UKC Management through Dynamic Underkeel Clearance Systems[1]

by

Dr Terry O'Brien

CONTACT DETAILS:

Name: Dr. Terry O'Brien
Title: Director
Company: OMC International Pty Ltd

Address: 6 Paterson Street,
Abbotsford,
Victoria 3067,
Australia

Phone: +61 3 9412 6500
Fax: +61 3 9415 9105

Email: admin@omc-international.com.au

---

[1] Paper submitted for presentation at seminar on "Ports of India – Future Development and Challenges", Mumbai, India, 15 September 2004.

ABSTRACT

Dynamic underkeel clearance (DUKC®) management systems have been developed at several Australasian and New Zealand ports since 1993. Since the first installation at Hay Point in 1993 this Australian technology has been installed at eleven (11) ports around Australia and New Zealand. Refinements have occurred as a result of continuing interaction between harbourmasters, pilots, shipping officers, port users and the OMC design team.

Traditionally, ports operate under fixed rules for under keel clearance which must be conservative to cover the broad range of conditions a vessel may be exposed to in transiting a channel. However, with the benefits of the ship modelling developed by OMC and integrated within the DUKC®, greater predictability can be achieved to assist decisions as to sailing times and vessel draft so that ships can transit channels with greater safety and efficiency. These improvements in port operation have provided economic benefits amounting to hundreds of 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.

The paper describes a recent case study involving the development, installation and full-scale validation of a DUKC® system at the Port of Marsden Point, Whangarei, New Zealand. This system was installed after groundings of crude oil tankers had occurred in April and July 2003 at a shoal in the main approach channel during heavy swells. The validation study showed that the DUKC® system provides an accurate and conservative prediction of net Under Keel Clearance throughout the port approach channels, provided that the vessels sail within the designated channels and within the modelled speed envelope.

INTRODUCTION

OMC is the inventor and sole international supplier of the Dynamic UKC® (DUKC®) system which is a real-time under keel clearance management system for use at ports. Since the first installation at Hay Point in 1993 the Australian technology has been installed at eleven (11) ports around Australia and New Zealand, as shown in Figure 1.

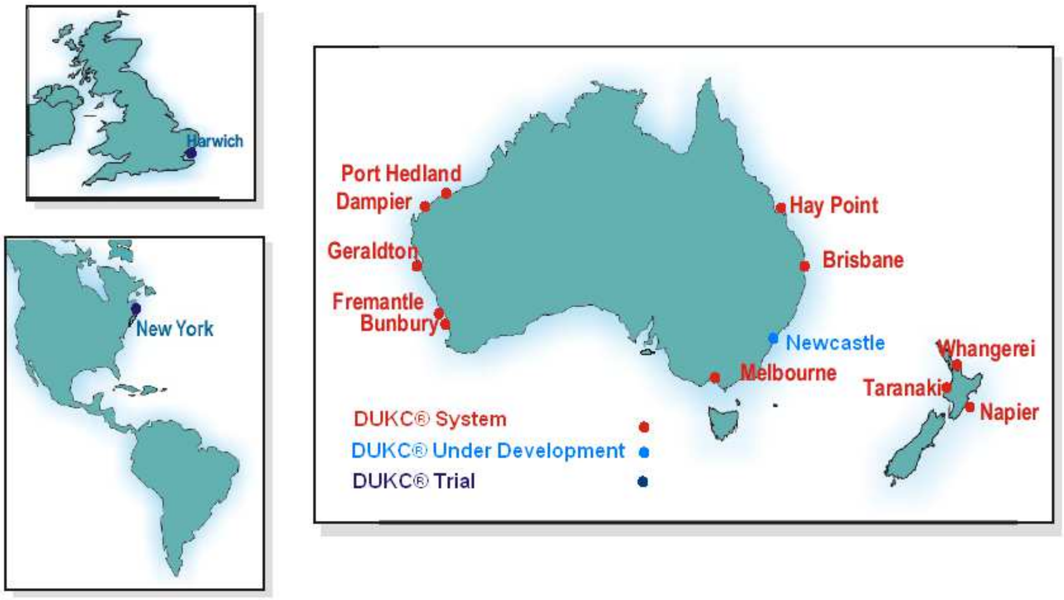

Figure 1 – Location of DUKC® Systems

Traditionally, ports operate under fixed rules for under keel clearance (UKC) which must be conservative 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.

However, with the benefits of dynamic underkeel clearance systems, greater predictability can be achieved to assist decisions as to sailing times and vessel draft so that ships can transit channels with greater safety and efficiency.

The economic benefits provided by DUKC® systems amount to **hundreds of millions dollars** in increased cargo throughput and decreased freight costs, obtained at a fraction of the dredging costs that would be required to gain the same equivalent increase in productivity.

These economic benefits to ports and shippers have been achieved whilst improving the certainty, and therefore the safety, of shipping transits. There have now been more than 18,000 sailings using the DUKC® system without incident.

Apart from safety benefits in reducing the risk of marine accidents, dynamic underkeel clearance systems can significantly reduce the costs and adverse environmental effects associated with dredging. In Port Taranaki, New Zealand, OMC was able to reduce planned dredging costs by approximately 50% through the introduction of the DUKC® system.

MANAGEMENT OF UKC

DUKC® is a near real-time under keel clearance management system for use at ports which have tidally restricted sailings on import or export ships.

DUKC® can assist in the management of UKC in the following stages of a shipping cycle:

1. ***Channel Design*** – DUKC® quantifies the UKC requirements of each section of a transit. This information can be used to create a channel depth profile which matches the UKC requirements. Significant savings on capital dredging can be made. The port can be confident that the maximum benefit will be derived from every dollar spent on dredging.

2. ***Channel Maintenance*** – UKC requirements quantified by DUKC® can be used to identify siltation areas which are most critical to vessel sailings. Maintenance dredging can be targeted at these areas.

3. ***Long Term Sailing Planning*** – The Q-DUKC can be used for long term planning of vessel sailings. This system uses DUKC® methodology to determine UKC requirements and thus plan sailing times. However, environmental information is based upon probabilistic estimates of conditions rather than real-time measurements. Q-DUKC has the advantage of allowing some of the additional draft benefit of a DUKC® system to be realised in long term vessel planning. Arrival/departure drafts required for scheduling trades such as tanker arrivals from the Middle-East or container services are determined with a methodology consistent with that used immediately prior to the vessel’s arrival/departure. Drafts can be scheduled such that the probability of delaying a transit due to adverse environmental conditions is low and consistent with the economic viability of the trade.

4. ***Short Term Sailing Planning*** – From approximately 30 hours prior to sailing the DUKC® system can be used to determine sailing windows and drafts. These calculations are based upon mathematical models of environmental conditions driven from real-time measured inputs.

5. ***In Transit Navigation*** – DUKC® Onboard is a pilot carry-on board system in which the pilot’s laptop computer receives GPS inputs of position and speed and calculates UKC for the remainder of a transit. The pilot has the option of selecting speeds in each section of the transit, in which case the system will return the resultant UKC. Alternately, optimum speeds for each section that will ensure adequate UKC can be returned. The DUKC® Onboard system enables pilots to shorten transit times through port channels to the minimum possible without compromising safety. The DUKC® Onboard system is currently being trialled by pilots at several Australian ports and is expected to be in operation at Port Hedland and Dampier by the end of 2004.

THE DYNAMIC UKC® CONCEPT

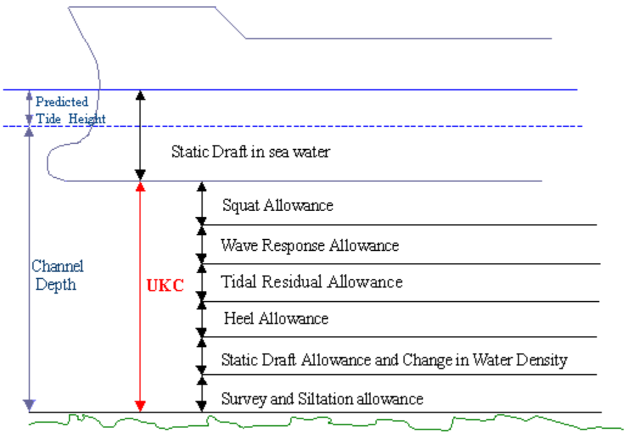

Figure 2 – UKC Factors

The DUKC® system takes into account all of the major factors shown in Figure 2, together with other allowances which may be required in particular circumstances.

The system has two major functions:

- Determination of the earliest and latest times for channel entry (export and import vessels).
- Maximisation of vessel drafts (export vessels).

DUKC® systems utilise real-time tide and wave measurements taken prior to transit to determine the minimum safe under keel clearance along the complete transit from berth to deep water. This system allows ships to use wider tidal windows or be loaded to greater draft 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 with minimum need for new port infrastructure or capital dredging and without compromising safety standards.

Import vessels have their drafts set at their previous port of departure and hence use the tidal windows facility. Because the DUKC® systems can be run shortly before the pilot enters the approach channel, there is minimum time for tidal residuals and swells to change and tidal windows will generally be very much greater than those corresponding to fixed rules set for worst case conditions. This means that waiting vessels can enter port earlier than would otherwise be possible and, at the other end of the tide cycle, gain entry on occasions when they might otherwise have to wait for the next suitable tide. Alternatively, the gains obtained from reduction of UKC allowances can be translated into increased arrival drafts by decreasing the gross UKC formulae used to schedule such drafts.

Wave conditions, ship speed and water depths vary along the transit. The effect of these variations is computed by the numerical ship motion model used in each DUKC® system. In addition, wave conditions and tidal residuals will change over time. These effects are accounted for in each system. Safety criteria for determining the maximum wave response allowance required at each point of each vessel transit are established for each port.

With respect to squat and heel, individual ships and the pertinent characteristics of the complete approach channel are modelled in each DUKC® system.

The magnitude and nature of UKC safety factors are established through consultation with the harbourmasters and pilots at each port.

DREDGE OPTIMISATION WITH DUKC®

DUKC® methodology can be used to optimise channel dredging. The intended aim of increasing allowable sailing drafts and tidal windows is delivered at a greatly reduced cost and with minimum environmental effects.

Vessel under-keel clearance (UKC) has two purposes:

1. ***Bottom Clearance*** (BC) - Prevent the vessel from touching the channel bottom.

2. ***Manoeuvrability Margin*** (MM) – Provide sufficient water flow under the hull and past the keel for the vessel to be manoeuvred.

UKC for MM differs from that for BC, in that vessel wave response does not affect UKC for MM and the channel depth for UKC for MM is not necessarily the shallowest depth.

DUKC® analysis involves individually calculating each of the factors that contribute to reducing UKC at all points of a transit through a restricted waterway. UKC for MM and for BC are separately calculated for each point in the channel. Consideration is given to the actual environmental conditions (waves, tides, currents, etc…), vessel dimensions, stability characteristics and speeds and actual channel configuration. The result of this analysis is a net UKC profile for each vessel transit. The critical points for UKC in the channel are identified.

Figure 3 illustrates a typical UKC profile for a vessel transit as generated by DUKC® analysis. UKC for MM and for BC are shown, together with their limiting values. The critical points in the channel occur where either UKC for MM or for BC are reduced to their respective limits.

In this scenario there are three locations where UKC for MM is reduced to its limit due to vessel heel on bends and one location where UKC for BC is reduced to its limit by wave induced vessel roll. It can be seen that to achieve a greater sailing draft the depth in these four locations must be increased.

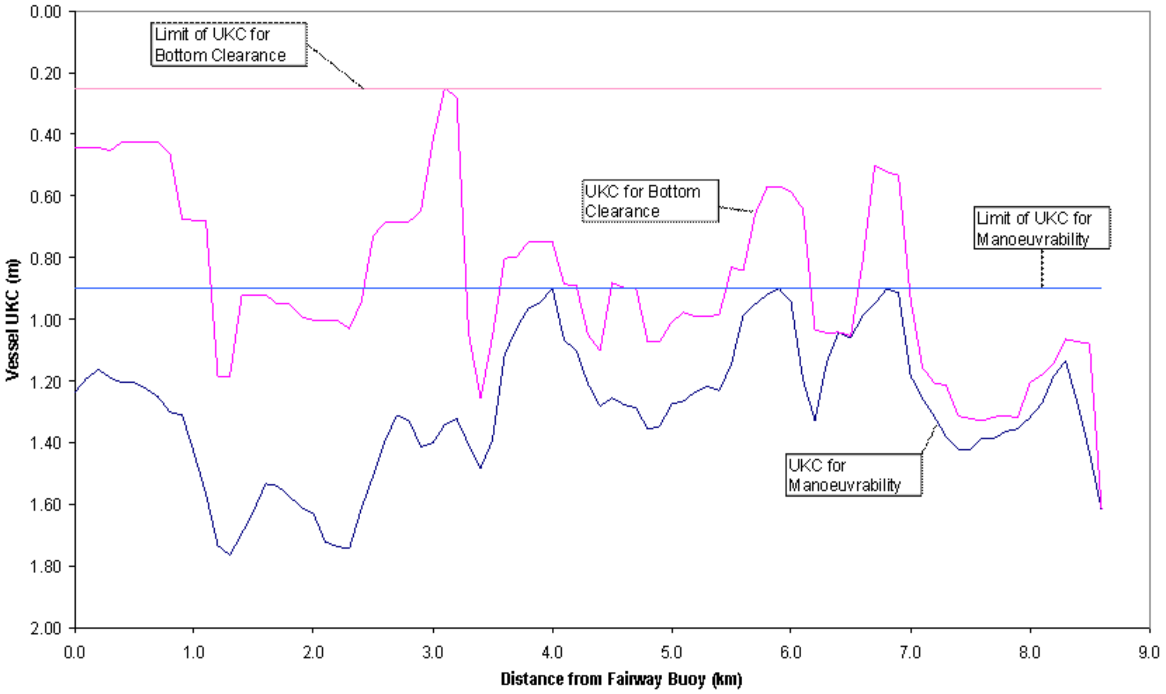

Figure 3: Dredge Optimisation with DUKC®

In a dredge optimisation study using DUKC® methodology the UKC profile is produced based upon statistical analysis of environmental conditions as well as the range of possible vessel types and speeds. The optimal UKC profile allows for the full range of conditions under which a vessel may be required to transit the channel.

Following channel dredging optimised with DUKC®, vessel sailing drafts and times should be determined by a real-time DUKC® system. This ensures that the UKC for each vessel transit is consistent with the existing channel bed profile. The DUKC® will set sailing times to make optimum use of the measured tide. It will also ensure that the vessel drafts or windows are reduced on occasions where the wave conditions of the day will induce vessel motions that exceed the channel design parameters.

Optimisation with DUKC® can significantly reduce the financial cost of dredging as well as its environmental effects. Continued use of a DUKC® system in real-time will ensure the most efficient use is made of the channel whilst maintaining a high level of safety against vessel groundings.

SYSTEM VALIDATION

Until recently it has been very difficult to validate existing squat models with any degree of confidence as there has been no method to accurately measure full-scale vessel squat. Advances in the area of dual-frequency RTK GPS have overcome this problem, making full-scale squat testing not only possible but also highly accurate over long baselines.

Three RTK GPS receivers, one at the bow and one on each bridge wing, are required to individually determine the vertical dynamic motions, including roll, pitch, heave, heel, trim and squat.

GPS data can be analysed to quantify UKC requirements and validate DUKC® predictions of UKC requirements of the measured vessel sailings. To validate these predictions, measured wave, current and tide data and ship particulars from the transit are required. In addition, state-of-the-art GIS Systems are used to derive the hydrographic depths at the location of the vessel at all points of the transit.

Since 1997, OMC has carried out full-scale vessel motion measurements using RTK GPS equipment on over 100 vessels at 12 ports around Australia and New Zealand. These have included all major vessel types. 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.

Ship squat at the bow and stern of a bulk carrier measured by the RTK GPS equipment is shown below in Figure 4. The oscillations shown indicate the vertical dynamic motions of the vessel. The vessel squat is taken to be the mean of these oscillations.

During the initial three kilometres of the transit the bow and stern squat are similar in magnitude, indicating that bodily sinkage is occurring. After this distance the ship begins to increase speed considerably and the vessel's trim alters to produce maximum squat at the bow, as expected for a full form vessel.

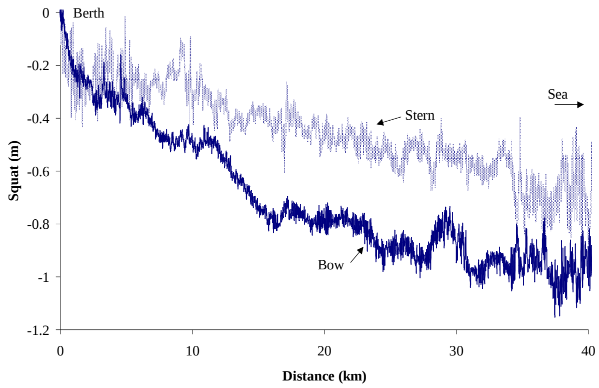

Figure 4: Measured Bow and Stern Squat for a Tanker

However as detailed above, there are other parameters besides speed which influence a vessel’s squat.

Two such influences which are not accounted for in empirical formulae but can be significant are vessel acceleration/deceleration rates and sea-bed topography. These factors contribute to what is termed “dynamic squat”.

The significant influence of acceleration effects is shown in Figures 5 and 6.

Figure 5 shows the measured squat against the OMC predicted squat for a vessel accelerating at a normal rate. For the same channel and vessel condition, Figure 6 shows the measured squat against the predicted squat (excluding acceleration effects) for a vessel accelerating at a rapid rate.

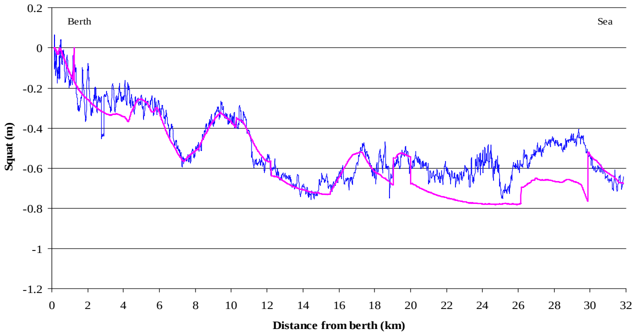

Figure 5: Measured and Predicted Bow Squat for a Tanker with normal acceleration

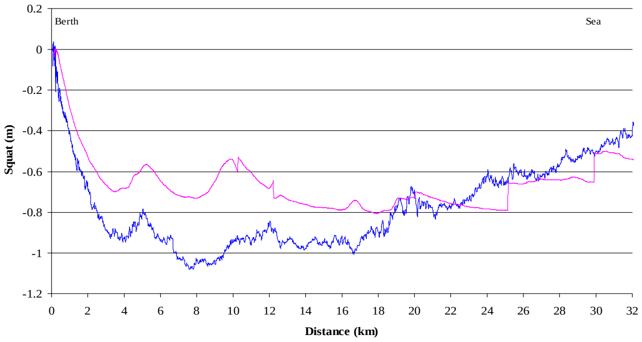

Figure 6: Measured and Predicted Bow Squat for a Tanker with rapid acceleration

The increase in squat following rapid acceleration is clearly evident. Importantly, the subsequent increase in squat is maintained for a significant distance, in this case for up to 15 kilometres.

Figure 7 shows the dramatic increase in squat as a vessel passes over significant sea-bed undulations.

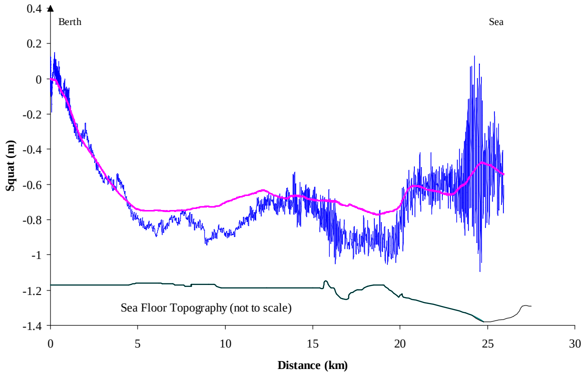

Figure 7: Measured and Predicted Bow Squat for a Tanker passing over Sea-Bed Undulations.

The results of such validation testing have highlighted the sensitivity of squat to particular channel configurations and provided an excellent record of actual vessel squat.

In addition to squat and dynamic motion data, the test programs also provide valuable data regarding ship speed along the various channels. This has enabled the DUKC® systems to be further refined to better reflect the actual vessel speeds in the approach channels.

The full-scale testing results have lead to operational changes which have increased economic benefits as well as improved safety at several DUKC® ports.

CASE STUDY

Port of Marsden Point, Whangarei, New Zealand

The Port of Whangarei is situated on the east coast of New Zealand's north island, about 17km north of Auckland.

Marsden Point is home to New Zealand's sole refinery, which is serviced by a two-berth terminal for import and export tankers. The refinery is operated by the New Zealand Refinery Company, a consortium formed by Shell, BP, Caltex and Mobil.

Approximately once a week super-tankers of 100,000 DWT arrive at 13-15m draft from the Middle East to deliver crude oil.

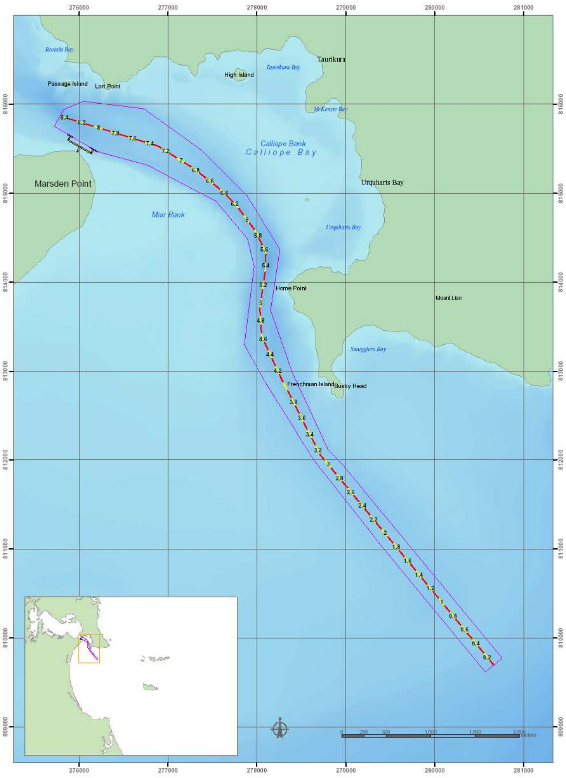

Figure 8 Marsden Point – Main Approach Channel

The approach channel is approximately 8 kilometres long (Figure 8) and is exposed to significant long period swell at its seaward end. In addition there is a shallow sand bar that rises sharply from deep water which the vessels must pass over near the beginning of an inward transit where the vessel is most exposed to swell conditions.

Historically pilots have used judgement as to the safe UKC conditions for a particular transit. There have been no wave measuring instruments at the port and the custom has been for pilots to board the vessel at a point 2 miles south-east of the channel, ascertain the likely vessel motions and make a judgement as to the safe passage.

However in 2003, two groundings of inbound laden super-tankers occurred at the location of the sand-bar, namely

- On April 14th 2003, the **Capella Voyager** carrying 108,000 tonnes of crude oil hit the sand bar, split the hull and took on several thousand tonnes of water. Heavy swells were reported at the time;

- On July 27th 2003, the **Eastern Honour** carrying over 100,000 tonnes of crude oil scraped the bottom of the shoal. Again heavy swells were reported at the time.

Following the two groundings, the Maritime Safety Authority in New Zealand (MSA) imposed significant draft limits on the port and recommended they implement a DUKC® System. This endorsement of the safety benefits obtained through the DUKC® System is highlighted in Recommendation 5.1 of the recently released MSA's report into the grounding of the first tanker, the "Capella Voyager" (see MSA's website: http://www.msa.govt.nz/Accidents/gettingreports.htm under the name - Report No: 03:3117 - Capella Voyager).

In September 2003, OMC was commissioned by NorthTugz Pty Ltd, the service providers for the Port of Marsden Point, to install a DUKC® System.

The first step in the installation of a DUKC® System was the implementation of a directional wave rider buoy. A Triaxys Wave Rider Buoy was positioned adjacent to the critical section of the channel around the shoal with telemetry hardware to provide real-time feed of spectral wave data to the Port's Control Room.

OMC then conducted a wave modelling study using the SWAN software package to transform the measured wave climate along the channel. SWAN is a 3rd generation model developed by Delft University of Technology. The results of the wave transformation modeling have been used in developing general transformation algorithms to determine wave conditions along the channel for measured wave conditions at the buoy. These algorithms are incorporated into the DUKC® model.

Customisation of a DUKC® system for Marsden Point was completed in early December 2003. Real time tide data, at one minute intervals from the existing tide gauge at the Refinery Berth, and wave data from the Triaxys wave rider at 30 minute intervals are fed into a dedicated computer in the Port Control Room on which the DUKC® system resides. This computer is connected to the Port's network system so that any user with designated rights can view the DUKC® results.

In late December 2003, OMC conducted full-scale vessel motion testing to calibrate, validate and provide user confidence in the accuracy of the algorithms integrated in the DUKC® system.

RTK GPS equipment sensitive to sub-decimetre accuracy was placed on-board four vessels visiting the port to measure vessel movements during transit. The GPS data containing vessel location and vertical elevation at each second of the transits were converted into local area co-ordinates, and adjusted for tide. The adjusted data were analysed for squat, heel and dynamic motions. The measurements were compared to predictions made by the DUKC® models simulating the same vessel and environmental conditions.

A plot of the measured versus predicted squat for the supertanker **CS Valiant** is given in Figure 9. The dramatic increase in squat as the vessel approaches the shoal between the Fairway and Beacon No.1 is clearly evident. Excluding this dynamic squat effect and applying the squat model for only the vessel characteristics, speed and channel blockage effect under-predicts the squat by approximately 6cm at a speed of only 5 knots. Clearly, it is vital that this effect is understood, quantified and included in the DUKC® System.

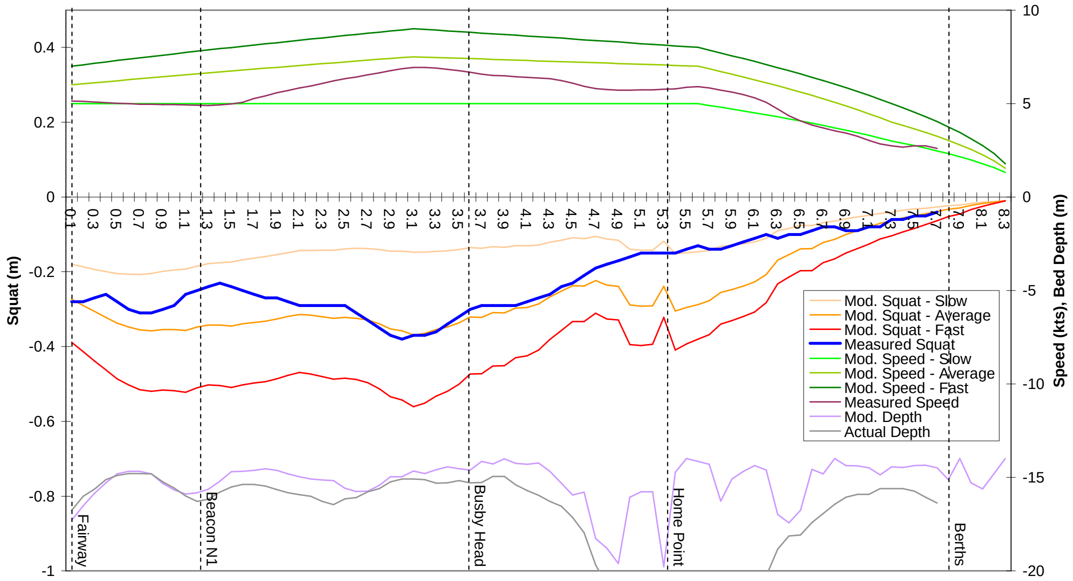

Figure 9: Measured and Predicted Squat for the CS Valiant

A plot of the predicted UKC for the **CS Valiant** against the actual UKC utilising the GPS tracks with the detailed hydrographic soundings is given in Figure 10.

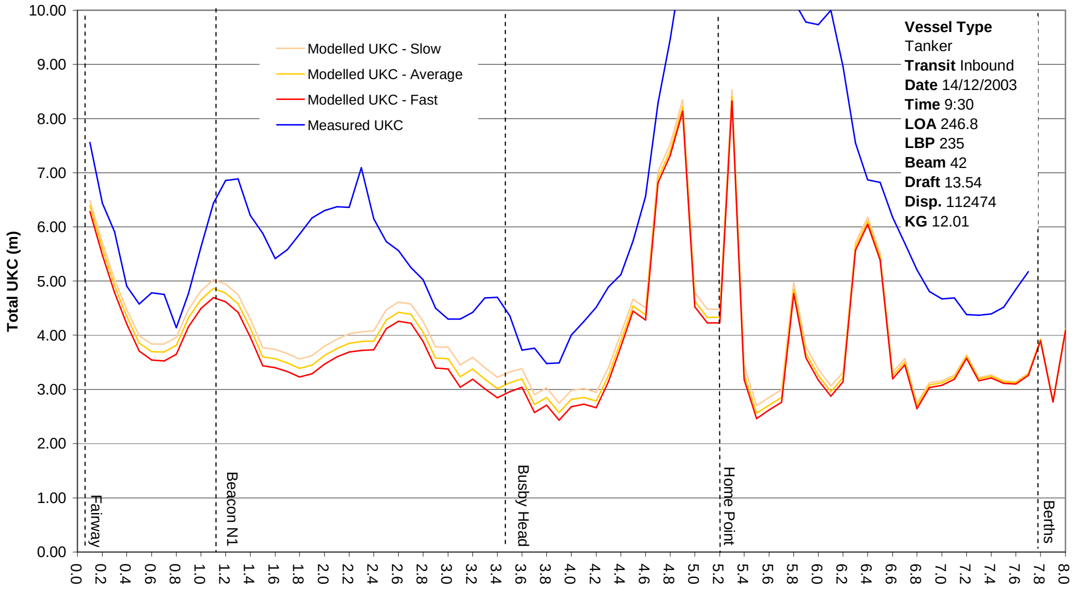

Figure 10: Measured and Predicted UKC for the CS Valiant

The full-scale validation study showed that the squat model used by the DUKC® system accurately and consistently predicts the measured squat when the vessels travel within the specified speed profile.

The dynamic motion measurements showed that the model used by the DUKC® accurately predicted the vessel motions with an appropriate conservatism to account for the probabilistic nature of vessel dynamic motions for a given seastate.

In summary, the validation study showed that the DUKC® system provides an accurate and conservative prediction of net Under Keel Clearance throughout the port approach channels, provided that the vessels sail within the designated channels and within the modelled speed envelope. In consultation with users and the MSA, it is planned to reduce incrementally the present degree of conservatism in the system. Such action will only be taken after considerable experience has been gained by users of the system and after further full-scale testing (with reduced underkeel clearances) has been conducted.

◆