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ON THE SCALE AND ELASTICITY EFFECTS IN DYNAMIC ANALYSIS OF MOORING LINES

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ABSTRACT

Due to the complexity of hydrodynamics aspects of offshore structures behaviour, experimental tests are practically compulsory in order to be able to properly evaluate and then to validate their behaviour in real sea. Moreover, the necessity to carry out hydrodynamic tests is often required by customers, classification societies and other regulatory bodies. Consequently, the correct simulation of physical properties of the complex scaled models becomes a very important issue which, sometime, is not correctly understood and applied. The present paper is trying to evaluate such kinds of problems which could arise based on some systematic tests on the dynamic behaviour of a mooring chain reproduced at five different scales. Dynamic effects as well as the influences of the elasticity simulation for 5 different scales are evaluated together. It is pointed out the necessity to pay a deeper attention to the simulation of the elasticity of coupling elements in order to ensure an acceptable level of accuracy of the experimental results. It is concluded that a much deeper investigation has to be performed.

Keywords: mooring line dynamics, experimental test, elasticity modelling, scale effects.

1. INTRODUCTION

The approximation of the forces in the mooring lines by using the static characteristic is, generally, valid when the behaviour of the floating structure in waves is close to the static case (low level of accelerations). This condition assumes that the natural periods of motions of the floating body are far from those of the predominant exciting waves on a specific location where it is going to operate. This condition is difficult to be practically reached and the results of the dynamic approach have to be considered during the design process. A variety of station keeping solutions able to fulfil operational requirements are now available. However, the ability to provide an acceptable operational capability in high sea, i.e. to have a reasonable "dynamicity" in order to fulfil the required comfort indexes and to ensure the structural integrity becomes a real challenge and requires a deeper investigation of the influences which can affect the accuracy of the results.

Moreover, the need for exploitation of larger oil and natural gas resources led to increasingly higher depths in open sea and ocean. Consequently, due to the harsh operating conditions in a wide range of wave heights and frequencies, simplified models and quasi-static analyses cannot be anymore applied.

The necessity for adapting the constructive solutions and the station keeping concepts to the location characteristics has generated a diversity of constructive solutions, and a general theoretical model applicable to all cases and physical solutions do not practically exists. The evaluation of the dynamic loads that occur in the mooring elements requires specific theoretical approaches, but, most of all, systematic experimental investigations for the large diversity of case studies as well as for the validation of mathematical models and computer codes.

The influences of various parameters such as amplitudes and frequencies of the oscillations induced by the motions of the structure, water depth, pretension, mass per linear meter and elastic properties of the mooring lines (chains, ropes, cables or combined) on the dynamic forces which could appear at the fairlead or anchors were revealed by systematic experimental research studies [1], [3], [9], [11].

Important influences due to the execution of the scaled models of the chains were found, a methodical approach of this issue being required in order to establish an adequate methodology for obtaining the full scale results and for being able to evaluate the errors of the method. That is why the consideration of the hydroelastic models became compulsory and in addition to Froude similitude, the Cauchy similitude is also necessary to be taken into account [2], [6], [10].

2. EXPERIMENTAL STUDY OF MOORING LINE DYNAMICS

2.1. Experimental parameters

Defining the experimental parameters is related to identifying the elements that influence the static and dynamic behaviour of the mooring line. Previous research [3], [4] and several studies presented in the literature [9], [11] which have underlined the limitations imposed by the available experimental facilities which impose restrictive modelling conditions by their size, especially by water depth and wave generation capacity (frequencies and amplitudes) were the basis for the present analysis. For very deep water cases, the so called hybrid experimental tests have to be taken into consideration and special techniques have been developed [7].

Based on the already existing data, five experimental scales were chosen in order to analyze their influence on the dynamic effect in the mooring line.

The basic chain, chosen as a prototype, has ϕ = 100 mm calibre and an air mass per linear meter of 219 kg/m. The water depth at full scale was considered of 52.5 m, representing the depth at which the SBM (Single Buoy Mooring) system was located in the Black Sea.

For these data, considered as input data, the Froude similarity law was used in order to extrapolate the results at full scale, considering that the predominant nature of the forces is a gravitational one. The characteristics of the obtained chain models are presented in Table 1.

Table 1. Main properties of chain models

Scale λ	Weight per linear meter				Diameter of chain wire, q [mm]	Water depth, h [m]
	Mass in air (calculation) [kg/m]	Scaled model [kg/m]	[%]	In water [kg/m]		
52.50	q_1=0.079	0.0785	-0.6	0.071	1.9	h_1 = 1.00
45.00	q_2=0.108	0.1050	-2.8	0.097	2.2	h_2 = 1.17
35.00	q_3=0.178	0.1740	-2.9	0.160	2.9	h_3 = 1.50
26.25	q_4=0.318	0.3090	-2.3	0.283	3.8	h_4 = 2.00
17.50	q_5=0.715	0.7120	-0.4	0.641	5.7	h_5 = 3.00

For the generation of a systematic experimental program [1], [4], the following parameters were considered:

a. Water depth;
b. Chain calibre;
c. Chain pretension;
d. Amplitude of the chain's free end oscillation;
e. Frequency of the chain's free end excitation;
f. Modelling scale.

The modelling scale does not appear as an explicit parameter in the analysis of the dynamic behaviour of the mooring line but is of great interest in the assessment of the correctness of its effects on the accuracy for a proper estimation of the obtained response values.

2.2. Experimental arrangement

The main elements of the experimental arrangement shown in Photo 1 are the mechanical oscillator which imposes a pure sinusoidal motion at the upper end (fairlead) of the chain, the pantograph type mechanism used to measure the amplitude of the imposed motion and the five chain models. The two component dynamometers used for measuring the forces in the mooring line are shown in Photo 2.

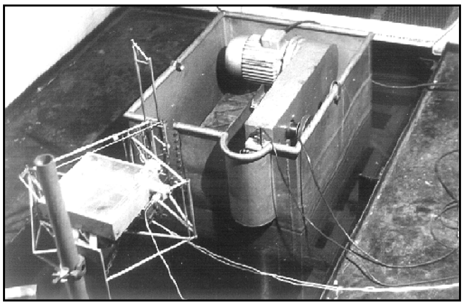

Photo1. General arrangement of the experimental tests

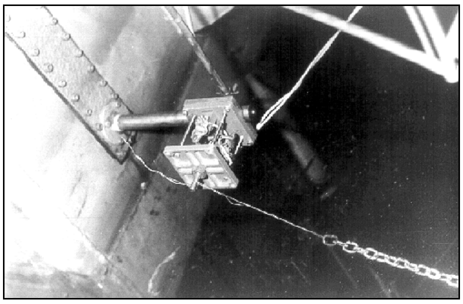

Photo 2. The two-component dynamometer

3. EXPERIMENTAL RESULTS

The influences of the differences between the model and the full scale elongation constant could be considered minor for the type of the performed tests (slack mooring), but could become very important for taut or higher depth mooring conditions.

Figure 1 summarizes the results of the experimental pull tests for the five models of the chain. Δl [mm] is the experimentally measured elongation, ε_r is the relative elongation, F_{tm} [Kgf] is the pulling forces at model scales, F_{tN} [tf] is the full scale pulling force and L_r [m] the reference length.

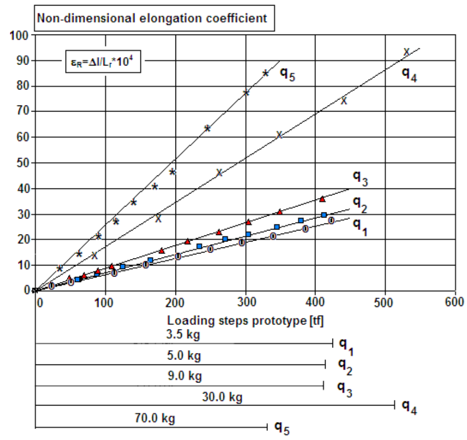

Fig.1. Results of pull tests for scaled chains

The results practically confirm a well known thing that the rigidity of the scaled model chain is higher with the increasing the value of the modelling scale, for the same value of the full scale pulling force, F_{tN}, which, in other words, means that the same material can't be used for the construction of the model and the prototype.

On the other hand, the achievement of the similarity between model and full scale has to be based on the elongation equivalence. This requires similar elongation constants between the model and the prototype [2]. The values of these model scale elongation constants, calculated based on the experimental tests results are presented in Table 2.

Table 2. Values of the elongation constants at model and full scale

Chain type	Prototype geometry Fig. 3 (a)	Model geometry Fig. 3 (b)	Model q_1	Model q_2	Model q_3	Model q_4	Model q_5	Prototype average values
Elastic constant (model), 10^6[cm/daN]	-	-	396.82	343.32	279.51	192.40	126.60	-
Elastic constant (prototype), 10^6[cm/daN]	8.152	7.483	7.568	7.629	7.986	7.330	7.401	7.584

It can be seen that the elongation constant decreases with increasing the calibre of the chain. Extrapolating these values to the prototype will allow the possibility to understand the modelling errors which could be introduced in the system with respect to the prototype values. The results are shown in Figure 2 and also in Table 2.

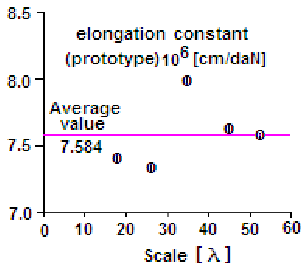

Fig.2. Elongation constants (full scale values)

The determination of the full scale elongation constant for the considered open studless chain (Fig. 3) is based on the following relation:

$$C_N = \frac{64}{\pi E} \cdot \frac{R^2\left(\frac{\pi}{2}R + l\right)}{d^4}$$

in which:

E – the modulus of elasticity with the value of $2.1 \cdot 10^6$ daN/cm^2;

d – the chain calibre [cm];

R – the curvature radius of the link [cm];

l – the length of the straight segment of the link [cm].

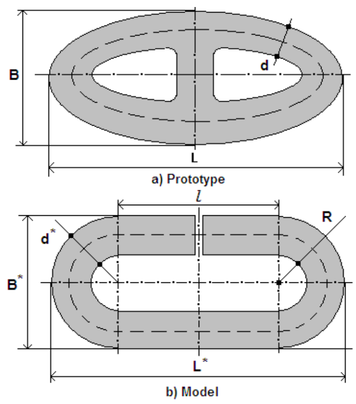

Fig.3. Chain geometry for prototype (a) and model (b)

The value of the elongation constant for the stud chain (prototype), see Fig. 3, was obtained based on the Finite Element Method. Both results as well as the average extrapolated values are outlined in Table 2.

Analyzing the results, summarized in Table 2, it can be concluded that a good correlation between model and prototype is enssured, with regard to the elasticity of the mooring line, by using open studless chains for experiment, which are compensating part of the elasticity of the prototype as compared to the model. The study of the model scale influence was an important element for the experimental research. The obtained results, summarized in Fig. 4 to Fig. 6, provide at least a qualitative indication about the limits of applicability of the experimental procedures. Mention should be made that, during the experiments, only the average value of the elongation constant has been used (see Figure 2) by means of an elastic wire shown in Photo 2.

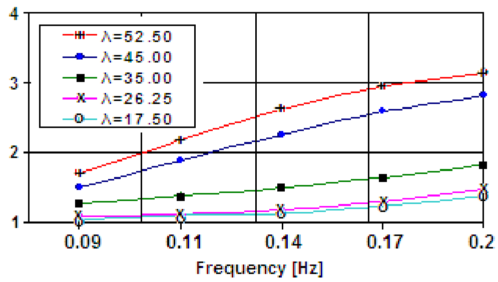

Fig.4. Influence of the model scale for a pretension of TN1=27.3 tf

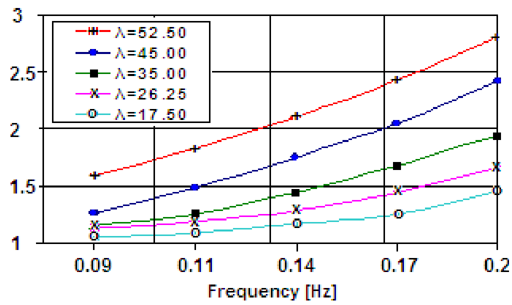

Fig.5. Influence of the model scale for a pretension of TN1=36.45 tf

The above mentioned observation is related to a possible "contribution" to the mooring line dynamics due to the lack of adequate simulation of the elongation constant for each chain used during experiments.

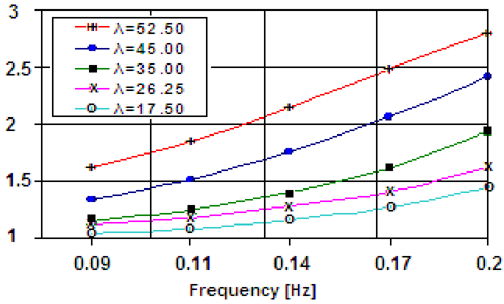

Fig.6. Influence of the model scale for a pretension of TN1=43.37 tf

It can be seen that for lower values of the pretension the dynamic effects are higher but it is difficult to correctly evaluate how much the above mentioned contribution is. The elasticity simulation becomes even more important if cables and synthetic ropes are considered. Just as an example, Figure 7 shows the large displacement values of the upper end of a 600 m synthetic rope in a water depth of 4 m for a range of forces (load - excursion curve) when the elasticity is also taken into account.

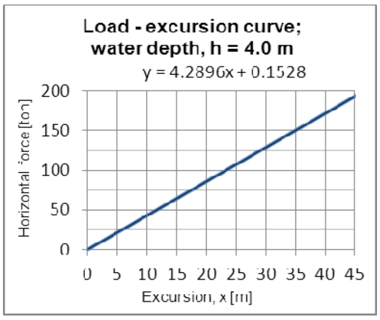

Fig.7. Typical load – excursion curve for a synthetic rope

The main limitation is the depth of the basin which practically requires the modelling scale of the experiment, i.e. the ratio between the full scale water depth and the real water depth of the facility [7] . It has to be noticed that the study on too small models can lead to overestimations of the dynamic effects in the mooring line. These results allow for an adequate assessment of the experimental model scale avoiding experiments with significant scale effects. However, a final conclusion can only be based on a full scale validation of the experimental results [8], [9].

4. CONCLUDING REMARKS

It is important to underline that the present paper is practically referring to only one aspect related to the influence of the elasticity of the mooring lines using scaled models. These partial results are part of a large research program dedicated to a systematic evaluation of mooring line dynamics taking into account the influences of different parameters.

Special care has to be paid when experimental tests have to be performed, the hydroelastic similitude being compulsory in order to reach valuable and accurate results. The dynamic effects are significantly increased when large modelling scales are used and the scale effects can't be evaluated in order to obtain reliable results for design purposes.

Overall, the practical utility of the complete results is related to the possibility to be used in the preliminary design stage when the main characteristics of the floating structure are known in connection with the characteristics of the location consisting of water depth, seabed, wind, sea current and waves. When the station keeping principle is defined, adequate theoretical and experimental investigations have to be performed.

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