

## Study on The Truncation Factor of Mooring System for a Ultra-deep Water Platform

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### ABSTRACT

With the continually increasing water depth of offshore structures being moored, it become harder to study the behaviour of such deep water mooring systems adopting model test with conventional scale ratio due to the limited depth and width of available model basins. According to this condition, an alternative approach is equivalent truncation method, which has been proved to be a feasible method. However, the effect of truncation factor is still not clear, when the truncation factor is too small, it is difficult to get a satisfied mooring system owing to the effect of the line dynamics and other factors.

This paper presents one taut mooring system of semi-submersible in full water depth of 1200m. Model test research using scale ratio of 1:62.5 is carried out in Deep Water Ocean Basin of CSSRC, which can satisfy the full depth model test demand which need the water depth 19.2m in model scale. And the mooring systems in water depth of 750m and 250m are initially truncated designed based on the static equivalent characteristics similar criteria, then optimize the truncation mooring system through iteration process via static load optimization and dynamic optimization. Truncation model test are numerical reconstructed, then extrapolated to full depth, which are compared with the full depth results subsequently. The comparison results show that the extrapolated results based on 750m water depth are coincident well with the full depth results, but the extrapolated results based on 250m do not dovetail with the full depth results. According to the comparison results, the effect of truncation factor to predict full depth results is analysed, pilot study show that aiming at this mooring system scheme, when the truncation factor is more than about 0.45, the predicted results based on truncation model test can be reliable.

### 1 INTRODUCTION

Model test verification has become an important approach in the optimization and hydrodynamic analysis of offshore structure and its mooring system. The whole system contains many aspects, such as platform, moorings, risers and many other accessories, only when all major complex details and coupling effect are taken into account, we can get valuable results. As the water depth increase, the challenges of model tests increase because available basins may be difficult to make space for complete systems at conventional model scales.

A possible alternative to solve the problem above is ultra-small scale model testing. Research has shown that small scale (<1:100) model testing is feasible although scale effects are becoming increasingly important [1] [2] [3]. However, many researchers doubt that the precision of the ultra-small model made and the reliability of data acquisition may affect the validity of results. Moreover, it cannot cover full depth of ocean no matter how small the scale selected and truncation is still required.

The second possible alternative solution is outdoor testing. Some scholars propose that inshore gulfs with a depth more than 40 meters can be used to carry out model test at conventional model scales. However, it is difficult to ensure the environment is consistent with design condition [4]. So limitation still exists for this approach.

Another alternative option is hybrid model test. This approach is to design a truncated mooring system that behaves similar to the full depth system. The step following is “model the model”, it means to reproduce the truncated system using a numerical tool, then carry out model tests using this truncated mooring system and tune the truncated numerical model to the model test results[5]. Finally, the tuning parameters obtained from the truncated model tests can be used in the full depth numerical calculations to assess the behaviour of the full depth mooring system [6]. This method has a great development prospect and has been proposed by ITTC[7] [8]. It has been applied to many projects, but it has not been verified by ultra-deep water model test yet. Besides the influence of truncation factor is not clear.

This paper presents the effect of truncation factor through contrast studying the behaviour of the full depth mooring system and the truncated mooring systems.

## 2 RESEARCH OBJECT AND MODEL TEST FACILITY

### 2.1 Research object

The research object selected is a drilling semi-submersible, and its particulars are given in Table 1. In order to comparative study the truncated mooring system, one suit of conceptual taut mooring system in full water depth of 1200m has been designed. The details of the mooring lines are presented in Table 2. The mooring system includes 8 mooring lines. And the lay out of the mooring system is 2×4, it means the mooring system is grounded into 4 bundles, each containing 2 lines. All the mooring lines are identical, each containing 3 segments (chain, polyester, chain). The model and layout of mooring lines are demonstrated in Figure 1.

Table 1: Main parameters of semi-submersible

Item	Unit	Value
Length overall (pontoon)	m	104.500
Breadth of pontoon	m	16.500
Height of main deck (from baseline)	m	37.550
Draught	m	17.50
Displacement	t	42710
Longitudinal center of gravity (From stern)	m	52.46
Transverse center of gravity (From midline)	m	0.00
Vertical center of gravity (From baseline)	m	21.00

Table 2: Parameters of mooring lines

Elements	Length (m)	Nominal axial stiffness (kN)	Wet weight (kg/m)	Pretension (kN)
Lower chain segment	105.0	2065349	390.0	1360
Mid polyester segment	1515.0	112640	20.73	
Upper chain segment	75.0	2065349	390.0	

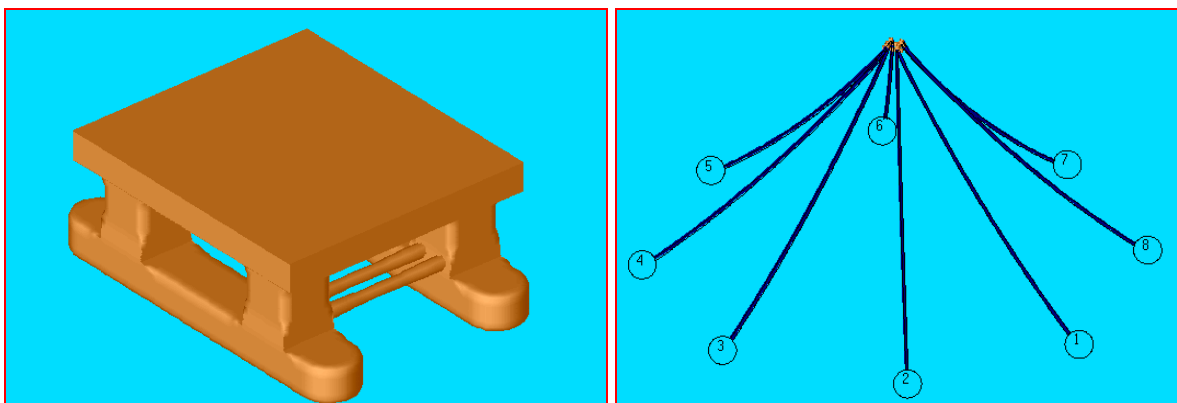


Figure 1: Model of semi-submersible and mooring system

## 2.2 Model test facility

Model test is carried out in Deep Water Ocean Basin of CSSRC, the dimensions of which is 54m(length)×40m(width) ×35m(depth). It is capable to carry out deepwater or ultra deepwater offshore platform model tests in wind, waves and currents, of which the maximum wind velocity is 15m/s, the profile current can be obtained in the basin, and it is capable of generating irregular wave of any defined spectrum with significant wave height > 0.5m or modelling waves in time domain, and short-crested waves. The wave direction from 90° to 180° can be generated in the wave basin, and its adjusted basin bottom helps to perform model tests at variable water depth from 0m to 32m.

According to this project, the model scale is 1:62.5, corresponding to the full water depth is 19.2m. In order to study the effect of truncation factor for the mooring system, another two truncated water depth 750m and 250m are selected, of which the mooring system need to be truncation designed.

## 3 TRUNCATION DESIGN AND OPTIMIZATION FOR MOORING LINES

### 3.1 Truncation design for mooring lines

The truncation design of mooring system should strive to obtain the motion response as close as possible to the full depth system. The following truncation rules are abided [9]:

- (1)The amount, components and layout of mooring lines are consistent with full depth system;
- (2)The static load curve is consistent with the full depth system;
- (3)The coupled response of platform is consistent with the full depth system;
- (4)The representative individual mooring line tension characteristics is consistent with the full depth system.
- (5)The fluid dynamic of mooring lines in waves and current is consistent with the full depth system.

According to the illustration above, the following truncation approach for taut mooring system is proposed.

1. Define the truncation factor  $\gamma$  as the ratio of the truncated water depth  $WD_t$  and the full water depth  $WD_f$ , that is the same with the ratio of the truncated line length  $L_t$  and the initial line length  $L_f$

$$\gamma = \frac{WD_t}{WD_f} = \frac{L_t}{L_f} \quad (1)$$

2. The length of truncated lines  $L_t$  is obtained by only reducing the length of the mid-section. The top section  $L_{top}$  and bottom  $L_{bottom}$  section remain unchanged.

$$L_{tm} = L_f \times \gamma - L_{top} - L_{bottom} \quad (2)$$

$L_{tm}$  is the length of the truncated mid-section.

3. Redefine the  $\mu$  as the ratio of the truncated mid-section line length  $L_{tm}$  and the full depth mid-section line length  $L_{mf}$ .

$$\mu = \frac{L_{tm}}{L_{mf}} \quad (3)$$

4. The EA value, submerged weight and diameter of the mid-section lines will be changed after truncation. We define them as  $EA_{tm}$ ,  $W_{tm}$  and. They can be calculated as following:

$$EA_{tm} = EA_{fm} \times \mu \quad (4)$$

$$W_{tm} = W_{fm} \div \mu \quad (5)$$

Although the mass  $M_{tm}$  and diameter  $D_{tm}$  of the lines have small influence to the static load of the mooring system, they will have an effect on the dynamic behaviour of the lines. However, the diameter, mass and

submerged weights are also coupled by the buoyancy of the line [6]. Therefore, these parameters can be calculated as follows:

$$M_{tm} = M_{fm} \div \mu \quad (6)$$

$$D_{tm} = D_{fm} \div \sqrt{\mu} \quad (7)$$

$EA_{fm}$ ,  $W_{fm}$ ,  $M_{fm}$  and  $D_{fm}$  is the EA value, submerged weight, mass and diameter of the full depth mid-section lines respectively.

According to the method above, we can get one initial truncation scheme of mooring system. Then next step we will optimize the truncation mooring system through iteration process via static load optimization and dynamic optimization. During the static load optimization, the adjusting parameters include length, axial stiffness and submerged weight of the truncated lines. And during the dynamic load optimization, the adjusting parameters include the mass and diameter of the truncated lines.

### 3.2 Optimization for the truncation design

#### 1. Static load optimization

For the taut mooring system employed in this paper, the stiffness of the mooring system is dominated by the elasticity of the line. Therefore, the EA value is the main parameter for static load optimization.

It should be noted that for different water depth, the rate of rotation of the pretension angle and line tension are different as the platform has the same excursions, especially when the truncation factor is too small, the deviation will be immensity.

After research, we found that increasing the pretension angle of the truncated mooring line could improve this problem. We define the pretension angle between the mooring line and the vertical axis as  $\beta$ , and the span of the truncated mooring line as  $X'$ , the length of the mooring line as  $L_t$ . Then the value is

$$X' = WD_t \times \tan\beta \quad (8)$$

$$L_t = \sqrt{X'^2 + WD_t^2} \quad (9)$$

After iterative analysis through adjusting the EA value and the pretension angle, the static load curve comparison of the full depth and the truncated mooring system is shown in figure 2 which include the surge force  $F_x$ , pitch moment  $M_y$  of mooring system and the axial tension of one representative single line.

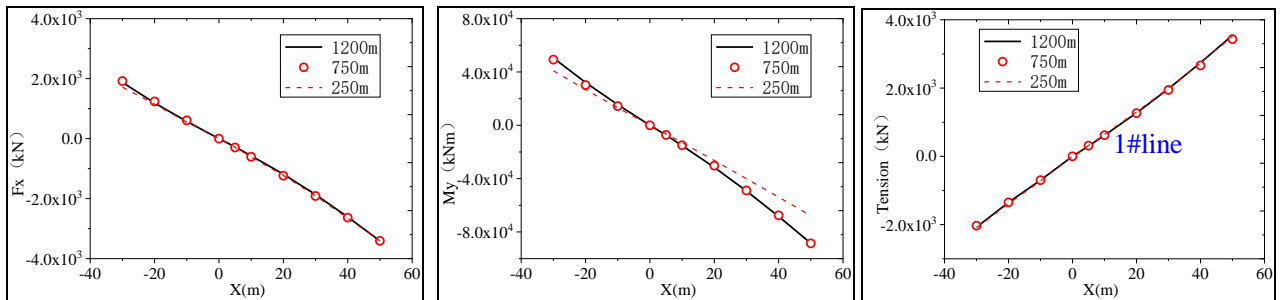


Figure 2: Static load results for 250m and 750m water depth

As is shown in the figure 2, the static load curve is reproduced well for the 750m water depth design. For larger offsets the 250m design starts to deviate from the full depth case of pitch moment although the slope of the line is still acceptable. Generally speaking, the static load character of truncated condition is consistent with the full depth.

#### 2. Dynamic load optimization

The main objective for dynamic load optimization is to ensure the dynamic line load response of truncated mooring system as close as possible to the full depth situation. During this process, the mass and the diameter may be adjusted on the premise that the quasi static behaviour will not be affected.

The dynamic line load responses can be quantified by applying a forced oscillation test on the floater. The line force response can be compared for the full depth system and the truncated system. In this paper, one dynamic response calibration device for single mooring line is employed to study the dynamic load character. The photo of the device and operate principle is shown in figure 3.

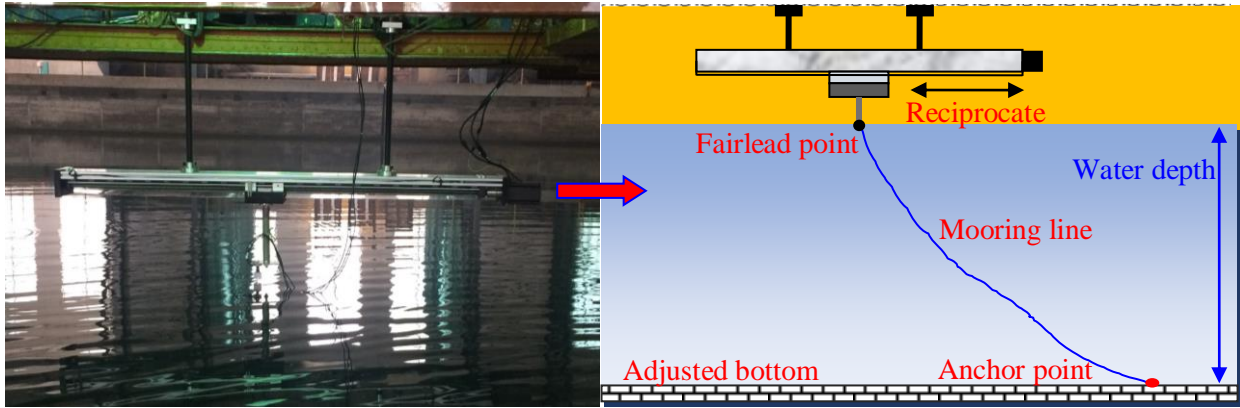


Figure 3: Dynamic response calibration device

As the device run, the fairlead point is connected to the manoeuvre bar, and the manoeuvre bar reciprocate along the slipway, driving the fairlead point reciprocate on the waterline. And the signal acquisition sensor obtains the time history of tension.

During the model test, sinusoidal reciprocating motions under low frequency, middle frequency and high frequency are performed in the basin.

On the premise of the final scheme after the static load optimization, dynamic load optimization is performed by adjusting the diameter and mass of the mooring line. After iterative analysis, the final dynamic response comparison is shown in figure 4 and table 3.

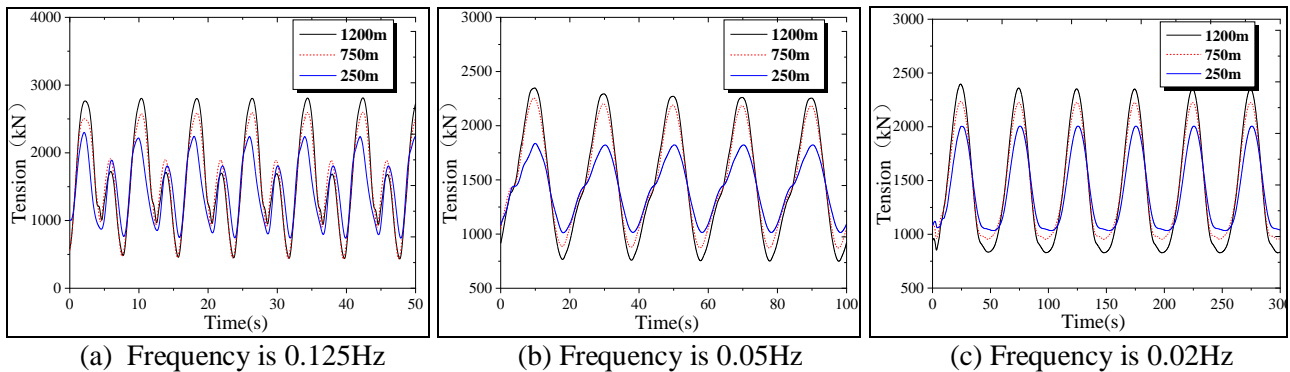


Figure 4: Dynamic response comparison of different water depth

Table 3: Dynamic response comparison of different water depth

Frequency(Hz)	1200m (kN)	750m (kN)	250m(kN)	Error-750m(%)	Error-250m(%)
0.125	2822	2605	2242	-7.7	-20.6
0.05	2247	2183	1822	-2.8	-18.9
0.02	2349	2225	2005	-5.3	-14.6

As is shown in the figure 4 and table 3, for the truncated system, the shorter lines have less dynamic response due to the shorter natural bending modes. For the 750m water depth mooring line, the results of the dynamic response is consistent with the full depth mooring line generally, the maximum error is -7.7%.

However, for the 250m water depth mooring line, there is significant deviation compare to the full depth mooring line, the maximum error is -20.6%.

After finishing the static and dynamic load optimization, the final truncated mooring system scheme is shown in table 4.

Table 4: Parameters of truncated mooring lines

Water depth (m)	Elements	Length (m)	Nominal axial stiffness (kN)	Wet weight (kg/m)	Truncation factor
750	Lower chain segment	105.0	2065349	390.0	0.625
	Mid segment	760.76	60310	40.68	
	Upper chain segment	75.0	2065349	390.0	
250	Lower chain segment	105.0	2065349	390.0	0.208
	Mid segment	127.5	66282	229.0	
	Upper chain segment	75.0	2065349	390.0	

## 4 MODEL TESTS AND COMPARISON OF DIFFERENT WATER DEPTH

### 4.1 Model tests of different water depth

The model tests are carried out for the full water depth (1200m), 750m and 250m corresponding to the prototype scale, resulting in truncation factors of about 0.625 and 0.208. And the model scale is 1:62.5, the model water depth is 19.2m, 12m and 4m respectively. Model test is performed in Deep Water Ocean Basin of CSSRC, the photo is shown in figure 5.

It should be noted that the waterline area of semi-submersible is very small, so the restoring moment for heave, roll and pitch is limited. Therefore, the pretension of the mooring system may have a profound influence for the draft, trim and heel of the platform. As the illustration above, the pretension angle in the equilibrium position has increased, so the vertical pretension are different from each other. According to this condition, slightly adjusting the mass distribution of the semi-submersible so as to ensure the different condition has the same draft.

100 year period return sea state in South China Sea are specified for this study, and the details are given in Table 5.

Table 5: Environment condition

Parameter	Unit	Value
Hs	m	13.6
Tp	s	16.3
$\gamma$	/	2.4
Wave spectra type	/	JONSWAP
Wave direction	°	180

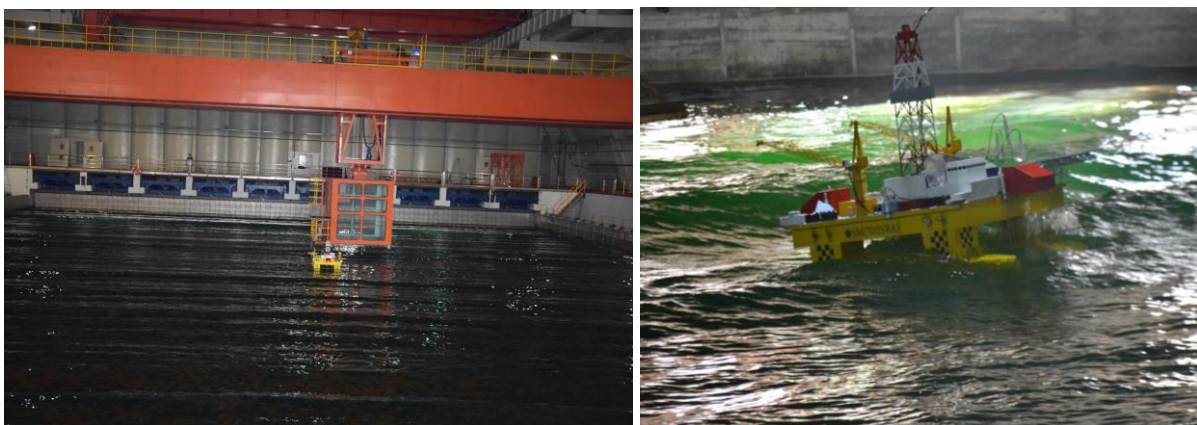


Figure 5: Model test in Deep Water Ocean Basin

## 4.2 Model tests results compared directly between different water depth

According to the model tests above, the test results of water depth 250m and 750m are compared to the full depth results. And the deviation is obtained through statistical analysis, and the duration of the analytical data is 3 hours for prototype. In order to compare the difference of different truncation factor, the deviation for the maximum value, minimum value, mean value and the RMS of surge, pitch, heave, 1#line tension and 2#line tension are selected and compared to the full depth. The details of deviation compared to the full depth is shown in figure 6.

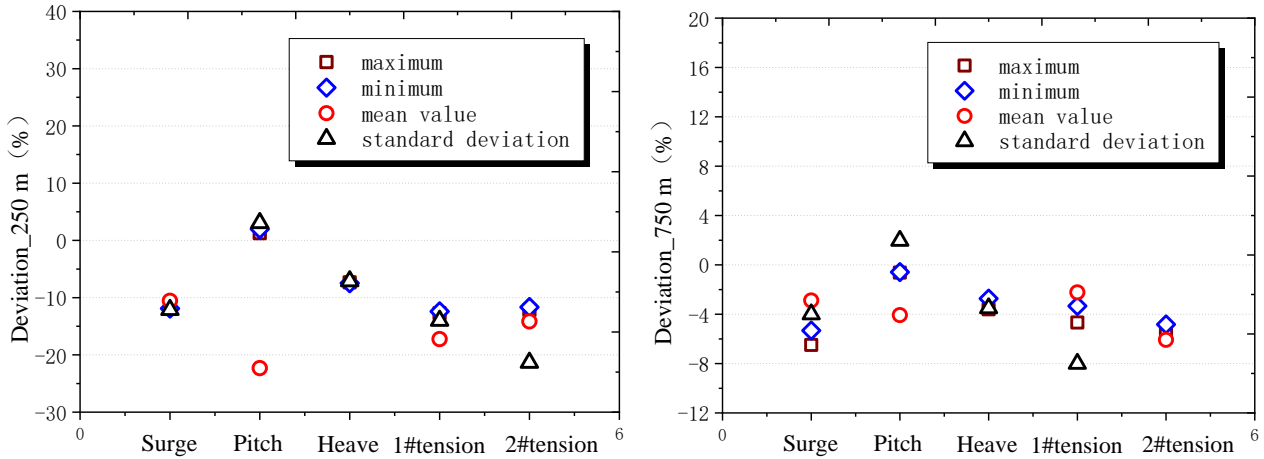


Figure 6: Deviation of truncated water depth compared to full depth

As is shown in figure above, the deviation range of the water depth 250m compared to full depth is 25%~5%, and for the 750m is -8%~4%, the deviation is increasing as the truncation factor decrease. So it is necessary to perform numerical reconstructed and extrapolated.

## 5 NUMERICAL RECONSTRUCTED AND EXTRAPOLATED FOR TRUNCATED MOORING SYSTEM

### 5.1 Numerical reconstructed for truncated mooring system

According to the hybrid model test, the final results is obtained from the numerical extrapolated using a reliable full-coupled time domain program. So the first step is “model the model”, it means to reproduce the truncated system using the full-coupled time domain program, and tune the truncated numerical model especially to tune the hydrodynamic coefficient based on the truncated model test results so as to ensure the hydrodynamic performance between the model test and numerical is consistent [10].

Based on the model tests results of 750m and 250m water depth, the numerical reconstructed is performed respectively. Take 750m mooring system as example, the figure 7 and figure 8 present the contrast results.

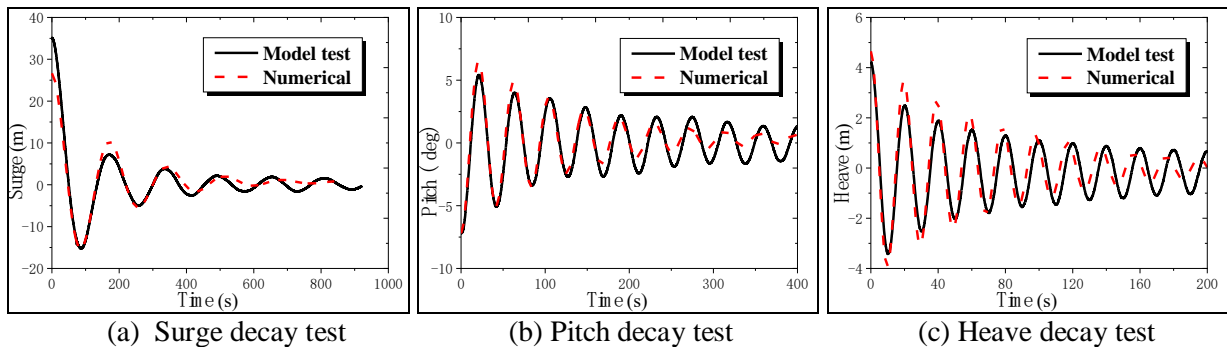


Figure 7: Comparison of the decay test time history

As is shown in the graphs, the surge decay test is consistent between the model test and the numerical results, however, for the pitch and the heave, it is agree well as the amplitude is large, but there is slight deviation as the amplitude is small. The reason is that the stiffness parameter adjusted in the program is constant, but actually the stiffness varies with amplitude, and it is nonlinear. Since the changing of the water depth has slight influence on pitch and heave, so the deviation can be negligible.

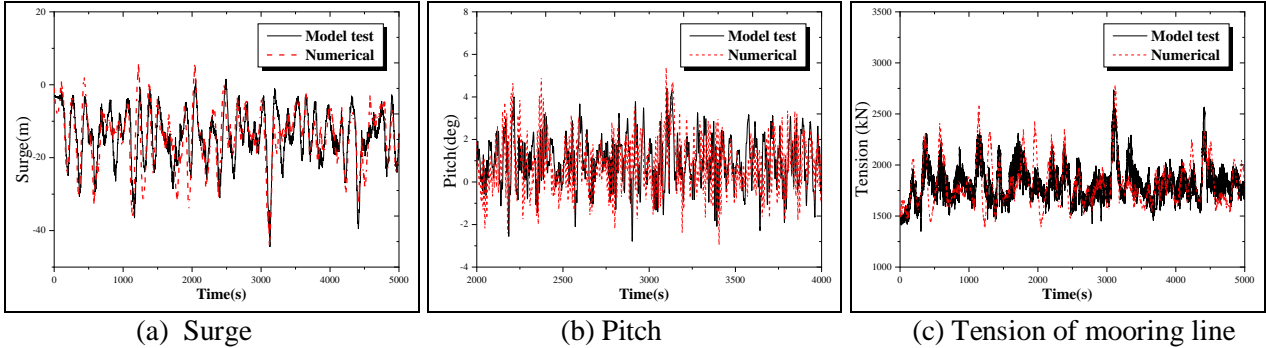


Figure 8: Comparison of the motion and tension time history

During the numerical simulation carrying out, the wave train measured in the model test is used as the wave input for numerical simulation instead of traditional wave spectrum so as to ensure the wave environment of numerical simulation is consistent with model test.

As is shown in the graphs, the motion and the tension is consistent between the model test and the numerical results. The deviation of the maximum value, minimum value, mean value and the RMS is selected and compared. The details of deviation compared to the model test is shown in figure 9.

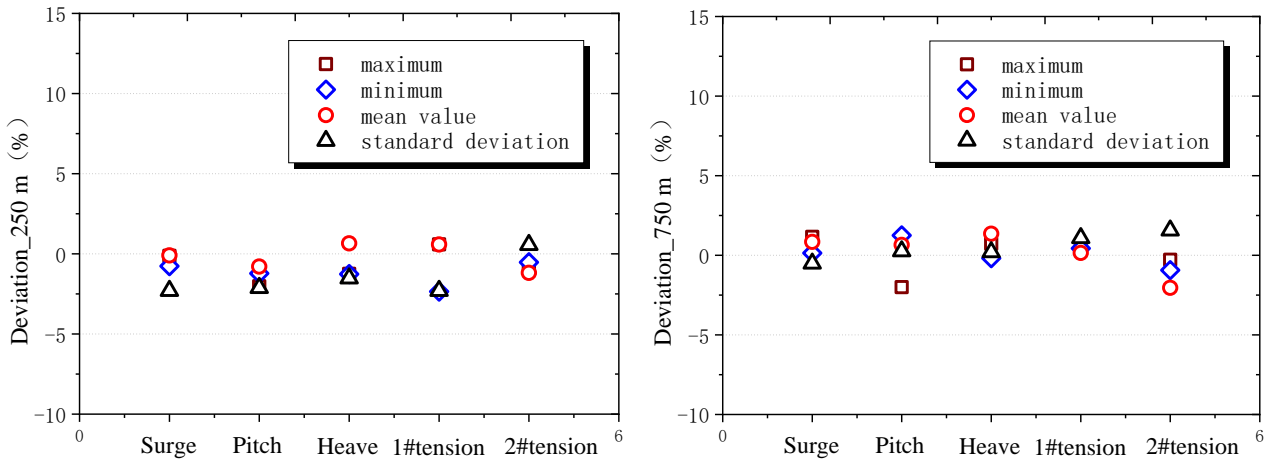


Figure 9: Deviation of numerical reconstructed compared to model test

As is shown in figure above, the deviation of the numerical reconstructed compared to model test is smaller than 2.3%, which indicate that the parameter tuned is feasible and reliable.

## 5.2 Numerical extrapolated and compared with the full depth

After finishing the numerical reconstructed process, the step following is that keep parameter tuning in the forward process unchanged and replace mooring system by the full depth mooring system. And then perform the numerical calculations to assess the behaviour of the full depth mooring system. That is numerical extrapolated.

After numerical extrapolating for the water depth of 250m and 750m, the representative statistical results of semi-submersible response and mooring forces are derived. These results are then compared with the full depth model test results, as shown in Table 6.

Table 6: Comparison of different water depth results

Item	Object	Surge (m)	Pitch (m)	Heave (m)	1#line tension(kN)	2#line tension(kN)
Maximum	Full depth model test	8.008	8.88	7.512	2945.800	1864.300
	750m extrapolated	7.895	8.90	7.447	2960.000	1829.000
	250m extrapolated	7.347	8.55	7.286	2749.594	1746.799
Minimum	Full depth model test	-52.901	-5.84	-7.867	1208.200	1214.400
	750m extrapolated	-52.370	-5.67	-7.813	1195.000	1220.000
	250m extrapolated	-49.398	-5.67	-7.316	1143.626	1159.392
Mean value	Full depth model test	-17.932	0.81	0.002	1696.400	1444.100
	750m extrapolated	-18.130	0.78	0.002	1683.000	1432.000
	250m extrapolated	-16.577	0.77	0.002	1597.652	1363.013
Standard deviation	Full depth model test	9.383	1.83	2.054	249.800	88.100
	750m extrapolated	9.215	1.78	1.994	251.500	85.500
	250m extrapolated	8.666	1.77	1.950	242.314	81.933

The details of deviation compared to the full depth model test is shown in figure 10.

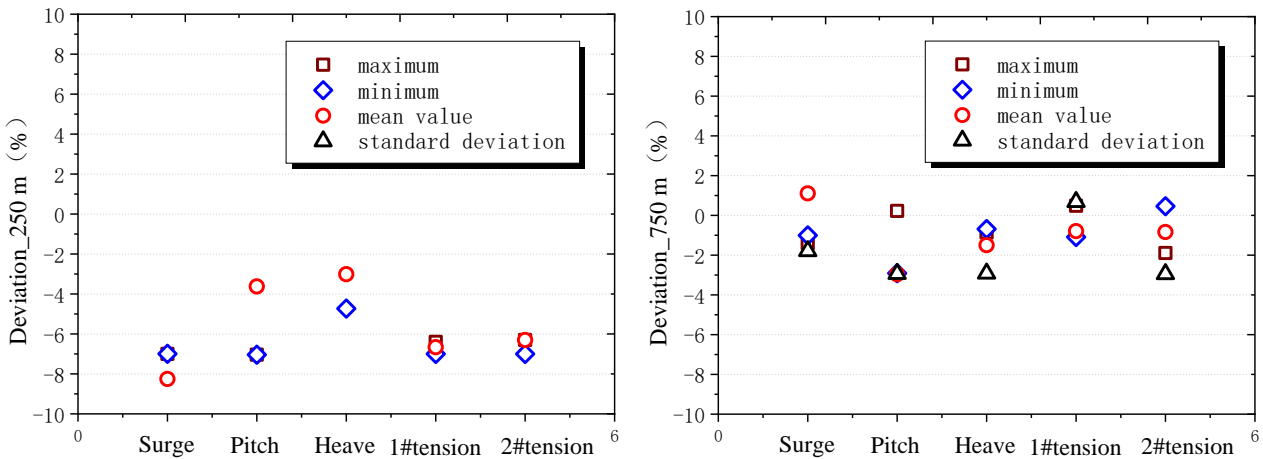


Figure 10: Deviation of numerical extrapolated compared to full depth model test

As is shown in figure above, the deviation range of the water depth 250m compared to full depth is -9%~-2%, and for the 750m is -3%~2%, it is observed that the response deviates significantly more for the 250 m water depth case than for the 750m water depth.

## 6 TRUNCATION FACTOR STUDY FOR THE SPECIFIC MOORING SYSTEM

According to the comparison above, the truncation factor has profound influence to the numerical extrapolated results. In order to find out the law of influence by truncation factor aiming at the taut mooring system. The effect of truncation factor is pilot studied based on the maximum deviation of the two water depth which represent the truncation factor as 0.208 and 0.625 respectively. The polynomial fitting method is employed in the analysis. The fitting curve is shown in figure 11. We assume 5% as the threshold of the numerical extrapolated results, it is observed that as the truncation factor is bigger than about 0.445, the deviation of the numerical extrapolated results is less than 5%, which we think is acceptable.

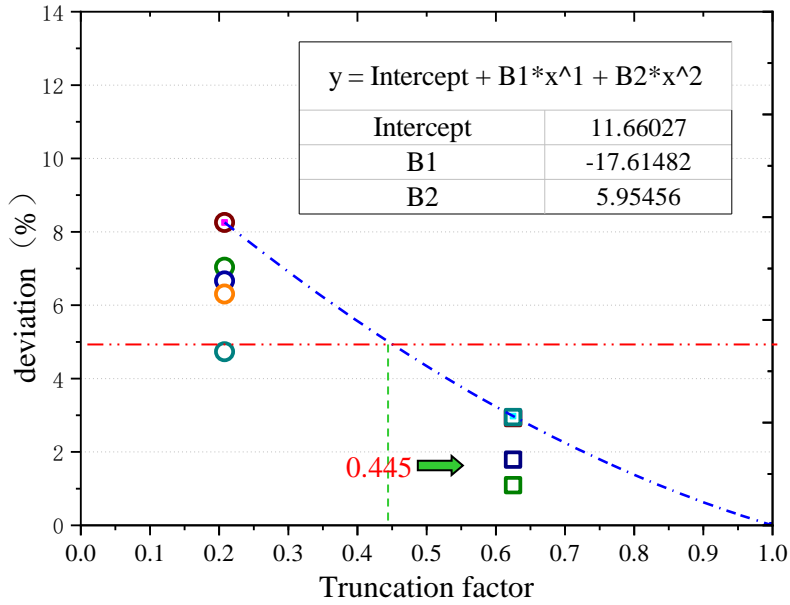


Figure 11: Truncation factor influence study

## 7 CONCLUSION

Based on the results of the hybrid model test process of the semi-submersible, the following conclusions can be drawn.

(1) The dynamic optimization program used is verified to be variable by the model test. And on the premise of the final scheme after the static load optimization, the deviation of the dynamic response of the mooring system increases as the truncation factor decrease.

(2) The model test results of the truncated condition cannot be used to assess the full depth response as the truncation factor is small since the results is significant difference compare to the full depth results. It is necessary to perform numerical reconstructed and extrapolated.

(3) The full coupled time domain program used in the paper is reliable, through tuning the relative parameter we can obtain satisfying results that is consistent with model test, the numerical reconstructed method is reliable.

(4) Based on the comparison of numerical extrapolated results and the model test, it is observed that the deviation increase as the truncation factor decrease.

(5) According to the taut mooring system, as the truncation factor is bigger than about 0.445, the deviation of the numerical extrapolated results is less than 5%, which we think is acceptable.

(6) Further research will be carried out to include wind and current environment condition. Also, the other mooring types such as the catenary mooring system should be further studied so as to obtain the universal law for truncation factor.

## REFERENCES

- [1] J.E.W. Wichers, A. Derksen, 'Investigation into Scale Effects on Motions and Mooring Forces of a Turret Moored Tanker', OTC paper 7444, Houston (1994).
- [2] C.T.Stansberg, S.I. Carlsen, E.G Ward, J.E.W. Wichers, M.B. Irani, 'Model Testing for Ultradeep Waters', OTC 16587, Houston (2004)
- [3] Simen Moxnes, Kjell Larsen, 'Ultra Small Scale Model Testing of a FPSO ship', OMAE98-0381, Lisbon (1998)
- [4] Wang Hongwei, 'Research on truncation technology of deepwater mooring system in model scale', Harbin engineering university (2011)
- [5] Yong Luo & Severine Baudic, Peter Poranski, Johan Wichers, Carl Trygve, Harald Ormberg, 'Deepstar study on Predicting FPSO Responses – Model Tests vs Numerical Analysis', OTC 16585
- [6] Olaf J. Waals, Radboud R. T. van Dijk. Truncation Methods for Deep Water Mooring Systems for a catenary moored FPSO and a Semi Taut Moored Semi Submersible. DOT 12087. Houston, TX, USA, 2004.
- [7] ITTC, Stationary Floating System Hybrid Mooring Simulation, Model Test Experiments[C], Proc of 23<sup>th</sup> ITTC, Chicago, USA: ITTC, 2002
- [8] ITTC, Truncation of Test Models and Integration with Numerical Simulations[C], Proc of 24<sup>th</sup> ITTC, Edinburgh & Scotland, UK:ITTC, 2005
- [9] Hongwei Wang, Yong Luo, Xiaoming Cheng 'Numerical Simulation and Truncation Design of A Deepwater Internal Turret FPSO Before Model Test', OMAE2010-20116, Shanghai (2010)
- [10] Zhang Huoming, 'Investigation on Hybrid Model Testing Technique of Deep-sea Platforms Based on Equivalent Water Depth Truncation', Shanghai Jiaotong university (2005)