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Wave Climate, Geotechnical and Geophysical Analysis of the Tillamook Jetties

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On behalf of Oregon Wave Energy Trust

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Oregon Wave Energy Trust (OWET) is a nonprofit public-private partnership funded by the Oregon Innovation Council. Its mission is to support the responsible development of wave energy in Oregon. OWET emphasizes an inclusive, collaborative model to ensure that Oregon maintains its competitive advantage and maximizes the economic development and environmental potential of this emerging industry. Our work includes stakeholder outreach and education, policy development, environmental assessment, applied research and market development.

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INTRODUCTION

Wave Energy AS (WE) is an ocean energy company from Norway established to develop, test, market and commercialize the patented SSG™ wave energy converter technology. Wave Energy AS is interested in developing their technology in North America and the Port of Garibaldi has been selected as a potentially good location to launch the first project.

An initial site assessment was conducted in Fall 2009 and based on the results, Wave Energy decided to proceed with a feasibility analysis of the proposed location as their first North American project site.

The approach was to carry out the analysis in two (2) subsequent phases. The objective of the first phase of the feasibility analysis (Phase 1) was to assess the physical environment at the proposed project site. The purpose of this phase of work is to determine whether or not the location would be physically compatible with Wave Energy's technology. If the results concur that the physical environment is compatible with Wave Energy's technology, the second phase of the feasibility analysis, or Phase 2, would subsequently be carried out. If implemented, the objective of Phase 2 would be to evaluate the engineering, economics, business requirements, permitting requirements and all other aspects of project development based upon the Phase 1 results.

The support and engagement of two important groups were instrumental in helping Wave Energy move forward with this study. The two groups include Tillamook Intergovernmental Development Entity (TIDE) and the Oregon Wave Energy Trust (OWET).

The Tillamook Intergovernmental Development Entity (TIDE) is a non-profit organization whose sole purpose and mission is to facilitate ocean energy development in their region. In early 2010, TIDE issued an RFP seeking interest by ocean energy developers to implement a project in Tillamook County. Following a proposal evaluation process and public review, TIDE selected three developers to establish a Memorandum of Understanding for ocean energy project development and Wave Energy was one of the three firms selected. This resulted in an important community "partnership".

The Oregon Wave Energy Trust (OWET) is a non-profit trade association whose mission is to advance wave energy development in Oregon. In Fall 2010, the Oregon Wave Energy Trust created a new grant program to support feasibility analysis of potential wave energy projects.

Following a formal application process, Wave Energy was awarded a grant to carry out the study described in this report.

The purpose of this report is to summarize the scope, approach and results of Wave Energy's Phase 1 study.

STUDY 0BJECTIVES

The primary purpose of the Phase 1 analysis was to gain sufficient understanding of the physical characteristics of the proposed project location and its potential compatibility with SSG technology. The specific objectives of the Phase 1 study were:

- ✓ To understand what the seabed configuration is (e.g. bathymetric profile) within a 1km radius from the jetties.
- ✓ To determine if the wave energy resource is sufficient for the SSG technology and learn what the extreme wave conditions are for engineering planning purposes.
- ✓ To understand what the physical dynamics are or what situations exist that could cause bed scouring and/or otherwise negatively affect potential operations and the structural stability of Wave Energy's technology.
- ✓ Determine what data gaps or key issues require further investigation.

The results of this study will guide the subsequent analysis by Wave Energy.

STUDY APPROACH

The following describes the key steps in carrying out this study:

- A high-level assessment based on existing data was carried out. This assessment developed a profile of the physical environment including an overview of the regional bathymetry, geotechnical and geophysical attributes and sediment dynamics. This assessment also identified data gaps and potential areas of concern that may require additional analysis for future decision-making.

- Modeling of near shore wave energy resource estimates and extreme wave analysis were carried out. This portion of work produced a summary of near-shore operational wave conditions and cumulative wave energy at the project site. Analysis of extreme wave conditions was also included.
- The results of the above were compiled into a final report for Wave Energy and OWET.

The approach planned for this study was intended to be a simple analysis based entirely on existing data and no in-situ investigations were included in this phase of the feasibility study.

Role of OWET:

In Fall 2010, the Oregon Wave Energy Trust created a new grant program to support feasibility analysis of potential wave energy projects. Following a formal application process, Wave Energy was awarded a $50,000 grant to carry out the study described in this report. The results of this analysis will be added to OWET's data repository.

STUDY RESULTS

Executive summaries from each of the two study areas (e.g. geotechnical/geophysical and wave climate) are included in Appendix A and B respectively. Key highlights include the following:

- The Tillamook/Garibaldi Jetties site is positioned in a high energy marine environment with a substantial wave energy resource. This energetic environment is located in a coastal inlet with a highly dynamic sand substrate that is exposed to severe wave climate, strong tidal currents, a relatively large tidal range, and large scale erosional and accretion trends occurring on the adjacent coast. There is significant sediment movement around this location.
- The Tillamook/Garibaldi Jetties have both experienced extensive damage and recession over their constructed lifetime primarily as a result of wave attack and toe scour. The Western portion of the receded jetties is currently submerged. If the jetties are not reconstructed to their original footprint, these sections could potentially serve as a foundation for structural improvements such as a wave energy conversion device, but this would have to be studies in more detail to be determined with certainty.
- The annual mean wave power at the Tillamook/Garibaldi Jetties varies between about 20kW/m at the jetty tips and 5kW/m in the shallow water closer to the coast.

- 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.
- Several data gaps have been identified and recommended to support preliminary engineering design and cost analysis.

The results of this study will guide the subsequent analysis by Wave Energy.

Contribution to renewable ocean energy industry

In addition to helping Wave Energy meet their project development objectives, the results of the Phase 1 study are intended to have extended benefits to others associated with the renewable ocean energy industry.

The results of Phase 1 study will reside in the public domain and are expected to provide overall benefit to the ocean energy industry in Oregon in a variety of ways, such as the following:

- As a central repository for ocean energy information in Oregon, the Oregon Wave Energy Trust will be able to add this new data to their base of knowledge. This data will then be readily available to any other ocean energy developer or members of the public who can use this information.
- The Port of Garibaldi will benefit from the Phase 1 study results as it adds to the base of knowledge about the physical environment associated with the North and South Tillamook jetties.
- As TIDE facilitates ocean energy development activities in their region, the results will serve as a basis of understanding about the nearshore physical dynamics of the ocean area adjacent to the Tillamook jetties. This will be helpful information to guide other ocean energy developers with nearshore projects.
- The US Army Corp of Engineers will benefit significantly. Since USACE has statutory authority for the planning, construction, repair and maintenance of the Tillamook jetties, the Phase 1 data will directly benefit them as they begin planning for the South jetty repairs.

APPENDIX A

Executive Summary – Geophysical & Geotechnical Analysis

Prepared by: Golder & Associates

REPORT

TILLAMOOK WAVE ENERGY PROJECT PHASE 1: FEASIBILITY STUDY

Coastal, Geophysical, and Geotechnical Assessment

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A world of capabilities delivered locally

EXECUTIVE SUMMARY

This report provides a coastal, geophysical, and geotechnical assessment of baseline conditions to support the first phase of a feasibility study to examine the potential development of wave energy conversion technology at Tillamook Bay Inlet, Port of Garibaldi, Oregon. Wave Energy AS of Norway (Wave Energy) is considering a wave energy conversion project as a value-added modification to coastal structure rehabilitation of the jetties at the entrance to Tillamook Bay. The objective of this analysis was to develop a high-level characterization of the physical environment at the Tillamook jetties site. This is required in order to assess and identify key issues and concerns with respect to construction and operation of a wave energy conversion device. This study serves as the first step toward investigating project feasibility at the Tillamook entrance jetty structures.

The scope of this study included a review of the local and regional geology, an assessment of the history and stability of the jetties, an analysis of sediment mobility and potential for scour, and an analysis of the geotechnical and geophysical setting. This study was executed by analyzing existing data in the vicinity of the Tillamook jetties. No new in-situ data were collected nor analyzed as part of this investigation. The report is divided into five major sections: The first is a background and introductory section; the second section summarizes relevant available historic physical data and provides a data gap analysis; Section 3.0 provides a general site characterization in terms of physical environment conditions; Section 4.0 provides a preliminary assessment of the geotechnical, geophysical and sedimentary process conditions relevant to establishing and maintaining a Wave Energy installation at the project site; finally, Section 5.0 provides a preliminary feasibility assessment and recommendations for further study.

Available coastal, geotechnical, and geophysical data for the site were reviewed and summarized, a data gap analysis was prepared, a preliminary assessment of project feasibility is provided from the perspective of coastal, geotechnical, and geophysical considerations, and recommendations for future work are included. As part of the data and literature review, the following datasets were analyzed:

- Regional geologic and fault data
- Regional and local well bore logs
- Historical shorelines
- Topographic beach profiles monitoring change over the past decade
- Bathymetric offshore beach profiles for the previous two years
- Bathymetric surveys of entrance channel and approach over past 3 decades
- Coastal physical process data for the past two decades: waves, wind and water levels

The major findings of this study include observations regarding regional coastal erosion; a dynamic sediment stability in the vicinity of the entrance jetties; also a substantial degradation of the jetties near the tips presents both a potential threat as well as an opportunity for a wave energy project. Analysis of the available bathymetric/topographic data, offshore wave data, and shoreline change literature indicate that regionally, this coastline is dynamic with an energetic wave climate.

The beach to the north of the north jetty has been undergoing substantial erosion over the past 2 decades, while the beach south of the south jetty has tended to be more stable exhibiting evidence of an accretion trend near the jetty in recent years. A storm erosion protection revetment was recently constructed at the north beach as a response to the erosion and the potential for breaching at the jetty root. The entrance jetties at Tillamook are hydraulically efficient, resulting in a general pattern of long-term net scour which helps maintain a relatively stable channel inside the entrance. Net bathymetry change on the shoreface (immediately offshore of the entrance) shows a net accretion of 0.25 to 2 ft/yr over a 21 year period (1984-2005). The net erosion and accretion on the shoreface varies from year to year typically exhibiting a range of +/- 2 to 4 ft. Accretion on the shoreface, especially on the north side of the entrance, indicates a sediment source to the jetty platform. The morphological evolution of the ebb shoal in the vicinity of the jetty tips appears to be closely related to the advance (construction of south jetty) and subsequent retreat of the jetty tips. In the decade following construction of the south jetty (1984-1995), the ebb shoal was positioned further offshore. As the jetty tips receded over the next decade (1995-2005), the ebb shoal migrated landward as a result of the changing strength and position of the ebb tidal current in the entrance channel.

The north and the south jetty tips have both experienced extensive damage and recession over their constructed lifetime primarily as a result of wave attack and toe scour. Average rates of recession are approximately: 5 m/yr (16 ft/yr) for the north jetty and 26 m/yr (86 ft/yr) for the South Jetty based on measured recession between 1998 and 2003. The north jetty was constructed in 1917 and therefore has been established over a longer period of time than the south jetty, which was constructed in the 1970s. In the case of the north jetty, a foundation of jetty rock has been built up over a number of construction, recession, and maintenance cycles. The presence of a broad foundation on the north jetty helps protect the jetty from the effects of toe scour and direct wave attack resulting in slower tip recession rates on the north jetty relative to the south jetty. As the jetties stabilize, toe scour protection and slope stability improve and become more robust over time. Construction considerations for a wave energy project include wave loading, settlement and degradation of the adjacent jetty structure and foundation, the presence of drift logs, and access for maintenance.

A number of data gaps have been identified as potential barriers to moving forward with a local site assessment that could be used at a level of detail sufficient to support preliminary engineering design and cost analysis. The following data gaps were identified:

- Limited sub bottom data and seismic geophysical information

- No in-situ data on coastal processes near the structures to characterize the outer jetty environment
- Limited detailed jetty structure survey information

The Tillamook/Garibaldi Jetties site is positioned in a high energy marine environment with a substantial wave energy resource. However, coupled with this energetic environment is a coastal inlet with a highly dynamic sand substrate that is exposed to severe wave climate, strong tidal currents, a relatively large tidal range, and large scale erosional and accretion trends occurring on the adjacent coast. Despite significant jetty tip recession, an opportunity exists to utilize the submerged jetty tip as a foundation for structural improvements such as a wave energy conversion device.

APPENDIX B

Executive Summary – Wave Climate Analysis

Prepared by: Garrad Hassan

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.