APPLICATION OF COMPUTER MODELING FOR HARBOR RESONANCE STUDIES OF LONG BEACH & LOS ANGELES HARBOR BASINS

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ABSTRACT

One of the major engineering problems for large harbors with container ship operation is the motion of moored ships due to long wave activity. In order that the wave-induced ship-motions may be effectively controlled, the response characteristics of the harbor basin due to incident waves must be accurately determined. This study focuses on the application of a computer model in the harbor resonance study in connection with modification of harbor basins. The computer model used is a finite element model with the mild-slope equations as the governing equations. Various boundary conditions are incorporated in the model: fully and partially reflecting boundaries, permeable boundary. Energy losses across the harbor entrance due to flow separation and frictional loss at the bottom are also incorporated in the model. Good comparison between the computer model results and the physical model data of the Los Angeles-Long Beach harbor basin has been obtained.

The computer model has been applied to the large scale harbor basin of Los Angeles & Long Beach Harbors. Effects on response characteristics due to incident wave system with and without breakwater at Pier J in Long Beach Harbor have been determined. The construction of the proposed breakwater outside Pier J in Long Beach Harbor appears to be effective in reducing the wave amplification for wave period less than 140 sec. The wave period associated with resonant peak has been shifted to 170 sec. or higher. With the advancement of computing power, it is found that computer model offers a very powerful alternative to physical model in the study of wave response characteristics. All the computation reported herein are done by Pentium 2-300 MHz personal computer.

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1. INTRODUCTION

One of the most important engineering tasks in the planning and design of a new harbor or modification of an existing harbor is the determination of the response characteristics of the harbor basin to the incident wave system. The long wave induced harbor resonance may cause unwanted motion of berthed ships, delaying the loading or unloading of cargo. It may even damage the ship or dock facilities and cause breaking of mooring lines and fenders. The response characteristics could be determined by either physical modeling or by computer modeling. Advancement in the computer modeling technique has progressed to the point that a convenient computer model can be applied to model a complicated harbor basins using personal computer including incident wave system of relatively short wave period range.

This study focuses on the effect of the proposed breakwater at Pier J on the reponse characteristics of the harbor basin.

2. THEORY OF THE COMPUTER MODEL

The computer model used for the present study is a finite element model. The governing equation is the well known mild-slope equation with appropriate boundary conditions as specified in the following:

Mild-slope wave equation:

$$\nabla\cdot(CC_g\nabla\Phi)+\frac{C_g\omega^2}{C}\Phi=0 \tag{1}$$

Boundary conditions:

$$\frac{\partial\Phi}{\partial n}=0 \qquad \textit{(for fully reflecting boundary)} \tag{2}$$

$$\frac{\partial\Phi}{\partial n}=-i\alpha k\Phi-\frac{i\alpha}{2k}\frac{\partial^2\Phi}{\partial S^2} \qquad \textit{(for partially absorbing boundary)} \tag{3}$$

$$\frac{\partial\Phi_T}{\partial n}=i\kappa\kappa_t\Phi_I \qquad \textit{(for permeable boundary)} \tag{4}$$

$$\Phi_1=\Phi_2+\Delta\Phi=\Phi_2+\frac{g}{i\omega}f_e|U|\frac{U}{2g} \qquad \textit{(for entrance boundary)} \tag{5}$$

$$\lim_{r\to+\infty}\sqrt{r}\left(\frac{\partial}{\partial r}-ik\right)\Phi_S=0 \quad where \quad \Phi_S=\Phi-\Phi_I \ (at\ infinity) \tag{6}$$

The energy dissipation due to bottom friction is described as an instantaneous complex energy flux, E_f, out through the bed under the water,

$$E_f=\tau_b U_b \tag{7}$$

where τ_b is the instantaneous complex shear stress at the bed.

τ_b can be expressed in terms of the water particle velocity near the bed as follows:

$$\tau_b=\frac{1}{2}\rho K_b|U_b|U_b \tag{8}$$

Here K_b is a dimensionless frictional coefficient, U_b is the near-bottom water particle velocity and can be expressed in term of the velocity potential Φ as follows:

$$U_b=\left(\frac{\partial\Phi}{\partial s}\right)_b=\nabla\Phi e^{-i\omega t}\left(\frac{1}{\cosh kh}\right) \tag{9}$$

Insert (9) into (7), we obtain

$$E_f=\frac{\rho}{g}e^{-2i\omega t}f_\omega\left(\frac{1}{\cosh kh}\right)^2(\nabla\Phi)^2 \tag{10}$$

Upon integrating (10), we introduce a new bottom friction coefficient, $f_w=\frac{1}{2}gK_b|U_b|$. Thus the resulting equation can be written as:

$$\int_A\left[\int E_f dt\right]dA=\frac{\rho}{g}e^{-2i\omega t}\int_A\frac{i}{2\omega}f_\omega\left(\frac{1}{\cosh^2 kh}\right)(\nabla\Phi)^2 dA \tag{11}$$

We introduce a quadratic headloss law at the harbor entrance. It is convenient to define $K_e=\frac{f_e}{2g}|U_0|$, where $|U_0|$ is taken as the average velocity at the harbor entrance computed based on the case of no entrance loss, and express the entrance loss, ΔH, as follows:

$$\Delta H=f_e\frac{U^2}{2g}=f_e|U_0|\frac{U}{2g}=K_e U. \tag{12}$$

where U is the new entrance velocity to be computed in the model, and f_e is the entrance loss coefficient similar to the one defined by Lapelletier (1980).

The Galerkin's method and shape function are used to transform the governing's equation and boundary conditions into a matrix form by discretizing the domain of interest into a finite number of elements. The Gaussian quadrature method is used for numerical integration terms.

By using $\Phi = N_i\Phi_i$, $\nabla\Phi = \nabla N_i\Phi_i = B_i\Phi_i$ and $\Phi_s = N_s c$, $\frac{\partial\Phi_s}{\partial r} = P_s c$, the finite element weak formulation can be obtained as follows:

$$[K][\Psi] + [Q] = [0] \tag{13}$$

where ψ are all unknown matrices, and

$$K = \begin{bmatrix} [[M]] & [[M_2]] \\ [[M_2]'] & [[M_1]] \end{bmatrix}$$

$$[M] = \int_A (CC_g B^T B - \frac{C_g\omega^2}{C} N^T N)\,dxdy - \int_{\partial B} i\omega C_g \alpha N^T N ds + \int_{\partial T} i\omega C_g K_t^2 N^T N ds$$
$$- \int_A \frac{i}{\omega} f_\omega (\frac{1}{\cosh^2 \kappa h}) B^T B dxdy - \int_{\partial E} i\omega CC_g [(1-K_j)N^T B - K_e B^T B] ds$$

$$[M_1] = \int_{\partial A} CC_g P_s^T N_s ds$$

$$[M_2] = \int_{\partial A} CC_g N^T P_s\, ds$$

$$[Q_1] = \int_{\partial A} CC_g N^T \frac{\partial\Phi_I}{\partial n_A} ds$$

$$[Q_2] = \int_{\partial A} CC_g P_s^T \Phi_I ds$$

$$K_e = \frac{f_e |U_0|}{2g}$$

This computer model takes into account the diffraction, refraction, reflection, boundary absorption, bottom friction, and separation losses at harbor entrance or other entrance to inner basins. Especially noteworthing is the ability of this computer model to obtain responses in the relatively short wave period range which was considered prohibitive heretofore. This was accomplished by the use of "substructuring technique" and "automatic mesh generation" system. The substructuring technique has been developed by dividing the entire modeling basin into several irregular shaped basin with solutions

matched at each of the imaginary common boundaries. The automatic mesh generation program is incorporated so that this computer model could be used as an effective iteration design tool to arrive at the desirable harbor geometry for a given permissible wave response within the harbor.

3. RESULTS AND DISCUSSIONS

One of the major objectives of this study is to use the computer model to investigate the basin response characteristics to incident waves which are related to any proposed modification of the harbor layout with the ultimate objective of reducing the dependence on physical model in reaching engineering decisions. At the very least, the computer model could be used to guide the use of physical model so that the physical models could be more efficiently conducted.

The layout of the Long Beach / Los Angeles harbor model basin is presented in Figure 1. This physical model basin was constructed by the Coastal Engineering Research Center of the Waterways Experiment Station of the U.S. Army Corps of Engineers. Also included in the figure are the location of all the wave height measuring gages used in the model basin.

Two computer model grid systems have been used and are shown in Figure 2 and Figure 3. Figure 2 is a smaller model which covers the harbor basin mostly in Long Beach Harbor region. This model grid has 14,895 nodal points with 6,325 elements. Also indicated in the grid layout are three of the incident waves directions.

Figure 3 shows the grid layout of a larger model it contains the entire model basin used in the physical model (as shown in Figure 1). It consists of 31,538 nodal points and 13,263 elements. One of the motivations of using this huge model is to utilize of the results of the physical model for verification of the computer model.

It should be noted that because of the nature of the long period wave, the wave length is long compared with characteristic length of the harbor basin, a true incident wave system for an open sea condition can not be achieved in the physical model. Instead, it is a wave generator system at one end of the harbor model basin surrounded by reflecting walls at the model boundaries.

Thus, in order to compare the computer model results with the physical model data, it is necessary to construct the computer model so that it will be identical to the physical model (that is a wave generator is placed at one end of the model basin, with reflecting boundaries comprising the three walls of the model basin).

An attempt has been made to compare the results of a computer model with a wave

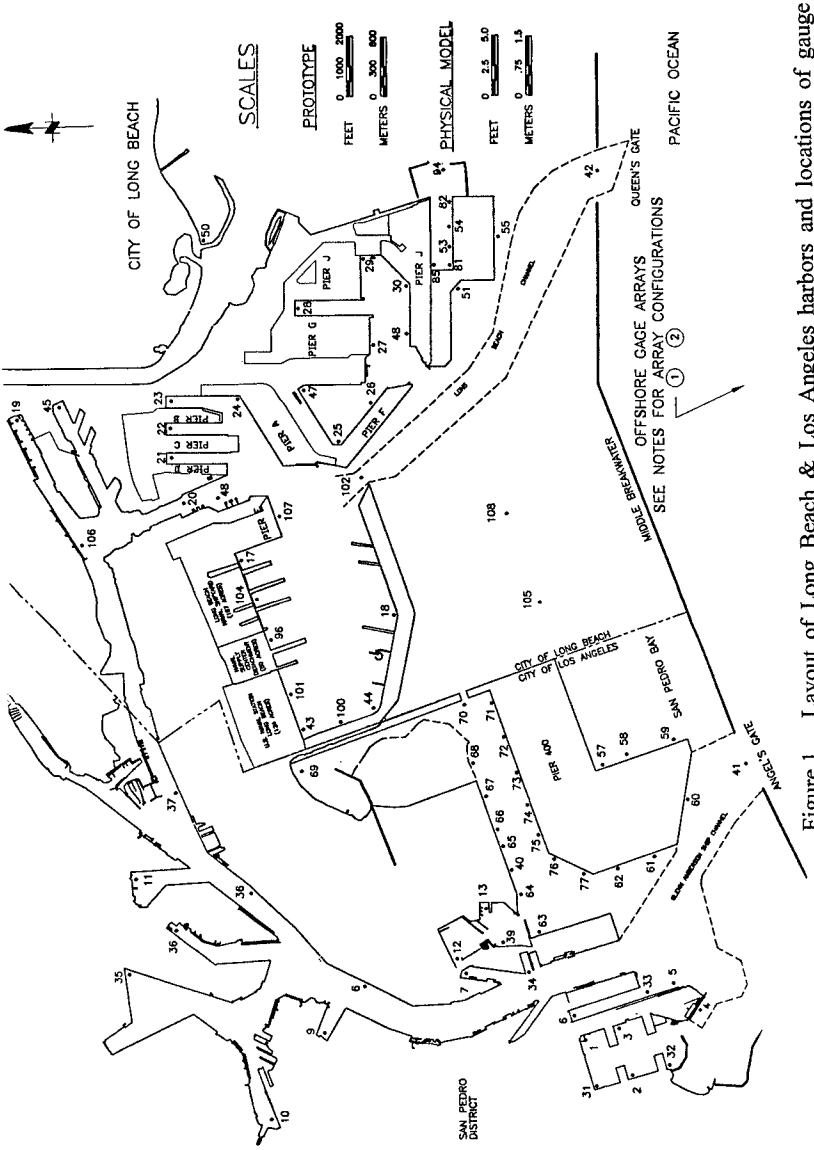

Figure 1 Layout of Long Beach & Los Angeles harbors and locations of gauge stations

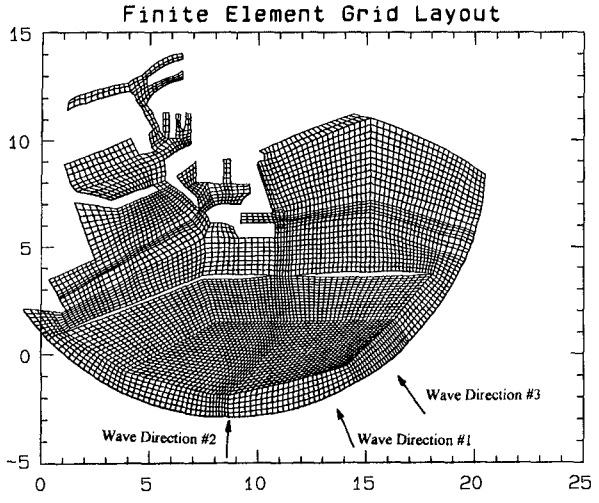

Figure 2 The finite element grid layout of small scale model (6325 elements, 14895 nodal points)

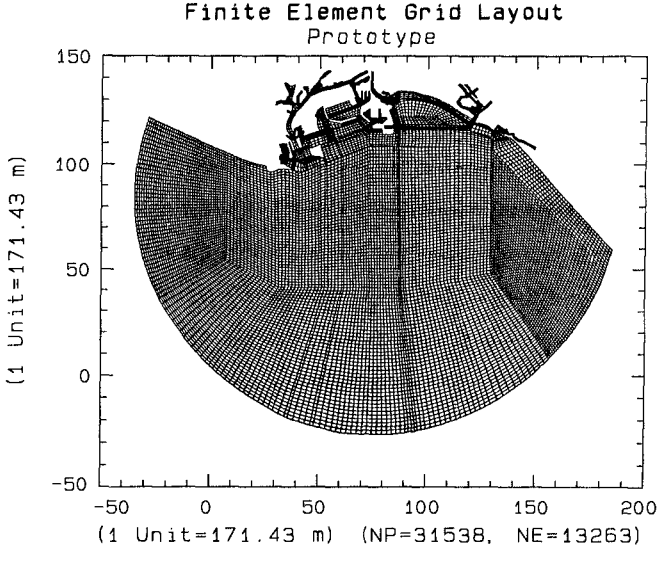

Figure 3 The finite element grid layout of large scale model (13263 elements, 31538 nodal points)

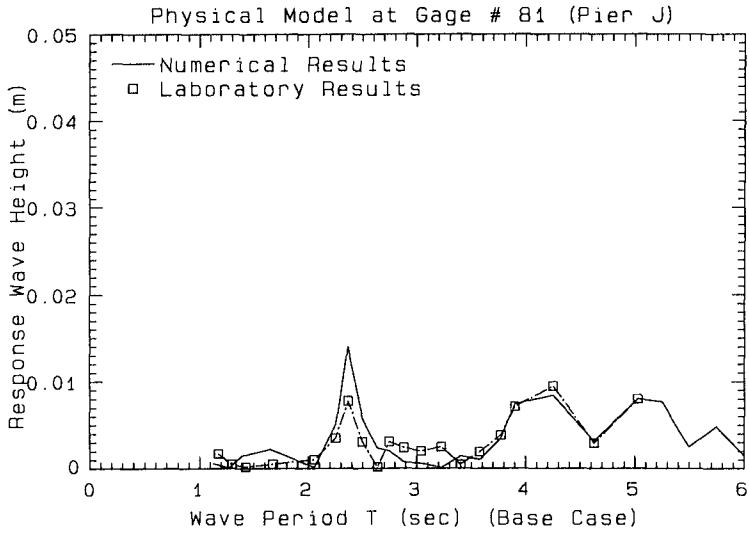

Figure 4 Comparison of response curves between the present numerical results and WES experimental results at gage #81 (Pier J)

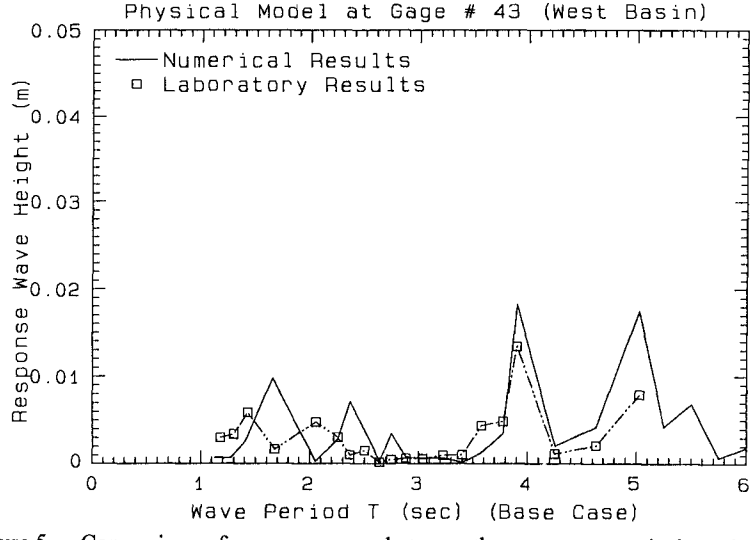

Figure 5 Comparison of response curve between the present numerical results and WES experimental results at gage #43 (West Basin)

generator system with the physical model data using the exact wave generator strokes registered by the physical models. This comparison is presented in Figures 4 and 5 for two gaging stations. These two figures show the comparison of the computed and measured wave heights at the specified stations as a function of the model wave periods. Gage #81 is located at the inner corner of the Pier J basin in Long Beach Harbor. Gage #43 is located at the left corner of the Long Beach West Basin. It can be seen that the comparisons are good in general further verifying the usefulness of the computer models.

The computer model with large grid layout covering a wide area of the harbor basin as shown in Figure 3 has been applied to study the effect of basin modification on long period wave response characteristics.

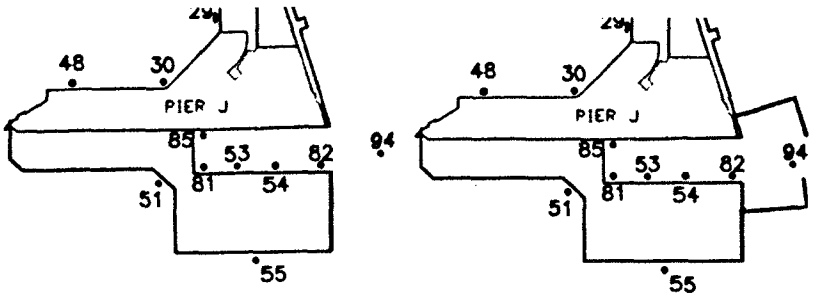

Figure 6 Detail layout of Pier J basin of Long Beach harbor without breakwater and with breakwater

Figure 6 shows the plan view of the harbor modification at Pier J. The sketch on the left shows the Pier J basin without the breakwater (the basin layout prior to the construction of the breakwater). The sketch on the right of Figure 6 shows the layout for the breakwater. It is clear that the introduction of the breakwater modifies the characteristic length of the harbor basin. The longitudinal length of the Pier J basin is increased by approximately 44%.

The response curves for four different gaging stations are presented in Figures 7 through 10 for Gage #81, #85, #82 and #94. Gage #81 and #85 are located at the back end of Pier J basin. Since the variations of water surface elevation for the wave period range under study is mainly in the longitudinal direction; thus, response curves for Figure 7 & 8 are almost identical. Comparing the two curves in both Figure 7 & 8 two major effects of the breakwater can be clearly shown: (1) The amplification factors for wave periods less than 140 sec. has been greatly reduced due to the introduction of the breakwater. (2) The major resonant mode at T=130 sec. has been shifted to T=170 sec.

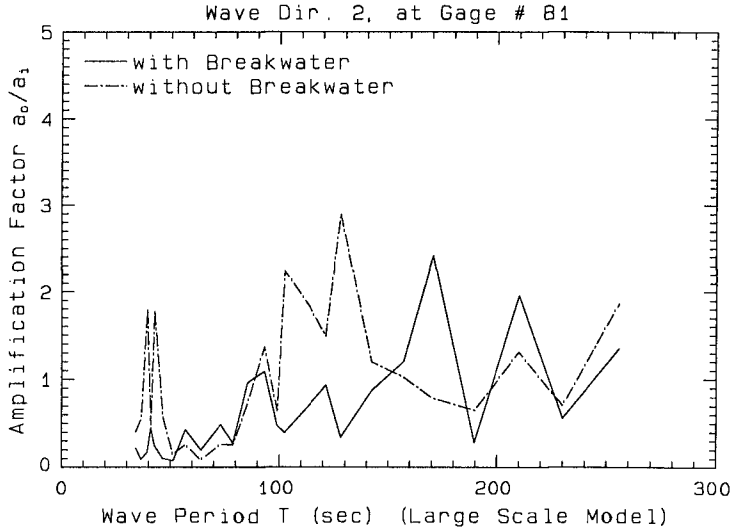

Figure 7 Comparison of computed response curves with and without breakwater at gage #81

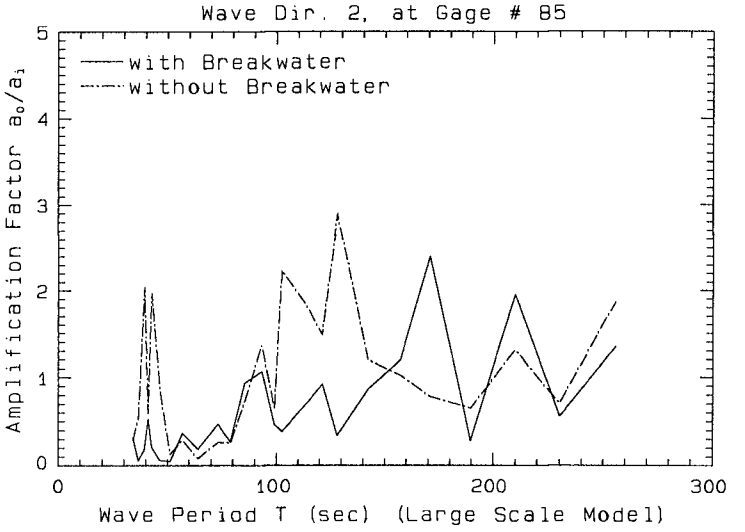

Figure 8 Comparison of computed response curves with and without breakwater at gage #85

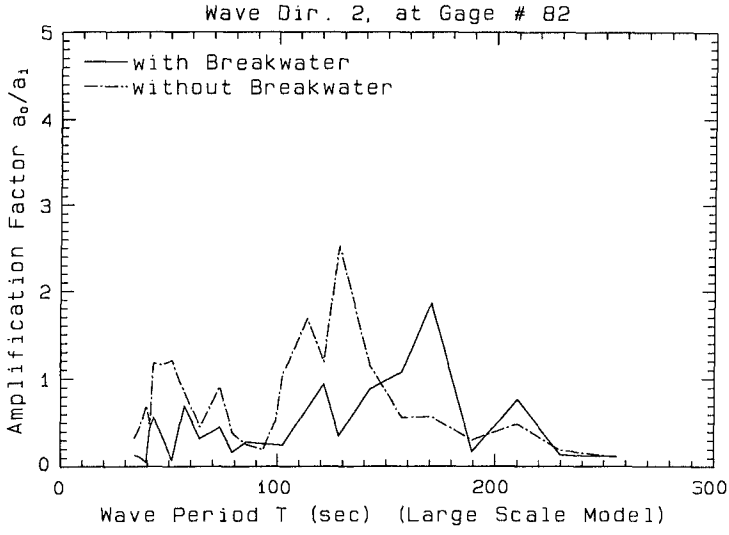

Figure 9 Comparison of computed response curves with and without breakwater at gage #82

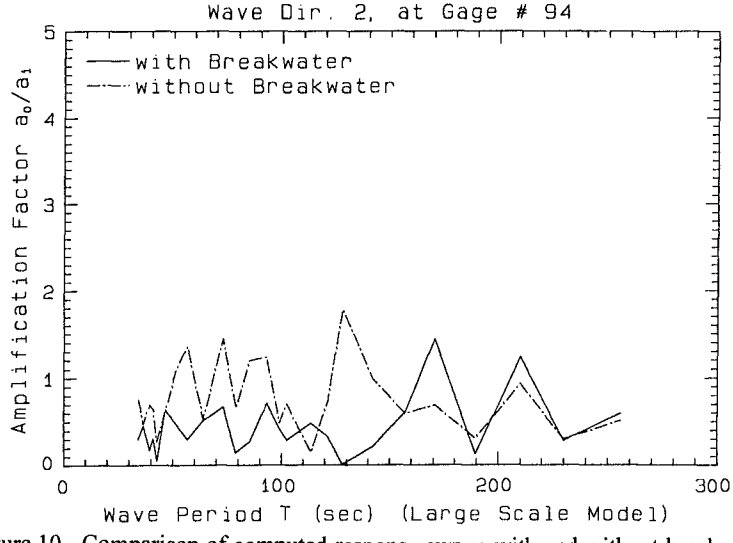

Figure 10 Comparison of computed response curves with and without breakwater at gage #94

By comparing the response curves shown in Figures 9 & 10 for the conditions with and without breakwater, it is also found that the two key features just mentioned also hold true here. Therefore, the introduction of the breakwater clearly shift the resonant wave period to higher values hopefully into the region not relevant to periods associated with possible ship motions.

Comparison of the computer model results with available field data at a location corresponding to that for gage #81 is presented in Figure 11.

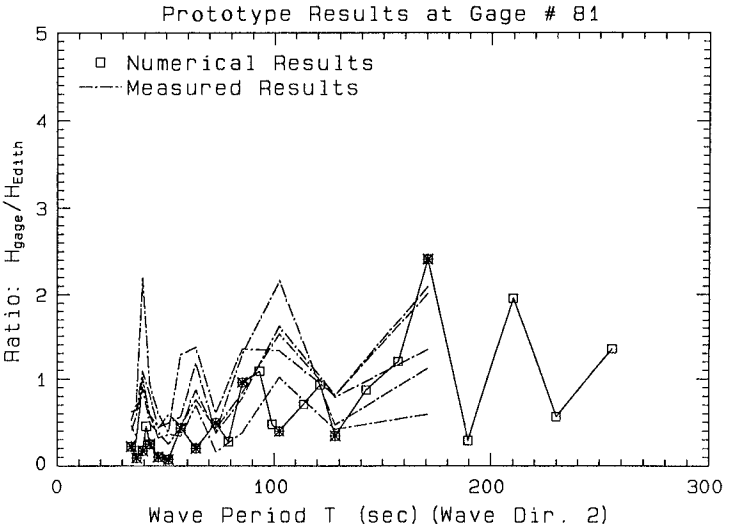

Figure 11 Comparison of response curves between the present numerical results and field measured data at gage #81

Field data were obtained during a three months period, December 1997, January and February 1998. Five sets of field data are included in Figure 11. Obviously without knowing the actual incident wave direction it is not certain what definitive conclusion can be drawn from them. However, it appears that some of the resonant modes are captured in the computer model even though the field data show considerable scatter. It should be noted that the computer results shown are for incident wave direction #2, with breakwater at Pier J Basin and with large scale grid layout (as that shown in Figure 3).

4. CONCLUDING REMARKS

Computer models by nature are an approximate solution to the more complicated prototype conditions. For important engineering projects one should use both the computer models and physical models. However, at the present time the computer model has been advanced to a degree that it can largely reduce (although not eliminate) the need for physical models. At the very least, the computer model can be used effectively for preliminary planning work and to serve as a guide to the use of physical model if the latter is still needed for important projects.

The results presented herein show that the computer model nicely reproduces the data obtained from the physical model. The introduction of the breakwater at Pier J at Long Beach Harbor effectively reduces the wave amplitude response for wave period less than 140 sec. It also shifted the resonant wave period to period larger than 170 sec., hopeful this will be in the wave period range not very significant for ship motion problem.

5. ACKNOWLEDGEMENT

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