CHAPTER 221

MODELLING OCEAN WAVES IN THE COLUMBIA RIVER ENTRANCE

L.A. Verhagen[1,2], L.H. Holthuijsen[1] and Y.S. Won[1]

Abstract

Observations by Gonzalez et al. (1984) and Gonzalez (1984) of swell penetrating the entrance of the Columbia River provide an excellent opportunity to test linear wave theory for wave - current interactions. In the present study a two-dimensional wave model for short-crested waves based on the linear wave theory is used. The model includes the propagation effects of currents and also generation and dissipation of the waves. The results agree fairly well with the wave observations in the river entrance, in spite of an uncertainty in the bathymetry and currents. Numerical experiments show that waves from westerly directions are focused in the entrance by refraction on a bar in front of the entrance and that current induced wave guide effects enhance this focusing in ebb conditions.

Introduction

Swell entering the Columbia River (United States west coast) may amplify considerably due to bottom and current effects. Gonzalez et al. (1984) and Gonzalez (1984) acquired observations in the river entrance which provide an excellent opportunity to study wave-current interactions. To compute the wave field, the same authors used a one-dimensional model for monochromatic, long-crested waves. Later, Rao (1990) used a two-dimensional model for random, short-crested waves. However, neither model takes the two-dimensional current structure into account nor generation and dissipation of the waves (except that the wave height or spectrum has an a priori imposed upper limit). In this study we use a model that is based on linear wave theory for short-crested waves with energy sources and sinks (in particular bottom and current induced wave breaking and bottom dissipation). It is a two-dimensional model that computes the two-dimensional wave field so that the two-dimensional structure of the wave field can be related to features in the bottom and current field. The effects of bottom and current induced refraction are addressed explicitly.

[1] Delft University of Technology, Stevinweg 1, 2628 CN, Delft, the Netherlands,
[2] presently at University College, Australian Defence Force Academy, Campbell, Australia

Observations

The Columbia River entrance is located on the Pacific east rim at the west coast of the United States of America (see Fig. 1). It is a rather energetic region with high waves (in one of the observed cases the significant wave height of the swell was about 6.5 m) and an average river discharge of 10,000 m^3/s and peak discharges of more than 40,000 m^3/s. On the average 850 search and rescue missions are conducted and about 10 lives are lost per year (Gonzalez 1984).

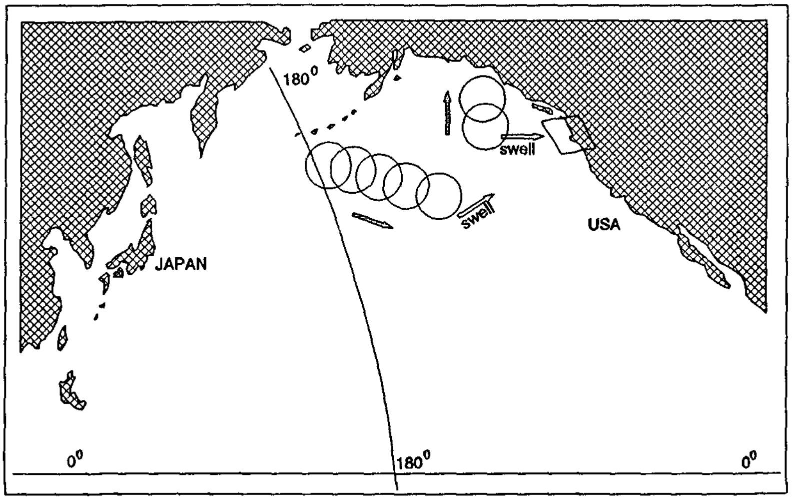

Fig. 1 The tracks of the two swell generating storms of this study. The box indicates the location of the Columbia River entrance.

Gonzalez (1984) and Gonzalez et al. (1984) observed swell that was generated in two severe storms in 1979 and 1981. From local observations at the Columbia River entrance and weather maps Gonzalez (1984) concluded that the first generating storm was a storm moving in a few days across a fair distance in the northern Pacific due west of the Columbia River entrance. The second storm was analyzed by Gonzalez et al. (1984) and they concluded from weather maps that it was a storm relatively nearby, moving from an offshore position to the Canadian coast. The tracks of these storms are schematically indicated in Fig. 1.

The bathymetry of the Columbia River entrance that we used in this study is given in Figs. 2 and 3. It is based on a map from 1983 (US Army Engineer District Portland MC-1-543) for the region seaward from the jetties (outer region) and a map from 1966 (C&GS 6151) for the region up-river from the jetties (inner region). These maps may not properly represent the bathymetry during the observations. In fact, in the outer-region we found considerable differences with the 1966 map (of more than two meters in depth near the south end of the "bar", see Figs. 3a and 3b). The map that we finally used for the outer region (the 1983 map, Fig. 3a) seems to be the closest in time to the observations that were available to us (see acknowledgements). The inner region is regularly dredged and we therefore assume that the bathymetry there has not changed dramatically over the years. To investigate the effects of this uncertainty in bathymetry we will show results using the map from 1966 for the outer region (Fig. 3b).

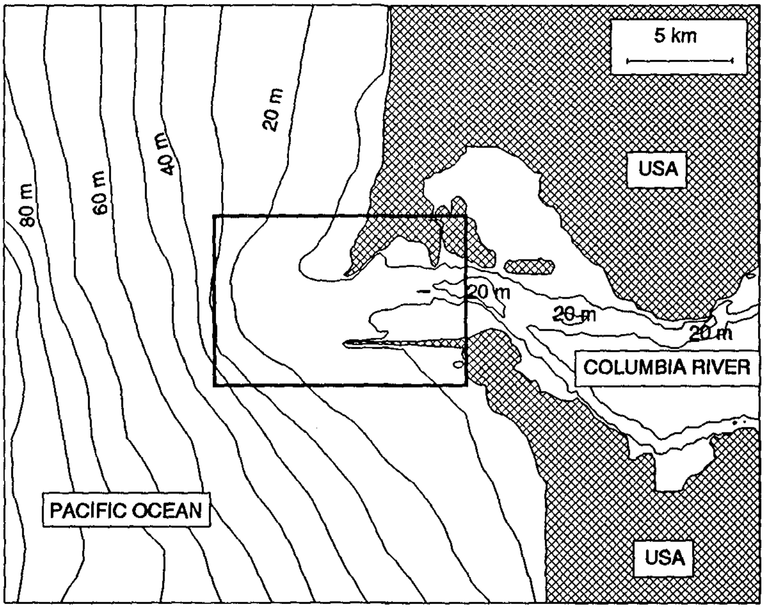

Fig. 2 The large scale bathymetry off the Columbia River entrance. The box indicates the region shown in Figs. 3 and 5.

From the observations we selected a young-swell case and an old-swell case. The young swell arrived on 12 September 1981. It had been generated in a storm moving to Canada a few hundred miles north-west from the Columbia River entrance in the period 8-10 September. The incoming significant wave height and the mean wave period were observed with a wave buoy (NOAA data buoy 46010, located about 10 km offshore) to be 2.8 m and 8.6 s (ebb case, 16:00 PST) and 7.8 s (flood case, 11:00 PST) respectively. We estimate the mean wave direction from the Side-Looking Airborne Radar (SLAR) images in Gonzalez et al. (1984) to be 290° true North. We estimate from the angle of view from the Columbia River entrance to the width of the generating storm area that the directional spreading of the waves was 13° (directional standard deviation of the directional energy distribution). In the river entrance a drifting waverider buoy measured the wave field (tracks shown in Figs. 3c and 3d). The old swell arrived at the location during the period 15 - 20 October 1979. It had been generated 9 days before in a severe storm in the northern Pacific moving from the date line towards the location. On October 19 at 16:00 PST the incoming significant wave height and the mean period were observed with a deployed waverider buoy to be 4 m and 15 s respectively. Gonzalez (1984) estimated the mean wave direction from the time development of the locally observed peak frequency and weather maps to be 270° true North. The directional spreading we estimate with the same technique as above to be 6°. The waves in the entrance were observed near buoy 8 with a waverider buoy (see Figs. 5c and 6).

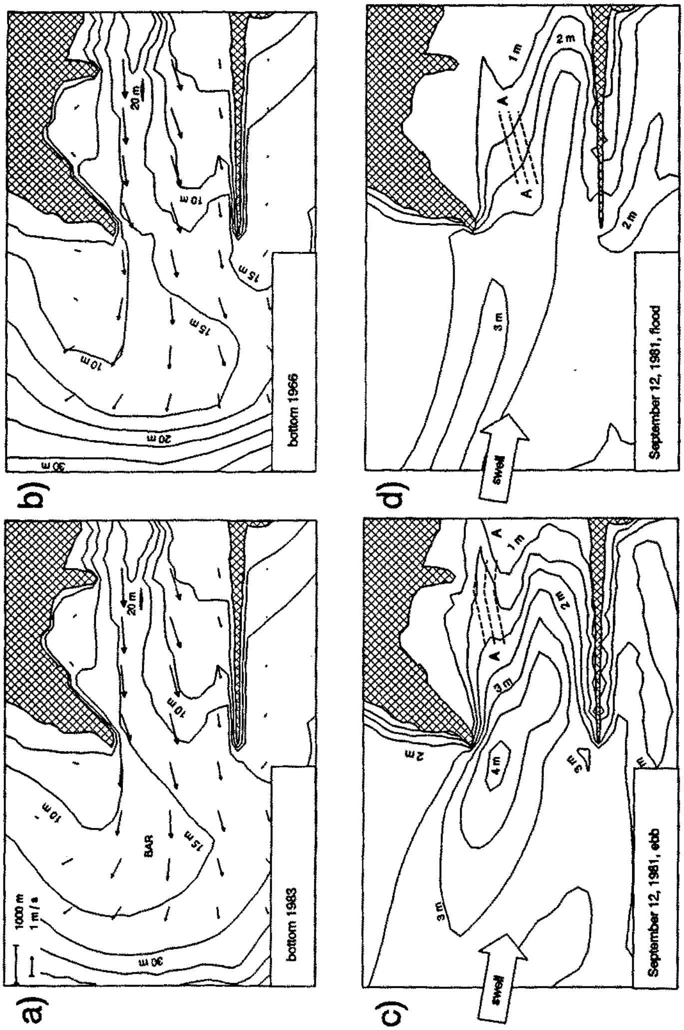

Fig. 3 Panel a) the bathymetry of the Columbia River entrance (1983 information) and the ebb currents for the old swell case. Panel b) same as a) from 1966 information. Panel c) significant wave height young swell case (ebb). Panel d) significant wave height young swell case (flood). Tracks of buoy shown as centre line between A and A (parallel lines at 250 m distance).

Wave and current models

The wave model that we used (the HISWA model, Holthuijsen et al., 1989) is based on a parameterization of the spectral balance of wave action (defined as wave energy divided by relative frequency). In the absence of a mean current it reduces to a parameterized energy balance. The parameterization is based on the presentation of the waves with a spectrum that is discrete spectral in the directions and parametric in the frequencies. This implies that the spectral representation of short-crestedness of the waves is maintained. All propagation in the model is based on linear wave theory while the sources and sinks are parametric representations of wind growth, wave breaking (whitecapping and surfing), bottom friction and blocking due to counter current. The model computes the spatial variation of this spectrum by integrating the local effects of wind, bottom and currents while propagating with the wave components on a regular grid covering the computational area (identical to the total area of Fig. 2 with 250 m resolution). Refraction is modelled as a continuous directional shifting of wave action in spectral space. For coastal regions the propagation time through the area is small compared to the time scale of wind and current variations. Time has therefore been removed as a variable. In the present study with swell in a coastal region, the only effective sources and sinks in the model are those representing wave breaking and bottom friction.

The tidal model which has been used (the DUCHESS model, Booij, 1989) to simulate the ebb and flood flow in the Columbia River entrance is based on the two-dimensional shallow water equations. It includes hydrostatic and atmospheric pressure gradients, bottom and wind stresses, Coriolis force and horizontal eddy viscosity. The inclusion of nonlinear terms such as advective acceleration, viscosity and stresses makes DUCHESS a nonlinear tidal model.

Results

To drive the tidal model, the tidal constituents at the open ocean boundary and at Tongue Point (up-river boundary in Fig. 2) were taken from standard tide tables (Admiralty Tide Tables). In spite of choosing a relatively low frictional coefficient, we were not able to reproduce the current observations of Gonzalez et al. (1984) and Gonzalez (1984). We therefore multiplied the magnitude of all computed current vectors with a constant factor to match the observed (corrected to depth-averaged) values (factor 1.08 in the young swell case (ebb), 1.50 in the young swell case (flood) and 1.23 in the old swell case (ebb)). The current pattern for the old swell case is shown in Fig. 3a for the 1983 bathymetry (and in Fig. 3b for the 1966 bathymetry). The ocean wave boundary conditions were taken from the buoy and radar observations.

The young swell case is considered first because the wave observations in this case provide some spatial information of the wave field in the Columbia River entrance and therefore provide a good test of the fidelity of the HISWA model. The wave field is computed with HISWA for one ebb case (12 Sept. 1981, 16:00 PST) and one flood case (12 Sept. 1981, 11:00 PST). The results for the ebb case are shown in Fig. 3c where also the track of the drifting buoy is shown. The maximum significant wave in the area is approximately 4.2 m. The HISWA results along the buoy track (and 250 m north and south of this track) are compared with the drifting buoy observations in Fig. 4. For the two up-river locations, the agreement seems

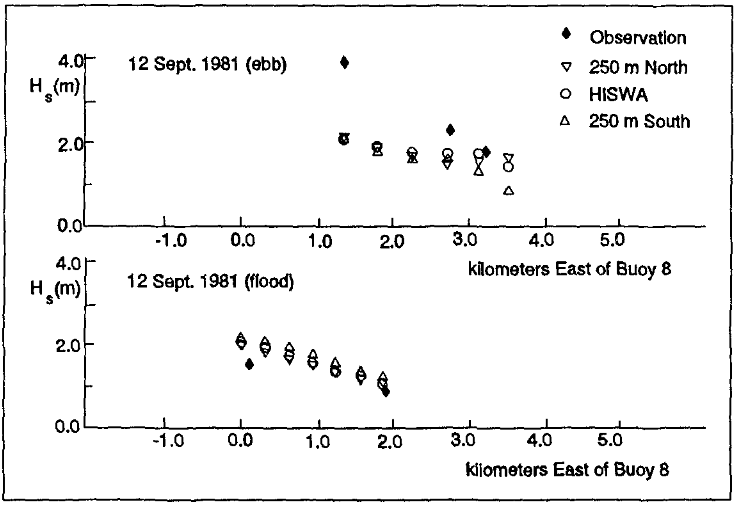

Fig. 4 The computed significant wave height for the young swell case compared with the buoy observations. Upper panel is ebb case, lower panel is flood case. The track of the buoy is shown in Fig. 3.

to be fair, considering the spatial resolution of the model (250 m). For the one down-river location, there is no such agreement (observed 4 m and computed 2 m significant wave height). Considering the spatial distribution of the waves, it seems unlikely that a simple error in the location of the buoy is responsible for this discrepancy. On the other hand, a large error in the model is not very likely either considering the other results (below). The results for the flood case are shown in Fig. 3d and 4 (maximum significant wave height 3.5 m). Again, the results seem to be fair considering the uncertainty in bottom and currents.

The old swell case is rather spectacular with a significant wave height of 4 m amplifying to nearly 6.5 m on the inner bar (near buoy 8). To inspect the physical processes to some extent we first show the HISWA results without currents and without bottom refraction effects (accomplished by de-activating the refraction terms in HISWA). The results are given in Fig. 5a. It is obvious that the remaining processes in the resulting quasi-one-dimensional situation (i.e. rectilinear propagation, bottom induced shoaling and bottom friction) do not affect the wave field considerably (maximum significant wave height of 4.6 m over the bar). When we add bottom induced refraction (still without current), the results are as shown in Fig. 5b. It is obvious that the bar concentrates wave energy in front of and between the jetties, probably by a caustic type refraction pattern. The maximum significant wave height is 5.8 m at the southern edge of the bar. If we finally add ebb currents to the situation we see from Fig. 5c that the current field enhances the waves further, probably by a wave guide effect (trapping of wave components around the centre of a counter current). The maximum significant wave height is now 6.25 m at the southern edge of the bar. There is a second maximum of 6.19 m between the jetties near buoy 8 (Fig. 6). This secondary maximum differs only 4.5 % from the observed 6.48 m of swell "near buoy 8" (quote from Gonzalez, 1984). This is a surprisingly good agreement considering the uncertainty in the bottom and current fields used in the computations. To show the effect of this

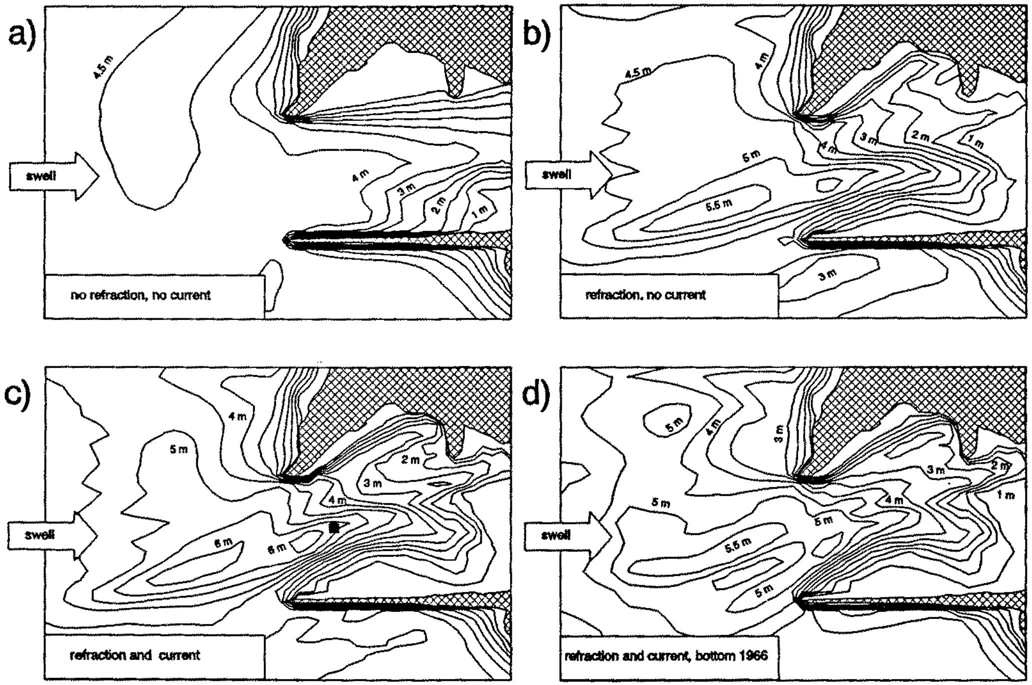

Fig. 5 The computed significant wave height in the old swell case. Panel a) without refraction and without currents (1983 bathymetry). Panel b) with refraction but without currents (1983 bathymetry). Panel c) with refraction and with currents (1983 bathymetry). Panel d) with refraction and with currents but 1966 bathymetry. Location of buoy 8 indicated in panel c) with black square.

uncertainty, we repeat the last computations with the bathymetry from the 1966 map (and corresponding current field). The results are shown in Fig. 5d where the maximum significant wave height is 5.9 m (at the southern edge of the bar).

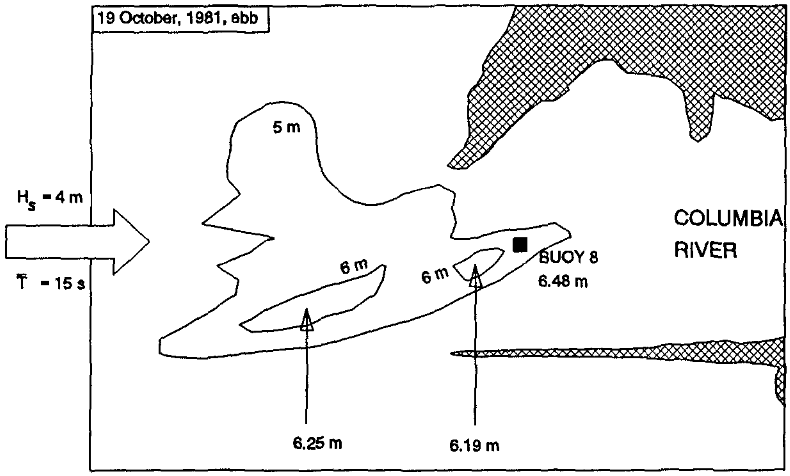

Fig. 6 The computed significant wave height for the old swell case compared with the buoy observation near buoy 8 (copied from Fig. 5c).

Conclusions

The observations of Gonzalez et al. (1984) and Gonzalez (1984) seem to provide an excellent opportunity to test wave-current interactions within the linear wave theory. This linear wave theory is represented in the HISWA model and we find general agreement between the computational results and the observations. However, this agreement is better than one would expect considering the uncertainty in the bottom and current data used in the computations.

Independent of this uncertainty we can conclude that waves approaching the Columbia River from the west are focused into the river entrance by bottom induced refraction. This focusing is further enhanced in ebb conditions by current induced refraction.

Acknowledgements

With pleasure we acknowledge that J. List of the U.S. Geological Survey helped us with obtaining the bathymetry in the Columbia River entrance. The work of one of the authors (Y.S.W.) was supported by the European Economic Community under contract MAST-0026-C(MB).

References

Booij, N. (1989). Delft University Computer program for 2-dimensional Horizontal Estuaries and Sea Surges (DUCHESS), Group of Hydraulic and Geotechnical Engineering, Delft University of Technology.

Gonzalez, F.I., M.R. Mulhern, E.D. Cokelet, T.C. Kaiser, J.F.R. Gower and J. Wallace (1984). Wave and current observations at the Columbia River entrance, 10 - 13 September, 1981, NOAA Technical Memorandum ERL PMEL-59, NOAA Environmental Research Laboratories, Pacific Marine Environmental Laboratory, Seattle.

Gonzalez, F.I. (1984). A case study of wave-current-bathymetry interaction at the Columbia River entrance, J. Phys. Oceanogr., 14, pp. 1065 - 1078.

Holthuijsen L.H., N. Booij and T.H.C. Herbers (1989). A prediction model for stationary, short-crested waves in shallow water with ambient currents, Coastal Engineering, pp. 23-54.

Rao, D.B. (1990). Local and regional scale wave models, Proc. Techn. Conf. Ocean Waves, Paris, 6 - 7 Feb. 1989, Rep. No. 24, World Meteorological Organization, pp. 125 - 138.