Introduction to Hydrodynamic Analysis with Ansys Aqwa

Appendix Slides

Release 2021 R2

Core Aqwa Programs

Aqwa-Line

- 3-D diffraction & radiation analysis program for wave force and structure response calculations; hydrostatic analysis

Aqwa-Librium

- Structure equilibrium position and force balance calculations; eigen-mode and dynamic stability analysis

Aqwa-Fer

- Spectral analysis of structure motion (wave frequency or/and drift frequency) and mooring tension in irregular waves

Core Aqwa Programs

Aqwa-Naut

- Time domain program for wave frequency structure motion and mooring tension analyses in regular and irregular waves

Aqwa-Drift

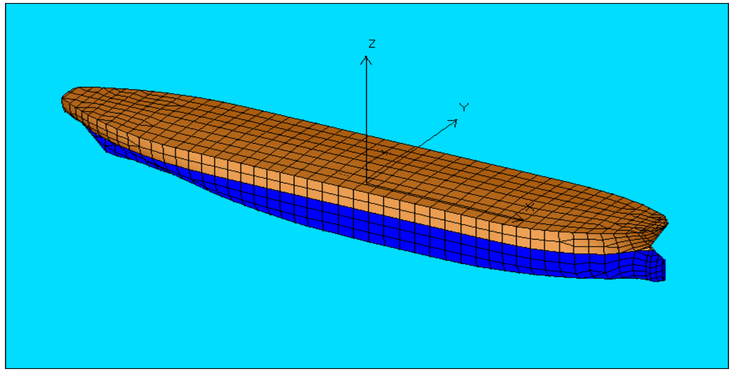
- Time domain program for drift frequency and wave frequency structure motion and mooring tension analysis in irregular waves

Aqwa Graphical Supervisor (AGS)

- Aqwa pre and post processor; on-line analysis

Aqwa-Line

- Aqwa-Line is a 3D diffraction and radiation analysis program
- Frequency domain
- Structures are described by a number of panels
- Source distribution approach (boundary integration method)
- A source is placed at the centre of each panel and then the program solves for the source strengths, subject to the boundary conditions (see Aqwa Theory Manual)



Aqwa-Line

Features

- Removal of irregular frequencies by auto-generated lid
- Multi-body hydrodynamic interactions (lid to suppress standing waves)
- Forward speed
- Second order forces
- Mean drift forces:
  - Far field momentum theory
  - Near field pressure-motion integration method
  - Full QTF matrix (difference & sum frequency components)

Aqwa-Line provides hydrodynamic coefficients for use in other programs in the Aqwa suite

Aqwa-Line

General Warnings

Requirements	Reason
Number of diffracting elements should be no more than 30k (12k in 32-bit)	Solution time
Maximum number of total elements is 40k (18k in 32-bit)	Solution time
Normals point out	Modelling Convention
No gaps in between panels	Force balance
Facets cannot cut surface	Solution requirement

Aqwa-Line

Geometric Property Warnings

- Area ratio of adjacent elements < 3
- Aspect ratio (AR) > 1/3, where

$$AR = \frac{area}{longest\ side^2} . C$$

(C = 1 for quadrilateral elements,

C = 2.3 for triangular elements)

- Element centres must be at least one facet radius (r_f) apart,

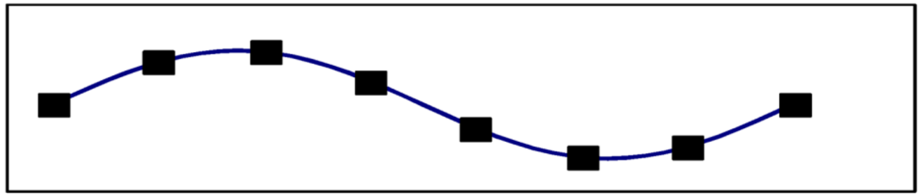
$$r_f = \sqrt{\frac{area}{\pi}}$$

- Shape factor (parameter for regularity of panel)
- <0.2 = warning
- <0.02 = fatal error
- See Aqwa Theory Manual for more detail

Aqwa-Line

Hydrodynamic warnings

- Minimum wave frequency (rad/s) > $0.001\sqrt{g/d}$
- Distance above sea bed must be > 0.5 r_f
- Longest side < 1/7 wavelength
    - Fatal error if more than 5% fail
- Nodes are not connected to another element = warning



Aqwa-Librium

- Equilibrium position, Static and Dynamic (oscillatory) stability
- Complex ship/offshore structure systems
- Various mooring, fender, pulley, winch, constraints configuration
- Equilibrium estimation under wave, wind and current combination
- Database approach for static catenary mooring line
- Finite element approach for dynamic cable (drag force)
- Iteration approach for determining equilibrium position
- Calculate the eigenvalues of linearized stiffness matrix to obtain static stability
- Eigenvalues of the impedance matrix to give dynamic (oscillatory) stability
- Series of wave spectrums

Aqwa-Librium

Theory in Aqwa-Librium

- **Equation for determining static equilibrium position**

$$X_{j+1} = X_j + \mathbf{K}^{-1}(X_j)F(X_j)$$

  - ❿ K is the stiffness matrix of the system,
  - ❿ F is the force matrix
  - ❿ The program iterates until ΔX=|Xj+1-Xj| is less than a defined tolerance

- **Static stability** $\mathbf{K}X - \lambda X = 0$
  - ❿ Eigenvalue λ (< 0, unstable; = 0, neutral; > 0, stable)

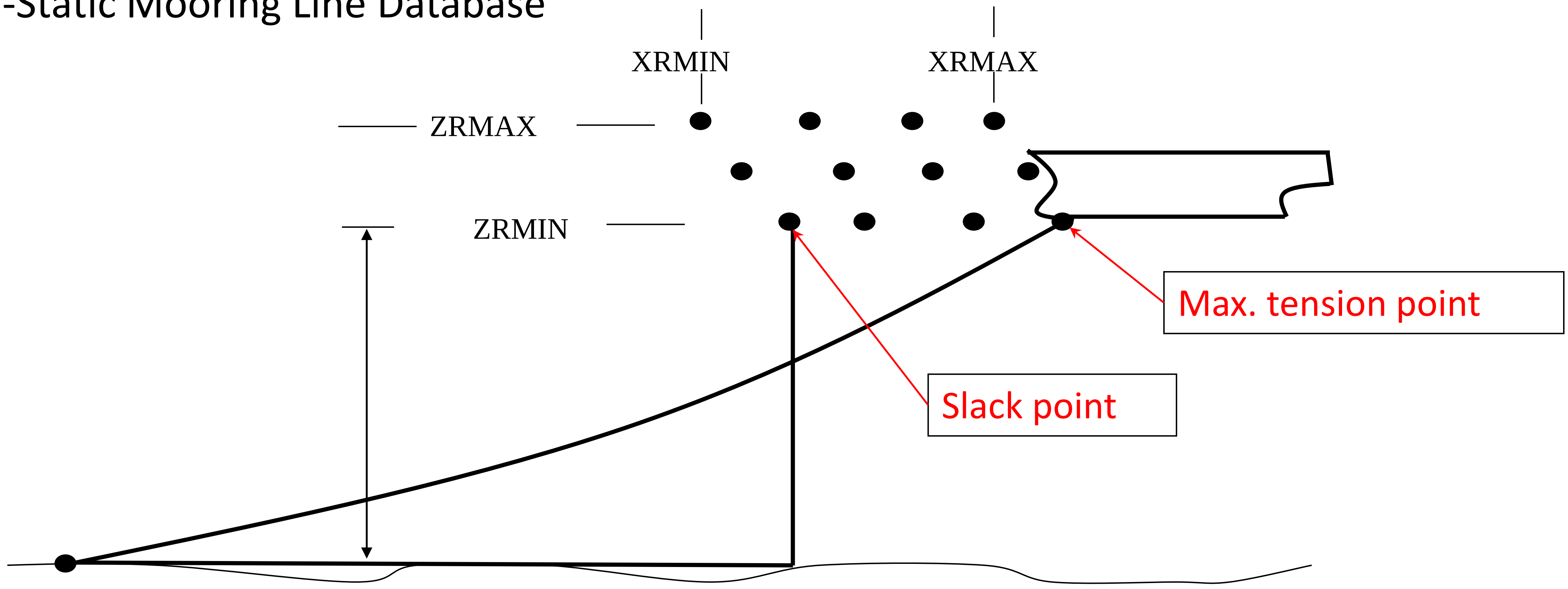
- **Dynamic stability**

$$\begin{bmatrix} \mathbf{M}^{-1}\mathbf{C} & \mathbf{M}^{-1}\mathbf{K} \\ \mathbf{I} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \dot{X} \\ X \end{bmatrix} + \lambda \begin{bmatrix} \dot{X} \\ X \end{bmatrix} = 0,$$

  - ❿ Eigenvalue λ $(\text{from } \mathbf{M}\ddot{X} + \mathbf{C}\dot{X} + \mathbf{K}X = 0,\ X = e^{\lambda t},\ \lambda = f + ig)$
  - ❿ f < 0, stable (converging oscillations)
  - ❿ f > 0 and g = 0, unstable (steady oscillations)
  - ❿ f > 0 and g ≠ 0, unstable (oscillatory divergence)

Mooring Lines

Quasi-Static Mooring Line Database



Aqwa-Fer

- Principally for calculating the significant response of amplitudes in irregular waves
  - Frequency domain program
  - Linearized stiffness matrix / damping to obtain the transfer function and response spectrum
  - Simple, inexpensive approach to make systematic parameter study
  - Series of wave spectrums and mooring configurations

Aqwa-Fer

Typical applications:

- Calculation of wave frequency RAOs for uncoupled/coupled moored structures.
- Calculation of significant motions and tensions for the system due to wave frequency (high frequency) excitation.
- Calculation of significant motions and tensions for the system due to drift frequency (low frequency) excitation.
- Calculation of significant motions and tensions for the system due to wave frequency and drift frequency excitation combined.

Aqwa-Fer

Theory in Aqwa-Fer

- Response spectrum in irregular waves

$$S_{x_i x_i}(\omega) = \sum_j [\mathrm{mod}(H_{ij}(\omega) F_j(\omega))]^2 S(\omega)$$

$S_{xixi}(\omega)$: response spectrum in i-th degree of freedom,

$H_{ij}(\omega)$: receptance matrix defined as

$$H_{ij}(\omega) = [-\omega^2 (M_s + M_a(\omega)) - i\omega B(\omega) + C]^{-1}$$

$F_j(\omega)$: frequency dependent force (in j-th degree of freedom) on the structure

$S(\omega)$: the wave spectrum

Aqwa-Fer

Linearization in Fer

- Stiffness: stiffness (hydrostatic, mooring etc.) at the initial position
  (= the static equilibrium position with RDEP option)

- Damping: catenary cable drag is linearized using the RMS velocity, when NLID used

$$F_D = (C_D.\ |V_{RMS}|)\ .V$$

wind drag is always linearized

current hull drag is linearized when LDRG option used

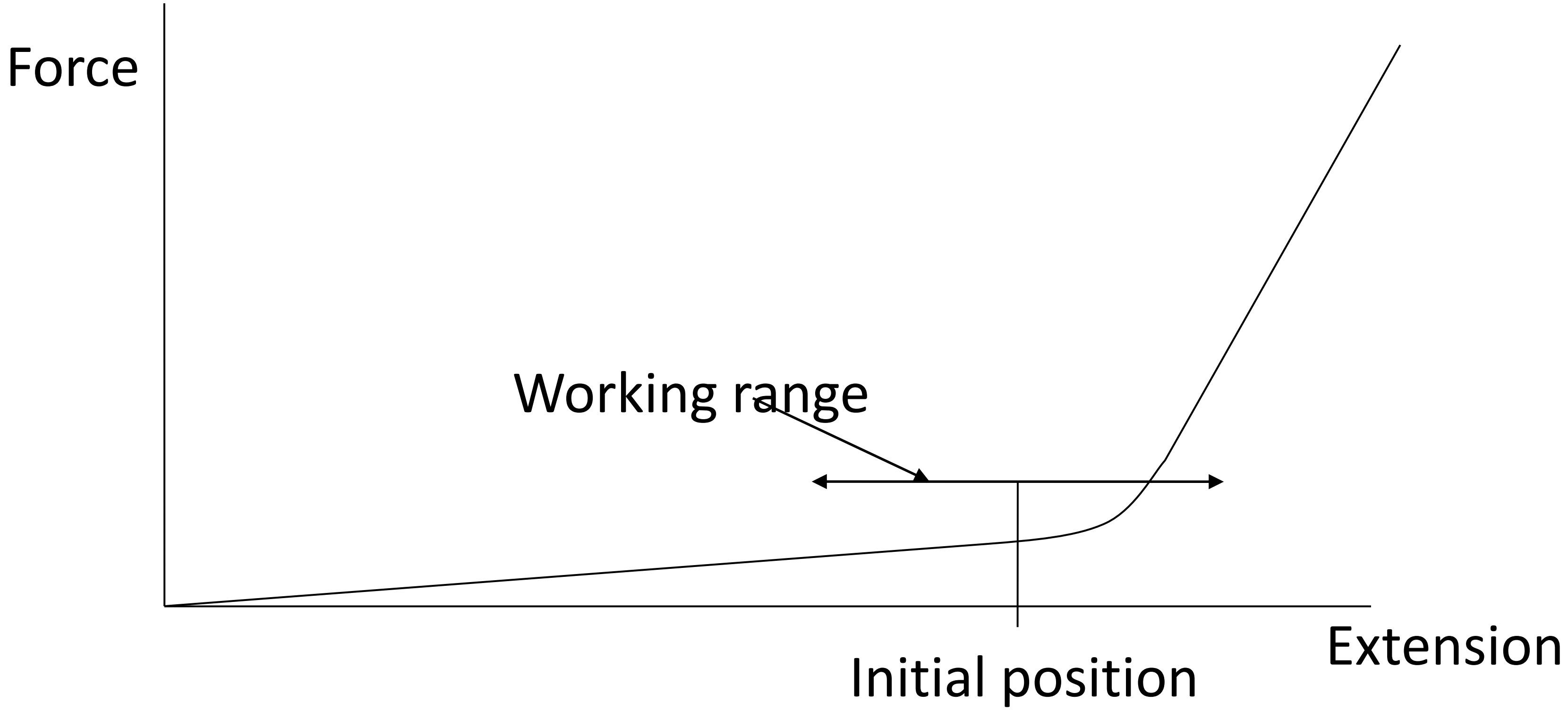
1st order hydrodynamic damping

any other input damping (fender, constraints)

- Forces: 1st and 2nd order wave forces

Aqwa-Fer Mooring Stiffness Linearization

Typical Force-Extension curve for catenary mooring



Aqwa-Fer uses stiffness (i.e. slope) at initial position
Aqwa-Drift/Naut uses changing stiffness over working range

Aqwa-Drift & Naut

- Aqwa-Drift and Aqwa-Naut are time-domain simulation programs
- For a series of time-steps they:
  - calculate the total force on the structure
  - calculate the acceleration
  - find the new position of the structure
- A two stage predictor/corrector integration scheme is used

Aqwa-Drift & Naut

Equations of motion in time domain

$$M_s \ddot{X}(t) = F(t)$$

- F(t) is the total force on the structure, including
  - Incident wave force
  - Diffraction force
  - Drift force
  - Mooring force
  - Radiation force (damping)
  - ….
- The equations of motion are solved in convolution integral form

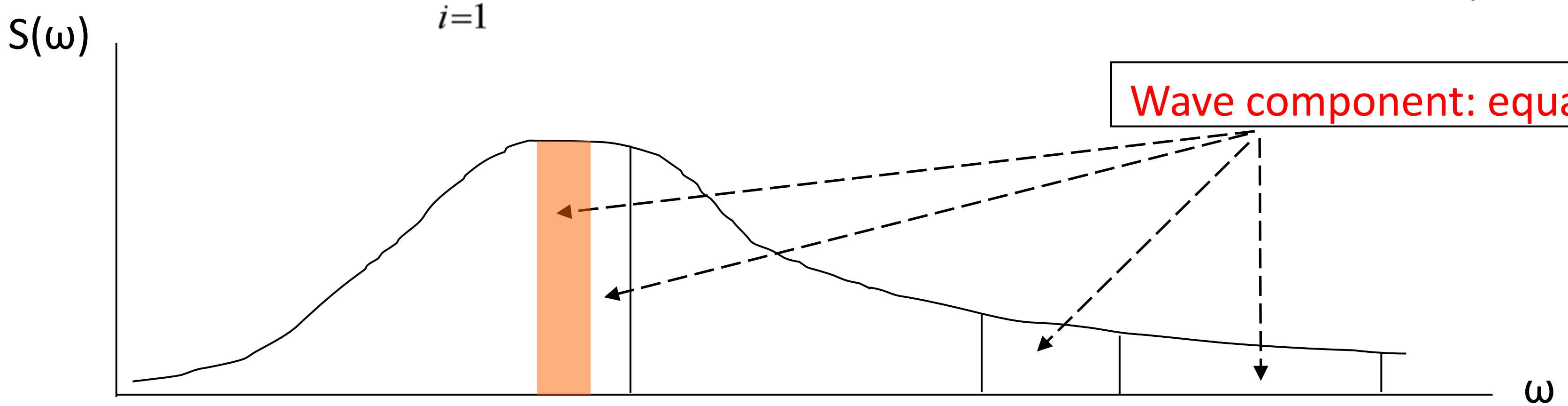
$$[\mathbf{M}_s + \boxed{\mathbf{M}_a(\infty)}]\ddot{X}(t) = KX(t) + \boxed{\int_0^t \mathbf{h}(t-\tau)\ddot{X}(\tau)d\tau} + F_1(t)$$

Aqwa-Drift & Naut

Simulation of irregular waves

- Wave spectra processing:
  - Spectrum is split into sections of equal area for integration
  - Wave components are defined with frequency at the centre of the section (Max. 200)
  - Wave components are added together with random phase angles

$$\zeta(x,y,t)=\sum_{i=1}^{N} a_i \cos(k_i x\cos\theta + k_i y\sin\theta - \omega_i t + \varepsilon_i),\quad a_i=\sqrt{2S(\omega_i)\Delta\omega_i}$$



Aqwa-Drift & Naut

Drift vs. Naut

Drift	Naut
Irregular waves only	Regular or Irregular waves
Linear hydrostatic stiffness (mean water surface)	Non-linear hydrostatics and incident wave forces (instantaneous wave surface)
2nd order drift forces	2nd order incident wave (omits drift forces but some 2nd order effects)

Summary

Linearity in Aqwa Programs

	Hydro-Statics	Diff / Radiation	Froude-Krylov	Drift Force	Mooring Force	Drag
Line	LIN	LIN	LIN	2nd order	-	-
Librium eqm	NON	LIN	LIN	2nd order	NON	Linearised
Librium stability	LIN	LIN	LIN	2nd order	LIN	Linearised
Fer	LIN	LIN	LIN	2nd order	LIN	Linearised
Drift	LIN	LIN	LIN	2nd order	NON	NON
Naut	NON	LIN	NON	-	NON	NON