# NDT Methods Applied to Fatigue Reliability Assessment of Structures

ASCE

SEI

# NDT METHODS APPLIED TO FATIGUE RELIABILITY ASSESSMENT OF STRUCTURES

SPONSORED BY
Fatigue and Fracture Reliability Committee
Structural Engineering Institute (SEI) of the American Society of Civil Engineers

EDITED BY
Jamshid Mohammadi

ASCE

SEI
Structural Engineering Institute

Library of Congress Cataloging-in-Publication Data

Non-destructive test (NDT) methods applied to fatigue reliability assessment of structures / prepared by Fatigue and Fracture Reliability Committee, Structural Engineering Institute, American Society of Civil Engineers ; edited by Jamshid Mohammadi.
p. cm.
Includes bibliographic references and index.
ISBN 0-7844-0742-8
1. Non-destructive testing. 2. Materials--Fatigue. I. Mohammadi, Jamshid. II. Structural Engineering Institute. Fatigue and Fracture Reliability Committee. III. American Society of Civil Engineers.

TA417.2.N654 2004
620.1'12--dc22 2004051812

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia 20191
www.pubs.asce.org


ISBN 0-7844-0742-8
Manufactured in the United States of America.

# Preface

This publication presents a series of papers on the application of non-destructive test (NDT) methods in fatigue and fracture reliability analysis of structures. The publication is intended as a collection of case studies where NDT methods have demonstrated to be an effective tool in the assessment of structural reliability. These case studies cover a variety of problems and provide the reader with in-depth discussions on very specific applications of the NDT methods. The Fatigue and Fracture Reliability Committee (FFRC) of the Structural Engineering Institute (SEI) of the American Society of Civil Engineers initiated this publication as a project through supports from SEI. FFRC has an active membership of 13-15 members at any given time. The project would not have been possible without the many hours of volunteer work by these FFRC members. The FFRC membership is pleased with the quality of papers presented in this publication and hopes that the papers presented herein can provide practicing engineers with an introduction of NDT methods with immediate applications to real world problems.

Fatigue and Fracture Reliability Committee

# Contents

# An Overview of Non-Destructive Test Methods in Fatigue and Fracture Reliability Assessment

Jamshid Mohammadi[1], MASCE

*Abstract*

With the growing demand for repair, retrofit and reconstruction of aging structures, there is a critical need for methods that can effectively and reliably be used in identifying potential modes of damage and the current condition of a given structure. When the applied load is of cyclic nature, an affected structure will be subject to fatigue damage. The decision to repair, retrofit or reconstruction of such a structure requires a careful planning and investigation on the nature and extent of damage and estimation of the remaining useful life of the structure. The estimation of damage and prediction of the remaining life can only be obtained through a probabilistic analysis using information on the applied stress history, fatigue and fracture behavior of the structure and the geometry of its critical components. Non-destructive test (NDT) methods play an important role in gathering such information and in conduct of a reliability analysis for determining the condition of the structure and estimating its remaining useful life. Depending on the type of a structure and its condition, NDT methods may simply involve an inspection process with data collection, especially on stress ranges at fatigue-critical components. More comprehensive methods may require a rigorous program of monitoring along with various tests and analyses to accurately assess the condition of the structure. The results of such techniques and analyses can be useful in establishing the fatigue reliability profile of the structure and in a cost-effective scheduling of future repair, retrofit or reconstruction activities. In this paper, an overview of NDT methods with specific applications to fatigue and fracture reliability estimation is presented. Specifically, this paper serves as an introduction to what is presented elsewhere in this volume on the subject of NDT methods to fatigue and fracture reliability assessment of structures.

---

1 Dept. of Civil and Arch. Engrg., Illinois Institute of Technology, Chicago, Illinois 60616

*Introduction*

Fatigue and fracture constitute major modes of failure to a large class of structures. The failure process often occurs in systems that are subject to a dynamic cyclic load action. Although the failure mechanism in essence is the same for various types of affected structures, the load process and the methods via which structures are assessed for failure may be different. The assessment usually begins with the evaluation of the current condition. This is then followed by a more rigorous assessment process that may range from visual inspection to X-ray inspection or detection of acoustic emissions (Byers, et al, 1997). These methods may also involve detailed structural analyses as well as long-term monitoring using sensors to compile data on applied stresses at fatigue- or fracture-critical components.

As it is well recognized, any such assessment programs will ensure the prolonged life of the structure and will be effective in preventing sudden failures. Various assessment methods, whether involve monitoring, analysis, and structural tests, are considered non-destructive if they do not interfere with the integrity and performance of the structure. A specific non-destructive test (NDT) method can be designed to address the structure's demand for fatigue and fracture reliability assessment. For lower-risk and less important structures, simple methods are often used; whereas, high-risk structures demand more detailed procedures that may require advanced NDT methods (Byers, et al, 1997). As expected, many NDT methods are available today; and newer methods are arriving every day. With such a variety of methods available, the decision on selecting a method for a given structure may become a challenging task. Successful past applications and case studies would offer an insight into whether a specific method is suitable for condition assessment in a given structure especially when fatigue and fracture modes of failure are prevalent.

The computation of fatigue damage for use in a reliability analysis is either based on the Miner damage rule or the fracture mechanics method utilizing crack growth behavior and stress cycle history. For either method, one needs to have information on the stress history, geometry, material strength, the dead load, and the overall fatigue damage or crack growth behavior of the component. The computation of the reliability is conducted for a given number of stress cycle and initial crack size (when the fracture mechanics method is used). For this computation, one of several common reliability analysis methods, such as the first or second order reliability method (FORM or SORM), or Monte Carlo simulation process may be used (see for example, Ang and Tang, 1984; Haldar and Mahadevan, 1999). The results are often presented in the form of a "reliability profile" curve, which shows the relation between reliability and stress cycles (or time). Regardless of the method of analysis selected for the system reliability estimation, the knowledge of uncertainty inherent in the system (or component) geometry, strength, fatigue or fracture behavior and stress history is needed. Various NDT methods may especially be helpful in providing data for use in the system reliability analysis.

To compile a series of sample application studies, the Fatigue and Fracture Reliability Committee (FFRC) of Structural Engineering Institute (SEI) initiated a project to compile a collection of papers that address the specific application of various NDT methods in fatigue and fracture reliability assessment. The papers presented elsewhere in this publication each focuses on a specific application and provides the reader with detailed information on how such methods can effectively be applied in real world problems. Applications cited discuss such problems as steel girder bridges, airframe systems, welded connections, bridge components (including concrete slabs) and other systems that may be subject to fracture failure. Although these applications are limited, they are intended to provide the reader with information on an overall process that may be used in similar situations.

*An Overview of Various NDT Applications*

As it is evident from several papers presented in this volume, structural monitoring dominates the NDT methods in fatigue and fracture reliability assessment. Structural monitoring is cost-effective and provides for the information needed for structural life estimation of structures. In some applications (such as in highway bridges), monitoring is applied for a relatively short period of time (a few days); whereas, in others (such as in aircraft) monitoring is often carried out for a much longer time (as long as several hundred cumulative flight hours). A discussion on the duration of data acquisition process for monitoring several types of structures (such as highway and railroad bridges, off-shore platforms, aircraft and structural members affected by vibrations generated by mechanical systems) can be found in Mohammadi (2001). The reliability assessment can be obtained only after an ample amount of data is compiled and a rigorous analysis is conducted to arrive at life estimates. The process of data compilation requires installation of sensors at various locations (where fatigue damage is more critical). Often a careful planning and evaluation of the structure will be needed to optimize the number of sensors and the data collection effort. Several of the application papers presented in this volume discuss the NDT application using the monitoring process (see papers by Fu; Mohammadi, et al; and Braun and Mohammadi).

In some applications, the process of condition assessment requires identification of the extent of damage, size of crack and deterioration of structural members. Non-destructive methods in these applications may involve using various available techniques such as acoustic emission, electro-magnetic, portable hardness test, liquid penetrant, magnetic particle, radiography, residual stress by hole drill, and ultrasonic methods. Each method is suitable for one or more problem areas such as local damages that cause discontinuity in the cross section and the material in the affected structure. Some of these methods may require use of test equipment and application of a force on the structure via an impact-producing device. The information from these methods can be used in identifying how the resistance capability of a component has been reduced. This in turn can be used along with a detailed structural analysis to determine the changes that have occurred to the