A new approximate technique for the hydrodynamic analyses of a huge floating structure

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1. Introduction

In Japan a huge box-shaped floating airport is now being proposed. The expected dimension is 5km in length and 1km in width while the depth will be around 5m. The structure is so huge that the direct application of conventional numerical techniques for its hydrodynamic analyses is practically impossible from the viewpoint of the cost or the time required for the computations. For example, let us suppose that we carry out a waveforce analysis by a singularity distribution method while discretizing the wetted surface of the corresponding structure into panels on which singularity strength is assumed to be constant. Since it may be reasonable to assume that at least 10 panels are needed in one wave length, the total number of panels needed for the analysis will be about 330,000 when the wave period is 5 second and about 20,000 when the wave period is 10 second. (This number only accounts for the panels on the bottom of the structure and thus the thickness of the structure is not taken into account.)

Although as illustrated above the analysis is difficult because the structure is huge, we show in this paper that we can exploit the very fact that the structure is *huge* to come out an approximate technique which can reduce the required computational effort drastically without appreciable loss of accuracy.

2. Theory and Results

2.1 A very long structure in beam waves

We first consider a very long structure in regular beam waves. Hereafter we suppose that we carry out a waveforce analysis by a singularity distribution method. If the structure were infinitely long, it is evident that the strength(including the phase) of the singularity on each panel located in beamwise direction should be identical. Then, when the length of the structure is finite but still very large, it may be justified to assume that the strength of the singularities on the panels located in beamwise direction at more than a certain distance from the both ends is identical. If this is the case, the structure need not be discretized into panels of equal size but instead a certain inner part can be represented by a single long panel on which the the strength (as well as the phase) of the singularity is assumed to be constant everywhere. This approximation can reduce the number of panels required for the analysis.

2.2 A very long structure in oblique waves

Next we consider a very long structure in oblique waves as shown in Figure 1. The approximate technique used in the case of beam waves can still be applied with a slight modification. In oblique waves, if the structure were infinitely long, it can be easily understood that the singularity strength on the panels along the beamwise direction should satisfy the following relationship.

$$\sigma_j = \sigma_i \cdot e^{ik(y_j - y_i)\sin\chi} \tag{1}$$

where σ_j, σ_i represent the singularity strength on the panel-j and panel-i respectively and y_j, y_i represent the y coordinates of the corresponding panels. k stands for the wave number. From the same argument used in the previous section, when the structure is finite but still very long, a certain inner part of the structure may be represented by a single panel on which the singularity strength is assumed to vary according to equation (1). Figure 2 confirms the validity of the present approximation. The figure compares the results on the beamwise distribution of singularity strength obtained by discretizing the structure into 300 panels of equal size on which the singularity strength is assumed to be constant and those obtained by discretizing the structure into 63 panels. Among the 63 panels, 60(10×6) panels are located at the both ends of the structure in order to account for the end effects while the 3 large panels occupy most of the inner part of the structure on which the singularity strength is assumed to vary as described by equation (1). The results obtained by this approximation are almost identical with those obtained by 300 panels.

2.3 A very long structure in head waves

Finally we consider a very long structure in head waves. If we apply the approximation given by equation (1) for the analysis in head waves by simply substituting $\chi = \pi/2$ into the equation, a noticeable difference is observed between the results obtained by 300 panels of equal size and those obtained by the approximation. That is, in the former ones the absolute value of the singularity strength decays from upperstream to downstream whereas in the latter ones the absolute value of the singularity strength are constant at the inner part of the structure as a consequence of equation (1). The decay of the singularity strength may be because the energy of the incoming waves is reflected more or less at each panel. This suggests that if the structure were really infinitely long, the singularity strength should be zero at infinitely far downstream because the amount of energy will eventually disappear as the waves travel across over an infinite number of panels, which indicates that even if the structure is very long there is no place where we can assume equation (1) holds. Among two tandem adjacent panels, the number of panels across which the wave travels until it reaches the downstream panel is always larger by 1 than the number of panels needed for the wave to travel across until it reaches the upperstream panel. Therefore the end effect persists to infinitely downstream. In order to illustrate these effects let us consider an infinite number of equally-spaced array of vertical 2-D truncated walls in head waves as shown in Figure 3. The flow field around $i-th$ wall may be decomposed as indicated in Figure 3, where $\phi_0 e^{i(kx-\omega t)} + \phi_i^+ e^{i(kx-\omega t)}$ represents the wave that comes from the upperstream, in which $\phi_0 e^{i(kx-\omega t)}$ stands for the incident wave. $\phi_i^- e^{-i(kx+\omega t)}$ represents the wave that comes from the downstream due to the reflection of waves by the downstream walls. Then for two adjacent walls i and j located at sufficiently long distance from the array front, the following relatioships should hold.

$$\phi_j^+ = \phi_i^+ e^{i\varepsilon_0} + A(\phi_0 + \phi_i^+)e^{i\varepsilon_0} + B\phi_i^- e^{i\varepsilon_0} \tag{2}$$

$$\phi_i^- = \phi_j^- e^{-i\varepsilon_0} + B(\phi_j^+ + \phi_0 e^{i\varepsilon_0})e^{-i\varepsilon_0} + A\phi_j^- e^{-i\varepsilon_0} \tag{3}$$

Here $\varepsilon_0 \equiv k\ell$ and $1 + A, B$ represent respectively the transmission and reflection coefficients of waves due to a single wall. From equations (2),(3) it can be known that ϕ_j^+, ϕ_j^- can be determined from ϕ_i^+, ϕ_i^- as:

$$\phi_j^+ + \phi_0 e^{i\varepsilon_0} = (1+A)(\phi_i^+ + \phi_0)e^{i\varepsilon_0} + B\phi_i^- e^{i\varepsilon_0} \quad (4)$$

$$(1+A)\phi_j^- = (1-B^2)\phi_i^- e^{i\varepsilon_0} - B(1+A)(\phi_i^+ + \phi_0)e^{i\varepsilon_0} \quad (5)$$

Then if we write the singularity strength that should be distributed on the wall-i and wall-j as $(\sigma_i^+ + \sigma_i^-)e^{-i\omega t}$ and $(\sigma_j^+ + \sigma_j^-)e^{-i\omega t}$ respectively, σ_j^+, σ_j^- should be able to be determined from σ_i^+, σ_i^- as:

$$\sigma_j^+ = (1+A)\sigma_i^+ e^{i\varepsilon_0} + B\sigma_i^- e^{i\varepsilon_0} \quad (6)$$

$$(1+A)\sigma_j^- = (1-B^2)\sigma_i^- e^{i\varepsilon_0} - B(1+A)\sigma_i^+ e^{i\varepsilon_0} \quad (7)$$

This should also hold for the tandem array of infinite number of horizontal panels that consist the bottom of a very long structure in head waves. The coefficients A, B can be determined prior to the analysis by solving the wave transmission and reflection problem of a single panel. Then by making use of the relationship given by equations (6)(7), an entire portion of the structure except a certain upperstream area may be represented by a single long panel over which the singularity strength is assumed to vary according to the equations (6)(7).

3. Conclusions

Using the present approximate technique the hydrodynamic analyses of a huge floating structure may be possible by discretizing the structure into a single huge panel that covers a large portion of the inner part of the structure and a relatively small number of panels located at the rim of the structure. Other than the diffraction analyses the present technique should be able to be applied for radiation analyses, motion analyses and even for hydroelastic analyses provided that the structural stiffness is uniform. The present idea can also be incorporated in other conventional numerical techniques. In the analysis of a structure of several kilometers long and wide, this approximation can reduce the number of panels by a factor of 10~20, which in turn reduces the time required for the computation by a factor of $10^2 \sim 20^2$.

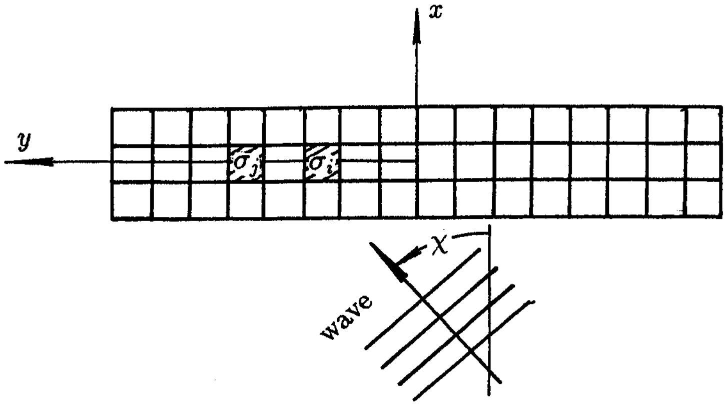

Figure 1. A very long structure in oblique waves

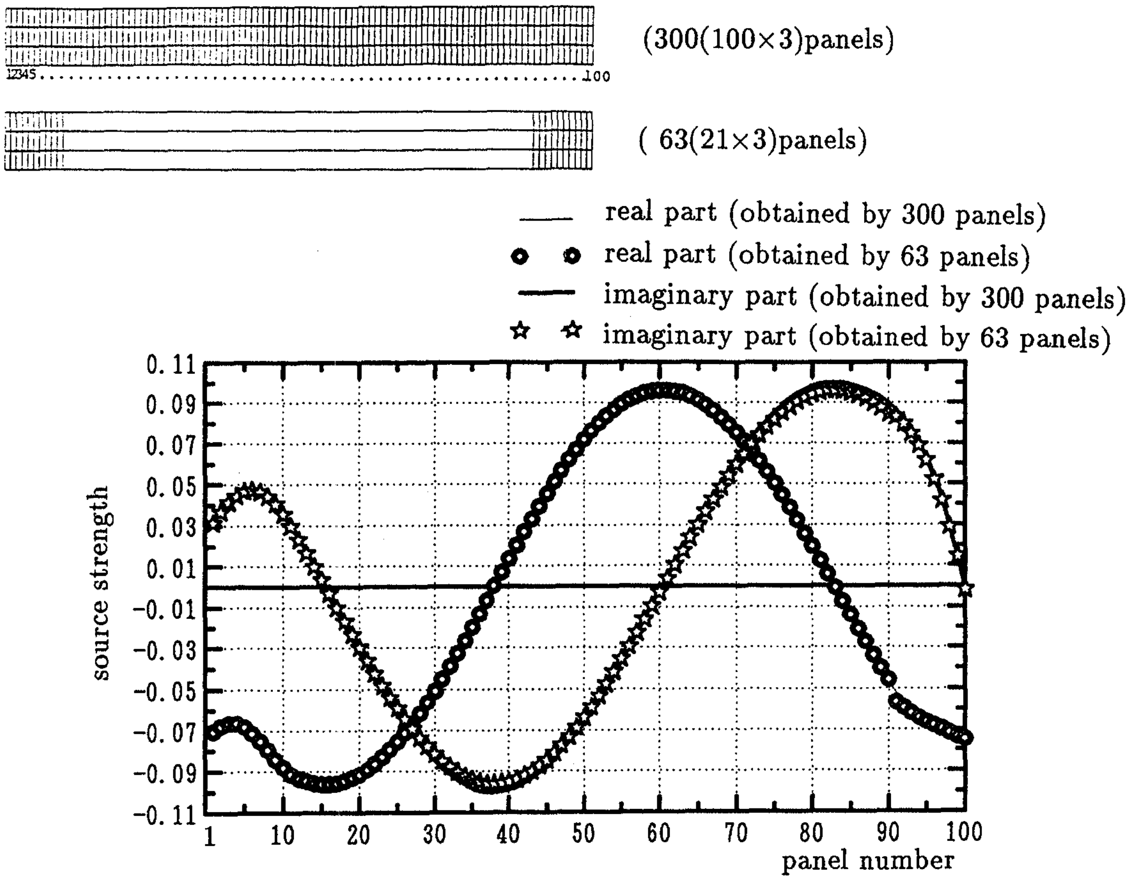

Figure 2. The obtained beamwise distribution of singularity strength in oblique waves ($\chi = 10°$)

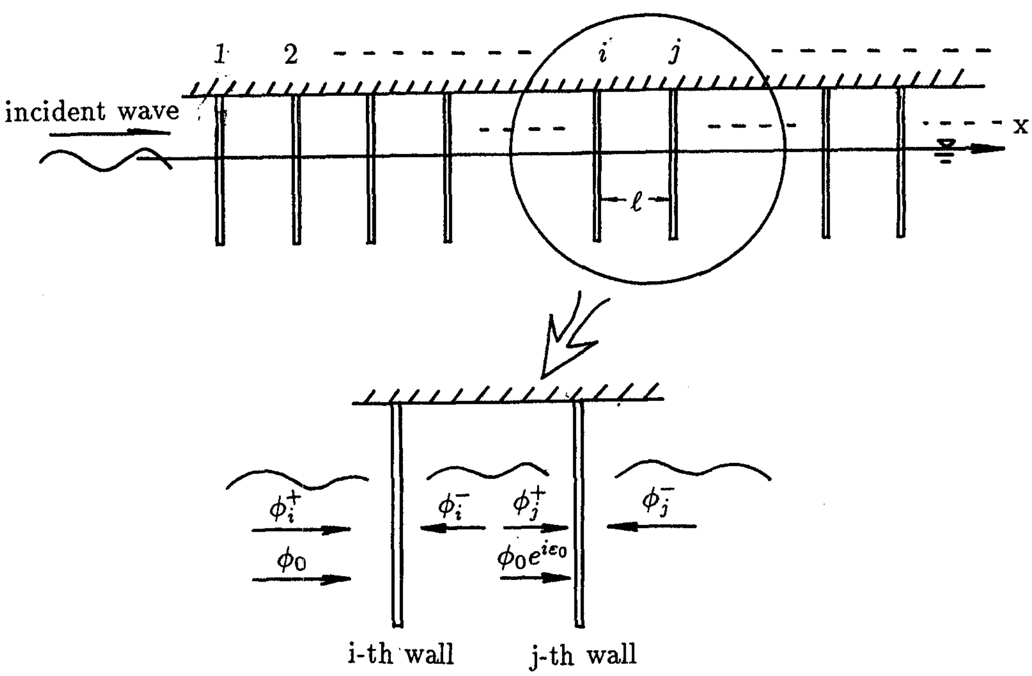

Figure 3. An infinite number of equally-spaced array of vertical 2-D truncated walls in head waves