Head-Sea Parametric Rolling and Its Influence on Container Lashing Systems

Presented By:

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Summary
Recent studies have demonstrated that parametric rolling in extreme head or near head seas can occur when unfavorable tuning is combined with low roll damping (reduced speed) and large stability variations (governed by wavelength, wave height, general hull form, bow flare and stern shapes). Parametric rolling is an unstable phenomenon, quickly generating large roll angles coupled with significant pitching. Rolling occurs in phase with pitch and on containerships introduces high loads into the containers and their securing systems. It appears that post-Panamax containerships may be particularly susceptible to this behavior. In view of the large number of such vessels in operation and scheduled for delivery in the next few years, head-sea parametric rolling has now become an important subject for thorough study.

Description of Casualty
In late October 1998, a C11 class, post-Panamax containership, eastbound in the north Pacific from Kaohsiung to Seattle, was overtaken by a severe storm. She carried a deck stow of some 1300 containers. As encounter with the storm became inevitable, the master hove-to to ride out the rough seas and winds.

The storm encounter lasted for some 11 hours, mostly at night. During the period of severest motions, port and starboard rolling of as much as 35 to 40 degrees was reported simultaneously with extreme pitching. The master later described the ship as absolutely out of control. About 400 containers were lost overboard and another 400 collapsed or crushed during these motions.

A thorough hindcast established that the vessel had encountered winds of Beaufort 11-12 and completely confused seas up to the highest level of International Sea State Scale, sea state 9, with significant wave heights ranging between 12 and 15 m. Extreme waves were estimated to have reached 31 m.

The C11 class vessels are 262 m LBP, 40 m Beam, and 24.45 m Depth with a loaded draft of about 12.5 m. Pre-construction model testing for the C11 design and for the predecessor C10 design (approximately the same dimensions), indicated no significant rolling in head and bow quartering seas. The U.S. Navy Ship Motions Program, widely used in ship design, predicted roll angles of up to 30 degrees, but only in severe following and stern quartering seas. In similar beam seas the maximum predicted roll was approximately 16 degrees. These predicted roll motions were for normal synchronous rolling, occurring when wave encounter periods approach the ship’s natural rolling period. Computer investigations for parametric rolling in following seas had also been carried out on the C10 design in 1987 yet no simulations for head sea parametric rolling were considered.

Parametric rolling does not result from direct excitation by external wave forces, but from the periodic variation of the vessel's stability characteristics. For a ship in head or stern seas, the uneven wave surface together with pitch and heave motions results in significant time-varying changes to the GM. When that time variation of stability matches a wave encounter period of one-half the vessel's natural rolling period, extreme rolling motions can result.

Parametric rolling has been known theoretically for many years but, historically, has only been of concern for smaller vessels of low or marginal stability in following seas. When the C10 design was computer modeled in 1987 in severe following seas at a GM and speed such that the wave encounter period was one-half the natural rolling period, rolls of between 30 and 35 degrees were predicted. At the time, that response was reasonably expected as the sensitivity of containerships to heavy rolling in following seas has also been studied for some time and is now a well-known problem. In 1995, IMO promulgated its MSC Circular 707 with operational guidelines for avoiding dangerous situations in following and quartering seas, including parametric rolling.

While parametric rolling could explain the large roll angles experienced by the vessel, the phenomenon had never been considered of practical concern in bow seas. No head-sea computer modeling or model tests were part of any accepted testing regimen during the design process for the C11 or C10 or similar vessels.

Subsequent Investigation

In defense of the numerous and costly cargo claims arising from the casualty, an extensive investigation was undertaken to determine whether head-sea parametric rolling could have been the cause of the vessel's extreme motions. Initially, computer modeling was carried out using nonlinear, time domain programs developed by the Maritime Institute of the Netherlands (MARIN) and by Science Applications International Corporation (SAIC), in Annapolis, Maryland. Both programs predicted rolling between 30 and 40 degrees for the vessel in the head seas encountered, with significantly decreasing roll amplitude as the wave direction exceeded about 35 to 40 degrees from the bow.

Model testing was next carried out at MARIN because of its newly opened sea keeping and maneuvering basin with its state-of-the-art wave making capability. The scale model was completely free running during the tests. After preliminary roll damping and speed and power runs were conducted, a series of tests at different speeds, headings and wave complexities were carried out for the loaded conditions at the time of the casualty.

Model tests demonstrated roll angles of up to 37 degrees (and 40 degrees when wind heel was added) in short crested head seas from the hindcast and at speeds corresponding to Vessel speeds at the time of the casualty. These proved to be conditions in which wave encounter periods approximated one-half the vessel's natural roll period, as parametric rolling theory predicted. Also, extreme rolls were coupled with extreme pitch: there were two complete pitch cycles for each roll cycle, with the bow always at maximum pitch down when the roll angle was greatest. When model test roll damping parameters were utilized in SAIC's computer code, predicted roll responses matched the model test results almost perfectly.

Aside from severe rolling in head seas, other significant results of the investigations were: decreased roll response with greater vessel speed and also with increased GM; significantly dampened roll response due to free surface effects; and a several second variation in the vessel's natural roll period during parametric rolling responses. Certain of these effects, translated into ship handling tactics, suggest that the vessel should have remained in beam seas during the storm or, if headed into the seas, should have slackened a ballast tank or increased speed to reduce rolling. All of these maneuvers are contrary to normal heavy weather ship handling practice and counter-intuitive for masters.

The final stage of investigation was an analysis of loads imposed on containers and lashings as a result of these extreme motions. Accelerations based on model test results when applied to maximum allowable container stack weights (according to the C11 lashing program) resulted in transverse container and lashing loads significantly greater than predicted worst-case design loads. Because of the coupling of roll and pitch, vertical tension loads at the stern and vertical compression loads at the bow were both much greater than design criteria. If fully loaded during the modeled parametric rolling, most of the container stacks forward of amidships exceeded tension and compression minimum breaking strengths by up to 10% and in the midships region loads were in excess of 110% of breaking strengths. Aft of the house, loads increased to more than 125% of breaking strengths.

Relevant Points of Discussion

Container lashing and securing design criteria for the C10 and C11 class vessels had been based upon the ABS Guide for Certification of Container Securing Systems, 1988. Other classification societies have their own published criteria. Importantly, the lifetime maximum roll angles predicted by these criteria are significantly less than those caused by parametric rolling. In addition, the various classification society criteria may not predict equivalent lifetime roll responses and accelerations. Accordingly current classification society criteria do not provide realistic or uniform design standards for container ships experiencing head-sea parametric rolling.

Any size vessel with extensive bow flare and a long, flat stern is susceptible to head-sea parametric rolling given the right combination of wave height, wave period, natural rolling period and speed. This includes ro-ro, passenger, reefer, and other vessel types. Resulting loads on ship structures and cargo for such vessels may far exceed design conditions. Anecdotal evidence since the October 1998 casualty suggests that head-sea parametric rolling might be relatively common although otherwise unfamiliar to mariners and vessel operators.

Additional details of these investigations are set forth in a SNAME technical paper titled "An Investigation of Head-Sea Parametric Rolling and its Influence on Container Lashing Systems" by W. France (Healy & Baillie, LLP), M. Levadou (MARIN), T. Treakle

(SAIC), Dr. J. R. Paulling (University of California, ret), R.K. Michel and C. Moore (both of Herbert Engineering Corp.), to be published in the October 2002 or January 2003 issue of *Marine Technology*. These investigations were also the subject of a Technical & Research presentation by the authors at SNAME's 2001 annual meeting in Orlando, Florida.

In order to further study this important subject, SNAME has established Ad Hoc Panel #13, "Investigation of Head-Sea Parametric Rolling and Resulting Vessel and Cargo Securing Loads".