WAVE RESOURCE ASSESSMENT FOR THE PORT OF GARIBALDI, OREGON

Client	WAVE energy AS
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Document No	41571/BR/01
Issue	B
Classification	Client's Discretion
Date	18 January 2011

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EXECUTIVE SUMMARY

WAVE energy AS is conducting a feasibility study for the installation of a wave energy converter near the entrance to the Port of Garibaldi, Oregon. As part of this study WAVE energy AS have contracted GL Garrad Hassan (GH) to assess the wave energy resource in the vicinity of the breakwaters which form the entrance channel to Tillamook Bay. The objective of the work was to provide information on the available wave resource and extreme conditions so that WAVE energy can determine if the installation of their Sea-wave Slot-cone Generator (SSG) device at this location is viable.

The analysis conducted by GH is based on existing data in the public domain. No collection of new in-situ data has been conducted. The analysis consists of three tasks:

1. Collation and analysis of existing wave, wind and tidal data for the area close to the Port of Garibaldi.
2. Modelling and analysis of nearshore wave conditions
3. Estimation of nearshore extreme wave conditions

A summary of the work conducted and the results of the analysis is provided below.

Task 1: Collation and analysis of existing wind, wave and tidal data

The National Oceanic and Atmospheric Administration (NOAA) operate a network of data buoys in US waters, which are owned and maintained by the National Data Buoy Center (NDBC). Four buoys close to the Port of Garibaldi were selected for use in this study. The buoys are in water depths between 60m and 130m and are located between 70km and 110km from Garibaldi. Wind and wave data for these buoys has been downloaded from the National Oceanographic Data Centre (NODC). The data covers the period 1979-2010, but with some gaps.

The wave data has been quality checked and processed to integral wave parameters: significant wave height (H_s), energy period (T_e), wave power (P), mean wave direction ($MDIR$). The offshore wave climate has been inferred from the buoy measurements and presented in terms of the joint and marginal distributions of H_s and T_e, H_s and $MDIR$, and P and $MDIR$. The annual mean H_s, T_e, and P at the offshore buoy locations is 2.4m, 9.1s and 36.5kW/m respectively. The mean wave direction is predominantly between south-west and north-west. The seasonal and interannual variability in the offshore wave conditions was also investigated. The individual monthly mean wave power varies between about 5kW/m and over 140kW/m for one exceptionally stormy month. The average monthly power levels vary between 60-70kWm in the winter months and ~10kW/m in the summer months. The interannual variability in offshore wave conditions was found to be fairly high, with the annual mean power varying between 22kW/m and 48kW/m.

The offshore wind data were analysed to determine the joint and marginal distributions of wind speed and direction and the seasonal variability in mean wind speeds. Individual monthly mean wind speeds varied between 3m/s and 10m/s, with the long-term average monthly means varying between 4.5m/s in the summer and 7m/s in the winter months. The wind direction is more variable than the wave direction and is mostly either northerly or southerly, with a much lower occurrence of easterly or westerly winds.

Tidal levels have been calculated using NOAA tidal predictions for the Barview station, located in the entrance channel to Tillamook Bay. The tidal datum can be summarised (relative to MLLW): mean sea level 1.20m, mean low water springs 0.05m, mean high water springs 2.33m, lowest astronomical tide -0.70m, highest astronomical tide 2.90m.

Task 2: Nearshore modelling

The SWAN model has been used to determine the nearshore wave climate close to the Port of Garibaldi, using the offshore buoy measurements as boundary data. An analysis of the offshore buoy data showed that the wave climate at the offshore buoy locations to the north and south of the project site can be considered equivalent. This enabled a smaller and more computationally efficient model domain to be used. The model domain used is a semi-circular region extending 25km to the west of the jetties at the entrance to Tillamook Bay, reaching the 150m depth contour at the western extent. A flexible triangular mesh has been used for the computational grid, with a resolution of 1.25km close to the boundary, increasing to 25m for the region within 750m of the jetties. This enables good resolution of physical processes in the complex shallow bathymetry close to the jetties, whilst requiring less computational demand in offshore areas where wave conditions are less variable.

The bathymetry used in the model was formed from a composite of two sources. The first is the Tsunami Inundation Digital Elevation Model for Garibaldi at 1/3 arc second resolution, obtained from the National Geophysical Data Centre. The second dataset comprises soundings made by the US Army Corps of Engineers (USACE) of the approaches and entrance channel to Tillamook Bay over the period 1982-2010. The USACE data showed that there is significant sediment movement around the channel mouth, with a shoal varying in depth between 5m and 10m.

To select representative boundary conditions from the offshore data, the wave spectra have been fitted using both unimodal and bimodal JONSWAP spectra. These representative cases were propagated through the model and the nearshore results for the entire boundary time series are interpolated from these. Maps of the annual mean H_s, T_e, wave direction and power were produced for the area close to the jetties. The shoal at the end of the jetties has a focussing effect, causing the waves to refract towards it and increasing the mean significant wave height and power in its lee. Both the average significant wave height and power decrease significantly in the shallow water close to the jetties.

For four points close to the jetties the model results were analysed in detail. Two of these points are located close to tip of each jetty and the other two are located half way along the north and south jetties. The joint and marginal distributions of H_s and T_e, H_s and *MDIR*, and *P* and *MDIR* were presented for these four locations, along with the seasonal variability in the mean values. The significant wave heights and wave power was found to be strongly dependent on the water depth. The range of directions is much more focused in the shallow water locations than for the offshore locations, due to refraction of the waves towards a direction perpendicular to the depth contours. The annual mean wave power varies between about 20kW/m at the jetty tips and 5kW/m in the shallow water closer to the coast. The southern jetty had a marginally higher average power due to the slightly deeper water. However, there were very few depth measurements along the northern jetty so the results about the mean wave power should be treated as indicative of depth rather than location.

Task 3: Extremes

An analysis of the offshore extreme wave conditions was conducted using the peaks-over-threshold (POT) method, with the Generalised Pareto Distribution used to model the threshold exceedances. The 1-, 10- and 100-year return values of significant wave height were calculated to be (95% confidence intervals in brackets): 8.9m (8.5, 9.3), 11.7 (10.6, 12.8) and 14.6 (12.0, 17.8) respectively.

The extreme conditions were propagated through the SWAN model to estimate the nearshore extreme conditions. Wave heights in the nearshore are limited by depth-induced breaking and were shown to be much more strongly affected by the tidal level than by the offshore wave height or direction. Simulations were conducted with tides at mean sea level, mean low water springs and mean high water springs. Extreme significant wave height was found to vary by around 1m depending on the tidal level. In the deepest location considered (around 8.5m at mean high water springs), the 100-year return value of significant wave height was found to be 4.4m.