

## SECTION 6

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### Seakeeping

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Seakeeping refers to motions of a vessel in waves. "Sea kindliness" is a characteristic sought after for research vessels. A sea kindly vessel is easy on its crew and easy on its gear. Trying to define seakindly is difficult. The deep sea mariner may use qualitative descriptions such as "an easy roll" or "a wet boat". The vessel designer and marine scientist must look for quantitative descriptions.

There are six degrees of motion in a vessel, three are linear (surge, heave, and sway) three are rotational (pitch, roll, and yaw). See Fig.1. Each of these degrees of motion has associated values of amplitude, velocity, and acceleration. For example, a vessel in a beam sea can be rolling up to 30 degrees (amplitude). The associated acceleration could be 0.5 g or 1 g. To a designer, the accelerations are usually the key value since they translate into forces on equipment and people. Motion sickness is a function of acceleration levels and periodicity. See Fig. 2 for the ASTM standards motion sickness graph.

The energy input for motions comes from waves. There are several terms that need to be considered. Each distinct wave has a height (distance between trough and crest) and a period (time between succeeding crests). The sea is a spectrum of waves, that is a variety of waves of different heights and periods. The spectrum can be characterized by two terms, the significant wave height and the modal period. If we collect a thousand observations of wave heights and periods we can produce a graph similar to Fig. 3. If we take the average height of the one third highest waves that number represents the significant wave height. This method quantifies what people have historically observed qualitatively. The modal period is determined by finding the average value of the wave periods.

Other factors that affect waves are the fetch and the water depth. Fetch is the distance of open water available for a wave system to develop. A protected bay has little fetch and waves cannot fully develop, regardless of the wind strength. Water depth can produce larger waves, especially when the depth of water is less than 1/2 the wavelength. A good example of this occurs at harbor entrances where a bar or local shallowing can develop. Such a bar can produce larger than ordinary waves as the wave energy is compressed by the rising ocean bottom.

In extreme seas two other characteristics come into play. These are deck wetness and slamming. Deck wetness refers to the presence of green water on deck, not just spray. Having waves board the vessel clearly limits the crew's ability to handle equipment or to safely move around. Deck wetness can be used as a good criteria for limiting operation.

Slamming is more serious. A vessel slams when the bow area is struck by or comes down on a wave. Slamming is characterized by zones of high pressure on the hull and associated shaking of the vessel. When slamming occurs the operator must reduce speed in order to prevent structural damage to the hull.

Mariners have long known that if the wind begins to blow on a open, calm sea, after a while waves will develop and build until an equilibrium condition is reached. This phenomena was categorized by the 19th century English sailor, Beaufort. This so called Beaufort scale matches wind velocities to wave conditions or Sea States as shown in Fig. 4. This terminology has been adopted to define design conditions for vessels.

For the designer of the vessel the sea kindness or ride quality must be expressed as a set of standards. Because of the varying nature of winds, operating areas, seasons of the year, resistance to motion sickness, etc. this usually means that statistics must be used. To say that a vessel has to work through sea state 3 and survive a sea state 5 is not precise. Before defining the governing sea state one must consider where the vessel is to operate, what kinds of seas are prevalent at what times of the year, and what type of work will be done with the vessel. For example a vessel handling a plankton net over the side can operate in higher sea states than one that will be handling an ROV. The designer and the scientists must both understand the mission and the vessel's limitations.

Having looked at the environment which provides the energy input to cause vessel motions, we next look at the vessel responses. The vessel system can be modelled as a linear mass spring system with a dampener. See Fig. 5. The vessel is the mass, the spring is buoyancy to restore the vessel to its equilibrium position as the waves passes under it, and the dampener is the sum of friction, turbulence, and drag. The equation of a linear system takes the form of  $F(t) = mg + mA + cV + kD$  where:

$F(t)$  = force varying over time

$m$  = mass

$g$  = acceleration due to gravity

$A$  = acceleration of the vessel

$c$  = damping coefficient

$V$  = velocity of the vessel

$k$  = buoyancy

$D$  = distance the vessel moves

Note that the vessel mass is a key factor in the equation. For a given wave height a heavy vessel will have lower accelerations, or move less, than a light weight vessel. Another factor is the damping coefficient. For example adding bilge keels to a vessel increases the drag and turbulence when a vessel rolls, and hence reduces the motion.

Finally, the buoyancy constant is proportional to the amount of waterplane area of the vessel. A slender spar buoy will move less than a fat can buoy.

This equation applies to each of the six degrees of freedom. Given the difficulties in solving 6 simultaneous differential equations some standard simplifications are used. First, surge and sway are typically ignored since their magnitudes are usually small compared to the other motions. Yaw can be assumed to be countered by rudder steering forces. This leaves roll, pitch, and heave as the primary motions of concern. There are some differences between these motions and the above equation. For example in roll the "spring" is the vessel righting arm. A low center of gravity due to weight in the form of ballast will produce a different ride from the same weight carried as deck cargo. Whether the ride will be better or worse will depend on factors such as hull shape, the wave spectrum, and how the weight is distributed. For the latter consider an ice skater spinning around. By changing the position of the arms the speed of the spinning can be altered, with the arms tucked in close to the body causing the highest rate of rotation. Similarly, the distribution of weight on a vessel can affect the pitch and roll performance.

Many different approaches have been tried to improve seakeeping, from fundamental differences in hull shape to active or passive appendages. A brief discussion of each of these follows:

**SWATH Hull** - This type of vessel, a Small Waterplane Area Twin Hull, has excellent seakeeping characteristics. The design consists of two submerged hulls with slender struts rising through the water's surface to support a cross-structure. Because the buoyant hulls are well below the water's surface and by keeping the struts as slender as possible there is little opportunity for the waves to act on the vessel. The main vulnerability is slamming on the cross structure when the waves get large enough.

**Catamaran Hull** - This type of vessel has some limits for seakeeping imposed by the hull design. If the wave period is twice the spacing of the hulls then the natural frequency in roll creates a resonant condition and extreme motions. Further, the cross structure is vulnerable to slamming if the wave heights are large enough. Finally, due to the relatively short hull length for the displacement, catamarans can experience significant pitch motions.

**Monohull** - The traditional monohull has been the subject of much investigation for seakeeping. What we have learned is that long slender hulls have less pitching behavior while short fat hulls are typically better in roll and heave. Deck wetness can be limited through good bow shape and hull flare. A round bilge hull will have less roll dampening than a hard chined hull. Hard chine boats can be subject to slamming in the bow area depending on the wave height and the vessel's forward speed.

**Anti-roll tank** - To combat vessel rolling people have used different designs of tanks holding water ballast. By placing such tanks up high on a vessel and by tuning them to the vessel's natural roll period, significant improvement in motions can be achieved. The disadvantage of such tanks is that they need to be located in prime parts of the ship to be effective. A particular advantage of such tanks is that they are effective at a range of vessel speeds.

Fin Stabilizers - By using airfoil shaped fins mounted low in the hull amidships, significant roll reduction can be achieved when the vessel is underway. Such fin stabilizers use a motion sensing controller that signals the fin to change its angle of attack to the water, thus producing a countering force to the wave motion. Fin stabilizers typically are electro-hydraulic units and are more effective the faster the vessel is moving.

Centerboards - Some research vessels have tried using centerboards with good effect. These boards are typically of an airfoil shape with a mechanism allowing them to be retracted into the hull. Placed at approximately 30% of the waterline length back from the bow they dampen rolling motion and incidentally allow sonar transducers to be placed well away from noise sources in the hull.

Bilge keels - These passive devices have typically been used to add damping in roll. A fixed plate running approximately 40% of the vessel's length along either side of the hull the bilge keel must be placed to maximize hydrodynamic drag in roll and minimize hydrodynamic drag while underway. A drawback of bilge keel is that gear being worked over the side can potentially foul on the bilge keels.

Active Rudders - Similar to the fin stabilizers, an active rudder system will turn the rudders to generate a counter force to vessel roll. This allows the use of existing equipment but obviously suffers in efficiency with comparison to fin stabilizers.

Bulbous bows - These were originally developed as a means of reducing vessel resistance. Later, researchers observed that depending on the bulb's size and shape it could improve pitch resistance. However, in extreme seas when the forefoot of the vessel emerges, an improperly designed bulb can contribute to slamming.