CHAPTER 171

Wave Uplift Forces on Platforms with Energy Absorbers

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ABSTRACT

Interaction of large amplitude wave with platforms or docks in a variable depth medium has been studied theoretically and numerically. The underside of the platform is equipped with energy absorbing linear spring in order to study the energy absorbing effect for reducing the uplift forces on the platform or dock.

The flow is assumed to be inviscid, irrotational without current. Laplace equation with full non-linear free surface equations are solved by isoparametric mapping technique. A Galerkin finite element model is used to model the transformed equations. The adaptive line SOR (Successive-Over-Relaxation) technique is used.

The results indicate that uplift wave forces on platforms or docks can be significantly reduced by very soft springs. Wave profile history confirms the manifested mechanism of energy absorption. The results also indicate that larger uplift forces are easier to be damped out by the prescribed energy absorbing mechanism than the smaller uplift forces.

1. INTRODUCTION

It has been found that as a finite amplitude ocean wave strikes an offshore platform which is located above the still water surface, the platform will register a positive uplift force followed by a negative force if the clearance between the platform is smaller than the wave amplitude (see El Ghamry (1963), Wang (1967), French (1969), Lai (1986), Lee & Lai (1986), Lai & Lee (1988)). Such repeated wave actions constitute a serious dynamic loading to the marine platforms.

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One of the ways to overcome this problem would be to place the platform at a distance significantly above the sea surface so as to ensure that no such dynamic uplift forces would occur. Such a design however, might place the platform in a height that could create other negative impacts. For example, the economic concern or the dynamic vibrations. Another approach would be to develop certain energy absorption mechanism on the platform allowing certain reasonable and moderate soffit clearance. In an earlier study by Lai (1986), Lee and Lai (1986), it has been found that this hydrodynamic force is strongly dependent on relative wave amplitude. As the relative amplitude of the wave increases, the maximum uplift force increases while the maximum negative forces decreases. From the point of view of the structure safety, the increase in maximum uplift force might create significant negative impacts on the structure.

The main objective of this study is to explore ways to reduce the maximum uplift forces when a large amplitue wave stikes a platform. To accomplish this the numerical model presented by Lai (1986) and Lee & Lai (1986) has been extended to allow the treatment of significantly large incident wave amplitude and to incorporate the energy absorption mechanism at the platforms.

2. THEORETICAL DEVELOPMENT

For the mathematical model, the flow is assumed to be inviscid, incompressible, irrotational, and without ambient current. The wave-structure interaction can then be solved by making use of a potential flow theory, the velocity potential must satisfy the Lapace equation. A definition sketch is shown in figure 1. The dynamic free surface condition is that the pressure must be equal to the atmospheric pressure at the free surface. On the rigid boundaries, normal velocity is prescribed, for rigid bottom this velocity is zero, and for a body in motion the normal velocity of the fluid particle at the platform must be equal to that of the platform velocity. In the analysis, we allow physical domain to be long enough to have "no flow" conditions at both far field boundaries. This requires that the horizontal velocity be zero at lateral boundaries at infinity. Therefore, the governing equation and boundary conditions at free surface are:

$$\nabla^2 \phi = 0$$

$$h_t + \phi_x h_x - \phi_y = 0 \qquad on \quad y = h(x,t)$$

$$\phi_t + \frac{1}{2}(\phi_x^2 + \phi_y^2) + gh = 0 \qquad on \quad y = h(x,t)$$

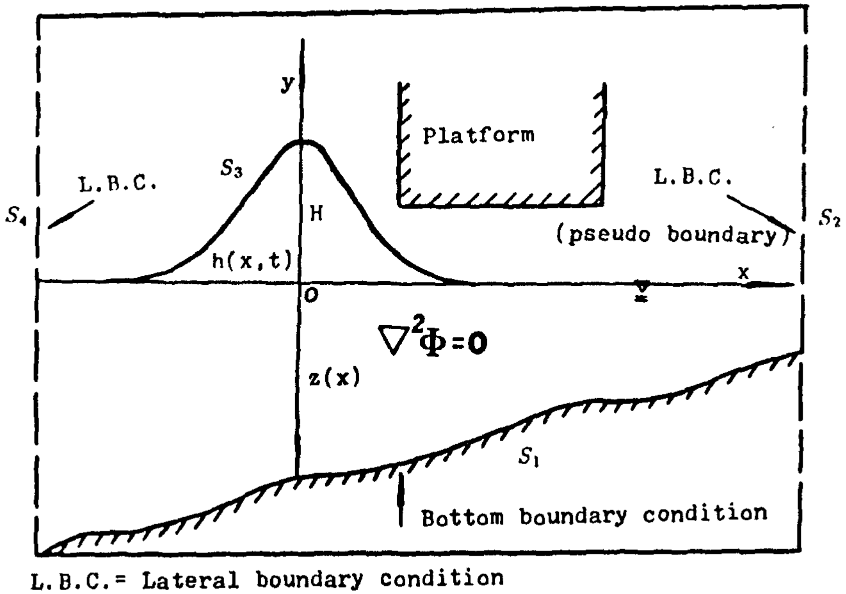

Figure 1 Definition Sketch for the Problem of a Wave Interacting with a Platform or a Dock

$$\phi_x = U = 0 \qquad on \quad S_2 \quad and \quad S_4$$

$$\phi_n = 0 \qquad on \quad S_1$$

$$\phi_y = V = \frac{ds}{dt} \quad (when \quad wave \quad hit \quad the \quad platform) \qquad on\ S_3$$

where S_1 , S_2 , S_3 , S_4 are surface boundaries.

It is noted that the difference between the present formulation and the prior studies by the authors is to allow the underside of the platform to move at the velocity ds/dt. This motion is resisted by a distribution of linear springs assumed to exist just above the surface of the underside of the platform. A rigid platform would correspond to the case of spring constant being infinite. A softer spring therefore would yield a larger velocity of the underside of the platform.

The difficulty of the problem lies in the nonlinearity and the coupling of the boundary conditions at the free surfaces, which are time dependent. The free surface elevation is an unknown a priori and it must be a part of the solution of the problem along with the Laplace equation on the interior of the fluid region as well as the equations at the free surface. To handle a moving free surface and an irregular bottom topography, we adopt a mapping technique to transfer the fluid region and its boundaries into a regular geometry.

The physical domain is transformed into a regular computational domain by using isoparametric mapping. The transformed governing equations are more complicated than the original governing differential equations. However, the advantage is that the solution region has a regular retangular shape in the parent plane. The nonlinearity of the moving free surface is no longer a serious problem in the transformed plane. The approximate solutions of the transformed equations are sought by using the Galerkin's finite element method. For a detailed discussion of the numerical procedure, the reader is referred to Lai (1986).

The finite element model is advanced in time by integrating the dynamic and kinematic free surface equations. The Runge-Kutta method is employed with mass lumping. The mass lumping technique can eliminate the coupling between the time derivatives of the unknowns at adjacent nodes and reduce the computer storage and computational steps with only a minor loss in accuracy.

A major difficulty in numerical integration of the free surface equations is the computational instability. Approximation of spatial derivatives by numerical methods introduces truncation errors.

These errors are amplified by nonlinear terms and as they accumulate for large time, would seriously affect the accuracy of the solution. Moreover, when a wave starts to hit a platform or a dock, run-up is created by the platform or the dock, and reflected wave can be formed at the frontal edge of the platform or dock. This discontinuity in the free surface profile causes a severe oscillation at the frontal face of the platform or dock for the large time. To avoid the instability of numerical integration, an artificial viscosity term has been introduced with their value determined by numerical experiments.

An adaptive line SOR algorithm is developed and used to speed up the repeated solution of linear algebraic equations resulting from finite element discretization of the transformed Laplace equation. The idea of adaptive line SOR method is to employ adaptive parameter of relaxation in LSOR to accelerate the convergence rate. It was found that the adapted line SOR algorithm could effectively reduce the error norm by several orders of magnitude for the similar number of iteration.

3. PRESENTATION AND DISCUSSION OF RESULTS

One of the simplest energy absorbing mechanisms which could be employed for numerical experiment is to place flexible spring just above the underside of the platform where wave could hit the platform. The spring allows the underside of the platform to deform upward as the postive uplift forces occur. It would also allow it to return to the original surface as the contact between the water surface and the underside of the platform ceases to exist. A variation of different spring constant has been experimented. It is noted that the case of rigid platform corresponds to the case of infintely large spring constant K.

Figure 2 shows the numerical results of the hydrodynamic uplift force in platform with a 3 inch soffit clearance in a water depth of 15 inch. The relative wave amplitude is 0.24. The ordinate of the figure is the ratio of the total hydrodynamic uplift forces which is integrated from the computed uplift pressure over the entire platform divided by the total hydrostatic forces. The hydrostatic force is taken as the integrated weight of the water above the elevation of the platform. The computed forces based on the present numerical procedure is plotted as a function of the normalized time history. Three different spring constants are used for comparison. The rigid body would represent a spring constant of infinity. It is seen that the softer the spring the smaller the computed uplift forces. The wave amplitude used for this case is not too large, therefore the positive uplift forces differ only slightly from the hydrostatic forces. From the numerical result it is also clear that in order to meaningfully reduce the uplift force (either positive or negative) the flexible spring has to be quite

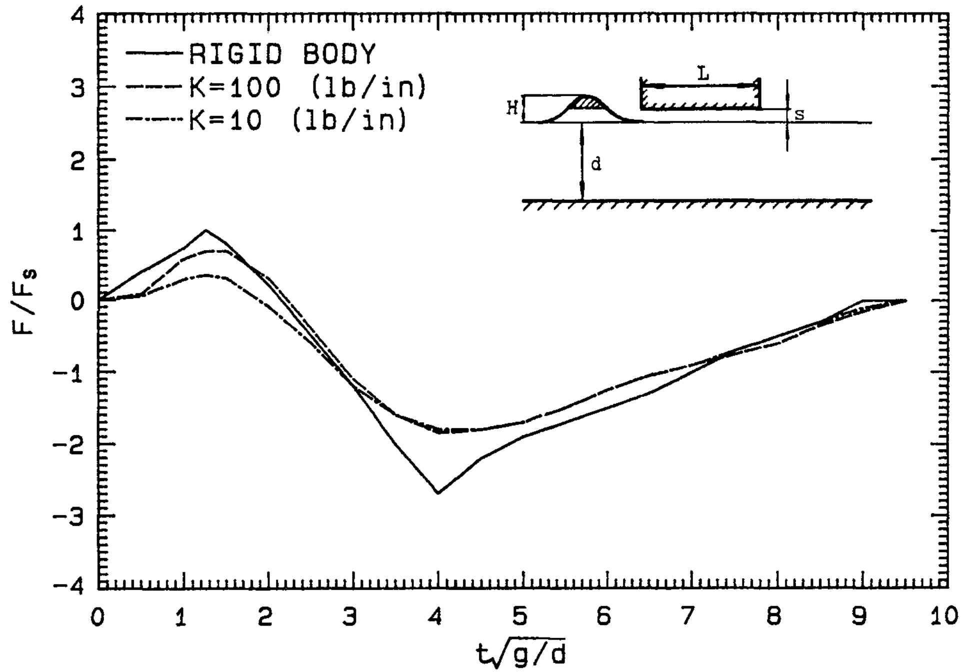

Figure 2 Normalized Total Hydrodynamic Force Per Unit Width. (H/d = 0.24, s/d = 0.2, L/d = 4, d = 15 in.)

soft.

Figure 3 presents the force history when the incident relative wave amplitude is increased to 0.32 keeping other parameters the same as that shown in Figure 2. In this case the positive uplift force is significantly increased, this phenomena has been shown in earlier studies by Lai (1986) and Lai and Lee (1988). Based on the numerical results it is surprising to find that for moderately stiff springs the magnitude of the forces can only be modified by a small amount. In order to reduce the maximum postive uplift forces by a significant degree the spring must be quite soft. A comparison of the results for K=100 lb/in and that for K=10 lb/in show that the magnitude of the positive uplift force is significantly reduced for K=100 lb/in the magnitude of uplift force is quite close to the case of rigid platform.

The normalized uplift force per unit width in a sloping bottom is shown in Figure 4 for a rigid platform and that with two different spring constants (K=100 lb/in and K=10 lb/in). The relative incident wave amplitude is 0.32 and that the platform is placed at the back wall allowing wave reflection from the back wall. As expected, the positive uplift force is drastically large than that shown in Figure 3 signifying the effect of wave reflection from the back wall. The effect of the energy absorbing spring to dampen the large uplift forces can clearly be seen from the numerical results.

It is interesting to learn how the wave form changes as the incident wave interact with the platforms or docks. Numerical result on the wave amplitude along the direction of wave propagation is shown in Figure 5. The parameters representing the wave channel, incident waves and the dock dimensions are the same as that shown in Figure 4. In Figure 5, wave profiles along the x axis at different time steps are shown for K=100 lb/in. It is seen that the wave crest have not reached the platform after 150 time steps thus the incident wave has been propagating unchanged toward the positive x direction. After 200 time steps portion of the incident wave hit the platform (as the soffit of the platform is smaller than the wave amplitude), thus wave form is changed accordingly and the relatively soft spring allow the underside of the dock to absorb energy by compressing the spring. This process continues through 250 time steps. At 300 time steps the travelling wave is reflected back from the back wall and is travelling away from the dock region. without the confinement of the underside of the dock platform, large amplitude oscillation is seen in the wave amplitude profile presented in the result for 300 time steps. This interesting phenomena is repeated in Figure 6 at 300 time steps for two different spring constants. For K=100 lb/in the maximum clearance between the still water level and the underside of the dock is less than 0.3 as shown in Figure 6. As portion of the wave travels back and moving away from the dock site, the wave (both positive

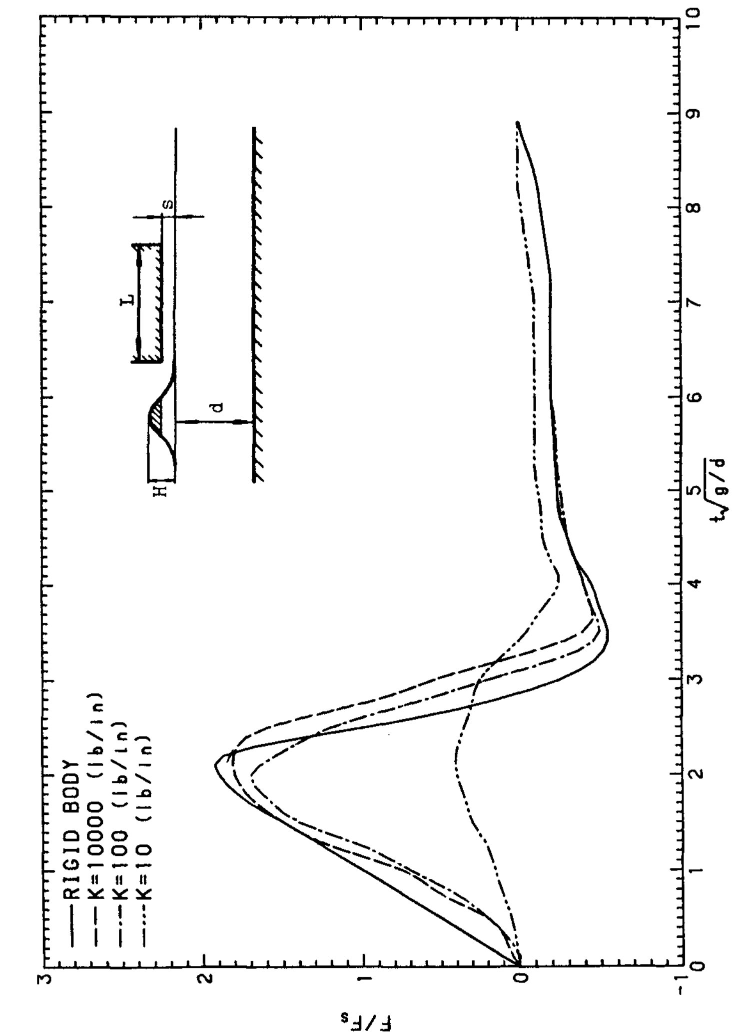

Figure 3 Normalized Total Hydrodynamic Force Per Unit Width.
(H/d = 0.32, s/d = 0.2, L/d = 4, d = 15 in.)

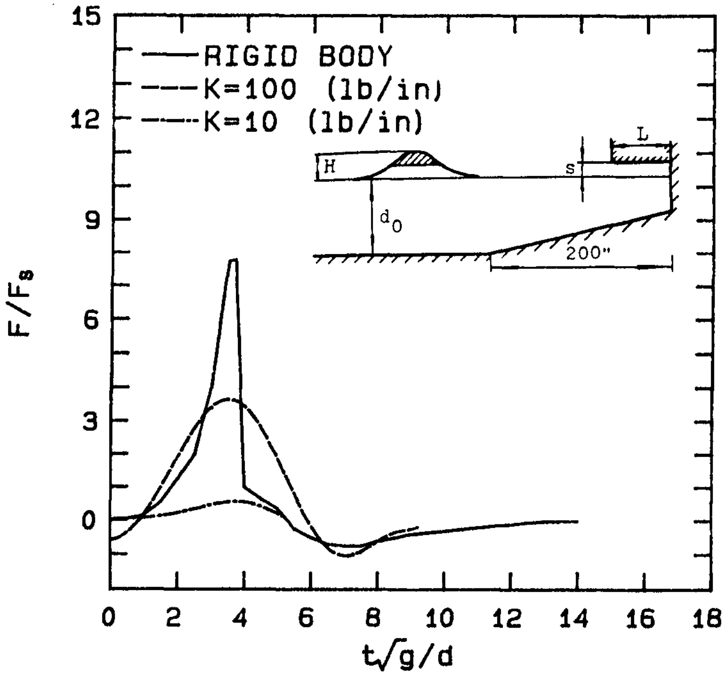

Figure 4 Normalized Uplift Force Per Unit Width (H/d_0 = 0.32, s/d_0 =0.2, L/d_0 = 4, d_0 = 15 in.)

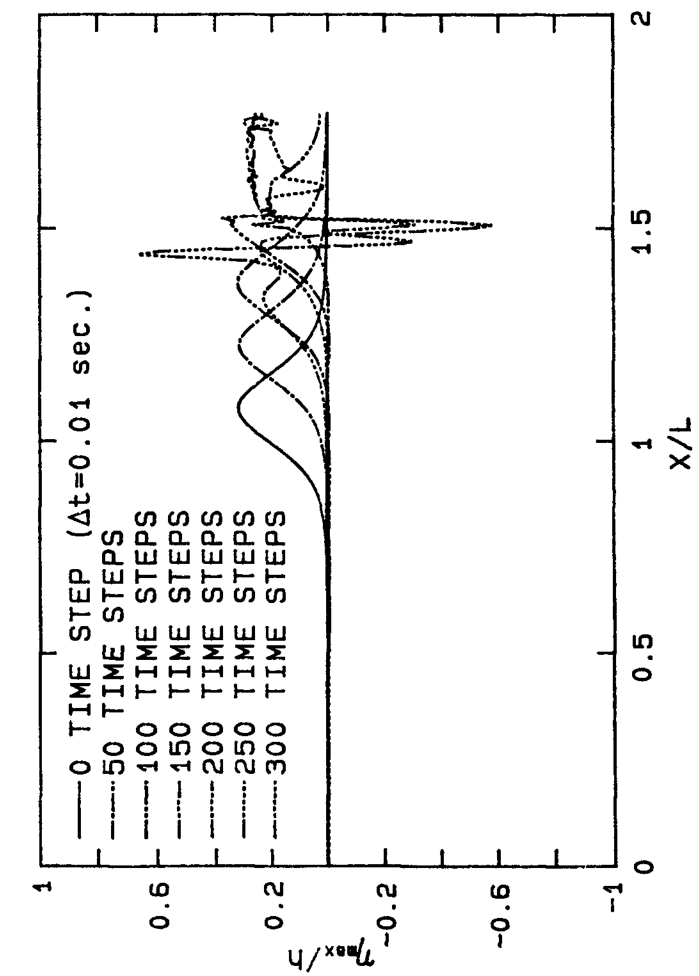

Figure 5 Wave Profiles at Different Time Step before and after Interacting with the Dock Placed at a reflecting Back Wall

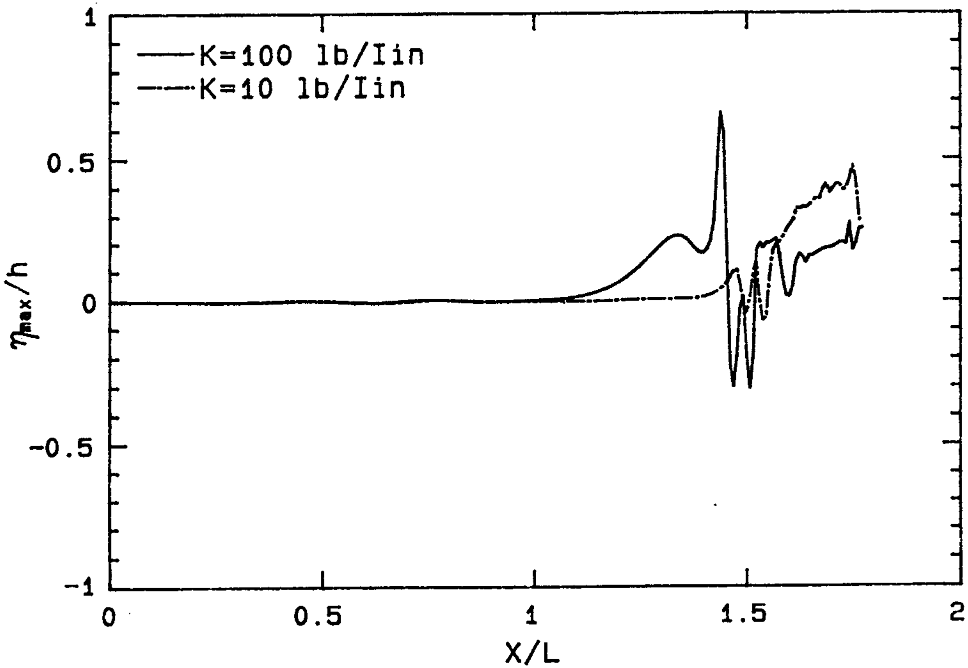

Figure 6 Wave Profile at 300 Time Steps Interacting with the Dock with Different Spring Constants Associated with the Energy Absorber

and negative) is significantly increased its amplitude. For a softer spring (K=10 lb/in) the underside of the dock is permitted to move upward thus the clearance is increased thereby absorbing a significant amount of wave energy. Therefore, wave profile for K=10 lb/in at 300 time steps is reduced. It is interesting to note the difference in wave phases for these cases for spring with K=10 lb/in, wave appears to travel at a slower speed.

4. CONCLUSION

The numerical experiments conducted in obtaining the effect of absorbing linear springs placed at the underside of the platform /or dock appears to be able to absorb certain wave energy and to reduce the positive uplift force induced by wave interacting with platforms /or docks. Significant reduction in this uplift force can only be achieved by very soft springs. For the dock problem (reflecting wall placed at the end of the dock) the energy absorbers appear to offer greater reduction in the uplift forces. The magnitude of the uplift forces experienced by the platform /or dock with spring attached at its underside can be computed using the present numerical model but can not be generalized by a simple formula due to the complexity of the problem.

5. ACKNOWLEDGMENTS

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