Simplified Mechanical Model of Ship Lift-Ship Box Structure

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Abstract. According to the connection feature of the gear and rack, an equivalent two-dimensional tandem and many freedom-degrees dynamic model of the structure system including the ship lift and the ship box was established based on the dynamic characteristics of three-dimensional finite element model. The results indicate that the simplified model can represent preferably the dynamic characteristics of the structural system, which can be used in seismic response analysis on the coupled system consisted of the ship lift, the ship box and water in box.

Introduction

By repeated type selection research, the Three Gorges Ship lift was determined to be gear-rack climbing type instead of the original wire rope hoisting type[1]. The relatively independent connection form between tower and ship box was changed into close contact. Under earthquake action, the ship box and water in it will shake following the ship lift pillar and water sloshing will affect the seismic response of ship lift main structure in turn. And then the ship lift structure, ship box and water form a fluid-solid coupling system. It is unrealistic to do dynamic calculation of the coupling system directly. It is necessary to establish a simplified mechanical model of the coupling system. There were some studies on establishing the simplified mechanical model of ship lift, but they did not talk about the correlation of ship lift pillar and ship box[2,3]. Some research showed that there was no inclination flips between gear and rack of the vertical climbing system[4]. So if the horizontal displacement between the gear and the rack is neglected and the vertical takeoff and landing movement is separated into various working conditions, there is no relative displacement between the ship box and the ship lift pillar in each condition. In this paper, an equivalent two-dimensional tandem and many freedom-degrees simplified dynamic model of the ship lift main structure-ship box system was founded based on the three-dimensional finite element model according to the characteristics of the gear and rack connection form. Only the condition when ship box was on the top of the pillar was considered to be as a typical working condition.

Three-dimensional Finite Element Model of the Ship Lift-Ship Box Structure

The Three Gorges Ship Lift is composed of four giant symmetrical reinforced concrete pillars which support a big span machine room at the top with total height of 160 meters and pillar height of 136 meters. The concrete slab thickness is 2.5 meters at the top of pillar. All the rest floor thickness is 0.5 meters. The shape size of ship box is 132m x 23.4m x 10m. The three-dimensional finite element model was established by ANSYS for half of the Three Gorges Ship Lift as shown in Fig.1. The pillar cylinder, the machine room roof at the top, all floors and ship box were defined as Shen63 elastic shell element. The lateral structure of the machine room was defined as Beam4 elastic beam element. The elastic modulus value of ship box shell element was assumed to be 3000GPa due to its very big stiffness. The thickness of the ship box shell element was calculated according to quality equivalent.

ANSYS modal analysis results show that the first vibration mode is overall translation in Y direction and the following eight vibration modes are all local vibration of machine room at the top of ship lift. Among them, the sixth and eighth vibration modes are torsion of the machine room. The first eight natural vibration frequencies and vibration modes of finite element model are shown in Table2.
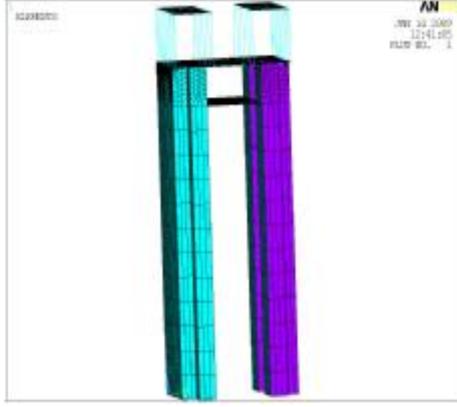
Fig. 1. Three-dimensional finite element model   **Fig. 2.** Simplified mechanical model
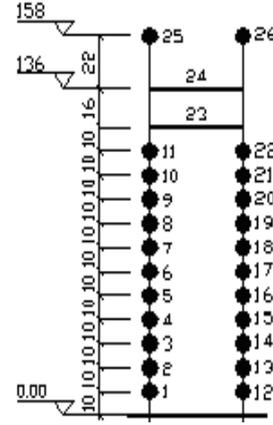
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Assumption. Three-dimensional finite element model was condensed to be two-dimensional simplified model more degrees of freedom using the lumped mass method. In addition to maintain the linear elastic hypothesis of the structure, the following assumptions were also adopted:

(1) The whole quality of floor was focused on node layer.

(2)The in-plane stiffness of floor was infinite under flat section assumption.

The two-dimensional tandem and many freedom-degrees dynamic model of the ship lift-ship box system was shown in Fig.2.

Mass matrix. The mass matrix of the simplified model was 26×26 diagonal matrix. The diagonal coefficient value as shown in table 1 was the total condensed mass of each floor.

Table 1 Concentrated mass of note layers of the simplified mechanical model [kt]

note	mass	note	mass	note	mass	note	mass	note	mass	note	mass	note	mass
1	5.492	2	5.492	3	5.492	4	5.492	5	5.492	6	5.492	7	5.492
8	5.492	9	5.492	10	5.492	11	5.492	12	5.492	13	5.492	14	5.492
15	5.492	16	5.492	17	5.492	18	5.492	19	5.492	20	5.492	21	5.492
22	5.492	23	16.78	24	21.99	25	3.427	26	3.427				

Lateral stiffness matrix. The solution process of the stiffness matrix of the simplified model was as follows [2]:

(1) The total horizontal force of unit 1 was applied on all nodes of i(i=1，2，3…) note layer of the three-dimensional finite element model;

(2) The note average displacement of j(j=1，2，3…) note layer of the three-dimensional finite element model was calculated to obtain flexibility coefficient δ_{ij} (i，j=1，2，3…);

(3) The flexibility coefficient δ_{ij} (i，j=1，2，3…)was integrated into flexibility matrix δ ;

(4) The stiffness matrix K was the inverse flexibility matrix, $K=\delta^{-1}$.

Damping Matrix. The frequently-used Rayleigh damping was adopted. That's:

$$C = l_1 M + l_2 K \qquad (1)$$

where $l_1 = 2w_1 w_2 (z_1 w_2 - z_2 w_1)/(w_2^2 - w_1^2)$, $l_2 = 2(z_1 w_2 - z_2 w_1)/(w_2^2 - w_1^2)$. w_1 and w_2 were the first and the second order natural vibration frequency. z_1 and z_2 were damping ratio which were both assigned 0.05 for the ship lift structure. So there were equations $l_1 = 0.1 w_1 w_2/(w_1 + w_2)$, $l_2 = 0.1/w_1 + w_2$.

Dynamic Characteristics of Simplified Model. The free vibration equation of the simplified model was:

$$Kx(t) + M\ddot{x}(t) = 0 \qquad \text{`} \tag{2}$$

where K was the stiffness matrix, M is the mass matrix.

The node layers were assumed to do harmonic vibration:

$$x(t) = \Delta \sin(wt + f) \tag{3}$$

where Δ was the displacement amplitude vector. The following equation can be obtained by (2) and (3):

$$(K - w^2 M)\Delta = 0 \tag{4}$$

Then the general characteristic equation was given as:

$$\left| K - w^2 M \right| = 0 \tag{5}$$

The natural vibration frequency of the simplified model can be gained by solving the above characteristic equation. The comparison analysis on first eight natural vibration frequencies of the simplified model and the three-dimensional finite element model was conducted as shown in Table 2. It's obviously that error margins were all less than 5%. So the dynamic characteristics of the simplified mechanical model and the three dimensional finite element model are equivalent.

Table 2 First eight natural vibration frequencies of finite element model and simplified model (Hz)

Vibration mode	1(Y)	2(X)	3(X)	4(Y)	5(Y)	6(T)	7(Y)	8(T)
finite element model	0.4493	0.7724	0.8127	1.2345	1.2386	1.2788	1.3185	1.3599
simplified model	0.4596	0.7884	0.8501	1.1863	1.2039	1.2409	1.2879	1.3008
error margin	2.24%	2.03%	4.40%	3.90%	2.80%	2.96%	2.32%	4.35%

Structural seismic response analysis

The basic intensity is 6 degrees in the three gorges project site where the seismic fortification intensity is 7 degrees. The three gorges simulating seismic wave was selected as shown in Fig.3. In order to do contrast analysis, the acceleration amplitude was in proportion to increase to 4.0m/s2.which was amount to the peak acceleration in 9 degrees seismic fortification intensity.

For the simplified mechanical model, under the earthquake action in machine room bent direction in which direction the lateral stiffness of the ship lift structure is smaller, the equation of motion of the ship lift structure is as follows:

$$[M]\{\ddot{y}\} + [C]\{\dot{y}\} + [K]\{y\} = -[M][I]\ddot{y}_g(t) \tag{6}$$

where $[M]$、$[C]$、$[K]$ are respectively mass matrix, damping matrix and stiffness matrix. $\{y\}$、$\{\dot{y}\}$、$\{\ddot{y}\}$ are displacement, velocity and acceleration vector of each note later to take the ground as reference. $[I]$ is the unit column vector. $\ddot{y}_g(t)$ is the ground motion acceleration.

The equation 6 was solved by Newmark - b step integral method to obtain seismic response of all the note layers of the simplified model. In order to further illustrate the effectiveness of the ship lift structure simplified mechanics model, the displacement response of simplified mechanical model were compared with the displacement response of finite element model as shown in Fig.4. The 25

note layer maximal displacement response of the simplified model and the finite element model was 74.1mm and 76.8mm respectively. The 24 note layer maximal displacement response of the simplified model and the finite element model was 57.2mm and 56.0mm respectively. The difference of the maximum displacement value of two models were all less than 5% which further indicated that the ship lift simplified mechanics model is effective.
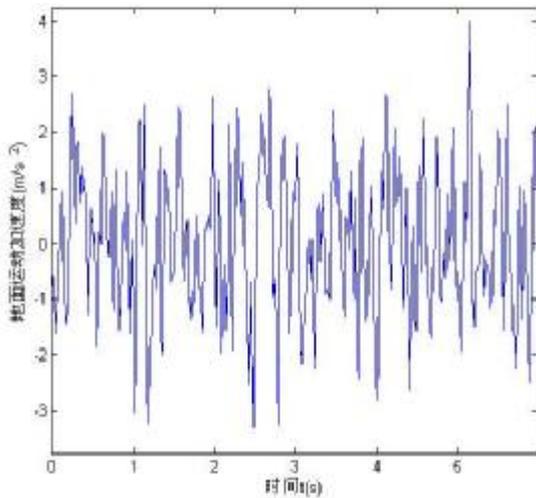

Fig. 3. The three gorges simulating seismic wave note layers
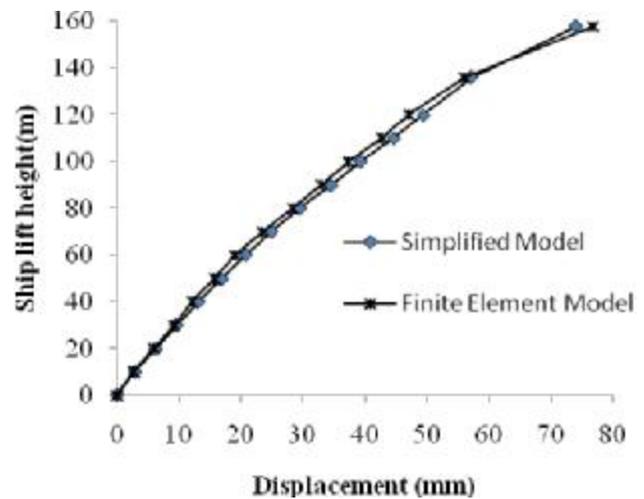
Fig. 4. Maximal displacement of all ship lift

Summary

a.   The dynamic characteristics of the simplified mechanical model is equal to the finite element model, the simplified model is effective.

b.   The simplified mechanical model can represent preferably the seismic response of the ship lift. It can be used in seismic response analysis on the coupled system including the ship lift main structure, ship box and water in it.

Acknowledgement

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