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Preliminary Insights from Surveys of Bridges at High Scouring Risk in West Piedmont

Mauro Aimar[a], Marco Civera[a]*, Sebastiano Foti[a], and Bernardino Chiaia[a]

[a]*Politecnico di Torino, Department of Structural, Building and Geotechnical Engineering, Corso Duca degli Abruzzi, 24, 10129, Turin, Italy*

Abstract

This study focuses on thirteen existing bridges of different structural typologies, located in West Piedmont (in the area under the jurisdiction of the Metropolitan City of Turin) and founded in different soil types. All of them have been previously classified as at high or very high hydraulic risk. For this reason, they are potentially subject to severe scouring, with detrimental effects on the structural behaviours and the seismic performance of the whole system. The visual surveys reported and discussed here aimed at a preliminary evaluation of the conditions of both the superstructure and the foundations. Particular attention was paid to the identification of signs of potential degradation phenomena, also in comparison with the available information from past in situ surveys. The results of these investigations highlighted some interesting cases that will be further addressed in the framework of the PNRR Spoke 7 "CCAM, Connected Networks and Smart Infrastructures" – WP4 "Resilience of Networks, Structural Health Monitoring and Asset Management"

Keywords: Bridge Surveys; Hydraulic Risk; Scouring, Metropolitan City of Turin; Geotechnical Engineering; Bridge Foundations

1. Introduction

Road bridges serve as vital infrastructure crucial for transportation and commerce. However, they face various threats of various kinds – related to their structural conditions or their surrounding environment. In particular, river

* Corresponding author. Tel.: +39 011-090-4911; fax: +39 011-090-4911.
E-mail address: marco.civera@polito.it

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crossings are notoriously affected mainly by hydraulic risks, such as overtopping flow, hydraulic forces acting on the deck/piers, and, most importantly, scouring.

Scour mechanisms, intended as ‘the erosion or removal of streambed or bank material from bridge foundations due to flowing water’ (Forest Service, 1998), can occur at different points of piers and/or abutments. To highlight the risks, it should be remembered that this is the leading cause of highway bridge failures in the United States, contributing to 60% of such failures alongside other hydraulic-related factors (Landers, 1992). For instance, in the recent failure of the Longobucco bridge near Cosenza (Calabria region) occurred in May 2023, one pier experienced extremely large rotations due to foundation scour. The consequent large displacements at the pier cap caused the collapse of the deck due to the loss of support (Fig. 1). In west Piedmont, it was one of the main causes of collapses for several road bridges during the flood events of November 4-6, 1994, October 13-17, 2000, May 28-30, 2008, and 21-25 November 2016, among many other minor floods.

Thus, scour poses a significant risk to road bridges as it can cause the subsidence and tilt of the piers. The phenomenon is difficult to investigate as it involves geotechnical, hydraulic, and structural considerations in a multiphysical approach (Ciancimino et al., 2021, 2022; Foti et al., 2023). Its negative consequences depend as well on structural factors such as the building material and structural typology. For instance, masonry arch bridges are particularly vulnerable, as they most commonly lie on shallow foundations (Borlenghi et al., 2022). In these cases, the differential settlement causes the accumulation of plastic strains (Scozzese et al., 2019) and thus the development of crack patterns (Civera et al., 2021). However, reinforced concrete (RC) and other bridge typologies are similarly considered at high risk (Wang et al., 2017).

All these risks are anticipated to grow due to the effects of climate change. The vulnerability of bridges to scour has been extensively studied, with simulations considering climate change scenarios indicating that roughly 20% of bridges in Europe will face substantial scour risks over the next two decades. This percentage is even worse for several Southern European countries such as Portugal (50%), Spain (42%) and Italy (39%) (Nemry & Demirel, 2012). Consequently, it is imperative to formulate effective strategies for assessing and managing the scour risk associated with road bridges.

For these reasons, Città Metropolitana di Torino tasked experts from Politecnico di Torino to perform visual inspections of thirteen existing bridges of different structural typologies, all previously classified as at high or very high hydraulic risk. This short contribution reports the main findings of these preliminary studies.

a) b)

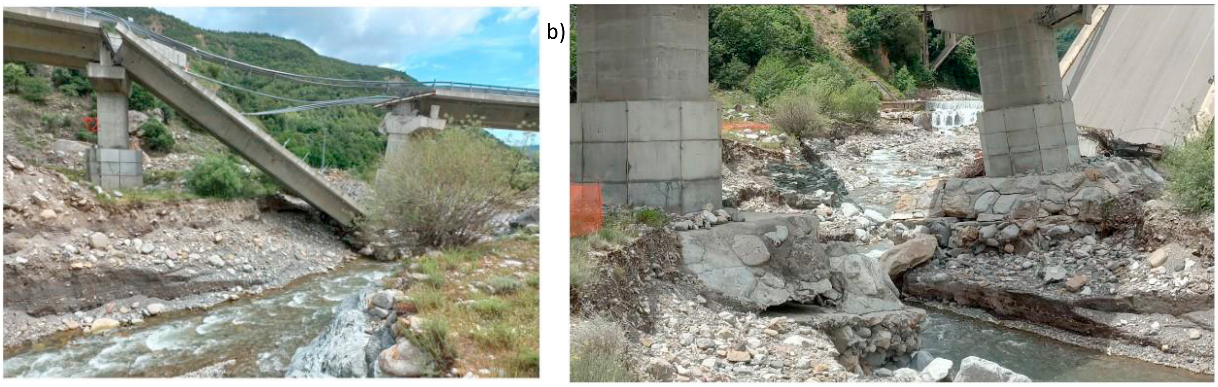

Figure 1. Collapse of the Longobucco bridge, near Cosenza: a) Collapsed deck span and rotated pier; b) Detailed view of the foundation of the rotated pier.

2. The Case Studies

The inspection campaign took place on February 3, 16, and 17, 2023 and it focused on 13 road bridges under the jurisdiction of the Metropolitan City of Turin. Fig. 2 reports their location, including additional information about the structural scheme, hydraulic hazard, foundation conditions, and seismic hazard.

As for the superstructure, Fig. 2a identifies the investigated bridges in terms of both the static scheme of the bridge deck and the year of construction. For simplicity, bridges were clustered according to three periods of construction, that is, before 1939, between 1939 and 1971, and after 1971. Indeed, in these years, the building codes through to the Regio Decreto Legge 2229/1939 and the Legge 1086/1971 were proclaimed. Thus, such clustering is consistent with the main steps in the evolution of the Italian building codes. In general, most of the investigated bridges were built in the 1950s-1960s and they are characterized by a stack of simply supported spans, consistently with the construction trends in those years. On the other hand, many bridges were built recently (i.e., end of the 1990s), although some of them are replacing collapsed bridges after flooding events, as it will be addressed below.

Being river bridges, the understanding of their interaction with the water channel is crucial. Fig. 2b overlaps the location of selected bridges with the hydraulic hazard map[†], which identifies regions with different degrees of hydraulic hazard, from low to high. Indeed, bridges in alluvial areas can be affected by hydraulic forces and foundation scour on both piers and abutments during flood events, inducing relevant damage or even collapse. To highlight this issue, Fig. 2b also indicates the bridges that needed significant repair intervention or a complete reconstruction after floods.

Fig. 2c reports available information on the geotechnical side. On the one hand, it shows a simplified representation of the surface geology, as it mainly affects the bridge behavior as well as the erosion. Bridges in mountain areas are typically founded on coarse-grained soils (i.e., gravels and cobbles), although most of the considered bridges are built on sands and gravels, being located in the plain. On the other hand, Fig. 2c labels each bridge as a function of the foundation type. To our knowledge, the information about the foundation is not available for 5 bridges. Instead, the remaining bridges are supported by pile foundations (with the exception of the Castiglione Torinese bridge, PCT, which adopts diaphragm walls), which reduce the sensitivity of the bridge behavior to soil erosion. However, the actual benefit on the structure depends on the foundation geometry (i.e., number, diameter and depth of piles), and the related information is currently missing for many of the considered bridges.

Finally, in Fig. 2d, the bridge map is overlapped with the seismic hazard map[‡], which represents the 475-year return period expected peak ground acceleration, $a_{g,475}$. This parameter can be considered as a proxy of the intensity of the expected ground motion. The investigated bridges are affected by different seismicity levels, with $a_{g,475}$ values ranging from 0.0025g in the plain areas up to 0.15g in the Alps. These amplitude levels are typical of low-seismicity areas, although they do no account for the local geology and the site topography, which can significantly increase the expected shaking level. This aspect can be critical for river bridges, as they are typically built on sedimentary areas and/or alluvial valleys, which are prone to stratigraphic amplification and basin effects.

† https://www.arpa.piemonte.it/, last visited 21 October 2023

‡ https://www.regione.piemonte.it/web/temi/protezione-civile-difesa-suolo-opere-pubbliche/prevenzione-rischio-sismico/classificazione-sismica, last visited 21 October 2023.

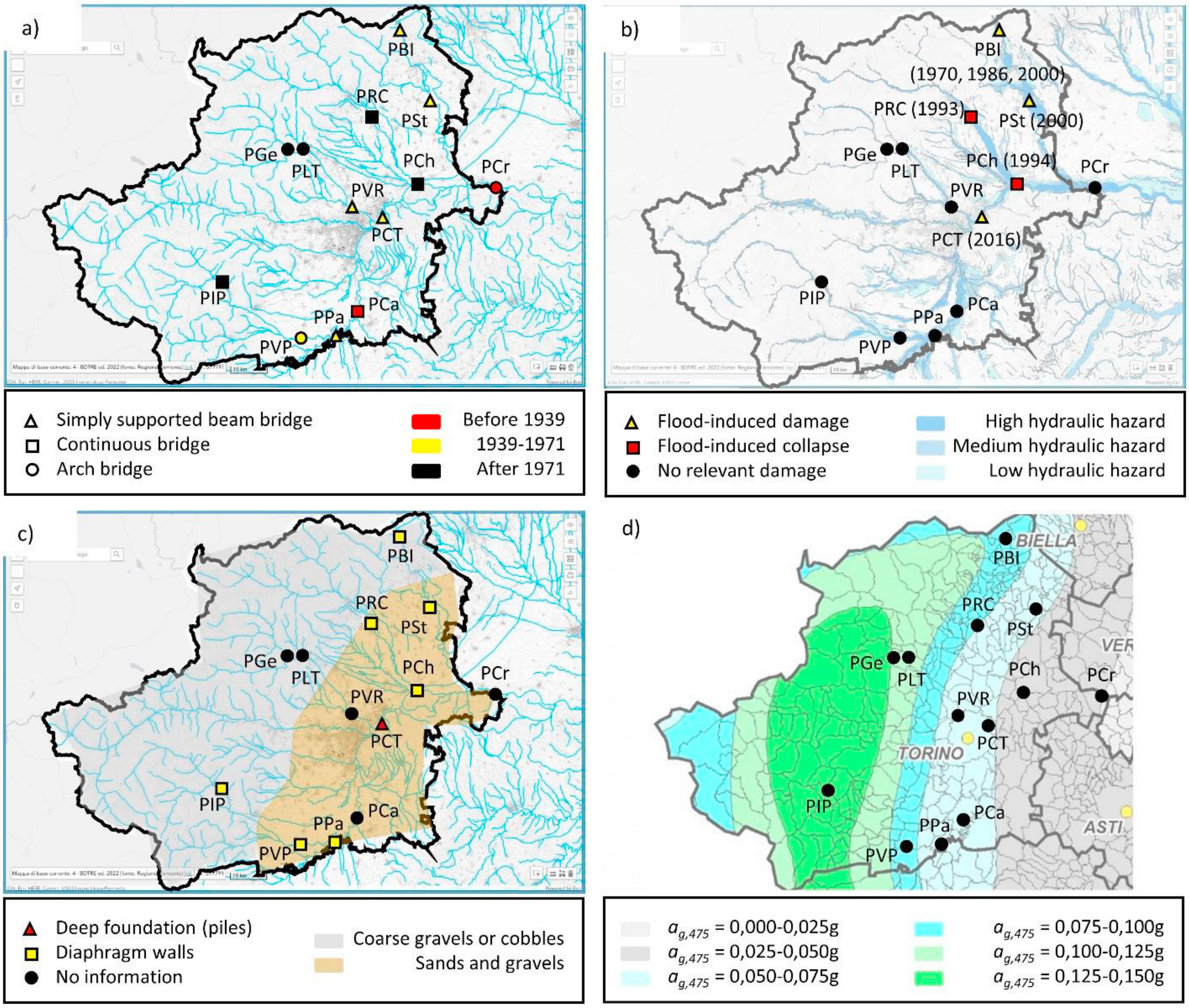

Figure 2. a) Location of the investigated bridges, labelled according to the structural scheme and the period of construction; b) Location of the investigated bridges in the hydraulic hazard map, classified according to the damage entity observed in past flood events and the event year; c) Location of the investigated bridges in the simplified map of the surface geology, labelled according to foundation type; d) Location of the investigated bridges in the seismic hazard map.

The selected case studies have been investigated in a past survey performed by the Metropolitan City of Turin in 2003, with the exception of the Inverso Pinasca and Lanzo Torinese bridges (PIP and PLT, respectively, in Fig. 2). Therefore, the inspection campaign tried to assess the evolution of bridge health from 2003 and 2003, both in terms of the superstructure and the foundation conditions. The evaluation of the structural components focused on the identification of degradation patterns (e.g., exposed rebars in reinforced concrete bridges and cracking in masonry structures) or peculiarities in the static scheme (e.g., variations of the span length or of the supporting conditions). Instead, the geotechnical survey mainly addressed the evidence of foundation scour (both general and local scour) and the presence of mitigation infrastructures in the riverbed, to mitigate the hydraulic risk. For simplicity, this study did not include the slope stability assessment.

3. Results of the in-situ surveys

This section provides a synthetic overview of the results of the survey, with a more detailed description of some relevant case studies.

Fig. 3 summarizes the main results, showing the number of bridges characterized by peculiar structural and geotechnical conditions (labels "S" and "G", respectively), that may require attention and further investigation. Specifically, Fig. 3a refers to the 2003 survey, whereas Fig. 3b results from the current inspection study (i.e., year 2023). To facilitate the comparison, Fig. 3c shows the number of considered bridges with unchanged conditions versus the number of those with peculiar structural and geotechnical conditions not originally identifies in the 2003 survey. The graphs also include the Lanzo Torinese and the Inverso Pinasca bridges (PLT and PIP, respectively), denoted through a different colour as not included in the 2003 study. In general, geotechnical-related issues are more frequently observed than structural problems. Indeed, notwithstanding the different age, the superstructure conditions are generally good or even excellent. Instead, foundations are often affected by flood-induced erosion. On the other hand, no relevant changes in the conditions were identified for most of the bridges from 2003 and 2023, despite the intense floods occurred in this time period. An increase in the foundation erosion was observed in the Crescentino and the Rivarolo Canavese bridges (PCR and PRC, respectively, in Fig. 2). Furthermore, the Castiglione Torinese bridge (PCT in Fig. 2) underwent a significant change in the structural conditions, which will be discussed in detail below.

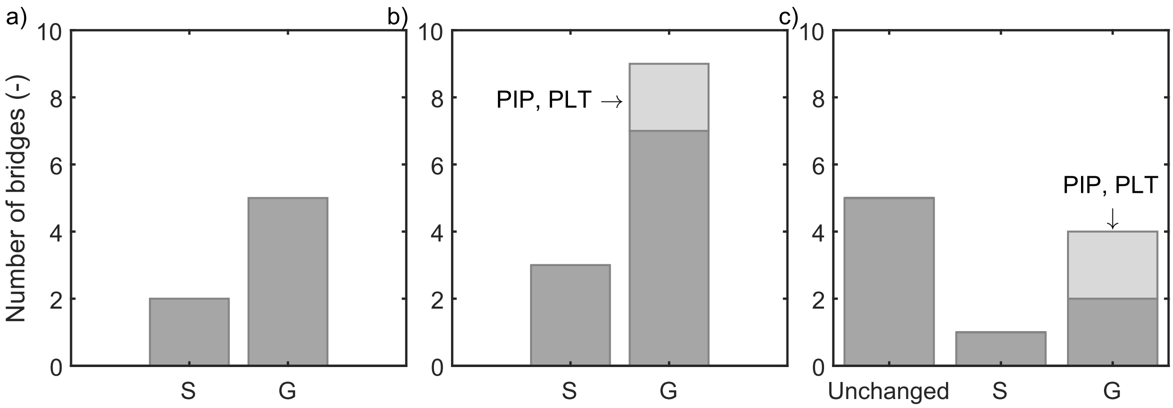

Figure 3. a-b) Bar plots showing statistics for bridges with structural issues (label "S") and geotechnical issues (label "G") for years 2003 (a) and 2023 (b). c) bar plot showing the number of bridges with unchanged conditions and variations in structural and geotechnical conditions. Data related to the Lanzo Torinese and the Inverso Pinasca bridges (PLT and PIP) are colored differently because they were not included in the 2003 survey.

Among all these bridges, some included relevant features for which they can be addressed in future survey and measurement campaigns.

On the one hand, the Inverso Pinasca bridge (PIP) is part of a thalweg road running parallel to the Chisone river, in the Western part of the Metropolitan City of Turin. The superstructure is characterized by a continuous, composite steel-concrete deck with excellent conditions, also due to the relative short age of this structure – the construction year is 2005. However, the river main channel has gradually shifted towards the road axis, thus inducing significant lateral scouring on the foundations of part of the piers (Fig. 4). As each pier is supported by deep, large-diameter piles, foundation scour should not dramatically affect the safety conditions of the bridge, in this case. On the other hand, the different entity of erosion from pier to pier may induce some asymmetry in the structural response. To avoid further extension of the erosion, the infrastructure manager planned a retrofit intervention, consisting in a restoration of the original morphology, soil improvement through jet grouting injections and protection through rock walls. For this reason, this bridge will be further investigated to better understand its behaviour and have an insight into the effects of such an intervention.

As stated above, also other bridges are affected by foundation scour, whereas the structural conditions are excellent. For instance, the Crescentino bridge (PCR in Fig. 2) is a multi-span masonry bridge crossing the Po river, where the spans crossing the main river channel are quite significantly scoured (Fig. 5a). Nonetheless, no damage was observed on the superstructure. Similarly, scouring is relevant at the Strambino bridge (PST in Fig. 2), on the Dora Baltea river (Fig. 5b-d). This case study is peculiar because it was retrofitted after the 2003 survey (specifically, in 2004). Indeed, the strong erosion induced by the 2000 flood urged for a reinforcement of the foundations of one of the central piers (Fig. 5c). This intervention and its effectiveness were addressed in detail (Nemry & Demirel, 2012). As shown in Fig. 5d, the 2023 survey highlighted a migration of the main river channel towards the Strambino side, worsening the foundation conditions of part of the remaining piers. Instead, the retrofitted pier seems not to be any longer affected by the main river flow. Therefore, the benefit of the retrofit intervention has been counterbalanced by the increased erosion on other piers due to river migration.

Finally, the survey highlighted that the Castiglione Torinese (PCT in Fig. 2) bridge on the Po River is characterized by both peculiar conditions, from both the structural and the geotechnical viewpoints. Indeed, in the aftermath of the 2016 flood in Piedmont, the bridge needed massive retrofit interventions as one pier was affected by strong erosion. For this reason, the pier was demolished and the corresponding spans were replaced with a longer, steel girder beam span (Fig. 6). This resulted in a significant change in the loading conditions of the nearby piers, as demonstrated by the addition of a reinforcement cage at the pier caps to mitigate the effects of the amplified compression. For this reason, PCT represents the only case characterized by a deterioration of structural conditions, not because of material degradation but as a consequence of the significant variation in the static configuration. However, also the foundation conditions play a relevant role, due to the historical and the current evidence of foundation scour.

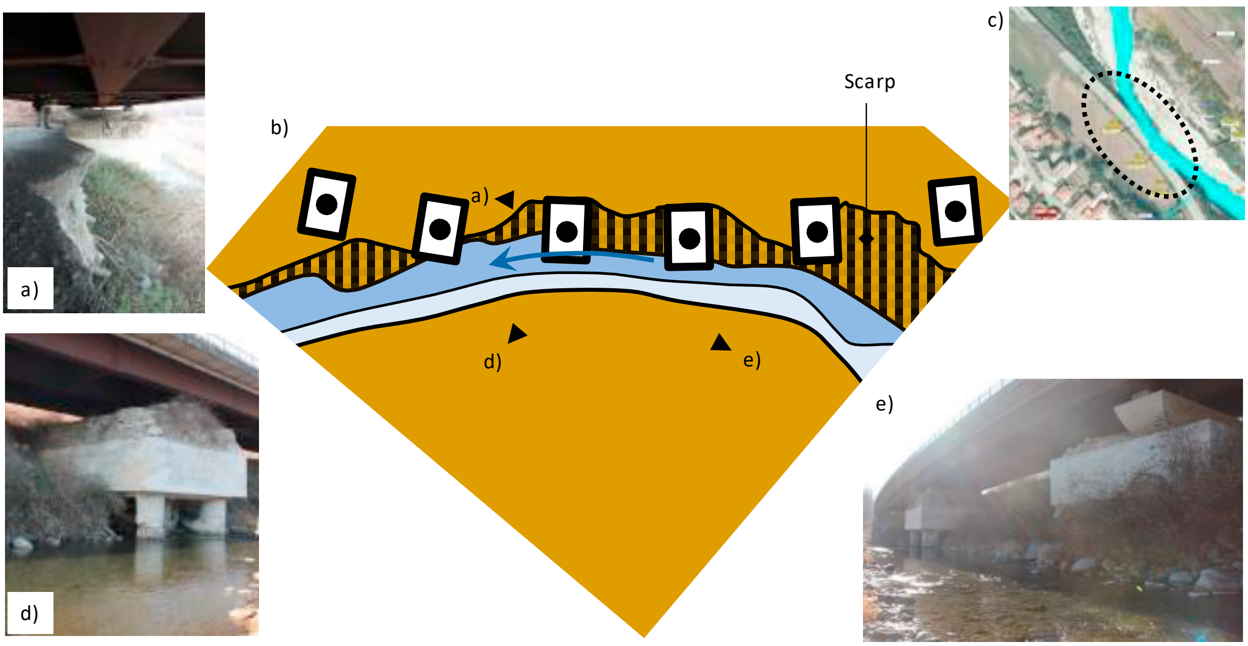

Figure 4. Plane view of the portion of the Inverso Pinasca (PIP) bridge affected by foundation scour (c, d). For simplicity, in (c) only the piers and the foundation pads are represented. The sketch is integrated with photos taken below the deck (a) and from the other side of the river (d, e).

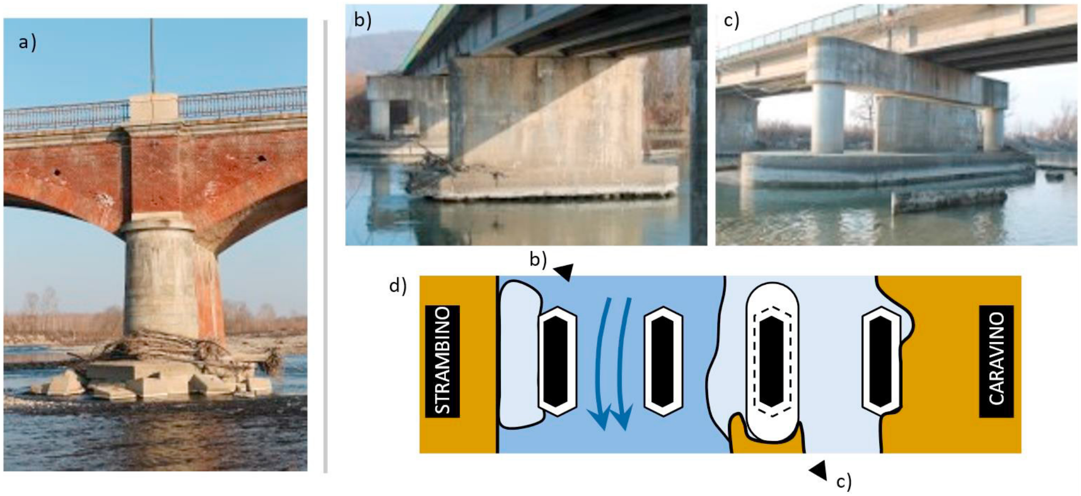

Figure 5. a) Photo of a pier at the Crescentino (PCT) bridge. The presence of concrete blocks indicates that the pier is affected by foundation scour; b-d) Survey results for the Strambino (PST) bridge: photos of original piers (b) and of the retrofitted one (c) and plane view of the piers with the location of the main river channel (d).

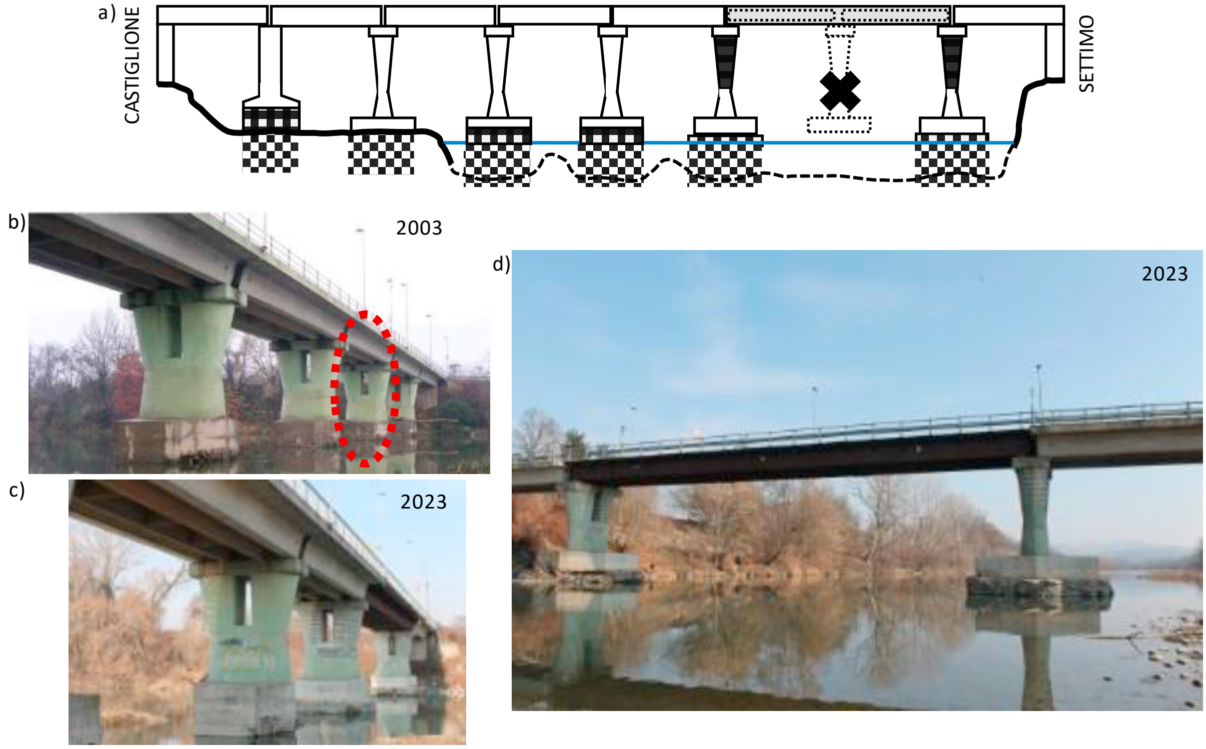

Figure 6. Castiglione Torinese (PCT) bridge: a) Side view, with the removed pier highlighted; b-d) Photos of the portion affected by the retrofit, before (b) and after (c-d).

4. Discussion and Conclusion

In this short paper, the results of the preliminary visual inspections of 13 river bridges have been presented and discussed. The investigated infrastructures are all located in West Piedmont, crossing the Chisone, Pellice, Stura di Lanzo, Orco, Dora Baltea, and Po rivers. They include case studies of different structural configurations (simply supported beam, continuous beam, and arch bridges), lying on different soils (coarse gravel and cobbles in the mountainous areas and sands and fine gravel in the plains), and with different building materials (also including one case of mixed steel-RC deck).

In general, the results show that the vast majority of these case studies are more likely to suffer structural damage from hydraulic causes, especially scouring, rather than from material degradation or other sources of risk. Hence, joint structural and geotechnical assessment must be recommended for these and similar cases throughout West Piedmont and the rest of the Italian territory.

More in detail, among the inspected bridges, Castiglione Bridge is noteworthy due to the presence of scour combined with the post-intervention altered static configuration. Finally, Crescentino, Strambino, and Inverso Pinasca Bridges are deemed of major academic interest due to their specific geotechnical conditions and hydraulic risks. These specific case studies will be the subject of future works.

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