Contents

1

Introduction

The increasing number of civil engineering structures in the field of traffic infrastructure entails the increasing significance of maintenance problems of such engineering structures. Bridges are monitored by periodic supervision measures with the aim of minimizing the safety risk for the user, on the one hand, and of keeping the costs for the maintenance as low as possible by the execution of rehabilitation measures at the right time, on the other hand.

Potential Impact

Civil engineers concerned with supervision of structures for safety and maintenance reasons are aware of the limitations of their current practice of condition assessment based on visual inspections. Typical routine applications of condition assessment are carried out on structures applying rating systems. The consequence would be unbearable costs on society for replacement and retrofit tightened up by shrinking budgets. The expressed intention of the bridge owners globally is to reduce the number of bridges rated deficient by 30% within a short time through the application of sophisticated methods based on measurements.

1.1 SCOPE OF APPLICATIONS

Owing to the quickly increasing traffic density, in particular in the field of sophisticated road networks, restrictions of unhindered traffic flow because of inspection works entail high economic costs. Therefore such works must be limited to the absolutely necessary minimum. The ambient vibration method

Ambient Vibration Monitoring H. Wenzel and D. Pichler
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(AVM) was developed under the premise that it can be used practically without any impairment of the traffic flow. The aim is to provide a system that makes it possible to reduce the employment of inspection devices to a minimum by well-aimed specification of problem zones, therefore maintaining the traffic flow in as undisturbed a way as possible during inspection works. The procedure can be applied independently of the type and construction of the structure and materials used.

The currently used procedures for bridge monitoring are dominated by manual methods. Visual assessments have a central significance. Devices such as binoculars, magnifying glass for measuring, levelling instruments, endoscopes, etc., are used but the results are dependent on the subjective recognition of damage by the personnel carrying out the examination. It is tried to objectify the recognition by check lists, comparative patterns, etc. Additional methods such as concrete cover measurements and chemically and technical tests help to document an objective image of the maintenance condition.

The AVM has an engineering character comparable with the main manual inspection methods currently used. By measuring the vibration behaviour ‘actual’ values are obtained, which – with certain restrictions – are not subject to the circumstances of the personnel carrying out the test. The objective condition of the tested structure is determined by a systematic analytical evaluation.

Of course the methods used formerly do not become obsolete but rather provide an additional assessment procedure that improves the application of the method. The examples presented in this report show how AVM can be usefully applied for the support of traditional methods of bridge monitoring. Apart from the requirements for bridge and structure monitoring AVM offers an abundance of further areas of application, which owing to its flexibility are also explained by means of practical examples.

1.2 LAWS AND REGULATIONS

In Austria, according to the relevant legal regulations (federal road law, provincial road administrative laws, building regulations for Vienna), the road administration is responsible for road building and road maintenance. The competent road administration is therefore also responsible for the safety of the engineering buildings in the course of its road network. This results in the following competencies for the Austrian road network:

- federal road network: the provincial governors by way of the indirect federal administration, special companies (ÖSAG, ASAG);
- provincial road network: the provincial governments, the district administration authorities, the mayors.

With regard to road construction and road maintenance no special legal regulations exist. Roads and therefore road bridges have to be built and maintained according to the respective state of the art.

In Austria bridge monitoring in the field of the federal road network takes place on the basis of RVS 13.71, *Straßenerhaltung – Überwachung, Kontrolle und Prüfung – Straßenbrücken* (road maintenance – monitoring, inspection and check – road bridges) at periodic intervals [1]. Here four types of monitoring are distinguished:

- constant monitoring;
- inspection;
- check;
- special test.

Constant monitoring includes the determination of damages that are discernible from outside and is carried out by inspection rides at least every four months. Inspections take place at least every two years with an increased examination depth for the substructure and superstructure by means of a checklist compared with constant monitoring, but usually no special devices are used for it.

The checks (also bridge checks or main checks) are, however, usually carried out every six years. For these checks bridge inspection devices are often used, which frequently require a partial road block. Special tests are carried out if a survey of the actual condition is required due to special events (e.g. after an accident). The scope of such tests corresponds to that of a regular main check; traffic restrictions therefore occur in a similar scope.

In Germany the decisive standard in this field is the DIN 1076, which is valid both for railway and for road bridges. This standard was globally introduced for road construction in all German Federal States in November 1999. For the German railways the D804 with various modules is valid for bridges and other civil engineering structures. They are, however, still being revised at the time of preparation of this publication. In particular, the D80480 is decisive for inspections and/or examinations but must be adapted to the new module system.

In France the decisive standards were published by the Division of Road Management in the Transport Ministry. They are generally known under the title *Technical Instructions for the Supervision and Maintenance of Engineering Structures*. What has to be pointed out is in particular fascicle 31 in part II (1990): *Reinforced and Unreinforced Concrete Bridges*, as well as fascicle 32 (1986): *Prestressed Concrete Bridges*. Fascicle 34 (1986) refers to *Steel Bridges*.

Furthermore, a regulation on the 'Classification of Structures' from 1996 as well as numerous publications and leaflets by LCPC (Laboratoire Central des Ponts et Chaussees), a governmental research institute dealing with building and infrastructure as well as town planning and environmental technology, are decisive. The following titles were analogously translated from French:

- *Handbook for the Identification and Interpretation of Reactions and Signs of Concrete Damages (Fatigue) in Engineering Structures*, LCPC (1998);
- *Examination of Cable Forces by Using Vibration Measurements*, LCPC (1993).

In Italy the decisive standards were published by the Ministry for Public Works (Ministero Lavori Pubblici) in 1971 and 1974. In particular the technical standards for the planning, execution and final approval of road bridges *(Norme tecniche per la progettazione, la esecuzione e il collaudo dei ponti stradali)* need to be mentioned, which were revised and complemented in 1991.

In Great Britain the decisive standards are basically divided into four groups: inspection, maintenance, repair and strengthening, and assessment of roads and bridges. In particular the codes of practice in section one (inspection), including inspection of highway structures and of post-tensioned concrete bridges, as well as inspection and records for road tunnels, and in section four (assessment), assessment of steel, concrete and composite bridges, are interesting.

In this connection the following leaflets as well as a German standard draft are interesting as important aids:

- Automatisierte Dauerüberwachung im Ingenieurbau, Merkblatt des DGZfp-Ausschuss für zerstörungsfreie Prüfung im Bauwesen (AB), dated 12 August 1997;
- Zustandsanalyse mittels modaler Analyse (ZMA) Merkblatt des DGZfp-Ausschuss für zerstörungsfreie Prüfung im Bauwesen (AB), dated March 1998;
- ISO/CD 14963, *Mechanical Vibration and Shock – Guidelines for Dynamic Test and Investigation on Bridges and Viaducts*, from DIN-Normen Ausschuss Bauwesen, dated 12 October 1999.

This standard is to form the regulation on which dynamic bridge monitoring will be based in the future.

Standardization is to be established at a uniform level all over Europe by means of the European network project SAMCO (structural assessment monitoring and control, project number CTG2-2000-33069 of the DG Research of the European Union). This is to be the prerequisite for a quick dissemination of dynamic methods. The progress of the project, which was started in 2001, can be followed under *www.samco.org* on the Internet.

1.3 THEORIES ON THE DEVELOPMENT OF THE AVM

The AVM is a practice-oriented procedure that closes the gap between basic research and application-oriented development by means of statistical methods and approximation methods. Therefore the following assumptions are made:

- The condition of a structure represents itself in the response spectrum.
- The linear static and linear dynamic approaches are not sufficient for describing correctly the dynamic characteristic mathematically.
- The measuring technique has been sufficiently developed.
- Data acquisition and evaluation via computers is efficiently feasible.
- The existing software is appropriate for meeting the requirements.

From the preceding assessment of the status quo the following results can be derived:

- The measuring technique is widely advanced and the data will be lasting.
- The theoretical evaluation can still be developed further.

A Very good conditions
B Good condition with local problem
C Problematic condition

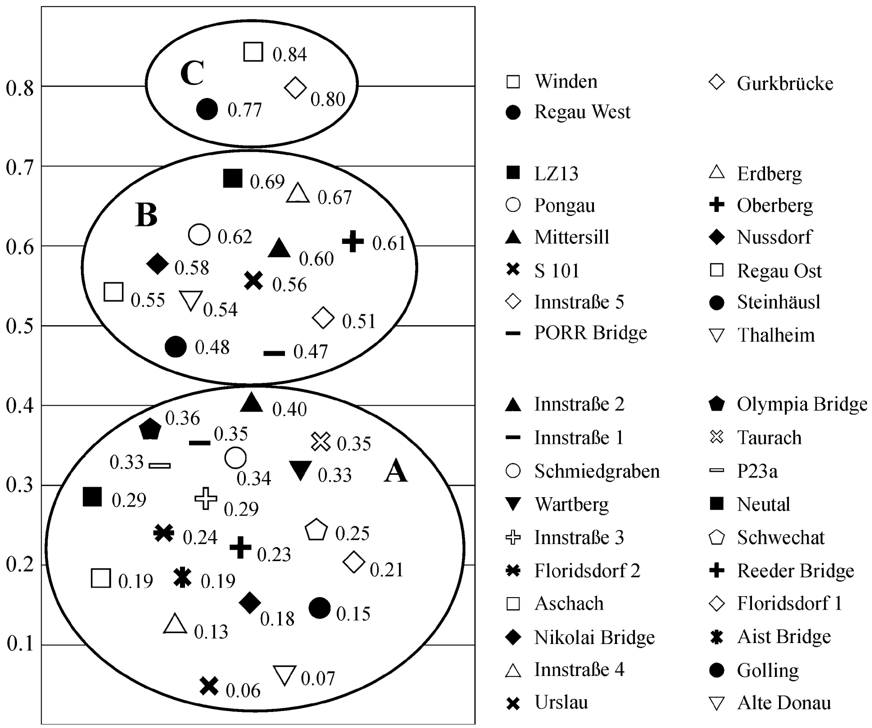

Figure 1.1 Classification of pre-stressed concrete bridges according to the AVM

The aim of this work is to close this gap by an empirical solution that will last until computer mechanics is in a position to supply sufficiently reliable results. The following theory, which is represented in a simplified way here, arises from this fact:

> The gap between measuring technology and calculation can be closed by simple statistic, empiric procedures based on probability.

The basic idea is to register the dynamic characteristic by means of the highly sensitive acceleration sensors and to measure absolute deformation values by means of a laser in parallel and simultaneously. The correlation of the two signals calibrates the measurement. The error arising from this can be estimated, but does not have any influence on the quality of the interpretation. This method can be replaced by more accurate interpretation procedures as soon as the required non-linear calculation methods are ready for application. The measurements are, however, so precise that they can offer reference data with a high qualitative value for every future evaluation method.

It is therefore justified to begin with periodic measurements of structures now, even if the tools for a more detailed analytical solution are not yet available. The empirical procedure already yields excellent results.

A classification of structures with a similar design is possible and can be used as the basis for a sequence of priorities. In Figure 1.1 the measuring results of 35 small pre-stressed concrete bridges, which were built between 1955 and 1965, are shown. The condition of the structures is reflected in the measuring values and therefore clearly shows the need for action.