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Low cost condition assessment method for existing RC bridges

Flavio Stochino*, Maria Luisa Fadda, Fausto Mistretta

Department of Civil, Environmental Engineering and Architecture, University of Cagliari, Italy

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ABSTRACT

Aging infrastructures represent a current engineering challenge. Huge budgets are necessary to keep their functionality and the lack of a proper and timely maintenance entails an increasing deterioration and therefore higher repair costs. Therefore, assessing the reliability of infrastructures becomes mandatory, with particular attention to the ones still in service even when their life limit has exceeded.

This paper aims to propose a new, fast and low cost method of condition rating for reinforced concrete bridges. This is based on visual inspection and non-destructive testing.

The main innovation is represented by the parameters taking into account the mechanical degradation of materials and the damage location at the structural sub-component level.

The analysis of some benchmark examples and the comparison with other methods are presented in order to assess the reliability of the new proposal.

1. Introduction

Aging infrastructures has become a paramount problem nowadays, particularly in countries, like Italy, where the main motorways were built more than 50 years ago. The infrastructure functionality closely depends on a good inspection activity. In addition, lacks of a proper and timely maintenance entail an increasing deterioration and, consequently, higher repair costs.

Therefore, assessing the reliability of infrastructures becomes mandatory, with particular attention to the ones still in service even when their life limit has exceeded.

Investments for the development of a reliable Bridge Management System (BMS) have recently increased. BMS is the set of inspection, investigation, maintenance and repair of a group of bridges or viaducts, organized according to priority, with the support of computer databases and algorithms. Usually, the conservation of a structure is assessed through qualitative judgments. As a matter of fact, bridge rating or scoring is a tool used in BMS to prioritize maintenance investments. The BMS estimates the bridge relevance at a project or network level, considering its serviceability and importance in the road network in order to prioritize maintenance activities, see [1].

An early approach to this problem was presented [2] by Znidaric and Perus, who analysed the condition rating techniques for Reinforced Concrete (RC) bridges. They suggested that a condition rating method should not be based on the simple scoring of the inspected members (or of the whole structure), but on the numerical evaluation of all those essential damage types revealed during the inspection, whose character, intensity and extent may have a substantial impact on the safety and durability of the inspected structural member or structural component.

Gattulli and Chiaramonte, see [3], enriched the approach introduced in [2] including the evaluation of steel and masonry bridges and assessing the condition of each subcomponent in an overall structural system. Also Kano and Morikawa, see [4], applied the above-mentioned condition rating system to some cases of RC structures damaged by chloride induced deterioration. In particular,

* Corresponding author.
E-mail address: fstochino@unica.it (F. Stochino).

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they introduced an interesting parameter representing the uncertainties of the inspection results.

In [5] the spatial time-dependant reliability analysis was merged with visual inspection in order to predict the likelihood of RC corrosion-induced cracking.

One of the declinations of the approach presented in [2] is the Slovenian Method. More details will be given in Section 2.3. In [6] Kušar and Šelih considered a huge set of bridges to point out that climate and exposure to water are the most important parameters influencing the bridge condition.

Quite different methods have been proposed to prioritize bridges and suggest maintenance strategies at a network level. In [7] an index is presented, called Integrated Bridge Index IBI that takes into account the vulnerability risk and the strategic importance of each net component. The index was calibrated through visual inspections, experts' surveys, and regression analysis.

A method for a fast and automatic evaluation of the bridges stability and resilience is presented in [8], while a ranking strategy based on a multi-attribute utility theory (MUAT) is proposed in [9]. Some interesting results have been obtained using fuzzy logic, see [10,11].

Particular attention should be drawn on bridges with historical value; in this case the priority queue should consider the cultural importance of these structures as well. Two very interesting papers dealing with this topic are [12,13].

The idea of using several sources of information for the data necessary to rank the infrastructure conditions has been thoroughly investigated in literature. For example, detailed information on the geometry and displacements of the bridge by means of laser scanners, see [14–15], can be useful and relevant.

The Non-Destructive Techniques (NDT) can produce another important set of information contributing to complete the visual inspection data and reducing the dependency on the inspector's judgment. A very interesting paper dealing with this topic is [16], where a classification of the damage levels, assessment flowcharts and NDT methods results are presented. Significant examples of these techniques applied to historical bridges are also present in the literature: [17–20].

In this paper, the authors present an improved version of the early method described in [2] which takes into account the mechanical degradation of materials and the damage location. This would allow a fast and low-cost condition rating of the RC bridge network that can be easily implemented in BMS.

The present paper is organized as follows: in Section 2 the proposed method is presented along with two other methods based on [2], necessary for a comparison. Section 3 further analyses four benchmark real case studies to show the efficacy of the proposed approach. Finally, perspectives and conclusive remarks are drawn in Section 4.

2. Methods

2.1. Proposed method

The assessment method proposed in this paper is divided into three main steps. In the first one a thorough visual examination is performed in order to detect any damages on the structure. Then, a set of non-destructive tests is developed in order to determine the mechanical characteristics of materials. Finally, the results of the first two steps are merged and analysed in order to obtain a Condition Rating Number *CRN* characteristic of each structure. It is a non-dimensional number related to the damage degree in the analysed structure. It is defined as follows:

$$CRN = \gamma\left(\frac{\sum_{m=1}^{k} F_{D\ m}}{\sum_{m=1}^{k} F_{D,ref\ m}}\right)\bullet 100 \tag{1}$$

where γ is an arbitrary scale constant that needs to be tuned for the considered case; F_{Dm} is the condition rating number for the m-th structural component while $F_{D,ref\ m}$ is the corresponding maximum value.

The definition of F_{Dm} is expressed by the following equation:

$$F_{Dm} = K_m \sum_{i=1}^{n} B_i \bullet K_{2i} \bullet K_{3i} \bullet L_i \bullet T_i \tag{2}$$

K_m is a coefficient representing the importance of the considered element in the structure. Its values are reported in the Appendix: Table A1, extracted from [2]. B_i denotes the potential effect on the structural element safety of the ith damage, see Table A2 in the Appendix. K_{2i} expresses the magnitude of the ith damage divided into IV classes, from the lowest to the highest, whose values are reported in Table A3 (Appendix). K_{3i} represents the extension of the damage along the structural element, whose values belong to the range 0–1 according to the indications reported in Table A4 (Appendix).

An innovative aspect of this work is represented by the specification of the damage location and of the material properties degradation in each structural element. L_i and T_i can respectively measure these two aspects.

L_i expresses the location of the ith damage in the structural element and it can assume binary values: 1 in case it is not a critical point, 2 when it is a critical point, see Table 1. With “critical point”, the authors mean the part of the single structural element that is “critical” for the structural safety. For example, the zones with the maximum stress values or with stress concentrations (beam midspan, support zones, holes etc.). Obviously, the critical points cannot be determined without knowing the boundary and loading conditions. Thus, for each different case a thorough assessment of this parameter is necessary.

T_i is the coefficient representing the material degradation. Its values are presented in the following Table 2 and they depend on the ratio between the design material strength $f_{mk}{}^{d}$ and the one measured by experimental tests (e.g. rebound index, coring strength