Wave Uplift on Platforms or Docks in Variable Depth

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ABSTRACT

Wave uplift forces on two dimensional platforms or docks in a variable depth medium has been studied theoretically and numerically. The incident waves are non-linear waves with maximum amplitude greater than the clearance between the still water surface and the underside of the platforms or docks.

The flow is assumed to be inviscid, irrotational without ambient current. Thus, the theoretical model solves the Laplace equation along with full non-linear free surface conditions. In order to conveniently handle the moving free surface in an irregular bottom topography with the presence of platform or dock an isoparametric mapping technique was used to transfer the fluid domain and its boundaries into a regular geometry. A Galerkin finite element model is developed to model the transformed fluid region. The resulting discrete equations are solved iteratively by using adaptive Line SOR (Successive-Over-Relaxation) technique. Artificial viscosity is included in both the dynamic and kinematic free surface equations to damp out the free surface oscillations in the front region of the platform or dock. The Runge-Kutta method is employed to integrate the time variation in the nonlinear free surface equations.

Results obtained by the numerical method were compared to the available experimental data obtained by others in order to demonstrate the workability of the proposed algorithm.

1. INTRODUCTION

In a storm or in the present of unusual wave activities, marine structures, such as platforms or docks, may be subjected to significant uplift forces even if they are built above the still-water level. These forces occur when large incident wave propagate beneath the structure and make contact with it. If these uplift forces are not properly accounted for in the design, they can ultimately destroy the structure.

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When waves approach the coastal region, they are continously modified by the bottom topography and the coastline configuration. The decrease in water depth contributes to the increase in the effect of nonlinearity of the wave. Due to the importance of nonlinearity effect in sloping bottom, finite amplitude wave theories has to be applied. Furthermore, if a platform or dock which is built above the still-water level is present then the problem will be more complex. The problem to be encountered is a combination of nonlinear free surface conditions, upper and bottom rigid boundaries, and shoreward edge rigid boundary (if dock problem is considered). A suitable numerical model must be applied to handle this complex problem.

The major objective of this paper is to present a convenient numerical model to investigate aspects of wave uplift forces on platforms and/or docks either in horizontal or a sloping bottom.

2. MATHEMATICAL AND NUMERICAL FORMULATION

To develop the mathematical model, the flow is assumed to be inviscid, irrotational and without ambient current. The entire physical problem can be illustrated in Fig. 1 and the governing equations for the velocity potential are:

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

$$\phi_y = h_t + \phi_x h_x \tag{1}$$

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

Due to the nonlinearity of free surface equations, irregular bottom topography, and the presence of platform or dock, the original physical problem is difficult to solve by ordinary finite element method. To overcome this difficulty, a transformation technique is applied to map the complex physical domain into a regular computational domain.

Two steps are needed to transfer the physical domain into a regular computational domain by using isoparametric mapping. The first step is to transfer the irregular free surface and the bottom boundary into straight line segments by using six-node isoparametric elements. In this stage, the flow field has been transfered into several rectangular cells. The second step is to consider each rectangular cell as being separately mapped by a local bilinear isoparametric mapping to a new isoparametric plane.

The transformed governing differential equations take the following form:

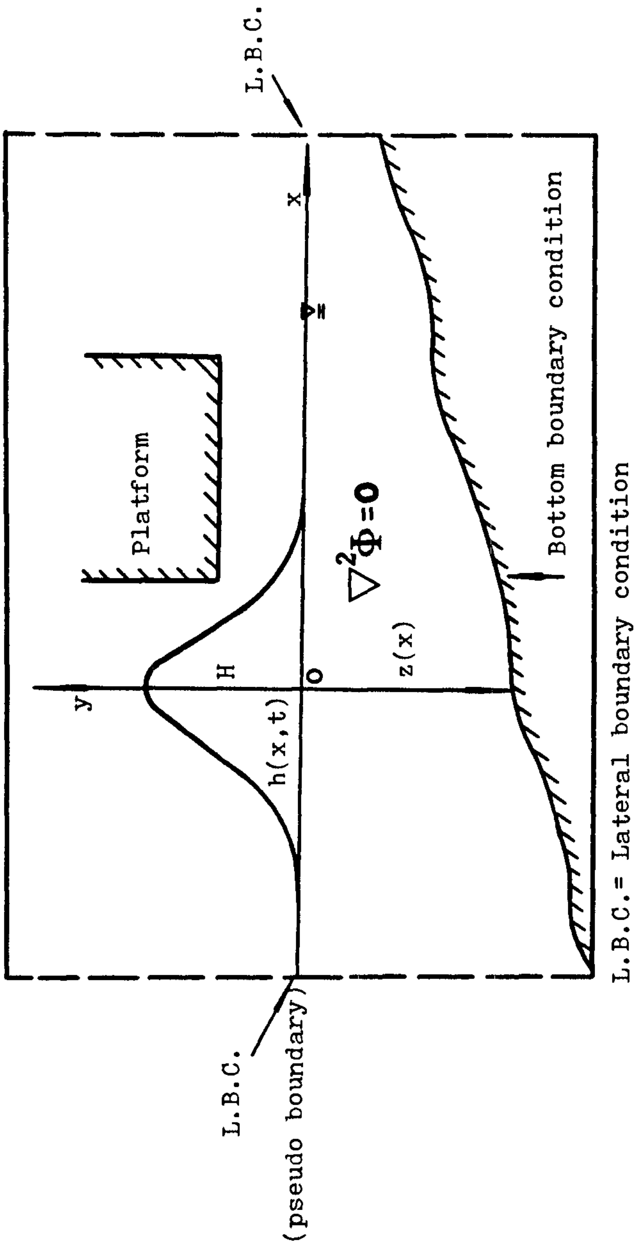

Fig. 1 Conceptual model of a solitary wave hitting a platform or a dock.

$$
\begin{gathered}
A_{KM}\phi_{\overline{\xi\xi}} + B_{KM}\phi_{\overline{\eta\eta}} + C_{KM}\phi_{\overline{\xi\eta}} + D_{KM}\phi_{\overline{\eta}} = 0 \\
\phi_t + \frac{1}{2}A_{KM}\phi_{\overline{\xi}}^2 + \frac{1}{2}B_{KM}\phi_{\overline{\eta}}^2 + \frac{1}{2}C_{KM}\phi_{\overline{\xi}}\phi_{\overline{\eta}} + gh = 0 \\
h_t + A_{KM}h_{\overline{\xi}}\phi_{\overline{\xi}} + H_{KM}\phi_{\overline{\eta}}h_{\overline{\xi}} - G_{KM}\phi_{\overline{\eta}} = 0
\end{gathered}
\tag{2}
$$

where the following various coefficients are defined

$$
\begin{gathered}
A_{KM} = \xi_x^2 \qquad D_{KM} = \eta_{xx}Q \\
B_{KM} = (\eta_x^2 + \eta_y^2)Q^2 \qquad G_{KM} = \eta_y Q \\
C_{KM} = 2\xi_x\eta_x Q \qquad H_{KM} = \eta_x\xi_x Q \\
\text{where } Q = \overline{\eta}_\eta = \frac{2}{\Delta \overline{h}}
\end{gathered}
$$

In the analysis, the approximate solutions of the transformed equations are sought by using the Galerkin's finite element method. The finite element model is advanced in time by integrating the free surface dynamic and kinematic equations. The Runge-Kutta method is employed with mass lumping. A major difficulty in numerical integration of the free surface equations is the nonlinear computational instability. To avoid the instability of numerical integration, artificial viscosity is included in both dynamic and kinematic free surface equations. An adaptive line SOR algorithm is developed and used to speed the repeated solution of linear algebraic equations resulting from finite element discretization of the transformed Laplace equation. It was found the adapted line SOR algorithm could effectively reduce the error norm by several orders of magnitude for the similar number of iteration.

3. NUMERICAL RESULTS

When ocean waves approach the coastal region, the wave shape and the propagation direction would change because of changes in coastal topography. A solitary wave traveling in a uniform depth region would not change its unique shape, however, it will break into a number of solitons when it propagates into a shallower continental shelf. Such "fission" phenomena have been found by many investigators (for example, see Madsen and Mei (1969) and Kim (1977)).

Fig. 2 presents the numerical solution of the development of an initial solitary wave over a shelf of 1:20 slope using the numerical model developed in the present study. The initial wave amplitude is 0.36 in., the water depth at the upstream of the shelf is assumed to be 3 in.; downstream of the shelf is chosen to be 1.5 in.. This bottom configuration has been used by Madsen and

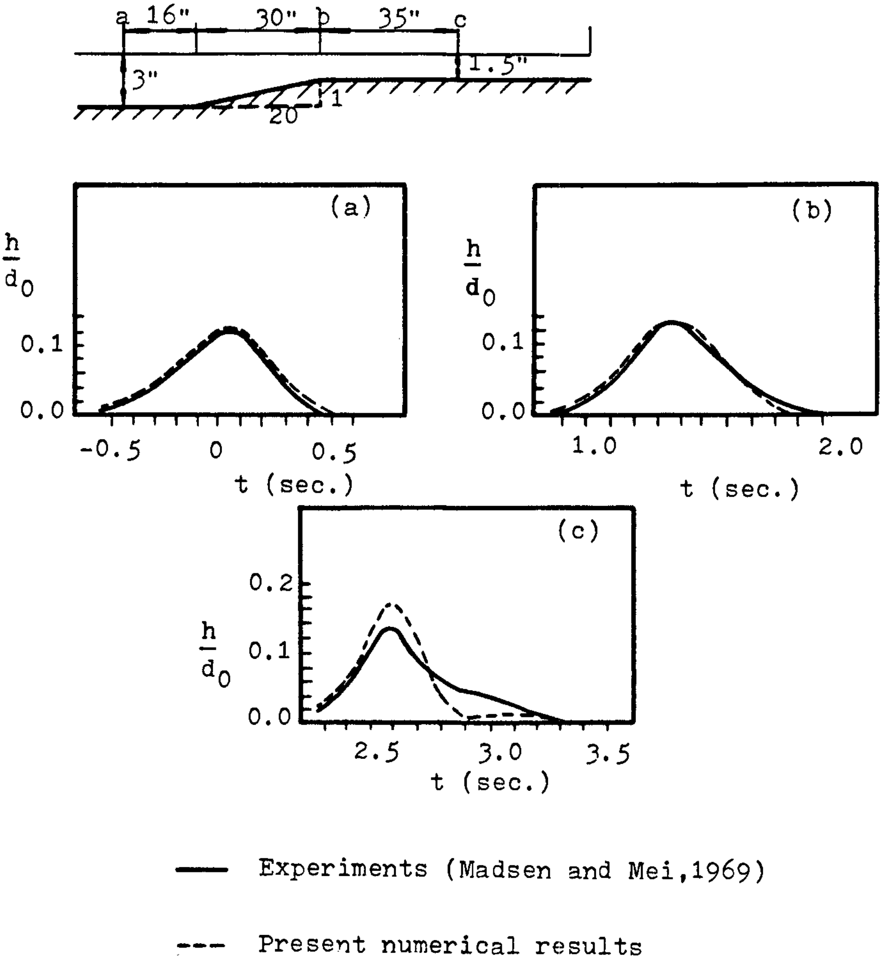

Fig. 2 The propagation of solitary wave over an uneven bottom. Comparison of numerical results and experiments. (H/d_0=0.12, d_0=3.0")

Mei (1969) in their numerical and experimental analysis. In our computational model, the time increment is taken to be 0.01 sec., and spatial interval is chosen to be 1.0 in.. The computational time for this case requires about 1 hour and 5 minutes (on VAX-11/780 machine).

The numerical results of wave profile at locations (a) and (b) in Fig.2 agree well with the experimental data obtained by Madsen and Mei (1969). However, by observing the wave profile at location (c) in Fig.2, there is disagreement between numerical and experimental values of wave profile. The maximum amplitude of computed wave profile is higher than that of experimental wave profile. A small hump in the tail of computed wave profile can be seen. This hump in the wave tail will be separated from the leading wave when the wave is propagated further downstream. This result have been found by Madsen and Mei (1969) and Kim (1977) using the same geometrical data and fluid parameters. This example demonstrates that the present numerical model is acceptable for sloping bottom.

Fig.3 shows the hydrodynamic uplift force on a horizontal platform resulting from a solitary wave travelling in a constant water depth. The ratio of the crest amplitude to the water depth is 0.24 which is 20% larger than the platform clearance. The ordinate is the ratio of the total hydrodynamic uplift forces (integrated from the computed uplift pressure over the entire platform) divided by the total hydrostatic force. The total hydrostatic force (Fs) is taken as the integrated weight of the water above the elevation of the platform which is denoted as the shaded area in the inserted sketch. The computed force based on the present numerical procedure is plotted as a function of the normalized time history. The experimental data was obtained by French (1969). The present numerical results are also compared with Iradjpanah's results (1983). It is seen from Fig.3 that the present numerical results agree reasonably well with the experimental data. It shows that when the solitary wave strikes the platform the platform experiences an uplift force followed by a negative force which is substantially larger than the positive uplift.

Fig.4 presents the time-history of normalized total force for a relative amplitude H/d=0.32 of wave propagating over a shelf. The platform is situated at the location which is 40 in. away from the beginning point of the slope. The horizontal dimension of the sloping bottom is 200 in.

It can be seen from Fig.4 that the effect of sloping bottom on the normalized total hydrodynamic force is very significant and the normalized total force increases in the sloping bottom. However, the total hydrodynamic force of the steep slope is slightly smaller than that of the mild slope.

If the platform is moved further away from the beginning point of the slope

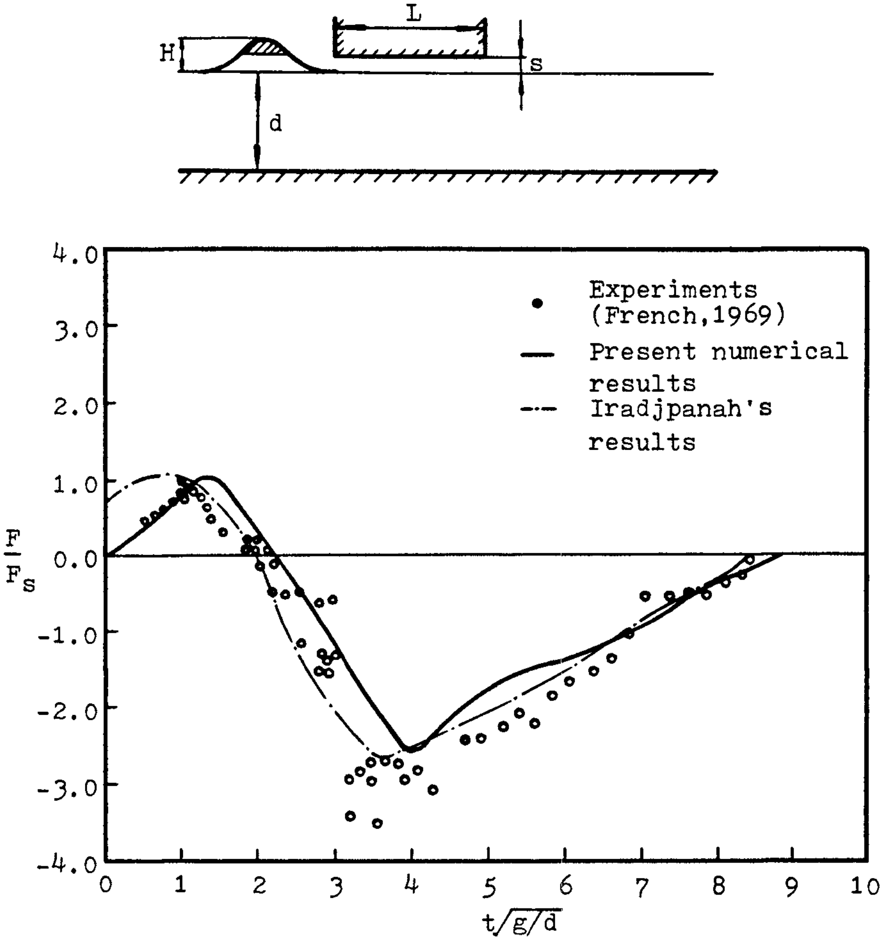

Fig. 3 Normalized total hydrodynamic force per unit width. ($H/d=0.24, s/d=0.2, L/d=4, d=15"$)

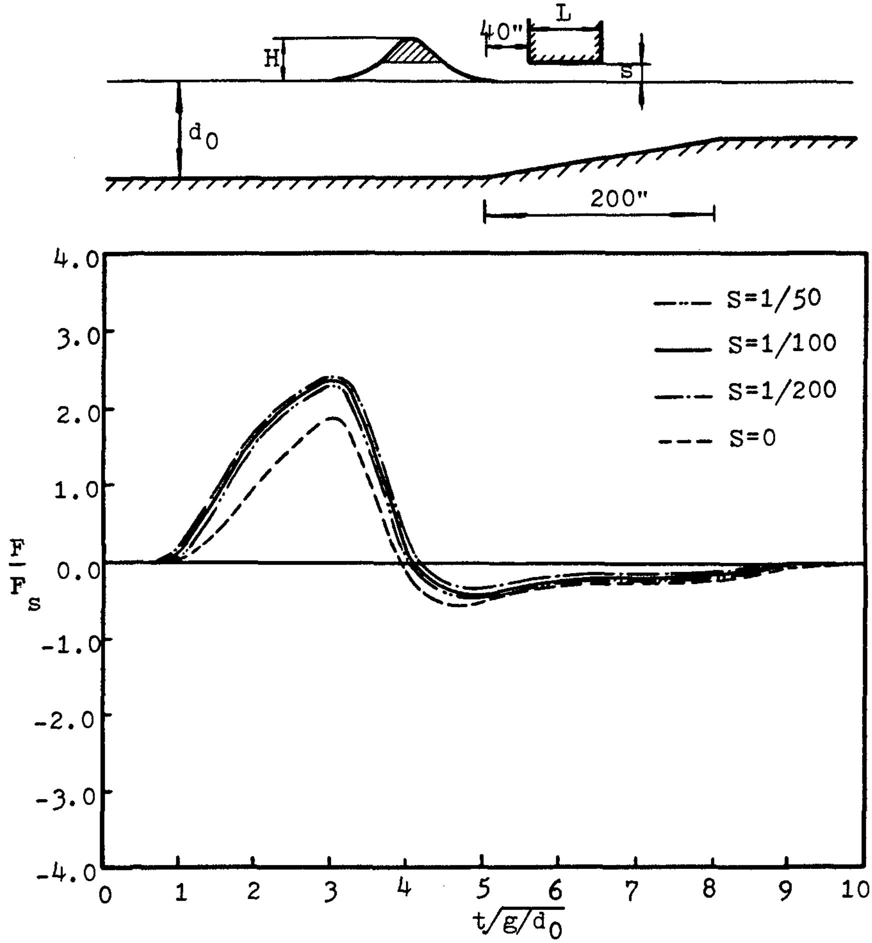

Fig. 4 Normalized total hydrodynamic force per unit width.
($H/d_0=0.32, s/d_0=0.2, L/d_0=4, d_0=15"$)

as shown in Fig.5, the nonlinearity and reflection effects of sloping bottom are more remarkable than that in Fig.4. The increase in the effect of nonlinearity increases the maximum amplitude of the wave, hence the total hydrodynamic force. This phenomenon is more significant for the mild slope than for the steep slope. A possible reason for this phenomenon is that the reflection effect reduces more nonlinearity effect for the steep slope than for the mild slope such that the amount of the increase of the total hydrodynamic force or the maximum amplitude is not proportionally increased.

Fig.6 shows the resulting uplift force when a reflecting boundary is introduced and the water depth is allowed to vary. This would represent a dock located near a reflecting wall. The ordinate and the abscissa are normalized as that shown in Fig.3. The incident wave height however is 60% greater than the platform clearance. By comparing the general feature of Fig.3 and 6, it is seen that the effects of the sloping bottom and the reflecting boundary significantly increase the positive uplift forces.

4. CONCLUSIONS

The numerical results computed from various incident wave heights in different bottom profile striking platforms and/or docks of varying nature show a consistent picture that the present numerical model works well. The platform experiences a positive uplift followed by a negative uplift force when a wave stikes the platform. The magnitude of this uplift force can be computed using the developed model but can not be generalized by a simple formula because of the complexity of the problem. For a dock problem (reflecting wall placed at the end of the dock) the positive uplift appeared to be significantly increased while the negative uplift is reduced.

5. ACKNOWLEDGMENTS

The authors appreciate the funding supports from the U.S.C. Foundation for Cross-Connection Control and Hydraulic Research (FCCCHR) and the NOAA Sea Grant Program.

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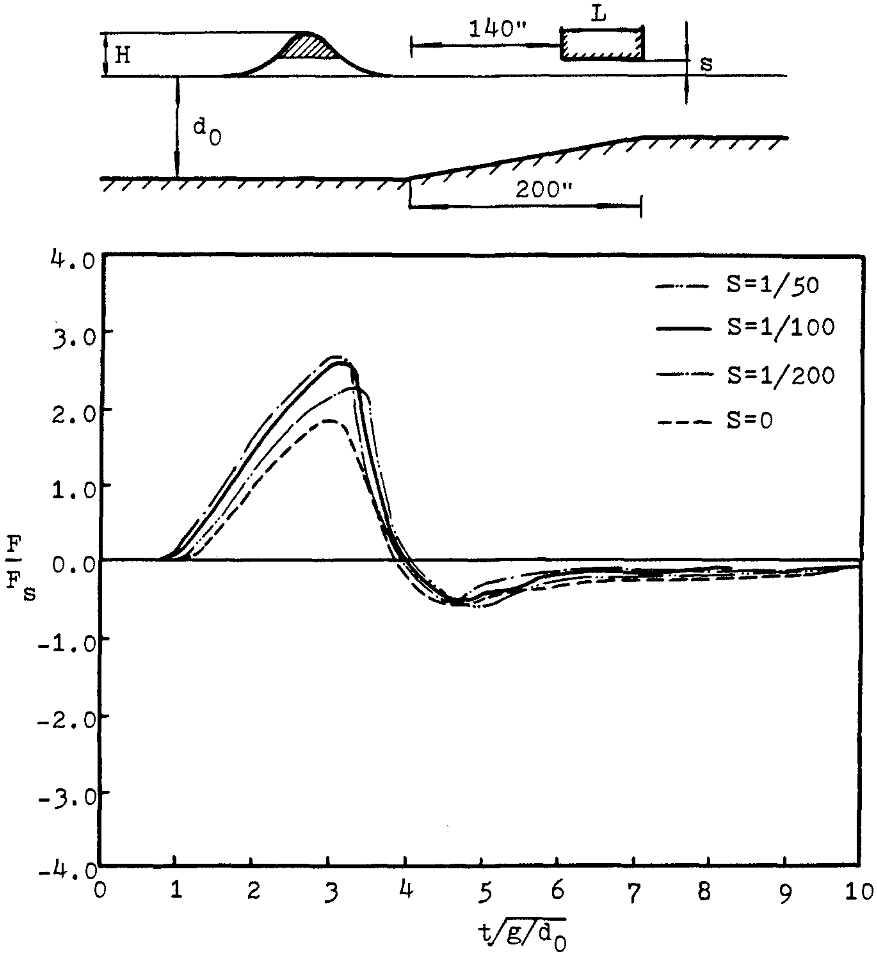

Fig. 5 Normalized total hydrodynamic force per unit width. (H/d_0=0.32, s/d_0=0.2, L/d_0=4, d_0=15")

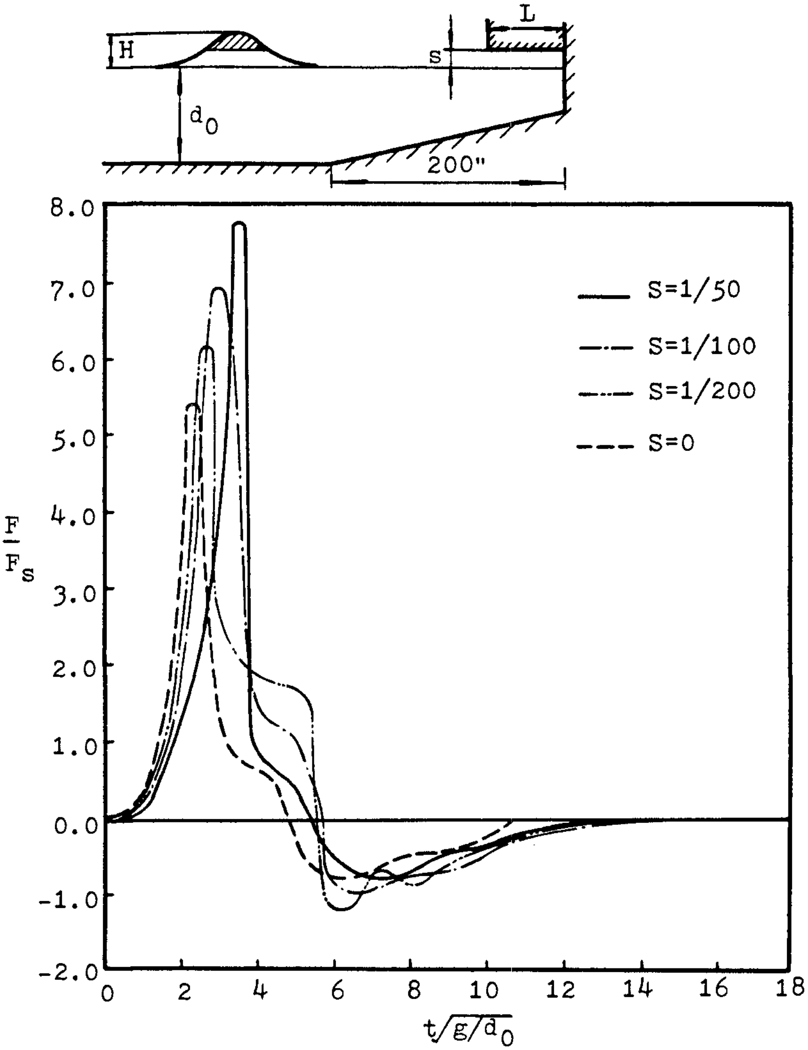

Fig. 6 Normalized total hydrodynamic force per unit width. (H/d_0=0.32, s/d_0=0.2, L/d_0=4, d_0=15")

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