Workshop on Model Testing of Deep Sea Offshore Structures

Session Chair: Prof. E. Huse

I INTRODUCTION

by Erling Huse, MARINTEK

Statement of problem

Until now most offshore structures have been tested on model scale with correct geometric modeling of the ocean depth. For instance gravity base and jacket platforms need to be tested at correct depth to determine wave loads and corresponding responses. It has become customary to determine design tensions in the mooring lines of FPSOs and in the tendons of TLPs from model tests at correctly modeled ocean depth.

In the near future we expect to be dealing with drilling and production systems at ocean depths of 1500 to 2500 m and more. If the structures should still be tested at "traditional" model scales of 1:50 or 1:70 it would require a depth in the wave and current basin of the order of 30 to 50 m. As we all know there is no wave basin of such depth in the world today, and it is very doubful that there will ever be.

For those of us who are acting as consultants to the industry an important question is: How can we determine or verify design loads and responses of the possible future deep sea installations ?

Test methods / strategies

A variety of test methods or strategies for design verification of deep sea structures can be imagined, for instance:

a) Testing models of the complete system in existing basins at very small model scales,

b) Testing models of the complete system in open-air facilities (fjords, lakes, or the open sea) at traditional model scale,

c) Testing complete model of floater but with simplified deep sea parts of the system (risers, mooring lines, tendons)

d) Testing elements of the system in existing basins at traditional model scale, measuring hydrodynamic coefficients, and synthesizing the complete system by computer simulation,

e) Relying entirely on numerical calculations, omitting all model testing.

Item a) would require extensive effort in developing miniaturization techniques for model production and instrumentation, a development which might well be realistic and possible to carry out. However, item a) might mean hydrodynamic scale effects so dramatic that they could not be corrected for sufficiently accurately to make the test results useful.

Item b) may look attractive . However, since we are not in complete control of the environment, the method is not suitable for verification of specific field development projects, where modeling of the site-specific design environment is essential. For more research-oriented projects, like experimental verification of general numerical methods, item b) represents a very interesting method for the future.

A typical example of item c) is to perform tests of turret-moored production ships by modeling the floater at a reasonably large scale, but simplifying the mooring lines or risers to fit the limited depth of the basin. This technique is already being used by several model tanks. If one is lucky this technique may yield reasonably correct motion responses of the floater, but one has to be very careful in interpreting any measured mooring line tensions or riser system performance.

Item d) is a method which we already use quite extensively. A typical example is measuring hydrodynamic coefficients such as drag damping, added mass, and wave drift force coefficients of different elements, and synthesize the complete system consisting of of floater, mooring, risers, etc. by computer simulation. The main drawback of item d), and of course also item e), is that they can at the best describe phenomena that have been included in the numerical model. When doing model tests for design verification of offshore structures, an essential part of the objective is often to detect any unknown or unexpected phenomena or problems with the concept being tested. This aspect is in general lost when using items c) and d).

The phenomenon / test method matrix

For many member organisations it would be useful if some relevant committee of the ITTC could produce recommendations or at least some intelligent considerations regarding which testing techniques are required for measuring different phenomena for different types of offshore structures. A possible starting point might be to define a matrix for each of the main types of offshore structures or systems to be tested. Along one axis the matrix should have the the different test methods a) through e) as outlined above. Along the other axis one should have the different phenomena of interest to be studied for the relevant type of structure. If the type of structure was for instance tension leg platforms, the interesting phenomena might be floater wave frequency and high frequency motion responses, tendon springing loads, airgap requirements, riser interactions, etc. At each cross-point of the matrix should be indicated to what extent the phenomenon can be studied by the method.

Furthermore the ITTC should of course stimulate further improvement of the different test methods, for example development of methods for scale effect corrections for very small models, miniaturisation of instrumentation, etc.

The development of cost-effective solutions for production of hydrocarbons from deep sea reservoirs is indeed a great challenge for the offshore industry at large. The ITTC and its member organisations should take their part of this challenge very seriously. We have an exciting future ahead of us.

II PRESENTATIONS

Model Tests On a Tension Leg Platform Using Truncated Tendons

J.J. Murray* and R.S. Mercier**

* Institute for Marine Dynamics, National Research Council Canada
** Shell E&P Technology Company, Houston, Texas

Introduction

As offshore installations move into deeper water, the associated model tests are confronted with the physical constraints of test facilities. This will require a departure from the traditional methods of testing mainly because of the water depth involved. The choices are basically to compromise in terms of scaling effects and use small models that can fully model the water depth or, in the case of the Tension Leg Platform, to truncate tendons to allow a larger scale model which will presumably reduce errors related to scaling.

Apart from scaling error considerations to be given to small models, the capability of the wave making equipment may be an issue. Low to moderate sea states can be difficult to model because of the high frequencies of the wave components, resulting in disintegration of small waves during propagation. Another consideration is the sensitivity of the data acquisition instrumentation.

Suggestions to deal with the constraints of the facility include: developing scale effect correction techniques for small physical models, conducting model tests in the outdoors using natural environments, or establishing hydrodynamic coefficients that can be injected into computer simulations of the fully integrated system. The preferred technique will depend primarily on the test requirements.

This presentation illustrates the technique of an integrated computer and physical model approach using sample test data from the Ursa TLP tests carried out at IMD. The objective of the test program was to measure high frequency tendon tensions and rigid body motions in moderate to low sea states while using as large a physical model as possible.

TLP Responses in Waves

The response of a TLP to waves can be loosely categorized into three frequency ranges: mean and slow drift frequencies, wave frequencies, and high frequencies. Slow drift frequencies are affected by the resonant conditions of the vessel in surge, sway and yaw while the high frequency responses are related mainly to heave, roll and pitch.

The hydrodynamics that affect the slow drift forces on a TLP are described as viscous forces, wave drift damping and wave drift excitation forces. These are difficult, if not impossible, to separate and quantify and are still a topic of research. Contributions to the tendon tensions from mean and slow drift motion are relatively small in low and moderate sea states. The high frequency responses in the form of motions and tendon tensions are affected by first-order wave components and higher second-order components occurring at sum-frequencies that correspond to resonant conditions. Since these responses occur around resonance they are significant. The physical model tests are normally aimed at providing empirical information to be used in numerical simulations of responses for all frequency ranges.

It is assumed that the low and high frequency responses are lightly coupled and can be treated separately. Therefore model tests simulating the wave and high frequency motions and tendon tensions require that the axial stiffness and the mean inclination of the tendons be correctly modelled. Under this premise it is possible to utilize existing test facilities and minimize scaling effects by using a large model and compromising the water depth.

Model TLP Description

The Ursa TLP has a basic geometry of four vertical circular columns supported by a closed square pontoon. The vessel has a nominal weight of 62,400 long tons and a total nominal displacement 88,900 long tons when at operating draft of 100 ft. The TLP has 16 tendons, four per corner, and a riser system up through the centre of the deck. The TLP hull was modelled at a scale of 1:25 while the tendons and riser were modelled as an equivalent system using two model tendons per corner and a single member to model the riser. The tendons and riser were constructed of steel rods with a spring attached to model the axial stiffness. The prototype vessel is intended to be installed in a water depth of approximately 4000 feet. The model was tested in a depth of approximately 300 feet.

A schematic of the model assembly as tested is shown in Figure 1. The tendon bases were attached to a rotation frame which was oriented at an angle to the direction of wave propagation to account for a particular heading.

The model was instrumented to make the following measurements:

- loads in each tendon
- loads in the riser
- six-degree-of-freedom displacements of the hull
- six-degree-of-freedom accelerations of the hull.

Rationale for Truncated Tendons

The effect of truncating tendons on the resonant response frequencies of the model TLP can be investigated using a quasi-static analysis of the global stiffness matrix. The analytical expressions to construct the restoring stiffness matrix from a system of tendons can be found in a number of sources such as [1] and for the sake of brevity are not repeated here.

Consider the global horizontal restoring stiffness coefficient **R'** on a model TLP. As the tendons are truncated to accommodate the water depth the global restoring stiffness coefficient will increase as illustrated in Figure 2. The restoring coefficients are normalized by the value for the full required length and plotted as a function of the tendon length ratio **(D'/D)**. The solid line in Figure 2 shows that as the tendons are truncated to approximately 10% of their prototype length (full required length), the global stiffness in the horizontal direction increases by a factor of twenty. This solid line assumes a zero-mean offset. The broken line in the figure shows the effect of introducing a nominal non-zero mean offset to the tendon system typical of that expected from a mean drift force. This has a noticeable influence on the global stiffness up to a tendon length ratio of approximately 0.40. The axial stiffness of the tendons is constant in both cases.

Figure 3 shows the offset that the TLP would experience, if subjected to the nominal drift force, as a function of tendon length ratio. The line in this figure is the reciprocal of the solid one shown in Figure 1 and illustrates a linear relationship between the offset and tendon length when a particular force is applied.

Figure 4 shows the ratio of the stiffness coefficient curves in Figure 1 as a function of length ratio. This figure illustrates the error introduced in the horizontal stiffness coefficient (or mean offset) when the TLP is subjected to a particular mean drift force. For example, at a length ratio of about 0.20, when the model moves to a non-zero mean position in responding to the mean drift force the offset is about 95% of that which the model would achieve if the full length tendons were used. More importantly, a 5% error in the mean offset results in an error of less than 0.1% in the heave and pitch stiffness for this length ratio. These errors can be tolerated in the vast majority of model tests. The influence of this error will be further reduced when the hydrostatic restoring force of the TLP is included. The result is that the resonant frequencies as well as hydrodynamic damping are maintained in the high frequency responses even when truncated tendons are used.

Sample Test Results

Data analysis included constructing a computer model of the physical test setup and cross-validating the measured and predicted slow-drift and wave frequency responses. In the high frequency range (periods shorter than 5 seconds) the computer model was known to be deficient since it did not include any nonlinear diffraction effects. Some of the discrepancy between the measured and computed high frequency responses was attributed to these nonlinear diffraction effects and were incorporated in the final design..

Samples from the test results are compared to the predicted value in Figure 5, 6 and 7. The predicted values are compared up to a frequency of 0.2 in all cases. Figure 5 compares the predicted and measured responses at one of the tendons. The figure shows excellent agreement between the measured and predicted values for the frequency range compared. The resonance peaks shown above the wave frequency range include the heave and pitch components. Similar comparisons with comparable agreement between the predicted and measured values are shown in Figures 6 and 7 for pitch and heave, respectively.

Conclusions and Recommendations

The use of physical model test facilities as design aids in the development of deepwater offshore installations are being constrained by the physical size of the facilities. Capital costs will limit the size of the deep pits in test facilities as the full scale water depths increase. The model test technique presented here illustrates the validity of truncating tendons when investigating the wave and high frequency responses.

Research efforts should continue to seek means of integrating computer simulation and model testing techniques in design. Model tests should be specifically designed to provide empirical information that cannot be obtained from computations. Today's challenge for the model tester is to develop techniques to define the system in separate components that need to be tested, and to incorporate external information to control these tests. Examples are: application of dynamic wind loads determined from wind tunnel tests, and modelling of equivalent deep water mooring systems in facilities of limited depths.

References

[1] Patel, M.H., "Dynamics of Offshore Structures", Butterworths, 1989.

Nomenclature

D' - model water depth
D - prototype water depth
R' - model restoring stiffness in surge
R - prototype restoring stiffness in surge

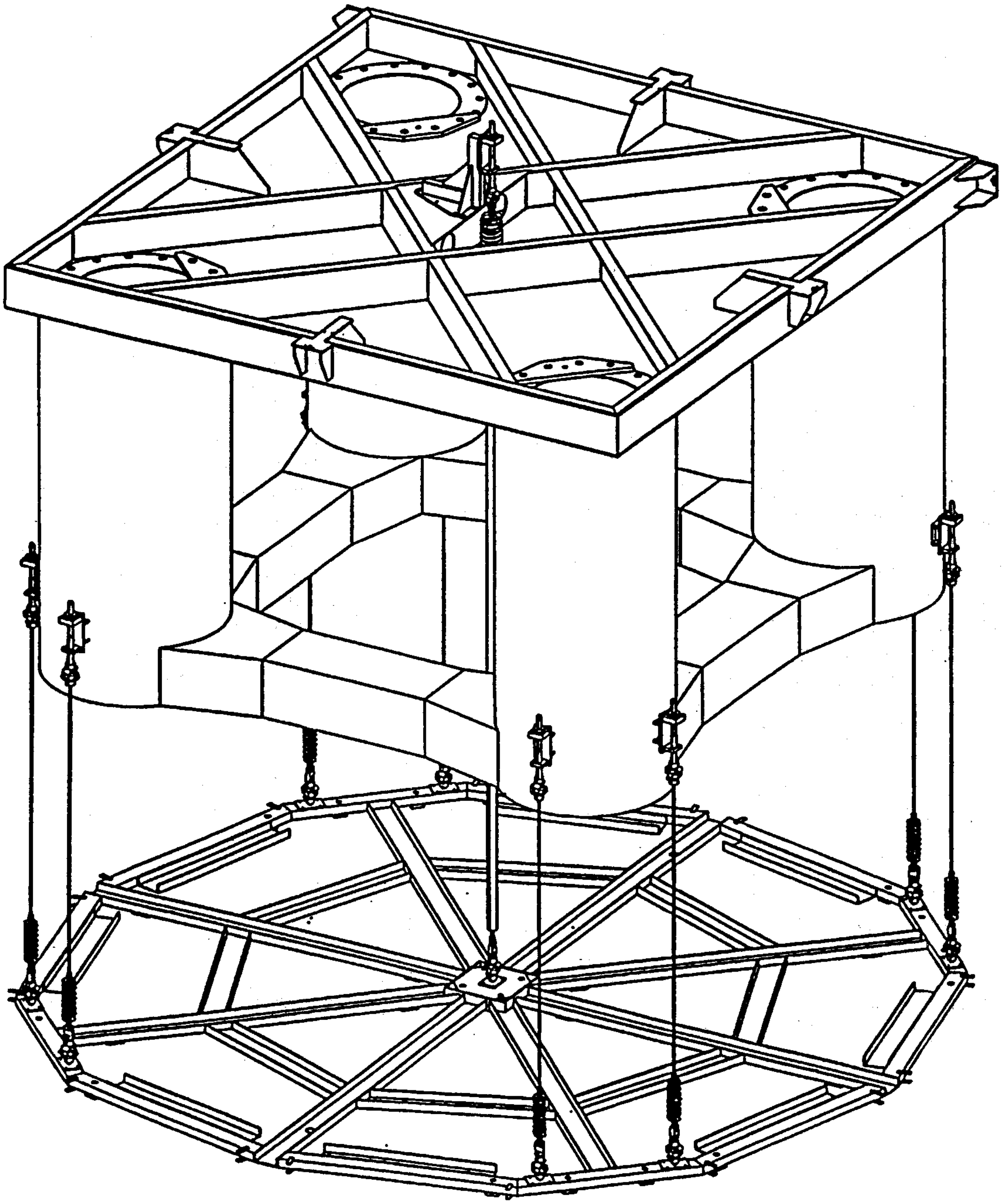


Figure 1 - Schematic of TLP Model

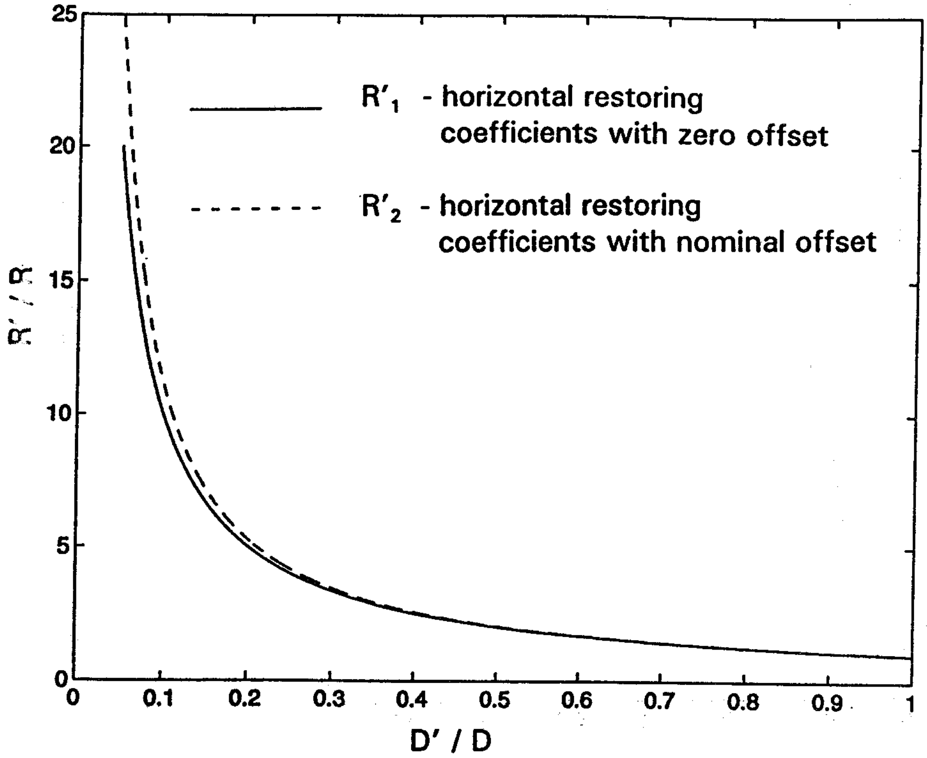


Figure 2. Horizontal Restoring Stiffness

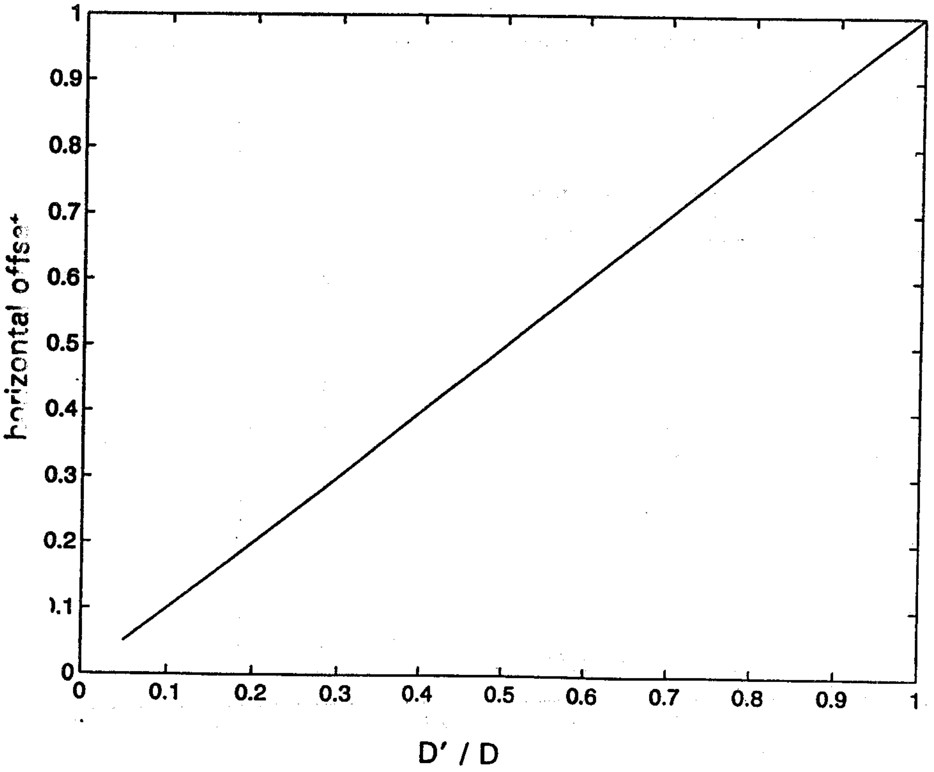


Figure 3. Horizontal Offset for Mean Drift Force

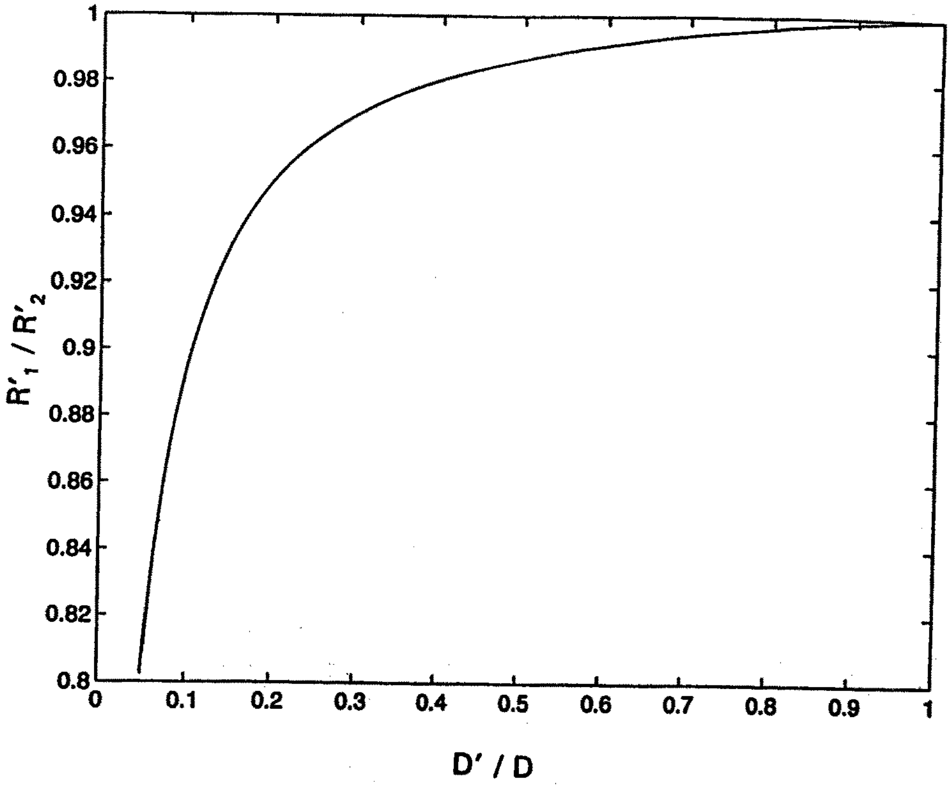


Figure 4. Offset Error

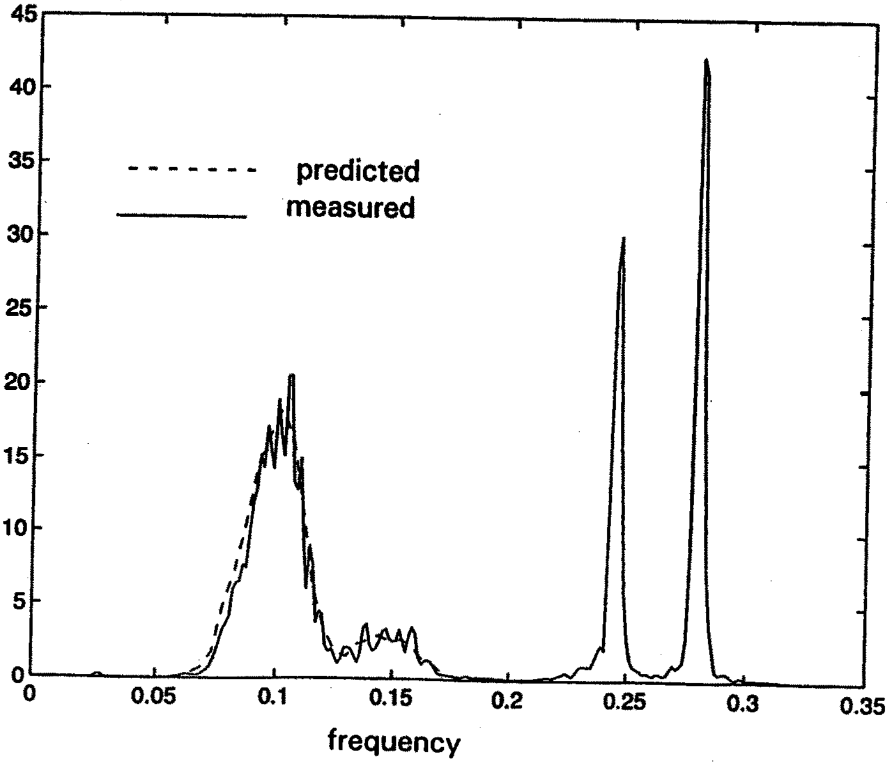


Figure 5. Tendon Tension Response Spectra

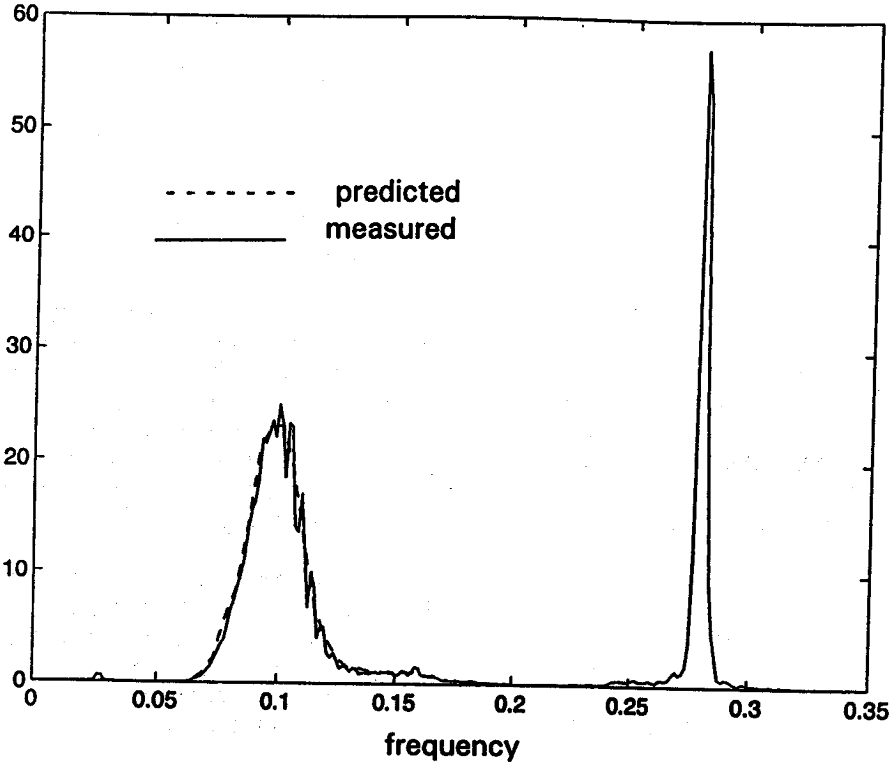


Figure 6. Pitch Response Spectra

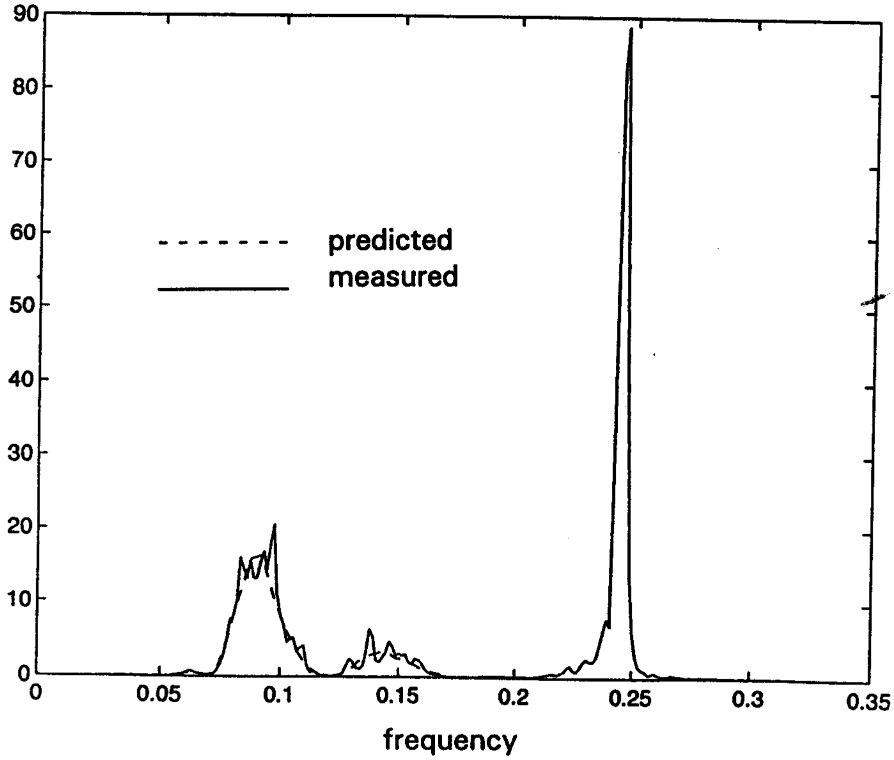


Figure 7. Heave Response Spectra

Dynamics of a hanging riser as CWP for OTEC

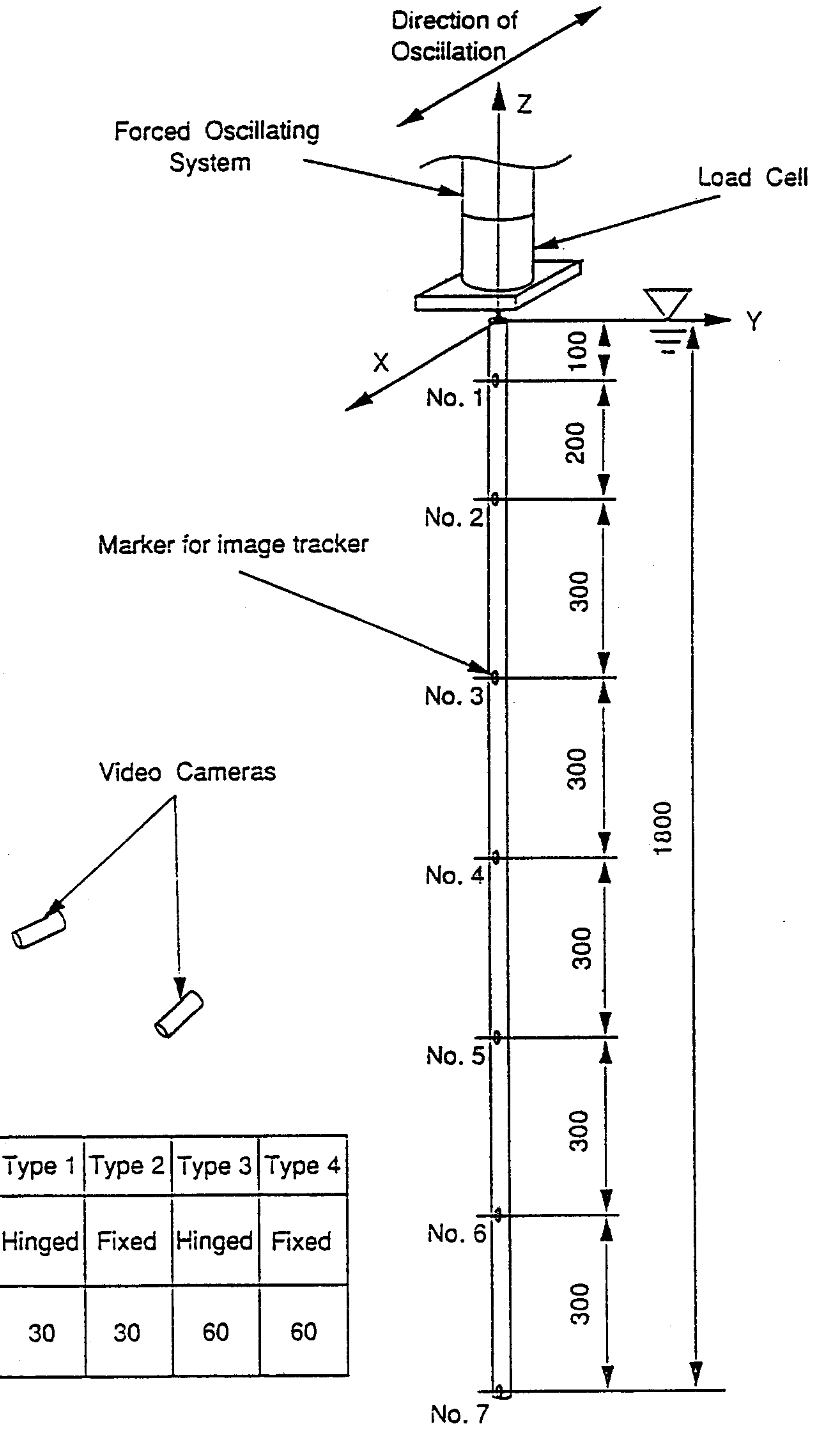
by Hisaaki Maeda,
IIS, University of Tokyo

The dynamic behaviour of a hanging riser in a model tank test is described. The actual hanging riser was used as CWP (Cold Water Pipe) for OTEC (Ocean Thermal Energy Conversion). The diameter of the actual pipe is 45 cm and 7 mm thick steel pipe. The length of CWP is 350 m. The CWP was hung down from a moored floating platform on which OTEC plant was installed. When a typhoon passed over the site in summer, the top part of the CWP was broken. And later during a certain severe sea condition in winter, one third part from the bottom of the CWP was broken and lost. We investigated the reason of the accident and we concluded that the reason was the fatigue of the steel pipe in salt water environment after executing simple calculation of the CWP dynamics in vertical 2D plane.

Several years later, we carried out the corresponding experiment of a har [illegible] which is made of synthetic rubber. [illegible] of the riser is 2 m and the diamete [illegible] 6 cm. We did the forced osci [illegible] which the top of the CWP is forced [illegible] harmonically in in-line direction. We ob [illegible] very interesting phenomena. The Reyno [illegible] number was 5000 and 10.000, and KC (Keulegan-Carpenter) number at the top of the CWP varies from 4 to 18. (See Fig. 1).

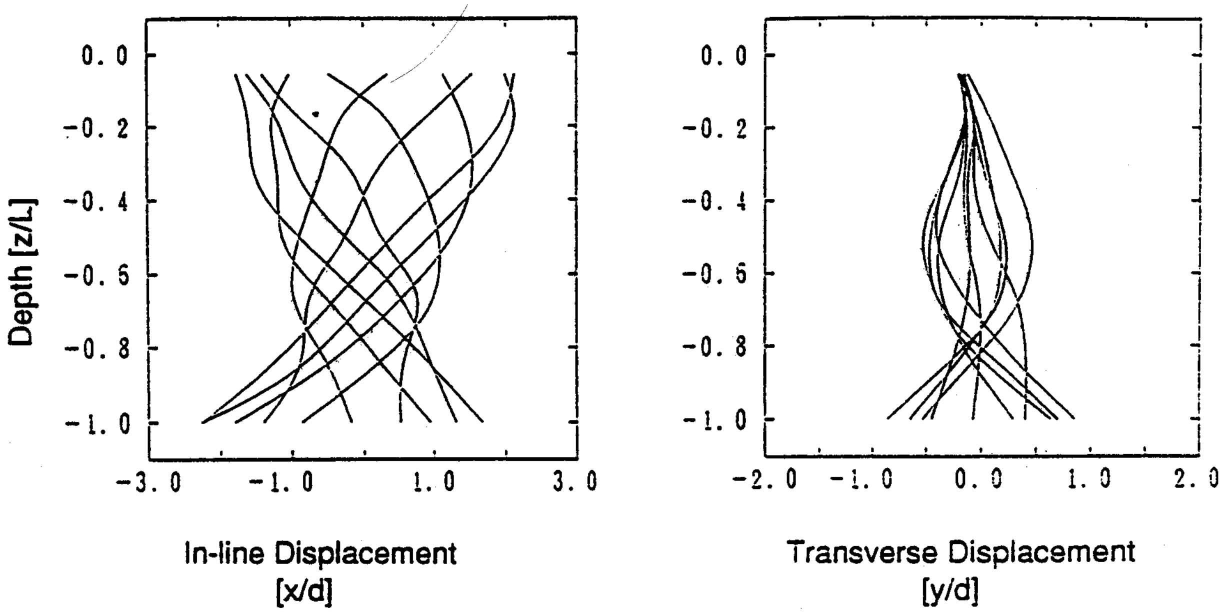
Figure 2 shows the vertical configuration of the CWP in in-line plane, and the one in transverse plane. Figure 3 shows the trajectory of the bottom end of the hanging riser CWP. We can see that the behaviour of the CWP is usually 3-D moving, not only in in-line plane, but also in transverse plane. In some cases it behaves chaotically.

We did the corresponding calculation in which CFD and flexible riser dynamics ar combined and only laminar flow is consi [illegible] The agreement with the experimental [illegible] not so good. The numeric [illegible] code is still under development.

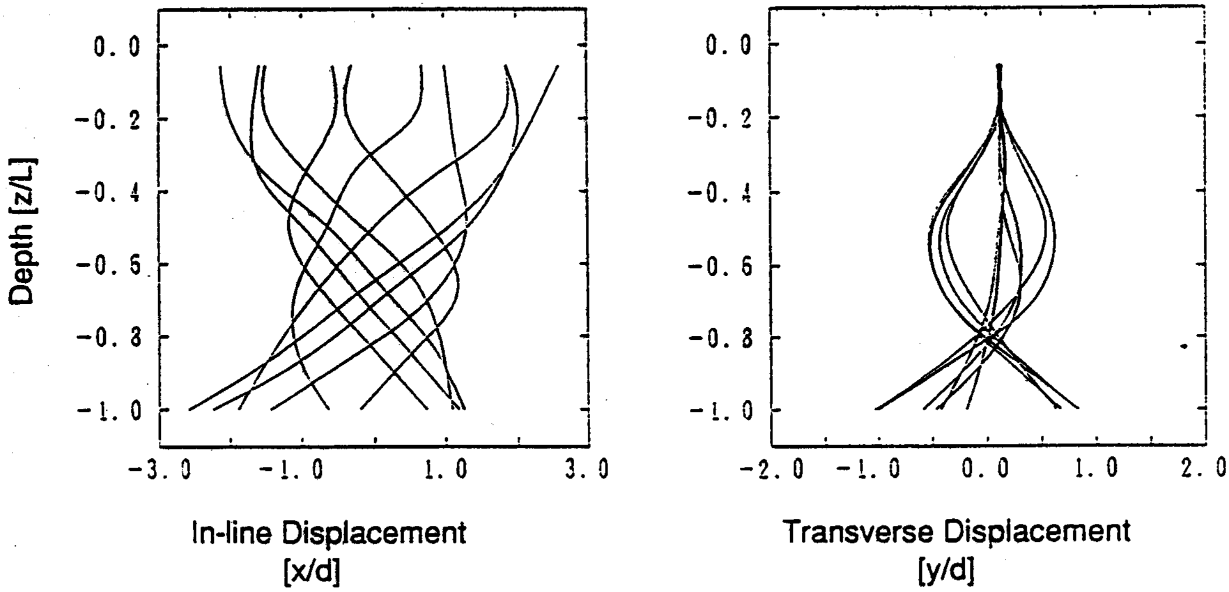


	Type 1	Type 2	Type 3	Type 4
Upper Joint	Hinged	Fixed	Hinged	Fixed
Diameter [mm]	30	30	60	60

Fig. 1 Modelling of line structure

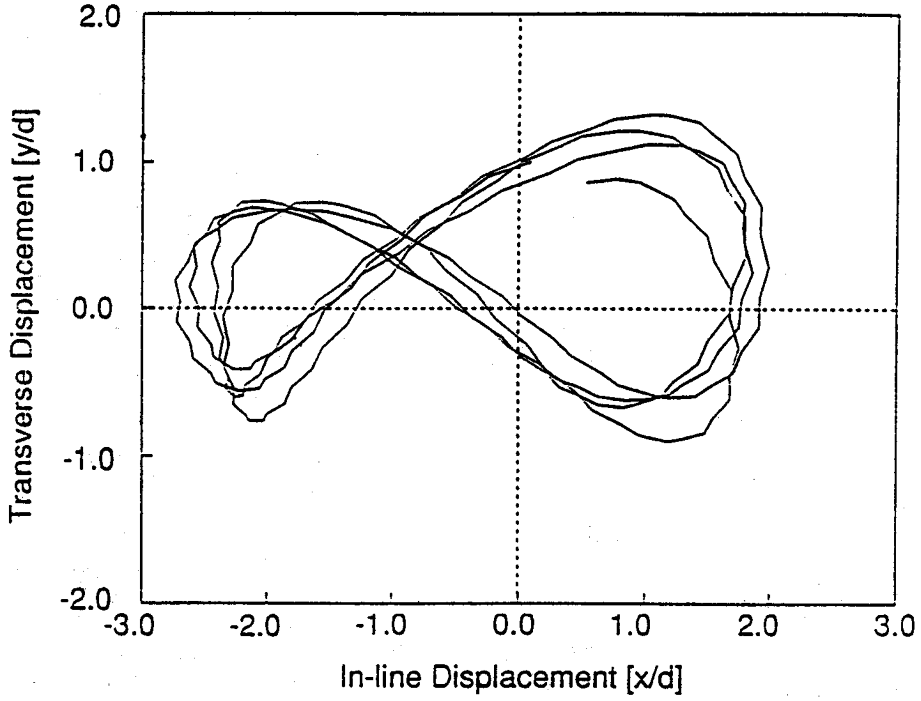


Type 1 (d=30[mm], Hinged)

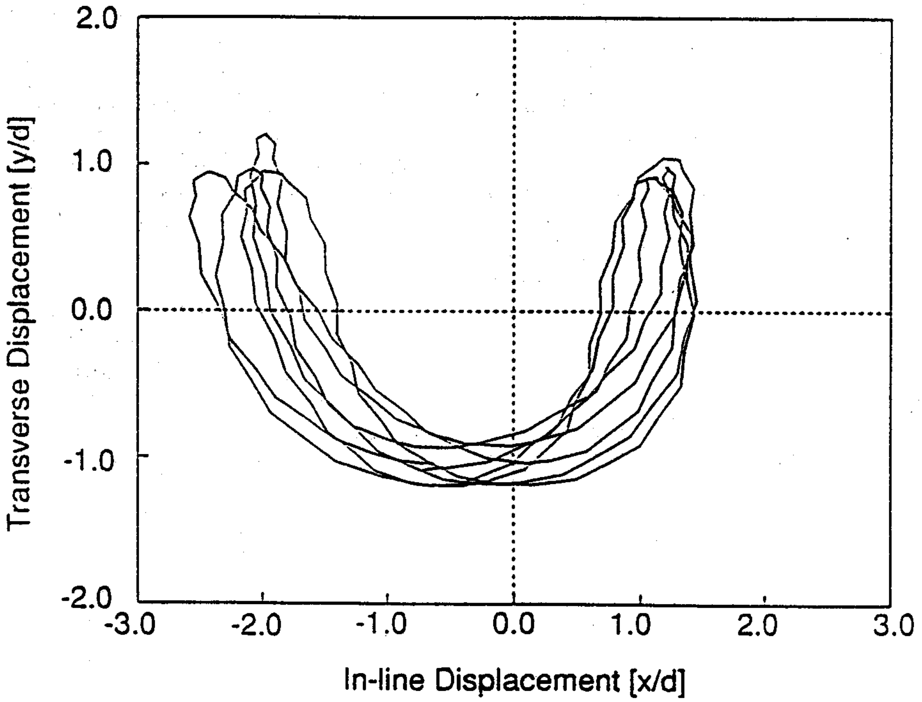


Type 2 (d=30[mm], Fixed)

Fig. 2 Configuration of Flexible Cylinder Deflection (Experiment)
Re = 5000
Kc = 14



Type 1 (d=30[mm], Hinged)



Type 2 (d=30[mm], Fixed)

Fig. 3 Configuration of bottom end (Experiment)
Re = 5000
Kc = 14

Model testing in waves, wind and current at large water depths

by Dr. M.W.C. Oosterveld/Dr. J.E.W. Wichers-MARIN

Introduction

During the last decade floating production systems have been applied in increasing water depths. Passive moored semi-submersible based production systems were already applied for several years in deep water with more moderate sea conditions (Offshore Brazil), while TLP structures were applied in more harsh environments like the Gulf of Mexico and the North Sea.

Nowadays not only semi-submersibles and TLP structures but also tanker based floating production storage offloading systems (FPSOs) are applied in deep water. These deep water oil and gas fields are under development in for instance typhoon-prone areas in Asia and Australia and in the harsh environment of the Northern North Sea.

The external loading on these large monohulls may induce large motions introducing large loads in the mooring system. Besides the mooring legs, also the underwater system consisting of risers, control lines and umbilicals will suffer under the action of waves, current and floater motions.

In order to carry out research on these important items, the need for deep water test facilities simulating (multi-directional) waves and generating current over the full depth is inevitable.

Test facility

Model testing of deep sea floating offshore structures is normally carried out at a scale factor of 1:85 or smaller. In order to study the total response of floating offshore structures MARIN will build new facilities, a Seakeeping Basin and an Offshore Basin. The Offshore Basin will measure 40*40 m with a maximum water depth of 10.5 m. The water depth is adjustable by means of a movable floor. Current can be simulated over the full depth, while different vertical current profiles can be adjusted. On the two sides of the basin multi-directional wave generators will be installed, having flapwidths of .4 m and which are able to generate significant wave heights up to .3 m.

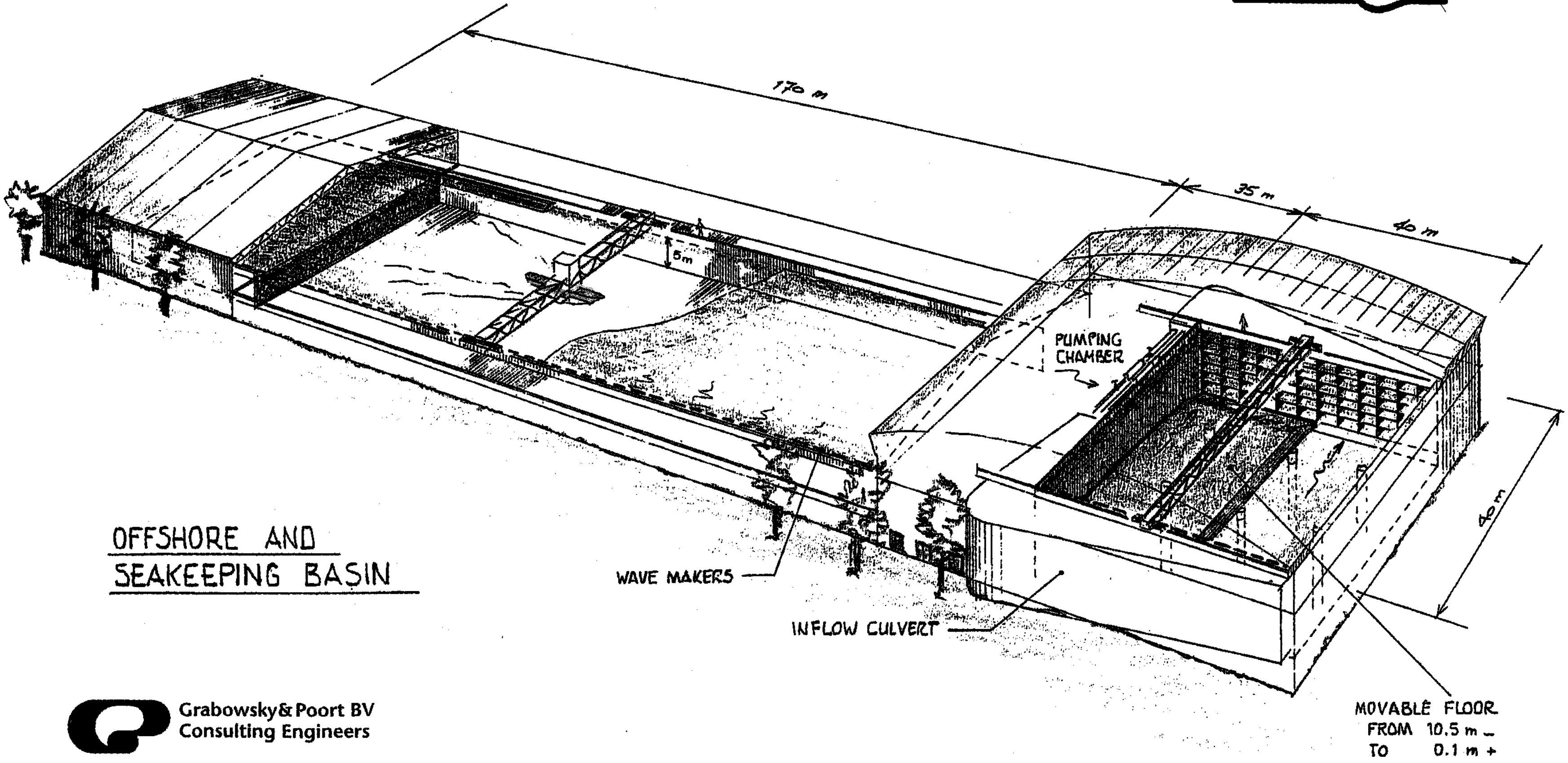
By means of this basin the maximum water depth will be nearly 900 meters for full scale.

Ocean depth exceeding 1000 m

For water depths larger than 1000 m a synthesis of model tests and computations will be necessary. As an example we consider a FPSO system in 2000 m of water depth. The first step may be the testing of the complete system designed for a water depth of approximately 900 m. The second step may be computations by using for instance the by MARIN developed computer program DYNFLOAT. By means of this computer program the computed results of the tanker motions, mooring legs, risers system etc. can be tuned using the measured results (including effect of vortex shedding). After this step the system may be finally designed for the 2000 m water depth by means of computer simulations. During this procedure scale effects can also be investigated.

In a last step the final mooring system may be simulated (same load-deflection curve in the horizontal plane) in the same basin in order to study green water, slamming and offloading operations.

MARIN



OFFSHORE AND
SEAKEEPING BASIN

Grabowsky & Poort BV
Consulting Engineers