Seakeeping Tests (with ships)

Experimental Methods in Marine Hydrodynamics
Lecture in week 43
Topics

• Why do seakeeping tests?
• What to do?
  – Activities
  – Details of model test set-up and instrumentation
  – Waves and wave calibration

• In-depth topics:
  – Test configurations
  – Measurement of global forces
  – Measurement of local (slamming) forces
  – Speed loss due to waves

• Example project – testing the ADX Express pentamaran
• Labtest 4
Why do seakeeping tests? Typical Objectives

- Reveal possible seakeeping problems with a new design
- Measure added resistance and speed loss due to waves
- Determine operational limits
- Optimization of design with respect to seakeeping
- Measure design loads
- Capsize and safety studies
- Development and testing of motion damping systems
- Studies of propulsion in waves
Activities (in typical sequence)

1. Manufacture of model (see pres. Week 38)
2. Do calm water performance tests (if ordered) (Week 34)
3. Instrumentation of model (Week 35)
   • Calibrate transducers (Week 34)
   • Mount all onboard instruments
4. Dynamic ballasting (Week 38)
   • Place ballast loads to obtain correct centre of gravity and radius of gyration in pitch
5. Calibration of waves (without model in the lab) (Week 38)
6. Performance of tests
7. Data analysis and reporting (Week 36)
Two test modes:

• **Free model**
  – Measurement of motions and accelerations
  – Possibly measurement of internal global or local (slamming) forces
  – This is the most commonly used method – a direct modeling of the real ship behavior

• **Fixed model**
  – Measurement of total forces on the model
  – Model might be given forced motions *(radiation forces)* or being fixed in incoming waves *(excitation forces)*
  – Used to verify and validate numerical methods
"Free" model – different test set-ups

1. Model free to heave, pitch (and surge)
2. Model with restricted horizontal motions
3. Model completely free
1. Model free to heave, pitch (and surge) - unpowered model

- Head and following seas
- With forward speed
- In a towing tank
- Measurements (typical):
  - Heave and pitch motions
  - Vertical accelerations
  - Added resistance due to waves
  - Relative wave motions
1. Model free to heave, pitch (and surge) - powered model

- Head and following seas
- With forward speed
- In a towing tank
- Measurements:
  - Heave and pitch motions
  - Vertical accelerations
  - Propeller thrust, torque and RPM
  - Speed loss and/or added power
  - Relative wave motions
2. Model with restricted horizontal motions
- Suspended in a system of thin wires and springs

- All headings
- With or without forward speed
- In a towing tank or seakeeping basin
- Measurements:
  - 6 DoF motions (by optical position measurement system)
  - Vertical accelerations
  - Drift forces
  - Relative wave motions
Setup typical for ocean basin tests at zero forward speed

**Note:** Natural frequencies of the mass-spring system must be far lower than the wave excitation frequencies.

What happens if the natural frequency is much higher than the wave excitation frequencies?
Set-up for test in towing tank at forward speed

Force transducers
Measuring force in axial direction

Beam
(fixed to model)

Pre-tensioned wires

Model

X-force transducer
3. Model completely free

- Must be self-propelled
- Must have active rudder/steering
- Should have auto-pilot
- Might have a bundle of cables to a carriage, or be completely free, with battery power
- Measurements:
  - 6 DoF motions (by optical position measurement system)
  - Accelerations (vertical, lateral and longitudinal)
  - Yaw rate (for auto-pilot) by rate gyro
  - Global forces in the hull beam
  - Local (slamming) forces
  - Relative wave motions
Waves – an important part of a seakeeping test!

- **Irregular wave spectra**
  - Direct measurement of seakeeping in a realistic sea state
  - Requires long measurement time series

- **Regular waves**
  - "Measurement" of Response Amplitude Operators (RAO), for comparison and tuning of calculations
  - Design-wave approach
  - Accelerated tests of dynamic stability

- **Transient wave (Impulse wave)**
  Can give RAO for many frequencies simultaneously

- “Pink noise”
  “White noise” with limited band-width
Transient waves

- A sequence of waves of increasing length is produced by the wave maker
- The longer waves travel faster than the shorter waves
- The wave train is tuned in order to have all generated waves reach one point at the same time

⇒ Result:
   One single wave containing many frequencies
Transient wave at various locations
Transient wave tests with 160 m cruise liner

Figure 5. Example from a transient wave test: Measured vertical acceleration at bow and estimated encounter wave. Heading=0 deg  Speed=18 kn.
RAO derived from transient wave tests

Figure 6. Linear transfer function (RAO) with phase vs. encounter wave period, $T_e$, from test in Figure 5 and 2 repeated tests.
“Pink noise”

Aim is to excite as much of the frequency range as possible in order to find RAOs.

Difficult to generate large frequency range with almost equal wave power spectral density:
- Wave-breaking limits energy in the high frequency range
- Wavemaker amplitude limits energy in low frequency range
Wave calibration

Example of comparison of wanted and measured wave spectrum

Comparison of wanted and measured wave spectrum. Adjustment of input wave parameters
Length of time series – irregular waves

- Depends on:
  - The period of the most low frequent phenomena in the tests
  - The system damping
  - The required standard deviation of the statistical results

- Common “rule-of-thumb”-type requirement:
  Time series *100 times longer than the period of the most low-frequent phenomena of interest in the tests* (⇒ ~100 wave encounters)
  - Wave frequency response ⇒ ~1000 seconds in full scale
  - Slow-drift forces ⇒ up to 10 hours, (3 hours is common practice)

- Slamming, capsize and other extreme events have much higher return periods!
Length of time series – general and in regular waves

- We are usually interested in stationary condition
  ⇒ transient response from start of test shall not influence
  ⇒ how long it takes from start to stationary conditions depend mainly on the damping:
    - Roll: low damping (transient ~5-10 times roll natural period)
    - Heave: high damping (transient < heave natural period)
    - Speed (for self-propelled models): Depend on the propulsion characteristics, but is of significant duration

- Regular waves: Need typically 10 wave cycles after reaching stationary conditions (depending on how equal the cycles are)
Testing of extreme and rarely occurring events

- Ultimate strength (maximum loads) are often assessed using a design wave
- Dynamic stability and capsize is often tested in large regular waves
- Slamming is tested in selected irregular sea states
Design waves

- Non-linear numerical calculations and also model experiments might take a long time to perform
- Instead of calculating or testing for a long time in a realistic, extreme irregular seastate, one might create a wave that is designed to be the worst possible in the given sea state
- Linear seakeeping theory is used to find the worst combination of the different frequency components in the irregular spectrum

“According to Airy wave theory, the most unfavorable wave condition for a vessel is not the wave of which all components have a peak at the same time instant, but the wave leading to a response for which this is the case.” (Drummen et. al. 2008)
Design waves – cont.

• Most Likely Response Wave (MLRW)
  – A wave designed to create a certain response
  – Linear theory is used to establish the link between waves and response
  – An advanced numerical method or model tests is used to find the actual response to this wave

• Conditional Random Response Wave (CRRW)
  – Like the MLRW, but superimposed on an irregular “background” wave

The fundamental assumption of wave conditioning techniques is that the nonlinear response is a correction of the linear response. (Drummen et. al. 2008)
Dynamic stability in waves

- Problems related to:
  - Broaching
  - Bow dive
  - Coupled pitch-roll-yaw

- Problems usually occur when groups of large regular waves are encountered

- Rarely occurring event!

- Model testing in equivalent regular waves of different height and frequency
Dynamic stability in waves

Wave Height H (m) vs. Wave Period T (s) graph showing different steepnesses and wavelengths (\(\lambda/L\) = 1.0, 1.25, 1.5, 2.0). The graph illustrates the capacity of a wave maker for different steepnesses (1/10, 1/15, 1/20).
Measurement of global loads

• **Purpose:**
  To determine the design loads, used for dimensioning of the ship structure

• **Modeling alternatives:**
  – Backbone model
  – Fully elastic model
  – Segmented model

**Backbone model**

**Fully elastic model**

Strain gauges
Backbone model – during calibration
Backbone model – during testing
Segmented model of bulk carrier

(Before segmentation of the hull itself)
Segmented models – frame and force measurement

Feather rod
3-comp. force transducers
Movable fastening block
Hinge
Aluminium frame
6-component force transducers

\[ \sum_{i=1}^{3} z_{1i} \]

\[ \sum_{i=1}^{3} y_{1i} \]

\[ \sum_{i=1}^{3} z_{2i} \]

Sum of forces:

\[ X = \sum_{i=1}^{3} x_i \]

\[ Y = \sum_{i=1}^{3} y_i \]

\[ Z = \sum_{i=1}^{3} z_i \]

\[ M_x = (y_2 + y_3) \cdot a_{z2} - y_1 \cdot a_{z1} \]

\[ M_y = (x_2 + x_3) \cdot a_{z2} - x_1 \cdot a_{z1} \]

\[ M_z = (y_3 - y_2) \cdot a_y \]
Location of segmentation cuts

• Depends on what you want to measure
  – Midship bending moment ⇒ midship
  – Shear force due to slamming ⇒ stern quarter

• For flexible models, it also depends on the number of flexible modes
Model Tests of the ADX Express

- CFD calculations
- Initial resistance testing, 4 smaller models
- Resistance test, new model
- Optimisation for the longitudinal position of the aft pair of sponsons
- Seakeeping tests with original and modified design
Segmented Pentamaran model
Segmented Pentamaran model - sponson
Objectives With Seakeeping Model Testing

- Evaluate the wave-induced motions and accelerations.
- Measure occurrences of air entering the waterjet inlets.
- Measure occurrences of slamming.
- Establish the speed loss in irregular sea states.
- Evaluate the wave induced forces on the central hull and on the bridging structures between the central hull and sponsons.
- Establish the response amplitude operators (RAO) in regular waves for certain parameters to verify different hydrodynamic calculations and computer code.
Model Configuration

- 41 knots testing speed.
- Self-propelled model with four waterjets and nozzles controlled by an online Autopilot.
- Interceptor plates installed onto the aft pair of sponsons controlled in the online mode by a PD-regulator by roll angle and rate of roll.
- Segmentation of the central hull into four sections with 5-component force transducers connecting the sections.
- Installation of 5-component force transducers on each bridging structure between the central hull and the sponsons.
- Maintaining the correct hydrostatic properties.
- Maintaining the correct LCG and mass moment of inertia around the transverse axis for each model section.
Measurement of slamming

- Slamming is important for:
  - Local loads ⇒ dimensioning of plating and stiffeners
  - Global whipping loads ⇒ dimensioning of hull beam
  - Noise and vibrations (comfort problem)

- Problem areas:
  - Overhung sterns (flat with low draught)
  - Bow flare
  - Flat bottom (small ships in extreme seas)
Characteristics of slamming loads

- High peak pressure values
- Very short duration
- Elasticity of the structure is important
What is Hydroelasticity?

(Hutchison, 2011)
Dynamic hydroelasticity

The deformation of the structure due to fluid loading has significant impact on the fluid loading

**Examples:**
- Wing flutter
- Many types of slamming loads
- Vortex-induced vibrations
- Sea loads on many types of floating fish-farms
Requirements for measurement

• Extremely high sampling frequency (~1 kHz)
• Fast rise time (quick response) of transducers
• Resonance frequency of transducer (including fixture):
  – Very low (by adding a big mass)
    or
  – Very high (by making an extremely stiff structure)
    or
  – Correctly modeled dynamic response
Note on stiffness of models and transducers

- If $\omega_n >> \omega_e \Rightarrow$ Stiff system $\Rightarrow$ measured force = hydrodynamic load
- If $\omega_n \leq \omega_e \Rightarrow$ flexible system $\Rightarrow$ measured force $\sim$ response $\Rightarrow$ to get hydrodynamic load we need to analyse the response of the model system

$\Rightarrow$ As a general rule, we prefer stiff model systems!
Different transducer configurations

- **Point pressure measurements**
  - Needs very many pressure transducers
- **Slamming panels**
  - Area similar to typical plating field
  - Measure the integrated force on a representative area
- **Segmented model**
  - Measuring force on entire afterbody or bow section
  - Useful if interested in global effects, like whipping

- Different transducer configurations are often used in combination
Different slamming transducer configs

- Slamming panels in bow flare
- Segmented stern for measurement of integrated force
- Slamming panels in overhung Flat stern
Running of self-propelled models
- Alternatives

• Constant carriage speed
  – controlling propeller revs manually to maintain same average speed as carriage (can be a challenging task!)

• Constant propeller revs
  – Easy to do with ordinary frequency-controlled AC motors or brushless DC servo motors

• Constant propulsion power
  – Can be easily done by using the built-in control system of the drives of brushless DC servo motors, which are increasingly used
Calculation of total speed loss

- Required power in calm water
- Required power in waves
- Prop. power at constant RPM
- Total speed loss
- Meas. speed loss
- Speed loss due to added power

\[ P_B \]
\[ V_S \]
Tank wall effects

Radiated waves = created by model motions
Diffracted waves = incoming waves reflected by the model

Wave group speed: \( c_g = \frac{g}{2\omega_e} \)

\[
U_{crit} = \frac{L_M}{t_w} = \frac{L_M \cdot c_g}{B} = \frac{g}{2\omega} \left[ \sqrt{1 + \frac{2L_M}{B}} - 1 \right]
\]

This is why you should not run zero speed tests in a towing tank!
Summary

- Purposes of seakeeping tests
- The three different test set-ups:
  - Fixed, free, partly restrained
- Types of waves
  - In depth: Impulse waves
- Recording time – length of tests
- How to handle rarely occurring events?
  - Example: Testing dynamic stability
- Model Tests of the ADX Express
- Slamming and global forces
- Measuring speed loss and added power
- Tank wall interference