Transactions on the Built Environment vol 42, © 1999 WIT Press, www.witpress.com, ISSN 1743-3509

Hydroelastic response analysis of a floating airport using numerical wave tank

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Abstract

Hydroelastic response of a floating airport subjected to long crested regular waves is analyzed in this study. The airport is assumed as a box shaped simple platform and a longitudinal section of it is taken as the two-dimensional computational model which is again idealized as an elastic beam. The fluid-structure interaction problem of this study is solved by a coupling technique in which the motion equation of the floating airport is implicitly coupled with the process of solving the continuity equation of fluid flow. The model is divided into several small segments and computations are carried out for different values of rigidity of the connecting system of these segments. A two-dimensional numerical wave tank developed by the author in an earlier study is used in this computation. Different frequency regular waves are generated in the numerical wave tank and motion responses of the floating airport subjected to these waves are computed. It is seen that the deflection of the structure becomes larger for relatively low frequency waves and the hydrodynamic loads exerted on the bottom of the airport can be reduced considerably introducing elasticity in the connecting system of the structure.

1 Introduction

Several types of floating structures, smaller and bigger, are built so far in the world. Floating hotel, hospital etc. are well known in many countries. Floating factory such as FPSO (Floating Production, Storage and Offloading) system may be one of the largest floating structures built in the recent years. And this kind of large floating structures are not uncommon nowadays. But the idea of building a gigantic floating structure, like an airport, is still uncommon in the world. Of course, Japan thought to build a floating airport 20 years ago and some conceptual designs were also proposed. But the project has not been realized yet. Many researchers, not only in Japan but also in other countries, are engaged nowadays with this problem and different kinds of studies and investigations are going on resulting new proposals and new ideas [2,3,5,8]. Numerous computations, experiments and numerical simulations considering different kinds of environmental forces are obviously required to predict the design criteria of this kind of gigantic floating structure. The most important and perhaps the largest environmental load which has to be encountered by this structure will come from the sea waves. Waves generated by rough sea conditions and due to earthquakes are especially dangerous for a floating airport. The conventional floating structures, built so far in the world, have reasonable ratios among their dimensions which enrich the load bearing capacity of these structures. But a structure like floating airport has peculiarity in its dimension ratios. It can be seen from the dimensions of a floating airport [4,6] that it has a very small vertical dimension compared to its longitudinal and lateral dimensions. And the peculiarity of their dimension ratios will obviously affect their strength and load bearing capacity. For smaller marine structures these problems may not predominate and only rigid body motion investigation may serve the purpose. But for a gigantic floating structure of several kilometer length, the elastic deformation may be of the order which cannot be neglected. Elastic response of such structure is, therefore, very important and should be investigated properly prior to its design. The investigation may be done by model experiments and by numerical computing methods. Numerical computing methods seem to be easier because of the advent of high speed and high capacity computers nowadays. The main aspect of present study is, therefore, related to numerical investigation of hydroelastic response of such a huge floating structure applying the numerical wave tank developed by the author in an earlier study [1].

In the present analysis, the motion equation of the floating structure is implicitly coupled with the governing equation of fluid flow. The analysis method adopted here is previously verified by the author by comparing the computed hydrodynamic loads on a rigid floating body with available experimental values [7] and now the flexibility of the structure is incorporated in the present analysis. Only the vertical motion of the floating airport is taken into account in this computation. Therefore the fluid flow due to other degrees of freedom motion has been ignored and thus it is an approximate analysis. The two-dimensional airport model is divided into a number of segments or blocks which are assumed to be connected to each other by some flexible means. Both rigid body motion and hydroelastic response of the floating airport are analyzed for regular waves of different frequencies. Different values of flexural rigidity of the connecting system of the blocks are used in the computation of hydroelastic response. It is seen that the rigidity of the structure has great influence in the hydroelastic response of the airport. The hydrodynamic pressure exerted on the bottom of the airport can be reduced considerably introducing elastic connecting systems among the blocks.

2 Assumptions and idealization of the structure

The principal dimensions of the box shaped floating airport used in this study are, length L=3000m, breadth B=800m and draft d=6.25m. A longitudinal section of the airport is considered as the two-dimensional model for the analysis of this study. In order to simplify the theoretical modeling of the problem, some other assumptions are made. The structure is considered as a two-dimensional uniform beam on elastic foundation and the slope of the deflection curve is assumed to be small enough to neglect the rotatory inertia. Hydrodynamic and hydrostatic forces due to vertical motion of any segment of the structure are to be uniform.

3 Mathematical formulation

The floating body is considered as an elastic beam of constant flexural rigidity EI and its equation of motion in a 2-D Cartesian co-ordinate system (x,z) is,

$$m\frac{d^2z}{dt^2} = F_f - mg - EI\frac{d^4z}{dx^4} \qquad (1)$$

where, m is uniform mass per unit length of the beam and g is acceleration due to gravity. Total fluid force, F_f, per unit length of the beam includes wave exciting, damping and restoring forces. Now, putting vertical velocity, w=dz/dt and a simple difference expression for acceleration, dw/dt=(w^{n+1}- w^n)/Δt we get,

$$w^{n+1} = w^n + \Delta t\left(\frac{F_f}{m} - g - \frac{[F_s]_i^n}{m}\right) \qquad (2)$$

where, w^n is the velocity at last time step n, w^{n+1} is the required velocity at the next time step n+1 and Δt is time increment. The body is divided into several segments and $[F_s]_i^n$ is the last term of eqn. (1) for segment i at time step n and calculated as follows. The beam is considered as both ends fixed (but the ends can move vertically) and the slopes of the elastic curve of the beam at two ends are zero. According to these assumptions, the forces exerted on N segments of the beam at time instant n can be expressed by,

$$[F_s]_1^n = \frac{12EI}{l^3}\left(z_1^n - z_2^n\right) \qquad \text{for segment 1,}$$

$$[F_s]_2^n = \frac{12EI}{l^3}\left(2\,z_2^n - z_1^n - z_3^n\right) \qquad \text{for segment 2,}$$

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$$\left[F_s\right]_3^n = \frac{12EI}{l^3}\left(2\,z_3^n - z_2^n - z_4^n\right) \qquad \text{for segment 3,} \qquad (3)$$

$$\vdots \qquad \vdots \qquad \vdots$$

$$\left[F_s\right]_N^n = \frac{12EI}{l^3}\left(z_N^n - z_{N-1}^n\right) \qquad \text{for segment N.}$$

Here, l is the distance between the centers of any two adjacent segments of the body and in fact equal to Δx, the x-directional grid length. The total force exerted by the fluid on the entire bottom of the body is obtained by integrating the fluid pressure over the bottom surface. The integration is performed by the summation,

$$F_f = \Sigma\left(p.\Delta x\right). \qquad (4)$$

The instantaneous fluid pressure, p, in above equation is for the cells containing the body segments and taken from the most updated values available after each iteration pass. The velocity obtained from eqn. (2) is used as the boundary velocity for the fluid cell containing the body segment, but it may not satisfy the continuity equation of fluid flow. The equation of body motion is, therefore, implicitly coupled with the pressure iteration process of the fluid dynamic calculation. In this way, the computation passes through the continuity relation of fluid flow and the new correct value of vertical velocity for a particular segment is obtained after satisfying the continuity equation by the adjustment of the fluid cell pressure and velocities. The vertical displacement, z, for any segment is then calculated from the latest correct value of the vertical velocity by the simple finite difference expression,

$$z^{n+1} = z^n + w\Delta t\,. \qquad (5)$$

4 Results and discussions

Results of the computation are summarized in the form of vertical displacement, hydrodynamic pressure on the bottom of the airport etc. Considering the practicality of the working environment of the floating airport, five different wave lengths, λ = 200, 300, 400, 500 and 600m are used in the computations with deep water condition. Wave amplitude, a, is taken as 3m. Rigid body motion of the airport is calculated first and the obtained result is compared with the result of another calculation done by Zhang using a different method (personal communication). The comparison is shown in Figs. 1 and 2 for heaving amplitude of the airport and corresponding hydrodynamic pressure p_d, normalized by ρga, where ρ is water density. Satisfactory agreement between the results can be seen from these figures. (Similar agreements with other calculated and experimental values for rigid body motion of a barge can be seen in [7]). It is observed that the motion of the floating airport for small length waves is very small, but it increases gradually with the increase of wave lengths.

Elasticity is taken into account in the next step of computation with EI = 2.1e06, 2.1e07 ($N.m^2$) and infinity. (EI=0, i.e., the case with no connectors, is also tested). Vertical motion amplitude of the floating airport and corresponding dynamic pressure for these EI values are shown in Figs. 3 and 4 for the leftmost segment (s/L=0.00416). Here s represents the distance in x-direction measured from the left end of the airport. It is seen that the left end of the airport, which is hit by the waves first, experiences bigger loads and the motion amplitude of this part is comparatively larger than that of other sections. Displacements are, in general, smaller for small length waves and increase with the increase of wave length as shown in Fig. 3. The response decreases with the increase of EI and ultimately becomes negligibly small for EI=infinity. The hydrodynamic pressure increases with the increase of EI (Fig. 4). For EI=0, the hydrodynamic pressure is very small compared to those for non zero values of EI and maximum hydrodynamic pressure is obtained in the rigid body motion (EI=inf.) of the airport. Again, the values of hydrodynamic pressure increase with the increase of wave length. Although the deflection increases with the introduction of flexibility, it helps in dynamic load reduction on the bottom of the floating airport. For small length waves, the dynamic loads decrease slightly but for long waves a drastic reduction is observed as can be seen from Fig. 4. The higher the value of EI is, the higher the hydrodynamic pressure results. Figures 5 and 6 are drawn for the time histories of vertical displacements and dynamic pressures for the leftmost segment of the airport. From these time histories we see that the motion amplitudes can be reduced considerably introducing higher EI values, but the loads will increase at the same time. By reducing the rigidity, the effective fluid loads can be reduces more than 50% from the loads experienced in rigid body motion. Selection of rigidity of the connecting system thus becomes critical. Because, the displacements of the segments should not exceed the tolerance limit for safe landing and take-off of aircraft. On the other hand, the fluid loads on the bottom of the airport should be as smaller as possible in order to avoid structural damage. Figure 7 shows the deflected shapes of the floating airport at different time instants and some typical velocity vector plots are given in Fig. 8.

5 Conclusion

Fluid-structure interaction problem of this study is solved by an implicit coupling technique. The motion equation of the floating airport is coupled with the governing equation of fluid flow. Both rigid body motion and hydroelastic motion of the structure are analyzed. It is seen that the deflection of the structure becomes larger for relatively low frequency waves. The floating airport is, therefore, weak against long length waves. It is also seen that the rigidity of the connecting system has great influence on the hydroelastic response of the airport. The hydrodynamic pressure exerted on the bottom of the airport can be reduced considerably introducing elastic connectors.

Acknowledgment

The author wishes to acknowledge Prof. Arai and Inoue of Yokohama National University, Japan for their guidance in author's doctoral study which has a relation to this work.

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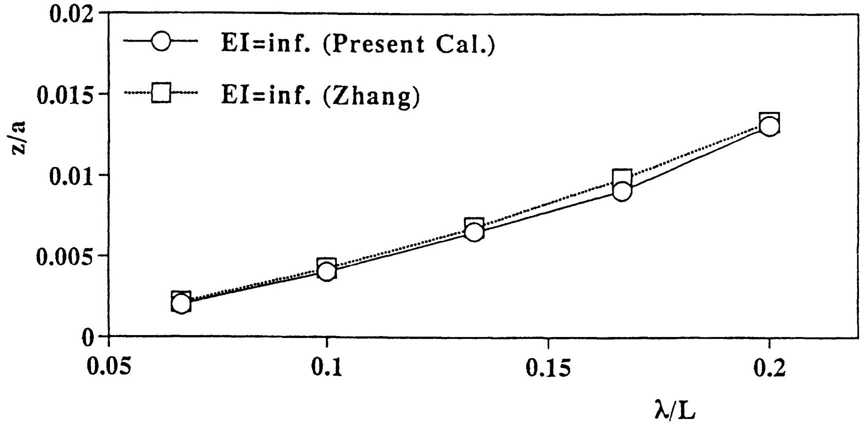

Figure 1. Heaving amplitude of the floating airport in rigid body motion

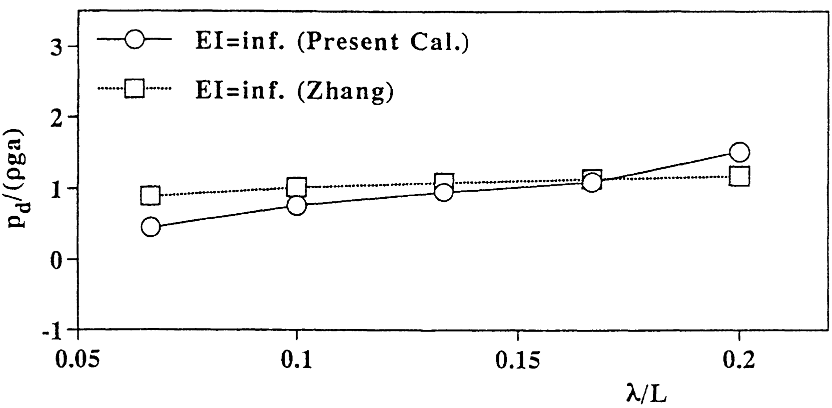

Figure 2. Hydrodynamic pressure on the bottom of the floating airport in rigid body motion (s/L=0.00416)

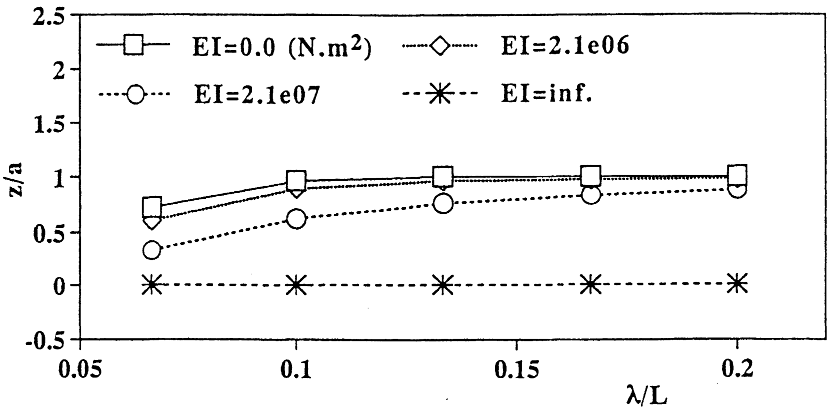

Figure 3. Maximum vertical displacements of the floating airport for different values of EI (s/L=0.00416)

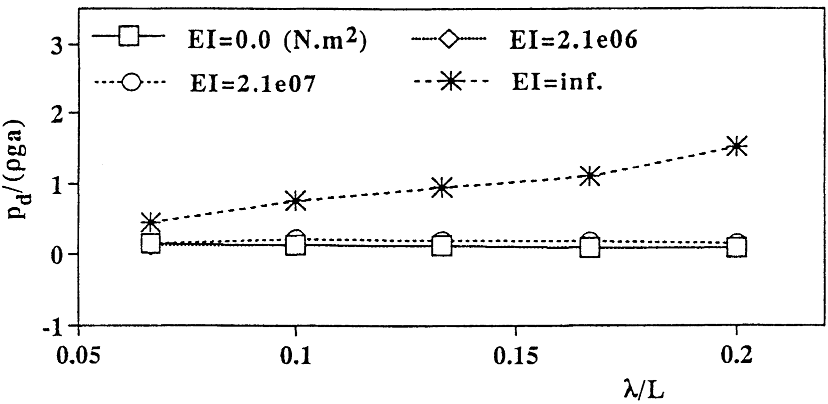

Figure 4. Hydrodynamic pressures on the bottom of the floating airport for different values of EI (s/L=0.00416)

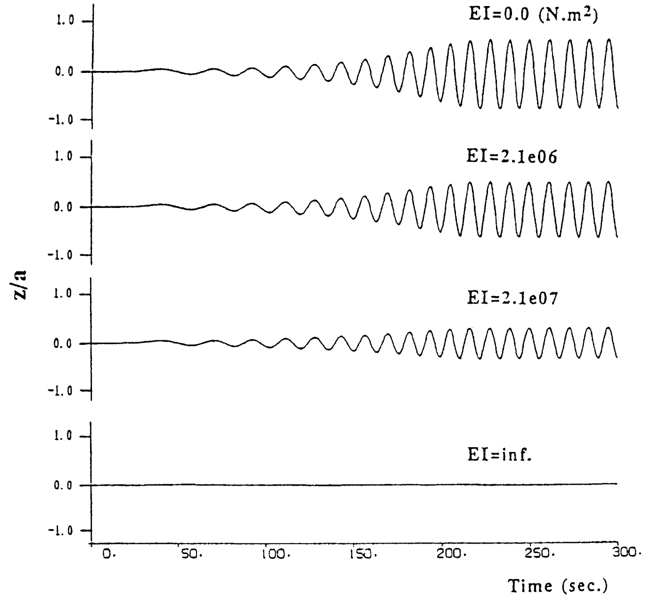

Figure 5. Time histories of vertical displacements at s/L=0.00416 for different values of EI (λ/L=0.067)

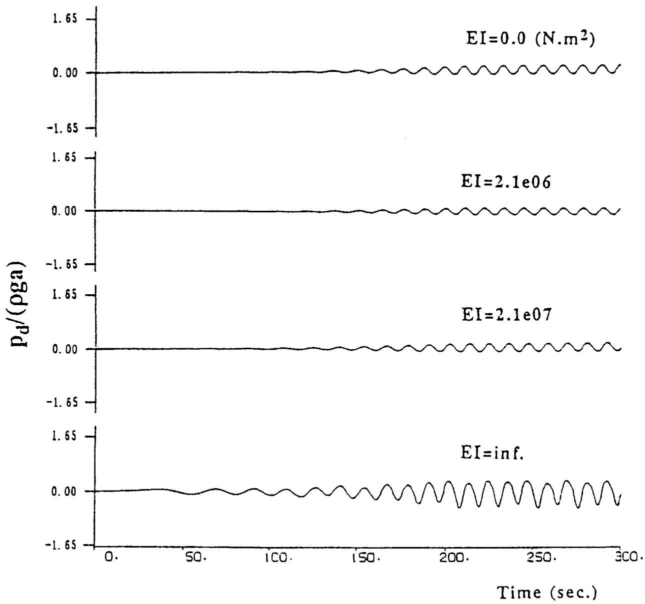

Figure 6. Time histories of hydrodynamic pressures at s/L=0.00416 for different values of EI (λ/L=0.067)

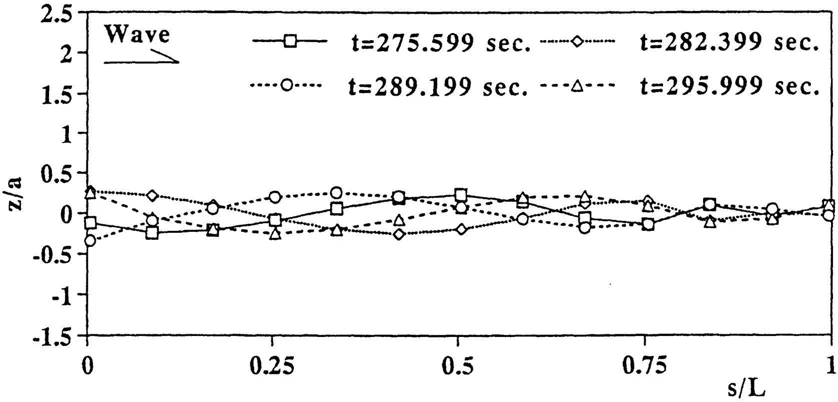

Figure 7. Deflected shapes of the floating airport at different time instants (EI=2.1e07 $N.m^2$, $\lambda/L=0.067$)

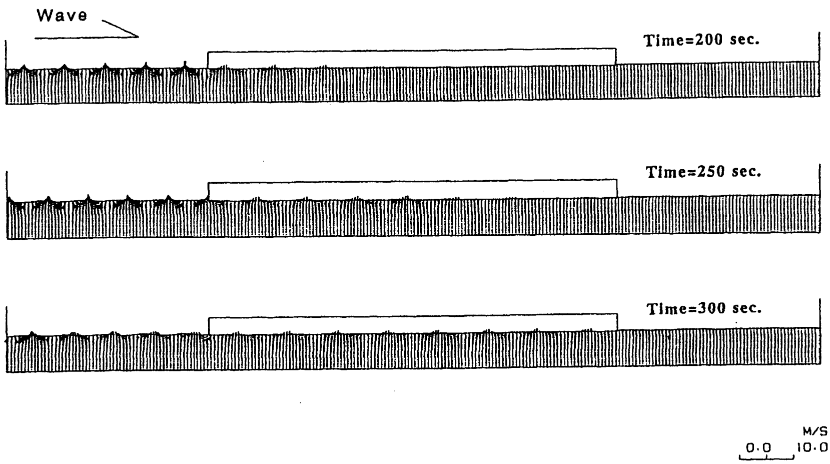

Figure 8. Velocity vector plots at different time instants for $\lambda/L=0.1$ and EI=2.1e07 $N.m^2$