EXPERIENCE USING DYNAMIC UNDERKEEL CLEARANCE SYSTEMS: SELECTED CASE STUDIES AND RECENT DEVELOPMENTS

by

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SUMMARY

The Dynamic Underkeeel Clearance (DUKC) system is the focus of this paper. This innovation has increased drafts and widened tidal windows at several Australian ports since 1993, without compromising vessel safety. These improvements in port operation have provided economic benefits amounting to millions of dollars in decreased freight costs and increased cargo throughput, at a small fraction of the cost involved in gaining equivalent improvements by dredging.

Since the DUKC system was first developed in 1993, ten customised versions have been commissioned by ports around Australia and New Zealand. Research and development of the DUKC system has continued during that time and has been greatly assisted by continuing interaction between harbour masters, pilots, port users and the design team.

Recent major DUKC developments include:

?? the application of meteorological and wave forecasting models to provide predictions of maximum drafts and tidal windows up to 36 hours prior to sailing;
?? the near real-time modelling of the dynamic motions in waves of each particular ship in its actual loaded condition;
?? continuous processing of real-time tide and wave data by the DUKC system, allowing predicted changes in maximum draft or tidal windows to be updated automatically during the final hours prior to sailing.

Two case studies involving the application of DUKC systems and the associated benefits obtained are described.
INTRODUCTION

Traditionally, most ports in Australia and elsewhere have operated under fixed rules which govern the minimum underkeel clearance (UKC) to permit safe transit along port approach channels.

UKC requirements are generally calculated to cover a broad range of environmental conditions and vessel parameters. If the requirements are too conservative, ships carry less cargo than they could, and the operation is not as economic as it might be. At the other extreme, inadequate criteria could jeopardise safety.

Because of their geographical situation on the coastline of an island continent, the approach channels of most Australian ports are subject to ocean swells generated by tropical cyclones or Southern Ocean storms. It is therefore essential that UKC requirements include not only vessel squat and the effect of wind and atmospheric pressure changes on predicted tides, but also the dynamic motions of vessels of varying size and stability characteristics.

UKC ALLOWANCES

The major UKC allowances are as follows:

![Figure 1: UKC Allowances]

**Wave Response Allowance**

In channels subject to wave action, ships will experience heave, roll and pitch motions which combine to produce vertical displacements of the hull. The magnitude of these dynamic and irregular displacements at each point of the vessel's transit depends on many factors, including:

?? Directional wave spectrum (describing wave energy distribution as a function of frequency and direction);
?? Ship dimensions, hull shape and stability data;
?? Ship speed;
?? Water depth/draft ratio.

**Squat Allowance**

Squat is a combination of bodily sinkage and change in trim of a vessel while sailing. The major factors affecting squat are ship form and initial trim, vessel speed through the water, vessel acceleration and deceleration, depth/draft ratio, channel width and depth of cut, abrupt depth changes, changes in fluid density, passing and overtaking vessels.
Changes in Water Level

In addition to the change in water level due to predicted astronomical and seasonal effects, water levels are also affected by meteorological changes in wind speed and direction and in barometric pressure. These changes in water level represent the difference between measured and predicted water levels and are known as the tidal residuals. In particular circumstances this difference can be substantial (of the order of ? 40 cm, or greater).

Information regarding the ‘movement’ of high tide is also important, particularly when the port approach channel/canal is quite long and/or subject to large tidal variations. The tidal range and phase needs to be identified and accounted for in the prediction of the ship underkeel clearance along the entire transit.

Changes in Water Density

Changes in water density have the same effect as a change in water level in terms of draft and the resulting underkeel clearance. It is important to identify where these changes occur and by how much the density has changed.

Safety Factors

As ports differ in many ways so too do the safety factors that need to be built into an underkeel prediction system. Safety factors may include allowances such as hydrographic survey tolerance, saltation allowance and draft tolerances.

THE DYNAMIC UKC CONCEPT

Dynamic UKC (DUKC) is a near real-time underkeel clearance prediction system for use at ports which have draft limitations on import or export ships. The DUKC system takes into account all of the major factors affecting underkeel clearance, together with other allowances such as heel and list which may be required in particular circumstances, as described in O’Brien (1).

The system has two major functions:

?? Maximisation of vessel drafts for the tide, or for a specified sailing time (export vessels)

?? Determination of the earliest and latest times for entry into the port approach channel(s) (import vessels and export vessels sailing at less than maximum draft for the tide).

In addition to knowledge of the ship dimensions and its stability parameters for the particular cargo and load condition, the following factors are essential to the UKC requirements of a vessel:

?? Real-time tide levels along the transit, at the time of passing each critical UKC control point;

?? Real-time wave heights, periods and directions along the transit and the associated UKC wave motion allowance for the particular ship and wave conditions, at the time of passing each critical UKC control point;

?? Real-time current speed and direction along the transit and the associated effect on UKC wave motion allowances for the particular ship and wave/current interaction conditions, at the time of passing each critical UKC control point;

?? Bed depth profiles across and along the channel, especially near each critical UKC control point, and effect of abrupt changes in bottom topography on vessel squat and heel;
Vessel trim and its effect on squat and heel;

Vessel speed through the water and over the ground (as affected by current speed and direction) and its effect on squat and heel;

Vessel acceleration or deceleration through the water and its effect on squat and heel;

DUKC systems utilise all the above factors using real-time tide, current and wave measurements to transit to determine the minimum safe under keel clearance along the complete transit from berth to deep water, thus taking advantage of favourable conditions and ensuring safety during unfavourable conditions.

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.

By measuring tide and wave data and using the actual measured values, as opposed to predictions, UKC calculations can be performed with a much greater degree of certainty for the conditions of any given day.

These systems allow ships to be loaded to greater draft or use wider tidal windows than is possible using fixed UKC rules, which are determined by safety requirements in extreme swells and negative tidal residuals. DUKC systems thus increase port productivity without the need for new port infrastructure or capital dredging and without compromising safety standards (all DUKC systems operate in accordance with internationally accepted safety criteria for bottom clearance and manoeuvrability requirements). This translates into significant savings to exporters, shipping companies and port authorities.

DUKC systems are customised for the vessel type, hydrography, tides and wave climate at each port. The system is designed to provide predictions up to 36 hours ahead to assist vessel loading and sailing scheduling. In the final hours before departure the DUKC system operates a Windows Monitor, which continuously updates sailing times and maximum drafts prior to sailing, enabling shippers to maximise cargo loadings while providing up-to-the-minute information for the ship handlers.

Since the first installation in 1993, research and development of the DUKC has continued and has been greatly assisted by continuing interaction between Harbour Masters, Pilots, port users and the design team. Full-scale field tests using highly accurate dual-frequency Differential GPS have been undertaken on over 70 vessels around Australia and abroad. These provide further validation of the predictive models used in the DUKC systems.

An example of measured bow and stern squat for a bulk carrier is shown in Figure 2. The oscillations near the seaward end of the channel indicate the dynamic motions due to heave and pitch. Roll (not shown) is measured by the difference in readings between sensors located on each bridge wing.
The vessels tested have included bulk carriers, up to Cape size, tankers and container vessels. A six week field measurement program on 10 container vessels has recently been undertaken at the Port of Melbourne, where swells up to 5m significant height at the entrance to Port Phillip Bay interact with currents up to 7 knots at peak ebb tides. Further real-time testing on container vessels has also been undertaken at Auckland and New York/New Jersey.

The range of conditions at each of these ports varies considerably, including narrow channels, undulating sea floors and variations in tide and wave conditions. Each study has highlighted the sensitivity of squat to the local conditions and individual channel configuration.

APPLICATIONS
DUCR systems have now been installed at seven Australian ports and one New Zealand port (Figure 3).

?? Hay Point/Dalrymple Bay, Queensland (1993) - one of the largest coal export ports in the world (approx. 70,000,000 tonnes per annum) - vessels to 230,000 dwt.

?? Fremantle, Western Australia (1994) - import of crude oil for BP Australia to Kwinana and later extension to Alcoa berth for export of alumina and to Inner Harbour for new generation of container ships (import and export).

?? Port Hedland, W.A. (1995) - export of iron ore for BHP Billiton (approximately 70,000,000 tonnes p.a., vessels to 250,000 dwt).
?? Dampier, W.A. (1995) - export of iron ore for Hamersley Iron (approximately 65,000,000 tonnes p.a., vessels to 250,000 dwt)

?? Brisbane, Queensland (1996) - import of crude oil (Post-Panamax vessels) and export of coal (Panamax and Post-Panamax vessels).

?? Bunbury, W.A. (1996) - regional port, using Handy and Panamax size vessels for export of alumina and import of caustic soda and petroleum products.


?? Taranaki, New Zealand (2001) – major New Zealand regional port for export of agricultural and petroleum products.

DUKC systems are currently being established for the ports of Melbourne and Geelong, including the entrance channel at Port Phillip Heads and the South Channel in Port Phillip Bay, and are expected to be commissioned by the end of 2002. A DUKC system is currently being trialled at the Port of New York and New Jersey, USA.

CASE STUDIES

Case Study 1 - Hay Point, Queensland

The Port of Hay Point is located on the north-east coast of Australia. It consists of two offshore loading terminals, each comprising two berths. The berths are located 4km offshore and are subject to swells approaching from near the beam.

For vessels sailing to maximum draft, a 24-hour prediction is performed and used as an indication for the Master and shipping agent of the maximum expected draft and optimum sailing time. The 12-hour prediction is usually adopted as the confirmed draft and departure time, after approval by the duty pilot. For export vessels sailing to less than maximum draft, a similar procedure is followed with respect to initial indication and later confirmation of earliest and latest sailing times.

The DUKC system at Hay Point has been continually developed and extended since its installation in March 1993. Currently, Stage IX of the DUKC system development is in operation. Typical increases in draft due to the application of the DUKC system range from 50cm to 1.2m, depending on the tidal residuals and wave conditions. In excess of 5,000 vessel transits have been undertaken to date using the DUKC system, without incident.

In the 1996/97 financial year the Hay Point system enabled 123 vessels to load an additional 743,246 tonnes of coal (an average 6042 tonnes per vessel); the freight savings from these increased shipments amounted to approximately US$7,500,000, the increased value of export earnings amounted to approximately US$30,000,000. Increases in the number of vessels using the system since 1996/97 (due to berths increasing from three to four) and from additional cargo loaded per ship (due to new refinements in the DUKC system) have led to annual coal shipments being increased by more than 1,500,000 tonnes per annum due to use of the DUKC system alone.
Two additional dynamic systems have been developed and installed at the Port of Hay Point, as follows:

a) DUKC system for maximising loading time of vessels over low water. Two of the four berths have insufficient depth in their berth pockets to allow vessels to continue loading during low water. Use of the DUKC system has enabled loading to continue over a longer portion of the low tide cycle than was previously possible with fixed-rule procedures.

b) Berth Warning System is a real-time berth warning system designed for use at ports subject to cyclones or to ocean swells. The Port of Hay Point experiences tropical cyclones in summer and long-period swells from storms in the Southern Ocean in winter. The Berth Warning System monitors the effects of swell growth, using hourly wave measurements to compute the expected dynamic motions of moored ships. The computations take into account the size of the ship, its loading condition and the orientation of the berth in relation to incident swells.

Case Study 2 – Port Taranaki, New Zealand

Port Taranaki is one of twelve ports handling New Zealand’s international trade and the second largest export port by volume. It is a small breakwater harbour situated on the West Coast of the North Island of New Zealand, halfway between Auckland and Wellington, serving the business of the city of New Plymouth and the surrounding area. Port Taranaki is New Zealand’s major petrochemical port.

Environment

The breakwaters provide protection from the swells of the Tasman Sea and the Southern Ocean (Ref. 3). The entrance channel is 200m wide with a controlling depth of 10.6 metres below chart datum and has a 70 degree turn between the breakwaters and 330 metre turning circle. The dredged channel is short with the natural 12 m contour occurring some 400 m from the port entrance. (Figure 4).

The port experiences semidiurnal tide with a spring range of 3.09 m and a neap range of 1.74 m.

Immediately offshore of the port in a water depth of 25m, significant wave heights than 2.0m occur for 19% of the time.

Swell waves approach the main breakwater from a north westerly direction and are diffracted/refracted by the end of the main breakwater. Vessels encounter beam seas throughout their turn into the harbour and so can experience significant rolling and pitching, thereby increasing their effective draft during this passage.

Wave heights decrease very rapidly once the shelter of the breakwater is reached.

To manage the safe passage of vessels through the port approaches and entrance channel the port has historically adopted a static underkeel clearance rule of 2.5 m.
Shipping Trends

Port Taranaki has received a number of enquiries in recent years from all its major market sectors about the possibility of either increasing depth for larger vessels or increasing the available operating windows for vessels at maximum draft.

With changes to the shipping contracts for dairy products, Port Taranaki became a prospect for larger container volumes provided it could handle vessels with departure drafts of up to 11.0 m. This was an excessive draft under the static underkeel clearance rules and could only be contemplated on MHWS tides in ideal conditions.

Figure 4 Partial view of Port Taranaki chart showing the line of ship tracks to and from the port and the location of wave recording sites (L1 and L2)
It has been the history of dredging in this port that such works have been difficult and expensive. Notwithstanding this fact, trends in shipping and the prospect of requiring increased depth for deeper draft vessels (both tankers and container vessels) raised the issue of further deepening being required in the near future. Studies on this subject revealed that the lead time for a dredging project would be long and the cost would be high.

The advent of DUKC provided an opportunity to achieve additional effective depth without significant quantities of capital dredging at very low cost (relative to capital dredging) and with a very short lead time. The only downside was that increased draft was variable according to the severity of wave conditions in the entrance.

Accordingly Westgate commissioned OMC to conduct a desk top study to assess the potential advantages of the system at Port Taranaki. Following that study the port commissioned the installation of a DUKC system in mid 2001.

The impetus for the installation of the system, and the initial focus was principally on increasing the operating window for sailing fully laden vessels and thereby freeing the berth earlier for following vessels or, importantly, increasing opportunities for maintenance without disrupting customer schedules. It was also expected that maximum draft could be increased, but this was not the principal objective at the time as one major user had recently built five ships specifically tailored for 10.0 metre loaded draft and was not likely to replace them.

Implications For New Trades Of Underkeel Clearance Requirements

Starting in September 2001 Maersk-Sealand established new services with weekly calls at the port of ‘N’ Class vessels and similar, with drafts up to 11.0 metres on departure and 10.5 metres on arrival.

A new trade in refrigerated LPGs is planned to commence in 2005 which may well, with the implementation of DUKC for all vessels using the Terminal, be able to be accommodated on the existing berths and obviate the need for investment in a new facility.

These drafts could not have been contemplated without the DUKC system and some associated dredging that flowed out of the desk study commissioned from OMC.

While the above benefits are immediate and obvious a very significant benefit is anticipated in the long term. It is highly likely that the port will require deepening at some time in the future. The ability to manage ship transits with DUKC is expected to reduce capital dredging requirements by the order of 50% which represents a potential saving in development cost of the order of $15,000,000.

Customisation, Testing and Implementation of DUKC System

Implementation of a DUKC system at Port Taranaki involved customisation of the DUKC software for the wave and tide conditions, channel configuration and bathymetry, ship motion models and other UKC related factors specific to the port. This work also involved development of software to input real time data from wave and tide measurement devices, as well as software to enable system operation to be maintained and monitored from OMC’s office in Melbourne. Installation and testing of the total DUKC system was completed by OMC in August 2001.
Westgate Transport undertook extensive monitoring of the DUKC system during September – December 2001, during which period the system was fine-tuned by OMC on the basis of operational advice provided by Westgate.

It was recognised at the commencement of project planning that a full understanding and acceptance of the DUKC theory and implementation parameters by the port’s pilots was essential to the success of the system and its operation. Their enthusiasm and dedication to achieving increased productivity and safety has been invaluable in the successful trialling and implementation of DUKC at Port Taranaki.

Pilots have been fully involved from commencement in setting bottom clearance and manouevring margins for various parts of the channel and advising on specific manouevres. The pilots also developed detailed operating procedures for DUKC and are ‘owners’ of the system.

An experienced pilot was appointed as project manager and coordinated the upgrade of the environmental monitoring system and its links with the DUKC software as well as developing analytical programmes for reviewing system performance and marketing support.

The system was installed in August 2001 and finally implemented commercially from 1 January 2002 after extensive trialling, proving and some modification of the environmental software links.

The trialling was assisted by the pilots installing a portable GPS receiver on the bridge to match track against echo sounder traces. These were played back after each transit and subjected to detailed evaluation. This process had two substantial benefits. It proved the accuracy of the system and by increasing pilot’s understanding of the ships track it led to a significant improvement in the accuracy of navigation under pilotage.

**Swell Forecasting**

Nowcast and 12-hour, 24-hour and 36-hour forecasts of directional wave spectra at deep water sites offshore from each DUKC installation are generated twice daily by the Bureau of Meteorology in Melbourne, using global and regional wind and wave generation models similar to those used by many other meteorological forecasting agencies throughout the world. These models have recently been extended to include the ingestion of satellite altimeter data on wave heights, with a significant increase in their predictive accuracy.

The nowcast and forecast wave spectra are downloaded automatically from the Bureau FTP site and transformed using site-specific relationships to obtain predicted spectra at the wave measurement sites at Port Taranaki. The transformed nowcasts are compared with the corresponding measured data and these comparisons are used to adjust the 12-hour, 24-hour and 36-hour forecasts. The adjusted forecast data are then used in the Port Taranaki DUKC system for the generation of 36-hour, 24-hour and 12-hour forecasts for maximum draft or tidal window applications. In ports with semi-diurnal tides, as occur at Port Taranaki, such forecasts provide scheduling information for shippers to use up to three high water levels prior to channel transit.

Similar swell forecasting systems are now under development for all other ports with DUKC systems and Berth Warning Systems.
Summary of DUKC Benefits at Port Taranaki

The major benefits that the DUKC system is providing users at Port Taranaki can be summarised as follows (Ref 3):

?? Positive improvements in operational efficiency and safety at an affordable cost
?? By using the DUKC system operating windows are nearly always increased, in some conditions by as much as 100%.
?? By using the DUKC system maximum transit drafts are nearly always increased, in some conditions by more than 2.0 metres.
?? By using the DUKC system it is readily evident when conditions are such that a more conservative approach should be taken than under the existing static rules.
?? The DUKC system adds science to experience and rule of thumb, in determining safe operating limits.
?? The trialling and implementation of the system has given the practitioners a far greater understanding of the issues of under keel clearance and ship motions.
?? The trialling and track review process has put a new discipline and emphasis on navigational accuracy
?? Significant commercial gains have been obtained by ports and their customers.
?? Potential exists to significantly reduce long term development cost by the optimisation of dredged depths
?? Forecasts of major swell events are provided up to 36 hours in advance of their occurrence.

The DUKC system at Port Taranaki optimises the competing objectives of economic advantage and navigational safety. As shown in Figure 5, when swells are low, tidal windows are more than doubled compared to previous static rules, thereby providing significant economic gains to port users; when swells are very high, the previous static rules do not provide adequate margins of safety against grounding. This example illustrates the gains to be made by the application of DUKC technology as well as the limitations of relying on static underkeel clearance rules.

REFERENCES


Available Sailing Window (Hours per Day) - 30,000 DWT tanker 10.0m draft

Date

Sea and Swell in metres

0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00

0
1
2
3
4
5
6
7
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Existing Rules
DUKC Rules
Sea
Swell

Figure 5 Graph comparing operating windows allowed by the static underkeel clearance rule and the application of DUKC at Port Taranaki. Note the correlation with swell height and the non-conservative situations with the static rule on the 19th and 25th of August 2001 (Ref. 3).

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