COMPARISON OF PIANC, ANKUDINOV and CADET SHIP SQUAT PREDICTIONS

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Outline

• Introduction
  – Squat major component of underkeel clearance (UKC)
  – Consists of underway sinkage (vertical motion of hull) and dynamic trim (rotation about center of rotation)
  – Increased interest in ship squat in deep-draft navigation community
  – Compare CADET predictions with Ankudinov & PIANC squat formulas

• PIANC Squat Formulas
  – Barrass
  – Eryuzlu et al
  – Huuska/Guliev
  – Römisch
  – Yoshimura

• Ankudinov Squat Formula

• CADET/BNT Squat Program

• Ship and Channel Parameters
  – Port of Savannah, Georgia
  – Susan Maersk Containership

• Comparisons
  – Unrestricted Channel (U)
  – Light and Fully-loaded
  – 3 Water Depths

• Summary and Conclusions
**Introduction**

- **PIANC ship squat formulas**
  - Empirical
  - Limited lab and field measurements
  - Developed for past generation ships
  - User friendly, but limited ship and channel parameters
  - 3 idealized channel cross-sections
  - Widely used and accepted
  - No one formula best for all scenarios

- **Ankudinov ship squat formula**
  - Recent revisions
  - Thorough and complicated
  - Ship & channel parameters
  - Mid-point sinkage & trim

- **CADET program**
  - Risk-based tool for predicting underkeel clearance (UKC)
  - Based on Navy’s tools for deep draft ships in shallow channels

- **CADET squat module**
  - Beck Newman Tuck (BNT)
  - Based on Beck Newman Tuck (BNT) slender body theory
  - Numerical modeling ship lines with potential flow theory
  - Validated with model tests
• Five of most user friendly and “popular”
  – Barrass
  – Eryuzlu et al
  – Huuska/Guliev
  – Römisch
  – Yoshimura

• All give bow squat

• Stern squat
  – Only Römisch predicts stern squat for all channels
  – Barrass stern only for unrestricted or open channels and other channels depending on $C_B$ value

Photo Courtesy BAW
• Barrass

\[ \frac{K C_B V_k^2}{100} = \begin{cases} S_b & C_B > 0.7 \\ S_S & C_B \leq 0.7 \end{cases} \]

• Eryuzlu et al.

\[ S_b = 0.298 \frac{h^2}{T} \left( \frac{V_s}{\sqrt{gT}} \right)^{2.289} \left( \frac{h}{T} \right)^{-2.972} K_b \]

• Huuska/Guliev

\[ S_b = C_s \frac{\nabla}{L_{pp}^2} \frac{F_{nh}^2}{\sqrt{1 - F_{nh}^2}} K_s \]

• Römisch

\[ S_b, S_s = C_V C_F K_{\Delta T} T \]

• Yoshimura

\[ S_b = \left[ \left( 0.7 + \frac{1.5T}{h} \right) \left( \frac{B C_B}{L_{pp}} \right) + 15T \left( \frac{B C_B}{L_{pp}} \right)^3 \right] \frac{V_e^2}{g} \]
• **Mid-ship sinkage** $S_m$
  – Ship propeller
  – Ship hull
  – Ship speed
  – Water depth
  – Channel

• **Trim** $T_r$
  – Ship propeller
  – Ship hull
  – Ship speed
  – Initial trim
  – Bulbous bow
  – Stern transom
• **Maximum squat** $S_{\text{Max}}$

$$S_{\text{Max}} = L_{pp}(S_m + 0.5T_r)$$

• **Mid-point sinkage** $S_m$

$$S_m = \left(1 + K_P^S\right)P_{Hu}P_{F_{nh}}P_{h/T}P_{Ch1}$$

• **Trim** $T_r$

$$T_r = -1.7P_{Hu}P_{F_{nh}}P_{h/T}K_{Tr}P_{Ch2}$$
CADET Organization

• Ship
  – Hull geometry and ship lines
  – Static draft and trim
  – Loading
  – Ship speeds
  – Control points
  – BNT ship squat
  – Heave, pitch and roll transfer functions

• Project
  – Channel reaches
  – Directional spectral waves and probabilities
  – Corresponding ships, BNT squat predictions, and loading conditions

• Analysis

• Results
BNT Ship Squat Predictions

- Based on early work of Tuck (1966 and 1967)
- Beck and Newman expanded to include typical dredged channel (1975)
- Sinkage and trim from dynamic pressure on hull
- Sorted by depth Froude Number and converted to squat
Savannah Entrance Channel, Georgia

- **14 nm Outer Channel**
  - Subject to waves
  - Existing depth of 44 ft MLLW
  - Plans to dredge to 50 ft
  - Tide range 8 ft
  - Offshore 5.8 nm segment like Unrestricted or open channel with Width = 600 ft
Susan Maersk Containership

- $L_{pp} = 1,088$ ft
- $B = 140.4$ ft
- Draft
  - Light load $T = 46$ ft
  - Full load $T = 47.5$ ft
- $C_B = 0.65$
- $V_K = 8$ to $14$ kts
Light Load \( T=46 \text{ ft}, \ h=50 \text{ ft} \ (h/T=1.09) \)

- No tide
- Available UKC=4 ft
- Ankudinov & CADET general agreement with PIANC predictions
- Both conservative
- Ankudinov tracks OK
- CADET tracks OK to \( V_k=10 \text{ kt} \)
- Example @ \( V_k=10 \text{ kt} \)
  - PIANC Ave=1.7 ft
  - Ankudinov=2.3 ft
  - CADET=2.4 ft
- Grounding due to squat at \( V_k=12+ \text{ kt} \)
• Tide=4 ft, 4 hr/day, 365 days/yr
• Available UKC=8 ft
• Ankudinov & CADET general agreement with PIANC predictions
• Both conservative
• Ankudinov tracks OK
• CADET tracks OK to $V_k=12$ kt
• Example @ $V_k=10$ kt
  – PIANC Ave=1.6 ft
  – Ankudinov=2.1 ft
  – CADET=2.2 ft
• No grounding due to squat
- Tide=8 ft, 1 hr/day, 7 days/yr
- Available UKC=12 ft
- Ankudinov & CADET general agreement with PIANC predictions
- Both conservative
- Ankudinov tracks OK
- CADET tracks OK to $V_k=12+\text{ kt}$
- Example @ $V_k=10$ kt
  - PIANC Ave=1.6 ft
  - Ankudinov=1.9 ft
  - CADET=2.0 ft
- No grounding due to squat
**Full Load** $T=47.5\text{ ft}$, $h=58\text{ ft}$ ($h/T=1.22$)

- Tide=$8\text{ ft}$, 1 hr/day, 7 days/yr
- Available UKC=$10.5\text{ ft}$
- Ankudinov & CADET general agreement with PIANC predictions
- Both conservative
- Ankudinov tracks OK
- CADET tracks OK to $V_k=12+\text{ kt}$
- Example @ $V_k=10\text{ kt}$
  - PIANC Ave=$1.6\text{ ft}$
  - Ankudinov=$2.0\text{ ft}$
  - CADET=$2.1\text{ ft}$
- No grounding due to squat
Summary and Conclusions

• Comparisons of numerical CADET with PIANC and Ankudinov empirical squat prediction formulas

• Theory, advantages, and disadvantages of PIANC, Ankudinov, and CADET squat predictions presented and discussed

• Susan Maersk containership, 3 water depths, 5 ship speeds for unrestricted or open channel type

• CADET and Ankudinov reasonable agreement with PIANC predictions, conservative side

• Ankudinov and CADET squat predictions can be used with confidence in deep-draft channel design
Recent Interest in Ship Squat

- Capt. Stephen Best, Port of Vancouver, Canada
- Capt. Richard A. Hurt, Port of San Francisco, CA
- Albert Lavanne, Engineer, Port of Rouen Authority, France
- Karin Hellström, 2nd Officer, M/T Prospero, Donsotank, Sweden
- Papoulidis Panagiotis, Master Mariner, Greece
- Capt. Marco Rigo, Venice, Italy
- Capt. Michael Lloyd, Senior Advisor, Witherby Seamanship International Ltd, United Kingdom
- Anton Holtzhausen, Cape Town, South Africa
- Capt. Jonathon Pearce, Marico, United Kingdom
- Nisrine Alderf, PhD. Student, UTC University of Technology of Compiegne, France
Challenge Questions

- Near term and long term visions for MTS
- Drivers shaping MTS
  - Size of ships
  - Safety
- Near term and long term research required
  - Ship squat for larger ships
  - Vertical and horizontal ship motion prediction
  - Ship interaction with entrance channels, non-symmetrical channels, other ships during passing and overtaking
- Advantages of national CMTS R&D strategy
  - Consistent and proven design and guidance
  - Improved safety
- Challenges of national CMTS R&D strategy
  - Consensus among various parties
  - Research funding