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Mathematical Modelling of Offshore Structures

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1 INTRODUCTION

In coastal engineering and offshore industry use is often made of moored barges and vessels. In order to design the system taking into account both strength and workability aspects, the motions and mooring forces have to be known when the system is exposed to a wave, wind and current environment. Dependent on the mooring lay-out but independent of the question whether the mooring system has either linear or non-linear characteristics, three types of mooring can be distinguished, viz.:

1. Stiff moored structures (for instance, spud pole-moored dredges)
2. Soft multi-point moored structures (jetty-moored vessels, spread moored vessels)
3. Soft single-point moored structures (SPM-moored vessels)

In calculating the behaviour of the structure and the mooring forces in operational and storm conditions and following the abovementioned sequence of mooring types, the corresponding mathematical models will be more and more complicated.

The complications are a consequence of the nature of the motions, viz.:

1. Stiff moored: high (= wave) frequency motions only
2. Soft multi-point moored: combined high frequency motions and relatively small amplitude low frequency motions
3. Soft single point moored: combined high frequency motions and relatively large amplitude low frequency motions

For each of the models the hydrodynamic and aerodynamic input data will be of prime importance. By using the flow diagram in Figure 1 as a lead a step-wise build-up of the abovementioned mathematical models will be presented.

2 STIFF MOORED STRUCTURE

2.1 High Frequency

For a stiff moored structure the natural frequencies are in the range of the wave frequencies and 3-dimensional linear wave diffraction theory can be applied to compute the hydrodynamic input data for the equations of motion. (Van Oortmerssen, 1976).

2.2 Cutter Suction Dredger

An example of a stiff system is a spud-moored cutter suction dredger as is shown in Figure 2. Having defined the mathematical description the solution shows high forces in the spud-pole as is presented in Figure 3. (Wichers and Van Drimmelen, 1983). In order to reduce the loads in the spud the mathematical model can be easily modified for alternative spud-moorings.
An alternative system can be applied by using the spud-pole active in sway/yaw/roll direction, but non-active in surge/pitch direction (uncoupled) and adding an auxiliary construction provided with a spring/damper system as is shown in Figure 2. The resulting mooring forces and cutter head motions are shown in Figure 3.

3 SOFT MOORED STRUCTURES

3.1 High and Low Frequency Motions

For multi-point and single-point moored vessels the natural frequencies of the motions of the vessel in the horizontal plane are far below the wave frequency range.
For such systems not the first order wave forces but the second order wave drift forces will dominate the motion behaviour (Pinkster, 1980).
The motion response will be dominated by the low resonance frequencies. At the resonance frequency the motion amplitudes will mainly be determined by the excitation force and the damping force.

3.2 Hydrodynamic Damping Forces

At low frequencies of motion the hydrodynamic damping can be split-up in a potential wave drift damping and in a damping caused by the low frequency viscous fluid reaction.

3.2.1 Wave drift damping

The potential wave drift damping is caused by the oscillating low frequency motion of the vessel in the wave field and is interpreted as the derivative of the wave drift forces to the low frequency velocity.
Applying the quadratic transfer function of the wave drift damping to the irregular waves the resulting damping can give a dominant contribution to the total damping (Wichers, 1986).

3.2.2 Viscous damping

Due to the low frequency motions of the vessel in the horizontal plane viscous fluid resistance will be encountered by the vessel. The low frequency (viscous) fluid reaction forces may be described by non-linear equations of motion. For the determination of the viscous fluid reactive forces planar-motion-mechanism-type experiments have been carried out (Wichers, 1986).

4 MULTI-POINT AND SINGLE-POINT MOORING

4.1 Multi-Point Mooring

For a (non-linear) spread moored 200 kTDW tanker a mathematical model in the frequency domain has been developed to determine by approximation the most probable maximum displacement of the coupled low frequency small amplitude motions in the horizontal plane, while the effect of the high frequency motions on the mooring forces will be treated separately as is indicated in Figure 4.

4.2 Single-Point Mooring

In wind and current only a tanker moored by means of a bow hawser can perform large amplitude low frequency motions in the horizontal plane as is presented in Figure 5.
Due to the large amplitudes the motions and mooring forces are strongly dominated by non-linearities in both aerodynamics, hydrodynamics and mooring system. Moreover, large variations in heading strongly affect the wave loading on the vessel. The complete description of the mathematical model in terms of all aspects involved is presented.

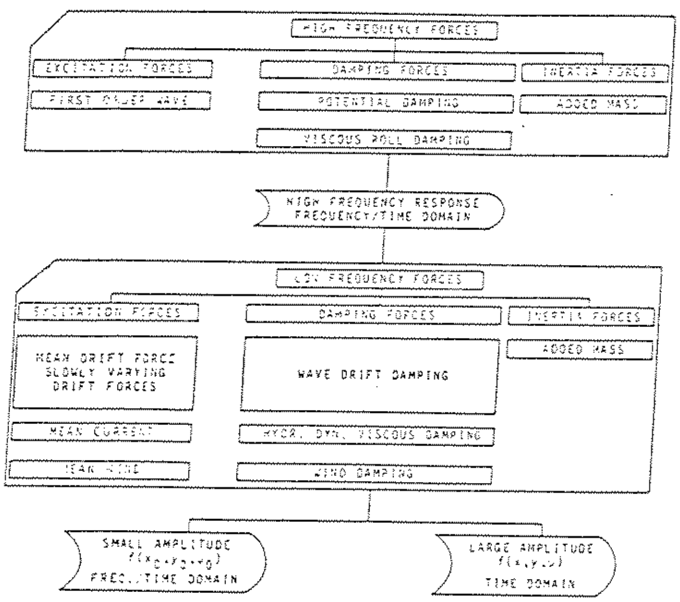

Fig. 1 Hydrodynamic and aerodynamic input for simulation programs

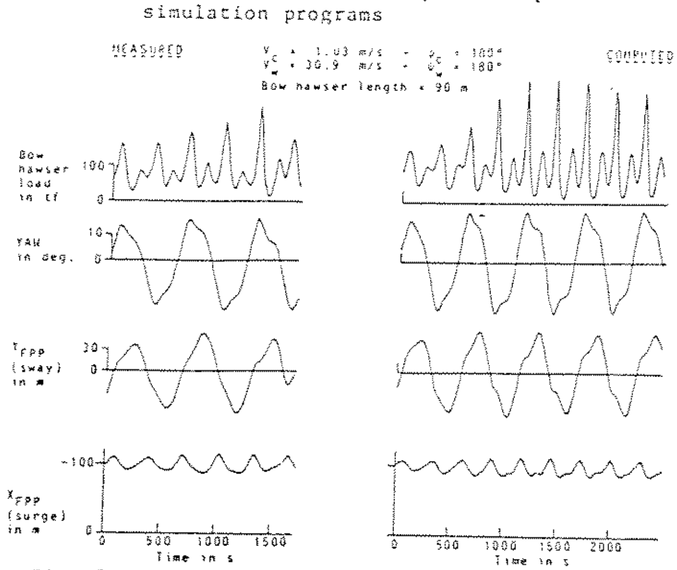

Fig. 5 Measured and computed unstable behaviour of the ballasted 200 kTDW tanker moored by means of a non-linear bow hawser

5 CONCLUSIONS

Dependent on the type of mooring distinction can be made in the mathematical model to be applied. By means of mathematical models alternative mooring systems can be easily evaluated. For systems with a dominant low frequency motion much attention has to be paid to the low frequency damping.

6 REFERENCES

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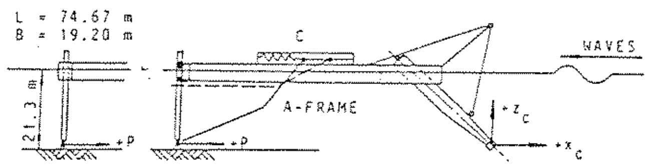

Fig. 2 Cutter suction dredger with conventional and alternative spud-mooring

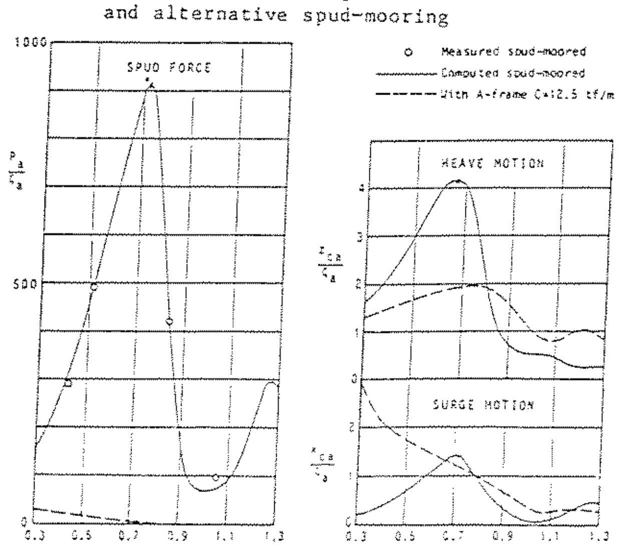

Fig. 3 Response function of spud forces and cutter head motions in head waves

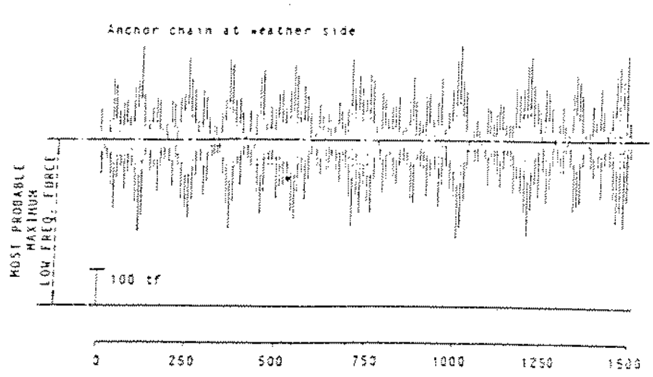

Fig. 4 Approximation of maximum low and high frequency anchor chain forces of a spread-moored 200 kTDW tanker in beam waves