THE GERMAN BMS AS A DECISION TOOL FOR SUSTAINABLE MAINTENANCE STRATEGIES

Ralph Holst
Federal Highway Research Institute (BASt)
Bruederstrasse 53
DE 51427 Bergisch Gladbach, Germany
Tel: +49 2204/43 841
Fax: +49 2204/43 677
E-Mail: Holst@bast.de

ABSTRACT

Due to the increasing globalization, the traffic grows in the world and steadily in Europe. This also means that the existing infrastructure is increasingly under pressure and exposed that with increasing age.

The Federal Highway Research Institute has carried out together with the Federal Ministry of Transport, Building and Urban Development (BMV at that time), and highway authorities of the federal states, a bridge management system (BMS) based on the information from the regularly bridge inspection according to DIN 1076.

This bottom-up-approach makes it possible, with the help of extensive catalogues and behavioural models, to generate different measures and combinations of measures over a determined period at a bridge and to calculate costs. Besides the calculation of direct construction costs, the German BMS considers also the impact on traffic and includes the results in the evaluation of strategies.

Because of this, important information for the sustainability aspects of "ecology", "economy" and social impact" are available within this BMS.

1 INTRODUCTION

Due to the increasing globalization, the traffic grows in the world and steadily in Europe. This also means that the existing infrastructure is increasingly under pressure and exposed that with increasing age.

The financial difficulties, particularly in Europe makes it clear, that participation in this globalization leads to higher spending for the states, for example to be able to keep pace with the increasingly rapid development in the communications world. At the same time the infrastructure and, as an important part the transport infrastructure, must be able to with-stand this development.

This means, that significant financial and human resources must be invested in the maintenance and upgrading of the road infrastructure.

A sustained, systematic maintenance planning is increasingly necessary. It offers the possibility to use the available financial resources optimally and sustainably. This can provide an important contribution to life cycle considerations, which makes it possible to consider not only the lowest construction costs, but also a part or the whole service life of a bridge.

The following article will outline the possibilities of the German bridge management system (BMS) for this area.

2 BOUNDARY CONDITIONS

Germany is a very strong transit country, also following the enlargement of the European Union. In order to grow the economy in Europe, the security and ease of traffic has to be guaranteed at all times.

It should be noted, that important conditions have changed with time:

- Significant increase in traffic, particularly heavy goods traffic,
- Increase of total allowable loads of vehicles,
- Overloading of trucks,
- Increasing bridge ages (Fig. 1).

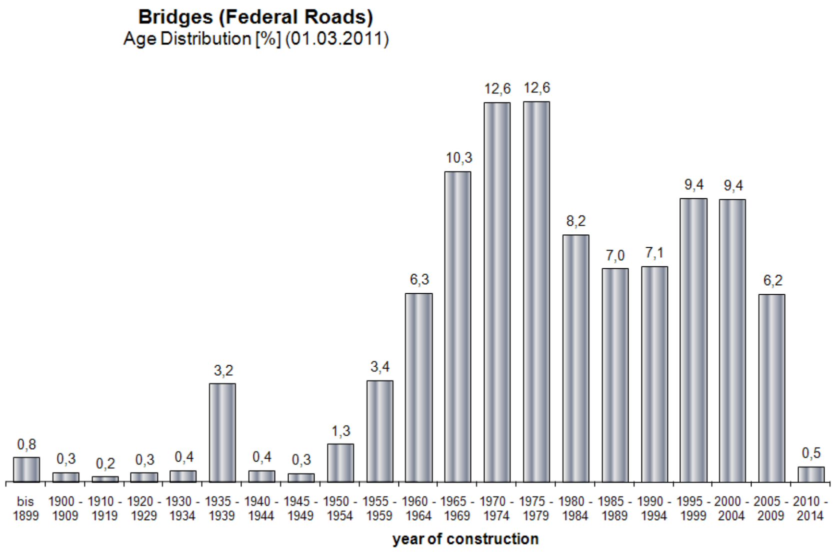

Figure 1: Age distribution for Federal Roads in Germany

These developments have left their visible marks on the bridges. There are increasingly more concrete spalling, cracks and corroded reinforcement on the component parts.

Due to limited budget funds available (Fig. 2), and the fact that in the past very often new measures were given preference before maintenance measures, in recent years (decades) has flowed too little money in the maintenance of bridges and engineering structures.

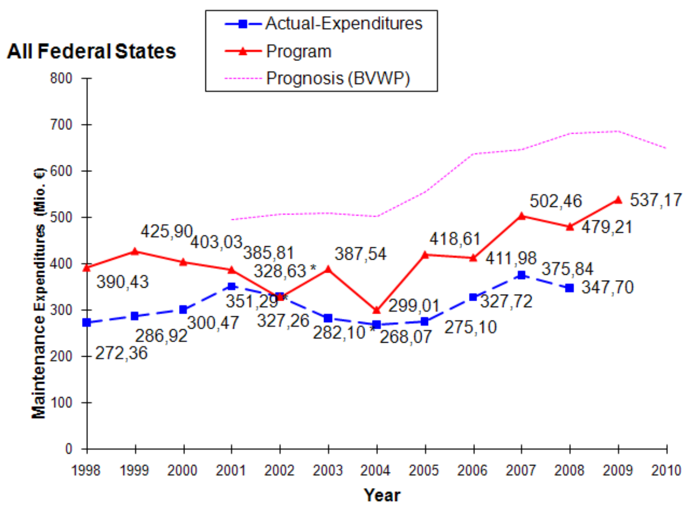

Figure 2: Maintenance Expenditures

Meanwhile there is a trend, that life cycle considerations find increasingly the way from the laboratories of universities and other research institutions into the daily practice. This happens thanks to the sustainability requirements of the political sphere.

3 BMS AND SUSTAINABILITY

The Federal Highway Research Institute has carried out together with the Federal Ministry of Transport, Building and Urban Development (BMV at that time), and highway authorities of the federal states in 1997 the first research projects to design a bridge management system for the area of federal trunk roads. After reviewing of management systems in the world, and considering the available information, e.g. from the bridge inspection in accordance with DIN 1076, it has been decided to develop a system that builds on these data structure data. This bottom-up approach enables starting optimization on both levels for total bridges and their individual damages (Fig. 3).

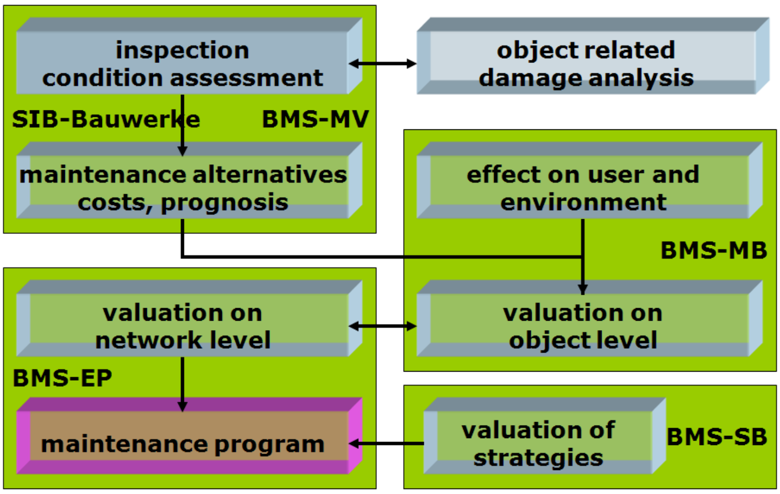

Figure 3: German BMS

4 CREATION OF SUSTAINABLE STRATEGIES

The concept of "sustainability" is used in the scientific world very different. Originally, the term was created for the timber industry and pointed out that only as much wood should be removed, as can grow back, so that the forest is able to regenerate again and again. Hereby, the two major components of sustainability are described. It should be possible for someone to satisfy his own current needs: This includes economic development and growth. However, in the choice of means and methods, it's to observe how the impact of allocating resources for future generations is. They may not be unduly restricted in their actions.

In Germany there has been established a seal of approval "Sustainable construction" of the German Sustainable Building Council for the construction sector. Thereby projects are evaluated, using a scoring system to predetermined criteria and weightings according to the result and get a certificate.

In the field of bridges a working group has formed to examine in what form such a rating system for bridges and other engineering structures in the course of roads can be developed or adapted.

Parallel to these activities, it is useful to consider the existing German bridge management system (BMS) to determine, whether and to what extent that system can generate sustainable maintenance strategies systematically.

4.1 Generation of maintenance strategies in the German BMS

Based on the necessary construction and damage data from the database "SIB Bauwerke", condition curves for the group component will be determined within the module BMS-MV, using behavioural models without consideration of damages, but the involvement of the respective model years. Then, because of damages and requirements regarding grouping criteria, technically practical maintenance measures variations will be produced. Here, the replacement of each component group and the replacement of the entire bridge are to be considered. Subsequently, these different measures will be assigned with direct construction costs. These approaches may also include necessary scaffolding and traffic steering.

Based on the observation of two time levels in BMS, then the combinations of measures are distributed to the individual years of the planning period of 6 years. Here, the condition scores of the individual component groups are matched with intervention levels. Because of a good condition of the bridge and its components, it can happen, that no actions will be proposed for the next 6 years. It is also possible that, necessarily due to a very bad condition index, measures up to a given year must be done to prevent, that the bridge comes in a not acceptable poor condition.

The implementation of a maintenance measure in a given year leads to the improved condition of the structure (Fig 4). This is realized by resetting the condition index on a better value in accordance with established rules. Here, the degree of resetting depends on the type of measures installed. Maintenance measures leads to a lower improvement of the condition of the bridge, as the replacement of total bridge or groups of components.

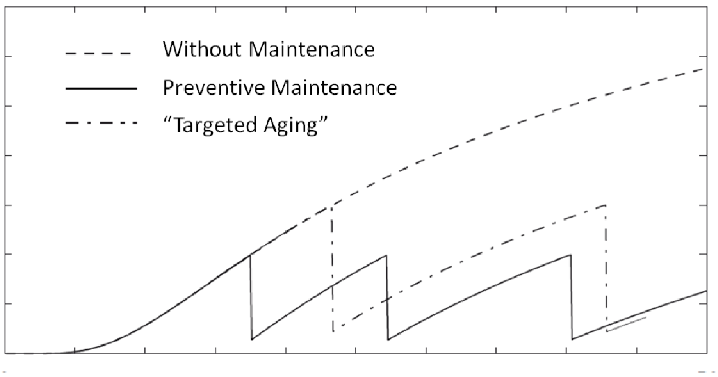

Figure 4: Maintenance Strategies

Indeed, within a repair action the substance of the bridge component group will remain and not get renewed in general. There is also the possibility that an aggrieved group of parts will be replaced, while another group is just repaired. In this case the improvement in the condition of the entire bridge depends on the measure and the affected component group in total.

In addition the improving of the condition of the bridge but also the costs of the action plays an important role. The replacement of the superstructure leads to a large improvement in the condition. But the direct construction costs will also be high, and in addition, the measure generally takes longer, affects traffic longer, and thus leads to higher indirect costs.

What action or combination of measures is purposeful ultimately still depends on another important point. This is the duration of a measure. It has a significant impact on how often a bridge has to be refurbished in a certain period of time, e.g. 50 years and how much direct and indirect costs accrue in the whole life time of the bridge. The determination of this effect for different durations of actions on separate components depends very much on the experience of those who define those values. A simple statistical analysis of information due to measures implemented and their duration of action is, in most cases, not useful, since materials and procedures (e.g. for corrosion protection coatings on steel structures) improve and thus affect the durability of these measure. However, you can't simply use the information of producer of these materials, since it can present conflicts of interest.

It is also very important, how exactly certain requirements can be met. This relates to:

- Cost and benefit rates (e.g. m² concrete replacement/h),
- Reset values of the state assessment,
- Behavioural models for component groups, particularly with regard to the behaviour after the measures,
- Damage assessment.

For this reason, the German BMS not only consider substitute measures for groups of components or the entire structure and basic repairs, but also smaller and more cost-effective maintenance measures. All the measures will be optimized also using indirect costs.

This ensures that different maintenance strategies can be viewed in terms of their effects on traffic flow.

4.2 Type of maintenance strategies as the basis for evaluation

Once in the previous section, the creation of maintenance strategies and the technical conditions have been explained, in this section shall be outlined, how sustainability issues can be considered in the creation of maintenance strategies.

For the bridges and other engineering structures, the term sustainability is concretized by essentially three aspects (Fig. 5). These are

- Ecology,
- Economy and
- Social aspects.

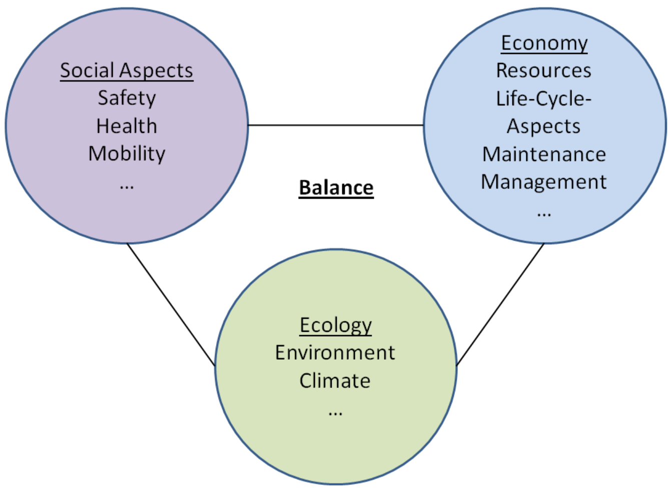

Figure 5: Sustainability Aspects

4.3 Economic aspects

This area affects especially the life-cycle costs. For bridges this is a combination of direct costs, over the life time of the bridge. These consists of

- Production costs (including planning costs);
- Direct costs for maintenance measures over the entire service life,
- Direct costs for replacement of the bridge or its demolition.

4.4 Ecological aspects

For this aspect the so-called "LCA" is of particular importance. This means which effects occur during service life because of different maintenance strategies in terms of warming potential, ozone potential (degradation or formation), acidification potential and eutrophication potential.

4.5 Social aspects

This aspect includes essentially the items "safety", of both the traffic itself, and protection from traffic, the "health" of road users and those persons, who are affected by the traffic and the "mobility". Which means how much a maintenance project, but also a (bad) condition may affect the ease of transport. In other words, answering the question, how far can a road provide their function any longer?

Apart from purely technically oriented standards in the creation of maintenance measures, the objectives of the respective construction agencies play a very important role. There are three fundamentally different strategies.

A national road authority, for which the safety level of its bridges is the most important criteria, is expected to select a preventive maintenance strategy. This means that there shan't, in any cases, be a critical condition at the bridge. This also means that either more robust structures must be chosen which are more resistant to external stresses or preventive maintenance measures shall be taken at regular intervals, but even before the onset of visible damages. This increases the encroachment on the road by a significantly larger number of maintenance measures during the period of use of the bridge or a possibility of temporary detouring must be given. All these measures increase the costs of the bridge over its lifetime.

Looking at the aspects of sustainability, the result for this strategy shows the following picture:

> The issue of "safety of transport infrastructure" has the highest priority. The mobility of road users is not affected by unforeseen events on the one hand; on the other hand, more maintenance measures occur over time, which have negative impacts on the traffic, the use of resources and on the environment. The overall picture depends on the individual case.

The opposite of this described strategy, is the possibility of "targeted aging." Here, the structure is maintained by minimal cost maintenance measures in such condition, that it just reaches the user requirements and the prescribed period of use. Then the structure is demolished or completely renovated. This strategy has the disadvantage, that it's very susceptible to unforeseen events. This can, in extreme cases, lead to short-term blocking or the collapse of the bridge. It can be assumed that the total costs in comparison to other structures turn out to be low, if there are no major loss events over time.

Both mentioned strategies have their advantages but also disadvantages. For this reason there is a third option.

This is an optimum balance between the four criteria:

- Interventions in the road should be minimal,
- Construction and maintenance costs should be minimized,
- It is at any given time to ensure the required level of safety and security and
- The service life should be guaranteed.

An important prerequisite for this method is that the road authorities have the opportunity to respond to changes in the structure.

From the perspective of sustainability the following points are important:

- The less intervention in the traffic, leads, in principle, to the lowest environmental costs resulting from
    - o Congestion,

o Loss of time
o Accidents and
o Additional distances,

- The less maintenance measures over the life time are necessary and the smaller the scope of these measures, the lower is the resource consumption of construction and operating funds.
- The higher the bridge level of safety against failure due to external influences, the less maintenance measures are necessary, with its consequences on the sustainability.

These global statements come in reality to its limits, since it is generally dealing with unique structures that behave differently due to external influences.

Therefore it is necessary that the above mentioned authorities have the opportunity to respond to changes in the structure.

The main factors that influence the behaviour of bridges over time are:

- Planning and manufacturing defects,
- Material mistakes,
- External influences (temperature, precipitation, wind, chlorides, carbonation),
- Traffic, especially heavy and heavy load traffic,
- Structural changes (conversion, expansion measures),
- Exceptional events (e.g. accidents, floods, fires).

These factors are sometimes stationary (e.g. manufacturing defects), others are changing over time. Thus, it is necessary to be able to represent changes to the structure over time to get adjusted maintenance strategies.

4.6 Possibilities of the German BMS in terms of sustainability

Before the various possibilities for the creation and evaluation of sustainable maintenance strategies can be addressed, it is important to make a distinction, what can be done in principle and what is not.

The German BMS is based on the fact that a bridge exists or is at least in its erection phase. Thus, that's his main goal, to show and assess comparisons between different maintenance strategies with respect to the design, manufacture, operation and renovation / demolition of a specific bridge. Because of the presence of a road, people in this area are biased concerning the "ecology", "economy" and "social aspects".

Thus, the question to be answered is: How can a bridge be built and operated in a most sustainable way?

The German BMS has been designed to optimize on both level, the network and structure level. Thereby the structure level can be used for sustainability considerations. Normally, the BMS assumes that the bridge has a certain age and damages on components are available. The configuration of the program is structured in such a way, that it's also possible to consider a bridge from the days of the completion. For this, the year of construction is set to the current year and it is assumed that no damages are present.

With the help of the stored damages and service life models, the behaviour of the next years or decades will be simulated.

For the component groups "superstructure" and "substructure", according to the main constructing material, linear and exponential models for chloride penetration, carbonation and corrosion, either by reinforcement or structural steel members are used.

For the other group of components, such as pavement, waterproofing, caps, protective equipment, bearings, expansion joints and foundations, lifetime models with partially type-related service lives are implemented. To get the possibility to compare the results of different damage and service life models, the future behaviour of the component groups based on the development of the condition index will be traced.

In the next step the program proposes, for the entire bridge, different repair or replacement measures on individual components, according to established guidelines for bundling. These measures include both, small measures to individual components, repairing only the heaviest damages, but also measures which repair the bridge in total or replace it completely.

The time for implementation of measures, results from the fact, that a so-called threshold values is reached. These values are given by the national road authorities for each group of components, which must not be exceeded.

These thresholds, combined with the reset values of the individual measures, reflect the respective maintenance strategy of the above mentioned authority. If they choose as a threshold value a number, which lie near the maximum permissible condition score (for Germany it's the value 4.0) in combination with "low cost" maintenance measures that have a small reset value, you can call this strategy a "targeted aging strategy".

If he chooses on the other hand relatively low thresholds, e.g. a value of 2.5, in combination with measures which have a large reset value, so this is to be considered a "preventative" maintenance strategy.

Maintenance strategies, which should reflect the ideas located between these two extreme strategies, can be represented by presetting of threshold values and actions.

Using these algorithms, the behaviour of a bridge and its components can be described over a determined period of time, e.g. a few years or several decades. It will be in time shown the resulting maintenance measures, the costs over time and the total construction costs.

Apart from the determination of direct construction costs, the influence of the maintenance measures to a third party, in the case of the German BMS, of road users, can also be calculated and reported. Any intervention in the traffic, either by carrying out a maintenance measure or by restrictions on movement, as a result of poor bridge conditions (e.g. weight limit) leads to costs (Fig. 6). This can be represented by

- Congestion costs,
- Detouring costs,
- Costs of accidents
- Costs due to increased emissions.

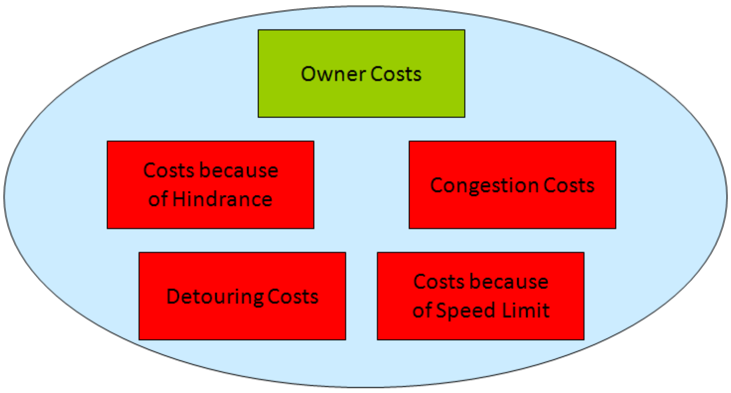

Figure 6: Aspects for indirect costs in BMS

After the calculation of maintenance measures for some years, so-called economic costs of third parties can be determined, based on the duration and the number of these measures in conjunction with traffic volumes. These costs are a measure of how much the traffic flowing and the environment are influenced.

If we now put the direct construction costs in relation to the economic costs through a cost-benefit analysis, the road authorities receives information about how, with respect to a chosen maintenance strategy, the direct construction costs behave to the economic costs. It can be concluded that for bridges in the course of heavily frequented highways, generally more expensive but more significant maintenance measures will lead to the desired results, while on less freighted roads it'll be possible to intervene much more often.

4.7 Evaluation of maintenance strategies for sustainable criteria

With the help of the BMS different maintenance strategies and their consequences can be generated. Measures, which

- Replaces bridge as a whole or substantial parts of it,
- Repair only the most serious damage to individual components,
- Combinations of these.

Sustainability considerations arising from the following important information:

- Amounts to be repaired, indicating the maintenance measure in relation to the individual component groups and for each measure in the evaluation period,
- Costs of direct action,
- Duration of action,
- Any kind of scaffolding,
- The kind of traffic management both on and under the bridge,
- With the information about measure durations, traffic control and traffic volumes calculated economic costs.

In combination with the masses and the building materials of the individual component groups, it's possible to calculate eco-balances over the service life of the individual bridge, because the following information is available:

- Type and mass of materials required,
- Location of the bridge and thus derivation of transport routes is possible,
- Duration of action.

Based on the available information about types and durations of activities over the lifetime of the bridge in conjunction with traffic volume data, the impact on the social aspects can be presented. It is all about answering the questions, how maintenance measures influence

- The safety,
- The health and
- The mobility

of road users and the people, which are affected from the road.

The necessary information can be obtained from the various maintenance strategies. Therefore for each maintenance strategy at every bridge in the studied road network

- Environmental issues (LCA),
- Economic aspects (cost-benefit analysis) and
- Social aspects

can be taken into account.

5 SUMMARY

A "bottom-up-approach" was chosen for the development of the German BMS. This requires the permanent availability of a huge amount of construction and damage data for each bridge. This is secured by the results of the regularly scheduled bridge inspections according to DIN 1076 and the storage of these data in the uniform program system "SIB Bauwerke".

This approach makes it possible, with the help of extensive catalogues and behavioural models, to generate different measures and combinations of measures over a determined period of time at a bridge and to calculate the costs.

Besides the calculation of direct construction costs, the German BMS considers also the impact on traffic and includes the results in the evaluation of strategies.

Because of this, important information for the sustainability aspects of "ecology", "economy" and “social impact" are available.

Due to the design of the BMS, primarily as an instrument for the standard maintenance planning, sustainability assessments are still not implemented explicitly. But the necessary basic data can be made available thereby.

6 OUTLOOK

How a sustainability assessment might look like in Germany for the area of bridges and civil engineering, is currently under discussion in relevant working groups.

Once the results of these consultations will be available and it’s desired by the above authorities, the BMS can be extended accordingly.

For this purpose it is particularly important to determine how

- The use of certain building materials and construction methods and
- The character and duration of traffic interventions as a result of maintenance measures,

will be evaluated.

The foundations for sustainable maintenance strategies are laid, but it still an existing research tasks, before sustainability belongs to daily life in the field of road maintenance.

REFERENCES

Deutsches Institut für Normung, 1999. DIN 1076 “Highway Structures – Testing and Inspection”, Berlin.

Haardt, P., 2002. Entwicklung eines Bauwerks-Management-Systems für das deutsche Fernstraßennetz Stufe 1 und 2, BASt Reports B43, Bergisch Gladbach.

Holst, R., 2005. Entwicklung eines Bauwerks-Management-Systems für das deutsche Fernstraßennetz Stufe 1 und 2, BASt Reports B50, Bergisch Gladbach.

Holst, R., 2010. Conventional/standard testing methods for concrete: an overview. In C. Maierhofer, H-W Reinhardt, G. Dobmann, Non-destructive evaluation of reinforced concrete structures: 117-136. Cambridge: Woodhead Publishing

Schmellkamp, C., Grundlagen zur Prozessverbesserung im Brücken- und Ingenieurbau im Hinblick auf eine nachhaltige Entwicklung, BASt Report (intern), Bergisch Gladbach