Underkeel Clearance Management Systems

Captain Jonathon Pearce
Senior Pilotage Advisor
Underkeel Clearance Risk Management (UKCM)

- The management of the touch bottom or grounding hazard

- Risk = Frequency * Consequence

- Frequency is low/rare and in region of $3 \times 10^{-5}$ (one in 33000 movements)

- Consequence can be Catastrophic

- Effective Management required
Sea Empress 1996

Sea Empress resulted in a total financial cost of £52m - £109m and similar environmental costs.
Port Hedland, was facing a loss of US$ 40 million for each tide that the channel remained closed when the Iron King grounded.
mv “Rena” 5 October 2011 NZ
Navigation in the Vertical Dimension
Static Underkeel Allowances

- Measured waves
- Measured tide and currents
- Measured wind and pressure
- Latest sounded depths
- Astronomical tides

“X” % of Draft

- Predicted Tide
- WAVE RESPONSE
- CHANGES IN TIDAL RESIDUAL
- SQUAT
- SAFETY ALLOWANCES

Ship in given load state

Ship speed envelopes
Static Rule History
Static Rule – A Top Down Approach

VARIABLE RISK
Nett Clearance changes for every transit
Is it Safe, Marginal or Unsafe?

Nett Clearance?
Optimism v Conservatism

Too optimistic - Safety jeopardised

Static Rules are:

Blunt compromise between economics and safety;

Nett clearances change from day to day, ship to ship and even transit to transit!
Safety Case Study – Marsden Point, NZ

Capella Voyager 16 April 2003
Eastern Honor 27 July 2003
Under most conditions a static rule will be conservative. However, groundings can occur when a ship is sensitive to the prevailing conditions (this is actual data!). Don’t be complacent about your existing rules!
1. Are existing rules adequate and justifiable?
2. Are all the factors that contribute to the static rule understood?
3. Does “no incidents” mean the rule is reliable?
4. Are there times when the rule may have been unsafe/marginal?
5. Are primary factors calculated and conveyed to the Master?
measured waves
measured tide & currents
measured wind & pressure
latest sounded depths
astronomical tides

ship in given load state

Dynamic UKC Methodology

ship speed envelopes

Dynamic UKC Methodology

Dynamic UKC Methodology

Dynamic UKC Methodology

Dynamic UKC Methodology
Underkeel Clearance Limits

• DUKCM limits in accordance with PIANC Guidelines

• Bottom Clearance
  – Bottom touch due to vessel motions

• Manoeuvrability Margin
  – Inability to manoeuvre
MM & BC

Manoeuvrability
Safety Limit
90cms

BC Limit
25cms

BC Limit
25cms

BC Limit
25cms
DUKC® - System Inputs/Outputs

- Real-time measured and forecast waves
- Real-time measured and forecast tides
- Astronomical tides
- Real-time measured and predicted water currents
- Real-time measured barometric pressure

**DUKC® Computational Engine**

- Wave transformation and propagation models
- Wave and swell forecasting models
- Wave induced ship motion models
- Tidal plane models
- Tide and water level forecasting models
- Water current models
- Squat and trim models
- Dynamic heel models
- Seabed and siltation models
- Vessel speed and acceleration models

- Real-time measured and forecast wind
- Vessel dimensions and load state information
- Planned and monitored vessel speeds
- Seabed profiles from high density surveys
- Waterway alignments and harbour configurations

**Outputs**

- Optimised tidal windows
- Optimised drafts
- Optimised dredge planning
High-resolution bathymetry grid
Bathy Nodes
Channel Segment

Channel Boundary

Channel Section
300m to channel boundary
100m segment

14.8m BC
Declared Depth

15.7m Max

MM 15.0m for 300m x 100m section

Scale exaggerated by 25x for emphasis
Hydrodynamic model

- Water level and currents within Prince of Wales Channel predictable
- Predictions use water levels at Goods Island and Ince Point
Complex tidal regimes

Recorded water level across Prince of Wales Channel 15/16 May 2007

Water level relative to AHD [m]

12:00 18:00 00:00 06:00 12:00
-1.5
-1
-0.5
0
0.5
1
1.5

booby
goods
hammond
nardana
ince
Tidal Residuals

Positive Residual

Negative Residual

Predictions

Measurements
Residual Analysis - Lagged tides
Vancouver Example - 2\textsuperscript{nd} Narrows Tide; Current; Air Draft
Squat

- Low pressure caused by return flow creates a local depression in the water surface
- Vessel must sink with depression and may change trim to balance its weight
Which formulae?

Comparison of Squat Formulas

\[
\Delta t_{\text{max}} = C_0 \frac{C_B B}{l_{pp}} \frac{F_{\text{nh}}^2}{\sqrt{1 - F_{\text{nh}}^2}}
\]

\[
S = 2.4 \frac{\nabla}{l_{pp}^2} \frac{F_{\text{nh}}^2}{\sqrt{1 - F_{\text{nh}}^2}} K_s
\]

\[
S_{bE} = 0.113B \left( \frac{T}{h} \right)^{0.27} F_{\text{nh}}^{1.8} \quad 1.08 < h/T < 2.75
\]

\[
S_{bD} = \frac{1}{95} V_k^2 \frac{T}{h} C_b
\]

\[
S = \frac{C_b}{45} \left( \frac{V_s}{\sqrt{h}} \right)^3
\]

\[
S_{bR} = C_v C_F K_{AT} T
\]

\[
S_{bS} = C_v K_{AT} T
\]

\[
S_{bH} = 1.96 \frac{\nabla}{L_{pp}^2} \frac{F_{\text{nh}}^2}{\sqrt{1 - F_{\text{nh}}^2}}
\]

\[
S_{bHs} = 2.4 \frac{\nabla}{L_{pp}^2} \frac{F_{\text{nh}}^2}{\sqrt{1 - F_{\text{nh}}^2}} K_s
\]

\[
S_{bR} = C_B S_2^{2/3} \frac{V_k^{2.08}}{30}
\]

\[
S_{bHs} = 0.01L_{pp} \left( 1.71 C_s \frac{1}{L_{pp}/T} - 0.6 \right) \frac{F_{\text{nh}}^2}{\sqrt{1 - F_{\text{nh}}^2}}
\]

\[
S_{bL} = 2.20 \frac{V_s^2}{S_c} C_b \quad \text{where} \quad S_c = \frac{A_t}{A_t - A_s}
\]

\[
S_{bJ} = \left[ \left( 0.7 + 1.5 \frac{1}{h/T} \right) \left( \frac{C_b}{L_{pp}/B} \right) + 15 \frac{1}{h/T} \left( \frac{C_b}{L_{pp}/B} \right)^3 \right] \frac{V_s^2}{g}
\]

Note: \( L_{pp} / B = R_{LB} \) and \( h/T = R_{bT} \)
Squat – Channel Blockage
Squat Case Study – Port of Lisbon
Actual Squat Example
Wave Response
Differing Wave Response

Formosa Fifteen 26 March 2009 Lbp 165m Beam 32.2m Draft 11.5m
(Torm Gudrun Lbp 234m Beam 42m Draft 12.5m, Corona Majesty Lbp 220m Beam 38m Draft 13.8m)

DUKC Predicted SA Roll:
Formosa Trader
0845 - 4.7 [6.1] degs, WRA - 1.7 [2.2]m
1230 - 6.7 [8.7] degs, WRA - 2.4 [3.1]m
Corona Maj
0845 - 2.8 [3.6] degs, WRA - 1.3 [1.7]m
1230 - 4.0 [5.2] degs, WRA - 1.8m [2.3]m
Torm Gudrun
0845 - 1.4  [1.8] degs, WRA - 0.7 [0.9]m
1230 - 2.2 [2.9]  degs, WRA - 1.4 [1.8]m

99% Exc
Wave Response Calculation

Offshore Swell height = 2m, period = 14 seconds

- **EBB**
  - Swell (2.8m Hm0)
  - PostPanamax: 1.18m
  - Handymax: 0.60m

- **FLOOD**
  - Swell (1.7m Hm0)
  - Bass Strait: 0.47m
  - 1.42m

- Tidal Current:
  - EBB: 5.0kn
  - Flood: 3.0kn
DUKC®—A Bottom Up Methodology

CONSTANT RISK
Minimum Clearance maintained for every transit
Always Safe!

Required Water Depth
Wave Response/Setdown
Heel
Squat
Tidal Residual

Minimum Clearance (Predetermined Limit)
UKC Safety Case Study – Port Taranaki
Benefit Case Study - Port Taranaki
Benefit Case Study - Port Taranaki

Static Rules not Sufficient in High Swell Conditions
Case Study – Torres Strait

AMSA

Under Keel Clearance Management System
Stakeholders Involvement
<table>
<thead>
<tr>
<th>Summary</th>
<th>Tide</th>
<th>Wave</th>
<th>Tidal Stream</th>
<th>Wind</th>
<th>Meteorological</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tide</strong></td>
<td><strong>Booby Island</strong></td>
<td><strong>Goods Island</strong></td>
<td><strong>Turtle Head</strong></td>
<td><strong>Nardana Patches</strong></td>
<td><strong>Ince Point</strong></td>
</tr>
<tr>
<td>1.40 m</td>
<td>0.97 m</td>
<td>0.82 m</td>
<td>1.23 m</td>
<td>1.28 m</td>
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<td>Tide</td>
<td>Tide</td>
<td>Tide</td>
<td>Tide</td>
<td>Tide</td>
<td></td>
</tr>
<tr>
<td>-0.03 m</td>
<td>-0.02 m</td>
<td>-0.01 m</td>
<td>+0.05 m</td>
<td>+0.09 m</td>
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</tr>
<tr>
<td>Residual</td>
<td>Residual</td>
<td>Residual</td>
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<th><strong>Nardana Patches</strong></th>
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<tr>
<td><strong>Varzin Passage 1</strong></td>
<td><strong>Varzin Passage 2</strong></td>
<td><strong>Varzin Passage 1</strong></td>
<td><strong>Varzin Passage 2</strong></td>
</tr>
<tr>
<td>0.5 m</td>
<td>0.7 m</td>
<td>2.3 kn</td>
<td>1010.0 hPa</td>
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<tr>
<td>Swell</td>
<td>Swell</td>
<td>Rate</td>
<td>Pressure</td>
</tr>
<tr>
<td>0.1 m</td>
<td>0.1 m</td>
<td>2.3 kn</td>
<td>25.2 °C</td>
</tr>
<tr>
<td>Height</td>
<td>Height</td>
<td>Speed</td>
<td>Temperature</td>
</tr>
<tr>
<td>4.3 s</td>
<td>8.3 s</td>
<td>260 °</td>
<td>60 %</td>
</tr>
<tr>
<td>3.8 s</td>
<td>9.6 s</td>
<td>14.1 kn</td>
<td>Humidity</td>
</tr>
<tr>
<td>Period</td>
<td>Period</td>
<td>Direction</td>
<td></td>
</tr>
<tr>
<td>209 °</td>
<td>234 °</td>
<td>Direction</td>
<td></td>
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</table>
**Summary**

Tide
- Booby Island
- Goose Island
- Turtle Head
- Nardana Patches
- Ince Point
- Town Island

Wave
- Vezin Passage 1
- Vezin Passage 2

Tidal Stream
- Vezin Passage
- Hornsby Rock
- Hammond Rock
- Nardana Patches
- Alan Patches

Wind
- Booby Island

Meteorological
- Booby Island
Voyage Planning Service

Voyage Plan for CAPT. STEFANOS (9227194)

Direction
Eastbound

Earliest commencement date
22May2011 1937

Latest commencement date
29May2011 0000

Target Draught
12.00 m

Maximum Draughts

22May2011 1947 : 12.20 m
24May2011 2102 : 12.20 m
27May2011 1014 : 11.55 m

23May2011 0527 : 12.20 m
25May2011 0740 : 11.56 m
27May2011 2222 : 12.20 m

23May2011 2027 : 12.20 m
25May2011 2132 : 12.20 m
28May2011 1118 : 11.47 m

24May2011 0651 : 12.16 m
26May2011 0901 : 11.81 m
28May2011 1415 : 11.30 m

24May2011 0778 : 11.94 m
25May2011 1517 : 12.20 m
28May2011 2246 : 12.20 m

Commencement windows for target draught: 9

Window open	Window close	Duration	Window open	Window close	Duration
23May2011 0438	23May2011 0647	2 hrs 9 mins	26May2011 2136	26May2011 2327	1 hr 49 mins
23May2011 0003	23May2011 2327	3 hrs 24 mins	27May2011 2153	27May2011 2337	1 hr 44 mins
24May2011 0808	24May2011 0721	1 hrs 13 mins	27May2011 2153	27May2011 2337	1 hr 44 mins

1 - The window may open before the earliest commencement time
Transit Planning

Available Windows: 05/1132 to 05/1242
Transit Commencement: 2010-11-05 12:00

<table>
<thead>
<tr>
<th></th>
<th>C1C2</th>
<th>1nm W of C3C4</th>
<th>C3C4</th>
<th>1nm E of C3C4</th>
<th>Larpent</th>
<th>Harrison</th>
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<td>8</td>
<td>8</td>
<td>8</td>
<td>11</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>11</td>
<td>12</td>
<td>12</td>
<td>10</td>
<td>12</td>
<td></td>
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<tr>
<td>Time (AEST)</td>
<td>05/1200</td>
<td>05/1230</td>
<td>05/1238</td>
<td>05/1246</td>
<td>05/1335</td>
<td>05/1400</td>
<td>05/1409</td>
<td>05/1410</td>
<td>05/1425</td>
<td>05/1437</td>
<td>05/1447</td>
<td>05/1457</td>
<td>05/1507</td>
<td>05/1510</td>
</tr>
<tr>
<td>Squat (m)</td>
<td>0.25</td>
<td>0.47</td>
<td>0.49</td>
<td>0.50</td>
<td>0.93</td>
<td>1.03</td>
<td>1.27</td>
<td>1.44</td>
<td>1.19</td>
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<td>2.09</td>
<td>2.05</td>
<td>2.04</td>
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<tr>
<td>UKC (m)</td>
<td>1.47</td>
<td>0.53</td>
<td>0.34</td>
<td>0.87</td>
<td>0.18</td>
<td>0.75</td>
<td>0.74</td>
<td>0.96</td>
<td>2.15</td>
<td>0.72</td>
<td>0.73</td>
<td>1.71</td>
<td>0.56</td>
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Recalculate

UKC

Distance (nm)

Static Draught | Dynamic Motions | Net UKC | Limit | Chart Depth | Tide | Breaching
## Transit Overview

### Available Windows: 05/1132 to 05/1242

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[Recalculate]

### UKC

- Static Draught
- Dynamic Motions
- Net UKC
- Limit
- Chart Depth
- Tide
- Breaching
Outputs and Reports

Transit Plan Report - KAKARIKI

Varzin Passage to Herald Patches

Jonathon Pearce
ID 174724.2

Transit Plan

Way Point | ETA | Actual Time | BTW [km] | Stream [kn] (dir) | SOG [kn] | Actual SOG | Tide (resid) [m] | Actual Tide | Depth [m] | Squat [m] | Heel [m] | UKC [m] | UKC-L [m] | % UKC [%]
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
C1/C2 | 140000 | 6.00 | 1.17 (064°) | 7.17 | 3.36 (+0.11) | 11.08 | 0.21 | 0.00 | 2.34 | 1.23 | 18.5% | 
C3 W | 140628 | 6.00 | 1.09 (064°) | 7.04 | 3.42 (+0.11) | 10.73 | 0.21 | 0.00 | 1.94 | 0.93 | 16.1% | 
C3/C4 | 140838 | 6.00 | 1.10 (065°) | 6.76 | 3.44 (+0.11) | 10.59 | 0.21 | 0.02 | 1.79 | 0.79 | 14.9% | 
C4 E | 140846 | 6.00 | 1.10 (066°) | 6.77 | 3.44 (+0.11) | 11.09 | 0.21 | 0.00 | 2.31 | 1.31 | 19.3% | 
Larrent NW | 140855 | 7.00 | 1.12 (066°) | 7.78 | 3.41 (+0.11) | 11.80 | 0.28 | 0.00 | 2.93 | 1.92 | 24.4% | 
Goods | 140938 | 8.00 | 1.26 (073°) | 9.18 | 3.21 (+0.11) | 11.80 | 0.28 | 0.00 | 2.62 | 1.62 | 21.3% | 
Tucker | 141006 | 8.00 | 1.52 (073°) | 9.45 | 3.10 (+0.11) | 11.69 | 0.54 | 0.00 | 2.25 | 1.04 | 18.7% | 
Round | 141023 | 8.00 | 1.69 (077°) | 9.57 | 2.84 (+0.10) | 11.90 | 0.50 | 0.00 | 2.25 | 1.04 | 18.7% | 
Turde | 141042 | 8.00 | 1.64 (080°) | 9.62 | 2.59 (+0.09) | 11.80 | 0.38 | 0.00 | 2.02 | 0.81 | 16.5% | 
Nardana | 141049 | 9.00 | 1.36 (082°) | 10.35 | 2.56 (+0.11) | 11.75 | 0.46 | 0.02 | 1.83 | 0.62 | 15.2% | 
Puller E | 141667 | 9.00 | 1.16 (088°) | 10.98 | 2.68 (+0.11) | 11.44 | 0.68 | 0.01 | 1.46 | 0.26 | 12.1% | 
Hoob | 141103 | 9.00 | 0.90 (082°) | 9.87 | 2.60 (+0.11) | 12.10 | 0.67 | 0.03 | 2.00 | 0.80 | 16.7% | 
Ince | 141116 | 9.00 | 0.48 (084°) | 8.47 | 2.64 (+0.11) | 13.10 | 0.44 | 0.00 | 3.30 | 2.09 | 27.5% | 
OG Rock | 141123 | 9.00 | 0.09 (078°) | 8.08 | 2.66 (+0.11) | 12.08 | 0.51 | 0.00 | 2.21 | 1.00 | 18.4% | 
Herald | 141134 | 8.00 | 0.02 (347°) | 7.99 | 2.67 (+0.11) | 12.51 | 0.51 | 0.00 | 2.67 | 1.47 | 22.3% | 

Transit Commencement Windows

| Gate | Window @ 8kn STW | Window @ 8kn STW | Window @ 10kn STW | Window @ 12kn STW | Window @ 14kn STW | Window @ 16kn STW |
--- | --- | --- | --- | --- | --- | ---
C1/C2 | 140453 to 141800° | 140515 to 141800° | 140547 to 141800° | 140634 to 141153 | 141628 to 141800° | N/A | 
C3/C4 | 140552 to 141800° | 140625 to 141200 | 140720 to 141033 | 141594 to 141800° | N/A | N/A | 
Goods | 140407 to 141800° | 140431 to 141800° | 140541 to 141800° | 1405640 to 141800° | N/A | N/A | 
Tucker | 140534 to 141800° | 140515 to 141800° | 140574 to 141800° | N/A | N/A | N/A | 
Turde | 140643 to 141800° | 140730 to 141726 | 140839 to 141745 | N/A | N/A | N/A | 
Nardana | 140850 to 141800° | 140929 to 141522 | 141027 to 141522 | N/A | N/A | N/A | 
Herald | 140701 to 141800° | 140808 to 141800° | 140917 to 141523 | 141034 to 141523 | N/A | N/A |
Transit Monitoring Service

Transit Plan Monitor

There are currently 0 monitored and 2 unmonitored vessels.
Benefits: Pilots - Port

- Enhanced decision making
- Improved Master/Pilot Information Exchange
- Contingency planning
- Increased transit plan accuracy
- Optimised safe speed profiling
- Removes commercial pressure from the Pilot - the hardest decision for a pilot to make is to say “NO!”

Port:
- Improves Safety
- Increases Economic Benefits
- Greater Operating Flexibility
Full Scale Vessel Motion Analyses (FSVMA)

Purpose:
• Determine accuracy of DUKC modelling.
• Calibrate DUKC models.

Outcome:
• Has ensured the safety of over 80,000 DUKC® transits Worldwide
  (in operational use every 1.5 hrs)
Full Scale Measurements

- Measurements at 30 different ports
- Over 280 vessels: Containers, Bulk Carriers, Tankers
- Swell ports, Rivers, Bars, Channels, Open Water
Measuring Dynamic Motions

- GPS Units
- Measured Pitch
- Lowest Hull Point
- Seabed
- Measured UKC
- Measured Roll
Squat Validation

WESER STAHL 8 Inbound Measured and Predicted Squat [m] 2008–05–14

- Measured Bow
- Measured Stern
- Modelled

Speed [kn]
- Speed TW
- Speed OG
Predicted Significant Roll

ANL Australia (outbound), 2007/7/8 - Roll

- Measured
- Slow
- Avg
- Fast
Predicted Significant Pitch

ANL Australia (outbound), 2007/7/8 - DUKC Pitch

Angle (degrees)

K.P. (km)

Measured
Slow
Avg
Fast
Severe conditions can make FSVMA hazardous or impractical.
iHeave

- Solid-state accelerometers & gyroscopes
- IMU Specification
- Pitch & roll to 0.03 degrees
- Heave to 0.05 meters (or 5%)
UKC developments
POADSS
Port Operational Approach and Decision Support System
European Research Project MarNIS
What is POADSS?
(Port Operational Approach and Decision Support System)

- POADSS
  Next generation Portable Pilot Unit (PPU)
  - Real-time position via laptop, charting software and GPS.
  - DGPS, (also RTK corrections)
  - AIS feeds

Includes:
- 3D position information
- IMU integration – measured heave, roll and pitch motions
- Broadband connection – real-time data, such as tide, weather, traffic, WMS
- Up-to-date HD bathymetric data
- Dynamic Underkeel Clearance (DUKC)

Prototype developed and tested (2008)
ADX XR – 1st POADSS type PPU 2011
POADSS Architecture
Real-time Transit Planning
Real-time Dynamic Motions
Dynamic Tide Contours
14.7m Vessel – 12k Area 1
14.7m Vessel – 16k Area 1
14.7m Vessel – 14k Area 2
14.7m Vessel – 16k  Area 2
What If – High Waves...
What If – Low Waves...
Optimised bed depth based on DUKC simulation
Thousands of simulations provide thousands of optimised bed depths
Different requirements result in different optimised depths.
1. Access for 14.5 metre draft tankers on 95% of high waters.
2. Access for all inbound vessels on 90% of occasions regardless of tide.
3. Minimum requirement of 4 hour operating windows for container vessels in winter.
Who is OMC International?

- Inventor and sole supplier of DUKC®
- 17 years in operation with over 80,000 safe transits
- Installed at 21 Australian, NZ and EU ports
- OMC is the approved supplier to AMSA for the Torres Strait UKCM system
Smarter Ports don’t come about by accident.

Questions Please.