

Seakeeping Analysis



Background

Evaluation of a vessel's seakeeping performance depends heavily upon the environmental conditions (wave spectra) and the defined criteria, and this is the principal reason why any comparison for alternative vessel speeds, incident wave headings, loading conditions, etc is a complex matter. Seakeeping analysis is essentially a three part problem:

1. Estimation of the likely environmental conditions encountered by the vessel, based on hind-cast or predicted weather data as applicable (e.g. wind, wind wave, swell);
2. Determination of the vessel's response characteristics (response amplitude operator, RAO);
3. Specification of the criteria being used to assess seakeeping behaviour (e.g. cargo acceleration, deck wetness).

Environmental Conditions

When observing the sea surface a mariner will see a procession of seemingly random waves (the height visually recorded typically represents the mathematical, significant wave height). Variation in surface elevation over time makes up what is referred to as a time domain series, and for practical analysis it is usual practice to convert this data to a spectral representation of the same data (i.e. frequency domain).

A wave spectrum describes the distribution of wave energy with frequency for a specified wave height and period, and therefore implies that the seemingly random waves can be represented by very many regular wave trains of differing amplitude and period superimposed upon each other. A wave spectrum is more useful for assessing the vessel's performance than time series data, and for this purpose idealised wave spectra (Bretschneider, Pierson-Moskowitz, ITTC Two-Parameter, JONSWAP, etc) have been developed according to the location and prevailing weather conditions, also accounting for aspects such as fetch. The choice of applicable spectrum is provided for by being already incorporated within seakeeping software, such as the Wolfson Unit motion program used by TMC.

Response Amplitude Operator

The motion characteristics of a vessel in any given seaway are defined by the manner in which the vessel ‘filters’ the input signal (seaway) which results in the actual motions. This filter is called the filter function or response amplitude operator (RAO). Typical RAO’s for heave and pitch motions will be such that at low frequency waves (long wavelength), the vessel follows the wave profile, riding up and down on them like a cork, hence the RAOs tend to unity. At the high frequency end of the scale (very short wavelength), there are so many waves along the length of the hull that their net effects cancel out and the vessel is unaffected by the waves. Somewhere in between these extremes, there is normally a resonant peak. This peak occurs at the natural frequency of the vessel, for example synchronous rolling at the natural roll period. At resonance, the vessel motion can be several times that of the wave and the height of the peak depends on the extent of motion damping. Motions such as heave and pitch are relatively highly damped, especially when compared with roll. RAO’s are calculated by seakeeping software used at TMC.

Seakeeping Criteria

These are differing levels of motions, accelerations or other events that can occur with or without affecting the vessel's operation and parameters for seakeeping criteria include: accelerations, relative motions, relative velocities, slamming, propeller emergence, deck wetness, motion sickness incidence, etc. The statistical nature of the analysis allows the calculation of probabilities of these criteria being exceeded (or occurrences per hour). These data can then be used as a meaningful comparison of scenarios for investigation in terms of limiting sea conditions for operability or safety of cargo, crew etc. Typical published criteria, such as those values below, are empirically derived values, subject to correction factors also given in the Code for vessel length, speed and breadth-stability ratio (B/GM).

Figure 1: Example of acceleration criteria - tabulated accelerations (extract from IMO publication “Code of Safe Practice for Cargo Stowing and Securing”).

Table 2 - Basic acceleration data

Transverse acceleration a_y in m/s^2										Longitudinal acceleration a_x in m/s^2
on deck, high	7.1	6.9	6.8	6.7	6.7	6.8	6.9	7.1	7.4	3.8
on deck, low	6.5	6.3	6.1	6.1	6.1	6.1	6.3	6.5	6.7	2.9
tween-deck	5.9	5.6	5.5	5.4	5.4	5.5	5.6	5.9	6.2	2.0
lower hold	5.5	5.3	5.1	5.0	5.0	5.1	5.3	5.5	5.9	1.5
0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	L
Vertical acceleration a_z in m/s^2										
	7.6	6.2	5	4.3	4.3	5	6.2	7.6	9.2	



Ship Motion Programs

TMC uses three separate programs for seakeeping analysis, and these can be used either as stand-alone or in combination, as required by the case.

Wolfson Unit MTIA program – a strip theory based program which assumes vertical sides and a given slenderness ratio. After inputting the hull form sections and weight data as necessary, waves are modelled either as unidirectional (long-crested) or directional, with a user-defined spreading function. As already noted, there are some limitations of 2D programs, involving hull slenderness ($L/B, B/T > 5$) and vessel speed ($F_n < 0.3$), and the hull form analysed is to be a displacement and mono hull only. Negligible viscous effects and no wave breaking are assumed, and ship response is assumed to be a linear function of wave amplitude.

AQWA program – a suite of integrated modules which addresses the vast majority of analysis requirements associated with the hydrodynamic assessment of all types of offshore/marine structure from spars to FPSO's, from mooring systems to buoys, from TLP's to semi-submersibles, from fishing vessels to large ships and from large ships to structure interaction. The AQWA Diffraction program uses frequency and time domain with random waves (incl. slow drift), nonlinear time domain with large waves, as well as static and dynamic stability including mooring lines.

Optimoor program – the Optimoor suite has a seakeeping option which uses special hydrodynamic coefficient files (HCF) to calculate first-order wave induced vessel motions. Each Optimoor HCF comprises a set of six degrees-of-freedom hydrodynamic data, which have already been generated from the AQWA program, above. Optimoor uses this HCF data to calculate the relevant RAO's for a particular water depth, vessel size, draughts, GM and roll damping which are all user specified. There is an option to take into account the effect of mooring stiffness on wave motions, although this effect will normally be slight except for vessels with short lines or hard fenders). HCF are available for a variety of vessel types including: LNG carriers, VLCC tankers, container ships and smaller vessels such as supply vessels and tugs.

Data Required and Results

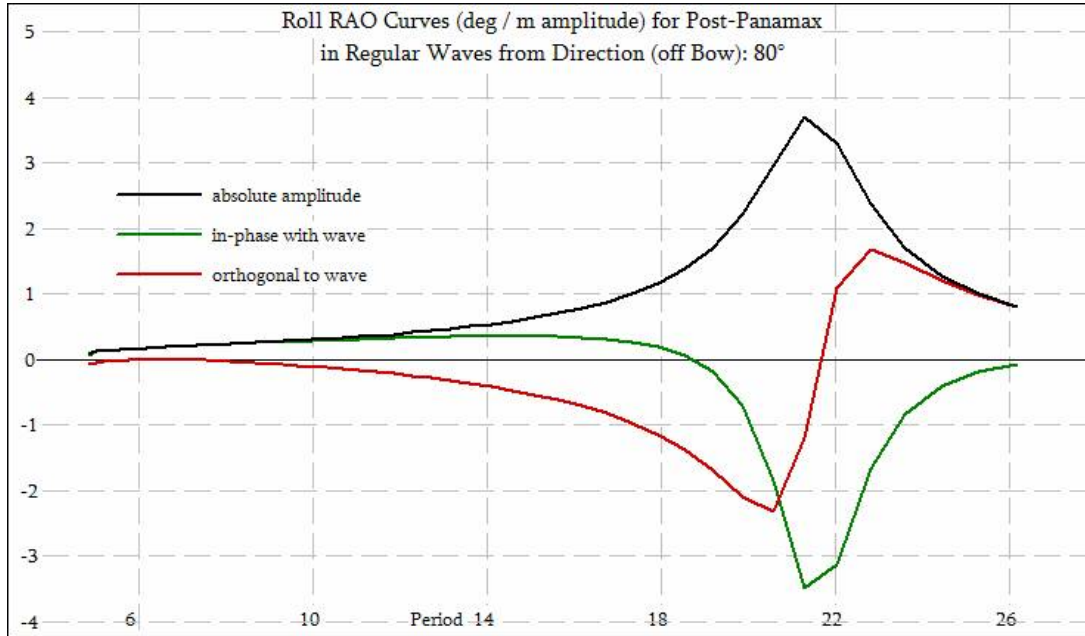
Input data required for a sea-keeping model typically comprises:

- Principal particulars (dimensions, displacement, draught, trim);
- Lines or body plan (or offsets);
- Appendages (skeg, rudder, bilge keels, stabilizers);
- Loading condition (GM);
- Centre of Gravity (KG, LCG);
- Radii of Gyration (for rolling, pitching, yawing);
- Vessel speed through water;
- Wave spectrum type;
- Wave direction, wave height, wave period (regular/irregular);
- Longitudinal weight distribution (necessary if wave-induced shear force, bending moment and torsion moment are required).



Motion data output comprises absolute motions, velocities and accelerations at arbitrary positions; Response Amplitude Operator (RAO) – for onward processing to determine meaningful ship motions results; added mass; damping coefficients; added resistance due to waves; seaway induced loads (shear force, bending moment, torsion moment); regular or irregular waves; deep water waves; forward vessel speed; any incident-wave heading scenarios.

Figure 2: Roll RAO curves generated from AKWA program and associated results



Water Level : 5.00 above Datum
 Draft: 14.0
 Trim: 0.0
 GM: 2.0
 Deck Level : 6.5 above Berth (at Target)
 Significant Wave Ht: 2.0
 Wave Mean Period: 7.0 sec
 Wave Direction True: 147°
 Wave Direction to Berth X-axis: 69°
 Wave Spectrum: Pierson-Moskowitz
 Significant Swell Ht: 1.5
 Swell Mean Period: 11.0 sec
 Swell Direction True: 50°
 Swell Direction to Berth X-axis: -28°
 Swell Spectrum: Narrow-Band
 Wind Speed: 50 knots
 Wind Direction True: 24°
 Wind Direction to Berth X-axis: -54°

Probable Maximum Angles in 3 hours... (mooring stiffness ignored) Roll: 1.4° Pitch: 1.1° Yaw: 0.5°

3hr Maximum Combined =±Acceleration=	Wave Motions at Ship Target	X Fwd Midship	Y Stbd from CL	Z Above Deck	===±Amplitude===			===±Velocity===				
					Surge	Sway	Heave	Surge	Sway	Heave		
Heave					0.24	0.51	0.81	0.13	0.28	0.46	0.07	0.16
0.27	Bow	140.0	0.0	10.0	0.15	1.09	3.11	0.09	0.64	1.87	0.06	0.39
1.17	Stern	-150.0	-15.0	15.0	0.27	1.88	2.92	0.17	1.08	1.80	0.11	0.65
1.16												

Applications for sea-keeping analyses include:

- Total loss investigations;
- Damage hull or cargo cases;
- Cargo securing for standard or project cargoes;
- IMO requirements compliance (cargo accelerations, stability);
- Comparison of sea-keeping characteristics for alternative conditions/designs;
- Response for any singular or coupled motion (i.e. for surge, sway, heave, roll, pitch, yaw);
- Deck wetness (freeboard exceedence);
- Relative wave elevation at ship's sides;
- Likelihood of propeller emergence;
- Likelihood of slamming;
- Motion sickness indicator, MSI, assessment (vertical acceleration);
- Intact/damage hull form behaviour;
- Study of ship variables (speed, heading, loading condition);
- Study of the environmental factors (waves, incident sea direction, wave spectrum);
- Cargo Accelerations;
- Behaviour in extreme conditions.

Model Tank Testing

TMC has access to the test tank facilities at Southampton Solent University – as used by the Wolfson Unit also for analyses and program results validation. These facilities may be used for small craft and ship model testing, to a suitably high scale and include a computer-controlled wave maker which enables tests in both regular/irregular sea states (and if necessary in breaking waves). Most of this work is completed mainly for head seas although some roll response work can be completed in beam seas. TMC has also arranged and/or overseen tank testing at MARIN, Newcastle University and the ship simulator at South Tyneside College.

Figure 3: Model testing at Solent University

