

COMPARATIVE ANALYSIS OF INTERNATIONAL REGULATIONS ON LANDSLIDE RISK ASSESSMENT AND MANAGEMENT FOR BRIDGES AND VIADUCTS

Alessio Domenico Leto¹, Luca Simoni², Fabiola Gibin², Fabio Gabrieli², Alessandro Scala², Lorenzo Brezzi²

¹ Department of Geosciences, University of Padova, via Giovanni Gradenigo 6, 35131 Padova, Italy

² Department ICEA, University of Padova, via Ognissanti 39, 35129 Padova, Italy

E-mail: AL: alessiodomenico.letto@unipd.it, LS: luca.simoni.1@studenti.unipd.it,

FG: fabiola.gibin@phd.unipd.it, FG: fabio.gabrieli@unipd.it, AS: alessandro.scala.1@studenti.unipd.it,

LB: lorenzo.brezzi@unipd.it

The tragic collapse of the Morandi Bridge in Genoa, Italy, in 2022 prompted the Italian Ministry of Infrastructure and Transport to establish new guidelines focusing on the classification, management, safety assessments, and monitoring of bridges. The Italian guidelines present a multi-level and multi-risk approach, progressing through phases of increasing depth and complexity, aimed at standardizing the prioritization of interventions based on various risk categories: structural, seismic, landslide, and hydraulic risks. Across different countries, regulations for landslide risk assessment vary significantly. Some focus on hazard probabilities or specific triggering factors without addressing infrastructure interaction, while others concentrate solely on structural risk, neglecting geotechnical or landslide factors. Furthermore, certain regulatory frameworks prioritize landslide hazard assessment over susceptibility estimation, while others provide general inspection guidelines rather than regulations focused on comprehensive risk assessment. These differences are further reflected in the underlying parameters for risk evaluation, which vary across countries. This comparative study gives an insight on international regulations and provides a detailed comparison between Italian, Chinese, and USA regulations, emphasizing the similarities and divergences between their approaches. The analysis of these international frameworks offers insights into the diverse strategies for managing bridge safety with reference to landslide events, facilitating the identification of best practices and effective methodologies for risk assessment in these complex interaction scenarios. Ultimately, this study contributes to the global discourse on infrastructure safety and maintenance, particularly in the context of landslide-structure interaction.

Keywords: Bridge management, guidelines, infrastructure assessment, landslide risk, geotechnical risk, prioritization, class of attention, safety assessment.

1. The Italian Guidelines

Ensuring infrastructure safety, particularly the protection of human lives, should be the primary concern of every nation worldwide. To this end, countries develop a variety of standards for evaluating and managing risks to infrastructure, codified into official documents such as guidelines and technical manuals. These standards aim to systematically address hazards to critical structures and ensure their continued functionality and resilience.

In Italy, the Ministry of Infrastructure and Transport established comprehensive guidelines aimed at providing a standardized, reliable tool for assessing and mitigating risks in areas such as structural integrity, seismic resilience, landslides, and hydraulic hazards (MIT 2022). The Italian approach introduces a multi-level methodology, structured to standardize prioritization across the entire national infrastructure portfolio. This framework focuses on landslide risk assessment through three key parameters: susceptibility, vulnerability, and exposure. Susceptibility is evaluated using a scoring system based on factors such as landslide activity, volume, and velocity, alongside mitigation measures already in place. Vulnerability refers to the degree of interaction between a structure and the landslide, influenced by factors such as foundation type and surrounding topography. Exposure, meanwhile, includes considerations like average daily traffic, the strategic importance of the structure, and potential environmental and functional consequences in the event of failure.

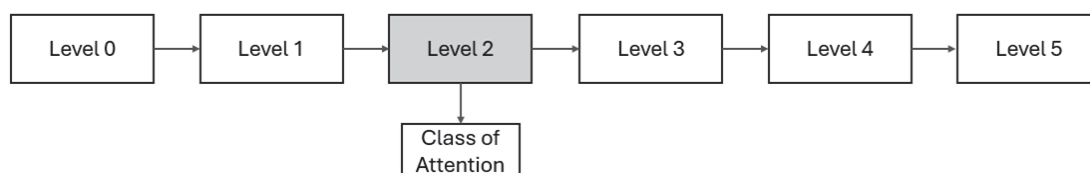


Fig. 1. Italian multilevel approach (Adapted from the Italian Guidelines)

This semi-quantitative approach helps directly link landslide risks with infrastructure, providing a new model for surveillance and maintenance. Some preliminary experiences in applying the guidelines are presented by

Salciarini et al. in 2024, highlighting the approach and the statistical implications on a fairly extensive sample of analyzed structures. The guidelines offer a systematic framework that assesses and classifies risks, culminating in an overall Class of Attention (CoA) for each structure, derived from level 2 of the classification (Fig. 1). The CoA informs necessary interventions, which may include detailed inspections or structural health monitoring systems.

2. National Guidelines from other countries: a Global Perspective

National frameworks for bridge safety and maintenance vary worldwide, shaped by local environmental conditions, technical expertise, and infrastructure demands. Below, the different approaches of some countries are presented.

In Bangladesh, the Bridge Inspection and Evaluation Manual (<https://www.rhd.gov.bd>) distinguishes between periodic and emergency assessments, focusing primarily on structural conditions. Landslide risks are treated as emergency situations rather than being integrated into regular maintenance strategies. In China, the Regulation JTG 5120-2021 (<https://codeofchina.com>) employs a multi-level classification system, ranging from "good" to "dangerous" conditions, with tailored maintenance actions for each category; it emphasizes proactive inspection and preventive measures, fostering a forward-looking approach to infrastructure maintenance. In France, the Detailed Inspection and Diagnostic Guide (<https://imgc.fr>) prioritizes structural assessments but lacks a comprehensive strategy for hydraulic and geotechnical risks. Other nations, including the United Kingdom (<https://www.standardsforhighways.co.uk>) and South Korea (<https://elaw.klri.re.kr>), emphasize structural integrity while providing limited guidance on geotechnical risks. Meanwhile, in the United States, regulations incorporate a dual focus on structural safety and landslide risk through documents like the National Bridge Inspection Standards (NBIS) (<https://www.fhwa.dot.gov>) Unstable Slope Management Program (USMP) (<https://highways.dot.gov>).

3. Comparison between Italian and Chinese Regulations

Italian and Chinese regulations for the maintenance and risk classification of bridges exhibit notable similarities and differences, reflecting both the specifics of the infrastructure and the technical and managerial approaches adopted. This chapter will compare the main provisions of the Italian regulations and the Chinese regulation JTG 5120-2021, which provides detailed guidance for the maintenance and management of road structures. The comparison is provided considering five aspects of the regulations: structure of the regulations; risk classification and technical conditions; monitoring and maintenance technologies; emergency prevention and response; approach to preventive maintenance.

3.1. Structure of the Regulations

The Italian and Chinese regulations share a systematic approach to infrastructure management but differ in the structure and classification of interventions.

- Italian Regulations: they focus primarily on risk classification based on various parameters (hydraulic, seismic, geotechnical, etc.). This classification is based on a hierarchy of CoAs, which determines the priority of intervention, and the level of monitoring required. The assignment of CoAs occurs by combining different parameters, such as minimum clearance height, erosion risk, and general conditions of the structure.
- Chinese Regulations: they primarily focus on preventive and corrective maintenance, with a classification of interventions into four categories: preventive, corrective, specific, and emergency maintenance. Additionally, the regulations provide for three levels of inspections (I, II, III), with a strong focus on continuous structural monitoring for the most critical structures.

3.2. Risk Classification and Technical Conditions

The methods of risk classification and assessment of technical conditions in bridges vary significantly between the two regulations, with notable differences in the methodologies employed.

- Italian Regulations: they provide for a multi-level risk classification, with particular emphasis on Level 2, which addresses local risk. Each risk is assessed individually and combined to determine the overall CoA. An example is the combination of CoAs for generalized erosion and localized erosion. This approach offers a detailed framework for planning preventive or corrective interventions.
- Chinese Regulations: they divide the technical conditions of bridges into five classes (from "Good" to "Dangerous") based on the current state of the structures. These categories directly determine maintenance strategies: structures in good condition require only preventive maintenance, while those deemed dangerous must be immediately closed and reconstructed. This more direct approach is oriented towards resource efficiency.

3.3. Monitoring and Maintenance Technologies

Continuous monitoring of structural conditions and the use of advanced technologies for maintenance represent a key component of both regulations, but with different approaches.

- Italian Regulations: they include a combination of visual inspections and structural health monitoring, particularly for bridges classified with high CoAs. The emphasis is on periodic risk assessment and the adoption of monitoring technologies to prevent damage before it can compromise the structure's safety.
- Chinese Regulations: they mandate continuous monitoring for bridges classified at Level I. Monitoring includes automatic systems for detecting abnormal loads and vibrations, allowing for rapid decision-making in emergencies.

3.4. Emergency Prevention and Response

Emergency management and the approach to prevention differ slightly between the two regulations, with the Chinese regulations introducing specific categories for emergency management.

- Italian Regulations: they promote prevention through risk classification and continuous monitoring but do not provide a detailed subdivision of emergency intervention categories. However, the focus on vulnerability and exposure is a key element in risk assessment to prevent catastrophic events.
- Chinese Regulations: they provide for an emergency maintenance category for unforeseen situations, such as floods, earthquakes, or road accidents. This subdivision enables authorities to react quickly and coordinately to prevent structural collapse or severe traffic disruptions.

3.5. Approach to Preventive Maintenance

Both regulations emphasize preventive maintenance, but with differences in implementation strategies.

- Italian Regulations: focus is primarily on risk classification and identifying structures requiring maintenance interventions. Interventions are scheduled based on associated risk levels and the priority assigned to each bridge.
- Chinese Regulations: preventive maintenance is strongly formalized in the JTG 5120-2021 regulation, with a clear subdivision into categories that include periodic inspections and regular interventions to prevent infrastructure deterioration. This approach is more structured and clearly oriented towards the lifecycle management of infrastructure.

4. Comparison Between Italian and USA Regulations

Italian and USA regulations for bridge maintenance and risk classification reflect distinct approaches tailored to their respective infrastructures and management philosophies. The Italian guidelines emphasize a detailed risk classification framework, while the USA regulations are rooted in a combination of inspection standards and geotechnical risk management. This analysis compares these regulations considering their structure, risk classification methodologies, monitoring technologies, emergency response, and preventive maintenance.

4.1. Structure of the Regulations

The structural organization of the Italian and USA regulations highlights differences in focus and operational frameworks.

- Italian Regulations: they prioritize risk classification using a hierarchy of CoAs based on structural, seismic, hydraulic, and geotechnical parameters. These classifications guide the level of monitoring and intervention.
- USA Regulations: they integrate the National Bridge Inspection Standards (NBIS) for inspections and the Unstable Slope Management Program (USMP) for landslide risks. It outlines inspection types (routine, in-depth, underwater) and includes federal standards implemented at the state level. The dual focus ensures both structural and geotechnical risks are addressed comprehensively.

4.2. Risk Classification and Technical Conditions

The methodologies for risk evaluation show distinct strategies tailored to national needs.

- Italian Regulations: risk is classified by combining parameters for hydraulic, seismic, geotechnical, and other risks into a global CoA. This multi-layered assessment informs targeted maintenance and monitoring priorities.
- USA Regulations: they employ standardized inspection intervals based on structural conditions, degradation patterns, and scour risks. For geotechnical risks, the USMP provides tools to evaluate slope stability and prioritize actions, considering exposure and vulnerability.

4.3. Monitoring and Maintenance Technologies

Both nations emphasize monitoring technologies but differ in their integration and application.

- Italian Regulations: structural health monitoring is used for high-risk bridges alongside periodic visual inspections. This dual approach ensures preventive measures are informed by evolving conditions.

- USA Regulations: advanced monitoring systems are integral to the USMP for unstable slopes, using GIS databases and mobile applications to track slope stability.

4.4. Emergency Prevention and Response

Emergency management approaches reflect different priorities in structural safety and geotechnical risks.

- Italian Regulations: prevention is embedded in risk classification, with less emphasis on explicitly categorized emergency responses. Structural vulnerabilities are mitigated through monitoring and prioritized interventions.
- USA Regulations: emergency interventions are explicitly addressed under NBIS and USMP. These include rapid responses to bridge scour risks or slope instability, supported by detailed action plans for critical conditions.

4.5. Approach to Preventive Maintenance

The emphasis on preventive maintenance demonstrates commitment to extending infrastructure longevity.

- Italian Regulations: maintenance schedules are based on CoA prioritization, focusing on risk mitigation and targeted interventions.
- USA Regulations: preventive maintenance is institutionalized, with NBIS providing detailed inspection schedules and USMP addressing geotechnical risks through proactive slope stabilization and monitoring.

5. General Discussions and Conclusions

This comparative analysis highlights the distinct approaches to landslide risk assessment and bridge safety management adopted by Italy, China, and the United States. While Italy's guidelines focus on a multi-layered risk classification system, prioritizing flexible, context-specific interventions, China's regulations emphasize real-time monitoring and structured frameworks for both routine and emergency maintenance. The USA regulations combine structural and geotechnical management, integrating inspections and emergency response plans with continuous monitoring.

Proactive infrastructure management in China offers valuable insights into improving risk management systems in emergency phases. The USA regulations provide a robust model, particularly in emergency management and the integration of geotechnical assessments. Meanwhile, Italy's approach remains a leading example in integrating landslide risk assessments with a multi-layered system but could improve in emergency protocols.

Other International guidelines like that from France, or UK underscore the need for a comprehensive approach that considers structural, geotechnical, and hydraulic risks. While global best practices, such as those from Italy, China and the USA, offer, everyone with the own nuances, key lessons for improving, monitoring, preventive maintenance strategies and emergency management.

Future research should prioritize the comparative analysis of case studies involving the implementation of various guidelines and manuals. Additionally, it is essential to assess the long-term effectiveness of these regulatory frameworks in mitigating risk, thereby providing empirical evidence on their impact as risk reduction measures.

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