

STRUCTURAL APPRAISAL AND REHABILITATION OF BRIDGES AND VIADUCTS

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ABSTRACT

A study is in progress with the targets of monitoring, aging management, repair and strengthening of a stock of bridge structures. For this purpose a review of the structural appraisal and restoration interventions of these structures has been performed. Among the numerous aspects of the problem, the following features have been individualized:

- Methods and procedures for the assessment of structural reliability;
- Planning on appraisal with regard to the refinement of the structural analysis and to the costs;
- Research on information regarding construction techniques, properties of materials and computational methods used in design of the structures
- Materials and techniques for structural repair and strengthening;
- Arrangement of procedures to develop a data-base of the frequent damages, and of the techniques and materials for repair and strengthening;
- Development of a monitoring system.

On the basis of the acquired results a model of a bridge management system is in definition.

Keywords: appraisal, bridge management system, monitoring, rehabilitation, database

1. INTRODUCTION

The main aspects of the management of existing bridges and viaducts are life prediction and maintenance management, structural rehabilitation and restoration of initial serviceability, technologies and materials for this purpose.

The inspection of the studies carried out on these subjects shows that the fundamental aspects of the problem are:

- to answer the question of whether the structure is safe enough at present. It is made by means of definition of the appraisal path, that is cyclical and consists of measurements and tests; a

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monitoring plan can be prepared, the information are studied and analysed and adequacy is checked;

- to propose typical repair and strengthening interventions on structural components in order to restore or to improve the initial performance conditions;
- structural and serviceability appraisal of the interventions performed;
- monitoring plan of structures after interventions, if it is necessary;
- upgrading of repair and strengthening technologies employed on the basis of evaluation of the obtained results;
- inserting all results in a data-base in order to handle above procedure more easily and to disseminate results among the interested people.

The problems that concern repair and restoration of serviceability of bridges are very important not only for specific aspects of scientific and technological research, but also for great costs requested to the owners of road-nets.

These bridges often have to be proportioned to the actual lane-width. Frequently no maintenance interventions were made on the latter and, after many years from construction, damages affects materials, structural or secondary elements. Actual loads include often seismic actions, frequently not included in the design codes at the construction phase.

The aim of this paper is to review the structural appraisal and restoration interventions of these structures. Among the numerous aspects of the problem, the paper individualizes the following features:

- Methods and procedures for the assesment of structural reliability; there are three stages:
 - i) a preliminary, broad assessment of apparent physical condition, robustness and strength of the structure, including simple calculations, where necessary;
 - ii) a complete assessment including, but not exclusively based on, numerical checks on stability of the whole structure as well as of the strength of each member;
 - iii) if (a) and (b) are not conclusive, a deeper analysis is required. This should be based on best knowledge of loads and materials' strengths that can be pratically obtained, either by measurements and tests, or if appropriate, by other investigations [1].
- Planning of appraisal with regard to the refinement of the structural analysis that is intended to develop and to the costs that anyone is disposed to support;
- Research of informations on construction techniques, mechanical, chemical and physical properties of materials, computational methods used in design of the structure and loads assumed when the structure was planned, especially for dated bridges and particularly for masonry bridges;
- Materials, techniques for structural repair and strengthening with particular regard to the durability and compatibility of new materials and those employed when the structure was made;
- For the most frequent typologies (arch masonry bridges, p.r.c. deck girder bridges) arrangement of procedures in order to realize a data-base of the most frequent damages, techniques and materials to repair and strengthening.

The paper tells of a bridge monitoring system, whose targets are monitoring, aging management, repair and strengthening of a lot of bridge structures (about two thousands), which is being developed on the basis of the results obtained from a review of the studies carried out in many countries on this problem.

2. OBJECTIVE AND STRUCTURE OF SYSTEMATIC BRIDGE MANAGEMENT

The problem of the management of a system of transports is tackled today under manifold points of view, whose common denominator is to assure the reliability of the system or to furnish the user the same performance with the time.

Bridge management is part of transportation management which in turn, is part of infrastructure management. Infrastructure management is an important part of the entire economic structure.

A systematic approach to networks management involves many aspects within which reliability of all components is the priority.

Among these problems the paper attempts to tackle current trends in bridge management, whose reliability involves large funding.

Bridge management system (BMS) has become a fundamental issue of infrastructure management in all countries where it is today under various stages of development [1] + [6].

The aspect of the problem is double: one concerns the management of existing bridges, another the design and construction of new one with particular regard to durability design.

Focal points of a systematic management of existing bridges are:

- Inventory
- Condition assessment
- Condition rating
- Determination of maintenance and rehabilitation interventions
- Economic evaluation of funding needs
- Economic efficiency considerations
- Planning of interventions
- Execution of interventions
- Management of repaired or rehabilitated bridges

Durability design of new bridges would be focused on these aspects:

- Inventory of most frequent defects encountered in existing bridges
- Determination of rules to be employed in design, execution, supervision, management and maintenance in order to extend service life
- Cost/benefit calculations in order to ensure optimal service life
- Development of codes for above operations to achieve foreseen targets.

The problems are very complex and not all above aspects have been developed today entirely: a systematic evaluation is in progress only for some of them.

3. MANAGEMENT OF EXISTING STRUCTURES

The stock of existing bridges differs notably from country to country. Bridges in Italy, for example, have been built since antiquity period: some in Roman age, others in Middle age, others in Renaissance, others in following age. Most are masonry bridges, some wood bridges, few steel bridges. Reinforced concrete bridges, prestressed concrete bridges and steel bridges were typical on road and railway network in the second half of the twentieth century, during the Post-World War II decades.

As far as bridge management is concerned, this means that most of the stock doesn't exhibit a homogenous structure aging and materials condition.

Masonry bridges have been realized up to the more recent years, with large rise in the years from first half of the XIX to the first decades of the XX, when the growth of r.c. structures yielded the progressive abandonment of masonry structures. Masonry bridges, built before World War II, are therefore present on all the national and provincial roads and they have to be adjusted to new volume of traffic (exercise loads and road dimensions).

Reinforced and prestressed concrete bridges of last decades begin to be subjected to destructive mechanism that are typical of reinforced concrete structures and that are due to maintenance lack.

As like in many countries as well as in Italy in order to ensure the structural stability, traffic safety and proper functioning of bridges in the long term, greater attention has been given to a bridge management system [7-9].

Because of the complex nature of the task involved, it is especially important to analyze other countries' experiences and use them in development activities.

In the USA since the early 1980s the individual states have used bridge management systems to support their maintenance planning. In the early 1990s FHWA has been developing a comprehensive BMS known as "PONTIS", which is characterized by conditions in the USA. e.g. damage model were geared to specific structural problems (steel bridges, suspended bridges) and to identically designed types of structure which, as a good experience had been gained with, were frequently used in the past [1].

Since the early 1990s in Germany, where bridge conditions were different in the West and in the East after reunion, a BMS is being developed whose structure has been subdivided into seven principal subject groups (modules). Bridges stock in Germany consists of a lot of types of structure and their mean age is low, because most of them were reconstructed after World War II. Today the deficiencies and damages relate mainly to traffic safety and durability problems [2].

Informations on Danish system is discussed in [3], the Swedish experience is described in [4], organization model for operation of major state owned toll bridges in California (USA) is discussed in [5], the Polish bridge inspection system is described in [6].

Focal points above mentioned will be dealt with later on.

3.1 Inventory

It is not surprising that many owners do not know how many bridges are in their networks. Inventory of bridges is a necessary starting - point for the appointment of BMS. The provision of basic data organized in a database is the fundamental feature of this module of the overall system. Data collected can be linked with other databases, in which traffic data, accident data, operating data, etc., are organized. This means to develop a comprehensive road information base and to make possible a link - up with other management systems.

It is necessary to take great care over the interpretation of collected data: a lack in basic informations, as that concern rehabilitation works performed, might cause erroneous results in even if sophisticated computer based analysis and suggests incorrect strategies in the final module of the overall system (cost - benefit analysis)

3.2 Condition assessment

Reliability of existing structures depends on:

- Material condition
- Efficiency of the static scheme
- External loads.

Carrying capacity and serviceability of materials are referred to:

- The carbonation front propagation or carbonation depth in concrete;
- Chloride penetration and content;
- Reinforcement corrosion.
- Loss of initial prestress due to corrosion of tendons and grouting problems.

This phase concerns provision of condition data derived from results of bridge inspections and the evaluation of the indentified damage.

It is rather articulated: it is followed by intervention phase immediately if condition ratings determine bridge maintenance, or by consecutive systematic inspections in order to know structure aging and materials condition. In any case the action required may be taken in phases, each phase depending on the findings of the previous one and the appraising involved people may be more and more experienced as the investigations are deeper.

In the preliminary assessment only visual inspections are needed and they may be of a routine nature, supported by appropriate procedures (e.g. after rainfall scuppers need to be inspected and cleaned). If that is the case the appraising people may not be specialized. More exhaustive, periodic visual inspections, carried out at some specific dates, include control of most notable among the rapidly deteriorating bridge components (joints, wearing surfaces, paint, bearings, pedestals, decks and primary members). These measures and material conditions may be inspected by specialized engineers.

The inspections have a cost and the expense has to be in any case justified by an investigation planning, particularly when interventions have to be performed.

Evaluation of defects and condition ratings, to make evaluation independent of the subjectiveness of the operator, may be assessed by normalized procedures. It is important

particularly when assessment doesn't depend on measurements of some selected control variables and in situ-tests.

For such purposes it is useful to predispose atlases or databases that visualize the defects that could occur to the operator, so that the evaluation may be performed on the basis of ratings previously set and with which good experience has been gained.

The preparation of the atlases of defects with their ratings is preliminary to the use of these procedures and to such purpose, for identically designed types of structures, condition ratings may be appointed by international cooperation.

A schedule of bridge inspection and condition rating reports, after inventory, need to be drawn up and a database has to be developed to include all data collected. Thus it is possible to follow progress of degradation for each individual bridge and to analyze in a systematic way the collected data if we are dealing with a group of bridges.

Experience of BMS in various countries in recent years has shown that it is worst to handle all data of an existing network as a whole, because average value is often meaningless.

In case of homogeneity for typologies or for environmental conditions or for both the characteristics, the data collected can be handled by the probabilistic approach.

To this end, monitoring systems and damage development models are to be integrated at a later date. The choice of the fittest procedure of investigation must be the object of an attentive evaluation, in-situ tests must be organized in several phases, each depending on the findings of the previous one. It is often necessary to plan investigations taking into account cost/benefit relationship. In addition to the costs of the in-situ tests it is necessary often take into account other costs as the scaffolding to carry equipments and operators on bridge members e.g in arch bridge on deep gorge.

In this phase of appraisal, calculations may be necessary and they may be simple, conventional design calculations or a deeper analysis is required.

There are three stages [10]:

1. A preliminary, broad assessment of apparent physical condition, robustness and strength of the structure, including simple calculations. If these checks are satisfactory no further investigation is required. If these checks indicate a dangerous situation, some temporary safety measures may have to be taken, pending further investigations.
2. A complete assessment including, but not exclusively based on, numerical checks on stability and integrity of the whole structure as well as of the strength of each member. Conventional design calculations will usually be used for these checks, although "working stresses", calculated using unfactored service loads, often give a better appreciation of the margin of safety, when compared to failure stresses of materials.
3. If (1) and (2) are not conclusive, a deeper analysis is required. This should be based on the best knowledge of loads and materials' strength that can be practically obtained, either by measurements and tests, or if appropriate, by other investigations. Such more precise knowledge may justify reduction of the (partial) safety factors used in the calculations.

3.3 Overall bridge condition rating

The experiences gained in many countries suggest the rating of bridges on the basis of damage and defects identified. In practice on the basis of inspection reports by means of a procedure independent from subjectivity of operator, overall bridge condition is averaged by a number, which is the product of condition ratings for all components and all spans. The experience and the

data by now available in bibliography and in the procedures already adopted by some countries enable to define an upper threshold under which interventions need and a lower one under which bridge fails and has to be rebuilt.

It is more advisable to integrate ratings based on condition data with a judgement on the bridge adequacy to the volume of traffic that is currently present on the road and the foreseen volume of traffic in the bridge residual lifetime. A bridge included in full maintenance program to extend its service period by measures applied to its most sensitive components may be insufficient with respect to the current volume of traffic; if that is the case decision must be adopted on the basis of a deeper and more comprehensive judgement.

With regard to materials and members condition bridge ratings will depend on the development of deterioration. Appraisal of annual deterioration rate is a very important task as it allows to foresee residual lifetime and to determine the plans for bridge maintenance, repair and reconstruction.

Many refined methods to predict the degradation of materials, e.g. the carbonation front propagation or carbonation depth in concrete and chloride penetration and content, have been performed [11-13]. These methods, undoubtedly for new bridges, will be useful, however their application may be associated with some difficulties if applied to existing one.

In practice, prediction methods are based on long-term experience and are unable to satisfy the immediate need for knowledge, because obtaining results takes long time

If the service life of a structure is long, the useful information obtained from experimental tests must take into account the exposure conditions which in turn depends on environmental conditions that today could suffer from sudden and not predictable variations. Moreover the results obtained from field tests are doubtlessly valid in condition exposures similar to those of the test site and cannot be applied to other environmental conditions.

Degradation depends also on other factors e.g condition of bearings, joints, scuppers, water erosion, soil movement etc.

Therefore it appears more advisable to include all these degradation factors by means of a comprehensive annual rate of deterioration which is a fraction of a rating point. In this way bridge annual deterioration rate averages all components annual one.

Deterioration rate of a point could be established on the basis of the results obtained either from network's owner or from other owners' experiences.

In literature it is pointed that undocumented rehabilitation and repair work could influence the choice of the annual deterioration rate of a point and that the behaviour of rehabilitated bridges differs from the new ones.

Typical values of annual deterioration rate are 0.1 and 0.2 of a point at full, no maintenance or rehabilitated bridges respectively; those at full maintenance (0.1) are speculative while those at reduced or no maintenance are based on many years of experience. Moreover rehabilitated bridges can never be restored to a higher condition rating [1].

On the basis of these values for annual deterioration rate of a point in 15 or 30 years bridge reach the threshold under which minimum maintenance is insufficient and the structure needs full maintenance and annual deterioration rate increases.

As above pointed it is necessary take into account the likely obsolescence from the insufficiency towards the volume of traffic.

3.4 Examination of the typologies of interventions to be performed

Maintenance interventions have been performed in all epochs, today principally reinforced concrete and steel bridges are involved in the maintenance programs.

This phase concerns products and technologies to be employed and the most important features are materials durability and interventions costs.

It must be pointed that in some cases the useful information obtained from experience-based tests on the durability of maintenance and rehabilitation materials and measures is restricted to those which are in use for tens of years and in many cases monitoring period is fairly brief. Therefore reliable judgements may not be provided from today available results.

Results obtained by laboratory tests simulate seldom real materials aging or environmental deterioration. The wisest thing is to perform in-situ tests using cast test specimens fixed to the real structure, exposed to the same environment and execution as the structure or structure itself; in the latter, a non destructive testing is usual and suitable to compliance with laboratory tests [12]. This procedure suggested for design of new structures appears suitable for rehabilitation or maintenance interventions too.

Therefore it is better to use products and technologies whose behaviour with the time is well known and documented, taking into account that the intervals between two successive interventions must be at least of 5-10 years e.g. for paint of steel or reinforced concrete members while a longer durability for other bridge components must be ensured.

In this phase of BMS it is essential to fix intended service period of bridge on which maintenance and or rehabilitation and the types of interventions depend consequently. As above mentioned above, not only structural reliability but also serviceability must be taken into account. In the latter and to this end BMS may be interfaced with other management systems and finally with a comprehensive systematic road management.

Sometimes problems arising from the use of materials in, the fast to their harmfulness only recently we are turning our attention, make more complex and expensive the choice of the fittest technologies and materials to be employed in repair or rehabilitation interventions [14].

All the procedures of this module of BMS could be computerized; the organization of databases in which various intervention typologies and their time depending behaviour are collected is an important tool for decision making.

The database has to be predisposed so that all results of inspections after every construction measures (repair, conversion, new construction) can be entered directly and new technologies and products can be enclosed.

3.5 Calculation of funding requirements

The above phases enable the calculation of funding requirements. The monetary evaluation for the maintenance of the total stock of structures could be drawn initially per square meter of bridge deck taking into account main features of bridge (predominant materials, type of design) and maintenance strategy (full maintenance, reduced maintenance, demand maintenance) [1].

These initial cost forecasts could be subsequently detailed by means of deeper investigations with experts being consulted and measures being selected in each individual case, using the appointed catalogues.

The results of this module combined with those of an overall road management system allow higher administrative levels, central government, to plan funding requirements, taking into account political, economic and technical conditions.

3.6 Cost/benefit analysis

This phase is crucial as it separates appraisal from intervention phase and to this end other conditions play an important part e.g. social, economic, political, strategic conditions, as above mentioned above. These conditions cannot be quantified and tackled through computerized analysis and procedures; the final decisions therefore could be taken on the basis of considerations that are beyond those here developed.

Nevertheless any decisional choice could not put aside the knowledge of all aspects of the problem and, therefore, purpose of any BMS is to define this form also.

3.7 Planning of the management measures

Planning of the interventions could be organized on the basis of the results obtained in the above phases, after cost-benefit calculations have been assessed. For this purpose if the local administrations develop one's database, it is necessary that collected data are interfaced and organized with those obtained from other local administrations, so that central government may decide which network are to be maintained, rehabilitated or reconstructed and may assign funding to the local administrations which in turn are responsible of implementation of interventions. To this end procedures adopted by the USA and Germany and other nations could be an useful reference for the organization of BMS.

3.8 Implementation of interventions

Once decision of full or reduced maintenance or rehabilitation has been reached, the measures must be implemented. This phase must be organized so that the basic data of any intervention are entered into the database and constitute useful references for further interventions and for the management of bridge itself.

The most recent results on the development of materials deterioration must be applied as this phase is similar to construction stage and, therefore, all the results on durability design and on prediction and extending lifetime of a structure could be applied.

As above mentioned products employed for repair and rehabilitation interventions should be monitored and deterioration rate with the time should be carefully controlled and measured by programmed inspections on the structure by means of non-destructive tests or by means of in-situ performed one using cast specimens fixed to the structure, exposed to the same environment and execution as the structure.

The most recent theoretical results on lifetime of concrete structures that take into account realistic materials modeling, structural damage evaluation and nonlinear structural analysis with deterministic reliability analysis could be employed and validated by means of in-situ tests and measurements [13]. It must be pointed that, as above mentioned, deterioration rate of rehabilitated bridges is greater than new one.

Most recent design codes impose provision of a manual of use and of maintenance in the design phase of new structures. Manuals' preparation could be performed on the basis of results acquired during development of bridge management system.

3.9 Management of repaired or rehabilitated bridges

Management of rehabilitated structures must be developed in a different way comparing to the past: basic data after any intervention must be entered in a computerized database, structures must be monitored by means of a program of systematic inspections in order to assure new intended

service period. So it is possible to collect in-situ data on the technologies and products employed and it is useful to enter all data in a computerized database to which each owner could approach for his management system. Moreover if all these databases are interfaced, central government, which has the responsibility for the road network and provides the required funds, can decide.

A group of authorities (municipal, provincial, regional etc.) manages road and rail networks each of one, often, acts autonomously. Data acquired are not interfaced and so they are not comparable: basic data as catalogue of structures doesn't exist often. If that is the case it is advisable that the central government develops BMS and imposes it to local administrations.

4. DESIGN OF NEW STRUCTURES

The essential features of durability design and construction of new structures doesn't substantially differ from the above discussed, but procedures must be organized so that peculiar problems of new structures are taken into account.

It is often impossible to deal with some questions in the same way and by means of the results collected in database appointed for the management of existing bridges. The latter, for example, could be examined by deterministic or probabilistic manner but the so called "golden rules of building operations" cannot be deduced from database.

In any countries, e.g. Italy, the reconstruction after World War II was performed privileging the isostatic schemes for the bridge in consequences of difficulties arising often from geotechnics and reinforced concrete structures were realized without any superficial protection. Degradation and deterioration after about 30 years result in a change of the above mentioned choice: new bridge privilege the static scheme of a continuous beam. So the number of structural joints is drastically reduced and it is possible to rely on the capacity of the structure to redistribute exceptional loads as seismic actions within its all components and the greater complexity in the construction phase is counterbalanced by the less need for maintenance.

For these reasons warnings have been appointed for construction of new bridges and collected in a publication with the aim of planning maintenance of roads [9].

5. MODEL OF BMS IN DEFINITION

As mentioned in the abstract, a study is in progress to define a BMS for a public provincial administration whose road network is about 2200 Km and on which a large stock of bridges exist. Many of these are masonry bridges, other are reinforced or prestressed reinforced concrete bridges and only few steel bridges. Today inventory and a computerized system to acquire bridge condition have been performed. The system appointed can acquire all data available from visual inspections and from information on bridges' construction and maintenance or repair interventions performed. To this end the staff of the Transportation Department of the provincial administration has been trained on aging of r.c. structures and particularly on bridges' deterioration. The next step of the program is to train the staff for application of the appointed system.

New modules of the BMS are in definition: module for condition rating and for determination of maintenance and rehabilitation interventions. A collection of the most frequent and utilized products and technologies for maintenance, repair and rehabilitation interventions is in progress:

the data acquired will be computerized by means of a program similar to the one just appointed for data on bridges conditions.

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