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Introduction and Motivation

Bridges are the flagships of civil engineering. They attract the greatest attention within the engineering community. This is due to their small safety margins and their great exposure to the public. Early bridges were the backbone of powerful empires from China to Rome and the Incas in America. Currently the transportation infrastructure is directly related to the economic success of a nation. Bridges are admired for their function but also primarily for their esthetic impact. Imagine New York without her bridges, Japan without the Honshu Shikoku project or Europe without the Greatbelt Link. This book will contribute to the preservation and maintenance of these important elements of modern society.

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1.1 Health Monitoring

The global higher transportation network operates about 2.5 million bridges. Current bridge management systems rate them using various methodologies and approaches. This results in very inhomogeneous statistics. The US Federal Highway Agency (FHWA) stated in 2005 that 28% of their 595 000 bridges are rated as being deficient, with only a portion of these (about 15%) being deficient for structural reasons. In Europe this figure varies around 10% being structurally deficient. No figures are available for the Asian networks. Nevertheless if we consider an average of 10% structural deficiency, we are looking at 250 000 bridges that definitely require structural health diagnosis, improvement and monitoring. As structural health monitoring (SHM) should be used in a preventive capacity before bridges become deficient, this considerably increase the number of its applications above the global estimate of 10% that are structurally deficient.

Structural health monitoring is the implementation of a damage identification strategy to the civil engineering infrastructure. Damage is defined as changes to the material and/or geometric properties of these systems, including changes to the boundary conditions and system connectivity. Damage affects the current or future performance of these systems.

The damage identification process is generally structured into the following levels:

- Damage detection, where the presence of damage is identified.
- Damage location, where the location of the damage is determined.
- Damage typification, where the type of damage is determined.
- Damage extent, where the severity of damage is assessed.

An extensive literature has developed on SHM over the past 20 years. This field has matured to a point where several accepted general principles have emerged. Nevertheless these principles are still challenged and further developed by various groups of interest. Strategies in mechanical engineering or

Health Monitoring of Bridges Helmut Wenzel
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aerospace adopt different approaches, but nevertheless the civil engineering community can considerably benefit from them. Separate approaches are necessary to consider that civil engineering structures are each a prototype.

1.2 Client Requirements and Motivation

The construction sector is conservative. The implementation of new technologies needs a clear requirement and motivation to be accepted by owners and operators. It has been recognized that the current practice does not satisfy the needs of shrinking budgets and aging structures. Nevertheless they satisfy valid codes and standards. Before a breakthrough in implementation of new technologies can happen the requirements and motivation have to be clearly understood and argued against potential clients.

Three main drivers might be approached in the promotion of SHM. The motivation to apply and order services based on the new technologies can be:

- Responsibility driven, which means the new methods become standard applications supported by codes, standards and guidelines.
- Economically driven, such as situations where a ranking of structures to be rehabilitated is necessary because of insufficient budget available or the need to use a structure for a certain time period longer than designed.
- Curiosity-driven motivations comprise those cases where clients would like to know more about their important and complicated structures. Results can also lead to better planning for future structures.

From the above-mentioned motivations the following requirements can be derived. These are typically services requested from the technology providers:

- A certificate that a structure satisfies the requirements from codes, standards and guidelines comprises a main business opportunity. Many recommendations already consider the increase of maintenance periods so that measurements can be taken. The provision of such certificates by engineers is common practice in Europe. Other parts of the world do not apply this system. It has led to an impressive evolution of bridge technology in Europe, which has been exported worldwide. It creates an environment for quality construction.
- The transfer of liabilities and responsibilities for structures in terms of technical and operational matters takes place with the huge privatization drive we can observe currently. Clients are systematically transferring the stock of structures into private hands. The new players involved are open to new applications that are able to support innovative and economic maintenance strategies.
- Special structures require special attention. The necessary top expertise cannot always be available with every owner or operator. The top experts for each region will be required to offer the newest technologies for their work.
- A shortage in the capacity of personnel to carry out routine maintenance and assessment works at the bridge stock also leads to new opportunities. As these services are normally tendered, new technologies might have an economic and technology edge.
- In case of emergency or accidents the generation of a secure situation is desired by affected owners. Any assessment based on the results of measurements is more likely to be accepted than subjective assessment by the expert. The clients want to sleep well because somebody else is permanently watching and assessing their structures.
- Ad hoc assessment in case of doubt or emergency also comprises this application area. The subjective conventional assessment produces too many negative scores on structures, and doubts are raised. A quantitative assessment is desired.

- The optimization of maintenance concepts requires input on which this process can be performed. The more data are available, the better the organization will be and the better the available maintenance concepts. A reduction of the remaining risks helps to make decisions with lower safety margins.
- The determination of priorities, through a quantification based on measurements, helps to satisfy the growing demand in combination with shrinking budgets. This assessment can come up with better scores, minimizing the number of structures requiring immediate intervention. Decision support for investment planning can be offered on the basis of the above-mentioned services. Every new measurement improves the database and as such improves the quality of the results and supports the necessary decision making.
- Life-cycle cost determination helps to increase the periods when budgetary planning is necessary. The demand for retrofit and maintenance can be estimated over the whole life period of a structure or even of a fleet of structures.
- The direct link of structural performance to operation of a structure can be established. Very often information about an optimal speed or frequency in the traffic can be determined that can be used by the operation personnel of a transportation infrastructure and communicated to the drivers through telematic devices.
- Hot spot identification technologies are very often requested in case the weakest point of the system or a significant accumulation of incidents is observed. Clients would like to know where to look first and what the background of certain phenomena could be.
- The prediction of structural performance for future loading scenarios is a further specific item requested. When a nonlinear behavior can be expected, special expertise becomes necessary.
- Fleet observation is desired to improve the quality of assessment when the number of structures is huge. For this the conception has to be subdivided into stages depending on the depth of information required.

The selection of a suitable observation concept has to be based on mainly external factors. These are the number of structures to be observed in combination with the budget available. For this purpose it is necessary to offer services on increasing quality levels. The levels can be subdivided into spot, periodic, permanent and online assessment campaigns at structures. The respective features are:

- A spot observation should comprise a very quick measurement campaign with a few simple to handle sensors only. It should provide information on the general condition of a structure in order to create a ranking.
- Periodic assessment means a measurement campaign on a structure, which is repeated after a specified period of time, to generate information on the performance over time. This spot information might comprise rather long periods.
- Permanent observation and assessment of structures becomes necessary when certain limits are passed. This observation allows a very detailed assessment based on permanent recordings and can help to implement quick decision making.
- Online observation and assessment allows warning through electronic media, be it through a short message service (SMS) in the simple case or an online status through the internet. Decisions might be taken by the computer based on the measurement data. These alert systems will only be applied at extremely critical structures.

In general it has to be stated that clients need and desire support of their work and not issues that make it more complicated. In this respect also the procedures have to be carefully watched and permanently improved. The information policy also plays a major role in the client–consultant relationship. The new methodologies are rather complex and require a deep understanding of structural dynamics, physics and measurement techniques. Due to the fact that this expertise is rarely available at the owner's engineering department, the fear to be exposed to unknown black box applications has to be taken from their shoulders.

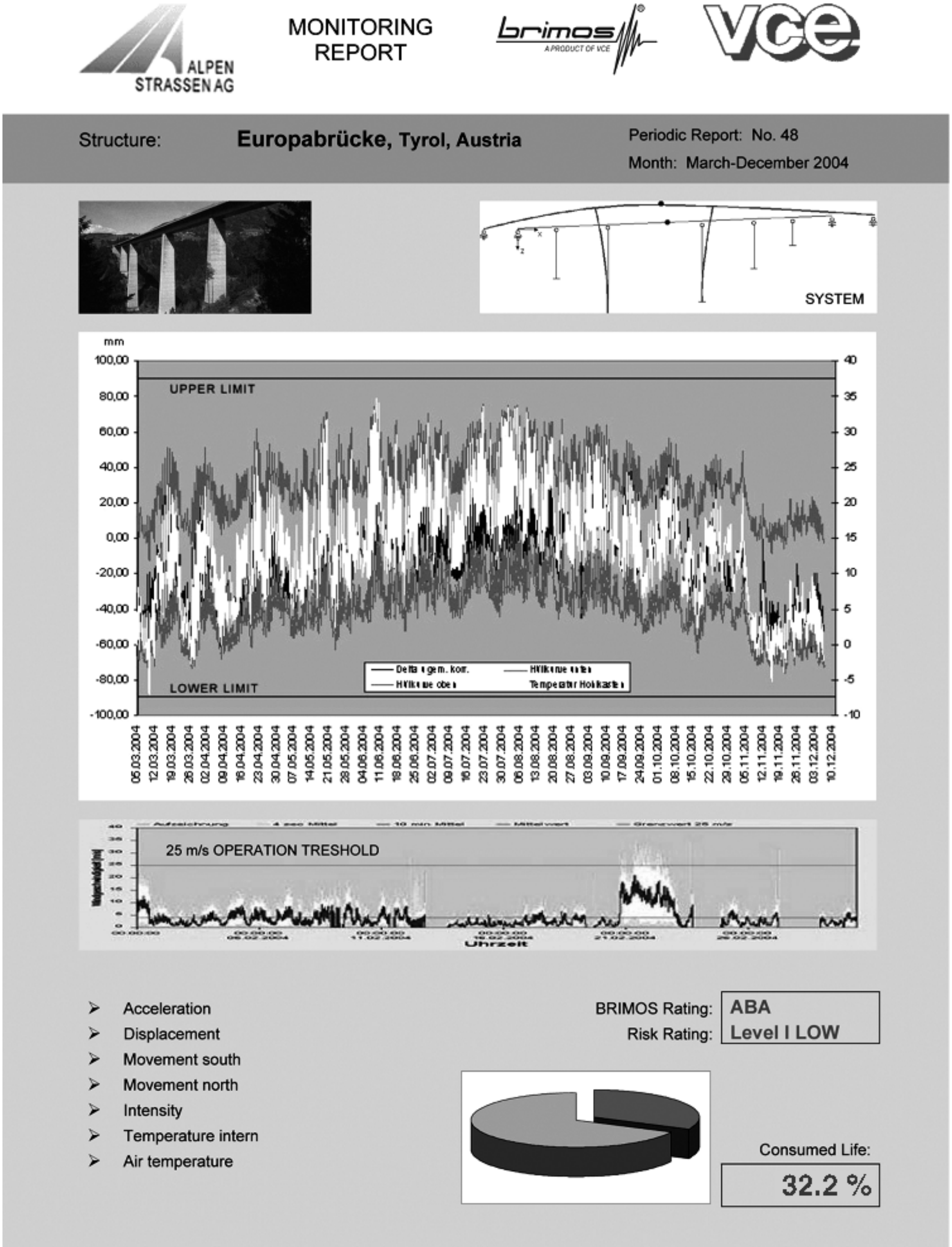

Figure 1.1 Periodic SHM report of a bridge

On the other hand they are spending considerable amounts of money and would like to be informed frequently about progress and results. Therefore we have to ensure that the technology part is in good and competent hands and that they will receive the necessary information they desire. The best success has been achieved with very simple reporting techniques. A periodic report received by email comprising single page information is preferred. The example shown in Figure 1.1 provides such a typical weekly report. The main information is provided in a single window, where upper and lower normalized thresholds are given and the measurement results within this period are placed within these thresholds. With one look at this graph the personnel can immediately see whether any of the thresholds have been exceeded. The client is satisfied because all indicators are positive and the ordered observation is permanently working.

The periodic report should provide on this single page the following information:

- A photograph and a system plot of the structure under observation for easy and quick identification.
- A window with the periodic results placed within the relevant thresholds over the observation period.
- Eventually a second window with special information required by the client, such as wind speed information or any other quantity desired.
- Finally a rating should be provided that is based on the measurements taken in the reporting period. This rating should enable the client to immediately see whether any changes have happened.
- Eventually the specification of a remaining life capacity can be provided if the necessary data are recorded.

Besides this one-page record for the client a scientific report should be generated by the system for the expert. This will enable a quick assessment of all the single measurements in order to acquire the necessary expertise or learn from the performance. Every year on average the system should be calibrated with the information gained. This might also comprise a change in the rating and will update the remaining life capacity based on existing knowledge.