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VIBRATION MONITORING OF AN OFFSHORE PLATFORM

by

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ABSTRACT

The Vibration Activity Monitor is a relatively simple hardware and software system designed to provide updated predictions of the fatigue-loading activity in the jacket major-member welds of offshore oil platforms. The vibration recorder, positioned on the platform cellar deck, measures platform deck motion with two orthogonal accelerometers, and these motions are processed in real-time to provide hourly records of the direction and frequency of platform motion. The continuously recorded data is combined with transfer functions from a finite element structural model, which may be the platform design model or a refined version thereof, in order to predict and rank the fatigue activity in the joints. These predictions are used: 1) to verify and refine the platform design fatigue analysis; 2) to focus on areas where unanticipated fatigue activity has been observed; and 3) to help select the welds for detailed underwater inspection. The monitoring system was tested for a 50-day period on a North Sea platform.

The monitoring system could be modified to also record low frequency or static platform deformations due to ice, wind, and current loads. The modification would necessitate the use of underwater strain gauge sensors.

BACKGROUND

In the North Sea, a great deal of effort is required to periodically inspect offshore platforms for structural damage in order to minimize the risks to human life, the environment, and production. Most comprehensive inspection programs involve several levels of platform underwater inspection. Sophisticated equipment including, for example, remote-controlled vehicles and ultrasonic scanners are becoming available to reduce the time required for inspections and to improve the accuracy of the detailed inspections. Even with the advent of these tools, for the near future it will probably remain impractical and unnecessary to conduct detailed inspections of a large fraction of the joints on fixed platforms' steel jackets, which have a thousand or more joints.

The goal of this project was to develop a monitoring system to provide an additional rationale for selecting which joints should be included in the detailed inspections and for generalizing the results of the inspections that are conducted. Currently, these joints are selected on the basis of a number of inputs, including: the joint fatigue analysis conducted during platform design, static analysis to identify critical members, and past experiences with damage or failure of joints. In the case of an existing platform, these inputs can be augmented considerably by taking advantage of continuous records of the platform response to the wave loads and also by utilizing a computer model with structural parameters adjusted to match measured characteristics of the platform.

We have developed and tested a technique that combines continuously recorded platform response data and structural analysis using a refined computer model of the platform to rank order the jacket joints according to their calculated cyclic stress activity during the monitoring period.

The technique could be extended to other types of structures and other loading conditions if the appropriate design computer models were available and response measuring sensors were installed on the platform.

TECHNICAL DESCRIPTION

The Vibration Activity Monitoring System (VAMS) involves three elements: 1) the deck vibration recorder, 2) the structural model, and 3) joint activity analysis. These three elements, the equipment and function of each, and the interrelation among the elements are shown in Figure 1.

Continuous recordings of platform deck motion in two orthogonal directions form the basis of the technique. A finite element structural model, similar to those used in platform design, is used to calculate transfer functions between the deck motion and the stresses in jacket joints. These transfer functions are combined with the statistics of the deck motion to calculate the cyclic stress activity in the jacket joints for the interval over which the vibration data were measured.

One of the fundamental aspects of the VAMS technique is that measurements of the platform deck motion itself are used to characterize the sea state. A more classical formulation of the platform dynamics problem would involve characterizing the excitation in terms of the wave height and direction predictions or measurements and then calculating the platform response. Here, we characterize the platform motion by the deck response states, bypassing the characterization of the sea state and calculation of the deck response. The deck-motion state is characterized in terms of the amplitude and direction of the deck motion at the wave-excitation frequency. The hourly records are sorted into four bins according to the direction of the deck motion at the wave frequency. The records corresponding to each direction are then sorted into ten different bins according to the amplitude of the deck motion at the wave frequency. Thus, the raw deck-vibration data is sorted into 40 bins, each of which specifies a different deck-vibration state. Each of these deck-vibration states corresponds approximately to a particular sea state (waves of a certain height coming from a certain direction). Since the platform is somewhat stiffer in the end-on direction than the broadside direction, the direction of platform motion at the wave frequency can be slightly different, on the order of five degrees or ten degrees, from the wave direction.

The calculation of the joint fatigue activity first involves analyzing the deck vibration data to sort the records into a number of deck-motion states determined by deck motion direction and amplitude. Next, the deck motion statistics are combined with structural model transfer functions to compute for each joint the average stress amplitudes and frequencies for each of the deck-motion states. Finally, for each of the jacket joints considered, the joint activity is computed by adding together the contribution due to each of the deck-motion states. In the demonstration for Phillips platform 2/4 Delta, 40 deck-motion states were considered and 920 joints were analyzed.

The cyclic stress activity at the structural joints is computed using two relationships commonly employed in fatigue-type analysis. The first relation is the AWS-X-modified S-N curve. The second relationship from fatigue theory which is utilized is the Palmgren-Miner Rule for variable amplitude loading. This rule states that stress cycles of different amplitudes act independently. This means that the cumulative effect is simply the sum of the effects caused by cycles at each stress amplitude without regard to the temporal sequence of the stress amplitudes. The rule is usually stated in terms of a summation involving ratios of the actual number of cycles per amplitude to the number of cycles to produce fracture. In this analysis, the rule is utilized without introducing the number of cycles to fracture by summing terms involving the actual number of cycles at each stress amplitude times the stress amplitude raised to the power 4.38.

DEMONSTRATION TESTS

During a 50-day period, 15 September to 4 November, the deck vibration recorder, shown in Figure 2a, was installed on Phillips platform 2/4 Delta (Figure 2b) in the Ekofisk field in the North Sea. The data gathered during this period were analyzed, and the weld joints of the platform were ranked according to fatigue activity.

The deck vibration recorder was located inside the control room on the cellar deck level of the platform. Two accelerometers, one facing north and the other east, were positioned near the recorder. Figure 3 shows a histogram of deck vibration plotted on a logarithmic scale versus time for the demonstration period. Each line of data in the histogram represents the deck displacement, at the wave forcing frequency, averaged over a 67-minute interval. The displacement plotted is the vector sum of the north and east motions. The histogram clearly shows the periods of high wave activity which appear to have commenced on about 30 September. The fatigue activities of 920 welded joints were calculated from the data recorded during the test period using the model illustrated in Figure 1. The system is configured so that these calculations can be implemented with a desk-top computer by the field engineers responsible for the platform inspection and maintenance. The wave activity data and calculated joint fatigue results for the test period appeared reasonable on the basis of other available information.

MERITS AND LIMITATIONS

The primary merit of the technique is that the best available experimental and analytical technology is combined in an effective manner. The input to the technique is actual data measured continuously on the platform of interest. The use of actual platform motion data offers a considerable advantage over fatigue design analyses, which utilize statistical models of sea state as the input. This approach also offers distinct advantages over monitoring systems using wave measurements as inputs. Platform motion is more conveniently measured than are wave characteristics, and this approach also circumvents the difficult problem of calculating platform response to a given wave configuration.

A second merit of the technique is that a number of design codes with varying degrees of sophistication are currently available for computing the stress transfer functions required by this technique. In some cases, the results of a platform design or reanalysis effort can be used as baseline inputs for the technique. When more accuracy is required or a particular aspect of the platform response requires additional attention, a more complex wave-loading or response calculation code may be utilized to calculate the stress transfer functions. In the present case, a Bayesian parameter identification technique was utilized to refine the model parameters using forced vibration test data.

A third area of merit concerns the simplicity and reliability of the system. The two primary components of the deck vibration recorder, the analyzer and microcontroller, are standard, proven equipment that communicate through a standard IEEE bus. If either of these units malfunction, it may be readily replaced or repaired by factory-trained representatives.

The primary limitation of the deck vibration recording is that, currently, vibration at only one position is measured. Continuous measurements at several locations, particularly underwater at various levels on the jacket, would increase the accuracy. A secondary limitation of the deck-vibration recorder is that, currently, only the direction of wave motion (e.g., north-south) and not the direction of wave incidence (e.g., north) can be determined.

Some limitations are associated with simplifying aspects of the code and structural model used to calculate the stress transfer functions. The limitations of the demonstration calculation may be eliminated without further development by utilizing more complex codes and input information that are generally available. For example, the effect of the wave slamming excitation of water line members can be calculated by codes that were not used in this analysis. A second limitation of the demonstration calculation is that only four different wave-loading shapes were utilized; it is common to consider eight or more wave directions and also different wave heights. Also in the demonstration analysis, the loads were calculated at only one wavecrest position relative to the platform (maximum overturning moment). A more comprehensive calculation would involve stepping the wave through the platform and calculating the maximum stress at each weld. this is sometimes done in very detailed fatigue analyses but it is expensive. A compromise approach would be to consider the wave position corresponding to maximum vertical force on the platform in addition to that for maximum overturning moment or maximum base shear. As for the finite element model utilized, it could be further refined by incorporating more elements of increased complexity and by varying joint fixity.

It should also be noted that mean stresses caused by weight, wind, and current are not included in the fatigue analysis. Mean stresses are seldom taken into account in fatigue analyses because their effects are very difficult to analyze and are usually insignificant.

Finally, the results are subject to the inherent limitations of the fatigue analysis relationships utilized to calculate cyclic stress activity: the peak count method, the complex stress history rule, and the stress exponent of the S-N curve.

CONCLUSIONS

A baseline Vibration Activity Monitoring system has been developed and tested. This effort demonstrated, for this particular case history, the viability of a system that combines data from a relatively simple platform response monitor with structural transfer functions from a rather sophisticated platform design model in order to estimate the platform fatigue history. This concept could be extended to other applications where the effects of low-frequency or static loads, such as, wind, current, and ice loading are considered. The modifications to the system would probably include utilizing data from underwater strain gauges mounted to the structure. The system could also be modified for use on structures other than steel jacket platforms. The only requirement is the availability of a valid structural model that relates the structural motion at the monitoring positions to the stresses or strains at the critical regions of the structure.

ACKNOWLEDGMENT

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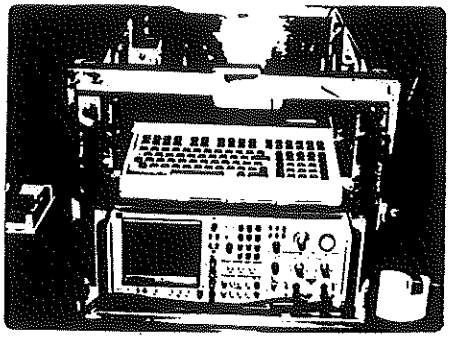

FIGURE 2a
Recorder

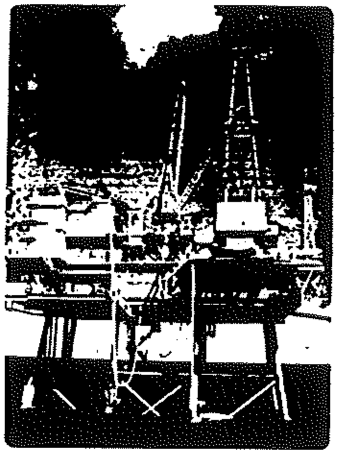

FIGURE 2b
Platform 2/4 Delta

VIBRATION RECORDER DEMONSTRATED
ON PHILLIPS PLATFORM 2/4 DELTA

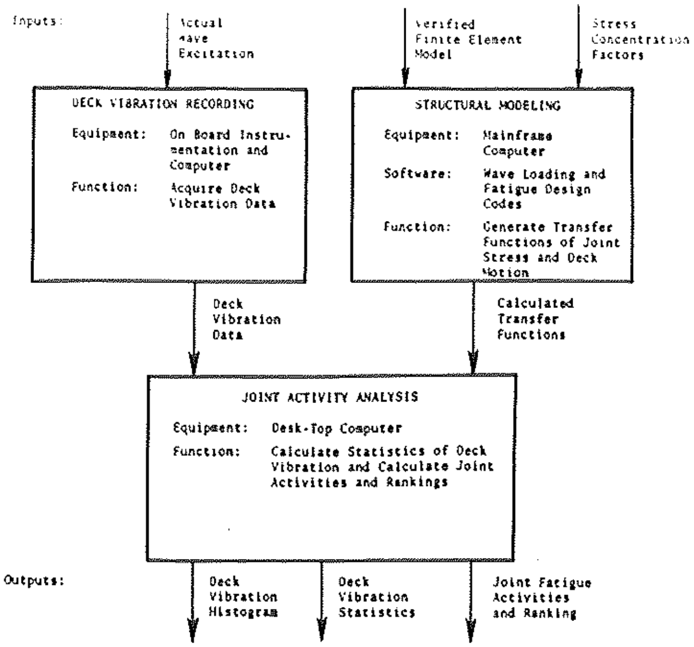

FIGURE 1: METHODOLOGY FOR VIBRATION
ACTIVITY MONITORING

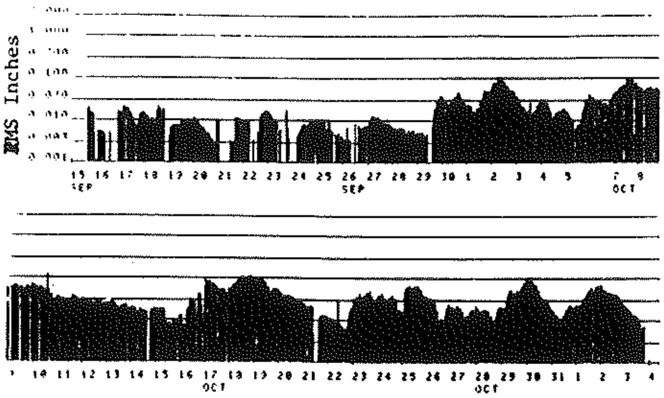

FIGURE 3

DECK DISPLACEMENT HISTOGRAM
TEST PERIOD (SEPT. 15 - NOV. 4)