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RESULTS OF WORKSHOP ON STRUCTURAL HEALTH MONITORING ROLE IN BRIDGE SECURITY

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Abstract

The role of Structural Health Monitoring (SHM) in the bridge security arena is not well defined or understood. In order to investigate this issue, a workshop was held with representative members consisting of bridge owners, academia/researchers, consultants, and security personnel. This workshop organized by the Weidlinger Associates was co-sponsored by the Federal Highway Administration and the New York State Department of Transportation. The workshop deliberated several aspects of this issue, including various SHM technologies, measurement methods, hazards that affect bridge security, temporal nature of security (before, during, and after event), interaction between hazards, bridge components and disciplines, and interaction between stakeholders. A summary of the workshop deliberations along with some of the relevant results, obtained using statistical analyses, are reported in this paper. Such results can be of help to the SHM and security communities in understanding the role of SHM in enhancing bridge security and to focus/prioritize their efforts in this field.

INTRODUCTION

Bridge security has emerged as an important subject. Protecting our bridge structures, which represent key components of our transportation infrastructure, is essential for national security, mobility, and economic vitality. Direct attacks on critical structures could lead to casualties and profound damage to regional and national economies. However, because each bridge is unique and complex, defining and securing vulnerable components against varied threats presents a challenge. Securing structural components of a bridge is only one part. Overall site conditions and lifelines often carried by bridges also need to be protected. These coupled with numerous stakeholders who must interact efficiently in times of crisis makes “bridge security” a complex subject (Ettouney and Alampalli, 2007).

Structural Health Monitoring (SHM) has also emerged recently as a viable engineering field with the potential of helping bridge owners increase safety while reducing operating and maintenance costs, and thereby increasing the service life of bridges. SHM has been shown to be of help in normal bridge operating conditions for monitoring corrosion and fatigue, and for monitoring structural behavior under abnormal hazards such as earthquakes, floods, and high winds.

Given the emerging complex needs of bridge security and the tools and techniques of SHM, we can ask the following questions (Ettouney and Alampalli, 2007):

- How pertinent is the use of SHM tools to the subject of bridge security?
- Even if SHM tools are pertinent for bridge security, how important are they in resolving bridge security issues?
- What is the current availability of SHM tools that can enhance bridge security?
- Is there a value (cost–benefit) in using SHM for enhancing bridge security?
- What are the needs of various stake-holders for efficient interaction of SHM-Bridge security demands (multidisciplinary issues)?
- Can SHM tools, which have been developed for other hazards, be utilized efficiently to enhance bridge security (multihazards issues)?

It is obvious that finding detailed answers to the above questions involves immense effort and research. The recently formed Bridge Security subcommittee of the FHWA Virtual Team on SHM embarked on an effort to address some of the above questions (Ettouney and Alampalli, 2007).

A workshop of the Bridge Security subcommittee of the SHM and Bridge Security Virtual Team was convened at the offices of the Weidlinger Associates, New York, NY on January 12, 2006. The number of attendees and length of the workshop was limited by available resources. Thus, the one-day workshop was limited to ten attendees who were representative stakeholders. The deliberations of the attendees during the workshop proved to be very valuable and useful to all the attendees and this Report's contents reflect the width and breadth of the deliberations. The findings of the workshop should help decision makers, who are responsible for enhancing bridge security and prioritizing their available resources to get optimal value. This paper presents the overall description of the workshop. One of the five topics that were deliberated during the workshop is also discussed. The complete workshop report will be published by the New York State Department of Transportation (Ettouney and Alampalli, 2007).

DESCRIPTION OF WORKSHOP

Overview

This section discusses the workshop structure. First, the metrics that govern SHM-Bridge Security are defined. This is followed by a description of SHM technologies and bridge components; both subjects were discussed in length during the workshop. The statistical rules followed in producing the quantitative results of the workshop are then presented. Finally the organization of the rest of the section is discussed (Ettouney and Alampalli, 2007).

Topics

The workshop deliberated several topics that pertain to SHM technologies and bridge security. Some of these topics are described below.

Applicability: As the term implies, the applicability issue explores whether one item (usually a SHM technology) is applicable for use with another item (usually related to bridge security).

Importance: The importance term explores the question that if the use of two items in a relationship to each other is applicable, how important is such a use? The answers and scores of this question can help decision makers in prioritizing their efforts so that important issues are accommodated first.

Availability: The availability issue explores whether a specific SHM technology is available for use in a given bridge security area. The answers and scores of this metric can help manufacturers, researchers, owners, and government agencies in prioritizing research and development efforts.

Current Practice and Future Needs: When two items are judged to be applicable and relevant to each other, sometimes it is beneficial to explore the adequacy of current practices in using a specific item (e.g., SHM technology) to improve another issue (e.g., particular bridge security issue). In addition, the future needs of this issue were also explored. The current and future needs help decision makers in understanding the present conditions and plan for the future.

Cost – Benefit and Value: The cost and benefit metrics were used in some of the questions during the workshop. Cost of several SHM activities is usually measured in monetary units, and sometimes, in non-monetary units (such as social and psychological costs). Benefits of the SHM measures are generally measured in terms of increased security. The value, for the purpose of this workshop, was defined as the benefit-to-cost ratio.
All parameters (cost, benefit, and value) were qualitative. Two types of value were considered: perceived value and actual value. A perceived value is the value as perceived by the public as a whole. Actual value is the value as judged by experts. Since all attendees in this workshop are considered experts in their field, it is assumed that they can estimate reasonably accurate evaluations (both perceived and actual values) of various SHM techniques in the bridge security field.

SHM Technologies
It was argued (see Ettouney and Alampalli, 2000) that the Structural Health in Civil Engineering (or SHM) community includes four major components: measurements (sensors and instrumentations), structural identification, damage identification, and decision-making. Due to the time and resource limitations, the current workshop was limited to the measurements component. Measurements relate to identification of the condition of the structure before, during, and after an event. These are important to document the baseline structural condition, to understand the collapse mechanisms, and to evaluate the structure condition immediately after the event for safety and continued use. As such, several technologies were identified that can be used in the bridge security field and include, but were not limited to the following: Strains / stresses, Motion (including displacements, velocities, and accelerations), Chem. – Bio, Remote Monitoring, Imaging techniques, Electromagnetic, and Biometric.
Some of the above technologies overlapped; however, it was felt that during deliberations the attendees could overcome such overlaps. During the workshop, it was also observed that the above categorization mixes measured subjects (such as motion and strains) with technology (such as electromagnetic). Such a shortcoming should be corrected in future activities.

SECURITY OF BRIDGE COMPONENTS AND SHM

Bridge security is a broad and complex subject. Hence, it was decided to divide it into five broad areas (Ettouney and Alampalli, 2007). Each issue in turn was subdivided as given in Table 1.

Table 1. Areas of Bridge Security

Hardening	**Redundancy**	**Integration issues**	**Guidelines**	**Management / Owners**
Superstructure	Fire	Risk Management and Assessment	General	Safety
Substructure	Total/partial collapse	Site Considerations	Structural	Cost
Utilities	Chem.-Bio.	Physical Security	Geotechnical	
Foundations				

Analysis (Statistical) Procedure

In all averaging processes, any blank entry was assigned a zero. There were several “NA” (Not Applicable) entries. However, the “NA” entries were not used consistently among the workshop participants, thus reflecting varying opinions regarding different issues. It would be more accurate to study the “NA” entries more closely, since they imply a different meaning than a zero entry. However, due to the time limits, an “NA” entry is treated in the averaging process as a zero.

The remainder of this section presents the findings of one of the five topics that were explored during the workshop. Only the bridge component topic is discussed. Details of the remaining four topics (Sequence of events during hazards, multihazards and multidisciplinary factors, current and future use of SHM technologies, and interaction between stakeholders) can be found in Ettouney and Alampalli (2007).

Each of the workshop deliberations looked at the interrelationship of SHM and bridge security from pertinent viewpoints. A form (questionnaire) was distributed at the beginning of each topic for participants’ input. The deliberations and the input summary for each topic were then presented. The averages of the numerical scores of those questions are included in different appendices. Some illustrative graphics and discussions are presented. Finally, important observations and conclusions derived from these efforts are given.

Bridge Components

The interrelationships between bridge components and SHM technologies were the subject of this part of the workshop. A blank form related to SHM technology and bridge security components was given to all participants for their input. For each cell in the form, the following questions were presented to the attendees and were asked to individually give their input to those questions in the form of a number between 0 (minimum) to 10 (maximum).

Applicability: How applicable is the utilization of security-related SHM technologies for a given bridge component?

Importance: How important is the utilization of security-related SHM technologies for a given bridge component?

Availability: How available is the utilization of security-related SHM technologies for a given bridge component?
The average scores of the answers to the questions above were tabulated and analyzed. To understand these results in simple terms, it was integrated vertically across the bridge components rows. This resulted in an average score for each of the SHM technologies in terms of applicability, importance, and availability. The strains, motion, and imaging techniques scored highest in applicability and importance. The workshop attendees indicated that current technologies for strains and motion are adequate. However, the availability of imaging techniques is lower, indicating a need for developing or implementing these technologies to meet security needs.

Figures 1-4 show how the attendees scored for different aspects of bridge security components (Ettouney and Alampalli, 2007). For hardening, the superstructure, substructure, and utilities were fairly similar in availability, importance and applicability (see Figure 1). The foundations scored consistently lower. This is not surprising considering that bridge foundations are not easily accessible and hence do not pose a big threat from a security point of view. This is perhaps one of the differences between bridge security as a hazard and other natural hazards such as earthquakes and scour where bridge foundations would be of utmost importance.

Of the three issues that constitute redundancy (see Figure 2) the fire issue ranked highest in applicability, importance, and availability. The Chem.-Bio issue seemed to rank fairly low. This is also understandable, since the Chem.-Bio hazard is not a major bridge security related issue. The low ranking of the total collapse is puzzling. Total or progressive collapse is an important issue for all infrastructures. One possible reason for such a low ranking might be the fact that this issue has not had as much publicity as it has in the building community. More attention should be given to this issue within the bridge community.

The attendees’ perception on guidelines in the field of bridge security is shown in Figure 3. This figure shows the clear need for general guidelines. Secondly, the structural guidelines scored a bit lower than the general guidelines. This indicated the recognition of the attendees of the importance of other issues, in addition to the structural issues, for bridge security. In all situations, it is acknowledged that the availability of such guidelines is not as widespread as they should be; there is a definite need for bridge security guidelines.

Finally, Figure 4 shows applicability, importance, and availability of SHM technologies to reaching the primary management goals – safety and cost. The safety generally relates to users of the structure in case of an event. Cost refers to resources required to fix anticipated structural damage. Higher safety is generally associated with higher costs, and thus, management goals are to reach an optimal solution depending on risk. The attendees indicated that safety concerns are more important than cost concerns. In both issues, the availability seems to be lacking when compared with importance.

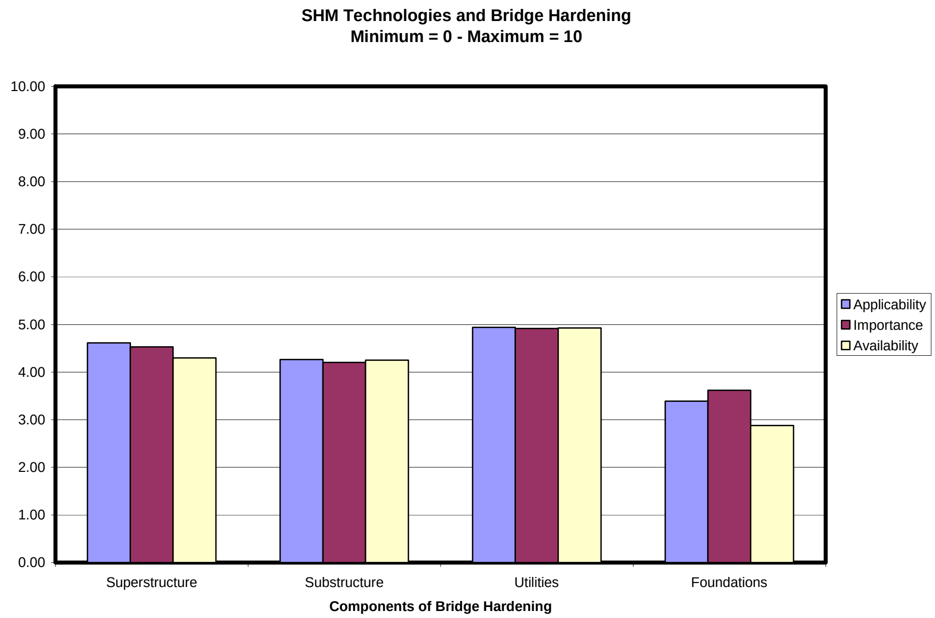

Figure 1. Scores for SHM Technologies and Bridge Hardening

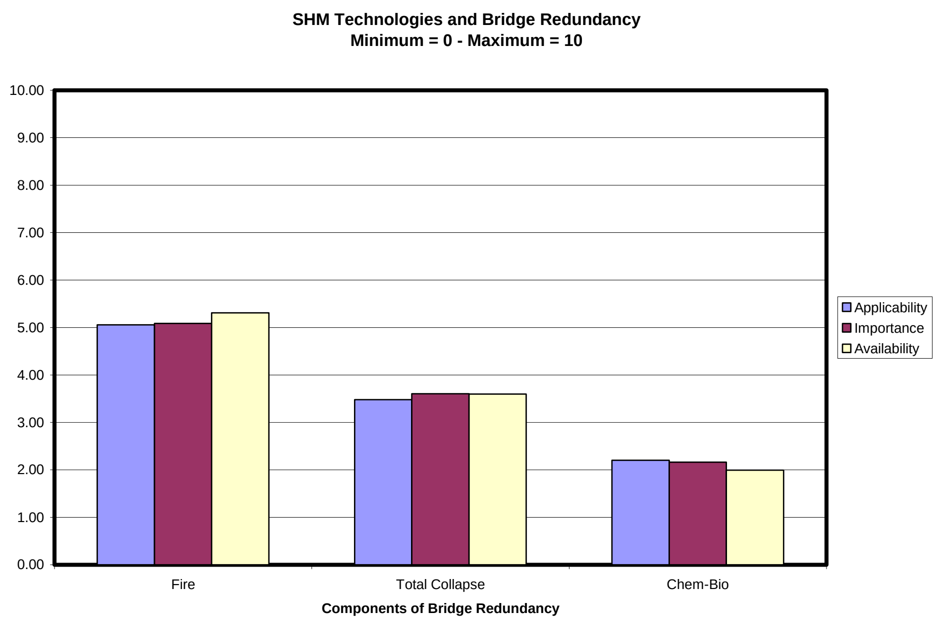

Figure 2. Scores for SHM Technologies and Bridge Redundancy

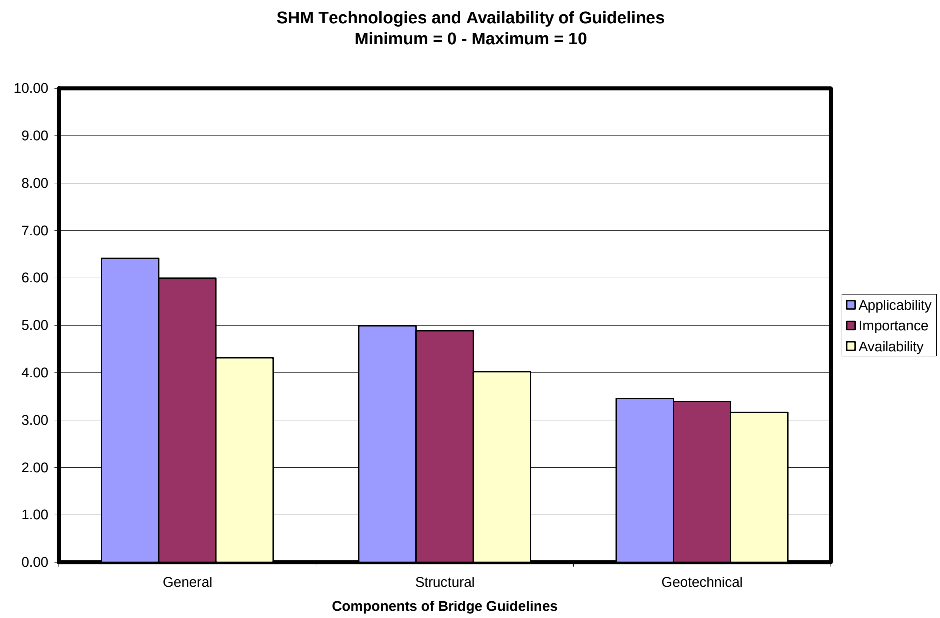

Figure 3. Scores for SHM Technologies and Bridge Guidelines

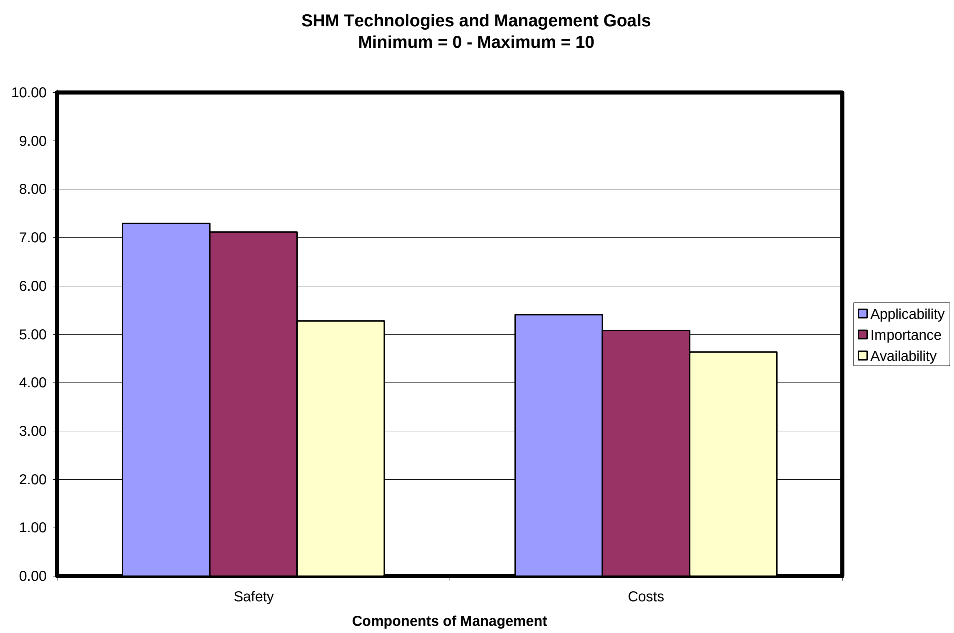

Figure 4. Scores for SHM Technologies and Bridge Management Goals

ACKNOWLEDGEMENTS

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