Evaluation of an approximate method for incorporating floating docks in harbor wave prediction models

Dongcheng Li, Vijay Panchang, Zhaoxiang Tang, Zeki Demirbilek, and Jerry Ramsden

Abstract: Computer models based on the two-dimensional (2-D) elliptic mild-slope equation are nowadays routinely used in harbor engineering applications. However, structures like floating breakwaters and docks, which are often encountered in the modeling domain, render the problem for locally three-dimensional model and hence are problematic to incorporate in a 2-D model. Tsay and Liu (Applied Ocean Research. 1983. Vol 5(1): 30–37) proposed a highly simplified but approximate approach that does not violate the overall two dimensionality of the problem. The validity of their approach is examined in detail, and it is found that although their approximation provides results with the correct trend, the actual solutions deviate considerably from the theoretical solutions. We have developed correction factors that may be used to produce more reliable results using the framework of Tsay and Liu. Application of the resulting method to a harbor in Alaska shows that docks in the harbor distort the wave field considerably and create a reflective pattern that has the potential to affect navigation safety in some areas. A by-product of this paper consists of plots of transmission coefficients for waves propagating past rectangular and cylindrical floating objects of infinite extent for a wide range of conditions encountered in practice. Such transmission coefficients are at present readily available in the published literature for selected cases only.

Key words: wave, model, mild slope, equation, floating breakwater, dock, marina, harbor.

Résumé : Les modèles informatiques basés sur l'équation de pente douce elliptique à deux dimensions sont couramment utilisés dans l'ingénierie des ports. Cependant, les structures comme les brise-lames et les quais flottants, que l'on rencontre souvent en modélisation, rendent le problème tridimensionnel localement et sont donc difficiles à incorporer dans un modèle bidimensionnel. Tsay et Liu (Applied Ocean Research. 1983. Vol 5(1): 30–37) ont proposé une approche extrêmement simplifiée mais approximative qui n'enfreint pas la bidimensionnalité globale du problème. La validité de leur approche est examinée en détail et il a été découvert que, bien que leur approximation donne des résultats ayant la tendance appropriée, les solutions réelles sont considérablement différentes des solutions théoriques. Nous avons développé des facteurs de correction qui peuvent être utilisés pour obtenir des résultats plus fiables en utilisant le cadre de Tsay et Liu. L'application de la méthode résultante à un port en Alaska montre que les quais dans le port déforment considérablement le champ de vague et créent un patron réflectif qui pourrait affecter la sécurité de la navigation dans certaines zones. Un dérivé du présent article consiste en des tracés de coefficients de transmission pour les vagues se propageant au delà d'objets rectangulaires et cylindriques d'étendue infinie pour une large gamme de conditions rencontrées dans la pratique. De tels coefficients de transmission sont présentement facilement disponibles dans la littérature publiée, mais uniquement pour certains cas.

Mots clés : vague, modèle, pente douce, équation, brise-lames flottant, quai, marina, port.

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1. Introduction

In projects involving harbor and (or) marina design or modifications, engineers often use computational models based on the elliptic mild-slope wave equation to estimate the requisite wave properties. This equation can be used to simulate the effects of wave refraction, diffraction, and reflections in regions with arbitrary geometry. Development of several robust codes to solve this equation in recent years and their integration with sophisticated finite element grid generators and graphical user interfaces has resulted in their use in many practical harbor problems. These include studies of Ste. Therese de Gaspe Harbor, Kahului Harbor, Morro Bay Harbor, Venice Lagoon, Los Angeles–Long Beach Harbor, Barbers Point Harbor, etc. (Tang et al. 1999; Thompson and Demirbilek 2002; Thompson et al. 2002; Panchang and Demirbilek 2001; Mattioli 1996; Kostense et al. 1988; Bova et al. 2000; Zubier et al. 2003; and others). Well-known models used by engineers include PHAROS, CGWAVE, and EMS.

The governing equation for these mild-slope wave models is

$$[1] \qquad \nabla(CC_g \nabla\Phi) + (k^2 CC_g)\Phi = 0$$

where, for a given wave frequency σ, $\Phi(x, y)$ is the complex wave potential from which the wave height and phase may be estimated, C is the wave velocity, C_g is the group velocity, k is the wave number. (The last three quantities are prespecified on the basis of the local depth $h(x, y)$ and given wave frequency.) Equation [1], which finds wide applicability in harbor studies because of its validity for both long and short waves, is a two-dimensional (2-D), vertically integrated form of the time-harmonic complex Laplace equation

$$[2] \qquad \nabla^2\phi(x, y, z) = 0$$

where

$$[3] \qquad \phi(x, y, z) = f(z)\Phi(x, y)$$

and

$$f(z) = \frac{\cosh k(z + h)}{\cosh(kh)}$$

The vertically integrated form [1], together with the assumption [3], has been demonstrated to be valid for $|\nabla h|/kh << 1$, a criterion that is usually met in practice. Being elliptic, the equation represents a boundary-value problem, which can accommodate internal non-homogeneities and boundaries. Hence, it forms a well-accepted basis for performing wave simulations in regions with arbitrarily shaped (manmade or natural) boundaries and arbitrary depth variations without limitations on the angle of wave incidence or the degree and direction of wave reflection and scattering that can be modelled.

One problem frequently encountered by engineers when using models based on eq. [1] pertains to the presence of floating structures in the modeling domain (e.g., floating breakwaters or docks in marinas). These structures of course violate the free-surface requirement of eq. [1]. Models for solving the full three-dimensional (3-D) problem (eq. [3]) are available (e.g., Yue et al. 1976; and later versions); however, these models assume a flat ocean bottom of infinite extent around the structure while solving for the wave patterns. No models are available at present for solving the full 3-D problem on the length scale of typical harbor with all its geometric variations, as the effort is prohibitively demanding on computer resources (especially for short waves).

To address this situation, Ohyama and Tsuchida (1997) developed a procedure for interfacing a locally 3-D model (near the floating structure) with a two-dimensional (2-D) model in the rest of the harbor domain. While the 2-D subdomain has a hyperbolic vertical variation (as in eq. [3]), the vertical variation in the 3-D sub-domain was described with a series of cosine functions. Although rigorous, the procedure for coupling involves practical difficulties that are too formidable for general and routine implementation. In fact, Koutandos et al. (2004) even now have had to limit their work only to the x–z plane while using a similar approach. In this paper, therefore, we explore in detail an approximate method suggested by Tsay and Liu (1983) (TL) for tackling floating structures in the context of 2-D harbor wave models. This approach, which we refer to as the TL approximation for convenience, merely calls for a suitable modification to the second term on the left-hand side of eq. [1]; Tsay and Liu (1983) examined suppressing this term. As a consequence, the method is extremely simple to implement with existing finite element models. A model grid is first generated as usual with no regard to the floating structure, then grid elements covering the floating structure (in plan view) are selected, they are assigned a depth value equal to the under-keel clearance, and the coefficient of the second term in eq. [1] is set to zero for these elements. Clearly, this is an ad hoc method intended for convenience in engineering practice, and although Tsay and Liu (1983) provided heuristic arguments in support of this approach, their testing of this procedure was rather limited. Tsay and Liu (1983) justified their approach on the grounds that under the structure, the basic continuity equation holds, while outside the area of the structure, the wave equation (eq. [2]) holds. In reality, there is wave motion under the structure also.

In view of the potential efficiency of this approach (vis-à-vis the full 3-D solutions), we undertake a detailed examination of the limits of this approximation, with the goal of determining the inherent errors for a wide spectrum of commonly encountered parameters such as the relative width ka and the relative submergence d/h (where a is the characteristic structure size and d is the draft). This is described in Sect. 2. Through numerical experiments, we have attempted to develop modifications to the TL approximation that can minimize its errors (Sect. 3), thus enhancing the reliability of this approximation for practical engineering problems. In Sect. 4, we validate the modified TL approximation using three independent tests for which theoretical solutions and (or) data are available. A by-product of this paper consists of plots of transmission coefficients for waves passing an infinitely long cylinder and a rectangular floating structure; while these problems have been solved analytically (to some extent) in the past, complex code must be developed to actually calculate these coefficients. In fact, the *Coastal Engineering Manual* (U.S. Army Corps of Engineers, 2002) provides these coefficients only for a specific geometry with regards to a rectangular floating breakwater, and Martin and

Dixon (1983) provide these values only for a specific cylinder geometry in deep water. We provide plots for the entire range of *kh*, *ka*, and *d*/*h* values likely to be encountered in practice. In Sect. 5, we provide a demonstration of the use of the proposed method, along with a 2-D finite element wave model, in Douglas Harbor (Alaska). The effects of incorporating the floating docks in the model are quite distinct and suggest that the presence of the docks can create reflections that could adversely impact small-craft operation in some areas.

2. Problem formulation

We consider the problem of estimating the transmission and reflection coefficients associated with the propagation of a monochromatic wave on a flat sea bed past an infinitely long, fixed, floating structure of rectangular cross section (Fig. 1). An incident wave $\phi_i = A_i \exp(ikx)f(z)$ is specified at the left boundary HA. (Here, we have set the incident amplitude $A_i = 1$). The left and right boundaries are placed far enough away from the structure so that the vertical distribution for the components propagating away from the structure may be assumed to be $f(z)$. Along the left boundary HA, the combination of the incident wave and an unknown reflected wave of the form $\phi_r = A_i R \exp[-i(kx + \beta)]f(z)$ (where R is the reflection coefficient and β is the phase shift on the upwave side) gives rise to the following boundary condition (Panchang et al. 1991):

$$\text{[4]} \qquad \frac{\partial \phi}{\partial x} = ik[2f(z) - \phi]$$

Along the right boundary CB, the boundary condition associated with an unknown transmitted wave (of the form $T \exp(i(kx + \delta))f(z)$) may be written as

$$\text{[5]} \qquad \frac{\partial \phi}{\partial x} = ik\phi$$

where T is the amplitude of the transmitted wave and δ is the phase shift.

Along the free surface HG and DC, we have

$$\text{[6]} \qquad \frac{\partial \phi}{\partial x} = (\sigma^2/g)\phi$$

and, finally, along the seabed AB and the boundaries of the structure GF, FE, and DE, we set the normal derivative equal to zero.

A solution to the Laplace equation in the *x*–*z* plane, subject to the above boundary conditions, is obtained using finite differences. The resulting discretized system of linear equations is solved by the method of conjugate gradients (Panchang et al. 1991). We used domains that were typically at least 7 wavelengths long and at least 17 layers in the vertical direction. We also used $\Delta x = \Delta z$, thus ensuring a very high level of resolution and accuracy in the solutions.

To obtain a solution for the TL approximation, we rewrite the governing eq. [1] as

$$\text{[7]} \qquad \frac{\partial(p\partial\Phi/\partial x)}{\partial x} + q\Phi = 0$$

where $p(x) = CC_g$ for all x, $q(x) = k^2CC_g$ for $x < x_1$ and $x > x_2$, and $q(x) = 0$ for $x_1 < x < x_2$. Note that to determine $p(x)$ when $x_1 < x < x_2$, Tsay and Liu (1983) recommend using the under-keel depth $d_1 = h - d$. The boundary conditions for eq. [7] are similar to eqs. [4] and [5], with the exception that ϕ is replaced by Φ and $f(z)$ is deleted. A solution to eq. [7] may easily be obtained by the finite difference method, since discretization leads to a tridiagonal system of linear equations that can be solved by the Thomas algorithm.

3. Comparison of theoretical results with the Tsay–Liu approximation

A total of 864 simulations were performed to cover a wide range of conditions encountered in practice. These included kh = 0.1, 0.25 (shallow water), kh = 0.4, 0.8, 1.2, 2, 2.8 (intermediate water), and kh = 4, 8 (deep water). The size of the structure was described by $0 < ka < 5$, and its immersion by d/h = 0.25, 0.5, and 0.75 corresponding, respectively, to shallow, intermediate, and deep draft. The code for solving the Laplace equation was checked by comparing its results against the analytical solution presented by Drimer et al. (1992) for one case. Our solutions were practically indistinguishable from those in Fig. 2 of their paper.

For brevity, we show (in Fig. 2) the computed transmission coefficients only for kh = 0.25, 0.8, 2.8, and 4 as representative of shallow (kh = 0.25), intermediate (kh = 0.8 and 2.8), and deep (kh = 4) water. Also, only the curves for d/h = 0.25 and 0.75 are shown; the curve for d/h = 0.5 lies in the middle. If the reflection coefficient is desired, it may be computed as $R^2 = 1 - T^2$. These curves may be used by engineers to supplement the single curve provided by the *Coastal Engineering Manual* (CEM) by the Army Corps of Engineers (U.S. Army Corps of Engineers 2002), which is applicable only for $0 < ka < 2.0$ and $d/h = 0.14$; or by Drimer et al. (1992), whose Fig. 2 is applicable only for $a/h = 1$ and $d/h = 0.7$ in water of finite depth.

The results of the TL approximation are plotted in Fig. 2. They appear to match the theoretical results very well in shallow water, but the degree of mismatch is high for intermediate and deep water. However, the TL approximation shows the same trend as the theoretical solutions. This suggests that a simple ad hoc adjustment to the method may yield results closer to the theoretical solutions. While several ways of doing this may be considered, we examined the approach of retaining $q = 0$ (as per the original proposal of Tsay and Liu (1983)) but adjusting p appropriately. While Tsay and Liu (1983) calculated p based on the under-keel clearance d_1, we attempted a simple modification of the form αd_1, where α is a correction factor. A large number of simulations were performed using trial values of α until the results of the “modified TL method” matched the theoretical solutions within 2%. The correction factors so obtained are shown in Fig. 3.

For shallow water and shallow draft, α is roughly equal to unity (as expected). But for deep draft, the TL approximation needs to be modified by $\alpha \approx 0.7$. For intermediate and deep water, α is not constant but shows an increasing trend with ka. In very deep water, the mismatch is large. Note that for short waves (relative to submergence), $T \to 0$. This re-

Fig. 1. Wave transmission past a rectangular floating structure of infinite extent.

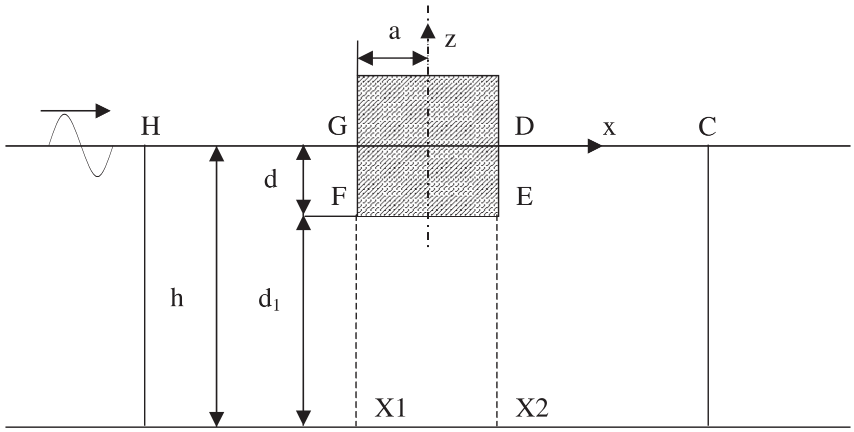


Fig. 2. Modelled transmission coefficients for wave transmission past a rectangular floating structure of infinite extent: (*a*) *kh* = 0.25, (*b*) *kh* = 0.8, (*c*) *kh* = 2.8, and (*d*) *kh* = 4.

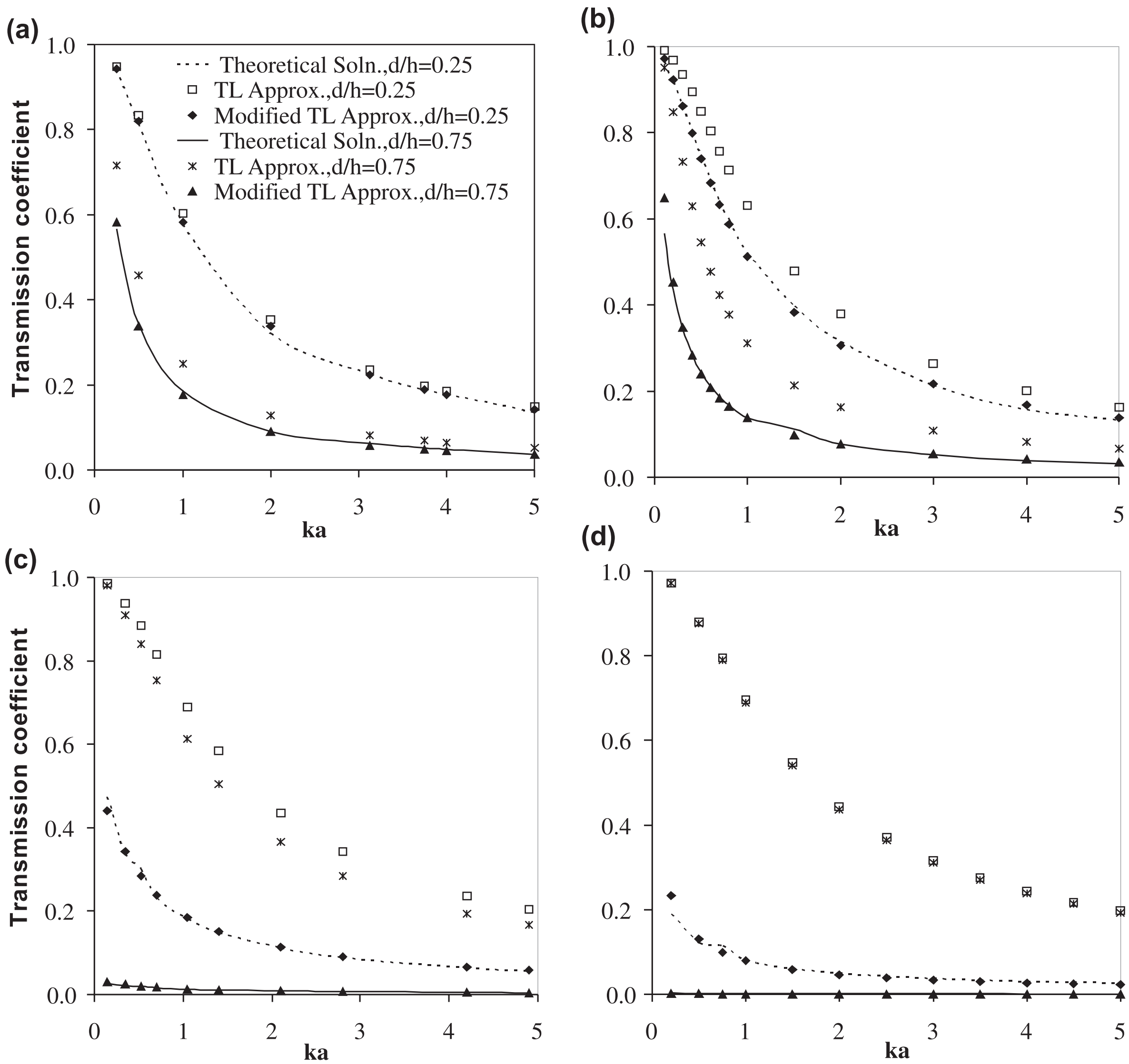
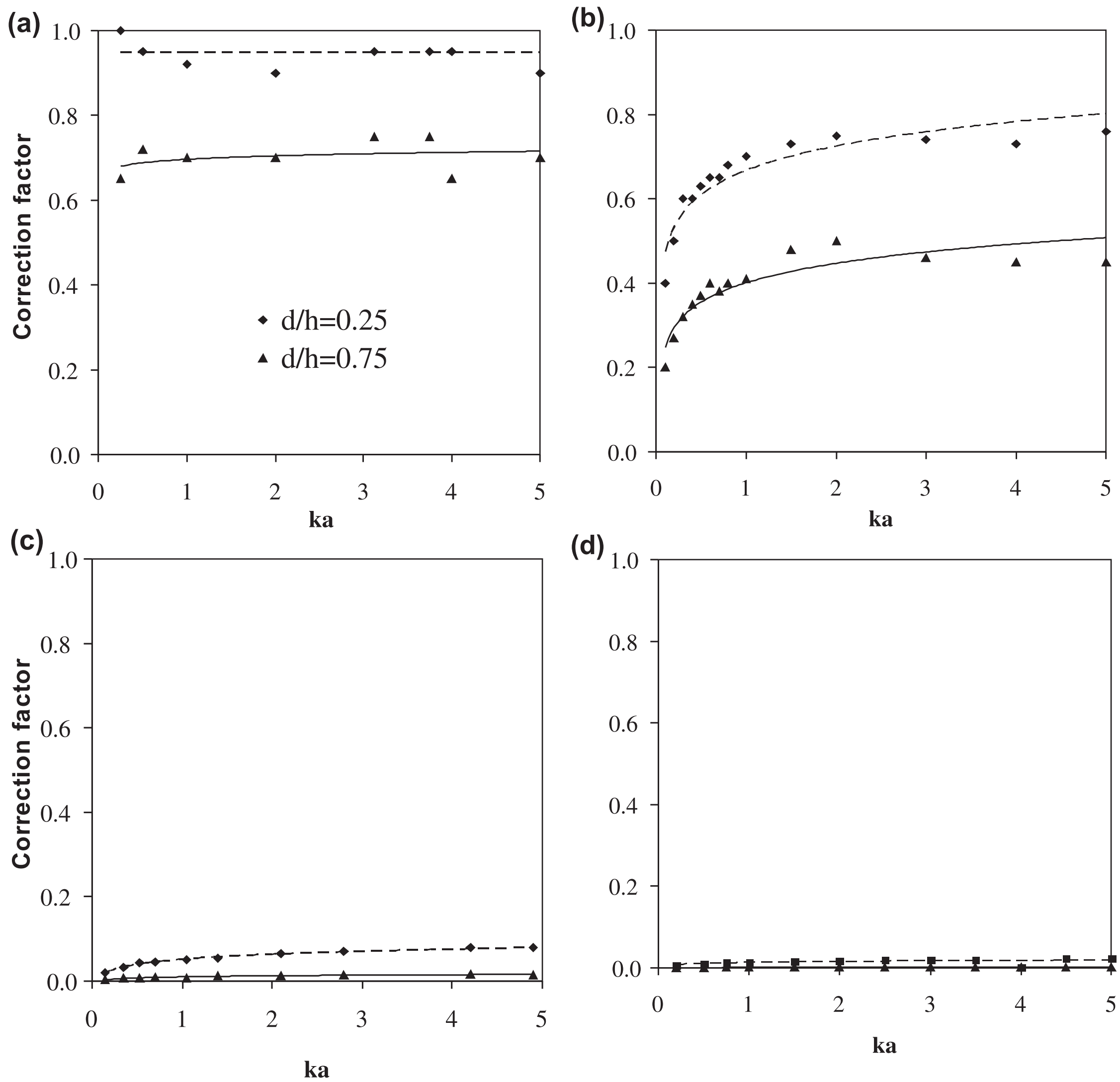


Fig. 3. Correction factors and best-fit curves: (*a*) kh = 0.25, (*b*) kh = 0.8, (*c*) kh = 2.8, and (*d*) kh = 4.



quires us to create a high level of wave blockage, which can be accomplished by $\alpha \rightarrow 0$ with the modified TL approximation, as seen in Fig. 3 (for kh = 4). Of course this result would not hold, if d/h were much smaller than the smallest value investigated here (which is typical in engineering practice).

Plots similar to those in Fig. 3 were produced for all cases examined. The best-fit curve for these had the form of $\alpha = A\ln(ka) + B$. The corresponding A and B are given in Fig. 4. For $kh < 0.1$ and $kh > 4$, we recommend using the A and B values corresponding to these thresholds. Results of the modified TL approximation obtained with A and B values selected from Fig. 4 are also plotted in Fig. 2. As expected, the results are close to theoretical solutions.

4. Validation

To test the validity of the modifications proposed above for situations other than the ones from which they were derived, the modified TL approximation was applied to the cases for which laboratory data or analytical solutions are available. These validation tests are described below:

Square floating breakwater

Koutandos et al. (2004) have presented data pertaining to transmission coefficients for waves passing a fixed, infinitely long, floating breakwater of rectangular cross section with d/h = 0.5 and a/h = 0.25. Although this case is similar to those described in Sects. 2 and 3, the laboratory data serve as an independent test of the modified TL approximation. This case pertains to wave propagation in intermediate depths. The results of the original TL approximation using the under-keel depth to calculate p are compared in Fig. 5 with the laboratory data. There is considerable mismatch, which seems to be increasing with ka. On the other hand, the results of modified TL approximation, obtained by using A and B values from Fig. 4, show good agreement with the measured transmission coefficients.

Infinitely long cylinders

Ijima et al. (1976) calculated transmission coefficients for waves passing one infinitely long cylinder and two in-line cylinders (Fig. 6) by solving the Laplace equation via the boundary element method. Their theoretical results, along with data they collected for these cases, are shown in Fig. 7.

Fig. 4. Values of A and B for determining α.

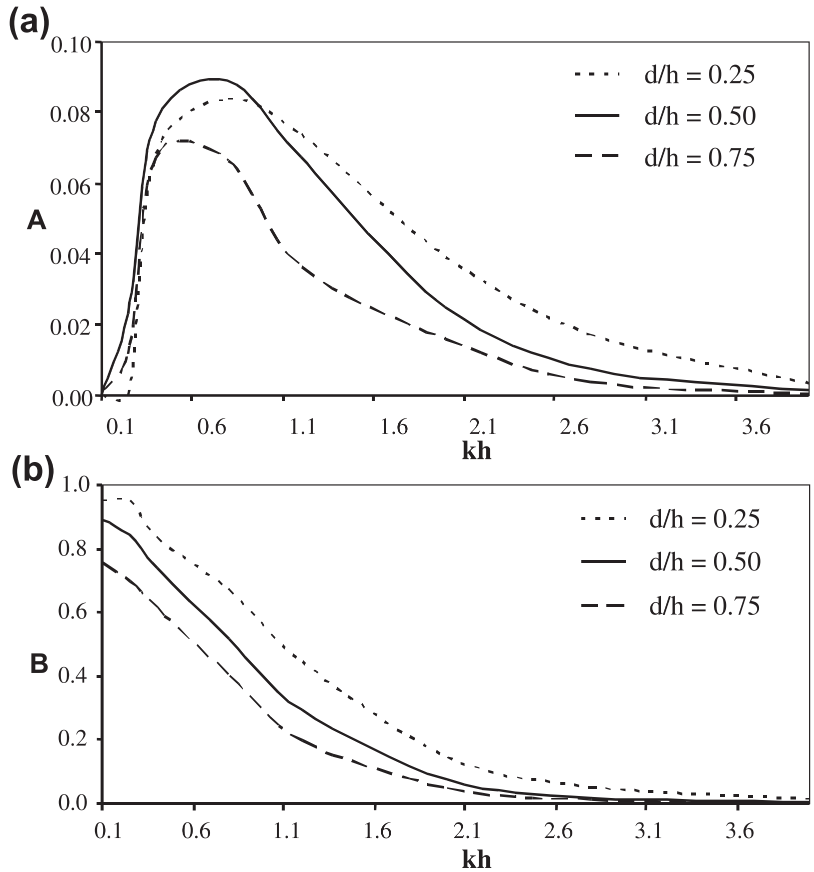
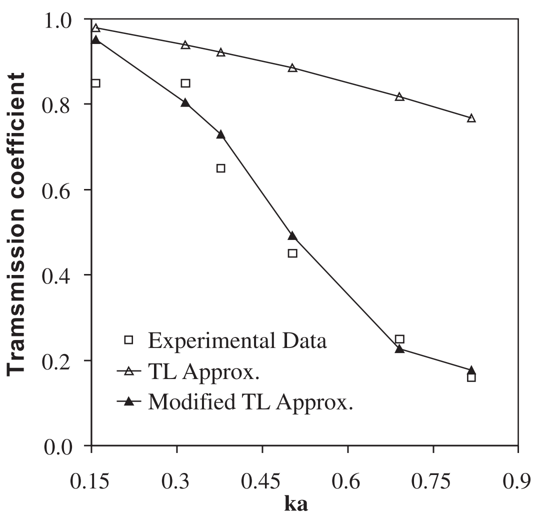
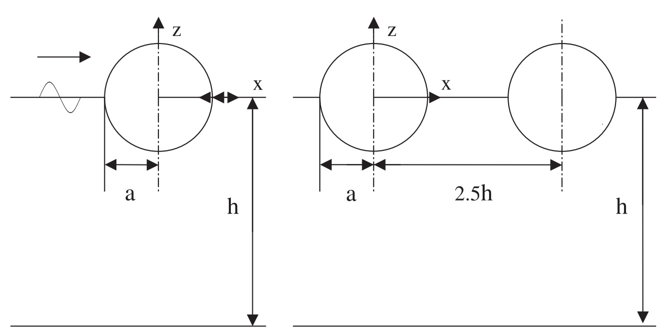


Fig. 5. Wave height comparison with data presented in Koutandos et al. (2004).



These tests pertained to the intermediate water depth regime. While using the modified TL approximation for these simulations, the under-keel clearance d_1 changes at every grid point. Although a variable α can be used, here an approximate value of α was estimated based on an equivalent rectangular immersed area of the same width as the cylinder. Figure 7 indicates that the results of the modified TL approximation show much smaller discrepancies than those of

Fig. 6. Wave transmission past floating cylinder(s) of infinite extent. (a = 0.16 m; h = 0.4 m.)



original TL approximation, when compared with both the theoretical results and the measured data provided by Ijima et al. (1976).

For the case of similar cylinders in deep water, Martin and Dixon (1983) developed an analytical method to calculate the transmission coefficient and presented them in the form of a table for the practitioner's benefit. By way of validation, we performed numerical simulations in the deep water regime for $ka > 3$. Smaller values of ka lead to smaller values of d/h ratios for a cylinder with its centreline corresponding to the water surface, as in Fig. 6. The results, shown in Fig. 8, again indicate that the modified TL approximation is a significant improvement compared with the original approximation.

Fig. 7. Wave height comparison. Theoretical solutions and data from Ijima et al. (1976): (*a*) one cylinder and (*b*) two cylinders.

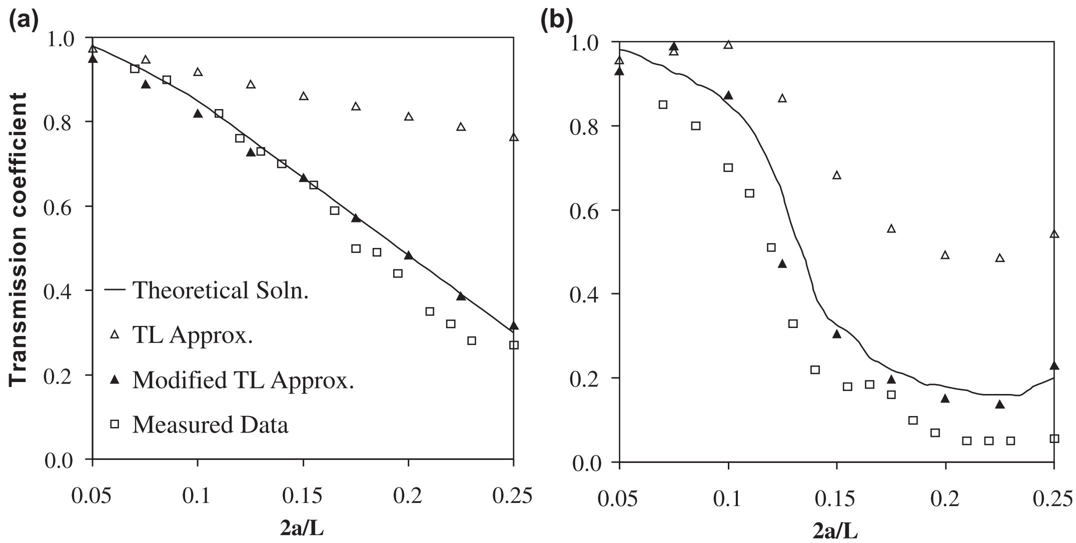


Fig. 8. Wave transmission coefficients for wave propagation past a cylinder in deep water.

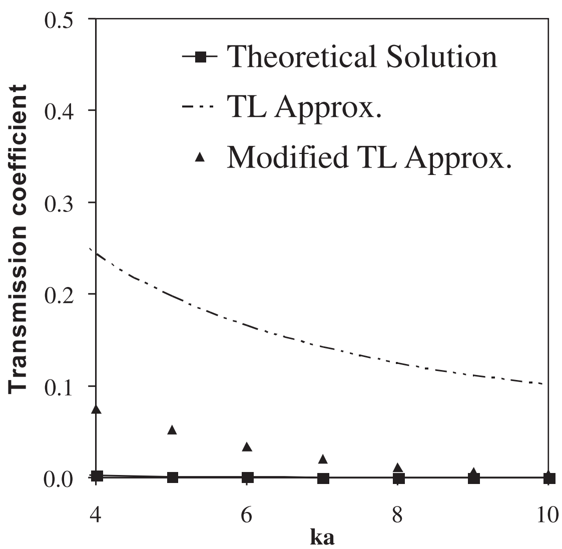


Fig. 9. Modelled transmission coefficients for wave transmission past a cylindrical floating structure of infinite extent.

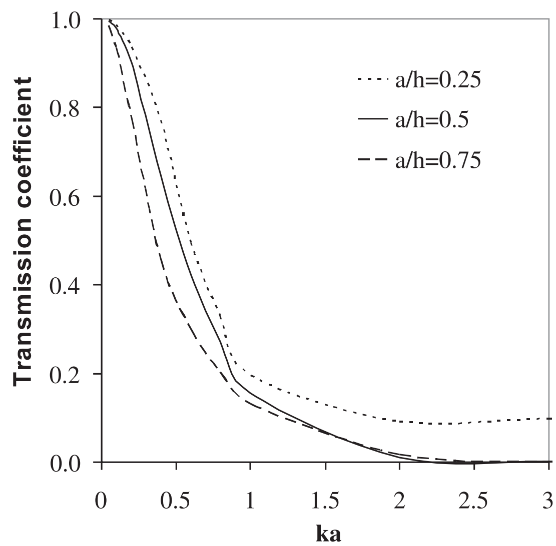
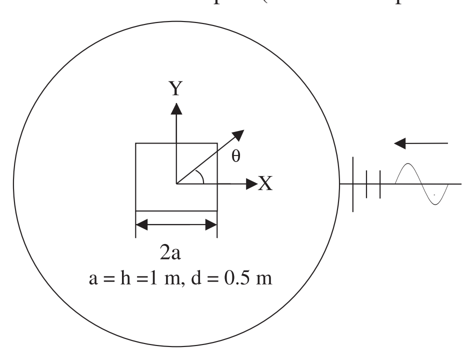


Fig. 10. Wave propagation past a rectangular floating dock in circular domain of constant depth. (x-axis corresponds to $\theta = 0$).

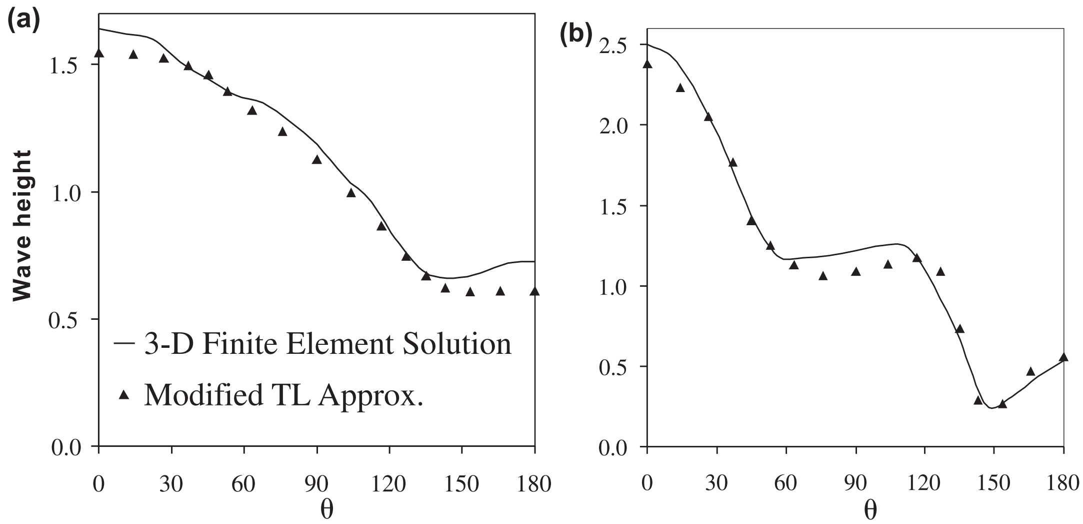


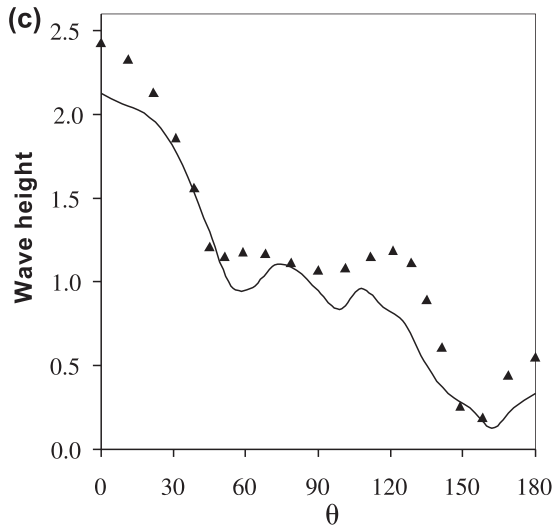
Since these simulations of selected cases pertaining to infinitely long cylinders show that the modified TL approximation is able to reproduce the theoretical results reasonably well, we use it as a surrogate for the Laplace equation to develop curves for transmission coefficients in shallow, intermediate and deep water depth. These curves, provided in Fig. 9, may be used by the engineer to supplement the table provided by Martin and Dixon (1983) for deep water applications.

Floating dock of square planform

Yue et al. (1976) have presented complete solutions of the full 3-D Laplace equation for wave scattering by a floating dock of square planform situated in water of constant depth (Fig. 10). Note that this is not an x–z problem anymore, and the TL approximations cannot be used with the one-dimensional eq. [7]. Rather, they are used with two-dimensional eq. [1] to which Bessel–Fourier functions (e.g., Mei 1983, Xu et al. 1996) are applied as open ocean boundary conditions. Equation [1] is then solved through the use of a finite element grid developed with the graphical interface contained in the

Fig. 11. Wave height comparison. 3d solutions from Yue et al. (1976) : (*a*) ka = 1, (*b*) ka = 2, and (*c*) ka = 3.





Surface Water Modeling System (Zundel et al. 1998). While developing the 2-D grid the area covering the dock is also filled with finite elements; each node is assigned a depth equal to the local under-keel clearance times the correction factor α and q is set equal to zero. The parameters in the simulations are $a = h = 1$ m, $d/h = 0.5$, and $ka = 1, 2, 3$ (corresponding to the cases described by Tsay and Liu (1983)). The results are shown in the form of amplification factors along the periphery of the dock in Fig. 11. Although the correction factor α was developed in Sect. 3 using infinitely long floating structures, its use in the present multidirectional scattering problem produces results close to the full 3-D results for a wide range of ka values.

5. Practical application

In view of the satisfactory results obtained with the modified TL approximation, it is used in conjunction with a frequently used harbor wave modeling package called CGWAVE (e.g., Zubier et al. 2003; Demirbilek and Panchang 1998; Tang et al. 1999; Thompson et al. 2002, etc.) to demonstrate the effect of floating docks in a marina. The application pertains to ongoing design studies for the expansion of Douglas Harbor, situated on the west side of the Gastineau Channel in Alaska. The channel is approximately 2 km wide, and one angle of wave incidence that is of interest to design considerations is normal incidence across the channel.

The depth in the harbor, which is approximately 325 m by 165 m in size, varies from approximately 9.5 m to very small values at the coastal boundary. The location of this boundary fluctuates because of a high tidal regime; only one tidal condition is described here. A part of the bathymetry is shown in Fig. 12. For discussion purposes we consider linear wave conditions with input period as 4.4 s and height as 2 m, although design wind wave conditions at the site may be different. A triangular finite element grid with 14 points per wavelength was constructed; this resulted in approximately 180 000 nodes and 355 000 elements. The coastal boundary was assigned zero reflection. The open boundary, denoted by the semicircle in Figs. 13 and 14, was treated as per the mathematical formulation developed by Panchang et al. (2000). A depth-limited breaking criterion was applied to

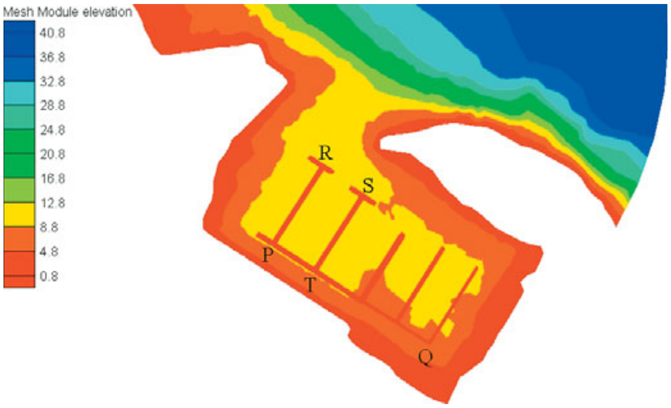


Fig. 12. Bathymetry for portion of Douglas Harbor modeling domain, containing five floating docks; depth in metres.

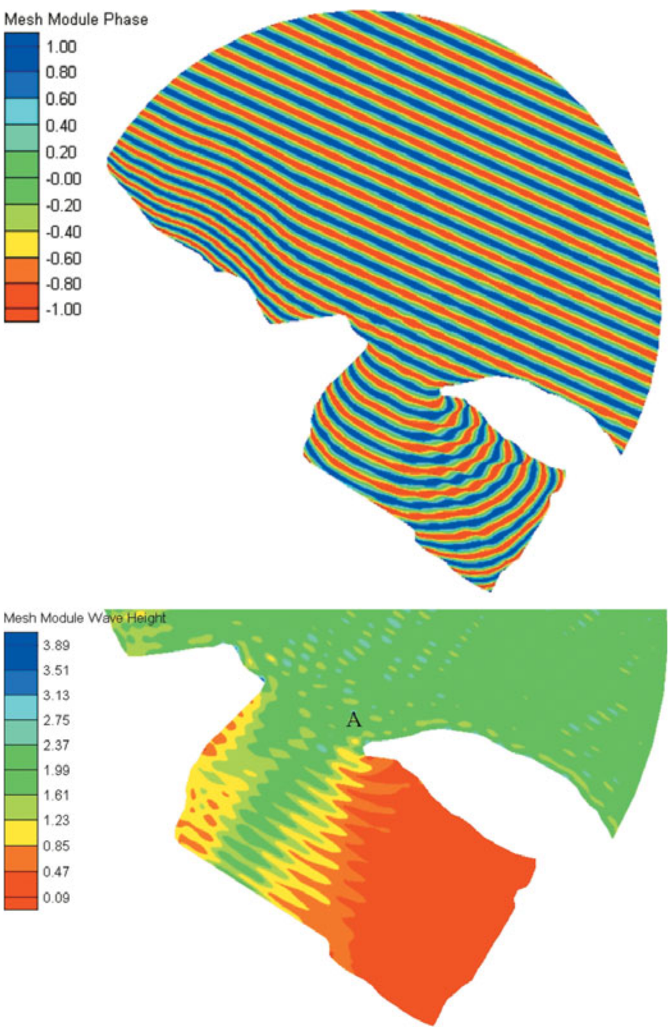


Fig. 13. Modelled phases and wave heights (metres) in Douglas Harbor, with no docks.

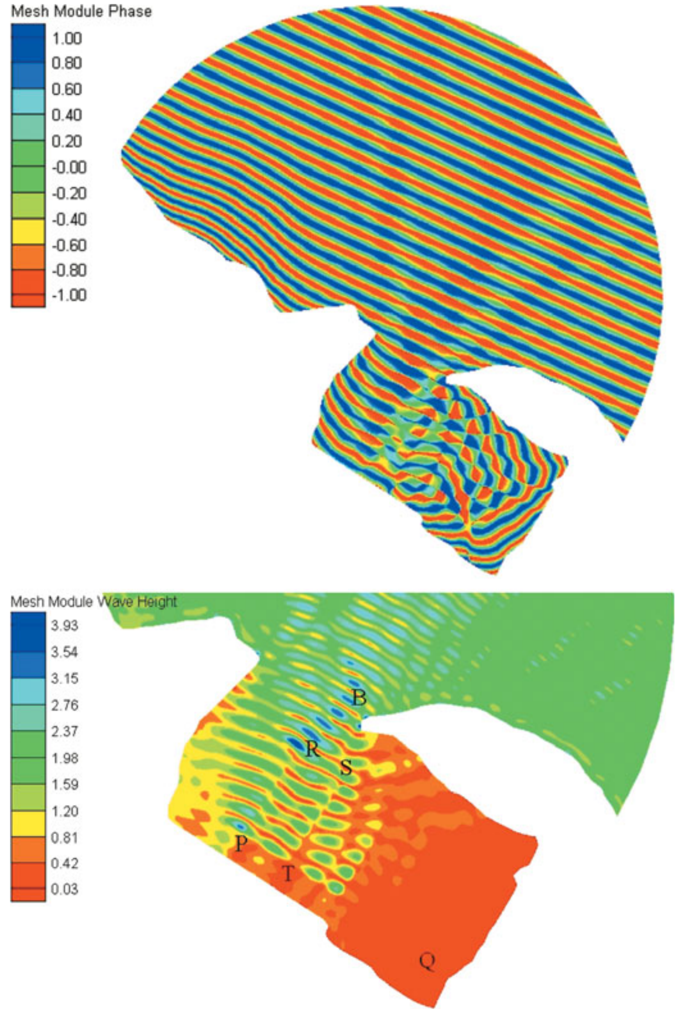


Fig. 14. Modelled phases and wave heights (metres) in Douglas Harbor, with docks.

the solution of eq. [1], although other breaking models could also be used (Zhao et al. 2001).

The results in Fig. 13, depicting modeled phases and wave heights for the case with no docks, show penetration of waves into the harbor and a nearly classical diffraction effect. The maximum wave height near the harbor entrance (near A) is approximately 2.6 m, representing an amplification of 1.3. However, the uniform phase pattern in the harbor is considerably distorted when 5 docks (of widths varying between 1.8 m and 4.8 m) are inserted in the domain. (The docks are assumed to be fixed and the wave field is assumed to be unaffected by the tethering mechanisms.) The simulation with the docks is accomplished by simply highlighting the grids representing the dock and modifying the depth (using the appropriate correction factor α to change the under-keel depth d_1 to αd_1); also, the grid resolution in the vicinity of the docks must be increased because the water depths are now smaller. This is not difficult to implement since most grid generators allow automatic refinement in selected areas. The resulting simulation (Fig. 14) shows three differences with Fig. 13. First, the presence of the docks leads to considerable attenuation of the waves on the lee side of the dock marked PQ in Fig. 12. Second, reflections within the dock area, manifested by the distorted phase pattern and considerable wave height variability, are seen in the model results. For example, the waves are as high as 3.2 m on the upwave side of the dock PQ (near P); also, changes in the range of 2.6–0.2 m in the region between RP and ST occur. This suggests that proper attention must be paid to the appropriate location of the docks to avoid undesirable motion of docked boats. Finally, and perhaps most significantly, a reflective pattern (near B), created largely by the dock RP, propagates upwave from the docks into the area outside the harbor. As a result, considerably larger wave heights occur near the harbor entrance (indicated by darker patterns in the gray-scale plots); the maximum value is approximately 3.9 m (near B), representing (nearly) standing waves and an increase of almost 50% relative to the case without the docks. This increase is consistent with the amplification on the upstream side seen in the theoretical results in Fig. 11. The standing wave pattern in the entrance channel area may be of some concern from a navigation perspective, especially for small craft using such harbors. At this time the US Army Corps of Engineers (Alaska District Office) is in the process of designing a reconfigured entrance channel at Douglas Harbor that includes a new wave barrier on the north side and an extension of the existing breakwater on the south side (not shown).

It is noted that these results are shown only by way of demonstration of the use of the modified TL approximation; the effect of mechanisms not included here such as frictional damping and wave-wave interaction (e.g., Panchang and Demirbilek 2001) may lead to different solutions.

6. Summary and conclusions

The approximate method proposed by Tsay and Liu (1983) to incorporate floating structures in a 2-D elliptic harbor wave model is extremely convenient for the engineers to implement with currently available harbor wave modeling technology; however, it produces results that deviate considerably from the solution of the Laplace equation. By performing a large number of tests that compared solutions of the TL approximation with those of the Laplace equation, a simple modification to the original TL approximation was developed. This involves adjusting the under-keel depth by a factor $\alpha = A\ln(ka) + B$, where A and B are given in Fig. 4 for different values of relative submergence. The modified TL approximation yields improved results, when compared with both laboratory data and theoretical results, for a wide range of conditions. By using practical demonstration, the modified TL approximation is applied to Douglas Harbor (Alaska). For the case examined, the floating docks in the harbor are shown to considerably attenuate the wave heights near some of the harbor coastlines relative to currently used models (that do not contain the facility to model the effects of the floating structures). However, the docks are shown to create a reflective pattern in the dock area and another reflective pattern that propagates up into the area of the harbor entrance and (or) navigation channels; these reflections, in principle, can be detrimental to transiting or docked vessels unless the dock layout is properly designed.

In the future, we plan to attempt field validation of the model enhancement described here. Many basic harbor wave simulation models have been validated in the field (e.g., Panchang and Demirbilek 2001), but without the effects of docks. The performance of the model under the influence of irregular waves will also be examined.

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List of symbols

a characteristic structure size
A_i incident amplitude
C wave velocity
C_g wave group velocity
d draft of floating structure
d/h relative submergence of floating structure
g acceleration due to gravity
h water depth
k wave number
ka relative width of floating structure
p parameter defined as CC_g
q parameter defined as K_2CC_g
R reflection coefficient
T amplitude of the transmitted wave
β phase shift of the reflected wave
δ phase shift of the transmitted wave
σ wave frequency
Φ 2-D complex wave potential
ϕ 3-D complex wave potential