in sand filled bridge caisson leading to leakage of sand fill into bottom stone bed was tested and described. Scour tests have shown serious scour holes outside the area covered by the scour protection.
2.6 Offshore wind turbines

Model tests have been carried out with wave load and ice load leading to a development of new design procedures valid both for stiff foundation and for more elastic foundations with interaction between the dynamic part of the wind, wave and ice load.

2.7 Conclusion

Many examples have been shown, which proves that experiments have been and still are a vital component in developing improved design practice in hydraulic and marine engineering. It is important every time to think carefully and select a unique model set-up which give the best possible chance to obtain the lacking knowledge. A general reference is given to the brief philosophy written by Mutlu Sumer, see Annex 1.

Good results are only obtained if the man’s mind is working interactive with the experiments and the mathematical modelling. All design practices represent a simplification to the complex physics. It is a challenge to identify if a simple rule is sufficient to form a safe and sufficient precise design basis. It is not necessary large but unique facilities, which is required (example the old U-tube). What is needed is a unique experiment, which may provide the lacking information.

2.8 References


Annex 1

Brief philosophy on experiments written by prof. Mutlu Sumer, MEK, DTU, Denmark:

First of all the methodology we basically adopt in our physical modeling studies (Please do not confuse the latter with the hydraulic scale model studies!) at ISVA/MEK, DTU may be summarized as follows:

- Conduct laboratory experiments, directed towards understanding of the hydraulic/hydrodynamic processes;
- Identify the parameters (normally in non-dimensional form) responsible for these processes;
- Once the “governing” parameters are identified, extend your test matrix so as to cover a reasonable coverage of the ranges of the governing parameters;
- Plot the hydraulic/hydrodynamic quantities from the data as functions of the governing parameters;
- Give physical explanations for the obtained variations;
- There are three By-products of such a physical modeling study:
  - By-Product 1: Plot the data in terms of design/guideline diagrams for the ranges of the governing parameters normally encountered in practice
  - By-Product 2: Set up mathematical models describing the actual physics of the processes that have been disclosed by the physical modeling study;
  - By-Product 3: Validate mathematical models (the one that has been set up as a result of the present study or the existing ones) against the obtained experimental data; and run the mathematical model for ranges of the governing parameters which can not be achieved in small/medium/even large scale experiments in the laboratory.
- Extend the design diagrams so as to cover the ranges achieved by the mathematical modelling

Our physical modeling work at ISVA/MEK has been developed over the years along these lines.