# CHANNEL WAVE REFRACTION EFFECT ON MOORED LNG CARRIERS

Wim van der Molen, Baird, wvdmolen@baird.com
Sean Garber, Baird, sgarber@baird.com
Matthew Zed, Woodside Energy Ltd., matthew.zed@woodside.com.au
Jan Flynn, Woodside Energy Ltd., jan.flynn@woodside.com.au

## INTRODUCTION

The Karratha Gas Plant (KGP), operated by Woodside, is located in Mermaid Sound on the North West Shelf of Australia and contains three loading jetties in open water. Mermaid Sound, shown in Figure 1, is protected from swells from the Southern Indian Ocean by several islands to the west. As a result, swells enter the Sound from the north. The bathymetry in the Sound is relatively flat but waves refract along the slopes of the navigation channel to the KGP terminal.


Figure 1 – Mermaid Sound

A single uni-directional swell spectrum close to the alignment of the channel was previously assumed to assess the moorings and agreed well with measured mooring line forces (Van der Molen et al., 2003). However, after the Pluto LNG Plant was developed to the south-west of KGP and operated with a dedicated channel, more westerly waves were observed by local pilots. Such waves were not consistently captured at the wave buoy that is permanently deployed near the terminal and so were not easily characterised. The objective of the study described in this paper was to determine the origin of these westerly waves and the effect on the vessel's response at berth.

## WAVE MODELLING

Wave modelling was conducted using both a spectral wave model, SWAN, and a phase-resolving Boussinesq wave model, Mike21-BW, for the part of Mermaid Sound covering the very gentle sloping foreshore and the navigation channels to the KGP and Pluto terminals. This was done for a range of swell periods and directions that characterised the wave climate based on wave buoy observation at the offshore boundary of the models.

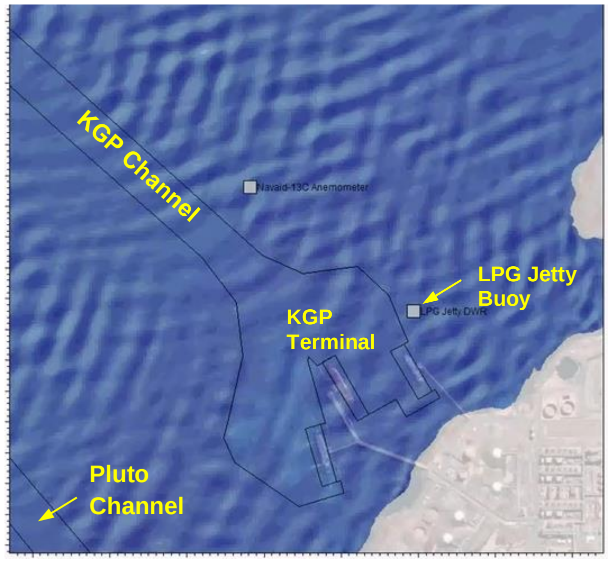


Figure 2 – Snapshot of wave surface elevations

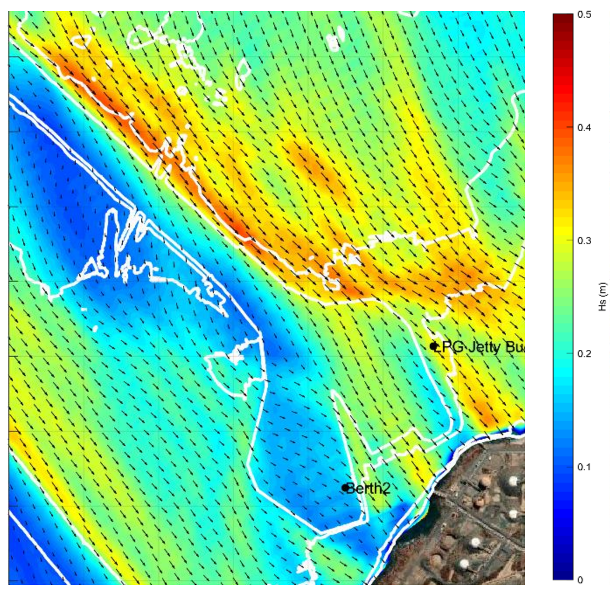


Figure 3 – Significant wave height near the terminal

A snapshot of the surface elevations in the phase-resolving model (Mike21-BW) for a peak period of 20 s is shown in Figure 2 and the corresponding significant wave heights in Figure 3. This clearly highlights the wave refraction and channel reflection effects along both channels and the multi-directional wave conditions from both channels at the KGP berths.

The two directions were also observed in the phase-averaged (SWAN) results but generally with slightly smaller wave heights and a less pronounced component of the refracted waves from the Pluto channel. More wave energy is refractively trapped along the KGP channel in the spectral model and does not enter or cross it due to the inability to include more complex 2D wave-wave interactions (Groeneweg et al., 2015). Further analyses were, therefore, carried out using the phase-resolving results. However, the spectral model results also showed a (smaller) component from a direction close to North, seemingly unaffected by the two channels. This component was also added in further assessments.

The simulated wave height at the LNG berth in the centre of the terminal was correlated to the simulated wave height at the NavAid9 buoy near the middle of the sound and to the LPG jetty buoy near the eastern end of the terminal. The plots in Figure 4 show that the correlation to the NavAid9 data is greater. This suggests that it is better to use the NavAid9 data during operation to assess the wave conditions at the berths even though this buoy is more distant from the terminal.

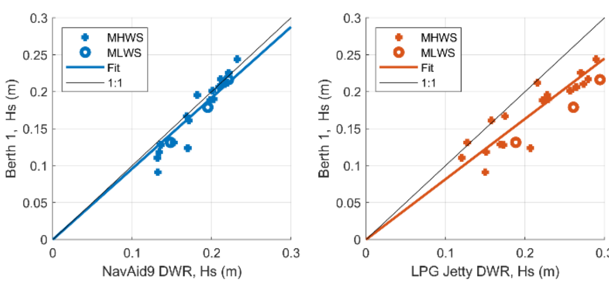


Figure 4 - Correlation of wave heights at Berth 1 near the centre of the terminal to wave heights at the NavAid9 buoy (left) and the LPG jetty buoy (right).

WAVE MEASUREMENTS

The wave buoy observations at the LPG jetty buoy on the eastern end of the terminal typically described uni-directional conditions coming from the mean of the two directions identified in the wave models. This highlighted a limitation in the capability of surface tracking buoys and subsequent spectral analysis in identifying two wave directions at the same peak frequency.

MOORED SHIP SIMULATIONS

Time series of wave forces on an LNG carrier at Berth 2 were calculated using wave forces obtained from the surface elevations and velocities from the phase-resolving wave model at the vessel hull (Van der Molen & Wenneker, 2008), and vessel motions simulated for these forces using Quaysim (Van der Molen et al., 2016). A second set of simulations was conducted using spectral wave input with the wave spectrum derived from spectral analysis of the wave model results including the three components mentioned above:

1. refracted from KGP channel (from Mike21-BW),
2. refracted from Pluto channel (from Mike21-BW), and
3. direct, close to North (from SWAN).

The two wave trains from the KGP and Pluto channels were considered either fully coupled (retaining phase and wave group pattern) or fully de-coupled. The de-coupled results agreed best with the full time-domain results and validation data available from a ship at berth.

Further mooring simulations were conducted for a wide range of conditions with wave spectra identified from a combination of the phase resolving and phase-averaged wave model results, accounting for the advantages of both models. The results of these simulations could be used to generate operability curves that define limiting wave heights at the berth for the full range of peak periods.

CONCLUSIONS

The results of this study confirmed the existence of the westerly waves at the KGP terminal consistent with operational experience at the berths. All wave direction components were considered to generate operability curves. Together with the forecast system for waves in the Mermaid Sound (Garber et al., 2019) this informs the terminal operator to schedule vessel visits with safe mooring conditions.

REFERENCES

Garber, Zed, Flynn, Taylor, Dent (2019). Innovative Wave Transformation Algorithm for Improved Short-term Wave Forecasting. Forum for Operational Oceanography Conference. Melbourne, Australia.

Groeneweg, Van Gent, Van Nieuwkoop, Toledo (2015). Wave propagation into complex coastal systems and the role of nonlinear interactions. *J. Waterway, Ports, Coastal, Ocean Eng.*, 141, 04015003.

Van der Molen, Ligteringen, Van der Lem, De Waal (2003). Behavior of a moored LNG ship in swell waves. *J. Waterway, Ports, Coastal, Ocean Eng.*, 129, 15-21.

Van der Molen, Scott, Taylor, Elliott (2016). Improvement of mooring configurations in Geraldton Harbour. *J. Mar. Sci. Eng.*, 4, 3.

Van der Molen, Wenneker (2008). Time-domain calculation of moored ship motions in nonlinear waves. *Coastal Eng.*, 55, 409-422.