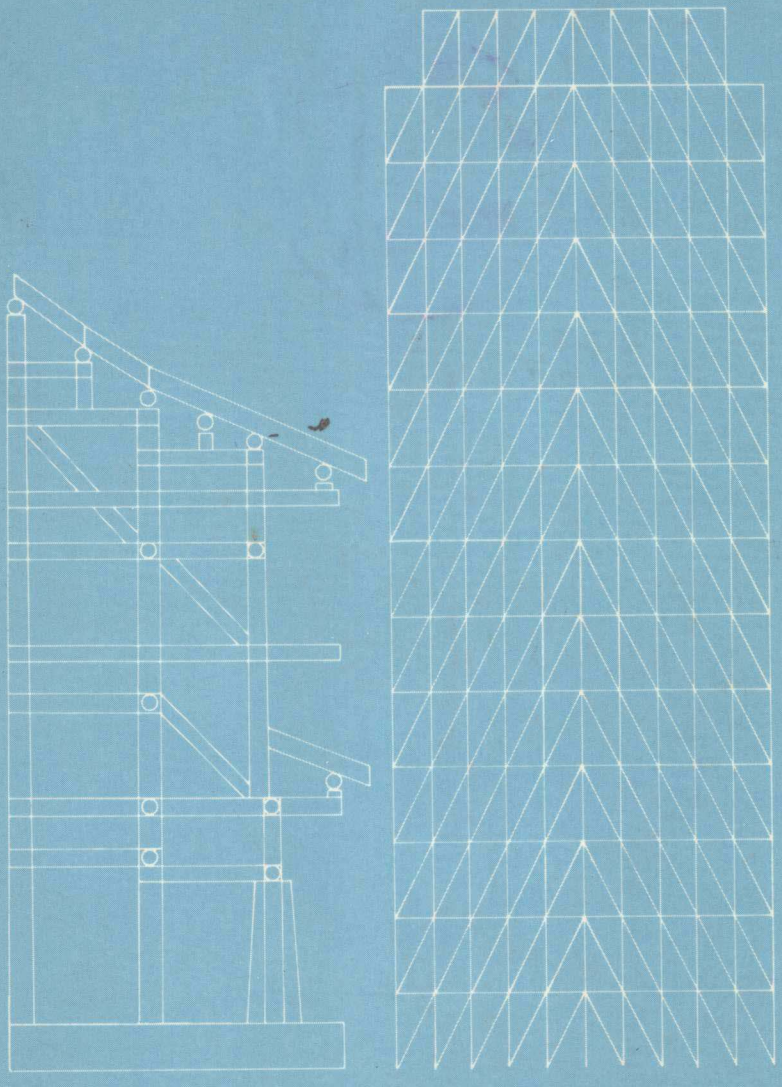
INTELLIGENT STRUCTURES-2

MONITORING AND CONTROL

Edited by

Y.K. WEN



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Preface

Construction is the largest industry in the world. Yet technology to monitor and maintain the health of building and structural systems under natural and man-made loadings has only begun to receive the attention that it deserves. Recently there have been fast developments in analytical/numerical modeling of the structural systems including uncertainty in both loading and resistance. At the same time, new technologies and hardware have been invented which make real time sensing, monitoring and control of structural systems possible and feasible. To promote exchange of information, research cooperation and introduction of new ideas and concepts, a trilateral US/Italy/Japan Workshop/Seminar on Intelligent Systems was held in Perugia, Italy, 27-29 June, 1991. Investigators from US, Italy, Japan and other Western European countries gave presentations of papers and participated in group discussion. The topical areas of interest were:

1 Assessment of state of system: damage and effect of uncertainty, methods of knowledge-based expert systems, and neural networks.

2 Measurement of system performance: sensor techniques and computer-aided adaptive systems.

3 Control and isolation of system: dynamic experiments, system design, and algorithm development.

The presentations and summaries of group discussions are included in this book. It represents a summary of the state-of-art of this new and fast growing research area and also suggests directions for further research. This is the second International Workshop* of this nature. The first one was held in Taipei, Taiwan in July, 1990.

Y.K. Wen

Acknowledgements

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NEW DEVELOPMENTS IN NONDESTRUCTIVE EVALUATION

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ABSTRACT

Due to environmental, man-made and natural hazards, infrastructure of public works in the world is deteriorating. Nondestructive evaluation (NDE) is essential for condition assessment for repair, retrofit, rehabilitation, and replacement (if needed) to insure the public safety. In this paper an overview of nondestructive evaluation projects, including a new initiative and four new awards on Quantitative NDE for Large Structural Systems, is presented.

KEYWORDS: Non-destructive evaluation; structures, condition assessment

INTRODUCTION

The world invests about US $1,430 billion annually in the construction of structures, including: buildings (residential, commercial, industrial, etc.), civil works, and utilities, such as highways, water and sewer structures, railroads, and transmission lines. Construction is the largest industry in the world amounting to 10% of the world's gross domestic product.

Structures are generally the most expensive investments/assets in any country. In addition

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Note: Part of this paper is taken from "Overview of Nondestructive Evaluation Projects and Initiative at NSF" by K. P. Chong, J. B. Scalzi and O. W. Dillon in Intelligent Structures, Elsevier, London, 1990.

*to present paper

structures have long service life compared with any other kinds of commercial product, and are rarely replaceable once they are erected. Yet the feedback and controls on the "state of health" of structures are practically non-existent (compared with say the much less costly automobiles). Nondestructive evaluation is an essential part of this feedback and monitoring system for infrastructures.

During the past several years, many reports have been published concerning the sad state of deterioration of the nation's public works, such as bridges, roadways, water and sewer systems, ports, harbors, airports, and buildings of all types. According to the 1988 National Research Council Report on "Building for Tomorrow" estimates of public infrastructure amounted to $409 trillion in 1984, and growing rapidly. The U.S. Interstate System, built in the 1950's needs repair, so do most of the state and county secondary roads. Some 42% of all U.S. highway bridges are inadequate and half of school buildings are 50 years or older. In the U. S. alone, recent bridge collapses include:

- Mianus River Bridge - Connecticut, 1986, 3 deaths
- Schoharie Creek - New York, 1987, 10 deaths
- Hatchie River - Tennessee, 1989, 8 deaths
- Miamis Town River - Ohio, 1989, 2 deaths

According to David Aschauer (Chief Economist of U.S. Federal Reserve Bank - Chicago), a 1% increase in public capital causes 1/3% rise in productivity. From 1971 to 1985 U.S. productivity growth fell 1.2%, out of which 1% was attributed to neglect of the infrastructure. If the present infrastructure deterioration continues, the Department of Transportation estimates that the U.S. economy will miss out on:

- 3.2% growth in GNP
- 5.9% disposable income
- 2.2% employment
- 2.7% productivity

The infrastructure ages and deteriorates with time. The deterioration is mostly a result of aging of the materials, excessive use, overloading, climatic conditions, lack of sufficient maintenance, and difficulties encountered in proper inspection methods. All of these factors contribute to the obsolescence of the structural system as a whole. As a result, repair, retrofit, rehabilitation, and replacement become necessary to insure the safety of the public.

THE PROBLEM

In order to evaluate the safety of a structure, it is essential to determine the remaining strength of the total system by a performance analysis based upon the strength and inspection data of the materials and the structural system.

A visual inspection process will provide data with respect to the external physical condition of the material such as the degree of corrosion and general deterioration. By past experience and judgement an engineer will evaluate the remaining life of the material and the contribution to the safety of the structure.

Strength determinations may be made by sampling the material and testing it in a laboratory. However, this method destroys some of the structure which subsequently must then be repaired. The repair is usually noticeable and disruptive, as a result, many engineers would prefer a nondestructive technique.

THE SOLUTION

Although there are many techniques for nondestructive evaluation (NDE) currently available for metals which are used in defense and manufactured products, there are only a few which are available for the construction materials such as wood, concrete, masonry, and steel. These current methods for construction materials are not very reliable and in some instances they can only be used on a comparative qualitative basis. Instruments specifically designed for construction materials and with greater accuracy than those

currently available are required in order to quantitatively evaluate the safety of the structure and to estimate its remaining life adequately.

NSF ACTIVITY IN NDE

The NSF Division of Mechanical and Structural Systems is encouraging basic research to investigate the requirements to develop suitable instruments for nondestructive evaluation of strength properties and other physical conditions for construction materials. The Program Directors in the Division are encouraging multi-disciplinary activities involving electrical, mechanical, chemical, computer, electronic and structural engineers, as suitable for the project to perform group or team efforts in the research projects. Unfortunately, this "encouragement" should not be interpreted as large sums of new money for this approach. Rather this is our personal assessment with which all of us agree.

NSF is also encouraging close cooperation and active participation by the industries involved in the manufacture of nondestructive equipment and/or instrumentation. By joint efforts viable products can result which will be of great help to engineers responsible for the safety and longevity evaluation of structural systems.

As a source of information on the type of questions which the engineering community would like to have answered by the use of nondestructive evaluation techniques, NSF supported two workshops to outline specific needs of the profession. One was held in February, 1988, at the University of Southern California, Los Angeles, and the Proceedings are titled, "Nondestructive Evaluation for Performance of Civil Structures." The contact person is Dr. Sami F. Masri. The other workshop was held in June, 1989, at the National Institute of Standards and Technology, at Gaithersburg, Maryland, titled International Workshop on Sensors and Measurement Techniques for Assessing Structural Performance," organized by Dr. Richard D. Marshall and his associates.

CENTERS AND OTHER NDE ACTIVITIES

In addition to NDE research done at MIT, Illinois, Cornell, West Virginia, Virginia Tech, New Jersey Institute of Technology, Georgia Tech, etc., the following centers concentrate on various aspects of NDE.

I. Johns Hopkins Center for NDE (R. Green)

- Heavy on experiment
- Advanced sensors
- Artificial intelligence
- Life cycle management - include fracture, fatigue
- Measurement science for microelectronics
- Process control

The closest project to large structural system is the infrared television for wall thinning of buried pipelines.

II. Iowa State Center for NDE (D. Thompson)

- NSF Industry/University CRC
- Modeling efforts emphasized
- Advanced ultrasonic NDE
- Advanced electromagnetic NDE
- X-Ray & thermal NDE imaging
- NDE for materials properties
- NDE for advanced composites
- Ultrasonic stress measurement

III. National Institute of Standards and Technology

- Transducer standards
- Pulse-echo testing of concrete
- Automated manufacturing
- Metals, plastics, ceramics, paints, etc.

IV. NASA - Langley NDE Center (J. Heyman)

- Space structures
- Aging aircrafts
- Imbedded sensors
- Smart structures

NSF INITIATIVE

Believing that "an ounce of prevention is better than a pound of cure," and that NSF should play a leading role in addition to be acting as a catalyst in the "Quantitative Nondestructive Evaluation for Large Structural Systems" in civil engineering, a NSF initiative was issued in April 1990. The deadline for receipt of proposals was set at June 1, 1990. The initiative was sponsored by the following four programs, totalling $1M, over a two year period. Program directors involved are listed below.

Dr. John B. Scalzi - Structures and Large Systems

Dr. Ken P. Chong - Structures and Building Systems

Dr. Oscar Dillon - Solid Mechanics

Dr. Thomas Zimmie - Geotechnical, Geomechanics
Academic and research institutions in the United States with engineering, research and educational programs were invited to submit proposals. The contents of the proposal must clearly relate to the research topics described in the Programs of the Division of Mechanical and Structural Systems of the National Science Foundation.

Projects were encouraged to be multidisciplinary in nature involving investigators from one or more departments at a single institution or from several institutions wherever the required expertise may be located. It was envisioned that projects may include researchers from the following engineering and science disciplines: structural, mechanical, material science, electrical, geotechnical, computer science, chemical or chemistry, electronic and others as appropriated. A team or group effort was strongly encouraged to achieve the desired result and final product of research. Contributions of all the participants must be combined into a single integrated proposal which conformed to the usual requirements and limitations of a proposal length. Each researcher must have a scope of work which contributes to the entire project.

Industry collaboration is highly desirable and may be in the form of participating personnel, loan of

equipment, gifts, supplies of various kinds, and/or financial contributions. The academic institution must be the prime research management organization.

A panel of experts have been convened to evaluate the proposals on a competitive basis. The investigators and the synergistic benefits derived, as well as how these interactions are to be organized and performed, are examined.

SPECIFIC TOPICS OF THE NSF INITIATIVE

Research efforts are to be directed toward increasing fundamental knowledge of quantitative nondestructive evaluation of construction materials and their application to large structural systems of wood, concrete, masonry and steel. The data developed for equipment may be for the material properties alone or for the fabricated forms as total systems. Some data may be used to determine how each system or material deteriorates with time and excessive loads. The data and prototype resulting from the research should be of such a nature that the resulting equipment may be useful for practitioners, and can be produced as a viable portable and economical commercial product.

SUGGESTED RESEARCH TOPICS OF INTEREST

The following topics of interest were published in the NSF Initiative.

- Determination of wood properties - above and below ground
- Determination of concrete properties - above and below ground
- Determination of masonry properties
- Determination of steel safety remaining as a result of corrosion
- Determination of initial cracking in steel and concrete, including welds and rebars due to fatigue, fabrication, or design faults