RISK MITIGATION THROUGH DUKC® - CASE STUDY PORT OF MELBOURNE

by

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ABSTRACT

DUKC® is a proprietary under keel clearance (UKC) management system (installed at 19 ports world wide) that predicts the UKC of vessels, accounting for the latest environmental, vessel and transit information.

Historically, DUKC® Systems have been recognised for the enormous economic benefits provided to waterway owners and users. However, increasing international recognition is being given to the significant benefits which dynamic determination of underkeel clearance provides as a risk mitigation tool. While OMC has pioneered this tool for 17 years, leading international bodies such as PIANC and IALA are now developing guidelines and standards around dynamic UKC determination.

Risk mitigation has been the primary motivation for the recent DUKC® implementation into the Port of Melbourne, Australasia's largest container port. The entrance to the Port is considered one of the most difficult pilotage and technical modelling challenges anywhere on earth. Long Southern Ocean swells up to 5m significant wave height, combined with tidally varying currents up to 7 knots over a complex and hard bathymetry produce wave/current interaction effects which are highly complex, both spatially and temporally; even large ships can plunge downward several meters in extreme conditions.

To manage these conditions, DUKC® technology has been integrated onto PPUs (carried by all 35 pilots) and into VTS centres to enable vessel speed and predicted under keel clearance ahead to be monitored onboard and ashore. While primarily a risk mitigation tool in this Port's challenging waters, the full DUKC® suite has been installed to also deliver efficiency benefits to port users.

This implementation process of DUKC® at the Port of Melbourne involved installing the latest state of the art instruments to provide data of the highest quality, further intensive technical modelling and trialling by full-scale vessel motion measurements to validate DUKC® predictions for use in this challenging stretch of water. In addition, PoMC commissioned independent risk assessment studies.

This paper will detail some key risk management studies undertaken as part of the implementation and validation process which concluded that the DUKC® System would significantly reduce the risk of large vessels grounding in its approach channel.

1 INTRODUCTION

Port Phillip Heads (The Heads) is located at the entrance to Port Phillip Bay, adjacent to the city of Melbourne on the couth coast of south eastern Australia (Figure 1). The Port of Melbourne is Australia's largest container port, with several hundred deep draft transits every year.

The Port of Melbourne Corporation recently commissioned OMC's world-leading DUKC® navigation technology to enhance the safety of large vessels passing through the treacherous entrance to Port Phillip Bay. This decision followed an extensive trial and validation process which confirmed that the system is capable of delivering improved safety and efficiency benefits to port users in comparison to existing static rules.

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The technology will be available to shippers for planning vessel sailing drafts and windows, to VTS operators for monitoring safe under keel clearance during transit of all deep-draft ships and to Melbourne's 35 ship pilots to control vessel speed such that adequate UKC is maintained throughout the transit from berth to the deep water outside The Heads.

At The Heads the bay is constricted to a width of approximately 3.0km, resulting in strong tidal currents up to 7 knots flowing to and from the bay from Bass Strait. The Heads is also exposed to large, long swells up to 5m significant wave height propagating from the South Ocean which interact with the strong tidal currents and complex hard bathymetry to create wave conditions that vary considerably spatially and temporally. Such conditions pose one of the most challenging waters for ship navigation to be found anywhere on earth. The history of shipwrecks since settlement began at Melbourne in 1835 attests to this reality.

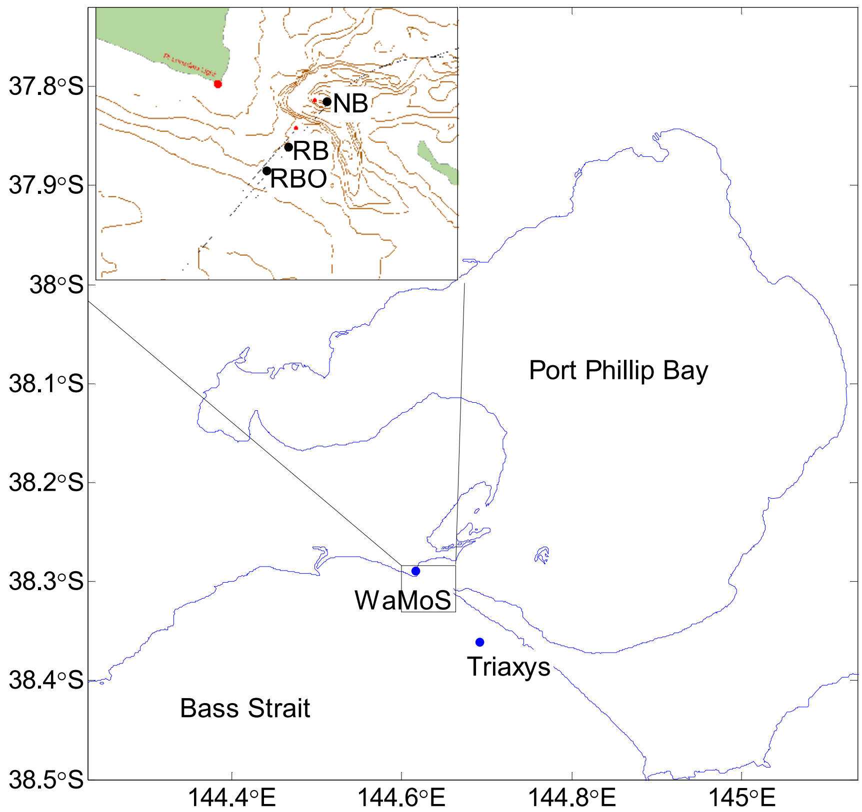

Figure 1: Location of The Heads at the entrance to Port Phillip Bay together with the location of the WaMoS and Triaxys instruments. The insert indicates the complex bathymetry within The Heads.

This paper will detail some key risk management studies undertaken as part of the implementation and validation process of DUKC® at the Port of Melbourne which concluded that the DUKC® System would significantly reduce the risk of large vessels grounding in its approach channel. Specifically this paper will cover the following studies:

1. Environmental Field Measuring and Algorithm Development Study
2. Full Scale Validation Study
3. Touch Bottom Risk Analysis

1 The Dynamic Underkeel Clearance (DUKC®) System

Traditionally, ports have operated under fixed rules which govern the minimum under keel clearance (UKC) to permit safe transit along port approach channels. To ensure safety, these fixed UKC rules are determined by requirements under extreme swells and negative tidal residuals.

If the requirements are too conservative, ships carry less cargo than they could, and the operation is not as cost-effective as it might be. At the other extreme, inadequate criteria could jeopardise safety and cause a grounding to occur.

The Dynamic Under Keel Clearance System (DUKC®) developed by OMC uses customised numerical models to calculate the UKC requirements of the particular ship sailing in the particular waterway in the environmental conditions at the particular time.

DUKC® modelling guarantees accuracy, repeatability and applicability. UKC requirements are determined based on the actual vessel and its stability parameters, real-time met-ocean conditions (wave height, period and direction, water levels, currents, tidal plane, wind), vessel transit speed and waterway configuration, including detailed bathymetry, at the time of sailing. Wave spectra, ship speed and water depths vary along the transit and the effect of these variations is computed by the numerical ship motion model used in each DUKC® system. In addition, wave spectra and tidal residuals will change over time, and these effects are accounted for in each system. With respect to squat, individual ships and the pertinent characteristics of the complete approach channel are modelled in each DUKC® system, including the effect of temporal and spatial variation of tidal currents.

The system, which was first installed in Queensland's Port of Hay Point in 1993, is now in operation at 20 ports around the world (12 in Australia, 3 in NZ and 5 in Europe). DUKC® has assisted more than 55,000 ship transits over the past 17 years, without incident. On average, there is now a DUKC®-assisted ship movement every two hours, somewhere in the world.

The accuracy of the numerical models used in the DUKC® System has been validated by undertaking more than 250 ship transits to obtain full-scale measurements of vessel speed, track and vertical displacements. These validation tests have been undertaken for a wide variety of channel widths, configurations and lengths, vessel types, sizes and stability conditions, vessel speeds, wave conditions, tidal regimes and current speeds.

The system has also been rigorously and independently tested by specialist risk management consultants to ensure that it satisfies internationally-accepted levels of risk for safely managing the UKC of vessel transits.

Recent innovations allow DUKC® technology to be taken onboard ships by pilots equipped with the DUKC® Portable Pilot Unit (PPU) and to be integrated into Vessel Traffic Services (VTS) with DUKC® VTS as is the case with the Port of Melbourne DUKC® installation. Both applications allow monitoring and control of under keel clearance by management of vessel speed during transit. Both applications are configured to provide a seamless transition from the shore based DUKC® Dynamic Passage Planning System.

DUKC® PPU and DUKC® VTS Systems provide Pilots and Vessel Traffic Operators, respectively, with look-ahead predictions of minimum under keel clearances during transit from berth to deep water (or vice versa).

The DUKC® PPU provides marine pilots with real-time under keel clearance management advice through vessel speed optimisation.

2 Environmental Field Measuring and Algorithm Development Study

The prediction of vessel motions subject to the complex wave climate in The Heads was the main technical challenge to a successful DUKC® implementation at the Port of Melbourne.

Waves interacting with opposing currents shorten and steepen, and conversely lengthen and flatten for following currents. This is particularly important for waterways such as at The Heads subject to large swells interacting with currents. The current has two effects on the resulting vessel wave response: firstly, influencing the encounter frequency of the vessel to the waves and secondly, altering the wave length (and height) of the waves, both of which can have a significant effect on resulting vessel motions. Accounting for this change in wave height and length spatially and temporally is vital for the accurate prediction of vessel wave response.

This knowledge is encapsulated in OMC's SPMS vessel motion model, which is used by the DUKC® however its reliability depends on the accurate forecast of the predicted wave conditions (height and length) in The Heads. Further it is required to understand the conditions both now for a transit about to occur and also into the future for a transit in, say 24 hours time, based on measured conditions now.

Initial attempts to configure a DUKC® system for the Port of Melbourne in early 2000 were thwarted by the technical difficulty of measuring and predicting wave conditions in The Heads. Subsequently from 2005 a large quantity of high-quality wave data has been collected in The Heads using new state-of-the-art instruments located at critical locations of the shipping channel and these data, together with sophisticated modelling techniques have allowed this obstacle to be overcome. This section will detail the process undertaken towards gaining this key predictability of waves through The Heads.

One of the main challenges at The Heads is that environmental conditions are too extreme for deployment of real time instruments. As such algorithms needed to be developed to transform spatially and temporally a measured offshore wave climate through The Heads (considering both wave height and length as detailed above) up to 36 hours in advance considering the key factors that influence the propagation of wave conditions, namely offshore wave height, period and direction and current speed and direction and tidal height through The Heads and their corresponding interdependencies.

To enable this Port of Melbourne Corporation invested heavily in wave measurement. Instrument types and locations were selected to provide reliable data at critical locations and to gain a sounds understanding of the spatial and temporal variations on the wave conditions experienced in The Heads. In particular, the following set of instrument types were deployed, each providing critical information to the understanding of wave information through The Heads:

- A group of Triaxys buoys were located some 8kn offshore from The Heads. The buoys provide the offshore real time wave information to the DUKC® System and transmit real time directional data ashore every 30 minutes.

- Bottom mounted acoustic profiles (Nortek AWAC's) were deployed at three critical locations on the channel centreline for 2 years in bursts of 6 week deployments.
- A WaMoS wave radar was installed at Pt. Lonsdale in order to measure real-time wave conditions in The Heads. The output of the WaMoS was validated against AWAC wave measurements from the channel centreline. The WaMoS data contributed greatly to understanding the spatial variation of wave conditions in The Heads.

The large quantity of high quality wave data recorded simultaneously at different locations in The Heads was vital for building the understanding of the transformation of the waves under these complex conditions. As well as the spatial complexity in wave conditions, a significant temporal variation is also observed relative to the offshore conditions. This is displayed in Figure 2 which presents a time series of significant wave height for both onshore and offshore locations. The lower panel shows the current phase and indicates the variation in wave height is highly correlated with the currents in The Heads.

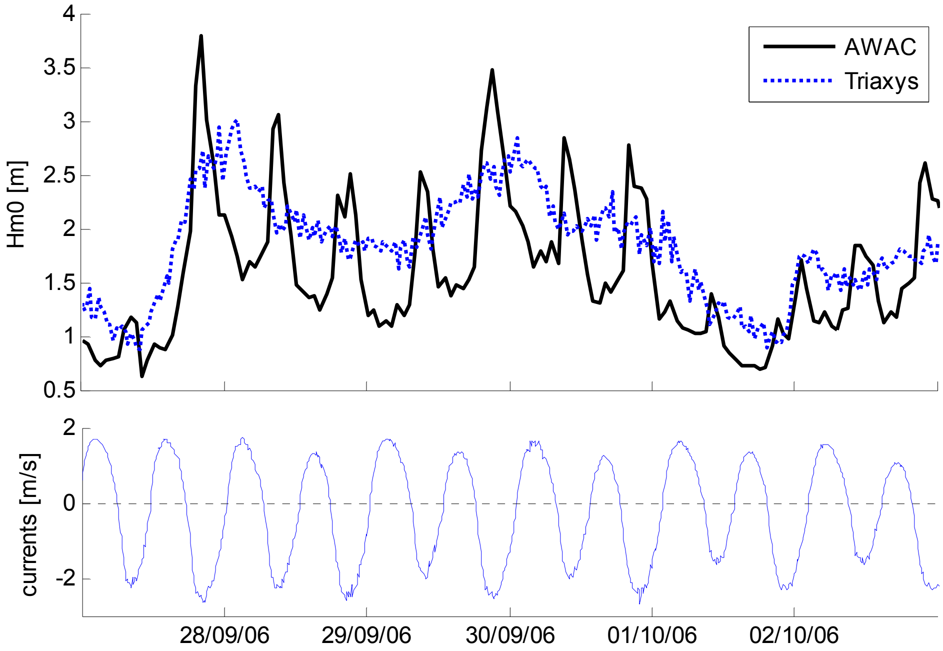

Figure 2 Timeseries of wave height and current speed (flood positive) recorded at AWA-1. Wave height recorded at offshore Triaxys buoy is included for reference. The amplification of wave height during ebb tide at this location is clearly visible.

Through investigation into the data, OMC were able to show that whilst extremely energetic and dynamic, the waves in The Heads are predictable. Using the 1D action balance equation and a prediction of the strength and direction of the tidal currents, wave-current transformation algorithms have been developed that enables the spectral wave conditions at locations in PPH to be predicted given measurements of the wave conditions offshore at all stages of the tide.

Because the implementation of the algorithm in an operational system requires real time knowledge of the currents in The Heads, and these cannot be measured in real time, an accurate predictor of the currents was also developed and validated.

These algorithms were subsequently integrated within the DUKC® system to provide prediction of wave conditions in The Heads based on measured wave data from the offshore buoys and the WaMoS wave radar and predicted tidal currents. The algorithms have been extensively validated using independent data and have been peer reviewed by an independent oceanographer with extensive experience of conditions in The Heads. The new wave and current algorithms have been independently judged to allow accurate determination of the subsequent dynamic effects on vertical ship motions for any specified ship and loading condition, including the strong wave-current interaction effects at The Heads.

3 Full Scale Validation Study

Following validation of the wave transformation algorithms, the next stage was validation of the forecast of vessel motions and UKC from the DUKC® System.

In 2007/08 a series of full-scale ship motion and under keel clearance measurements were undertaken by PoMC for 12 vessels transiting the Port of Melbourne channels. The DUKC® System was run "blind" for each ship and the results were provided to PoMC for their independent validation of the accuracy of OMC's ship motion predictions.

The resulting forecasts of vessel wave response allowance were validated against full scale vessel motion analysis (FSVMA) measurements. A FSVMA analysis is performed by fixing 3 GPS receivers to a vessel prior to its transit: one at the bow and one on each of the bridge wings. A fourth receiver is positioned on land to act as a base station. By calculating the differential position of the mobile receivers relative to the fixed base station sub decimetre precision of the 3 dimensional position of the onboard receivers can be achieved. These data allow the vessel motions and UKC components that occur during the transit to be established. By comparing the various UKC allowances calculated by the DUKC® against those measured by FSVMA the accuracy of the DUKC® modelling can be validated.

Comparisons of the DUKC® predictions against the precise DGPS measurements confirmed that the system accurately predicted squat and turning heel in the Yarra River and South Channel and vessel wave response in The Heads under a wide range of wave/tidal current conditions and vessel types and sizes.

In this section, we will highlight through two FSVMA examples the importance of consideration of all factors that influence vessel wave response, and in particular the accurate prediction of wave length considering the prevailing current.

As detailed in the previous section, in addition to wave height which is intuitive, accurate knowledge of wave length can be just as critical in UKC predictions. Whilst the effect of bathymetry and water depth on wave length is well understood, just as important from a vessels dynamic response at places exposed to strong currents like Melbourne is the impact on wave length from currents. When waves propagate through a current field the dispersion relationship is affected. This has the effect of changing the wave length for a given wave period. If this effect is not taken into account the model will incorrectly compute the hydrodynamic coefficients leading to inaccurate vessel response predictions. For the PoMC DUKC® system the SPMS model was modified to include the effect of the strong currents that occur in The Heads on the wave dispersion relation. The impact of these changes on the computed wave response allowance, and the importance of inclusion of this effect, was well illustrated in the FSVMA analysis.

In the examples provided in the following, one of these transits was conducted under strong current conditions (Vessel 1), the other under mild (Vessel 2) current conditions. The environmental conditions prevailing at the time of transit are listed in Table 1. As the table shows during the Vessel 1 transit the ebb current through The Heads exceeded 1.9 m/s (3.7 knots), while for the Vessel 2 transit the ebb current only reached 0.7m/s (1.4 knots).

Parameter	Vessel 1	Vessel 2
Offshore Hs swell [m]	2.01	1.11
Current at The Heads	1.99m/s, 206N	0.71 m/s, 219N

Table 1: Environmental conditions in The Heads prevailing during the FSVMA transits.

The measured and predicted vessel wave response allowance for these vessels is presented in Figure 3 and Figure 4. In these figures the actual vessel wave response motions as recorded by the 3 GPS receivers are contrasted with the calculated allowance. The impact of ignoring currents in the vessel wave response calculation is also illustrated.

In the Vessel 1 export transit, moderate vessel motions are experienced by the vessel with a peak of about 1.5 m downwards displacement near Rip Bank Outer. The measured wave response is within the range allowed for by the DUKC® confirming that in this case the DUKC® wave response allowance provided an adequate level of safety. Contrasting the case of including and excluding currents, it is clear that ignoring the effect of the waves in calculating the vessel dynamic response would result in the wave response allowance being overestimated by 0.8 – 1.0 m. While the safety is not compromised in this case, by ignoring waves potentially an additional 0.80 m of draft for this vessel would have been lost. In other instances of course, the converse would be true and safety would be jeopardised without consideration of the currents.

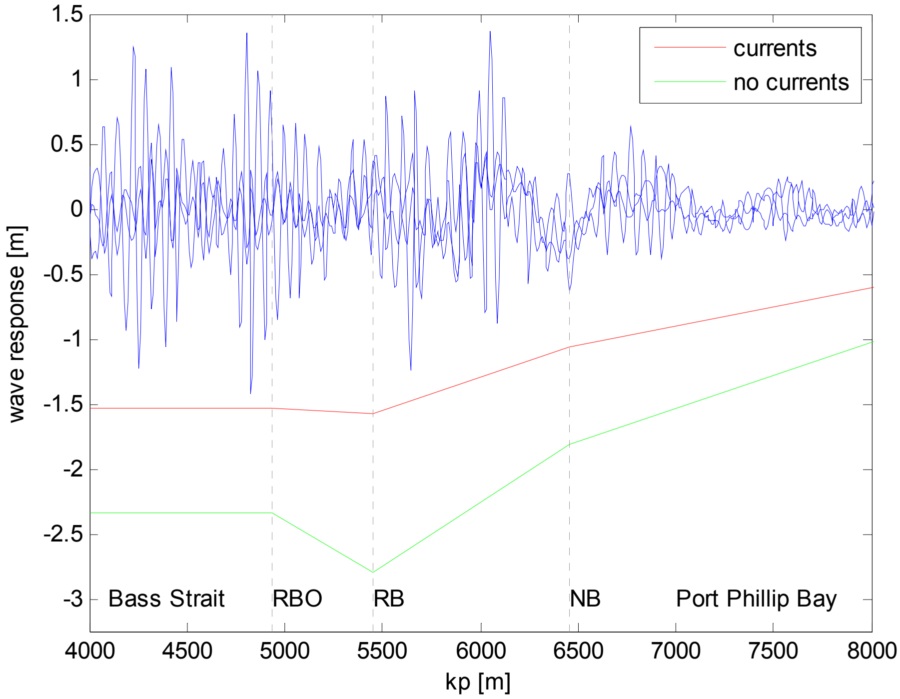

Figure 3: FSVMA analysis of Vessel 1 transiting The Heads on 8 July 2007. The measured maximum downwards wave response is contrasted with the wave response allowance calculated by the DUKC® both with and without allowance for the currents. In this case not accounting for currents greatly overestimates the wave response allowance, reducing yield.

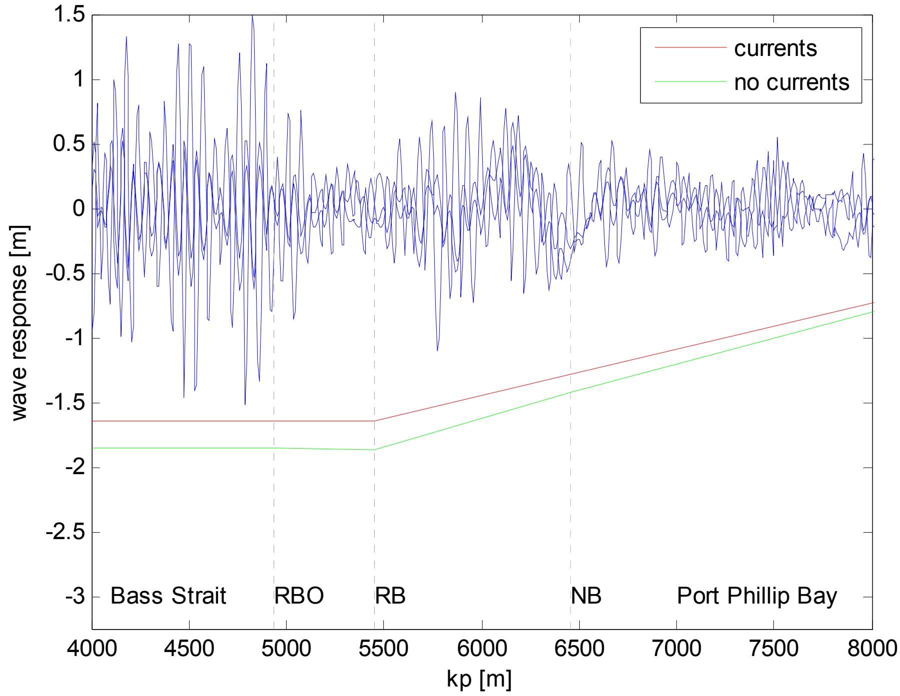

Figure 4: FSVMA analysis of Vessel 2 transiting The Heads on 21 March 2007. The measured maximum downwards wave response is contrasted with the wave response allowance calculated by the DUKC® both with and without allowance for the currents. In this case the weaker currents reduce the impact of ignoring them in the calculation.

For the Vessel 2 transit the measured wave response is within the wave response allowances validating the calculated vessel wave response allowance. In this case the impact of the currents on vessel wave response allowance is less because of the weaker currents.

4 Touch Bottom Probability Study

Following validation of the full DUKC® System as detailed in the previous section, PoMC commissioned OMC to calculate the touch bottom probability (TBP) of vessels transiting the Port of Melbourne under the guidance the DUKC® System.

TBP's were calculated for a range of typical container vessel classes frequently calling at the Port of Melbourne. Comparisons were made to also to International TBP guidelines, in particular:

1. A grounding rate oaf 0.03 incidents per 1000 ship movements (PIANC 1997)
2. The chance that a vessel touches the channel bottom during transit must always be less than 1% for all weather conditions (Savenije, 1996)

A set of historical environmental conditions occurring in The Heads was produced by resampling the recorded offshore data, Lorne tidal data and AWAC wave and current data recorded through The Heads over a 10 month period from February 2006 to December 2006. The data was cross checked against 3 years of recorded offshore data and found to be representative, if not, marginally conservative of the range of expected conditions.

The resulting data set was quality checked and erroneous data removed, resulting in a data set of 4683 hourly environmental conditions. As even this number of events is insufficient for the number of Monte Carlo simulations required (2.5 Million) for the TBP analysis, the set was resampled to provide a sufficient number of input conditions for UKC calculations.

A Monte Carlo approach was used whereby the environmental conditions were randomly (and repeatedly) sampled from the 4683 environmental conditions. The UKC components of a transiting vessel under the sampled conditions were also sampled from the underlying distributions. By combining the sampled UKC components and comparing them with the total amount of water available in the channel a UKC residual is calculated, which indicates the amount of water remaining under the keel.

A positive residual indicates the vessel would have transited safely with a negative residual indicating the vessel would have touched the bottom.

The Monto Carlo approach ensures that by repeatedly sampling the various UKC distributions over a large range of conditions the large number of UKC residuals generated sufficiently describe the UKC residual probability distribution function. A "per transit" TBP is found as the division of the number of times the UKC residual is negative by the total number of Monte Carlo transits simulated. Each TBP reported was based on 2.5 million sampled transits.

Value of the different UKC components that contribute to the UKC residual are randomly sampled from their underlying distributions.

The results showed that the Touch Bottom Probabilities of typical vessels operating under the advice of the DUKC® have been found to be at least 2 orders of magnitude safer than the present static rules and are at least 3 times safer then suggested by international guideline. Introduction of the DUKC® System was found to considerably reduces the probability of touch bottom events occurring at the Port of Melbourne.

5 Conclusion

The process undertaken in implementing DUKC® at the Port of Melbourne as described in this paper confirmed the successful implementation of a DUKC® system at a port that contains one of the most challenging stretches of navigable water in the world. Through a scientific approach of identifying and predicting relevant UKC components the DUKC® ensures that safety at the Port of Melbourne meets world's best practice.

A number of key steps undertaken in the implementation process have been detailed in this report and summarised as:

1. Given the technical difficulty of measuring and predicting wave conditions in The Heads, a large quantity of high-quality wave data were collected in The Heads using new state-of-the-art instrumentation at critical locations.

2. Wave and current transformation algorithms were developed utilising the new wave data collected in The Heads. These algorithms allow the prediction of wave conditions in The Heads based on measured wave data from the offshore buoys and predicted tidal currents. The algorithms have been validated using independent data and have been peer reviewed by an independent oceanographer with extensive experience of conditions in The Heads.

3. The DUKC® system was developed to use data from the new wave and current transformation algorithms, the cluster of offshore buoys, a number of tidal gauges and the WaMoS wave radar.

4. The modified and reconfigured DUKC® system has been validated against DGPS measurements of vessel motions and under-keel clearance for 12 ships transiting the Port of Melbourne. For each vessel DUKC® simulations were performed 'blind' before the measurement data was made available – mimicking the operation of the real system. Comparisons of the DUKC® predictions against the precise DGPS measurements confirms that the DUKC® accurately predicts vessel response at all times.

5. Touch Bottom Probabilities of typical vessels operating under the advice of the DUKC® have been computed and found to be considerably safer than vessels operating under the existing static UKC rules and well within international guidelines.

6 Acknowledgements

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7 References

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