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Study on Model Scale Rounded-Shape FPSO's Mooring Lines

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ABSTRACT

This paper is proposed to discuss the model scale mooring line selection process and preparation for hydrodynamic model experiment. The model scale mooring line should be proper select for model experiment and the error should be minimized because the error in model scale mooring line will be enlarged by the scale factor and influence the design in full scale model. In this study, tensile test experiment for model scale wire ropes was conducted to collect the material properties data of the wire ropes. The data collected from the tensile test is applied to obtain the stiffness of mooring lines in the model scale. To achieve the target to select the model scale mooring lines, the minimum breaking load of the wire ropes and the elongation curve of the wire ropes are collected from tensile test for each wire rope sample. By applying catenary theory and the data from tensile test, the stiffness curve of the mooring line in model scale was estimated. The Difference between the stiffness curve between model scale and full scale is within acceptable at the required experiment range.

KEY WORDS: *Tensile Test, Wire Rope, Mooring Line, Catenary Mooring System, Model Experiment.*

1.0 INTRODUCTION

In recent development, Liquefied Natural Gas, LNG becomes an important energy source for human and the demand to the LNG is increasing from year to year.The development of offshore structure suitable for LNG exploration is very challenging and it required complexity analysis and high accurate result in design. To ensure the offloading process which involved multiple floating structures arrangement in small air gap can be safe when the FLNG is operated in open sea, the mooring system for the FLNG must be designed not only able to withstand in rough sea condition also must be able to provide enough restoring force to the FLNG when the shutter tanker come close to the structures.

To ensure the structures design and mooring system design can be worked according to the design condition, model test can be carried out to estimate the safety of whole system before fabricate of the full structure. The model test which completed with the mooring lines and rise in model scale is more preferred if the laboratory facilities are allowed. This is because the involved all the system in the model test can illustrate the response of the structures with more realistic condition when receiving the external load such as wave, wind and current.

In this study, the model scale mooring lines design is focused in this paper. The procedure to selected the model size mooring line and the scaling rule apply is highlighted here. Due to the limited of the reliable data for the suitable wire rope in model size, the tensile test also conducted by this research to collect information to simulate curve of mooring lines. The precaution to conduct the tensile test so the reliable data can be obtained also presented in this paper.

Finally, this paper will also presented the final designed mooring line and the stiffness of the mooring line between model size and full size. The difference between the stiffness of full size and model size stiffness is within the acceptable range and assumed will not cause large difference to the motion response of the model scale experiment which will conduct as the next step in the structures mooring design.

2.0 MOORING MODELLING

2.1 Scaling Rule

In this study, the mooring lines in model scale are scaling follow the Froude similarity. Froude's law of similarity is the most appropriate scaling law applicable for the free and moored floating structure experiments. The Froude number has a dimension corresponding to the ratio ofu^2/gD where u is the fluid velocity, g is the gravity acceleration and D is a length of the model or prototype. The Froude number Fr is defined as$Fr = u^2/gD$.

Let the subscripts p and m stand for prototype and model respectively and λ is the scale factor, then the scaling for length, speed, mass and force is shown in Table 1.

Table 1: Scaling law between model and prototype

Dimension	Scaling equation
length, l (m)	$l_p = \lambda l_m$
speed, u (m/s)	$u_p = \sqrt{\lambda} u_m$
mass, m (kg)	$m_p = \lambda^3 m_m$
Force, F (N)	$F_p = 1.025\lambda^3 F_m$
Mooring line segment weight in water, K (N/m)	$K_p = 1.025\lambda^2 K_m$

2.2 Modeled Parameter for Mooring Lines

There are three important parameter must be scaled correctly to ensure the mooring lines are properly scaled for the selected environment and the simulation of the structure response is properly scaled to the model size. The parameters of the mooring lines must be scaled as follows [1]

- Pretension of Mooring line
- Stiffness of the mooring designed for the selected site condition
- The restoring force generated by the mooring lines to limit the movement of structures due to external load.

All the three parameter of the mooring system must be scaled to the model scale appropriately to ensure the experiment result is correct represent the structures response.

2.3 Catenary Theory

In the preliminary design, static catenary design method is typically selected to design the catenary type of mooring system for floating structure. To able apply this method to design a mooring system, few assumption of must be applied to the design. The assumptions as follows [2]:

- The seabed condition is fully flat and horizontal
- Bending stiffness of the mooring line can be neglected.
- The mooring lines is only in a vertical plane where involved with X-Z plan only.

The second assumption assumed that the bending stiffness can be neglecting is typically agreed forchain type mooring line. If wire rope mooring line is used in the mooring system, it must be ensure that the curvature curve is small.

The catenary model of mooring lines and the axial force acting onevery segment of mooring line is illustrated on Figure 1 and Figure 2respectively.

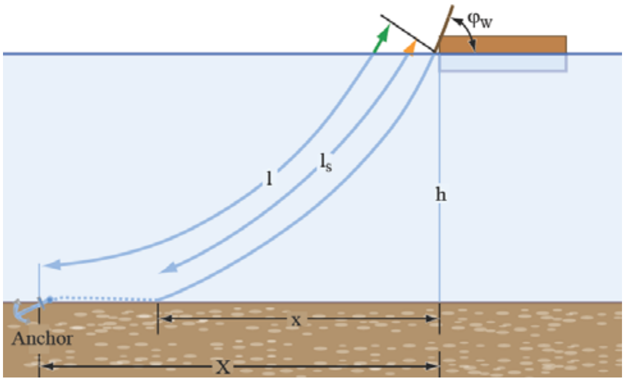


Figure 1: Single Mooring lines [3]

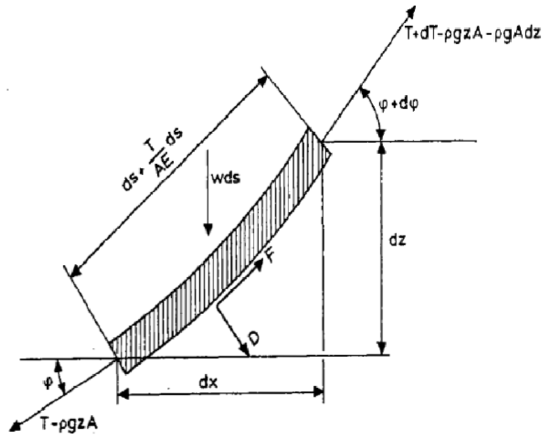


Figure 2: Segment tension of the mooring line

From the Figure 2, w is submerged unit weight/length of mooring line, A is mooring line cross-section area, $E$is the modulus elasticity of mooring line and T is tension force in line.

The axial tension of mooring line in the segment of mooring line in Figure 2 in static equilibrium condition can be estimated by the following equation [2].

$$dT - \rho gAdz = \left[w \sin\varphi - F\left(1 + \frac{T}{AE}\right)\right] ds \quad (1)$$

$$Td\varphi - \rho gAzd\varphi = wcos\varphi + D\left(1 + \frac{T}{AE}\right) ds \quad (2)$$

To solve the above equation, the effect from current, D is ignored, hence the equation become

$$T' = T - \rho gzA \quad (3)$$

By solving the equation above, the segment tension of the mooring line become as follow.

$$T = T_H + wh + (w + \rho gA)z \quad (4)$$

In equation (4), h is water depth, T_H is the horizontal tension of mooring line.

The vertical tension of the mooring can be calculated by equation (5)

$$T_z = wl_s \tag{5}$$

If the maximum external load, T_{max} act on the mooring line is known, then the minimum mooring lines length, l_{min} required to ensure the whole mooring line do not fully raise up can be calculated by equation (6)

$$l_{min} = h\left(2\frac{T_{max}}{wh} - 1\right)^2 \tag{6}$$

Also, the restoring coefficient, C generate by the design mooring line can be calculated from the equation (7) to (9) [3].

$$X = l - l_s + x \tag{7}$$

$$X = l - h\left(1 + 2\frac{T_H}{wh}\right)^{\frac{1}{2}} + \frac{T_H}{w}cosh^{-1}\left(1 + \frac{wh}{T_H}\right) \tag{8}$$

$$C = \frac{dT_H}{dX} = w\left[\frac{-2}{\left(1+2\frac{T_H}{wh}\right)^{1/2} + cosh^{-1}\left(\left(1+\frac{wh}{T_H}\right)\right.}\right]^{-1} \tag{9}$$

2.4 Mooring Line Material Properties Test

From the section 2.3, it is presented the mathematical solution to obtain the mooring line curve and horizontal tension. The required information need to obtain before the mathematical model at section 2.3 are the design parameter such as the length of mooring line, water depth, mooring line material properties.

To obtain the mooring lines material properties, tensile experiment should be conducted to obtain the required information.The information targeted to collect from tensile test are breaking load of wire rope and modulus of elasticity. The example stress-strain curve for wire rope tensile test is shown in Figure 3.

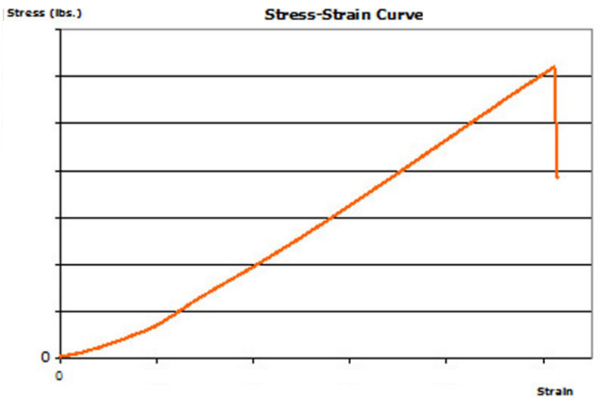


Figure 3: Wire Rope Tensile Test Stress-Strain Curve.

From the Figure 3, the breaking load of the wire rope sample can be obtained from the maximum load apply to the cable. To obtain the modulus of elasticity from the tensile test, Hook law can be applied [4]. According to Hook law, stress is directly proportional to strain.

$$\sigma = E.\varepsilon \tag{10}$$

Where, σ is stress, E is modulus of elasticity and ε is strain. The stress apply in the wire rope can be calculated by equation (11)

$$\sigma = \frac{F}{A} \tag{11}$$

Where, F is the tension force applies to the wire rope, A is the cross section area of wire rope. Also the strain from wire rope can be calculated by equation (12)

$$\varepsilon = \frac{\Delta l}{l_0} \tag{12}$$

Where, Δl the wire rope elongation and l_0 is the initial length of wire rope.

By rearrange equation (10), the modulus of elasticity for the sample wire rope can be calculated as in equation (13)

$$E = \frac{\sigma}{\varepsilon} \tag{13}$$

3.0 WIRE ROPE TENSILE TEST

Difference to the solid bar tensile test, tensile test for wire rope required more precaution to obtain acceptable result. This is because the wires rope is the roll together by several numbers of strands of metal wire laid. In this situation, the clamping tool for the tensile test and the preparation to the sample need to ensure the load apply to the wire rope can be fully distributed to all strands of metal wire laidand without concentration of force in the single strands of metal wire laidto avoid the wire rope break at the lower tension load condition due to bad distribution of force to all strands of metal wire laid.

To ensure the tension force can be distributed to all the wires in the wire rope, the wire rope end termination is claimed at both the end point of wire rope and then tensile test machine will claim at the wire rope end termination to apply the load to the wire rope during tensile experiment. The end termination applied in this experiment is showed in Figure 4, while the claimed wire rope before the experiment start is showed at Figure 5.

Figure 4: Wire rope with end termination.

Figure 5: Wire rope tensile experiment setup

Besides, there are many factors can be leaded to the failure of tensile test. From the previous experiment, it is facing few failures due to improper experiment setup. The failure face are non-uniform distribute of tension force, breaking in end termination before the wire rope failure and slip. Examples of failure tensile experiment are shown in Figure 6 and Figure 7.

Figure 6: Sample of failure tensile experiment due to breaking of end termination.

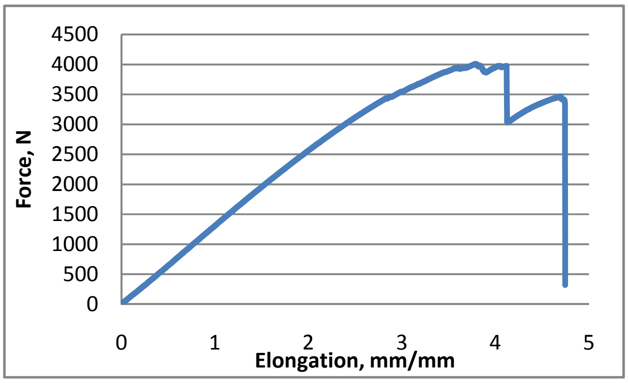
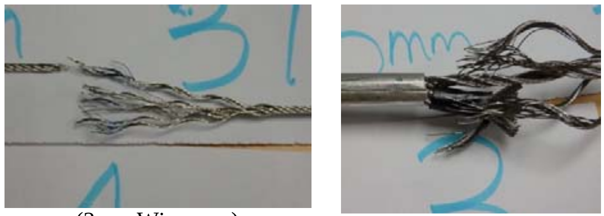


Figure 7: Sample of failure tensile experiment data.

In the tensile experiment, stainless steel wire rope with length of 200mm and nominal diameter of 2mm, 2.5mm, 6mm and 8mm were tested. Sample of success tested wire rope is showed in Figure 8 and the result from the tensile test for the wire rope nominal diameter 2.5mm and 6mm is showed in Figure 9 and figure 10 respectively.



(2mm Wire rope) (6 mm wire rope)

Figure 8: Tested wire rope samples.

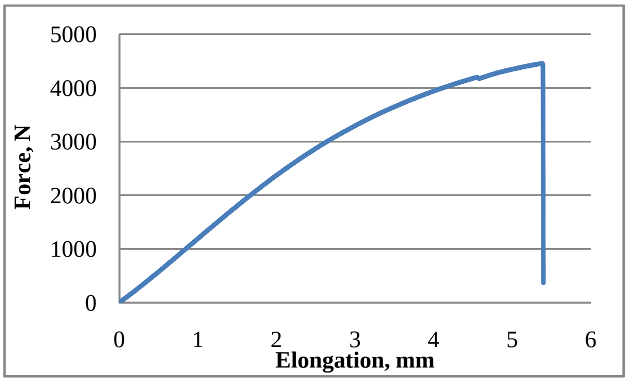


Figure 9: Tensile test result of 2.5 mm nominal diameter wire rope.

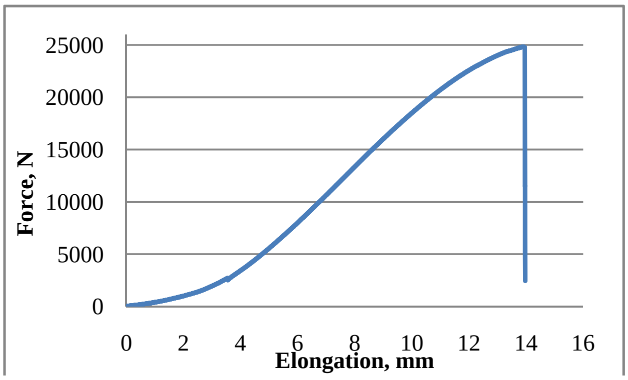


Figure 10: Tensile test result of 6 mm nominal diameter wire rope.

From the tensile test, it is obtained that the modulus of elasticity for the 6-strands wire rope is 61.0 GPa while the standard result for this type of wire rope based on specification is 58.86 GPa [5]. Besides, the minimum breaking load of the wire ropes of nominal diameter 2mm, 2.5mm, 6mm and 8mm are 3.6 KN, 4.5 KN, 24.89KN and 36.25 KN.

4.0 MOORING STIFFNESS

To simulate the effect of mooring to structures motion, the stiffness of mooring lines must be scaled properly. After the elasticity modulus and breaking load of wire ropes in model scale is knew, the calculation on mooring stiffness can be made based on the mathematical model in section 2.3. The final selection of the mooring lines and its properties is showed in Table 2 and Figure 11. And the stiffness is presented in figure 12.

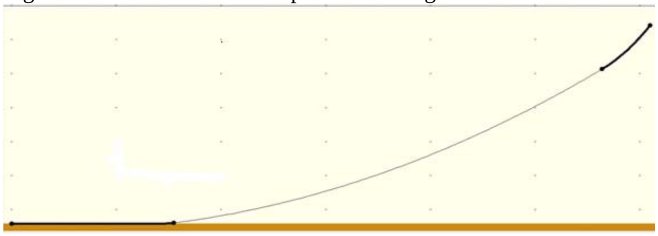


Figure 11: Mooring line profile

Table 2: Mooring line segment information

Particular	Segment A	Segment B	Segment C
	Model	Model	Model
Nominal Diameter (mm)	3.0	3.0	3.0
Type	Chain	Wire Rope	Chain
Segment Length (m)	4.2	11.3	1.4
Air Weight (kg/m)	0.16	0.0369	0.16
Water weight in water (kg/m) Model scale water density: 1000kg/m^3	0.1425	0.03119	0.1425
Breaking Load (KN)	10.79	5.40	10.79
Modulus Elasticity (GPa)	114.59	61.00	114.59

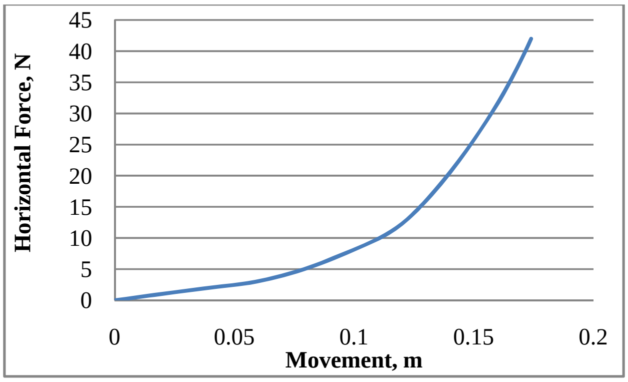


Figure 12: Restoring force from mooring line in model scale.

Besides, the comparison of horizontal restoring force generated by the model scale mooring lines and prototype is showed in Figure 13. The predicted motion of floating structures for the motion experiment is up to 8.5 meters. In the comparison, it can predicted that the motion of floating structures in model scale will slightly larger compared to the actual due to the lower restoring force provided by the model scale mooring lines.

The slightly difference between both mooring lines is expected because it is impossible to scale the entire particular from full scale to model scale. As example, the scaling of elasticity modulus is difficult to achieve because it involved the material properties of the mooring lines. To ensure the result from the model experiment is reliable, the different of the mooring lines horizontal stiffness is tried to keep as same as possible between models and prototype at the selected test range.

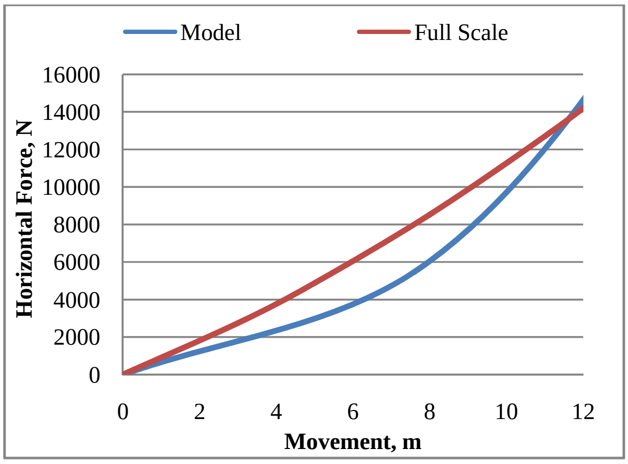


Figure 11: Comparison of horizontal restoring force generated by the model scale mooring lines and prototype.

5.0 CONCLUSION

This paper presented the mooring line preparation to conduct the hydrodynamic tank test. In this study, the static catenary theory is applied to predict the mooring lines stiffness and it generated restoring force to the structure. To able the calculation of mooring lines stiffness be conducted, tensile test of the model scale mooring lines are conducted to obtain the required information such as breaking load of the wire ropes and modulus of elasticity. The precaution of the tensile experiment is taken in this study to ensure the tensile test data is reliable to the calculation. Finally, the comparison of the mooring lines stiffness between model and prototype showed that the model size mooring lines is slightly less stiffness compared to the prototype, however, the difference is still within the acceptable for the range of restoring force required by the tank experiment.

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