DAMAGE EVALUATION OF AN OFFSHORE STRUCTURE MODEL USING MODAL ENERGY DISTRIBUTIONS

PAUL D. DSOUZA

Department of Mechanical and Industrial Engineering

APPROVED:

Dr. Roberto A. Osegueda, Co-Chair

Dr. W. Lionel Craver, Jr., Co-Chair

Dr. Chris K. Wu

Associate Vice-President for
Research and Graduate Studies

To

Mom and Dad

for your love, your sacrifices and your dreams

DAMAGE EVALUATION OF AN OFFSHORE STRUCTURE MODEL USING MODAL ENERGY DISTRIBUTIONS

by

Paul D. DSouza, B. Eng.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Mechanical and Industrial Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

December 1992

ACKNOWLEDGEMENTS

I wish to thank Dr. Roberto A. Osegueda for his support and guidance during the course of this study. He created an atmosphere of learning and creativity, in which I learned a lot and for which I am extremely grateful.

I would like to thank Dr. William Craver Jr. for co-chairing my thesis committee and for his encouragement and support. I also wish to thank Dr. Chris K. Wu. for his review and comments on this thesis.

This project was supported in part by the grant titled "Probabilistic Vibrational Damage Evaluation of Offshore Structures", Grant No. 03661-022, under the Advanced Technology Program of the Texas Higher Education Coordinating Board.

I would like to thank my parents, my sister and my relatives for their moral support during my study. My girlfriend Marina deserves special thanks for her constant encouragement and patience. I also appreciate Shekar, Qiang, Shashikantha, Jayanth, Probal, Rajesh and all my friends for their help.

ABSTRACT

The subject of evaluating damage in offshore structures using vibration measurements is revisited. Vibration signatures taken before and after the infliction of damage are considered. The perspective of using frequency and mode shape measurements to evaluate internal modal energy distribution among the elements is taken. Comparisons of normalized modal energy distributions of the undamaged and severed structure provided trends for the identification of the inflicted damage. Damage experiments were conducted on a three-level laboratory model housed within a tank. Element distribution of modal energy indicated the sensitivity of the modes to damage and the specific elements that are likely to affect the modes. If a particular mode is sensitive to damage in an element, damage in that member is reflected by an apparent increase in the energy of the member, accompanied by energy changes in adjacent elements.

TABLE OF CONTENTS

CHAPTER PAGE NO

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE NO.

FIGURE PAGE NO.

FIGURE PAGE NO.

FIGURE PAGE NO.

FIGURE PAGE NO.

FIGURE PAGE NO.

CHAPTER 1

INTRODUCTION

The importance of establishing a damage evaluation monitoring system for offshore structures ranges from reasons of safety - to inspection costs - and to protect investments and operations of the offshore drilling infrastructure. Predominantly, most of the inspections of platforms are performed by underwater inspection and ultrasonics. These techniques are expensive and require significant amounts of diver-hours and the use of expensive equipment underwater. Furthermore, the marine growth and corrosion in these environments make the inspections less effective. Although, there is no data available on the effectiveness of current inspection methods, occasional collapses of oil rigs illustrate the problem.

The main advantage that an effective vibrational method may offer over other inspection methods is that once a system is installed, underwater diving may not be as routinely required. Such method could also evolve into a continuous integrity monitoring system that may trigger an "alarm" to evacuate workers if a dangerous situation is diagnosed. This future potential could make vibrational methods superior to any other inspection method for offshore applications.

1.1 Overview of Vibrational Damage Evaluation of Offshore Structures

The use of vibration measurements for detecting and evaluating damage in structures is based on the fact that the vibration characteristics are functions of the structural parameters, i.e. stiffness, mass and damping [1,2,3,4]. Since stiffness losses usually accompany damage, damage causes changes in the vibration characteristics. Thus, evaluation methods from vibration measurements use resonant frequency shifts and changes in mode shapes and damping ratios to infer damage or failures.

Offshore structures have been the subject of damage evaluation studies using vibration measurements [5,6,7,8,9,10]. All the proceeding studies have either relied on ambient-induced forces or on mechanical shakers to excite the structure while the response in sensed using accelerometers. Vandiver [11] was among the first researchers to investigate the detection of structural failure from measurements of the dynamic responses. He used statistical energy analyses to interpret results of a computer model. Loland and Dodds [12] reviewed and discussed experiences in developing and operating structural monitoring systems. Wajnorowski, *et al* [8] and Stevenson and Rubin [13] have presented descriptive papers on the subject. Duggan and co-workers [14,15] and Rubin [16] independently performed damaged tests on platforms in the Gulf of Mexico using ambient excitations. Duggan, *et al* [14,15] concluded that positive identification of the fundamental modes was possible but repeatability of dynamic measurements was difficult. They also concluded that changes of the modes would not be distinguishable

from shifts caused by normal drilling operations. Rubin [16] added that frequencies of higher modes can be detected but the mode shapes could not be evaluated. Rubin and Coppolino [17,18] further evaluated the acquired data and studied damage sensitivities aspects of their research. This work led to the development of a flexibility monitoring method for the detection of major damage as reported by Rubin and Coppolino [19]. The method considers the fundamental modes and uses parameters related to the shear flexibility of each framing bay. They observed that failures in vertical diagonal braces produce changes in the shear flexibility parameters. Kenley and Dodds [6] showed that complete severance of a member can be detected from vibration measurements.

Crohas and Lepert [5] field tested a damage-detection monitoring system by comparing transfer functions at specific braces of a platform before and after damage, and concluded that the method can detect and locate a flooded or damaged brace.

This review has revealed a significant variation in experimental approaches and procedures. In experimental methods, the approaches used by Crohas and Lepert [5] and Nataraja [7] consisted of mechanical excitations of the platform to generate frequency response functions. The method used by Yang and co-workers [9,10] relied on the random forces of wind, waves and currents to provide the excitation. In all cases the motion was sensed using accelerometers.

The analytical procedures to analyze the transduced signal were equally varied. These procedures included the Random Decrement Method [9,10], Fast Fourier Transforms [5], spectral energy analysis [6,11] and engineering judgement [8]. In each case, the analytical procedure yields a vibrational signature of the damaged structure that is compared to either the signature of the undamaged platform [5,7,9,10] or to the vibrational characteristics of a finite element model [6,8].

Each method makes a different claim regarding the effectiveness and practicality of the structural integrity technique. For example, Nataraja [7] concluded that such techniques comprising accelerometers can only detect global changes but cannot locate the damage. Yang and co-workers [9,10] claimed that the Random Decrement Technique was able to detect damage and non-damage situations. Crohas and Lepert [5] concluded that their vibro-detection technique possesses considerable capability for integrity monitoring and design of offshore platforms.

It is interesting to observe that although all the above methods have the objective to evaluate damage in offshore platforms, and that the experimental phase of each method produces the same modified vibrational characteristics, such a broad variation existed on the prevailing models. This variation was later unified by Stubbs and Osegueda [20,21,22,23] where a theoretical basis for damage evaluation of a structure from changes in vibrational characteristics was presented.

This deterministic formulation initially reported by Stubbs [20] and Stubbs and Osegueda [21], and then adapted for fixed offshore platforms [22], consisted of analytically relating the sensitivities of damage as a function of location to the changes of eigenfrequencies due to damage. The formulation was analytically verified using damage simulations in finite element models [22] and experimentally verified [23] using data acquired by Kenley and Dodds [6] before and after a damage was inflicted. In general, the location of the damage was located. Chen [26] and Hussaini [27] experimentally have also verified Stubbs' method using experiments on a two-dimensional and three-dimensional laboratory truss, respectively.

The fact that such structures are massive, and that shakers and other natural methods of excitation fail to excite but few modes [6], the number of experimentally extracted eigenfrequencies is usually limited. Therefore, if the structure is too complex, the Stubbs' method may fail to provide the location of the damage.

In a recent development, Osegueda [24] expanded Stubbs' formulation [20] to include relationships between the changes of modal shapes to structural damage as a function of location. He found that the inclusion of a modal shape into the previous formulation provides an equation for each point at which the modal amplitude is measured. Therefore, it may not be necessary to monitor a large number of frequencies (difficult to measure) but it may be necessary to acquire the modal shapes by using

several measuring locations.

The extraction of mode shapes in conventional structures is routinely performed using established modal analysis methods which are widely reported in Reference [25]. However, modal analysis presupposes linearity and requires the measurement of the input excitation. Because the fluid-structure interaction encountered in offshore structures causes the structure to behave non-linearly, the level of excitation must be controlled and consistent before and after the damage, and the use of impact testing is prohibited. When mechanical shakers are used (displacement method), the modal identification is a linearized solution. The problem is also complicated by the fact that excitations provided by wind, waves and currents are almost impossible to measure.

Therefore, despite the number of attempts to establish a monitoring system of offshore structures by vibrational methods all of the above factors may have contributed to the different claims about the effectiveness and practicality of the methods mentioned.

In these studies, the experimental procedures yielded vibrational signatures of the damaged and/or undamaged structures. These signatures consisted of frequency response spectrums, natural frequencies, mode shapes and damping ratios. The integrity evaluations were all attempted by comparing the signatures of the severed structure to either the signatures of the undamaged structure or to the characteristics of finite element