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## The application of the Italian Guidelines

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# Multi-risk assessment for bridges: the application of the Italian Guidelines

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## Abstract

Bridges are essential elements in the built environment since they underpin the functioning of transportation systems. Nevertheless, they are vulnerable due to aggressive environment, demand beyond the design level, and other contingencies such as extreme events. The management of bridges represents a significant challenge for improving transport performance and ensure the safety of users. In Italy, bridge management is addressed by the recent "Guidelines for risk classification and management, safety evaluation and monitoring of existing bridges" which were issued by the Italian Ministry for Public Work in 2020. The guidelines propose an operational approach with distinctive characteristics: (i) risk-based, i.e., based on the typical parameters of hazard, vulnerability, and exposure; (ii) multi-level, i.e., they include six assessment levels (0-5) of increasing complexity; and (iii) multi-risk, i.e., they assess structural/foundation, seismic, hydrological and landslide risk. This paper presents a general overview of the 2020 Italian Guidelines and their application to a selected case study. Lessons from the application to the case study are drafted and possible criticalities highlighted.

## Keywords

Bridge management, infrastructures, Italian guidelines, structural safety, risk assessment, risk classification

## 1 Introduction

Bridges are critical components of transportation infrastructure, providing essential connections for people, goods, and services. Bridges may deteriorate faster than anticipated, increasing the probability of failures and the associated economic and social costs. To address these challenges, it is crucial to develop robust and comprehensive management and maintenance strategies that account for the unique characteristics and needs of each bridge in a transportation network.

One approach to bridge management and maintenance is to use risk-based methods that prioritize activities based on the likelihood and consequences of potential failures. In addition to slow deterioration phenomena, it is also important to consider the potential impact of natural hazards on bridges. This process can involve incorporating hazard assessments and risk analyses into management plans to identify vulnerable bridges and prioritize the implementation of protective measures [1]. The development of standard operating procedures is currently a primary necessity.

In France, Cerema (Centre d'études et d'expertise sur les risques, l'environement, la mobilité et l'aménagement) developed a multilevel method to evaluate the level of risk of existing bridges related to scour [2]. Similarly, in the United Kingdom, the National Highways released a technical guideline concerning the risk assessment due to scour and hydraulic actions [3].

Italy is subjected to numerous natural hazards, including earthquakes, landslides, and flooding. Furthermore, Italy has one of the oldest bridge portfolios in Europe. The collapse of the Morandi Bridge in Genoa in August 2018 brought attention to the need of assessing the conditions of bridges in Italy, and the need for actions to ensure their safety.

To ensure a uniform level of safety of the transportation network over the national territory, in 2020, the Italian Ministry for Public Work released the "Guidelines for the classification and management of risk, the evaluation of safety and the monitoring of existing bridges" [4].

The main scope of the Italian Guidelines (IG) is assessing the level of risk of existing bridges to organize monitoring and maintenance activities. The new IG are characterized by:

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- a multi-level method composed of six phases of analysis (from Level 0 to Level 5) with increasing degrees of detail;
- a risk-based approach that accounts for hazard, vulnerability, and exposure;
- a multi-risk analysis that includes structural/foundation, seismic, hydrological, and landslide hazards.

Existing literature on the IG is mainly focused on the first levels of analysis, i.e., from Level 0 to Level 2. For instance, Pregnolato et al. [5], and Cosenza and Losanno [6], apply the IG up to Level 2 and qualitatively describe the further levels. Baratono et al. [7] provide a comprehensive description of all levels of the IG and report the application to Level 2 for a sample of 261-bridges.

Currently, the IG are being tested by several technical bodies to identify possible aspects of improvement. The latest version of the document proposed a few changes, e.g., some corrections to Level 2.

In this paper, a complete application of the IG is presented to identify the main criticalities of the levels from 0 to 4; Level 5 is not addressed since it is not fully developed in the IG. The main goals of this paper are to (i) present an application of the IG to a real case study (one bridge - all levels of analysis), and (ii) identify and discuss possible criticalities.

The remainder of the paper is organized as follows. In Section 2, the IG are described with particular emphasis on the innovative multi-level and multi-risk procedure. Section 3 illustrates the results of the analysis applied to a case study, which consists of a reinforced concrete bridge built in 1931 over the Oglio River, Mantua, Italy. Section 4 concludes this paper by highlighting the main criticalities of the IG and possible areas of improvement.

## 2 The Italian Guidelines

The IG encompass six levels of analysis, from Level 0 to Level 5 (Figure 1). As the level increases, the complexity, the details, and the resources needed increase too. Instead, the number of bridges that requires the analysis and the degree of uncertainty of the results decreases.

Level 0 aims at creating an inventory of data for each bridge in the network, including general design data, the geometry of the structural elements, and specific information about the traffic on the road. This phase also supports the following levels of analysis.

Level 1 involves in situ inspections to verify and improve the information collected in the previous level. Inspectors must evaluate the state of preservation of each bridge in the portfolio by identifying the level of degradation of its structural elements.

Level 2 represents a novel aspect of the IG compared to other procedures: through a multi-risk approach the LG consider several risks for the overall assessment of the structure. Specifically, each bridge is analyzed and classified with regard to four risk types: (i) structural/foundation, (ii) seismic, (iii) flooding, and (iv) landslides. Each

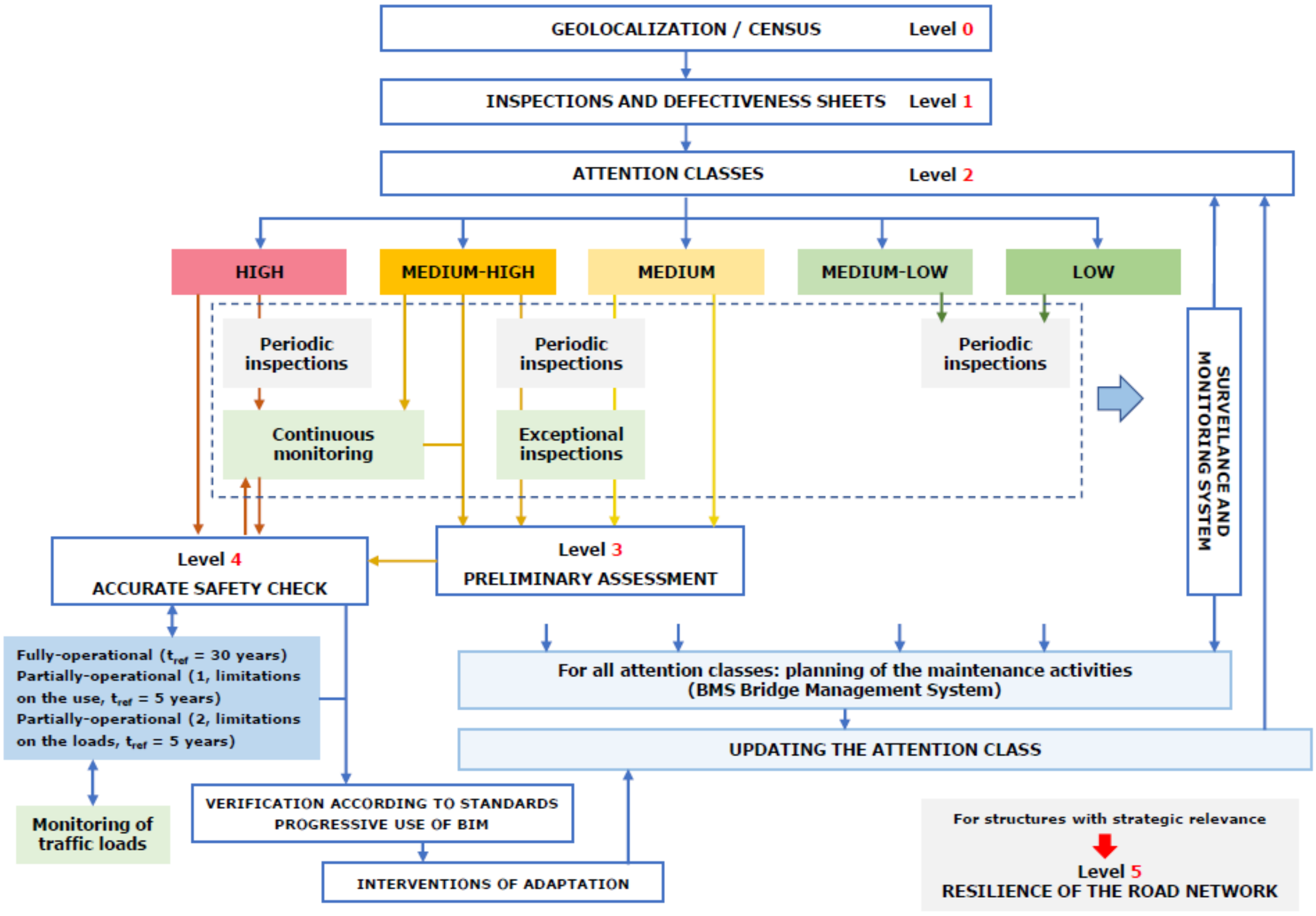


**Figure 1** Logical flow of the levels of the Italian Guidelines (adapted from CSLLPP, 2020)

risk type is rated through an Attention Class (AC). By combining the ACs relevant to the different risks, a Total AC is evaluated and assigned to the bridge. There are five ACs, namely: Low, Medium-Low, Medium, Medium-High, and High. The evaluation of all bridges of the Italian territory is compulsory up to this level. The higher levels of the multi-level procedure should be applied only in specific cases listed in the IG or to bridges that have been classified with AC medium, medium-high or high.

Level 3 regards a preliminary assessment of the structure to give an overview of its safety level. In particular, the analysis requires a comparison of the structural response to the loads provided by (i) the standards in force at the time of the construction of the bridge and (ii) the current design standards. This level of analysis involves more input data than that required for Level 2, especially regarding the bridge static scheme, supports, etc., and it may require the use of software tools to perform the calculations. No information about the current structural capacity is required.

At Level 4, a safety check of the bridge is carried out according to the current Italian standards [8]. The structural capacity is estimated, and the bridge is classified into different performance classes, namely: (i) code-conforming, (ii) fully-operational, (iii) partially-operational 1, according to the NTC traffic loads, and (iv) partially-operational 2, according to the Highway Code [9].

Finally, Level 5 involves a resilience analysis of the road network. This entails a study of the consequences on the entire transport network due to the loss of functionality of the bridge. This level is only mentioned in the IG [10] and therefore, it is disregarded by this study.

## 3 Case study

As a demonstrative case, the procedures of the IG are applied to the Marcaria bridge (Figure 2) over the Oglio river, in the Mantua Province (Italy). Its construction began in 1931 and ended in 1932. The bridge has a total length of approximately 124 m, and it consists of five spans: the two end spans have a length of 15.55 m each, whereas the central three spans have double lengths. An expansion joint is placed in the middle of the central span dividing the structure into symmetric parts. Regarding the geometry, the bridge superstructure is composed of multi-cell box section tapered beams; the piers have a tapered rectangular cross-section; the abutments and the foundations are rectangular. The beams, the abutments and the piers are made of reinforced concrete. Some reinforcement details and soil characteristics are not available. Therefore, some conservative assumptions are made throughout the following analysis.

The Marcaria bridge is representative of the Italian infrastructural asset because of the following common characteristics: (i) it was built in the first half of the 20th century, (ii) the main structural material is reinforced concrete, (iii) each span has a length lower than 50 meters [11], and (iv) it is located on a secondary road [10]. Besides, this bridge belongs to the exceptional transport road networks. For these reasons, it was chosen as a case study to verify the actual applicability of the IG up to Level 4. The results of the safety evaluation of the Marcaria bridge are summarized in the following paragraphs.

### 3.1 Level 0 and Level 1

First, the available data on the bridge are collected from the archive of the Province of Mantua, which is in charge of managing the bridge (Level 0). After that, an in-situ visual survey was carried out to assess the state of the bridge and fill the “defectiveness sheets” (Level 1). The most significant defects include (i) corrosion of the steel supports (Figure 3), (ii) cracks on the concrete elements, (iii) missing portions of the concrete cover, (iv) different heights of the deck where the expansion joint is located (Figure 4). Level 1 prescribes a general assessment of the natural hazards which may affect bridge safety. The local authority, i.e., Autorità di Bacino del Fiume Po, reports that the bridge area is prone to hydraulic risk due to the presence of the Oglio river but not to the landslide risk, which is therefore neglected in the analysis.

**Figure 3** Corrosion of the steel support.

**Figure 4** Different heights of the deck at the expansion joint.

**Figure 2** The Marcaria Bridge.

## 3.2 Level 2

In the context of Level 2, a Total AC is assigned to the bridge accounting for the different risk types. The individual ACs depend on hazard, vulnerability, and exposure, and are analyzed according to primary and secondary parameters described in the IG. In this analysis, several assumptions are made, such as regarding the soil characteristics and reinforcement details. Regarding the structural/foundation AC, the *level of defectiveness* is found to be “High”. Other parameters considered are the average daily truck traffic, load limitations, the year of construction, the static scheme, the materials, and the typology of the crossed entity. Following the IG, since the *level of defectiveness* is “High”, the structural/foundation AC is “High” as well. The assessment of the seismic AC takes into account parameters such as the peak ground acceleration and the soil class. The strategic function of the bridge is considered in the exposure evaluation. The “High” *level of defectiveness* leads to a “High” seismic AC for any soil class. Indeed, no assumption on the soil class was done at this level. Regarding the hydraulic risk, the AC is determined considering: (i) insufficient minimum vertical clearance, (ii) general scour, and (iii) local scour. Based on the values of the hydraulic parameters, among which are the clearance, the characteristics of the riverbed and the floodplains, and the assumed dimensions of the foundations, the Marcaria bridge results in a “Medium-High” hydraulic risk.

By combining the five ACs associated with structural/foundation, seismic, and hydraulic risks, the Total AC obtained for the Marcaria bridge is “High”, as shown in Figure 5.

## 3.3 Level 3

In the case of a “High” AC, the IG prescribe to directly perform the analysis at Level 4. Nevertheless, in this study, Level 3 is addressed to highlight possible criticalities and provide an overall overview of the procedure presented in the IG. The evaluation is carried out through the preliminary assessment of the main beams of the bridge with respect to traffic loads. In particular, the safety of the structure is guaranteed if the ratio between the internal actions calculated according to the original design standards, e.g., [13], and the ones determined by the current standards [8], is greater than one. For the analysis of the Marcaria bridge, the original design documents provide the loading scheme used in designing the structural elements. In particular, the beams were designed to resist a set of heavy military trains each composed of a tractor of 12 tons and 2 wagons of 40 tons positioned longitudinally along a side lane of the bridge. On the contrary, current standards [8] impose different loadings on two parallel lanes along the bridge resulting in an asymmetric and overall larger load. The maximum bending moments on the bridge beams are compared. Figure 6 and . Figure 7 display the envelope of the bending moment caused by respectively the traffic loads of the original design, and the traffic loads computed according to the NTC 2018.

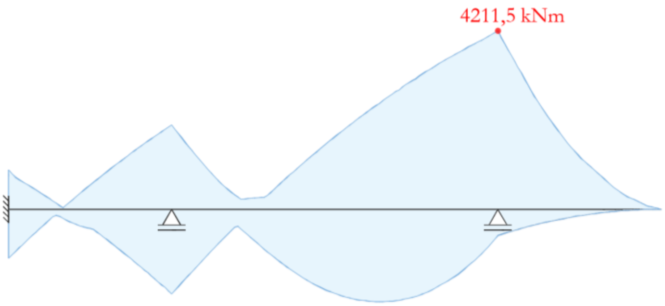


**Figure 6** Bending moment according to original design (in red: maximum moment).

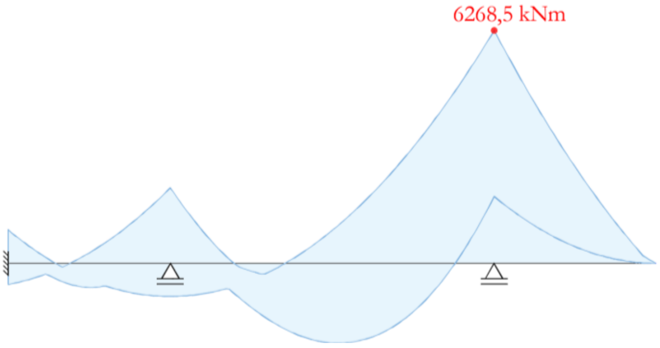


**Figure 7** Bending moment according to current standards (in red: maximum moment).

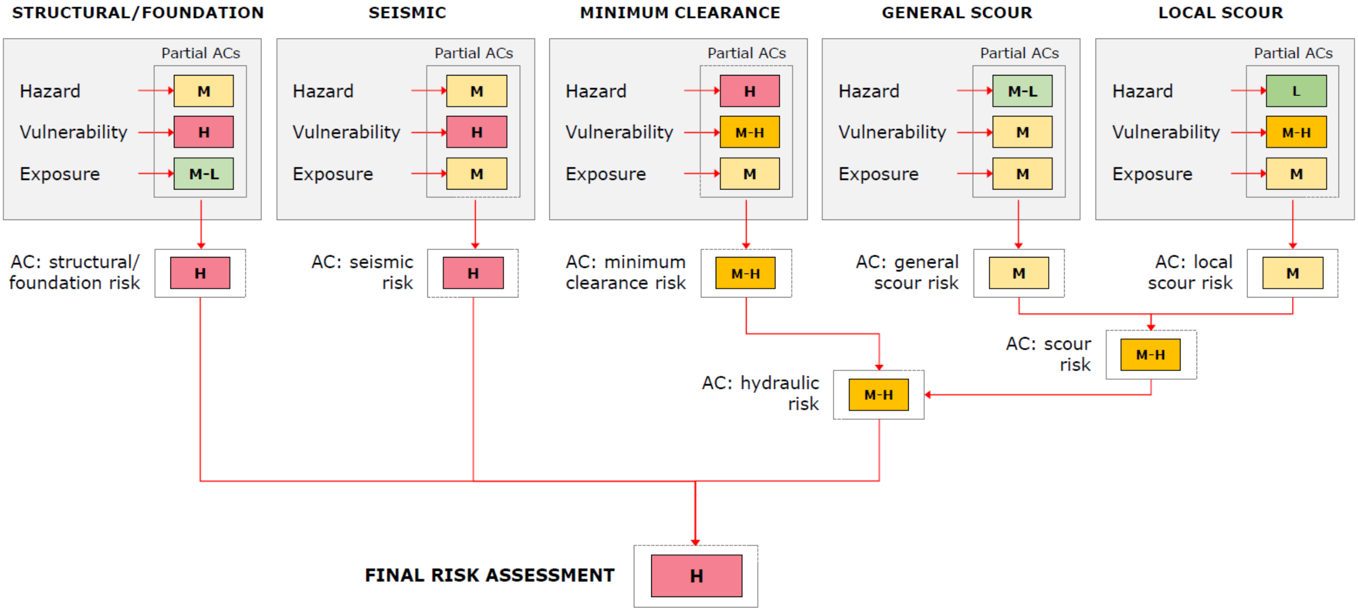


**Figure 5** Risk assessment of Marcaria Bridge according to Level 2.

In both figures, only half bridge is considered due to its symmetry. The maximum bending moments are reported in red. The ratio between the two maxima is lower than one (4211,5 / 6268,5 = 0,672 < 1). Therefore, the bridge is furtherly assessed at Level 4.

### 3.4 Level 4

For the analysis at Level 4, a Finite Element Model (FEM) is created using the Midas Civil software [14] (Figure 8). The beams (Figure 9), the four piers, the two abutments, and the six foundations are analyzed and verified according to the current Italian standards [8]. Several hypotheses on the shear reinforcement details of the main beams, designed to be "Code-conforming", and for soil characteristics, i.e. angle of friction $= 25°$ and saturated density, $\gamma_{sat} = 21\, kN/m^3$, are made due to the lack of information. In real applications, this information should be obtained before the application of Level 4 as critical in the assessment of structural safety. For this paper, the above-mentioned assumptions are done and then discussed.

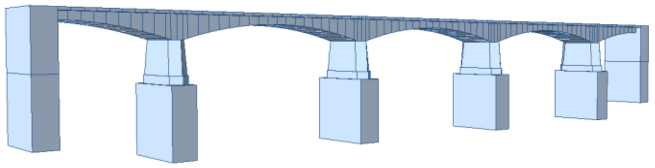


**Figure 8** Finite Element Model of the Marcaria bridge, using Midas Civil.

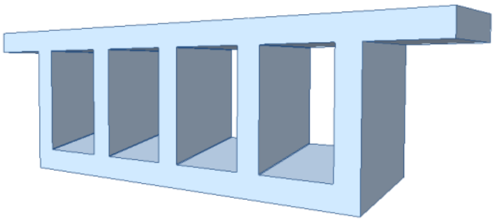


**Figure 9** Section of the beam.

In the evaluation of structural safety, the following actions are considered: dead load, traffic load, acceleration/deceleration force, wind load and snow load. Each structural element is evaluated by considering the actions to which the component is subjected and the relative capacity.

The IG prescribe the evaluation of existing structural safety against the performance requirements from current standards. To this purpose, two parameters should be computed, namely:

$\zeta_{v,i}$ is the ratio between the value of the maximum admissible vertical variable action $v$ on the $i$-th component and the one that would be used for the design of the same component according to current standards;

$\zeta_E$: is the ratio between the structure seismic capacity and the maximum seismic action that would be used in the design of the same structure according to current standards.

If the ratios are higher than one, then the "code-conforming" performance class is assured, and no further analyses are needed. Alternatively, the verification towards lower performance classes must be performed. The IG indicate three lower performance classes, namely "fully-operational", "partially-operational 1", and "partially-operational 2", which must be consecutively checked. For each performance class, the action and material safety factors are evaluated considering a specific reference time, which is equal to 50 years for the "code-performing" class, 30 years for the "fully-operational" class and 5 years for the "partial-operational 1" and "partial-operational 2" implying different limitations and restrictions.

Table 1 summarizes the verifications performed and the results obtained for the different structural components.

**Table 1** Verifications of the structural components at the ULS.

| Element | Verification type | Verified for class |
|---|---|---|
| **Beam** | Bending moments | Code-conforming |
| | Shear forces | Fully-operational |
| **Piers** | Axial force | Code-conforming |
| | Bending moment | Code-conforming |
| | Shear force | Code-conforming |
| **Abutments** | Axial force | Code-conforming |
| | Bending moments | Code-conforming |
| | Shear forces | Code-conforming |
| **Foundations** | Ultimate load | Code-conforming |
| | Sliding | Code-conforming |
| | Global stability | Code-conforming |
| | Axial force | Code-conforming |
| | Bending moments | Code-conforming |
| | Shear forces | Code-conforming |

No information is available about the shear reinforcement that has been assumed sufficient according to current standards. Despite this assumption, beams result to be verified only to the "Fully Operational" performance class due to the concrete quality, on which information is available. As shown in Table 1, the foundations are found to be verified, for the assumed soil characteristics. A sensitivity analysis permitted to estimate the minimum values for the friction angle $\Phi$ (°) and saturated density $\gamma_{sat}$ $(kN/m^3)$, for each class of verification, e.g., "code-conforming" ($\Phi > 24.8°$, $\gamma_{sat} > 21$) and "partially-operational 2" ($\Phi > 23.6°$, $\gamma_{sat} > 20.8$). Lower values would affect foundation stability and therefore structural safety.

The analyses at Level 4 are limited to the static verifications.

## 4 Discussion

In this section, a sensitivity analysis is conducted to investigate the importance of each risk type in the determination of the Total AC at Level 2 and the need to perform further analyses at Levels 3 and 4. The sensitivity analysis is generic and not specifically related to the analyzed case study. After that, the main criticalities found throughout the application of the IG to the Marcaria bridge are listed. Finally, additional criticalities highlighted by other authors are reported.

The sensitivity analysis focuses on each $AC_{ij}$, where $i$ ($i = 1, \ldots, I$) relates to the AC value, ranging from $i = 1$ (Low) to $i = 5$ (High) and $j$ ($j = 1, \ldots, J$) to the risk type, namely $j = 1$ (Structural/Foundational), $j = 2$ (Seismic), $j = 3$ (Hydraulic), and $j = 4$ (Landslide). Given $AC_{ij}$, a set of $N = I^{J-1} = 5^3$ Total ACs are determined by considering all the possible combinations of the ACs corresponding to the other risk types. For each $AC_{ij}$, an index $r_{ij}$ is defined, as follows:

$$r_{ij}(\%) = \frac{n_{ij}}{N} 100 \qquad (1)$$

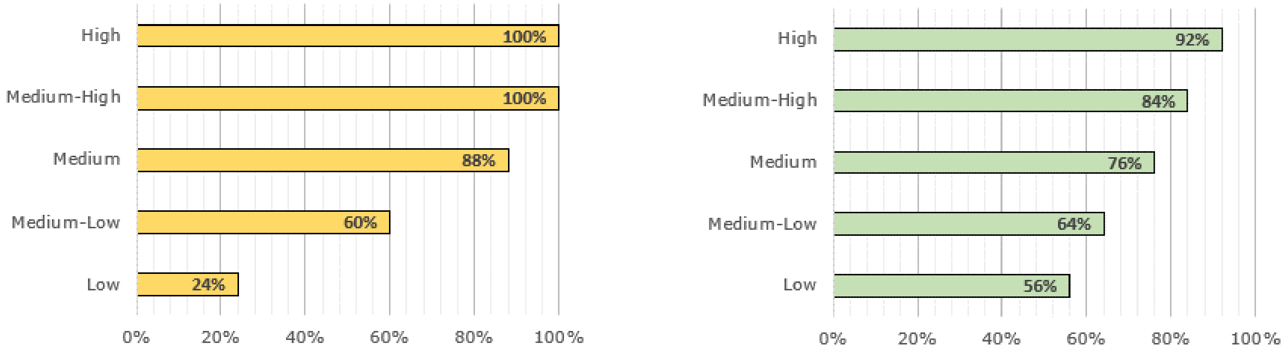
where $n_{ij}$ is the number of times that Total ACs corresponding to $AC_{ij}$ are Medium, Medium-High or High. In these cases, the analysis at Level 3 or 4 must be performed.

Figure 10 shows the results of the sensitivity analysis. Results highlight that the structural/foundation AC has the major influence on the Total AC: if this risk type is classified “High” or “Medium-High”, the analyses of Levels 3 and 4 must be performed in 100% of cases, regardless of the other risks. Instead, if the result of the structural/foundation AC is “Low”, only in 24% of cases Level 3 and 4 analyses must be performed. The seismic, the hydraulic and the landslide ACs do not have the same impact on the evaluation of the Total AC. Specifically, it is found that the hydraulic and the landslide AC have little influence on the Total AC in comparison with the AC relevant to the other risk types. On the contrary, the AC relevant to the structural/foundational risk has a high impact on the Total AC.

Table 2 lists the criticalities of the procedure described in the IG identified during the analysis of the Marcaria bridge.

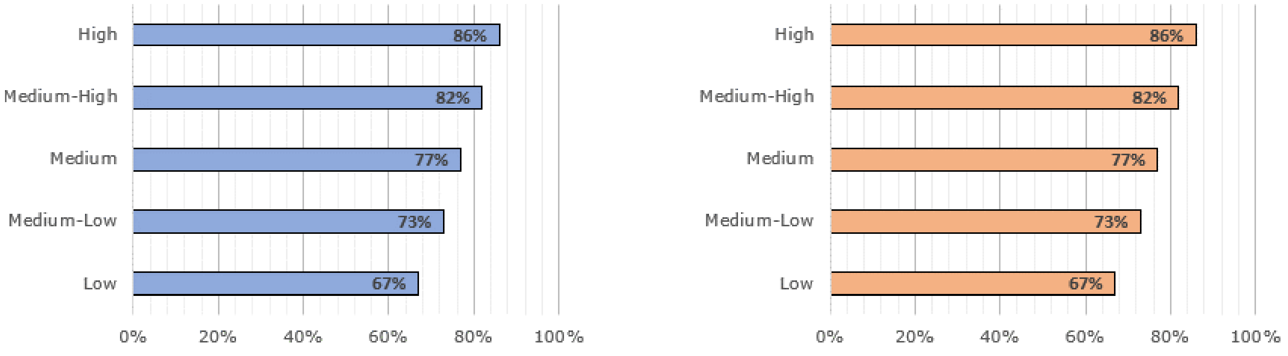
**Table 2** Identified criticalities..

| Level | Identified criticalities |
|---|---|
| 1 | The IG do not directly refer to technical documents and maps released by national bodies; this could instead increase the consistency of the results. |
| 2 | In the definition of the structural/foundation AC, the rapidity of the degradation depends only on the year of construction, regardless of the location, loads, and usage. |
| 2 | The “design standards” for the structural/foundation AC refer to the road categories “I” and “II”, which are not reported in the latest version of the Italian standards NTC 2018. |
| 2 | The current level of defectiveness affects considerably the results of the vulnerability of the structural/foundation AC and of the seismic AC. |
| 2 | In the estimation of the seismic hazard, the topographic characteristics are expected to amplify the seismic acceleration; however, additional factors regarding the structure should also be considered. |
| 2 | The “strategic interest” of the bridge is not defined |



(a) Structural/foundational AC

(b) Seismic AC



(c) Hydraulic AC

(d) Landslide AC

**Figure 10** Percentage ratio of the number of times Level 3 and/or Level 4 analyses are required.

| | |
|---|---|
| | appropriately. |
| **2** | The "road alternative" is not appropriately defined. It is left to the manager to decide if an alternative route is suitable in terms of additional travel time for the users and road adequacy. |
| **2** | In the definition of the hydraulic AC, tables for non-embanked rivers are provided, while they are missing for the case of embanked rivers. |
| **2** | The vocabulary used for the scour actions can lead to misinterpretation: the Italian term "erosione generalizzata", literally translated in English as "general scour", actually refers to the phenomenon commonly known as "contraction scour". |
| **2** | For the parameters $C_a$ and $C_g$ of the scour analysis it is written that their calculation is derived from "typical empirical formulas from the literature", but there is no explicit reference to these documents. |
| **3** | It is assumed that the static scheme and the usage of the bridge have not changed over the years. |
| **3** | Changes in the factors of safety between the old codes and the current standards are not considered according to [15]. |
| **3** | The steps of the analysis are only defined generally. The ratio between the stresses given by the original design codes and the current standards is not ascribed to any specific structural component. Therefore, the same analysis could be performed for the axial loads on a pile and the bending moments for a beam. |
| **3** | It is not clear how to consider the results of Level 3, since no threshold is defined for the ratio between the actions calculated considering original and current standards. In the analyzed case study this threshold was set to 1. |
| **4** | The steps of the analysis are mostly described qualitatively. |

As mentioned, other criticalities have been reported in the literature, even though often limited up to Level 2.

Specifically, the analysis at Level 2 is considered time-consuming, see e.g. [16], and often conservative, see e.g. [17]. The "level of defectiveness" of the bridge heavily influences the final AC classification: if the "level of defectiveness" (and therefore, the vulnerability) is considered "High", the structural/foundation AC is "High" and consequently, the bridge Total AC is "High" as well. The major impact of the vulnerability on the result of Level 2 is stated by different authors (e.g. by [17]), through computational analyses. Furthermore, the classification includes only 5 ACs with qualitative attributes not allowing prioritization of interventions to bridges at high risk [17].

## 5 Conclusion

The new Italian Guidelines (IG) have introduced a comprehensive risk-based method for prioritizing safety checks and interventions and represents an important step forward in ensuring the safety and reliability of critical infrastructure systems. In this paper, the IG have been applied to a real case study, i.e., a reinforced concrete bridge located in the North of Italy. The application of the different levels of analysis outlined in the IG (ranging from Level 0 to Level 4) allowed for the identification of some criticalities throughout the whole process. The findings of this study could be used to refine the IG and improve its effectiveness in managing and maintaining the safety of infrastructure assets over time.

## 6 Acknowledgement

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