Woods Hole Oceanographic Institution
Upper Ocean Processes Group

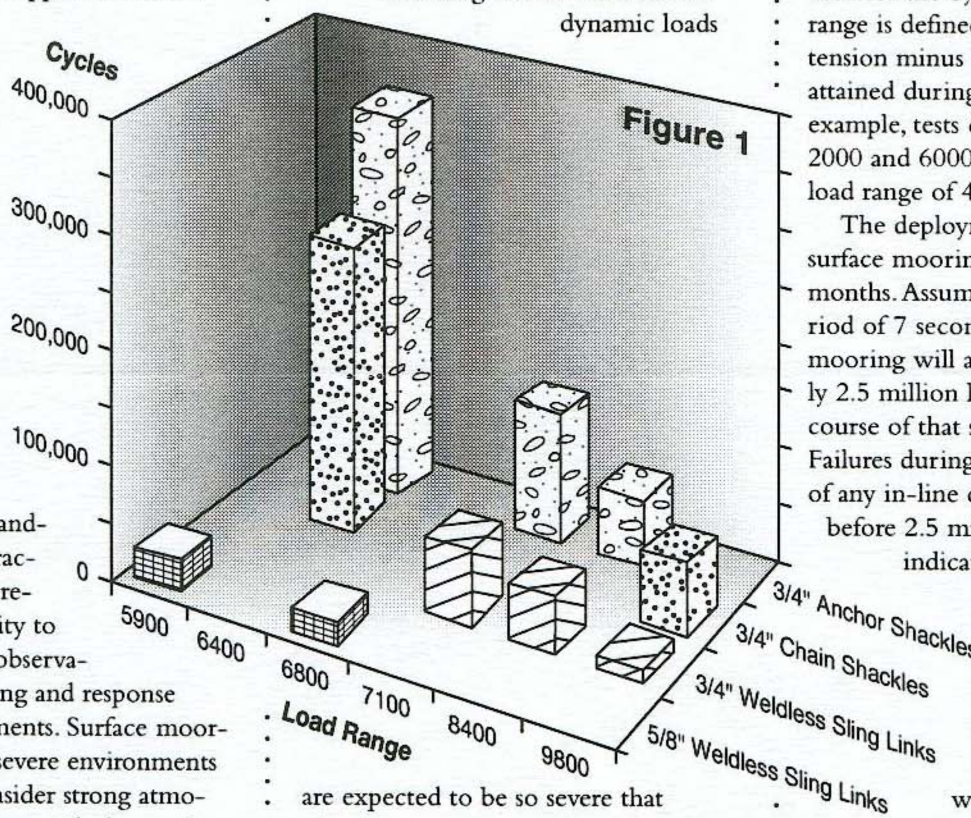
Technical Note

Mooring Hardware Fatigue Tests for the Arabian Sea Surface Mooring

Materials tests recently conducted on a variety of mooring hardware components provided valuable results which were used to specify the type hardware to be used on the heavily-loaded WHOI surface mooring deployed in the Arabian Sea. Special care was taken during the design of the Arabian Sea surface mooring since environmental conditions there are believed to be more severe than in other regions where surface moorings have been deployed in the past.

For years, the efforts to investigate air-sea interaction and upper ocean variability with surface moorings have focused on regions characterized by light to moderate atmospheric forcing. Wind and wave conditions have, therefore, not been considered critical factors in the design process. Recently, the desire to increase the understanding of air-sea interaction processes has required the capability to make time-series observations of both forcing and response in severe environments. Surface moorings designed for severe environments have begun to consider strong atmospheric forcing along with the steady current conditions. Waves generated by strong wind events impose a dynamic load on mooring components. Superimposed on the background static tension from the currents, there is an oscillating dynamic tension that is generated by each passing wave. In a recent experiment south of Iceland, mooring tensions ranged from less than 1000 to over 8500 pounds with tensions changing by up to 5000 pounds over less than four seconds.

It is believed that the static and dynamic loads that the Arabian Sea surface mooring will experience during the southwest monsoons are of such magnitude and duration that conventional designs for such a heavily loaded mooring would not last. The dynamic loads are expected to be so severe that ultimate strength considerations will be superseded by the fatigue properties of the standard hardware components.



Concerns about all in-line mooring components and their fatigue endurance dictated the need for an independent series of cyclic fatigue tests. The components tested included shackles of various sizes, configurations, and manufacturers; wire rope, instrument cages, chain, and a variety of interconnecting links such as weldless sling links and end links. All tests were conducted in a dry environment and the frequency of the applied cyclic loads was between 3 and 5 hertz. Load ranges between 4000 and 10,000 pounds (representative of what a surface mooring could possibly experience in the Arabian Sea) were used for the cyclic fatigue tests. Load range is defined here as the maximum tension minus the minimum tension attained during each load cycle. For example, tests conducted between 2000 and 6000 pounds tension had a load range of 4000 pounds.

The deployment of the Arabian Sea surface mooring is planned for six months. Assuming an average wave period of 7 seconds, the Arabian Sea mooring will accumulate approximately 2.5 million load cycles during the course of that six-month deployment. Failures during the cyclic fatigue tests of any in-line component occurring before 2.5 million cycles would be indicative of a potentially weak component.

Due to the expense of conducting the fatigue tests, it was not possible to obtain a complete data set whereby all components are tested for all ranges. Figure 1 is a plot of the number of cycles to first failure as a function of load range for 5/8" and 3/4" weldless sling links, and 3/4" chain and anchor-type shackles. The combined plot clearly shows the trend that as the load range increases, the number of cycles to first failure decreases. A relatively small increase in load range can significantly reduce the number of cycles the component can endure. Take, for example, the 3/4" anchor shackle. By increasing the load range from 6400 pounds to 8400 pounds, or a 31% increase in load range, the number of cycles to first failure dropped from 351,000 to 58,000 cycles, or by 83%. Hence, moderate increases in the loading on a mooring can greatly shorten its life expectancy.

Additional fatigue tests cycled various in-line components between 2000 and 6000 pounds. This range covers more than 90% of the loads predicted for the Arabian Sea surface mooring. Of particular concern was the fatigue characteristics of the 3/4" shackle since it appeared to be one of the weakest components in the mooring.

Thirteen galvanized 3/4" Crosby chain shackles were cycled between 2000 and 6000 pounds. The first failure occurred after 911,320 cycles. Of the remaining 12 shackles, five, or 42%, failed between 911,320 and 2,972,720 cycles. These results are obviously unacceptable for an intended deployment of six months since the risk of failure is too great.

Larger size shackles are not necessarily the answer, since the existing instrumentation cannot accept a shackle larger than 3/4". Fabrication of new instrument cages with larger bales is costly and was not budgeted. Larger components also mean more weight which translates to less payload that the mooring can support.

Shot peening is one technique that was tested to improve the fatigue life of the shackles without physically increasing their size. Shot peening is a process whereby a component is blasted with small spherical media called shot in a manner similar to the process of sand blasting. Each piece of shot acts like a small ball peen hammer and tends to dimple the surface that it strikes. At each dimple site the surface fiber of the material is placed in tension. Immediately below the surface of each dimple, the material is highly stressed in compression so as to counteract the tensile stress at the surface. A shot-peened part with its many overlapping dimples, therefore, has a surface layer with residual compressive stress. Cracks do not tend to initiate or propagate in a compressive stress zone. Since cracks usually start at the surface, a shot-peened component will take longer to develop a crack, thereby increasing the fatigue life of the part. Fatigue test results from shot-peened 3/4" shackles were compared with fatigue results obtained from non-shot peened shackles.

Eight 3/4" Crosby chain shackles were shot peened and cycled between 2000 and 6000 pounds. The first and only failure occurred after 5,000,000 cycles which is a factor of five better than the non-shot peened parts. Six of the remaining seven shackles were further tested and all reached 7,727,410 cycles without any failures. Of those six, four were randomly selected and cycled to 14,000,000 cycles without any failures. Based on these results shot peened 3/4" shackles were chosen for use on the Arabian Sea surface mooring. The test results indicate that the shot peened component could withstand the number of cycles expected during a six month deployment.

The effects of corrosion have not been considered in these fatigue tests. It is known that corrosion can reduce the fatigue strength by as much as half [1]. Use of a factor of safety between predicted loads and actual component performance helps to offset uncertainties about actual loading and the effects of corrosion.

The information gained from these cyclic fatigue tests is applicable wherever hardware is subjected to dynamic loads. Any structure subject to surface waves, whether it be in a moored or towed application, is stressed both statically and dynamically. Little information is currently available about the fatigue characteristics of hardware of this type. Hardware manufacturers are concerned primarily with the static load carrying capability of their products. Static loads are, however, only one part of the problem. Rarely does a manufacturer conduct any fatigue analysis of their product for a duration typical of mooring applications. Failures can occur quite rapidly even when components are subjected to cyclic loads which may be considerably less than the component's ultimate strength. The magnitude of the static and dynamic loads, duration and component fatigue endurance are important considerations which cannot be ignored in the design process.

ACKNOWLEDGEMENTS

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REFERENCE

[1] Battelle Memorial Institute, 1941: Prevention of Fatigue in Metals, John Wiley and Sons, Inc., New York

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