Diffraction effects and ship motions on an artificial seabed

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(24th IWWWFB – Zelenogorsk, Russia – 19-22 April 2009)

The effects of varying bottom depth on wave propagation, which are lucidly described by Mei [1], can be important in predicting wave effects on ships at offshore terminals. For large vessels such as LNG carriers the change in depth may be substantial over the vessel's length. However both model tests and computations are usually performed in water of constant depth, and it is difficult to represent varying depth effects which extend over large horizontal scales. Buchner [2] has performed experiments and computations using an artificial sloping bottom of restricted length and width; substantial differences and variations of the vessel motions are reported, compared to results in a fluid of constant depth, and the results are sensitive to the width of the sloping bottom. We show here that such effects can be expected, and special care is required to design appropriate surrogates for the sloping bottom.

In [2] a seabed of nominal slope 1:20 is considered, shoaling from 35m to 8m over a length of 550m as shown in Figure 1. For the experiments and initial computations the width of this structure is 550m and both the sides and back are vertical, as in the perspective plot 3B1 shown in Figure 2. After observing significant refraction effects, additional computations were performed with a sloping bottom of width 1650m (3D1), and also for variants with sloping sides and back where the slope extended over widths and length on the order of 100m. In all of these cases there were indications of significant refraction, and it was concluded that *'Without special measures it is not possible to model a sloping seabed as a second body in diffraction theory. The refraction and interference effects are too strong and affect the wave exciting forces on the LNG carrier in an incorrect way. A large size of the second body and smoother edges of this body do not improve the situation.'*

Since LNG carriers are sensitive to relatively long waves, the computations in [2] include frequencies as low as 0.1 rad/sec, corresponding in 35m depth to a wavelength of 1164m. In such long waves it can be expected that diffraction will be important for these bottom configurations. Ideally, to represent a gradually shoaling bottom which extends over a large horizontal domain, a similarly large configuration should be used in the physical or computational model, but this is not practical in either experiments or computations. Even at higher frequencies it is known from simple two-dimensional studies [1] that substantial reflection will occur from abrupt depth changes, and partial trapping can occur in the shallow region.

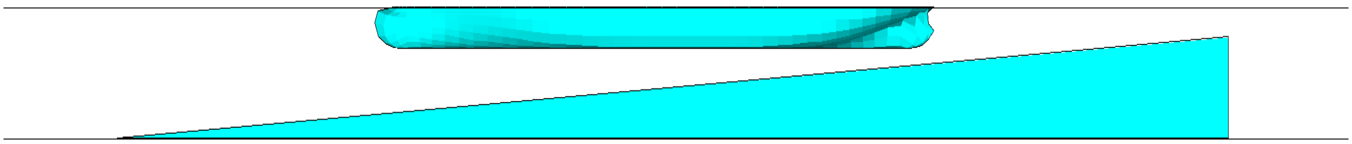

Figure 1: Profile of the ship hull above the sloping bottom with a vertical end.

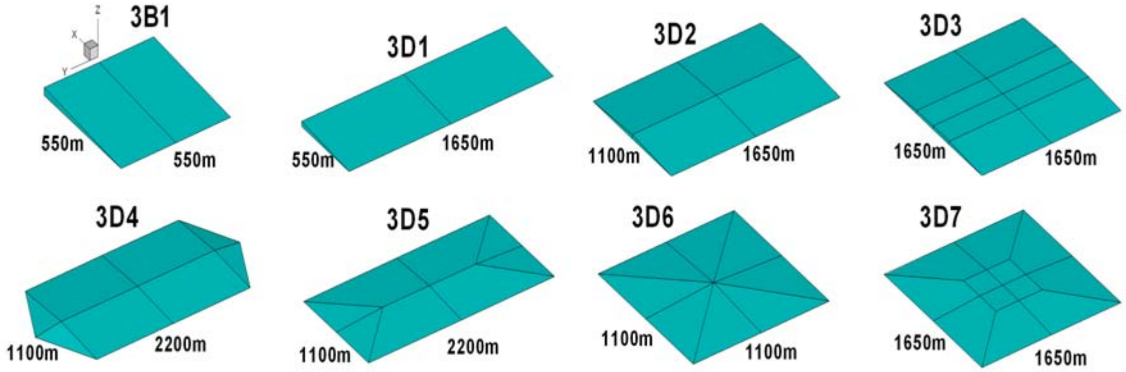

Figure 2: Perspective views of bottom configurations. 3B1 and 3D1 have the same profile as shown in Figure 1. The other configurations are symmetrical about $x = 0$. Incident waves propagate in the $+x$ direction, from the lower right toward the upper left in each figure. The maximum widths and lengths are indicated on the lower left and lower right sides of each configuration. In all cases the minimum depth is 7.5m at the top of the slope, and the depth is 35m in the region outside the artificial bottom.

In the present work we compare the diffraction effects of different sloping bottom configurations. The configurations with abrupt sides and back are affected by both refraction on the sides and reflection from the back. Improved configurations are found using more gradual transitions on the sides and back. The results are briefly summarized here, including computations of the free-surface elevation without the ship, and also computations of the added mass, damping and motions when a ship is located above the sloping bottom. More detailed results will be presented at the Workshop.

Figure 2 shows the configurations which are considered, and Figure 3 compares the results for the wave elevation along the centerline of the sloping bottom. The configurations 3B1 and 3D1 have essentially the same profile as is considered by Buchner [2]. 3D2 and 3D3 are intended to provide more gradual transitions back to the deep region behind the sloping bottom, to reduce two-dimensional reflection. However these configurations suffer from transverse waves which are reflected back and forth between the vertical sides. Thus the configurations 3D4-7 are introduced, with sloping sides. It is evident from Figure 3 that 3D6 is the best, in terms of uniform amplitude of the waves along the centerline; surprisingly, this objective is achieved with relatively compact horizontal dimensions.

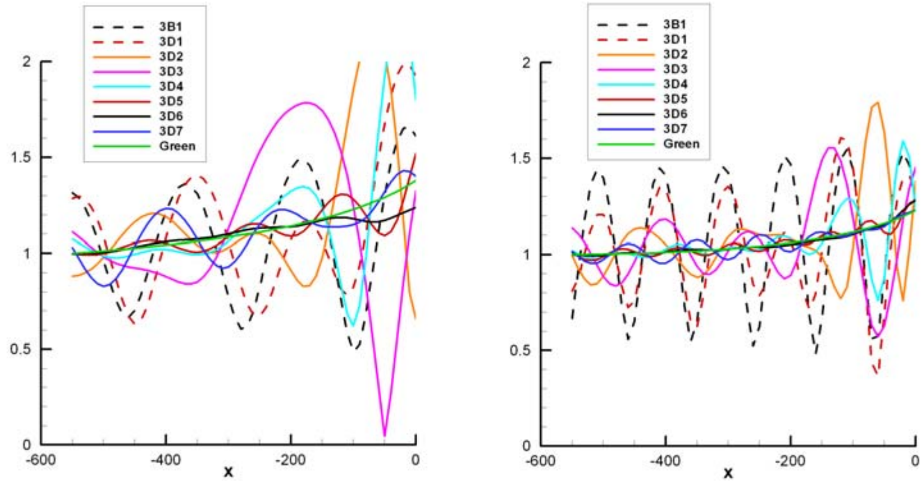

Figure 3: Free-surface elevation along the centerline of the sloping bottom, for each of the configurations shown in Figure 2. The frequency is 0.3 radians/sec in the left figure and 0.5 radians/sec in the right figure. The 'Green' curve is the approximation known as Green's law [1], based on zero reflection.

Before considering the presence of the ship we summarize the principal conclusions for the bottom configurations:

1. abrupt depth changes should be avoided, not only on the front but also on the sides and back
2. a horizontal extension of the shallow region appears to be detrimental
3. increasing the width increases transverse resonance effects
4. the optimum configuration, among those investigated, has gradually sloping sides and back but no extra width

Next we consider the effect of different bottom configurations on the heave and pitch motions of an LNG ship. The ship has the same dimensions as used by Buchner [2], with length 274m, beam 44.2m and draft 11m. It is oriented as shown in Figure 1, with the midship section above the center of the sloping bottom and the bow facing toward the deep water. Only head seas are considered. Calculations of the added mass, damping, and RAO's are shown in Figures 4-6 for the bottom configurations 3B1, 3D5 and 3D6 shown in Figure 2. 3B1 is included here since it was used by Buchner [2]. 3D5 and 3D6 are included since they have relatively good diffraction characteristics without the ship. The results for 3B5 and 3B6 are practically identical, except for the heave RAO at very low frequencies. The agreement between these results supports their validity, as surrogates for a sloping bottom of different width. Conversely, the results for 3B1 are oscillatory, especially in the context of the RAO's which indicate the sensitivity of the exciting force and moment to diffraction effects.

Results are also shown in Figures 4-6 for water of constant depth 21.25m, equal to the average along the length of the ship. The differences between these simpler computations and the results with the sloping bottom are surprisingly small. This implies that reasonable estimates of the heave and pitch motions can in fact be obtained using the average depth along the length of the ship, at least for a sloping bottom with depths similar to those considered here. However differences in depth at the bow and stern do have a substantial effect on the cross-coupling coefficients, as noted by Buchner [2], and thus the phases of the heave and pitch motions are not as well approximated by the computations with constant depth. Also, at certain values of the wavelength partial standing waves may occur on a slope of finite length, with significant effect on the exciting force in heave; this is illustrated by the oscillatory heave RAO in the vicinity of 0.1 radians/sec in Figure 6. This particular feature of a wide sloping bottom is not adequately represented by the narrower 3D6 configuration. And of course, in a situation where the sloping bottom is much longer and the depth at the deep end is much greater, substantial amplification of long waves can be expected based on Green's law.

In conclusion, when an artificial bottom is used in either experiments or computations, attention is necessary to avoid reflection and refraction effects associated with the dimensions and shape. On the other hand, the results in Figures 4-6 indicate that in some practical cases reasonable estimates of the wave effects on a ship can be achieved without modeling the nonuniform depth. It is evident that the dangers from an unsatisfactory model can outweigh the benefit of including an artificial bottom with nonuniform depth.

References

[1] Mei, C. C. 'The applied dynamics of ocean surface waves,' 1st Edition, Wiley-Interscience (1983).

[2] Buchner, Bas 'The motions of a ship on a sloped seabed,' Proc. 25th OMAE, 2006 (OMAE2006-92321).

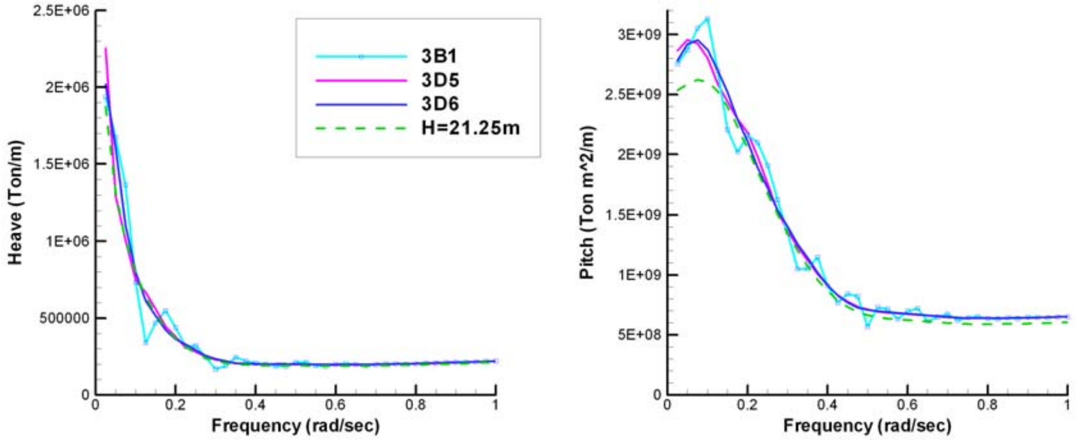

Figure 4: Added inertia of the LNG ship due to heave and pitch motions. Bottoms 3B1, 3D5 and 3D6 are defined as shown in Figure 2. The green dashed curve is for a constant depth of 21.25m.

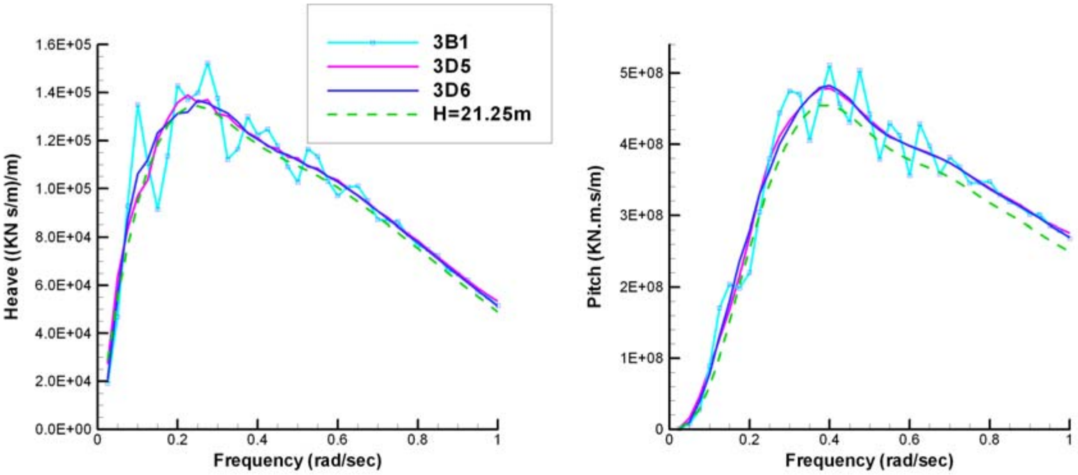

Figure 5: Potential damping of the LNG ship due to heave and pitch motions.

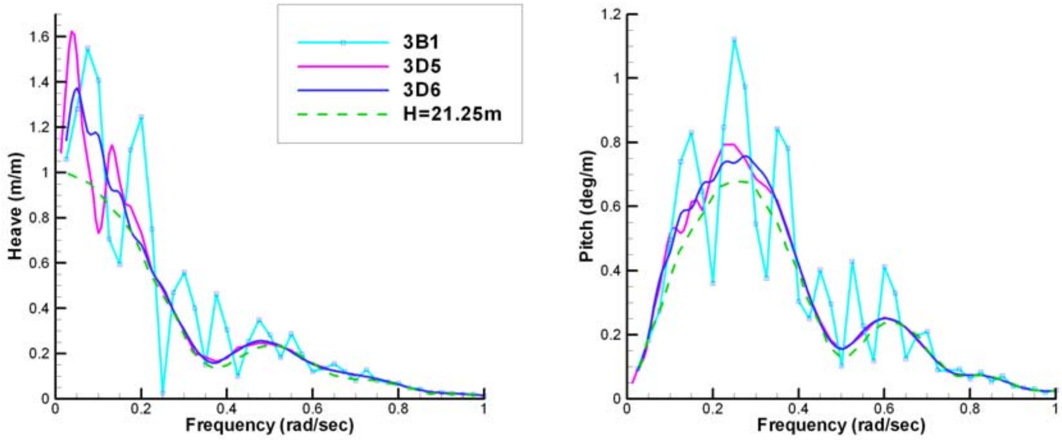

Figure 6: RAOs of the LNG ship in heave and pitch in head seas.