40-YEAR WAVE CLIMATE MODEL FOR THE CHILEAN COASTLINE

Project SHOA, Waves in Chile

A detailed study of swell wave conditions in the southern Pacific Ocean has been performed, with particular emphasis on the western Southern American coastline. This study was one part of an overall wave hindcasting investigation undertaken for the Servicio Hidrografico y OceanogrÃ¡fico de la Armada de Chile (SHOA) to define the inshore wave climate at various locations along the Chilean coastline.

Chile is a long, relatively thin country that stretches along the western edge of the Southern American continent, as may be seen in Figure 1. It experiences large meteorological variability along this length. The climate varies from arid desert in the north at latitude 17Â¡S to a much colder and wetter environment in the south at latitude 56Â¡S. One important topographic feature is the presence of the Andes mountain chain that runs down the eastern edge of the country.

Regional Setting
Similar to the meteorological setting, the incident wave climate shows considerable variability, with the following principal considerations:

-Seas generated by local wind conditions, which vary along the length of the country
-Swells generated in southern Pacific mid-latitudes by the passage of cyclonic systems. These swells, in combination with the locally generated seas, are an important consideration in establishing the design wave conditions for coastal structures
-Swells generated in northern Pacific mid-latitudes which propagate some 15,000km and impact the Chilean coastline
As will be shown in this article, the long period wave energy that arrives at the Chilean coastline is a seasonal interplay between the swells propagating from the northern and southern hemispheres. This has major implications for port planning and operations. Many of the existing ports in Chile are located in north-facing bays and are well protected from the southern seas and swells but can be highly exposed to northern swells. New port development must now consider this issue. As a result of this project, a quantitative description of these wave modes can now be produced to support the port planning process and thus increase marine navigation efficiency.

Application of Wave Model
The WAVAD wave model, as summarised in Resio (1981) and Resio and Perrie (1989), was used for all hindcasting carried out in this study. WAVAD is a second-generation (2G) spectral wave model that maintains equilibrium between the wind source and non-linear wave energy flux, with an assumed f-4 shape for the wave spectrum.
The numerical model grid covered a domain extending from 120Â°E to 66Â°W and from 64Â°S to 56Â°N with a resolution of 1.0Â°. The model bathymetry for much of the Pacific Ocean was derived from a global (ETOPO30) database.
A forty-year hindcast (1961-2000) was performed. The hindcast model output was archived every two hours at grid points along the Chilean coastline and at each of the data comparison points. Both the full directional spectra and files containing the integrated summary parameters were stored at each of the archival points.
Wind fields derived from the NCEP/NCAR Reanalysis Project dataset (Kalanay et al., 1996) were used as the primary driving mechanism for the wave model. A typical view of waves in the Pacific Ocean as represented by the WAVAD model is shown in Figure 2.

Model Validation
An extensive hindcast validation process was considered prior to final production of the 40-year wave climate. Model validation is a process whereby historical wave measurements are compared to hindcast data for the same geographical location and period of coverage. For the Olas Chile project, the following measured wave data were used for model validation purposes:

-SHOA have measured waves over the past twenty years using Datawell non-directional Waveriders and more recently wave measurements have been conducted by means of a TriAxys directional buoy
-The US National Oceanic and Atmospheric Administration (NOAA) operated a non-directional 3 metre discus buoy to the west of northern Chile at location 18.0Â°S and 85.1Â°W from 1986 to 1995 and buoys in the North Pacific (46003 near the Aleutian Islands, 46059 and 46042 near California) were also employed in the study for hindcast model validation
-Satellite altimeter wave data from the Topex/Poseidon mission was extensively used

The locations of the validation data from all three sources as described above are shown in Figure 3. Figure 4 provides a typical validation comparison of hindcast versus measured wave data.

Wave Conditions and Transformation
As noted previously, one of the areas of interest in this work was the relative contribution of northern and southern swells to the wave climate along the Chilean coast. Comprehensive directional wave measurements for Chile are not yet available thus the wave model provides an initial indication of the importance of swell to coastal infrastructure design.
As a first step towards developing an understanding of swell impact, a procedure for isolating the individual wave systems from the wave

model directional spectra was developed based on the work of Hanson and Phillips (2001). Basically, this procedure breaks down each individual spectrum into subsets representing each of the sea and swell wave components.

From analysis of the results it becomes evident that for a very high percentage of the time the Chilean wave climate is multi-modal; that is, more than one wave system influences the wave climate. There is also an increasing trend towards multi-directionality from north to south. Part of the sharp change in multi-directionality in the north of the country may be associated with northern sheltering created by the western â€˜bulgeâ€™ of South America.

Clearly, part of the multi-directionality may be attributed to issues of simulation of northern swell and a possible over-estimation of the magnitude of these swells. Nevertheless, the complexity of the wave climate in Chile is apparent and this has many implications with respect to how nearshore wave transformation should be performed. It is important that the multi-modal nature of the waves be considered in shallow water modelling procedures, as opposed to the use of traditional summary wave parameters such as the Mean Wave Direction which are not meaningful in this context. To accurately represent the nearshore wave climate in Chile the use of 2D (directional) wave spectrum in deepwater is fundamental, followed by the use of spectral transfer methodologies employed such that each spectral mode is adequately transferred to the nearshore site.

The importance of the use of spectral data is shown in Figure 5. This figure shows a comparison between the results of transformations from recorded directional wave data outside Valparaâ€™so, using two different techniques, and nearshore recorded wave records for the same period of coverage. The red line represents the nearshore measured wave data (the desired match line). The blue line represents the deepwater wave data transferred to the wave gauge location using summary parameters (Hm0, MWD) and the black line represents the same deepwater wave data transferred using an spectral transfer technique. It is clear that the spectral technique provides a good match (the red and black lines) whilst the wave transfer using the summary parameters seriously underestimates wave height (the red and blue lines). The reason for this discrepancy is that the wave climate is clearly bimodal, therefore the use of summary parameters in the transformation of the wave climate inside a bay eliminates part of the energy.

Conclusions

An investigation into swell wave conditions in the southern Pacific Ocean was carried out by means of 40-year wave hindcast using a second-generation wave model and wind fields derived from the NCEP/NCAR Re-analysis Project. The wave studies clearly showed the complexity and multi-directional nature of wave conditions offshore of Chile, with important implications for nearshore climate This implies a significant impact upon coastal engineering works, including port design and sediment transport analyses.

Another outcome of this work has been the development and implementation (by the SHOA) of a new â€˜Waves Normâ€™ or standard for wave analysis work in Chile. This norm specifies the use of 2D (directional) in deepwater and spectral transfer for shallow water, wave climate development.

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