CHAPTER 78

THE PENETRATION OF SHORT-CRESTED WAVES THROUGH A GAP

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Abstract

The propagation of long-crested and short-crested waves through a gap such as between two breakwaters is affected by diffraction. If the water depth is not uniform, refraction may also affect this penetration. It is shown with a navigation channel between two breakwaters (academic case and a realistic harbour case) that the effects of diffraction are small compared to those of refraction in regions where waves can penetrate with refraction only (e.g. where wave rays can penetrate). This region is relative large for short-crested waves. Outside these regions diffraction is dominant. With another example of waves penetrating through a tidal gap against a strong ebb current, it is shown that the short-crestedness of the waves destroys to a very large extent the waved guide effect of such currents. Both set of experiments show that the inclusion of short-crestedness in the wave computations causes some smoothing of the wave field, and that diffraction is a minor effect in regions with considerable wave motion. This is of some scientific and economic relevance as refraction can readily be combined in wave models with other physical phenomena such as wave generation and dissipation. Moreover, such models require less computer capacity than diffraction models which do not readily absorb wave generation and dissipation.

Introduction

To compute the propagation of waves through and beyond a gap between two obstacles such as breakwaters or islands, several aspects of the waves are important for modelling these waves numerically. As a boundary condition it is important to consider the waves as a harmonic, long-crested wave or as random, short-crested waves. In and beyond the gap several conservative and non-conservative processes should be considered. The conservative processes are: refraction, diffraction and

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reflection. The non-conservative processes are wave generation (by wind) and dissipation (by bottom friction and breaking, also during reflection). We are interested in these aspects from a modelling point of view because of the choice that has to be made between using a model for combined refraction-diffraction or a model for refraction only. A refraction-diffraction model requires considerable computing power, in particular for short-crested, random waves. Moreover, the inclusion of generation and dissipation is primitive or non-existent in such a model. A refraction model requires less computing power and is readily supplemented with generation and dissipation mechanisms, but it lacks diffraction. The question is, can a refraction model provide at least a reasonable estimate of a short-crested wave field in the absence of diffraction?

Method of the study

To make a tentative step towards an answer, we consider three cases of waves propagating through a gap: (a) a fairly academic situation of waves propagating over a navigation channel between two breakwaters (b) a similar situation with a fairly realistic harbour beyond the gap and (c) an actual tidal inlet with a strong ebb-current.

We use the two different types of models mentioned in the introduction. The refraction-diffraction model is the PHAROS model of Delft Hydraulics (Kostense et al, 1988) and the refraction model is the HISWA model of Delft University of Technology (Holthuijsen et al, 1989). The major differences is that the refraction-diffraction model reconstructs the actual sea surface of an harmonic wave that is long-crested in deeper water by computing the phase and amplitude of the surface elevation whereas the refraction model computes the directional energy distribution of waves that are short-crested in deeper water. The short-crested cases are computed with the refraction-diffraction model by superimposing a number of computed harmonic waves. The long-crested cases are computed with the refraction model by considering a very narrow directional energy distribution in deeper water. For the interpretation of the results it is important to note that the HISWA model does not compute wave propagation in directions more than 60° at either side from a pre-determined direction (chosen as the initial wave directions in this study).

For economic reasons we consider only waves with one constant period. The waves that we consider are 10 s in period and either long-crested (PHAROS only) or short-crested with directional distributions of the type $D(\theta) = A\cos^m(\theta)$ ($m = 100$ for simulated long-crested waves in HISWA only or $m = 4$ for simulated short-crested waves in PHAROS and HISWA).

We consider the similarities and differences in the results of the two models for the three cases mentioned above.

The academic gap

The bottom topography for the situation with a navigation channel between two breakwaters is given in Fig 1.a. The channel originates in water of 15 m deep and the channel is maintained at that depth. Outside the channel the water depth decreases to a uniform depth of 11 m beyond the gap. The slope of the shoulders of the channel is 1:10 and the gap is 480 m wide (i.e. 5.5 wave lengths) The breakwaters and the circular boundary beyond the gap are fully absorbing. This means that the region beyond the gap may be interpreted as infinitely large.

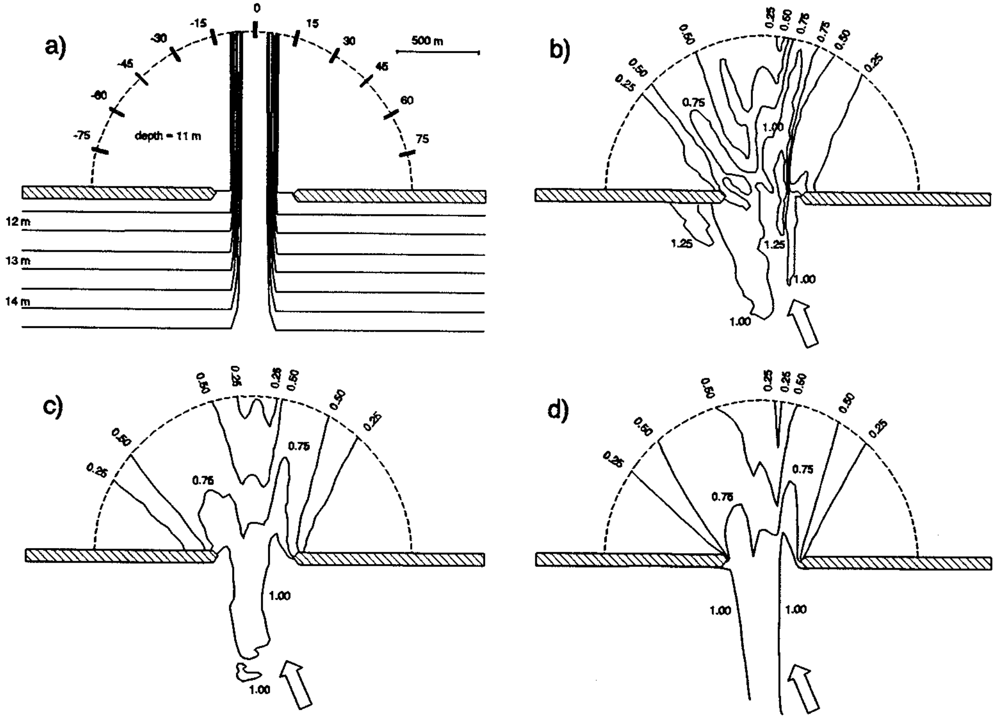

Fig. 1 The penetration of waves from 24° incidence with channel through a gap in terms of relative (significant) wave height H / H_i. Panel a) bottom topography and position indication along absorbing circle. Panel b) combined refraction and diffraction, long-crested waves. Panel c) combined refraction and diffraction, short-crested waves. Panel d) refraction only, short-crested waves.

We computed the wave situation with various initial wave directions and we found that the shoulders of the channel refract the waves such as to spread wave energy in fingers to the sides. From the initial (mean) wave directions of 0°, 12°, 24° and 36° (angle of incidence with the channel axis), we selected the results of the 24° case as representative. The effects shown next are slightly more extreme for the 12° case (the critical angle for reflection on the channel shoulder is appr. 24°) and slightly less extreme for the 0° and 36° cases).

In Fig. 1.b the results are shown for the refraction-diffraction computations for long-crested waves (in terms of the local wave height H divided by the incident wave height H_i). The finger pattern of the wave penetration is obvious with energy concentration slightly over 1.25 just beyond the gap. The pattern is smoothed somewhat by introducing short-crestedness as shown in Fig. 1.c where the finger pattern is still obvious but not as concentrated. The effect of removing diffraction from the short-crested waves situation is shown in Fig. 1.d where the results of the refraction computations are shown. Again the finger pattern is obvious and in fact not very different from that in Fig. 1.c where diffraction was included.

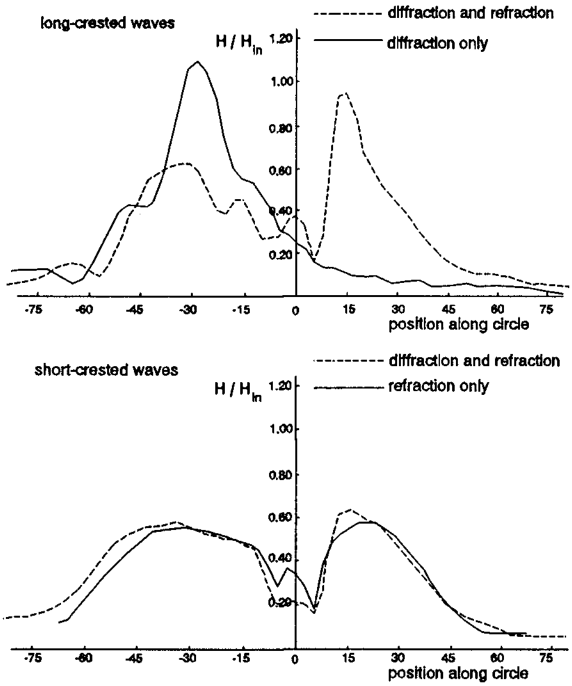

Fig. 2 The results of the computations of Fig. 1 along the absorbing circle. The results for the long-crested waves compared with the results for the short-crested waves for refraction only, diffraction only and combined refraction/diffraction. Diffraction only was achieved with constant water depth of 11 m.

A further comparison is made in Fig. 2. A pure diffraction computation for long-crested waves (obtained with the refraction-diffraction model with a uniform water depth of 11 m) is included (upper panel). Introducing the channel in these computations has the effect of splitting part of the energy propagation towards the right (looking down-wave, same panel, compare with Fig. 1.b). Adding short-crestedness in these computations gives a smoother distribution of the energy (lower panel of fig. 2, compare with Fig. 1.c). Using the refraction model instead of the refraction-diffraction model gives very similar results (lower panel), except where the refraction model does not compute (more than 60^{o} from the incident wave direction), confirming the conclusion from Fig. 1.

The harbour

The bottom topography for the harbour with a navigation channel very similar to the above is given in Fig. 3.a. The channel originates also in water of 15 m deep and the channel is maintained at that depth towards the deep basin in the harbour at the same depth. Beyond the deep basin, a shallow basin at 11 m depth is protected by a mole. The slope of the shoulders of the channel is 1:10 and the gap is 330 m wide (i.e. 4 wave lengths). For the purpose of this study the breakwaters and the quays are assumed to be fully absorbing.

We computed the wave situation with the initial (mean) wave direction along the channel axis and (of course) we again found that the shoulders of the channel refract the waves such as to spread wave energy in fingers to the sides.

In Fig. 3.b the results are shown for the refraction-diffraction computations for long-crested waves. The finger pattern of the wave penetration is obvious with energy concentration as high as 1 just beyond the gap and a fairly deep penetration behind the left breakwater. The pattern is smoothed considerably by introducing short-crestedness as shown in Fig. 3.c but the deep penetration behind the left breakwater is hardly affected. The effect of removing diffraction from the short-crested waves situation is shown in Fig. 3.d where the results of the refraction computations are shown. Again the pattern is obvious, including the deep penetration finger, and in fact not very different from that in Fig. 3.c. The patterns are nearly equal, although the penetration in the refraction-diffraction computations is slightly higher than in the refraction computation (5% difference where the finger behind the left breakwater touches the harbour contour). Again these computations demonstrate the marginal effect of diffraction in this case.

If reflection against breakwaters and quays is taken into account in the refraction-diffraction computation (not possible with the HISWA model) it appears that wave energy can penetrate virtually everywhere in the harbour and that diffraction remains relatively unimportant.

Tidal inlet

To further illustrate the considerable effect of short-crestedness on the wave pattern, we compute the wave field in an actual tidal gap. It is the 3 km wide tidal entrance to the Wadden Sea between Den Helder and the island of Texel

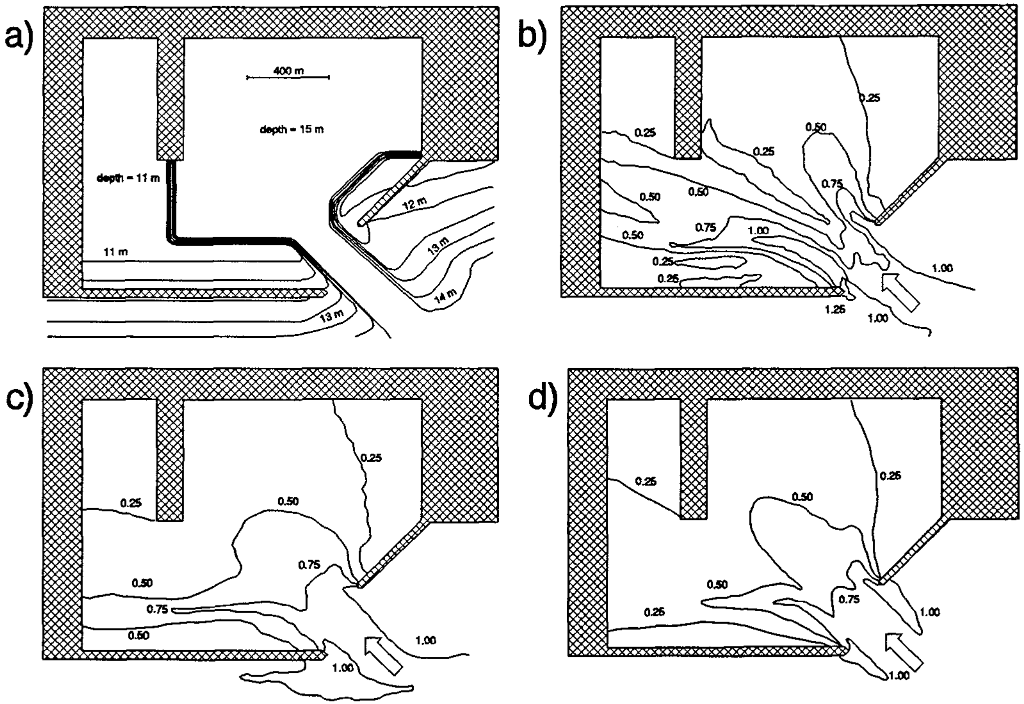

Fig. 3 The penetration of waves parallel to the navigation channel between two breakwaters in terms of relative (significant) wave height H/H_i. Panel a) bottom topography. Panel b) combined refraction and diffraction, long-crested waves. Panel c) combined refraction and diffraction, short-crested waves. Panel d) refraction only, short-crested waves.

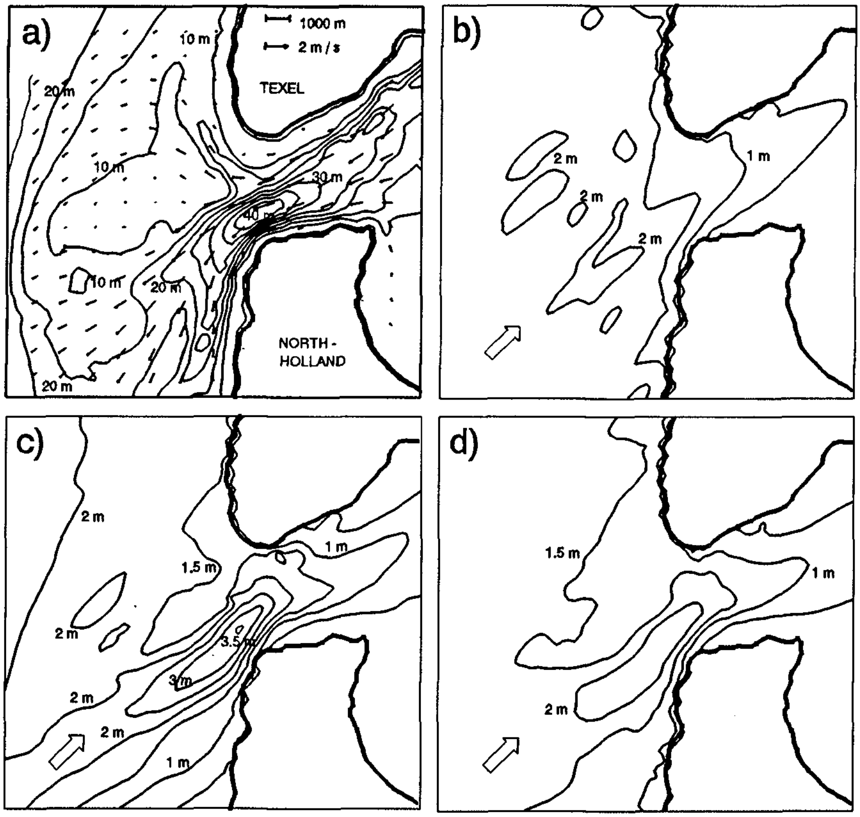

Figure 4. The penetration of waves into a tidal inlet computed with refraction model. Panel a) bottom topography and current velocity field. Panels b,c,d) isolines of significant waveheight. Panel b) long-crested waves without current. Panel c) long-crested waves with current. Panel d) short-crested waves with currents.

in the North of Holland. The bathymetry and the ebb-current pattern are given in Fig. 4.a. The current pattern has been computed with a two-dimensional nonlinear tidal model WAQUA (Leendertse et al., 1981 and Stelling, 1984) for a severe storm case. The waves that we consider propagate from deep water towards the gap from the South-west. The wave period is 6s and the significant wave height is 2m. For long-crested waves and no currents, the results of the refraction computations are shown in Fig. 3.b. Refraction-diffraction computations have not been carried out as the area is too large for that. The results show some increase in wave height before the waves reach the shallows (probably due to shoaling) and a considerable decrease at the shoal. Adding currents dramatically changes the results as the waves now increase just in front of the gap to 3.55 m (see fig. 3.c). This is almost certainly a wave guide effect, that is, the waves are trapped by the counter current by current-induced refraction. However, adding short-crestedness to the computations destroys to a large extent the wave guide effect, resulting in dramatically lower waves (maximum 2.6 m, Fig. 3.d).

Conclusions

From numerical experiments with a combined refraction-diffraction model and a refraction model, we come to the following conclusions.

Beyond a gap with a natural or dredged navigation channel, the shoulders of the channel may displace and focus waves in certain areas beyond the gap. This focussing is tempered by short-crestedness of the waves. In such cases and probably in similar cases, refraction computations without diffraction seem to provide a reasonable first estimate of the waves in those regions beyond the gap where waves can penetrate with refraction (e.g. where wave rays can penetrate). In other regions diffraction is essential.

In addition to these considerations of accuracy, the choice of using a refraction-diffraction model or a refraction model is one of convenience and economy. The computing power required for a refraction model without diffraction is considerably less than for a refraction-diffraction model (in the present study roughly a factor of 10). A refraction model without diffraction has the added advantage of readily combining other physical phenomena with the propagation of the waves, including current effects. Reflections (not considered in the present study) are relevant in harbours and can be included in both types of models. Reflection is included in the PHAROS model.

It further appears that diffraction models which assume a flat bottom are useless for any harbour with an entrance channel.

The above conclusions relate to wave computations in which short-crestedness is accounted for. The inclusion of the short-crestedness of waves also tends to smooth the wave guide effect of concentrated counter currents in a gap such as an ebb current between islands.

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