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# Application of Italian Guidelines for structural-foundational and seismic risk classification of bridges: the Fabre experience on a large bridge inventory

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**Abstract**

The recent issuance of Guidelines for the classification and management of risk, safety assessment, and monitoring of existing bridges has standardized the methodology for analyzing the safety and managing bridges at a national level. The Guidelines propose a multi-level analysis approach, where the assessment of structures is conducted with increasing levels of detail and complexity. This paper describes the work carried out by the Fabre Consortium, the Italian scientific alliance on risk assessment and monitoring of civil infrastructural systems, together with ANAS s.p.a., one of the major Italian road authorities, for the implementation of the Italian Guidelines to a large bridge inventory distributed over the Italian territory. This paper is specifically devoted to structural-foundational and seismic risk classification. The results of the application of the methodology to a large database is presented together with statistical analyses on parameters determining hazard, vulnerability and exposure and with the definition of the most recurrent typological bridge classes within the bridge inventory.

*Keywords:* Italian Guidelines for bridges; risk classification; structural-foundational risk; seismic risk.

## 1. Introduction

In many Countries around the world, the road infrastructure asset is progressively becoming old and inadequate to withstand joint effect of natural hazards and increasing level of traffic. Bridges suffer the consequences of aging processes, which often are not balanced by suitable and timely maintenance operations, as demonstrated by several collapses occurred in recent years. Although nowadays there is common awareness of the necessity of road infrastructure maintenance, this is still a complex and challenging task, since Bridge Authorities are responsible for management of large infrastructure networks and dispose of limited economic and human resources.

In this context, a standardized methodology for bridges risk classification and rational resource administration at national scale is of primary importance to provide efficient approaches for safety assessment, risk mitigation strategies and recovery actions. In the technical and scientific literature, some authors and infrastructures authorities propose different methods for the operation and management of bridges (O&M), to optimize the economic investment for their conservation (AASHTO, 2019; Woodward et al. 2001). To provide a uniform approach to bridge management, the Italian Ministry of Infrastructures and Transportation (MIT) issued in 2020 the "Guidelines for risk classification, safety assessment and structural health monitoring of existing bridges" (MIT, 2020; ANSFISA, 2022). The Italian Guidelines (IG) provide a multilevel approach for the risk classification based on survey, inspection, preliminary risk assessment, detailed structural analyses and safety checks. A few studies have been recently published reporting investigations about the application of Italian Guidelines, most of which are devoted to the application of the methodology to single assets or specific structural typologies (Santarsiero et al., 2021; Palmisano et al., 2022; Fox et al. 2023; Miluccio et al., 2023; Meoni et al., 2023; Rossi et al., 2023; Zizi et al., 2023).

Since the issuing of IG, the Fabre consortium has been supporting road Concessionaires in the application of the IG methodology to a large bridge stock over the Italian territory, deriving useful suggestions to improve IG applicability and favor the refinement of the entire process. In this paper, a database of bridges managed by ANAS s.p.a. and analyzed by Fabre is presented and analyzed. Statistical processing of the parameters influencing risk classification according to IG has been carried out, to investigate their effect on the results in terms of warning classes.

## 2. Application of Italian Guidelines to a large bridge inventory

In 2021, ANAS s.p.a. entrusted Fabre Consortium with the task of risk classification of 1112 bridges managed by the company. A dataset of 447 bridges of the inventory, almost uniformly distributed over the Italian territory, has been selected and analyzed to provide statistics of primary and secondary parameters influencing hazard, vulnerability, exposure and risk assessment (MIT, 2020). The analyses presented in the following sections regards the parameters related to structural-foundational and seismic risk classification.

### 2.1. Dataset processing

Data collected during the census and on-site inspections on the case-study sample of bridges are allocated in a tailored spreadsheet database. The spreadsheet is composed of several information fields, designed appropriately to implement systematically the general knowledge data and allow further statistical elaborations. First, it includes initial bridge's general information (e.g. identification code, road code, municipality), directly derived from the authority's database, and geographical location (i.e. latitude, longitude of both the abutments). In addition, appropriate fields are provided to collect the information dataset which is needed to perform the warning class assessment.

A programming framework composed of Python code routines is designed to support visualization and analysis of the collected data. Indeed, such routines are developed to automatically import the spreadsheets and produce statistical elaborations (i.e. bar and pie charts), depending on selected input bridge characteristics that can be easily selected by the users. Furthermore, the framework allows for converting the input spreadsheets into shapefiles, which can be directly used in Geographical Information System.

### 2.2. Classification of the bridges sample based on geometric and typological parameters

The classification of the bridge inventory, based on geometric and typological parameters, is presented in Figure 1, showing the frequency distributions of the total length of the bridges, the number of spans and the static scheme. Most of the bridges are less than 150 meters long (62.9%), have less than 5 spans (68.5%), and the deck is made of simply supported or continuous beams (77,7%). Figure 2 shows the classification based on road use typology and geographical distribution over the Italian territory.

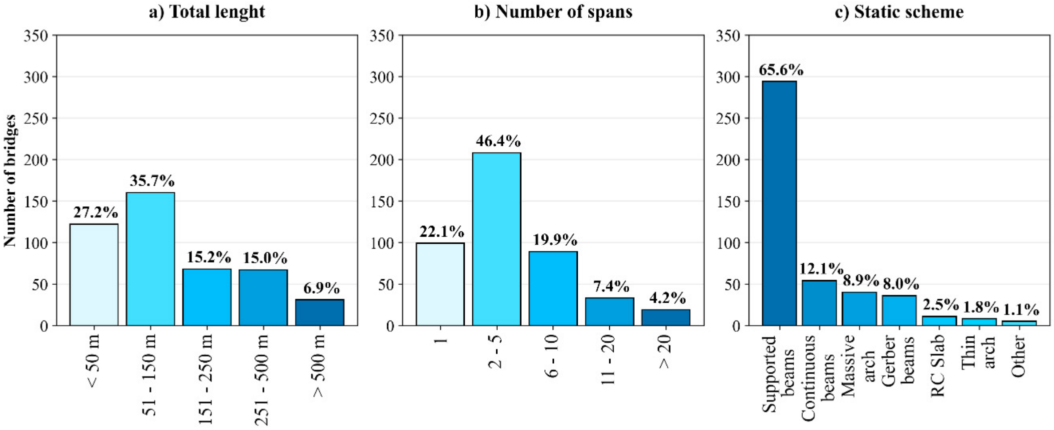

Fig. 1. Bridge classification based on total length (a), number of spans (b) and static scheme (c).

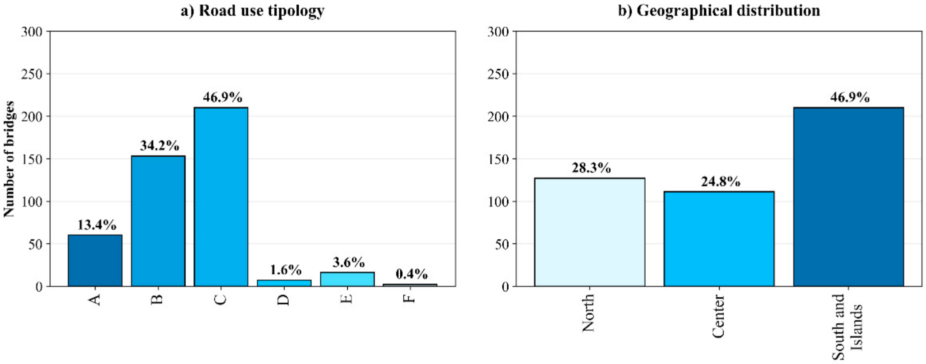

Fig. 2. Bridge classification based on total length (a), number of spans (b) and static scheme (c).

Additionally, a typological classification based on typological structural features is carried out. By using the abovementioned database structure, knowledge data on the case-study bridges are analysed based on 1) number of spans, 2) maximum span length, 3) superstructure material, 4) design period, 5) static scheme. Table 1 illustrates the results of the preliminary classification by reporting the most populated bridge typologies. The results in Table 1 show that the most recurrent bridge typologies are prestressed concrete (PC), multi-span and simply supported, with length varying between 25 and 50 meters, built between 1945 and 1980 or later. The largest number of bridges (250) are PC structures, while a smaller part (68) is made of masonry, reinforced concrete (RC), composite (Steel-RC).

Table 1. List of the most populated bridge typologies (RC: Reinforced Concrete; PC: Prestressed Concrete).

| Single o multi-span | Maximum span length | Superstructure material | Construction period | Static scheme | Num. [-] | Percentage [%] |
|---|---|---|---|---|---|---|
| Multi | 25-50 | PC | Post-1980 | Simply Supported | 102 | 22.82 |
| Multi | 25-50 | PC | 1945-80 | Simply Supported | 77 | 17.23 |
| Single | - | PC | Post-1980 | Simply Supported | 31 | 6.94 |
| - | - | Masonry | - | Arch bridge | 27 | 6.04 |
| Multi | 25-50 | PC | Post-1980 | Continuous | 27 | 6.04 |
| Multi | - | RC/PC | 1945-80 | Gerber beam | 26 | 5.82 |
| Single | - | PC | 1945-80 | Simply Supported | 23 | 5.15 |
| Multi | <25 | RC | 1945-80 | Simply Supported | 17 | 3.80 |
| Multi | 25-50 | Steel-RC | Post-1980 | Continuous | 9 | 2.01 |
| Multi | >50 | PC | Post-1980 | Continuous | 7 | 1.57 |
| Multi | >50 | Steel-RC | Post-1980 | Continuous | 7 | 1.57 |

## 3. Statistical analysis of the bridges sample based on risk parameters

The IG provide the methodology for Structural-foundational and Seismic risk assessment based on primary and secondary parameters affecting hazard, vulnerability ad exposure. In the following Sections, results of statistical analyses on the parameters classes will be presented, to identify the most recurring conditions and the variability of parameters. Results will be presented for parameters related to hazard (Sect. 3.3.1), vulnerability (Sect. 3.3.2) and exposure (Sect. 3.3.3), for both structural-foundational and seismic risks.

### *3.1. Hazard parameters*

The evaluation of the structural-foundational and the seismic attention classes requires the definition of the hazard parameters. The distribution of the hazard parameters for structural foundational class evaluation over the bridge inventory is shown in Figure 3, where the frequency histograms of the Average Daily Truck Traffic (ADTT) (Figure 3(a)) and the possible traffic limitations (Figure 3(b)) are reported. Most of the bridges (40.6%) has an ADTT higher than 700 and no traffic limitations (90.8%).

The distribution of the hazard parameters for seismic class evaluation is displayed in Figure 4. In particular, the frequency histograms of peak ground acceleration at bedrock (PGA), the soil category and the topographic category are shown. The soil categories from A to E and the topography categories refer to soil and topographic classification presented in the European and Italian Codes (CEN, 2004; MIT, 2018).

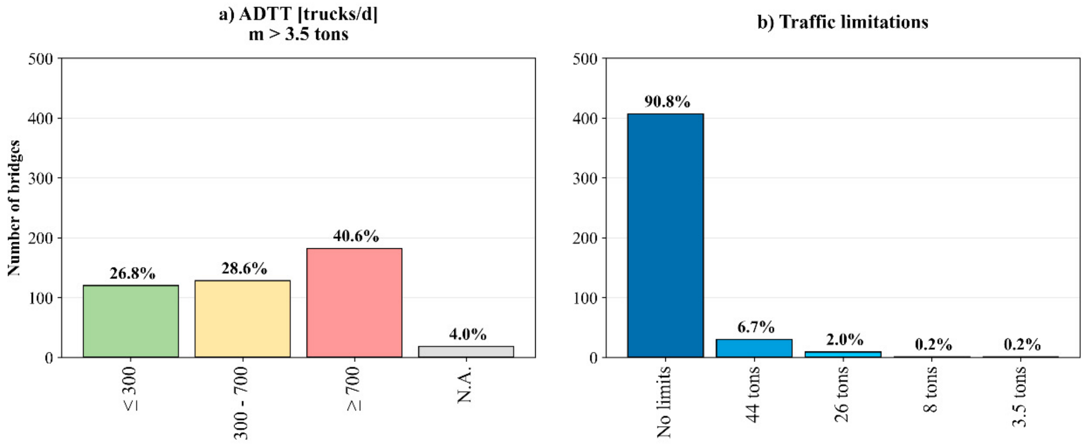

Fig. 3. Frequency histograms of Average Daily Truck Traffic (a) and traffic limitations (b).

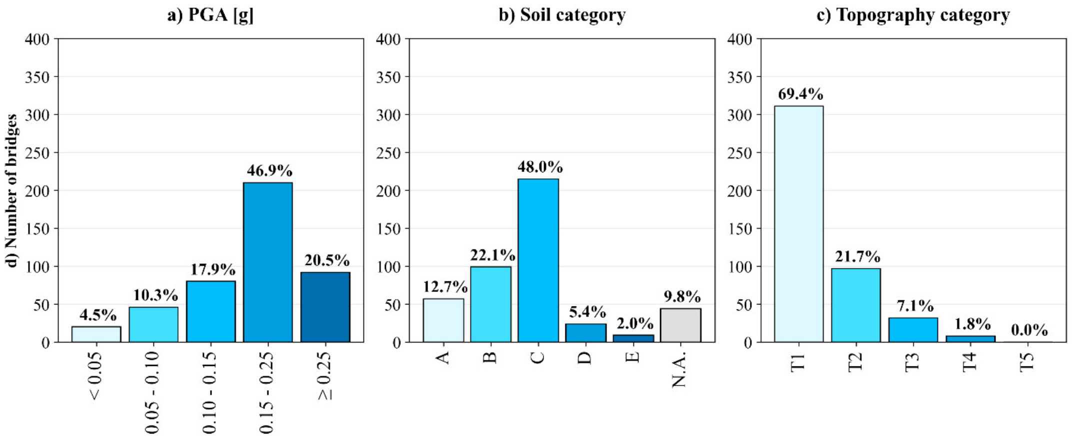

Fig. 4. Frequency histograms of peak ground acceleration (PGA) at bedrock (a), soil category (b) and topographic category (c).

### *3.2. Vulnerability parameters*

One of the primary parameters for vulnerability assessment is the defectiveness level, which is evaluated based on the results of visual inspections on the bridge’s structural elements. Each element of the bridge is inspected at close distance and its defectiveness is evaluated based on assessment grids avalable in element-type dependent sheets (MIT, 2020). The defectiveness level of the bridge is selected among five classes: HIGH, MEDIUM-HIGH, MEDIUM, MEDIUM-LOW and LOW, adopting the criteria specified by the Guidelines as a function of the type, extension and intensity of damage of the various elements. Figures 5(a) and (b) display the defectiveness level distribution among the classes for both structural-foundational and seismic risks, respectively. It can be observed that the 34.0% of the analyzed bridges have HIGH or MEDIUM-HIGH defectiveness level for structural-foundational risk. Only a few bridges (9.6%) have LOW defectiveness level. The percentages slightly vary for defectiveness levels related to seismic risk. The 29.2% of the analyzed bridges have HIGH or MEDIUM-HIGH defectiveness level while the 11.6% have LOW defectiveness level.

It is possible to observe that the 34.0% of bridges for the Structural-foundational and the 29,2% of bridges for Seismic risk have defectiveness levels HIGH or MEDIUM-HIGH and therefore most likely will be in a vulnerability class HIGH or MEDIUM-HIGH.

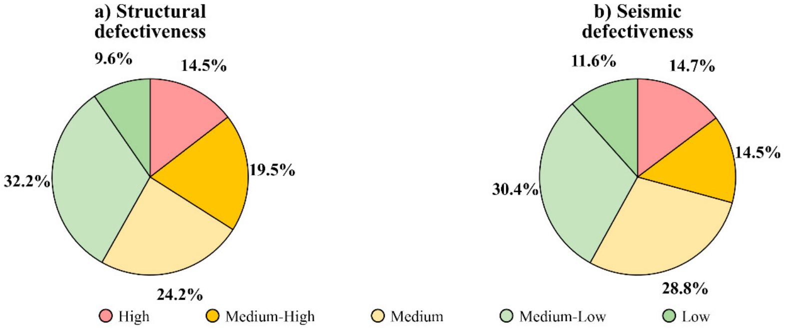

Fig. 5. Defectiveness level distribution among the classes for both structural-foundational (a) and seismic risk (b).

Other primary parameters for seismic vulnerability assessment are the structural scheme (isostatic or hyperstatic), the superstructure material, the number of spans (single- or multi-span) and the maximum span length. Figure 6 shows the distributions of the parameters used for vulnerability assessment.

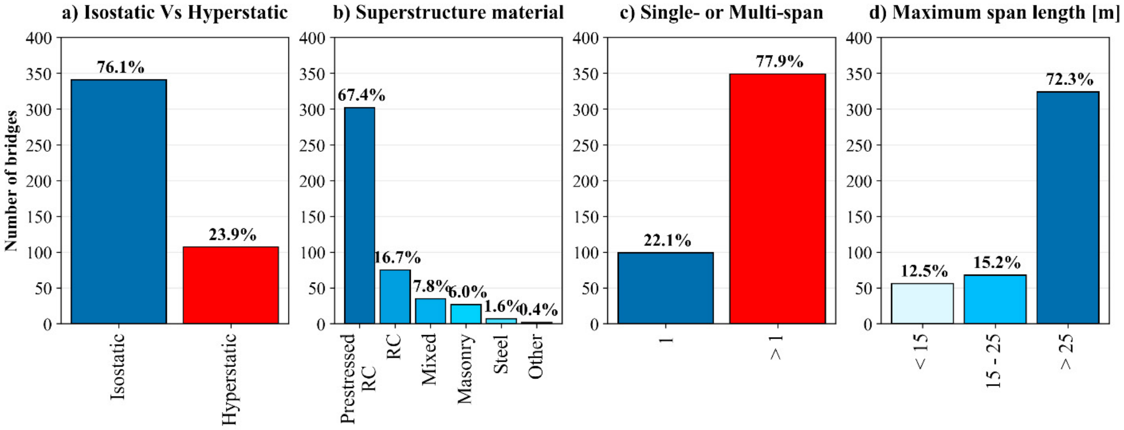

Fig. 6. Statistics on a) structural scheme (isostatic vs hyperstatic), b) superstructure material, c) number of spans (single or multiple) and d) maximum span length.

Figure 7 shows the bridges classification based on secondary parameters for vulnerability assessement. In particular, Figure 7(a) illustrates the frequency diagram of the construction period, which influences the speed of degradation evolution. Figure 7(b) displays the Class of design standard according to Italian Guidelines, and Figure 7(c) the Seismic design class (seismic or not seismic design), affecting structural-foundational and seismic vulnerability assessment, respectively.

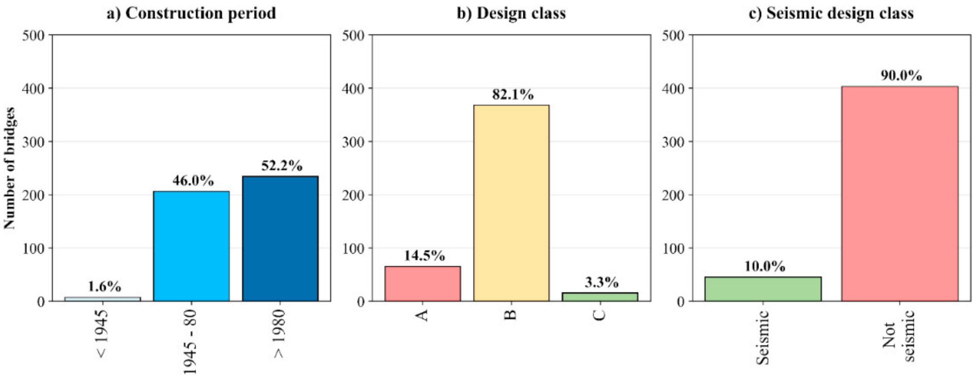

Fig. 7. Period of construction (a), Class of design standard (b), Seismic design criteria (c).

### 3.3. Exposure parameters

Figure 8 displays the parameters useful for exposure assessment: Average Daily Traffic (ADT) and average span length, while Figure 9 shows the relative frequencies histograms of the presence of road alternatives (present or not present), the exposition of the overpassed obstacle and the strategicity of the bridge. It can be observed that the 60.7% of bridges are subjected to ADT of less than 10000 and that the 71.9% of bridges have an average span length between 20 and 50 meters. Most of the bridges do have road alternatives and are considered as strategic infrastructures.

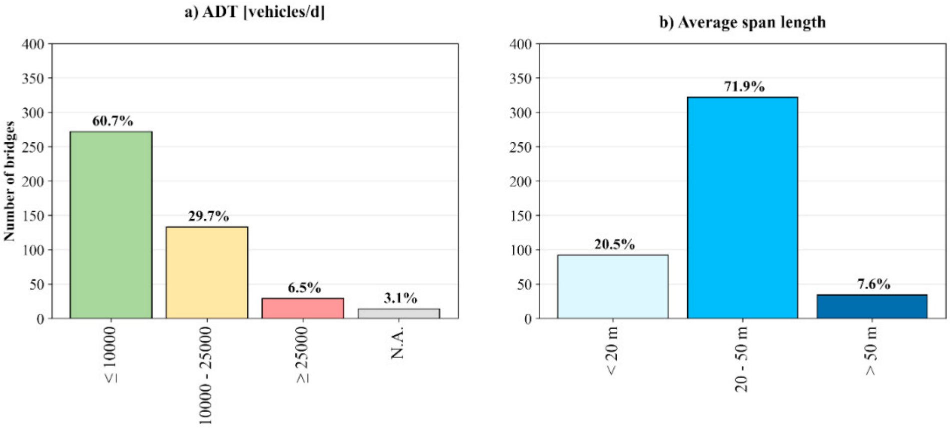

Fig. 8. Statistics on a) average daily traffic (ADT) and b) average span length.

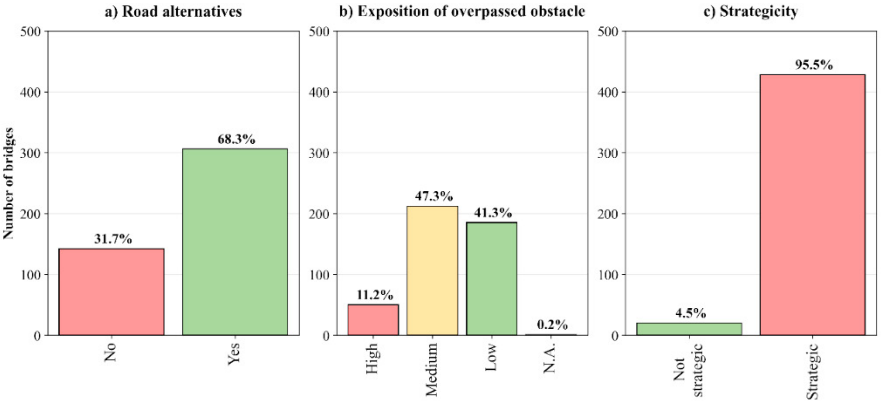

Fig. 9. Statistics on a) road alternatives, b) exposition of the overpassed obstacle and c) strategicity.

### 3.4. Structural-foundational and Seismic risk Warning Classes

By using the logical operator approach provided by the Italian Guidelines, the hazard, vulnerability and exposure parameters are combined to obtain the structural foundational and seismic warning class. Then, by the combination of the different warning classes for structural-foundational, seismic, hydraulic and landslide risks, the total warning class is computed. Figure 10 shows the pie charts representing the distribution of the warning classes for structural-foundational (Figure 10(a)) and seismic (Figure 10(b)) risk, as well as that of the total warning class. It can be observed that the 74.7% of the bridges have a HIGH or MEDIUM-HIGH structural-foundational warning class, the 80.1% of bridges have a HIGH or MEDIUM-HIGH seismic warning class and the 63.2% or bridges have a HIGH or MEDIUM-HIGH total warning class (considering also landslide and hydraulic risks).

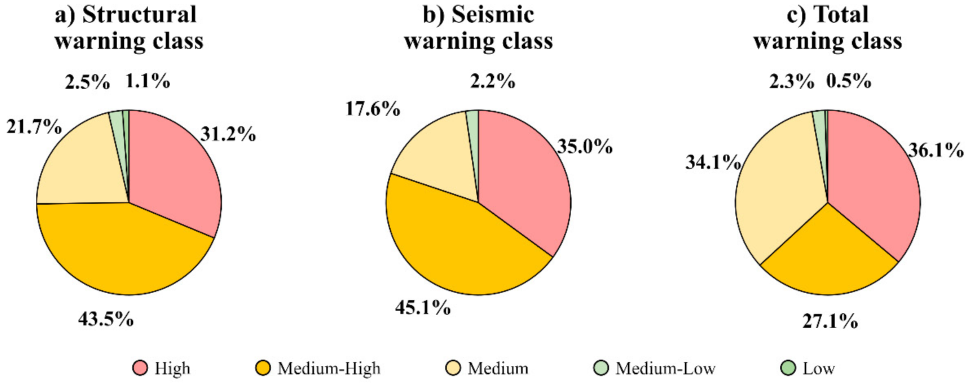

Fig. 10. Statistics on a) structural-foundational warning class, b) seismic warning class and c) total warning class.

## 4. Conclusions

In this paper, the results of the application of the risk classification methodology provided by IG to a large bridge inventory is presented. Automatic database processing is performed with the aim of identifying the most recurrent typological bridge classes and statistically analyzing the parameters determining hazard, vulnerability and exposure. The availability of this large bridges database with allow further analysis on the most influential parameters to the warning classes and on the effect of parameters uncertainty on the results.

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