ANSYS

Lecture 2: Aqwa Basics – Hydrodynamic Diffraction

Introduction to Hydrodynamic Analysis with ANSYS Aqwa

ANSYS Release 19.2

ANSYS Hydrodynamic Analysis Overview

What is Aqwa?

- Aqwa is a modularised, fully integrated hydrodynamic analysis suite based around three-dimensional diffraction/radiation methods
- ANSYS Workbench implementation provides a modern interface to develop and solve Aqwa models

History of Aqwa

- Developed since 1971 (by WS Atkins)
- Owned and developed by Century Dynamics since 2001
- Century Dynamics acquired by ANSYS February 2005
- Now integrated into the ANSYS Workbench system

ANSYS Hydrodynamic Analysis Overview

ANSYS Aqwa Capabilities

- Diffraction/Radiation including Morison elements
- Multiple body hydrodynamic interaction (up to 50 structures across 20 interacting groups)
- Modelling of moorings, fenders and articulations (connectors)
- Static stability
- Frequency domain dynamic analyses
- Time domain with irregular waves including slow drift effects
- Time domain with non-linear survival waves
- Coupled cable dynamics
- Transfer of motions and pressures to ANSYS Finite Element models

ANSYS Hydrodynamic Analysis Overview

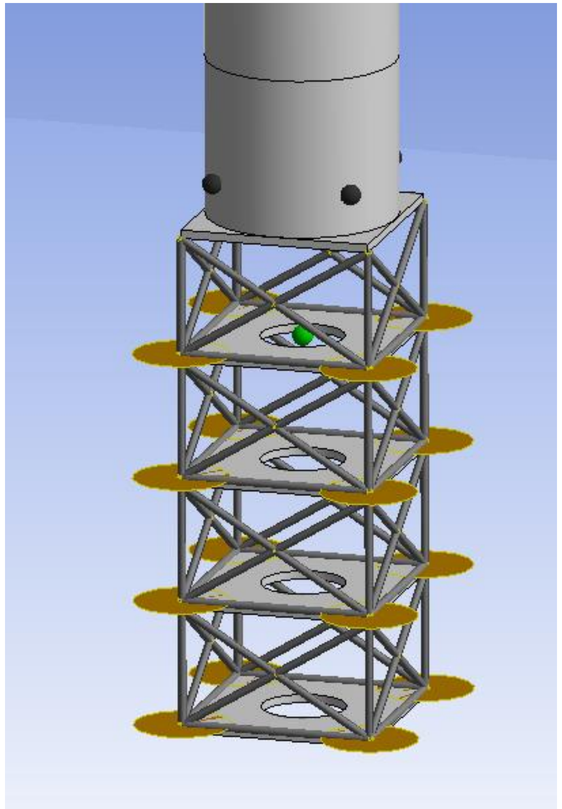
ANSYS Aqwa Applications

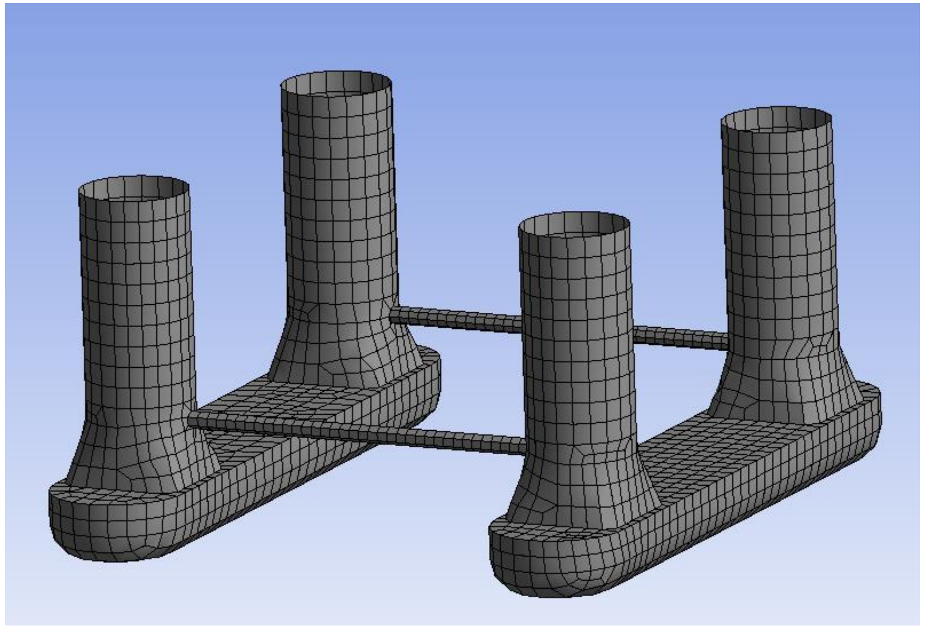
- Determination of Response Amplitude Operators (RAOs)
- Wave bending moments
- Splitting force calculations for semi-submersibles
- Design and analysis of mooring systems
- Time history of motions
- Determination of air gaps
- Calculation of shielding effects of ships and barriers
- Multiple body interactions
- Coupled mooring line-structure interaction
- Tension Leg Platform (TLP) tether analysis

Description of Program Capabilities

Modelling in Aqwa – Geometry

- Diffracting or non-diffracting mesh elements
  - ➢ Triangular panels
  - ➢ Quadrilateral panels
- Morison elements
  - ➢ Cylinders and cylindrical tubes
  - ➢ Non-axisymmetric slender tubes
  - ➢ Discs
- Point masses
- Point buoyancies

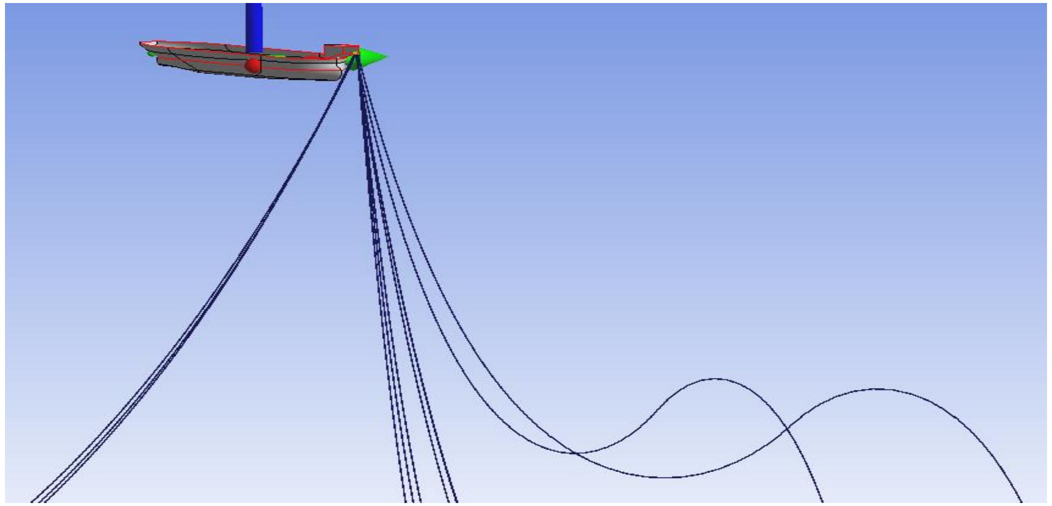


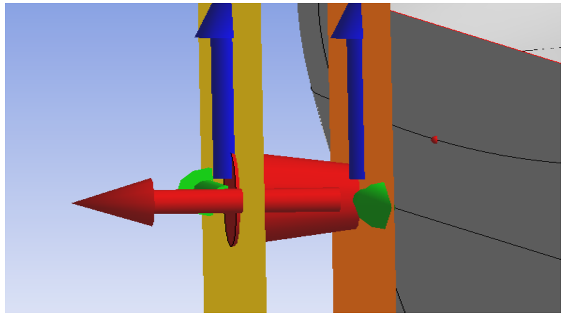


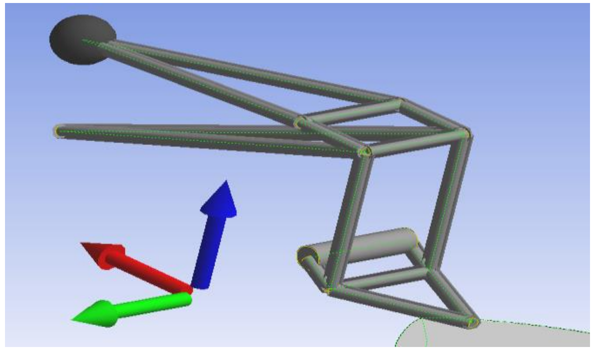
Description of Program Capabilities

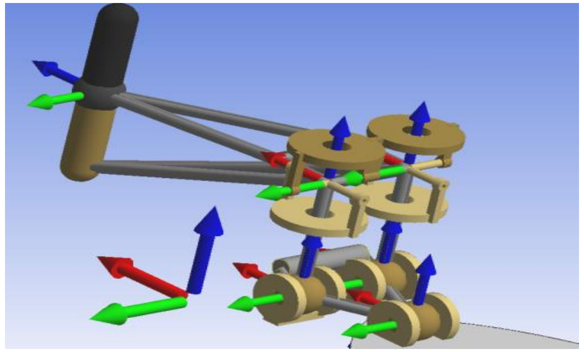
Modelling in Aqwa – Connections

- Moorings
  - ➢ Linear springs
  - ➢ Elastic catenaries
  - ➢ Intermediate buoys
  - ➢ Clump weights
  - ➢ Pulleys
  - ➢ Tethers
  - ➢ Winches and cable failures
- Fenders
- Articulations
  - ➢ Rigid
  - ➢ Ball-and-socket, universal, hinged









Description of Program Capabilities

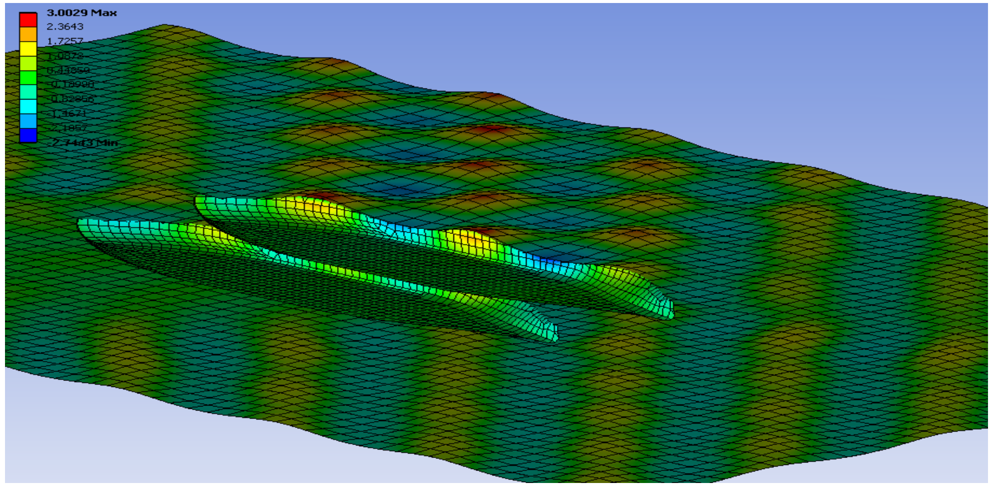
Modelling in Aqwa – Environment

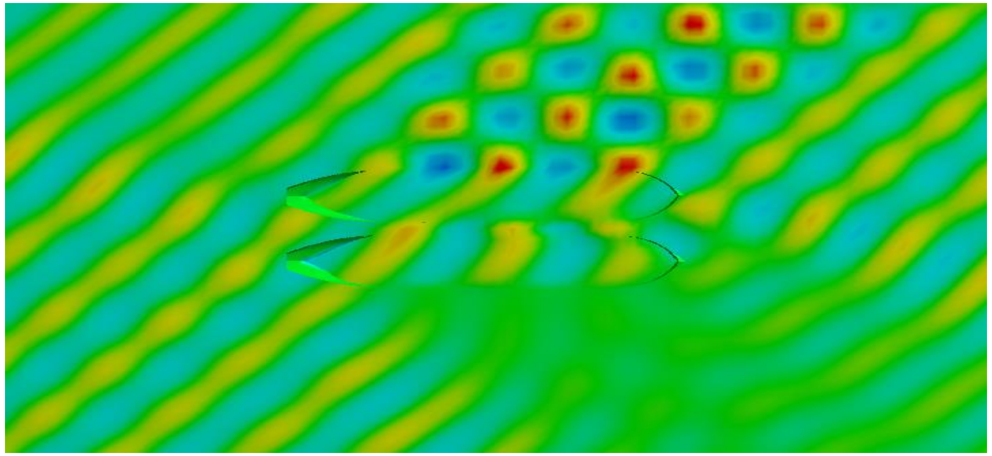
- Regular waves
- Multi-directional wave spectra
- Current
- Wind

Description of Program Capabilities

Radiation/Diffraction

- Multiple structures including hydrodynamic interaction
- Hydrodynamic coefficients (added mass and damping)
- Response Amplitude Operators (RAOs)
- Drift coefficients (Near/far field, full QTF matrix)
- Drag linearization for Morison components
- Shear force/bending moment
- Splitting forces
- Pressure distribution for transfer to structural model





Description of Program Capabilities

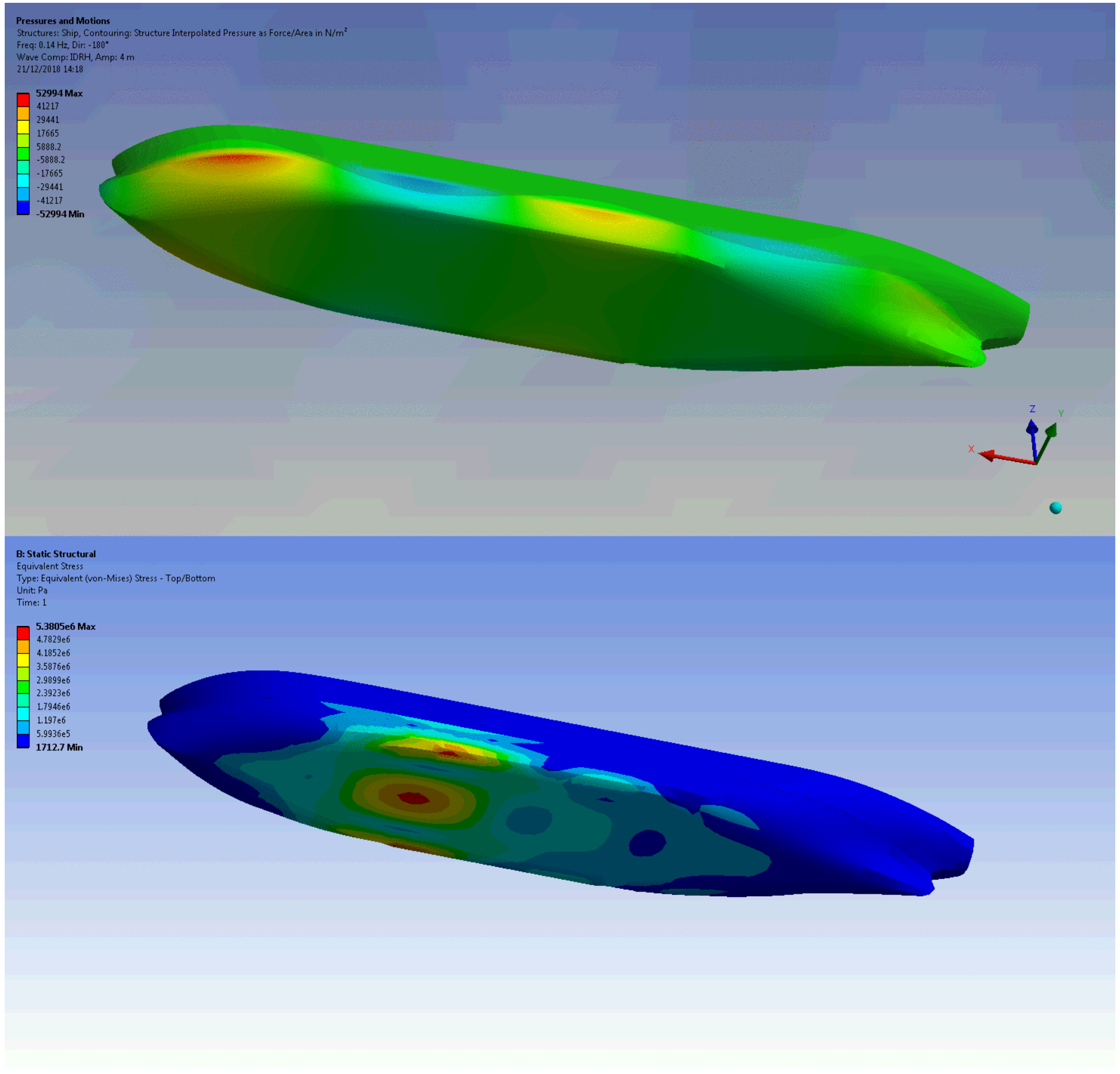
Hydrodynamic Pressure Transfer

- Calculation and transfer of hydrodynamic loads to ANSYS Mechanical Static Structural analysis

Aqwa Hydrodynamic Model

Pressures, Accelerations, Beam Loads

ANSYS Mechanical Model



Description of Program Capabilities

Equilibrium and Stability

- Computes static equilibrium position for given environmental and mooring configurations
- Preliminary mooring design
- Calculates static/dynamic stability, including natural modes

Description of Program Capabilities

Frequency Domain

- Significant motions at low frequency/wave frequency in frequency domain
- Drag linearization for Morison components
- Permits rapid analysis using linearized parameters of mooring systems
- Graphs for response spectra/RAOs and other parameters

Description of Program Capabilities

Time Domain

- Time history analysis of multiple structures with irregular waves
- Can use full QTF matrix for shallow water conditions
- Import of wave height time history
- Input of forces via user-defined .dll or Python server
- Output of motions and forces
- Graphical and animation results
- Large amplitude motions
  - Non-linear time-history analysis with large (survival) waves
  - Regular or irregular waves
  - Integration of pressure over wetted surface

Description of Program Capabilities

Cable Dynamics

- For more rigorous simulation of mooring line behaviour
- Provides full coupled vessel/mooring line analyses

Excel Interface

- Aqwa specific functions add-in for Excel for data and results retrieval, processing and report generation

AqwaReader executable

- Provides command line access to most Aqwa binary output
- Can be used for automated results extraction

Description of Program Capabilities

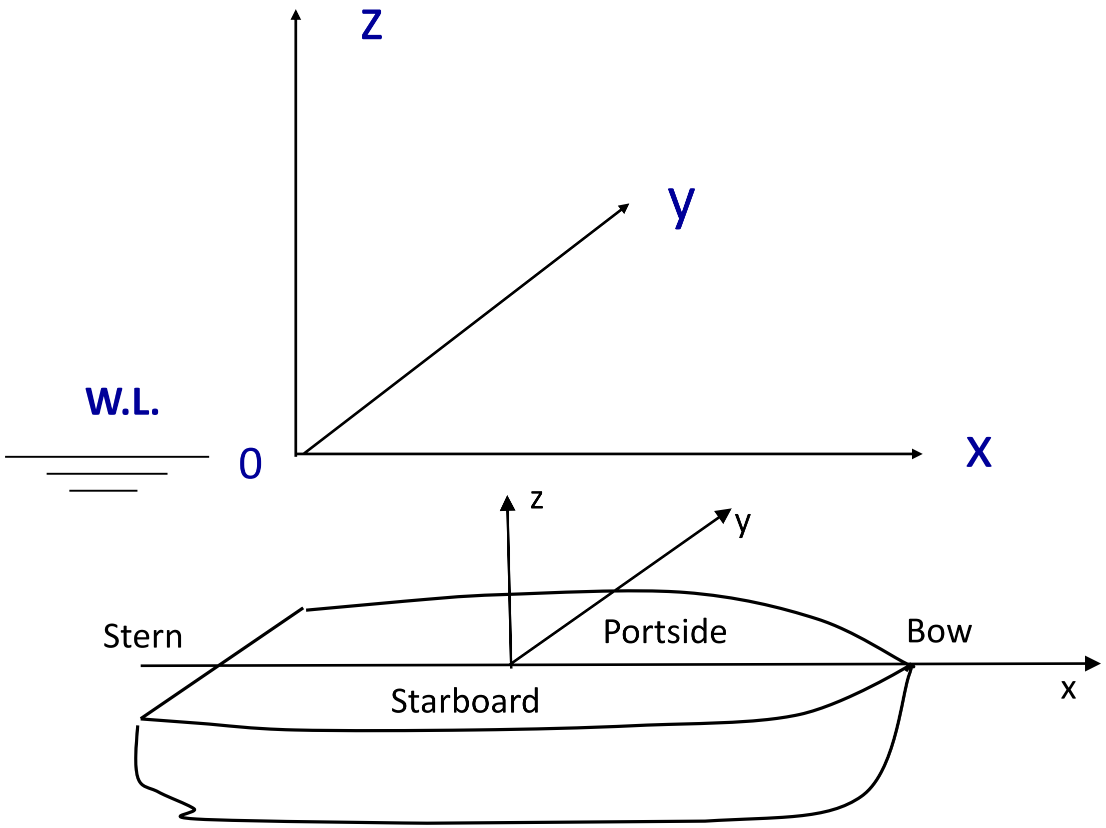
Currently in Workbench (Release 19.2)

- Import of geometry from ANSYS DesignModeler and SpaceClaim
- Interactive data modification and editing
- Native meshing or using ANSYS Meshing application
- Diffraction/radiation analysis
- Wave surface and pressure contour plots
- Definition of moorings, articulations, tethers and fenders, ocean environment
- Static and dynamic stability analysis; frequency domain analysis; time domain analysis
- Graph plotting and visualization

Aqwa Basics – Coordinate Systems

Aqwa Global Coordinate System

- Referred to as the Fixed Reference Axes (FRA):
  - The origin lies in the still water plane
  - The positive z axis is vertically upwards
  - A right handed system
  - It is not related to the directions North, South, East and West
- Rigid body motions
  - Surge, Sway, Heave - translational
  - Roll, Pitch, Yaw - rotational
  - The direction of motion is relative to the geometry definition of vessel/structure (x is not surge by default!!)



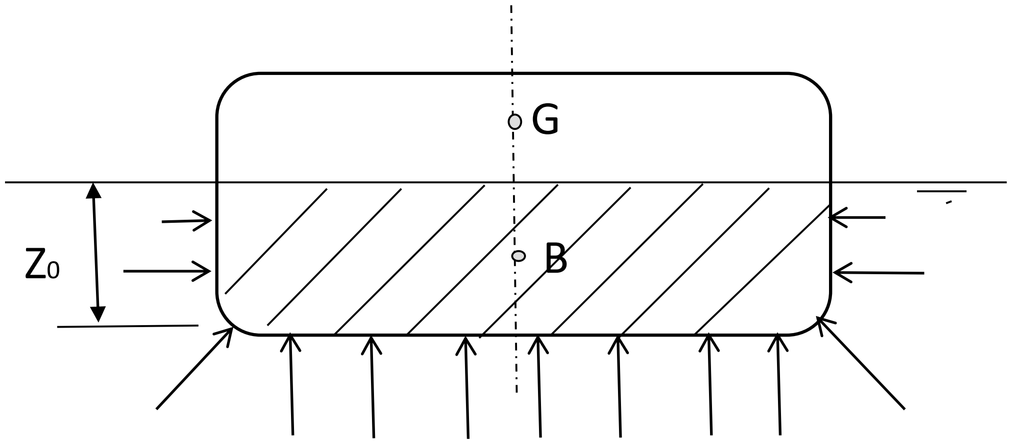
Aqwa Basics - Hydrostatics

Hydrostatics

- Archimedes' principle
  - ➢ Buoyancy of an immersed body is equal to the weight of the fluid displaced

- Hydrostatic pressure

$$p = \rho g Z_0$$



G: centre of gravity (COG)

B: centre of buoyancy (COB)

Buoyancy is the resultant of all hydrostatic force over the wetted surface

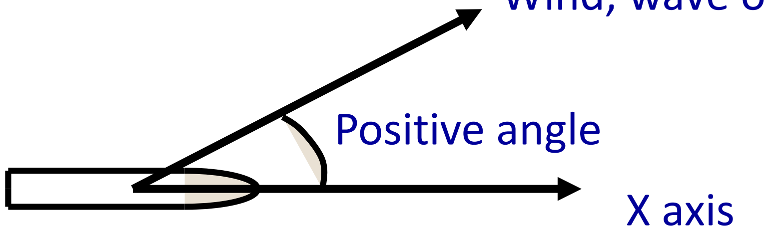
Aqwa Basics – Environment Definition

Environmental direction in Aqwa

- The wind, wave and current directions are defined in Aqwa as the directions that they are travelling towards.

- The direction is defined as the angle between the wind, wave or current and the positive x axis, measured anti-clockwise. For a ship facing forward to positive x axis, this means 0° is astern seas and 180° is head seas.

- Directions in Aqwa are input and output in degrees.



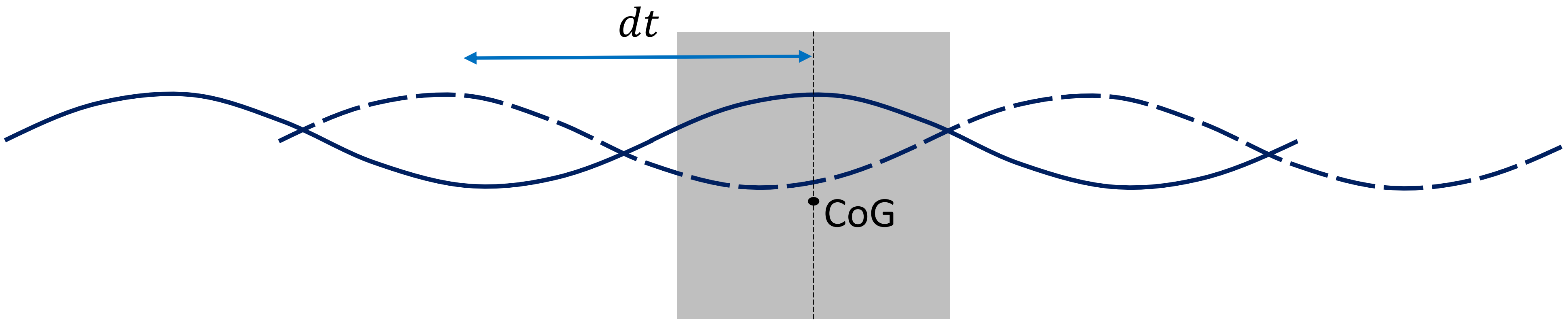
Aqwa Basics – Phase Definition

Phase angle

- In Aqwa, the phase angle (φ in degrees) of a parameter defines the time difference (dt) from the time when the wave crest is at the COG of the structure to the time when the parameter reaches its peak value:

$$dt = \varphi T/360, \text{ where } T \text{ is the wave period}$$

- A positive phase angle indicates that the parameter lags behind the wave.



Aqwa Basics – Wave Definitions

Regular waves

- Airy waves (linear wave)

  $\eta = A\cos(-\omega t + kx)$, where A is wave amplitude; ω is wave frequency (rad/s); k is wavenumber

- Stokes second-order waves

$$\eta = A\cos(-\omega t + kx) + \frac{1}{2}kA^2\cos^2(-\omega t + kx)$$

Irregular wave spectra

- Pierson-Moskowitz, JONSWAP, Gaussian formulated spectra
- User-defined spectrum
- Cross swell (using any of the above)
- Imported time history of wave elevation
- Can be long- or short-crested (directional spread seas)

Aqwa Basics – Wind and Current Definitions

Wind

- Uniform wind
- Ochi and Shin wind spectrum
- API wind spectrum
- NPD wind spectrum
- User-defined wind spectrum

Current

- Uniform velocity current
- Velocity profiled current
  - ➢ Dimensional
  - ➢ Non-dimensional
  - ➢ Formulated from tide and wind specification

Basic Theory in Aqwa

Wave forces for diffracting structures (modelled with panel elements)

- Incident wave force (Froude-Krylov force) from the pressure in the undisturbed waves
- Diffraction force due to a stationary structure disturbing the incident waves
- Radiation force due to the oscillation of the structure, which generates waves
- Drift force which is the net force due to high order effect

Basic Theory in Aqwa

Three-Dimensional Potential Theory solution:

- Ideal fluid, irrotational, incompressible
- Small wave elevation
- Viscous forces are not taken into account

Boundary Condition problem is solved by satisfying:

- Body boundary condition
- Linearized free surface condition
- Sea bed boundary condition
- Radiation condition
- Solution for diffracted and radiated wave potentials uses a pulsating source distribution (zero speed solution with optional forward speed corrections)

Basic Theory in Aqwa

Theory applies to finite depth and diffraction problem is solved in frequency domain

- Shallow water solution is available

Both first-order and second-order wave forces are calculated

- Second-order forces can be calculated from either near field or far field solutions

Basic Theory in Aqwa

Hydrodynamic forces for non-diffracting structures (modelled with Morison elements)

- For slender cylindrical elements ($\frac{D}{\lambda} < 0.2$, in which D is the element diameter and λ is the wavelength) the hydrodynamic force F (including drag) per unit length can be calculated using the Morison equation:

$$F = \underbrace{\rho\Omega a_w}_{\text{Froude-Krylov}} + \underbrace{\rho C_a \Omega a_w}_{\text{Wave inertia}} - \underbrace{\rho C_a \Omega \ddot{X}}_{\text{Radiation}} + \underbrace{\frac{1}{2}\rho C_d D V|V|}_{\text{Drag}}$$

  - a_w and $\ddot{X}$ are the accelerations of the flow and of the body, respectively
  - C_a and C_d are the added mass and drag coefficients of the element
  - V is the relative velocity between the flow and the body
  - Ω is the volume of the element (per unit length).

- The Froude-Krylov and wave inertia terms are sometimes combined and written in terms of the inertia coefficient, $C_m = 1 + Ca$

Basic Theory in Aqwa

Full Quadratic Transfer Function (QTF)

- Components at both difference and sum frequencies
- Each with in-phase and out-of-phase parts
- The second order wave potential does not contribute to the diagonal terms of the QTF matrix, so that it has no effect on the mean wave drift force. However, the second order wave potential contributes to the off-diagonal terms of the QTF. It has been found that in shallow water the drift force coefficients can be increased significantly by the second order potential. Therefore, the inclusion of the second order incident and diffracted potential is necessary for the accurate evaluation of the second order wave exciting forces in shallow water. In Aqwa this is done using the Pinkster approximation (Pinkster, 1980).

Basic Theory in Aqwa

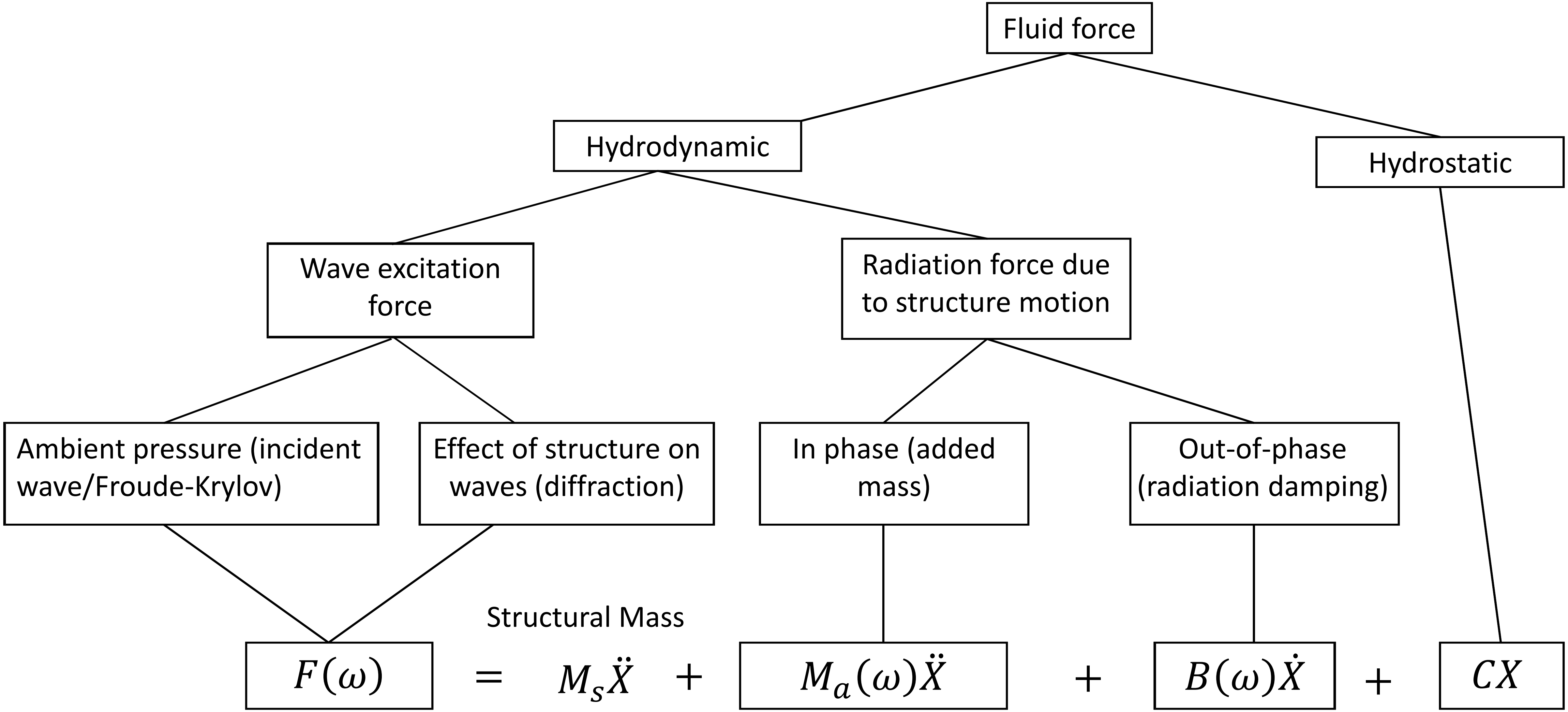
Equations of Motion

- The response X of a structure in waves is calculated by solving the equation of motion in the frequency domain for a unit wave amplitude:

$$\left[-\omega^2\left(M_s + M_a(\omega)\right) - i\omega B(\omega) + C\right]X(\omega) = F(\omega)$$

- M_s is structure mass
- M_a is added mass (frequency-dependent)
- B is damping (frequency-dependent)
- C is hydrostatic stiffness
- F is wave excitation force (incident and diffracting forces).

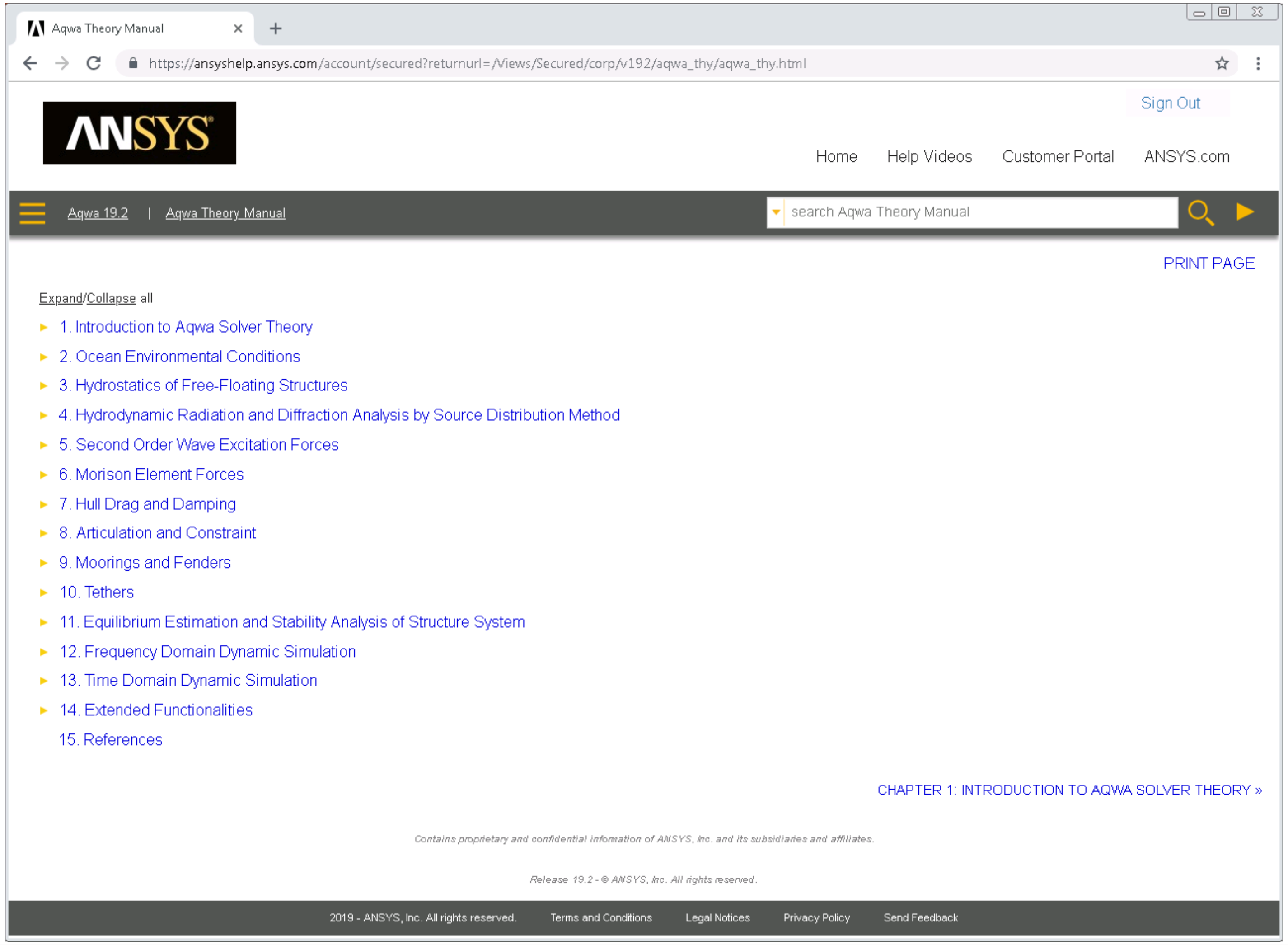
Basic Theory in Aqwa



Theory in Aqwa

Full theoretical background can be found in the Aqwa Theory Manual, available via the ANSYS Online Help System

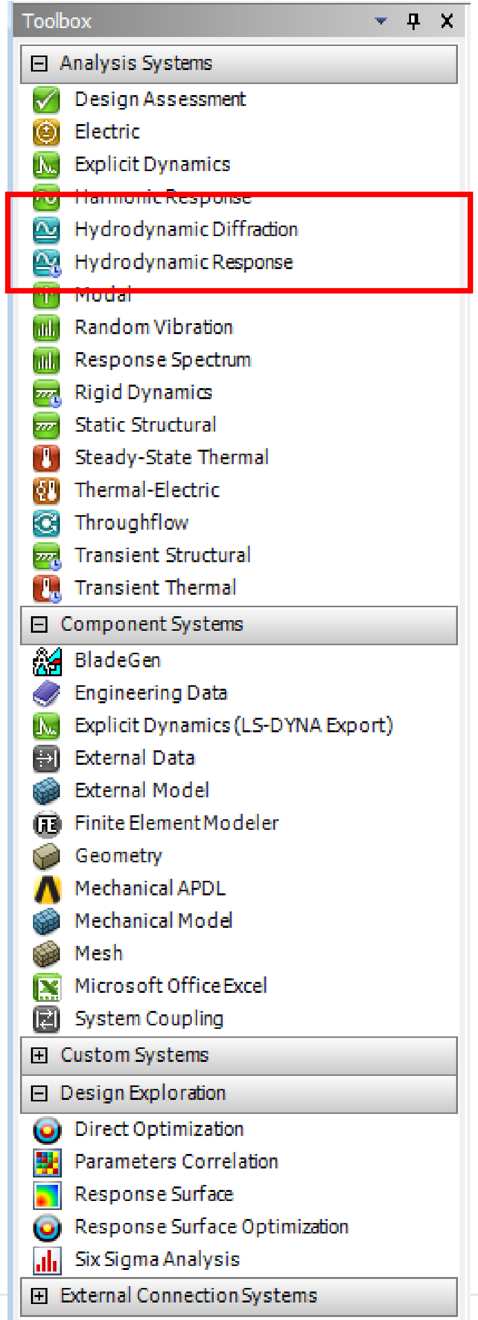
ansyshelp.ansys.com



Aqwa Workbench Basics

There are two Aqwa Workbench systems available:

- Hydrodynamic Diffraction (HD)
- Hydrodynamic Response (HR)



Aqwa Workbench Basics

Aqwa Workbench shares common conventions with other Workbench products, where appropriate.

The basic interface consists of a number of areas:

- Toolbars
- Analysis tree
- Details panel
- Graphical model representation and results presentation or textual results

Aqwa Workbench Basics

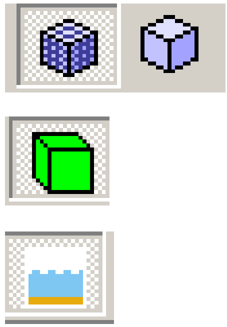
Standard Workbench Toolbars

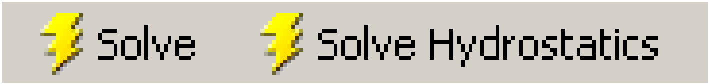
View manipulation

Selection control

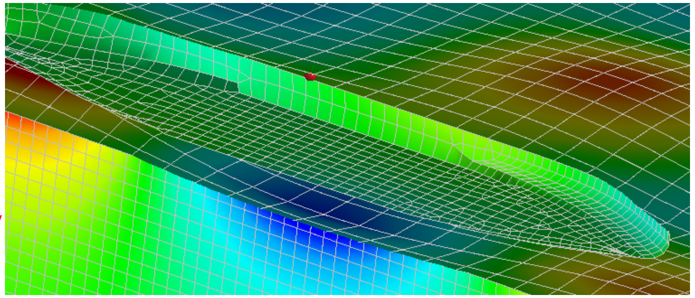
File shortcuts

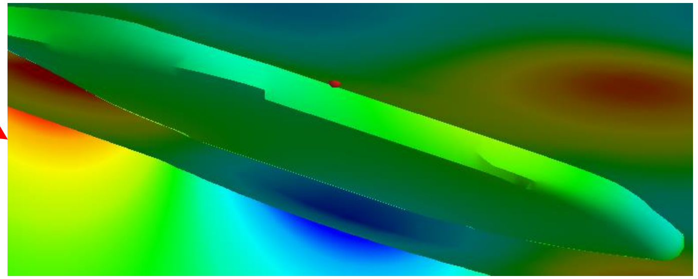
Aqwa Specific Toolbars





Show/Hide element boundaries





Turn on/off object highlighting

Show/Hide Seabed and Water Surface

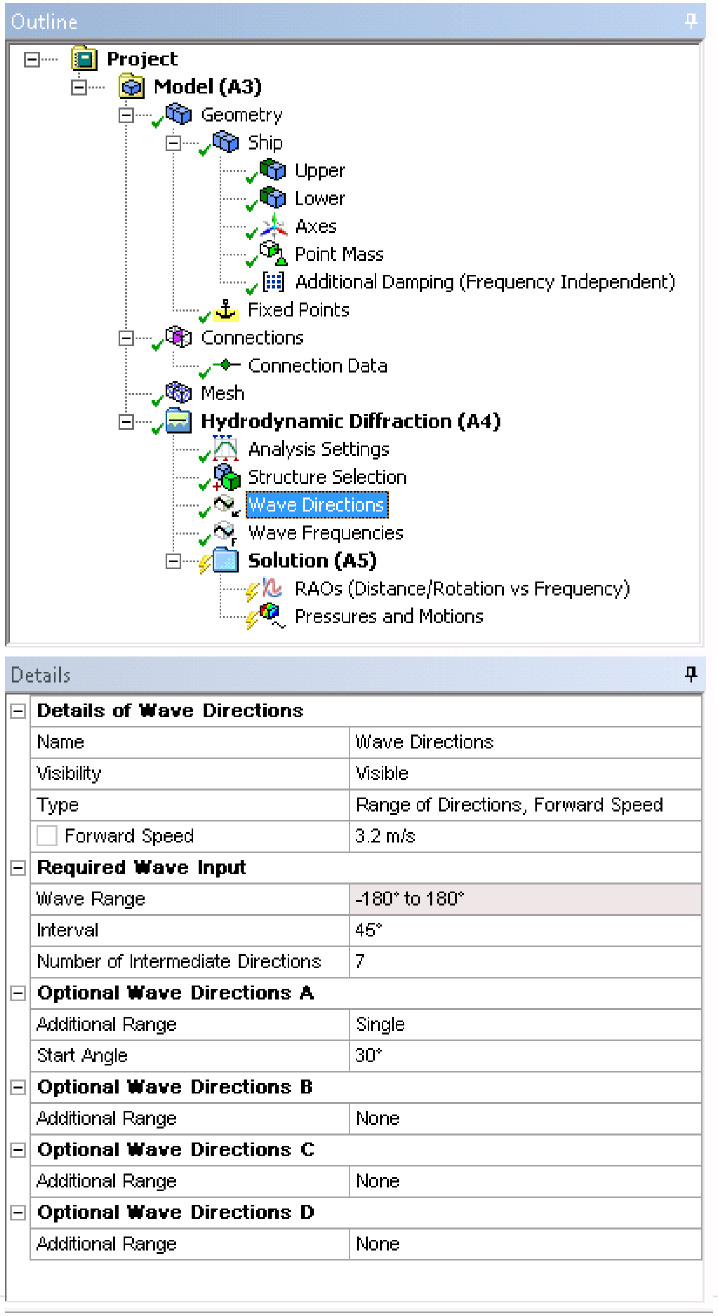
Solve shortcuts

Aqwa Workbench Basics

Tree view

- As with other Workbench applications, the Outline tree and Details panel are used to define the organization of the simulation requirements and associated data.

- As a tree object is selected the data related to that object will be presented in the Details panel.



Aqwa Workbench Basics

Tree view

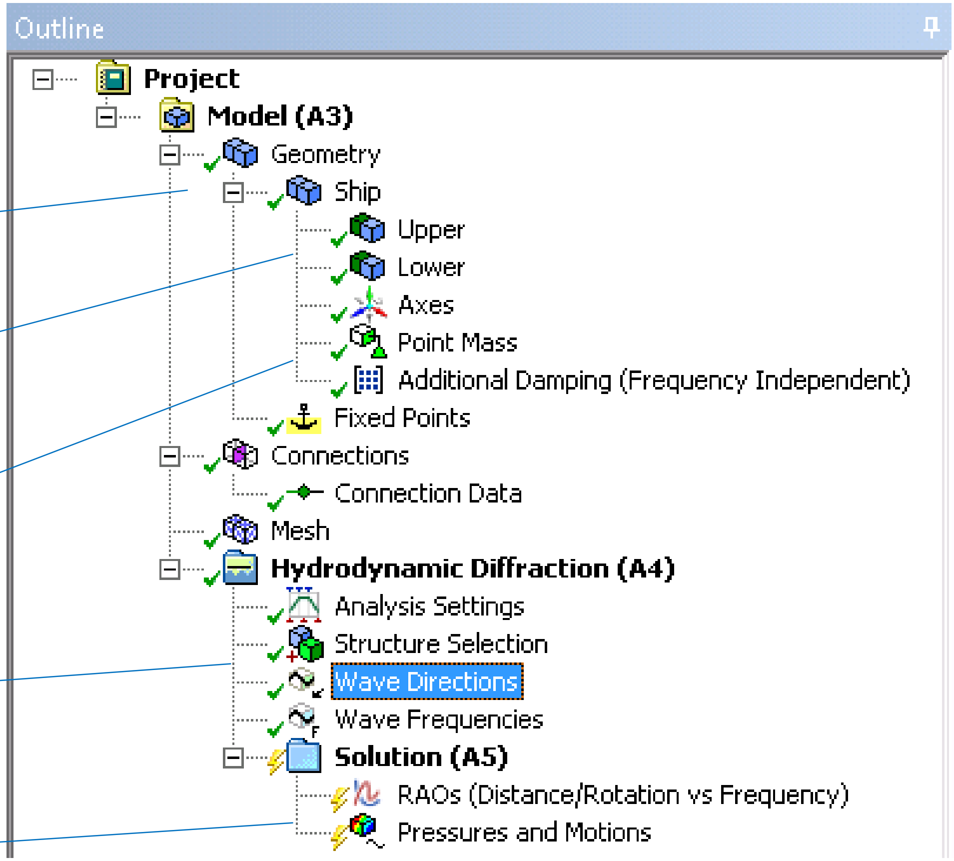
Each vessel/structure is associated with a Part – in this case “Ship”

Bodies make up a Part. These are defined in the CAD system (e.g. SpaceClaim)

Some Aqwa-specific geometry-based objects may be added directly within Aqwa Workbench

Objects that define the additional data required for undertaking the Hydrodynamic analysis

Results objects that may be added as required. When selected, they change the view in the main Graphics window



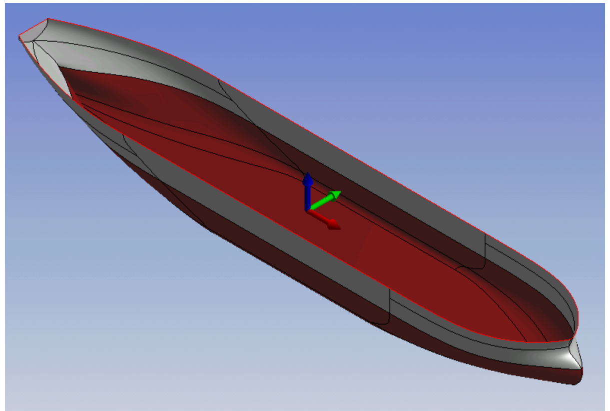
Object states:

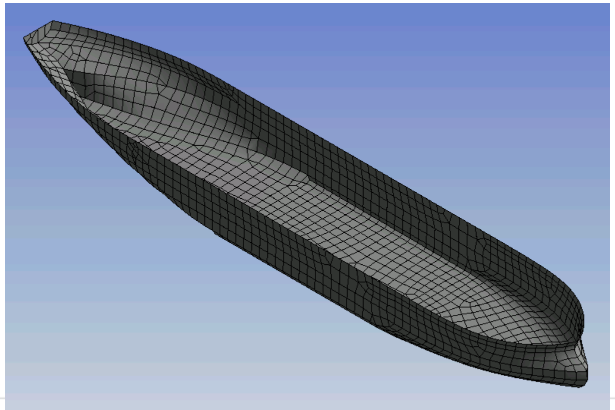
- Object excluded
- Object included, and up-to-date
- Object invalid or requires attention
- Object requires update
- Object is up-to-date for the Hydrostatics solve

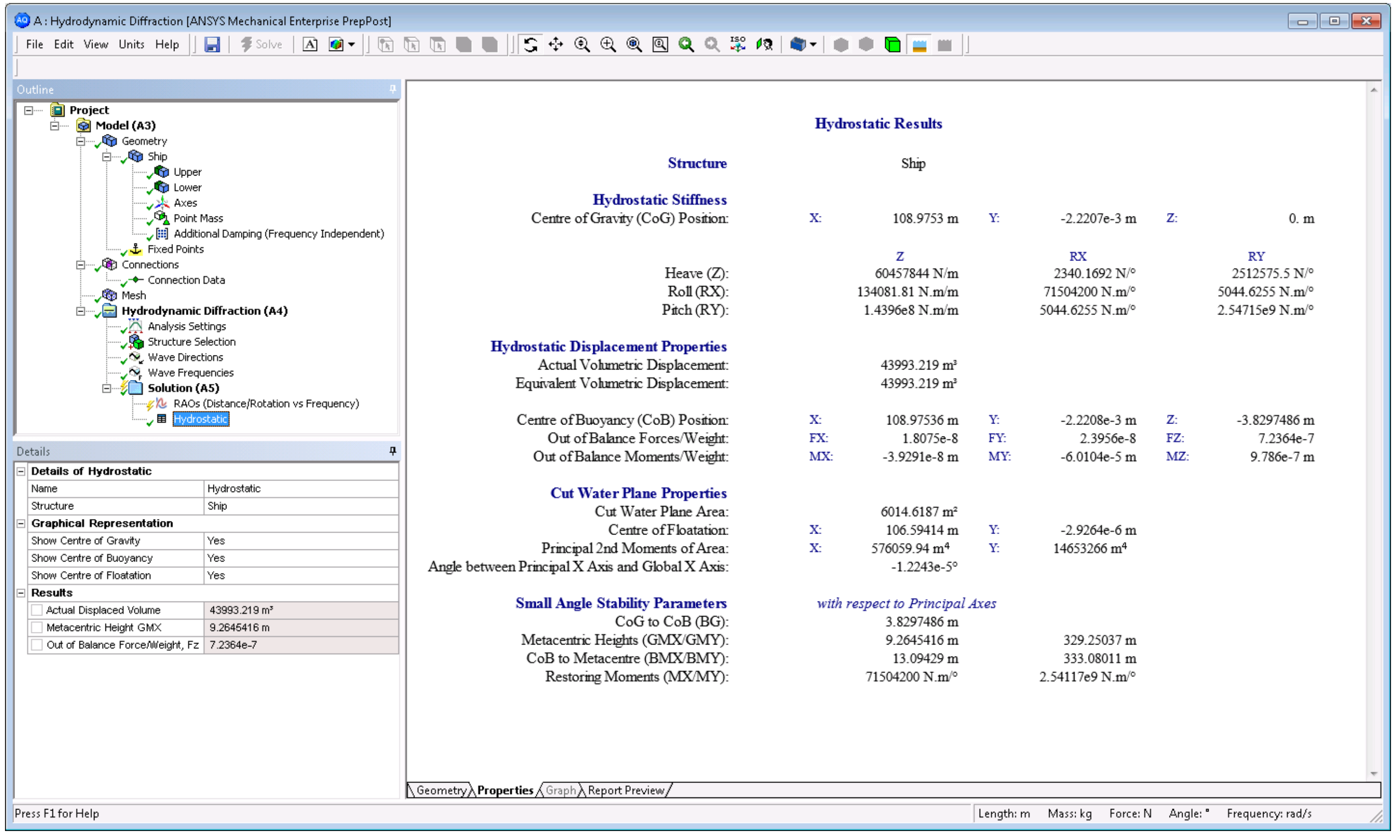
Aqwa Workbench Basics

The main graphical area responds to what is selected in the object tree

- If geometry or mesh-based information is selected, this will show a visualization of the information requested on the Geometry tab.
- If textual results are requested (such as Hydrostatic information) these will be shown on the Properties tab.

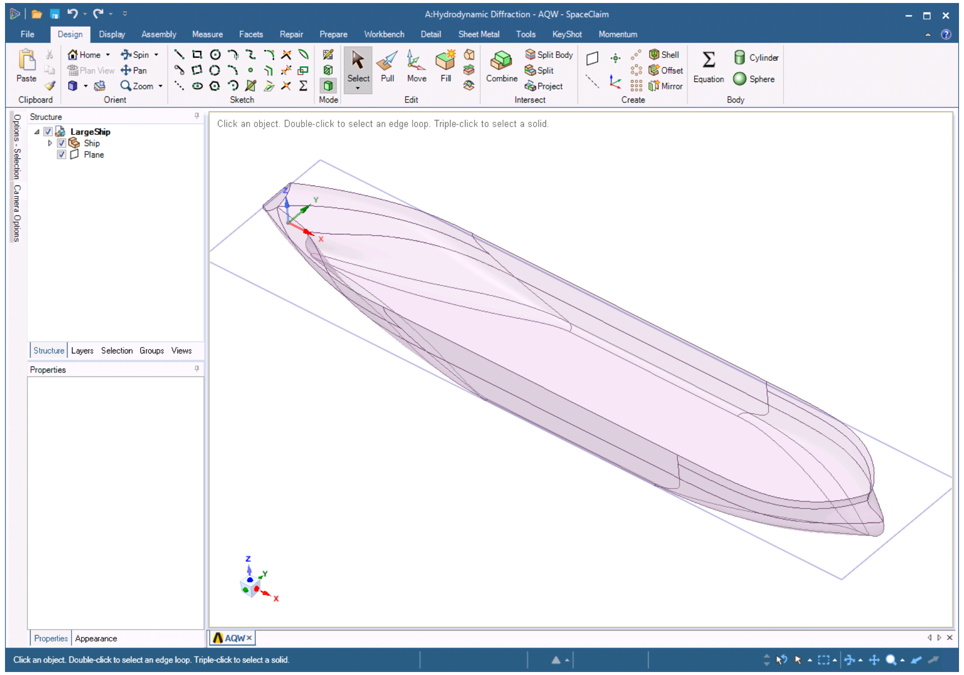


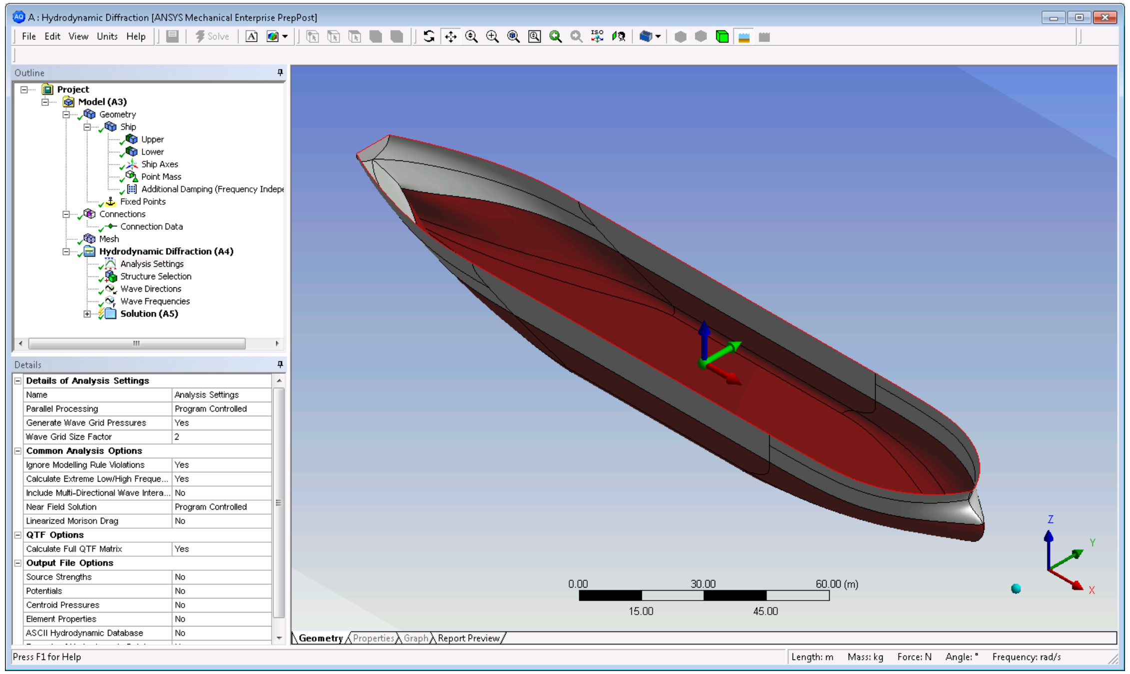




The Hydrodynamic Diffraction Simulation Process

CAD → DesignModeler or SpaceClaim → Hydrodynamic Diffraction - - → Hydrodynamic Response





Creating Geometry for Import to Aqwa Workbench

Aqwa Workbench imports geometry from SpaceClaim, which is used to create the majority of the Aqwa model (using either the generation capabilities of SpaceClaim directly, or importing from an external CAD system)

- Hull definition
- Morison elements

For Aqwa-specific geometry this is input via the Aqwa Workbench user interface

- Point masses
- Disc elements

The main requirements for an Aqwa Workbench analysis can be summarized as follows:

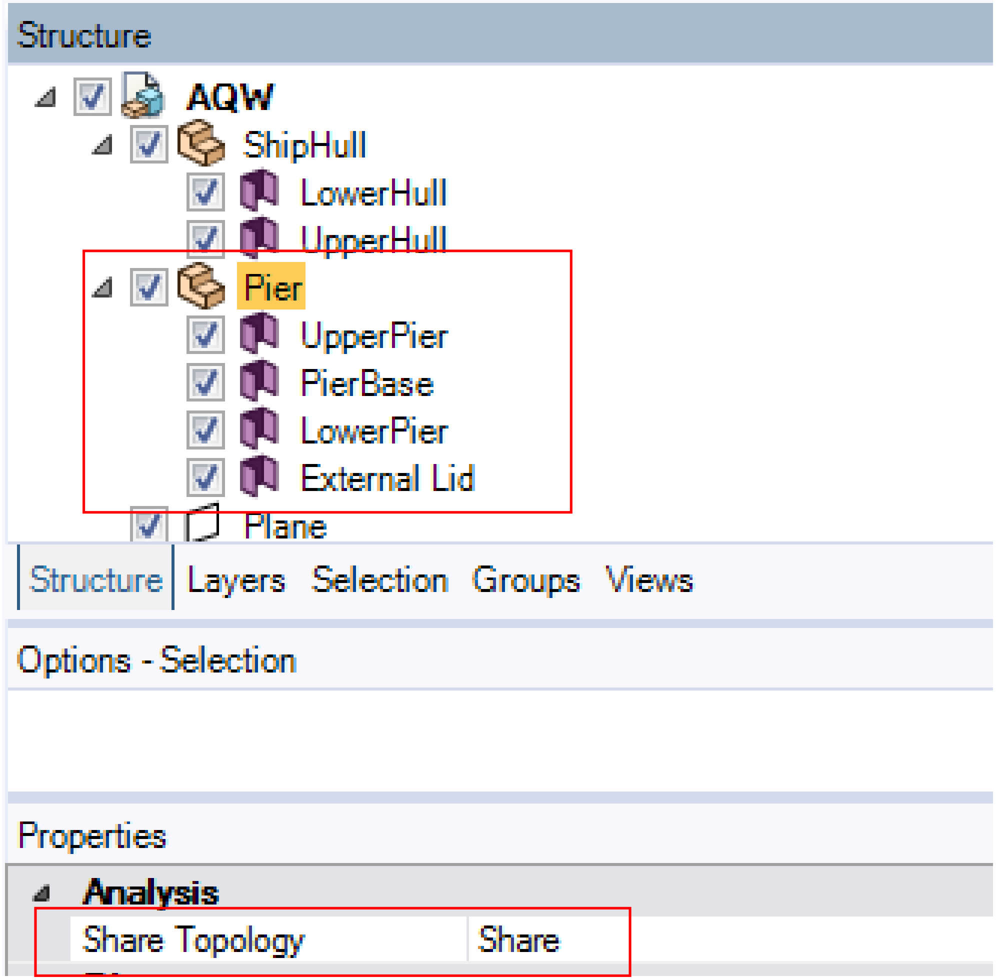
- Each vessel (or structure) is represented as a component with shared topology, as generated in SpaceClaim.
- Only a surface definition of the panel model is required, there is no thickness associated with the hull(s)
- The panel model must be such that the mesh is up to the waterline.
- The water line defines the global vertical origin for the analysis.

Vessel/Structure Definition

Each vessel or structure may consist of one or more bodies, but must be contained within a component with shared topology.

Here we have a ship and a pier:

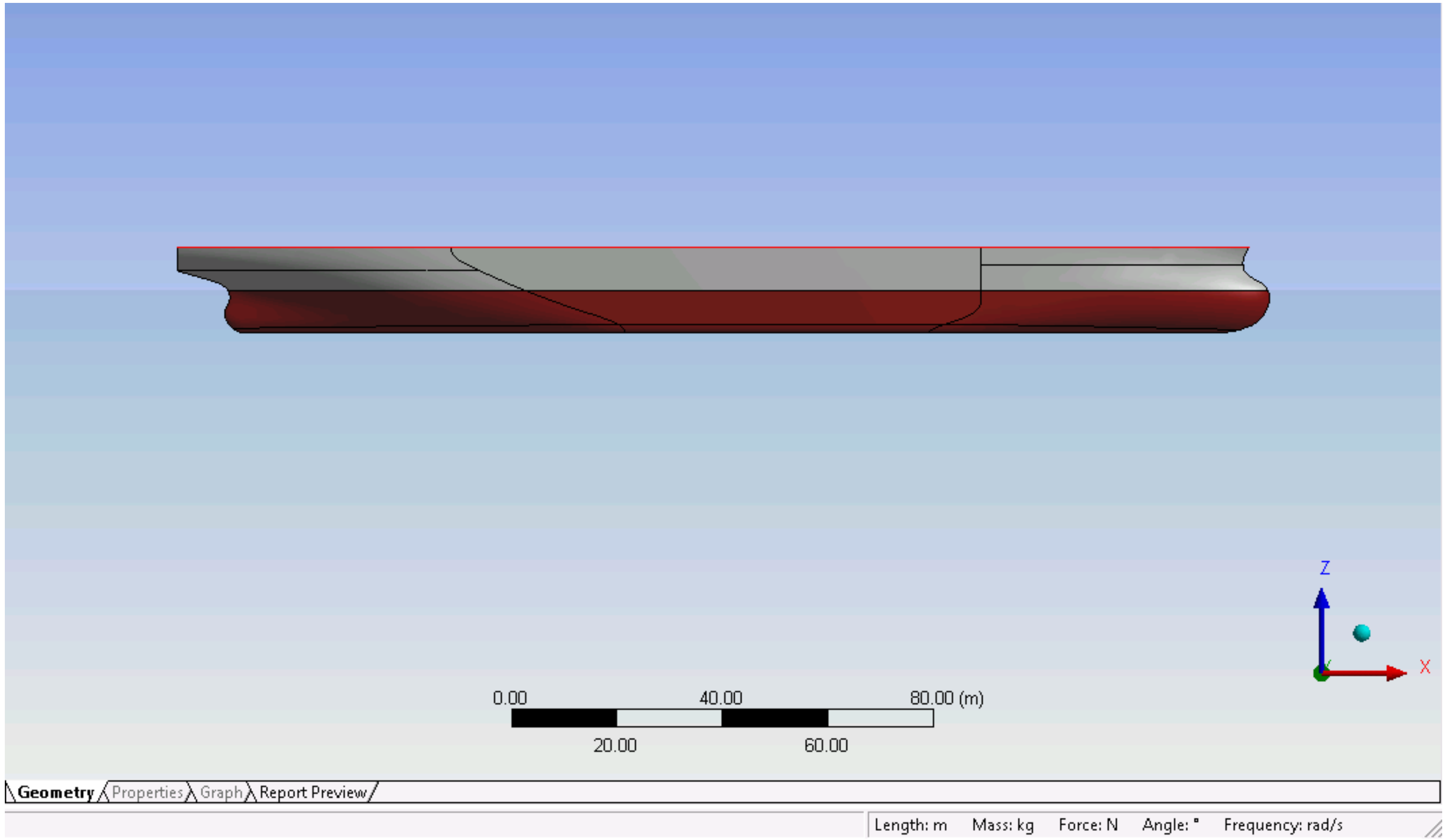
- The ship consists of two bodies – one above the water line, and a second below the water line.
- The pier has three bodies, defining the above and below water sections, plus the base, which has special considerations (more on this later).



Global Axis System in Aqwa

The water line defines the Aqwa fixed reference axes (FRA)

The geometry is divided at this point to allow meshing above and below the water line



Radiation/Diffraction Analysis Stages

The Hydrodynamic Diffraction analysis consists of six stages:

- Insert Hydrodynamic Diffraction system and associate geometry
- Add Aqwa specific parameters
- Add Aqwa specific elements
- Mesh
- Solve
- Post-processing