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A multidimensional approach for hydraulic risk assessment on existing bridges: outcomes from in field applications

Paola Di Fluri[a], Alessandra Dovichi[b], Giuseppe Tito Aronica[c], Natasha Petruccelli[a], Alessio Domeneghetti[a], Armando Brath[a]

[a] *University of Bologna, Bologna 40136, Italy*
[b] *Consorzio Fabre, Pisa 56122 , Italy*
[c] *University of Messina, Messina 98158, Italy*

Abstract

The Italian Superior Council of Public Works has recently released the "Guidelines for risk classification and management, Safety Evaluation and monitoring of Existing Bridges" (LLGG). A large-scale implementation of the prescribed procedures was developed within the Fabre Consortium to assess the class of attention of existing bridges concerning the hydraulic risk. A first round of practical applications of these guidelines enabled to reach a deeper knowledge of the existing infrastructures, collecting fundamental technical and functional details of a large number of bridges.
The in-field assessments also suggested a series of procedural refinements for the application of the LLGG in order to improve the value of the collected material and to guarantee homogeneity, at national level, in their application.
This contribution aims at providing a statistical interpretation of the extensive data collection and hydraulic class assessment carried out so far. Although LLGG application has proven to be innovative and efficient, critical aspects and enhancing proposal are also discussed within this contribution.

Keywords: existing bridges, risk assessment, FABRE, class of attention

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1. Introduction

The safety level of existing bridges is in many cases threatened by the marginal consideration that hydraulic phenomena had during the design phase. However, scientific literature demonstrates that hydraulic phenomena constitute the primary cause of bridge collapses (Ballio et al., 1998). These findings underscore the urgent need to adopt a new integrated approach, wherein hydrogeological phenomena are not merely treated as marginal aspects but are addressed synergistically to ensure the safety and stability of the infrastructures.

In the context of a constantly evolving climate, the increase in flood-related phenomena and, more generally, hydrogeological instability emerges as a concerning reality, outlining increasingly complex scenarios. During extreme events that have affected the Italian territory in recent years, bridges have shown a significant level of vulnerability, evidenced by a significant number of damages and collapses (Brath A. & Montanari A., 2000). Although collapses typically occur during flood events, it is essential to highlight that often the operational conditions of road crossings are already compromised in ordinary hydraulic contexts. In such circumstances, the interaction between ordinary flows and the structural elements can trigger erosive phenomena potentially harmful to the structural integrity of the bridge.

It is within this context that the "Guidelines for the classification and management of risk, safety assessment, and monitoring of existing bridges" (LLGG) are positioned, approved by the Council for Public Works No. 88/2019 on 17.04.2020 to assess the complex interaction between bridges, viaducts, and watercourses.

The Fabre Consortium (Research consortium for the evaluation and monitoring of bridges, viaducts and other structures; www.consorziofabre.it/), in collaboration with public entities and Italian Universities, has implemented the procedures prescribed in the LLGG on a large sample of bridges distributed throughout the national territory. This document reports on the statistical analysis of the results obtained during this first set of experimental applications and offers the opportunity to highlight and discuss risen critical issues concerning the complex interactions between watercourses and existing bridges.

2. Methodological approach

The activities of the first round of application (i.e., first year) involved the implementation of the assessment levels L0, L1, and L2, as outlined in the LLGG. Level 1 of the multilevel approach entails visual inspections of all structures potentially at risk. These visual inspections aim at verifying the reliability of the data collected in the Level 0 survey, gathering additional information on the real geometry and structural characteristics of the structure under examination and also enable, even if in a preliminary manner, the degree of conservation of the structures. Level 1 results in the compilation of inspection forms, prepared for each of the potential risks (i.e., structural, seismic, geotechnical and hydraulic) contributing to the definition of the final attention class.

Level 2 aims at defining the attention class for each surveyed bridge, with the final purpose to establish priority levels for scheduling further in-depth investigations. The guidelines specify five attention classes:

- High
- Medium-High
- Medium
- Medium-Low
- Low

The risk assessment is carried separately for each risk: namely: structural, seismic, geotechnical and hydraulic.

Regarding the hydraulic aspects, three main phenomena are considered for the assessment: overflow, constriction and localized erosion. Erosion phenomena are combined into a single attention class for bed erosion phenomena. The final attention class concerning hydraulic risks is defined as the most severe among the two attention classes previously obtained.

3. Results and discussion

As previously stated, this work reports the results obtained during the first year of activities, providing an overview of the data collection and class assessment done to date. Thus, outcomes may change as the working teams analyze additional infrastructures.

The information received so far has allowed the construction of a database containing demographic information of the structures, useful for localization and initial characterization. The current database comprises structures in 14 regions; their territorial distribution is illustrated in Figure 1.

The construction of the database involved a pre-processing phase in which information received from different contributors (e.g., entities and universities involved in the application) was collated and standardized based on specific attributes. The construction of the database has identified and corrected relevant errors, such as typos in attribute definitions and geolocation.

As shown in Table 1, the database also collects information concerning the hydraulic characteristics of the water bodies crossed by the bridge, as well as the attention classes obtained after Level 2 assessments. The following analysis was conducted on 168 bridges for which it was necessary to perform the hydraulic risk assessment. Their spatial distribution (blue points), together with other infrastructures that do not interact with any water bodies (red points) are shown in Figure 1, panel b.

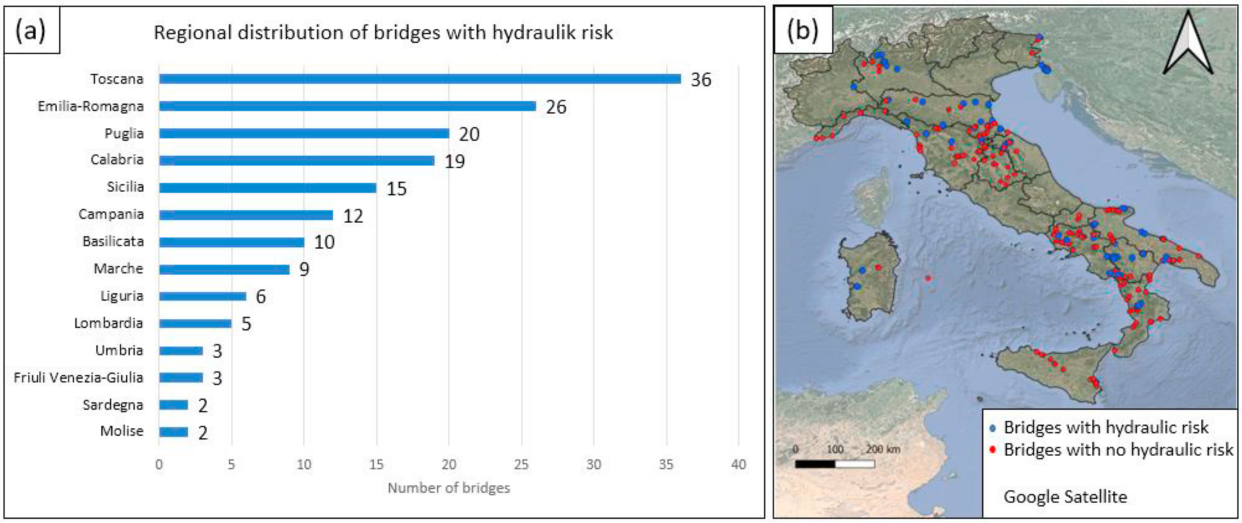


Fig. 1. The regional distribution and georeferencing of the 168 analyzed bridges.

Table 1. Parameters present in the database for data analysis and their related attributes.

Parameter	Attribute
Typology of water body	Protected by embankments, not protected by embankments
Typology of hydrographic network	Main, Secondary
Watershed Area	Extension in Km^2
River section with noticeable curvature	<45°, >45°
width of the incised streambed	Extension in m
width of the piers	Width in m
type of foundations	Shallow, Deep, Not Evaluable
height of the intrados from the streambed	< 15, >15
Hydraulic span (m)	< 25, >25
Hydraulic water level elevation for PGRA flood scenarios	Water level P2, Water level P3
Signs of recent inundations	Yes, No
	Yes, No
Attention class for overflow	Low, Medium-Low, - Medium, Medium-High, High
Attention Class for general scour	Low, Medium-Low, - Medium, Medium-High, High
Attention class for local scour	Low, Medium-Low, - Medium, Medium-High, High
Attention class for scour phenomena	Low, Medium-Low, - Medium, Medium-High, High
Exposition	Low, Medium-Low, - Medium, Medium-High, High
Hydraulic attention class	Low, Medium-Low, - Medium, Medium-High, High

It is worth mentioning that, for a significant portion of the analyzed bridges, it was not possible to access the project documentation. Level 1 inspections and field surveys are often insufficient to ensure a reliable assessment of the structure characteristics (e.g., foundation type, dimension, etc.). Referring to the database populated with structures at hydraulic risk, documentation was unavailable for 127 out of 168 structures, as illustrated in Figure 2. This results in a limited knowledge of the structural parameters that are relevant for the assessment of the class risk associated to hydraulic loads.

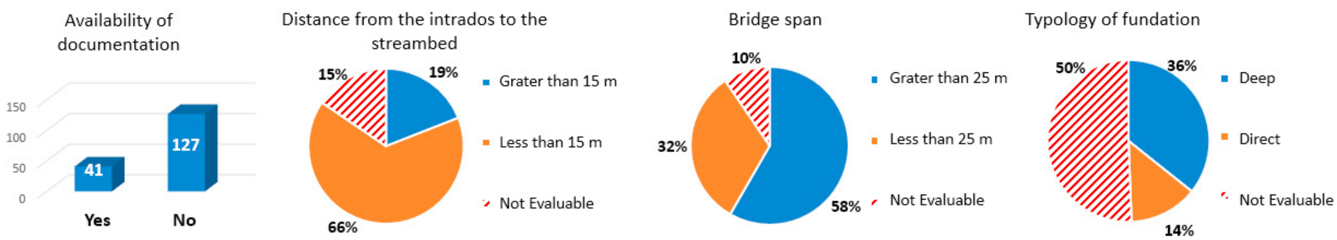
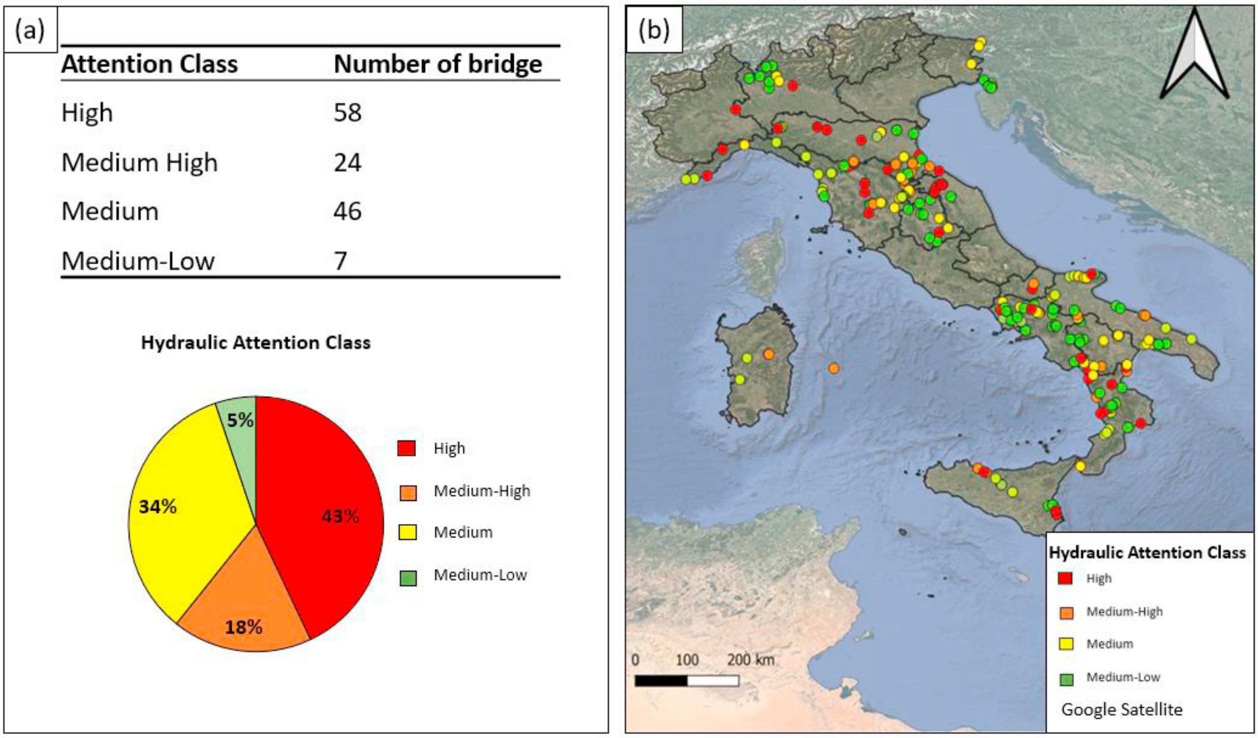


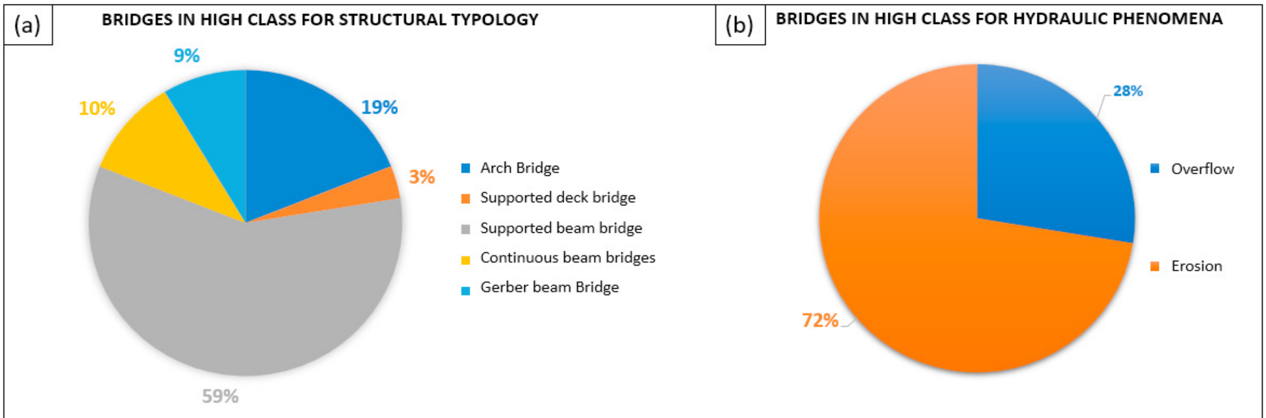
Fig. 2. Statistics of geometric parameters that affect the definition of the hydraulic attention class.

The overall analysis of attention classes for hydraulic risk reveals that 43% of bridges are in the High Attention class, 18% in the Medium-High Attention class, 34% in the Medium Attention class, and 5% in the Medium-Low



Attention class (Figure 3). The Low Attention class has not been graphically represented as it is assigned in cases where hydraulic risk is deemed absent or it is believed that flood events cannot impact the structure under consideration.

Fig. 3. Assignment of the hydraulic attention class for the analyzed bridges (a) and their glocalization (b).



Type of structure	N° Bridges
Arch Bridge	11
Supported deck Bridge	2
Supported Beam Bridge	34
Continuous beam Bridge	6
Gerber beam Bridge	5

Type of hydraulic phenomena	N° Bridges
Overflow phenomena	16
Erosion phenomena	42

Fig. 4. Bridges in the High Hydraulic Attention class categorized by structural type (a) and most relevant hydraulic phenomenon (b).

In Figure 4, the bridges in the High Hydraulic Attention class are reported based on structural type and the type of hydraulic phenomenon leading to the classification of this class: concerning this latter aspect, the majority of them exhibit issues related to erosive phenomena. In almost all cases, the assignment of a High Attention Class for erosive phenomena is due to localized erosion. Further investigation into this aspect revealed a strong correlation between High Attention class attribution and the absence of project documentation. Hence, it can be intuitively assumed that the absence of documentation regarding the foundation type leads to a potential overestimation of the risk associated with this phenomenon, primarily due to the cautious approach outlined by the LLGG.

Similarly, an in-depth analysis was conducted to define a High Attention Class for the overflow phenomenon. In 99% of these cases, the attribution is due to a deck height above the riverbed of less than 15 meters and small dimensions of the watershed beneath the crossing section. These two conditions contribute to the definition of High and Medium-High hazard and vulnerability classes, which, combined with the exposure class, often result in the assignment of a High class for the overflow phenomenon.

The investigation of these aspects allowed the identification of potential biases on the overall assessment, which can be mitigated through the introduction of improvements to the LLGG. The following integrations have been proposed:

• For bridges with a deck height (D) greater than 15 meters above the riverbed, directly consider a Low Attention class for overflow, without proceeding with the assessment of the attention class.

• Reduce by one vulnerability class for the bridges subject to hydraulic monitoring.

• Accept the use of more accurate formulas for estimating localized erosion in cases where the necessary data are available.

4. Conclusions

A review of the outcomes gathered after the first year of implementation of the LLGG has led to some critical considerations on their applicability. In particular, the activities aimed at defining the hydraulic attention class have highlighted the complexity of formulating a standardized approach to the application of the Guidelines, given the wide variety of scenarios possible in the interaction between the bridge and watercourse. In particular, a significant correlation between the final hydraulic attention class and the level of knowledge (or the amount of missing data) on some relevant structure aspects (e.g., foundation) has been highlighted. The analysis of hydraulic parameters has indeed brought to light aspects (especially concerning the absence of project documentation) that may act as drivers for a potential risk overestimation.

The challenges identified through the review and statistical analysis of data have led to a series of proposed improvements to the LLGG. These enhancements will enable the development of a consistent and balanced approach for assigning the Attention Class for hydraulic risk.

Acknowledgements

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