RESEARCH OF HARDWARE-IN-THE-LOOP SIMULATION TESTING FOR OFFSHORE PLATFORM WITH BUCKET FOUNDATION ON RAISING AND LOWERING

Wu Haibin Zhu Shiqiang Chen Ying
The State Key Laboratory of Fluid Power and Control, Zhejiang University, 310027, Hangzhou, P.R.China
Sd9915911@sfp.zju.edu.cn

ABSTRACT

When offshore platform raises or lowers as a floating body in ocean, its movement property and stability are both variable. This paper demonstrates the practicality of real-time hardware-in-the-loop simulation testing (HILST) as a technique for offshore platform in such temporary condition. The real-time simulations of stability and movements for platform are investigated, and the control system is also checked up by HILST.

INTRODUCTION

In recent years, there has been rapidly growing interest in new-style offshore platform with bucket foundation. Because it has the following advantages: simple structure, convenience for fixing and perching, ability to re-using, and low costs, etc., more and more scholars have been researching on it in the world. Despite some success, many basic theoretical and practical issues remain to be further addressed. Among the most urgent and important issues is platform stability analysis on raising and lowering, because of the re-using. Whether the stability is satisfied depends on the structural design

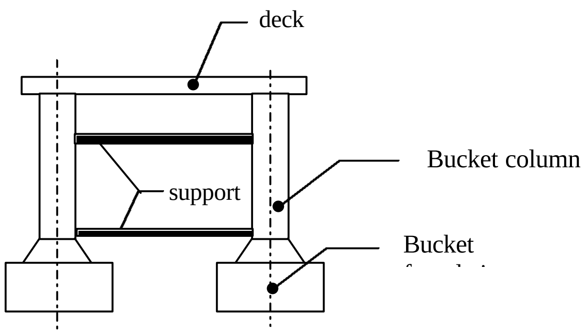


Fig.1 Structure of platform with bucket

of platform. In this paper, the discussed platform structure is shown in Fig.1, which has two characteristics: (1) every under-soil foundation are like a cup standing upside down; (2) columns are also made up to bucket style. However, there is a clapboard between column and bucket foundation. These bucket columns have two functions besides supporting platform. Firstly, they can be used for storing oil during oil extraction; secondly, the raising and lowering processes can be implemented by pumping water out from or injecting water into bucket columns. That is to say, avoiding the use of large construction equipments will be possible. If successful, a considerable amount of fixing costs will be reduced. In this paper, the variable stability of platform in the temporary conditions is discussed by the means of hardware-in-the-loop simulation testing.

What is hardware-in-the-loop simulation testing (HILST)? It can be explained that some real components connected in the simulation testing loop, computer and physical reactive equipment together model the system. Its principle is shown in Fig.2.

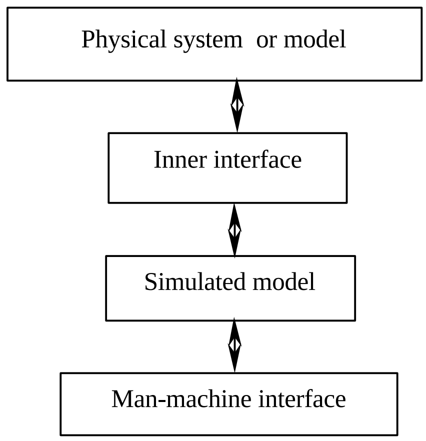


Fig.2 HILST principle

HILST takes physical reactive equipment and real components into the loop. Therefore, experiments and simulations must be done simultaneously. It is known that HILST has been widely used in avigation, spaceflight and subsea engineering. To a certain extent, it can remedy the shortage of outfield experiments effectively, and provide support for technology and administer decision-making. This paper describes the application of HILST in offshore platform design.

MATHEMATICAL MODELING OF OFFSHORE PPLATFORM ON RAISING AND LOWERING

Analysis should be carried out by applying spacial analytic geometry theory, if the location and pose of the platform in the water could be described exactly. The coordinates and parameters are shown in Fig.3. It is assumed that relative coordinate center is located in the center of the plane of platform's underside, and absolute coordinate center is located in marine bottom. The water depths in four buckets are as the independent variables

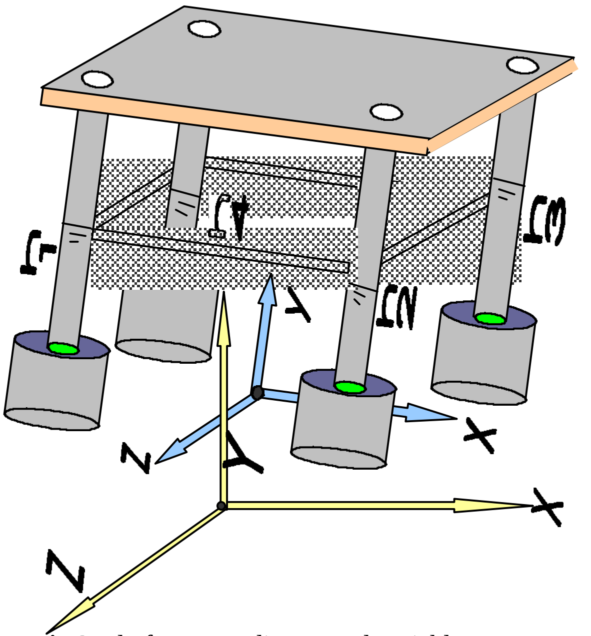


Fig.3 Platform coordinates and variables

on model development, and the location and pose parameters of platform are as the consequent variables, since raising and lowering of platform depend on injecting water into and pumping water out from buckets. Furthermore, it is assumed that the water depths in four buckets are h_1, h_2, h_3 and h_4, corresponding to bucket 1, 2, 3 and 4, while the vertical span is *a*, and the longitudinal span is *b*. Barycenter of platform is (0, 0, h_0), and barycenters of water in four buckets are (a/2, -b/2, h_1/2), (a/2, b/2, h_2/2), (-a/2, b/2, h_3/2) and (-a/2, -b/2, h_4/2) respectively. Based on all above, the mathematical model is developed as follows

$$a_{11}^2 + a_{12}^2 + a_{13}^2 = 1 \quad (1)$$

$$a_{21}^2 + a_{22}^2 + a_{23}^2 = 1 \quad (2)$$

$$a_{31}^2 + a_{32}^2 + a_{33}^2 = 1 \quad (3)$$

$$a_{11}a_{21} + a_{12}a_{22} + a_{13}a_{23} = 0 \quad (4)$$

$$a_{11}a_{31} + a_{12}a_{32} + a_{13}a_{33} = 0 \quad (5)$$

$$a_{21}a_{31} + a_{22}a_{32} + a_{23}a_{33} = 0 \quad (6)$$

$$x_G = x_F \quad (7)$$

$$y_G = y_F \quad (8)$$

$$a_{ij}a_{ji} = 0, \ i \neq j \text{ and } i, j = 1,2 \quad (9)$$

$$M_0 + p\,r^2(h_1 + h_2 + h_3 + h_4)r = p\,r^2 r\frac{4(H - z_0)}{a_{33}} \quad (10)$$

Where

a_{ij} matrix elements of constituting the state transform matrix of platform;

(x_G, y_G) barycenter coordinate;

(x_F, y_F) center of buoyancy coordinate

M_0 initial quality of platform

z_0 the depth from center of relative coordinate to submarine bottom;

H water depth

Ñ water density.

Barycenter (x_G, y_G) and center of buoyancy (x_F, y_F) are calculated respectively based on definition.

The location and pose are fully confirmed by three parameters which are two swing angles (rolling and pitching) á,â, and depth parameter z_0. All of them can be resolved with above model. So we can obtain the equation style as follows

$$a = f_1(h_1, h_2, h_3, h_4) \qquad b = f_2(h_1, h_2, h_3, h_4)$$

$$z_0 = f_3(h_1, h_2, h_3, h_4)$$

Hence, the location and pose of platform can be calculated, if the water depths in four buckets are detected.

Above model is based on ship statics. In the system of HILST, there are two tasks to perform. One is the design of control system including platform, controller and sensor, etc., the other is the simulation for dynamic mathematical model. It is the static model applied to control platform, because platform inertia is too big, and flow used for raising and lowering relatively tiny. The dynamic mathematical model is not discussed in this paper because of paper length.

THE HILST SYSTEM OF PLATFORM

In brief, HILST is that some components of the complicated system are simulated in software, and other components are made to physical model or actual entities, between which appropriate interfaces are constructed to transform signals. Therefore, it is possible to simulate an actual system. In this paper, the HILST for offshore platform with bucket foundation is shown in Fig.4.

(1) the Design and Implement of the Control System of Platform

The spot platform is a huge system, whose weight is thousands of tons. The raising and lowering speed of the

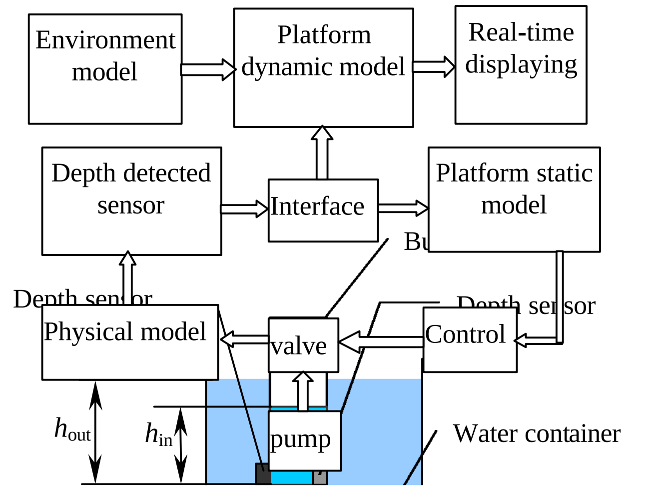
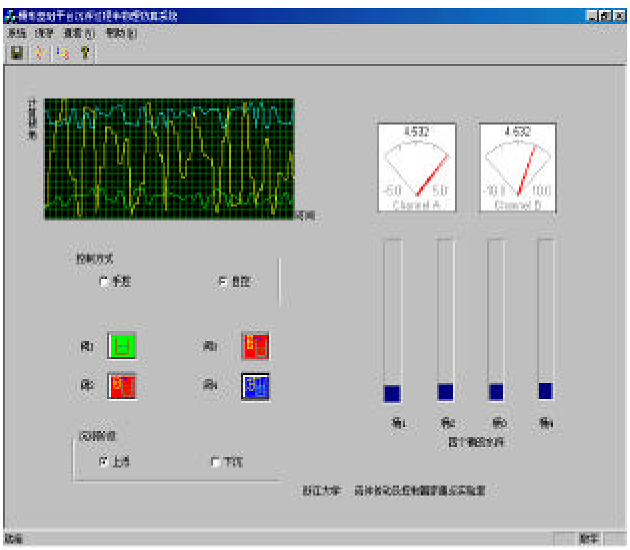


Fig.4 Hardware-in-the-loop simulation system for platform

Fig.5 Sensor distributed

platform is so slow, and flow for changing the platform weight is so little that the process can be considered static. We know that the disturbance of ocean environments is inevitable, including wave, wind and current. However, the little flow for injecting water into or pumping water out from buckets are hard to realize the dynamic balance. Thus, we take the measurement that platform angles are not controlled directly (in another word, platform angles are not as the direct feedback signals any more). What controlled is the barycenter location which can be modified by adjusting the distributing weight of platform. When the barycenter is adjusted to coincide with shape-center of platform, optimal stability is gained. Then, how to calculate the barycenter coordinate? The sensors for detecting water depth are shown in Fig.5. There are two sensors for every bucket. One (inside bucket) is used to detect the inner water depth h_{in}, and the other is used to detect the undersurface depth h_{out} of bucket. Inner water depths h_{in} are used to calculate platform barycenter, and furthermore calculate the platform angles indirectly based on above mathematical model. At the same time,



undersurface depths h_{out} of buckets are used to detect the angles of platform directly. By contrasting between the direct and indirect results, we can perceive whether the mathematical model is exact. The model may be modified furthermore, if it is not ideal. This is the advantage of using HILST. As a testing, we set two modes: hand-control and autocontrol, in order to insure the security. As such, raising and lowering of the platform are also different in control algorithm. Therefore, selecting one of them is necessary before testing. The control system software interface is shown in Fig.6.

(2) Control algorithm

How to control the flow so that the platform can raise or lower with a reasonable speed? One method is that the speed curve on raising or lowering is given. The following Fig.7 is implementation process.

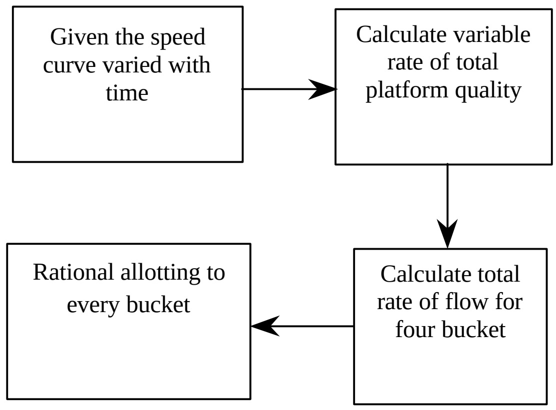


Fig.7 one of control algorithm flow chart

(3) Fluid loop used for control

Raising and lowing of platform depend on changing the water weight of every bucket. In experiment, we used one valve for every bucket, in order to realize balancing. Fluid loop used for raising is shown in Fig.8, and for lowering shown in Fig.9.

Results of detecting and simulating

Fig.10 and Fig.11 are the simulation results of swing period and metacentric height, while the experimental result on raising is shown in Fig.12 whose ordinate is platform angle and abscissa is raising height. From simulation results, we can see that the swing period becomes decrescent, but metacentric height becomes

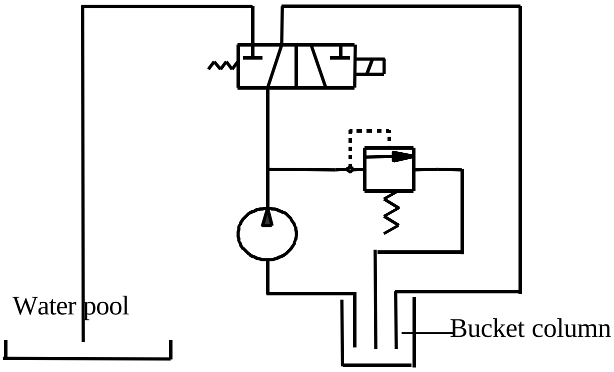


Fig.8 Fluid loop on raising

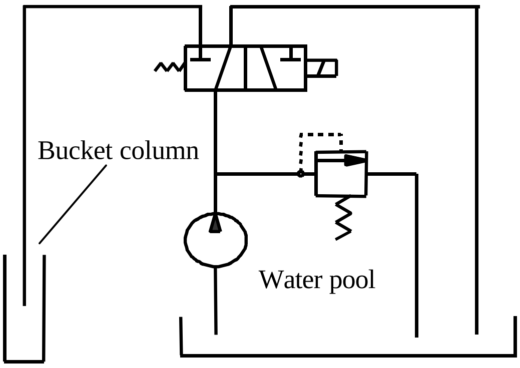


Fig.9 Fluid loop on lowering

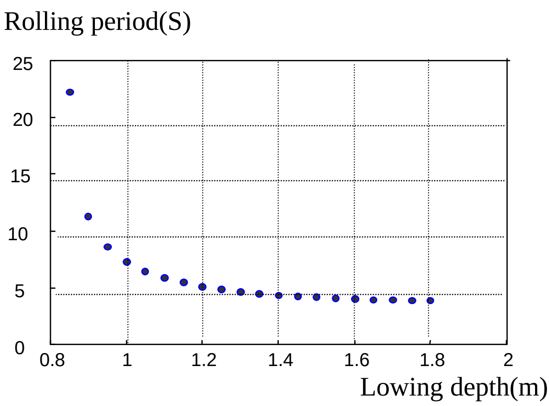


Fig.10 Rolling period varied with lowering depth

enhancive as platform lowers. It is known that metacentric height is the most important parameter that measure the platform stability. In another word, The stability will be reinforced as the increase of metacentric height. At the same time, Swing period represents the magnitude of platform restoring moment which is another important parameter to measure the stability. But inversely, swing period will be reduced as the increase of restoring moment, while the increase of restoring moment improves the platform stability. In a word, stability is reinforced continuously as platform

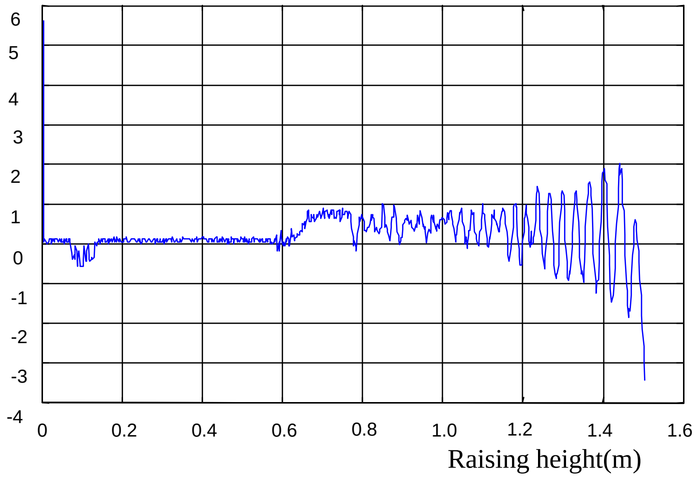


Fig.12 The curve about swing angle varied with raising height

lowers. In addition, experimental result(Fig.12) also obviously proved the same conclusion, because from Fig.12 we can see that the swing period and magnitude of swing angle is increasing as platform raises, and at last the platform lose the stability.

CONCLUSIONS

Raising and lowering are the important stage of the whole lifetime for platform, and the stability is the key in this stage. The purpose of this work is to better understand that hardware-in-the-loop simulation can be applied successfully in offshore platform stability analysis. Applying HILST is able to shorten developing period, and reduces costs by decreasing dependence on spot platform testing. HILST, as one of the methods of engineering technique, must be applied to a broader range in the future. Especially when investments and facilities are both giant, or there is destructive so that testing is unable to proceed, HILST will show its matchless advantages.

AKNOWLEDGEMENT

The project is granted by National 863 Youth Fund. Special thanks goes to Dr. Wu Xingjun, Dr. Jin Bo, and so on. They give me much rewarding help and guidance.

REFERENCE

[1] Zhu Shiqiang, Wu Xingjun, Jin Bo, Semi-physical simulation—One effective engineering design method, Northwest University Transaction,1999,(2)(in Chinese)

[2] Wu Xingjun, Study on Hardware-in-the-loop Simulation of Raising and Lowering of Mobile Offshore Platform with Bucket Foundation, Doctor Degree Dissertation of Zhejiang University, 2000(in Chinese)

[3]I.R. Kendall, R.P. Jones , An investigation into the use of hardware-in-the-loop simulation testing for automotive electronic control systems, Control Engineering Practice, 1999 ,(7)

[4] Yoshida, K.; Iijima, K.; Suzuki, H.; Oka, N. Analyses of response of large floating structures in waves and hydrodynamic interaction effects on their design Nihon Zosen Gakkai Ronbunshu/Journal of the Society of Naval Architects of Japan, 1995, 178