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Managing rockfall risk on the Italian road network with the new UX131 guideline

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Abstract

Rockfall is a severe natural hazard that poses significant risks to infrastructure, particularly along road networks. While commonly associated with mountainous regions such as the Alps and the Apennines, rockfall events also threaten coastal roads and tunnel entrances. To mitigate these risks, rockfall barriers are widely deployed. These systems are engineered to intercept falling rocks and dissipate their kinetic energy, with current technologies capable of withstanding impacts up to 10,000 kJ. However, the long-term effectiveness of these barriers is challenged by ageing and environmental degradation. To address this, the new guideline "UX131 – Metodologia per la gestione delle barriere paramassi a rete esistenti attraverso l'individuazione di classi di attenzione in funzione del rischio", issued by UNICMI, introduces a structured methodology for the assessment and management of existing rockfall barriers. This initiative, whose concept was initially developed by the authors, is the result of a collaborative effort involving public authorities, engineers, geologists, and major barrier manufacturers, with scientific support from Politecnico di Torino.

At the core of the UX131 guideline is a detailed inspection methodology that identifies and classifies potential damage types based on their impact on the barrier's functionality. The inspection results serve as a key input to a multi-component analysis that integrates hazard, vulnerability, and exposure to determine the system's attention level. This risk-based framework enables targeted maintenance strategies and enhances the resilience of Italy's road infrastructure against rockfall hazards. An example of application will be presented, illustrating the practical implementation of the guideline and demonstrating its effectiveness in supporting decision-making for the maintenance and upgrading of rockfall protection systems.

Keywords: Rockfall; risk management; road protection; maintenance

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1. Introduction

Rockfall is a significant natural hazard that presents substantial risks to people, structures and infrastructures, particularly along road networks in regions characterized by steep terrain and unstable slopes (Scavia et al., 2020). While the phenomenon is most commonly associated with mountainous areas, it also poses a growing threat to coastal and mining environment (Ferlisi et al., 2012; Guzzetti et al., 2004). Among infrastructures, roads, bridges' piers and tunnel entrances can be particularly affected (Cao et al., 2024; Budetta et al., 2016; Wang et al., 2017). The potential for rockfall events to disrupt transport networks, damage infrastructure, and endanger lives underscores the importance of effective risk management strategies (Marchelli et al., 2024). In response to this hazard, rockfall barriers are extensively deployed to mitigate the impact of falling rocks. These protective systems are designed to intercept and dissipate the kinetic energy of rocks, with current technologies capable of withstanding impacting energies up to 12,500 kJ. This protection system is essentially made of a net, intercepting and stopping the falling blocks, sustained by metallic posts and connecting components, i.e. ropes and connecting devices, which transfer the impact loads to the foundations.

However, despite their widespread use, the long-term effectiveness of rockfall barriers is often compromised by factors such as ageing, material degradation, and environmental conditions (Marchelli 2020; Marchelli et al., 2022; Xu et al., 2024; Zhang et al., 2023). Over time, these barriers may lose their ability to function at optimal levels, requiring regular maintenance and assessment to ensure continued protection. In this framework, the challenge lies in developing systematic approaches to evaluate the condition and performance of existing barriers and to identify appropriate interventions before failures occur.

To address these concerns, the introduction of the "UX131 – Metodologia per la gestione delle barriere paramassi a rete esistenti attraverso l'individuazione di classi di attenzione in funzione del rischio" guideline by UNICMI marks a significant advancement in the management of rockfall protection systems. Developed through a collaborative effort involving public authorities, engineers, geologists, and key barrier manufacturers, with scientific support from Politecnico di Torino, the UX131 framework provides a comprehensive approach to the inspection and management of these protective structures. This guideline proposes a structured methodology for the assessment of existing rockfall barriers, aiming to improve their resilience and ensure their continued effectiveness over time. At the heart of the UX131 guideline is a robust inspection methodology that classifies damage types according to their impact on the functionality of the barrier. By integrating hazard, vulnerability, and exposure in a risk-based framework, the guideline facilitates the identification of barriers requiring urgent attention and informs targeted maintenance strategies.

This paper presents the methodology and an example of the practical application of the UX131 guideline, demonstrating its utility in real-world scenarios. The case study highlights how the methodology supports decision-making for the maintenance and upgrading of rockfall barriers and illustrates its potential to enhance the resilience of Italy's road infrastructure against rockfall hazards.

2. Methodology

The UX131 guideline proposes a structured, multi-level methodology for the assessment and management of existing rockfall protection barriers. The approach integrates inventory data, condition assessment, risk-based prioritisation, and, where required, detailed engineering evaluation. The core objective is to assign an Attention Class (CdA) to each installation, representing its relative priority for maintenance or further investigation. The methodology combines a set of qualitative and semi-quantitative criteria based on hazard conditions, exposure, and loss of efficiency of the existing mitigation measures, incorporating both primary and secondary parameters in a logical-base procedure. The procedure comprises four progressive levels of investigation, whose scope and analytical depth increase. Fig. 1 depicts the proposed flowchart.

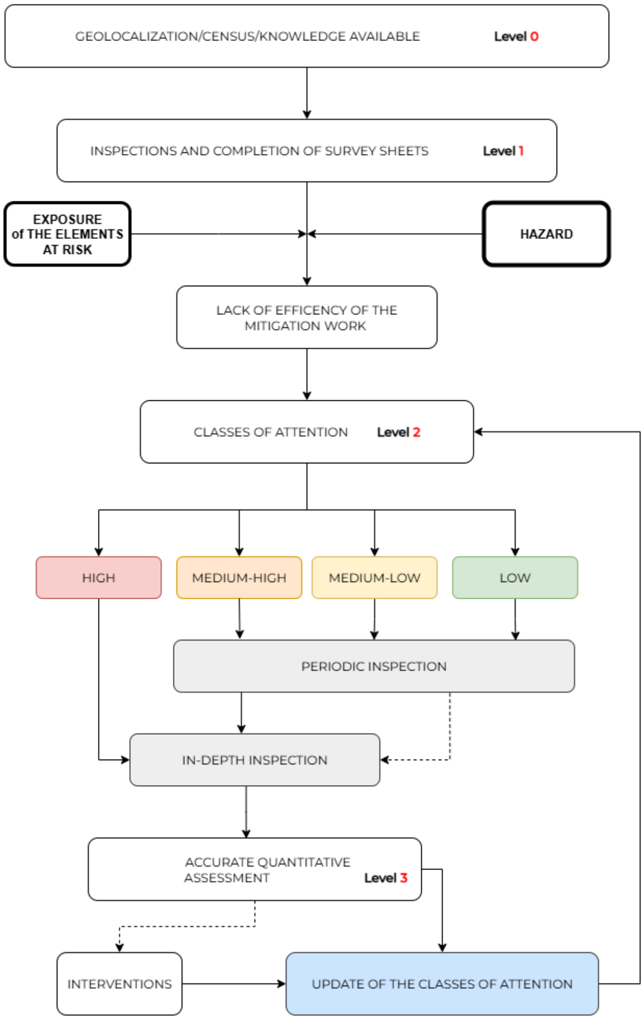

Fig. 1: Flowchart of the proposed method.

2.1. Level 0: Inventory and Data Collection

The process begins with the systematic inventory of all existing rockfall barriers within the area of interest. The objective is to define the number, typology and spatial distribution of installations and to collect baseline information to support prioritization of subsequent inspections. Minimum required attributes include location, ownership, type of barrier, geometric characteristics, year of installation (where available), presence of certification (pre- or post-ETAG 027 (2008)), and the protected infrastructure type. Where accessible, additional technical data such as anchoring systems, brake components, and structural configuration are also recorded. This level establishes a harmonised dataset for all barriers.

2.2. Level 1: Visual Condition Assessment

Level 1 inspections aim to verify the accuracy of the initial inventory data and assess the condition of the rockfall barrier system by documenting its current state. All inventoried barriers undergo a structured visual inspection aimed at verifying inventory information, documenting the actual configuration, and recording degradation phenomena. At the initial time of installation (t0), it is assumed that the rockfall barrier system has been assembled and installed correctly, following the manufacturer's guidelines. Proper installation is critical to ensure the system's functionality and effectiveness during its operational lifetime. Thus, during the first Level 1 inspection, any deviations from the prescribed installation procedures, as outlined in the installation manual, should be carefully checked. If any installation or assembly issues are detected, these conditions must be immediately flagged, as they may compromise the barrier's performance. In such cases, urgent intervention is necessary to restore functionality and prevent potential.

To ensure consistency among different operators and territorial contexts, a standardised inspection procedure, originally developed by the authors (Marchelli et al., 2019; Marchelli, 2020) and formalised within the UX131 framework, was adopted. To guarantee its general validity and applicability across different technologies, installation typologies and generations of rockfall barriers, the methodology begins by identifying the principal structural and functional components common to all barrier systems (e.g., principal and secondary mesh, posts, longitudinal, upslope and lateral ropes, anchors and brakes). For each component, a comprehensive list of control parameters was defined, corresponding to the full spectrum of potential damage mechanisms or observable degradation states. This structure enables systematic recording and comparison of condition data, irrespective of barrier technology or design lineage.

Damage states are recorded via a predefined three-level scale: 0 = no damage, 1 = moderate damage, 2 = severe damage. The procedure also requires inspectors to flag critical conditions, defined as defects that, based on expert judgement, could compromise the energy absorption or interception capacity of the barrier during an impact event (e.g., ruptured components, missing anchors, or unrepaired impacts). In such cases, an immediate maintenance intervention is recommended.

2.3. Level 2 – Definition of Attention Classes

Level 2 constitutes the core of the methodology and establishes the Attention Class (CdA), which represents the priority level for management action. The CdA results from the combination of three contributing factors: (i) Hazard level (H), (ii) Lack of efficiency (LE), (iii) Exposure (E). Each factor is derived from a set of primary and secondary parameters which are aggregated using a logic-based classification system.

The hazard level H reflects the activity of the source rock mass. In the absence of updated geological or geotechnical studies, hazard is conservatively assumed to be high, as the presence of the barrier implies a prior rockfall threat. Hazard may be reduced to medium-low only where studies demonstrate that the triggering rock mass has become inactive relative to the original design event.

The Lack of efficiency LE, that accounts for deterioration, incorrect installation, missing components, or prior impact damage, is determined using a multi-step procedure: (i) definition of the "Degree of Damage"; (ii) evaluation of the "Damage Diffusivity"; (iii) combination of (i) and (ii) to define the "Defect Level"; (iv) evaluation of the "Lack of Efficiency". The first step was proposed observing that not all damage types contribute equally to structural performance: for this reason, each control parameter is associated with a component-level degradation weighting, defined Class of Importance (CI) and reflecting its relative role in the global behaviour of the barrier system. Based on a-priori engineering judgment evaluation, the guideline defines three importance levels: CI1 = low relevance; CI2 = medium relevance; CI3 = high relevance. The observed damage level and the assigned CI are combined through a matrix correlation method, producing a semi-quantitative indicator referred to as the "Degree of Damage". The worst Degree of Damage obtained among each control parameter represents the Degree of Damage of the whole system. This approach ensures that severe deterioration affecting high-importance components (e.g., anchors, brake elements or primary mesh) has significantly higher relevance than similar deterioration affecting non-structural secondary components. Beyond severity, the spatial extension of deterioration within the system plays a critical role in functional performance. The method therefore introduces the concept of "Damage Diffusivity", defined as the extent to which defects are distributed along the barrier alignment. Diffusivity may be assessed either qualitatively, based on inspector judgement, or quantitatively, through an optional scoring method included in the guideline, proposed by the Authors.

The combination of the degree of damage and damage diffusivity yields a global indicator termed the “Defect Level”. Defect Levels are assigned to one of four classes, i.e. Low; Medium-Low; Medium-High; and High. The Defect Level is then integrated with additional information regarding whether the barrier was constructed before or after ETAG 027-based certification, and whether tests on anchors or foundations are available. These two supplementary criteria refine the reliability of the estimated functional state, acknowledging that certified systems and installations with verified anchorage performance exhibit more predictable behaviour under impact loads. The resulting output is the “Lack of efficiency” (LE) of the barrier, categorised as: Low; Medium-Low; Medium-High; and High, and represents the outcome related to the barrier.

Similarly to hazard, exposure level E reflects the number and vulnerability of assets protected by the barrier. Two classes are defined: High for transport infrastructure with regular traffic, railways, or permanently inhabited structures, and Low for infrastructure with limited use or facilities with sporadic human presence.

The three contributing factors (hazard, lack of efficiency, exposure) are combined using a predefined decision matrix (Table 1). Lack of efficiency has the highest weighting: whenever the lack of efficiency is high, the resulting CdA is automatically high, irrespective of the hazard or exposure level. The final Attention Class consists of four levels, i.e. Low; Medium-Low; Medium-High; and High.

This class value represents the output of Level 2 and serves as the operational basis for maintenance planning and prioritisation.

Table 1. Evaluation matrix for the CdA

High hazard			
		Exposure	
		High	**Low**
Lack of efficiency	**High**	High	
	Medium-high	High	Medium-high
	Medium-low	Medium-high	Medium-low
	Low	Medium-low	Low
Low hazard			
		Exposure	
		High	**Low**
Lack of efficiency	**High**	High	Medium-high
	Medium-high	Medium-high	Medium-low
	Medium-low	Medium-low	Low
	Low	Low	Low

2.4. Level 3: Detailed Assessment

Barriers assigned to the higher Attention Classes may require advanced analyses, including rockfall trajectory modelling, structural verification, or targeted testing (e.g., anchor pull-out tests). These investigations confirm whether rehabilitation, replacement or system upgrade is necessary.

3. Example of application

This case study demonstrates the application of the UX131 methodology to assess and manage two rockfall barriers located in Northwestern Italian Alps. The barriers are designed to protect critical road infrastructure, but during recent inspections, significant issues were discovered that required the application of the methodology to ensure their continued effectiveness.

Barrier 1 is a 90-meter long and 4-meter high rockfall protection system designed to withstand a maximum energy of 2000 kJ (Fig. 2a). Despite identifying the barrier's manufacturer, no documentation related to the installation or certification was available, making the inspection process challenging. Given the lack of available documentation, a comprehensive inventory was created with direct measurement of the geometry and characteristic of each component. During the Level 1 visual inspection, several defects were identified that could severely affect the barrier’s performance. In particular, several anchors were either not grouted (installation error) or had become dislodged (Fig. 2b), weakening the barrier's ability to withstand impact. Significant voids were observed at the foot of the barrier, which could compromise the stability of the structure. Referring to the intercepting structure, there were tears in the secondary mesh (Fig. 2c) and several missing connection elements in the primary mesh. Considering all the ropes, only some rope clips of a couple of upslope ropes were not installed according to standards, further jeopardizing the system's integrity. As a result of these findings, the Degree of Damage is high, but with a low Damage Diffusivity low (6.67%), resulting in a high Defect Level. Considering the absence of tests on the anchors as well as European certification, the Lack of efficiency becomes high.

Considering that the barrier is located in an area with frequent rockfall events (high hazard), and that the road protected by the barrier serves as a critical transport route (high exposure), the CdA results high.

Fig. 2 (a) Overview of Barrier 1, (b) anchor not grouted, (c) tearing of the mesh (d). Barrier 2, (e) rope anchor.

Barrier 2 spans 40 meters in length and 3 meters in height. It has a maximum energy absorption capacity of 500 kJ, and the installation is ETAG certified, though the barrier is heavily impacted by vegetation growth (Fig. 2d,e).

During the inspection, the following issues were identified. Heavy vegetation obstructed a full visual inspection, especially around the posts and connection points, and could interfere with the barrier’s ability to function during a rockfall. Furthermore, vegetation promoted the swelling of the intercepting structure. Some upslope ropes were found to be slack or tensioned abnormally, which can lead to improper functioning during impact. Damage to the connection between ropes and posts was observed, with some connectors either severely corroded or completely detached. There was widespread corrosion on several components, including the ropes and anchors, particularly in areas where the metal was exposed to the elements. This corrosion threatens the structural integrity of the barrier.

Also in this case the Degree of Damage is high, but with a low Damage Diffusivity of 45%. Despite being certified, the score for Defect level is high. Similarly to Barrier 1, both hazard and exposure level result high as well, resulting in a high CdA.

Both barriers were thus classified within the High Attention Class (CdA) due to severe damage and significant risks to their effectiveness. The application of the UX131 methodology provided a clear and structured process for assessing the barriers' current condition, identifying critical defects, and prioritizing the required maintenance actions. Barrier 1 required immediate attention to correct the installation issues, anchor grouting, and mesh repairs. Meanwhile, Barrier 2 needed urgent vegetation clearance, rope adjustments, and corrosion treatment to prevent failure during rockfall events.

4. Conclusions

This study demonstrates the effectiveness of the UX131 guideline in assessing and managing rockfall barriers along road networks, offering a comprehensive framework for ensuring their continued resilience and functionality.

The core contribution of the UX131 guideline lies in the introduction of Attention Classes (CdA)**,** which effectively prioritize barriers based on hazard, lack of efficiency, and exposure. The multi-levels approach, combining inventory data, condition assessments, and risk-based prioritization, enables systematic identification of barriers requiring maintenance or further investigation. The progressive nature of the UX131 methodology (multi-level approach), ranging from initial inventory collection to detailed engineering evaluations ensures that assessments are both comprehensive and adaptable to varying conditions and technologies.

The presented case study illustrates the practical application of the UX131 methodology for assessing and managing rockfall barriers in two critical locations in Northwestern Italian Alps. Both barriers, designed to protect vital road infrastructure, presented significant challenges during recent inspections, highlighting the necessity of a structured, risk-based approach for ensuring their continued effectiveness.

In conclusion, standardising inspection criteria and introducing harmonised attention classes, the UX131 methodology supports public authorities and infrastructure operators in transitioning from reactive maintenance to a risk-based asset management framework. The system ensures consistency, transparency, and comparability across territories and manufacturers while enabling optimisation of available resources and enhancing the long-term performance of rockfall mitigation systems.

To further improve the effectiveness of the UX131 methodology, a few key areas for enhancement could be considered, as the frequency of inspection, eventually based on the CdA**.** Additionally, inspections should be triggered by significant rockfall events or after severe weather conditions, as these factors can rapidly deteriorate the performance of the barrier. Moreover, to ensure that rockfall barriers function effectively throughout their lifespan, a comprehensive check at the time of installation should be detailed, including both assembly and installation verification requirements.

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