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Structural defects for condition assessment of existing bridges: some results of a territorial case study

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Abstract

Recent events involving the tragic collapse of existing bridges have led to an increasingly detailed study of infrastructure and its maintenance. Italy's intricate road system has a large number of existing bridges demanding urgent and costly maintenance interventions. This study presents a critical review of several defects inspected on existing bridges located in the Basilicata region. The work is addressed at describing the defects surveyed, and at critical evaluating the main causes also due to the interaction with the environmental context surrounding each bridge analysed. Moreover, the paper discusses on how the detailed context knowledge can help to properly identify the correct maintenance intervention on existing bridges.

Keywords: structural defects; bridge assessment; deterioration; inspections; maintenance interventions

1. Introduction

To date, infrastructural buildings management is becoming an increasingly debated issue in Italy, especially considering the number and complexity of the bridge system characterizing the Italian territory. As of 2019, Italy's

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road network covers 167,565 km, counting 6,977 km of highways, 137,283 km of regional and provincial roads and 23,305 of other roads of national interest (Drupal-ISPRA, 2019). Willing to consider only those bridges with a span greater than 6 m on which the new Guidelines (MIT, 2020) are to be applied, on the entire Italian territory there are an estimated 120,000 bridges managed by major associations such as ANAS and AISCAT, and a multitude of provinces and municipalities, but there are about 1,400 constructions that currently do not have owning entities, out of regular maintenance and control. As of 09/20/2023 ANAS S.p.A., one of Italy's largest concessionary entities, alone operates a total of 32,529 km of roads, divided into highways, state highways, interchanges and service roads (ANAS S.p.A., 2023b). The number of infrastructural buildings owned by the company has reached 18,602, including bridges, viaducts and overpasses, which are regularly inspected, monitored and maintained (ANAS S.p.A., 2023a). The AISCAT association, on its side, counts 4,613 km of motorway network with 1,647 infrastructures including bridges, viaducts and tunnels in 2022 (AISCAT, 2022).

It must also be considered that most Italian bridges were built in the 1960s, and that they were often not built in a state-of-the-art manner, using low quality materials, and in absence of regular maintenance over the years (Braga et al., 2019). Besides this, these constructions are scattered in an area naturally prone to instability phenomena such as landslides and floods, as illustrated in Fig. 1 - (ISPRA & SNPA, n.d. 2023).

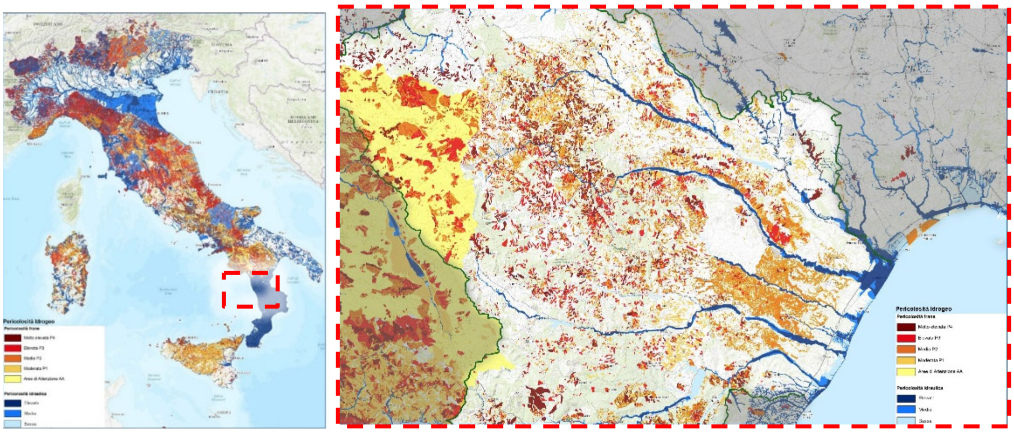

Fig. 1. Hydrogeological Hazard and Risk indicators on the Italian territory and on Basilicata region.

Considering also the limited availability of original design documentation and the multiplicity of existing structural types, it becomes necessary to think about a program for a systematic classification, evaluation and control of existing bridges so as to be able to monitor their conservation state. In Italy since 2020 the new Guidelines for existing bridges issued by the Ministry of Transport and Infrastructure (MIT, 2020) have proposed a multi-level and multicriteria approach with the aim of simplifying bridges classification, management, and risk assessment.

This work presents preliminary results of surveys campaign carried out by applying the Italian Guidelines (MIT, 2020) on existing bridges located into Basilicata region (south of Italy) and managed by ANAS S.p.A.. The sample consists of existing bridges realized starting from 1960s and serving Statal Roads (SRs). At first, an overview of the bridges stock considered is given. Then, main defects surveyed are shown and commented.

2. The multilevel approach

The multilevel approach proposed by the Italian Guidelines for bridges permits of ranking existing bridges at a territorial level, in order to define priorities and to plan more detailed numerical evaluations. It is essential in this approach to evaluate the overall risk of each bridge, named Overall Class of Attention (O-CoA), strictly depending on Structural-Foundational risk (SF-CoA), Seismic risk (S-CoA), Hydraulic risk (H-CoA), and Landslides risk (L-CoA). Therefore, in accordance with this approach also combined effects of structural and hydrogeological aspects on the bridges are considered (MIT, 2020). The multilevel approach proposed includes five levels of knowledge and analysis, having an increasing level of complexity and detail. In this study aspects related to the first three evaluation levels (Level 0, 1 and 2) are discussed. They require the basic bridge knowledge through census, geolocation, and visual inspections with defects survey for the current conservation state assessment, and the subsequent definition of the Overall Class of Attention (CoA).

3. Investigation at a territorial scale

This work aims at critically assessing the defects on a territorial case study, consisting of no. 23 bridges located in different areas of the Basilicata region (in the south of Italy). In this first part, a panoramic of the information requested in the Italian *"Guidelines for the classification and management of risk, for the evaluation of safety and for the monitoring of existing bridges"* (MIT, 2020) is illustrated. In particular, construction period, structural system, number and average length of spans, materials and type of risk are the parameters taken into account.

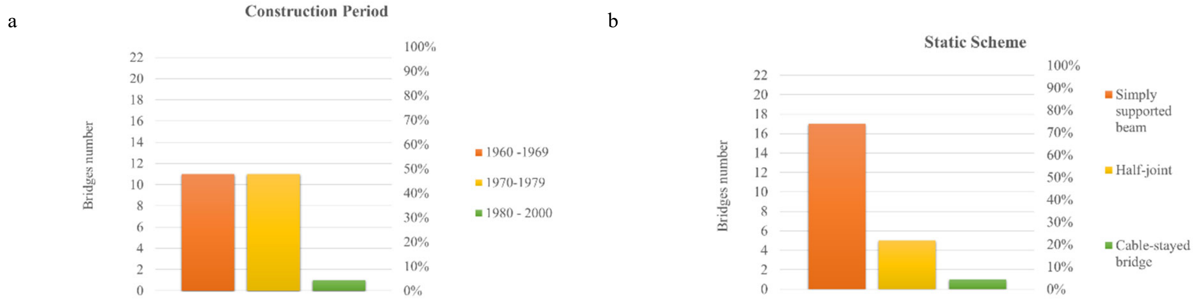

Fig. 2. Bridges classification in terms of: (a) Construction period; (b) Structural system.

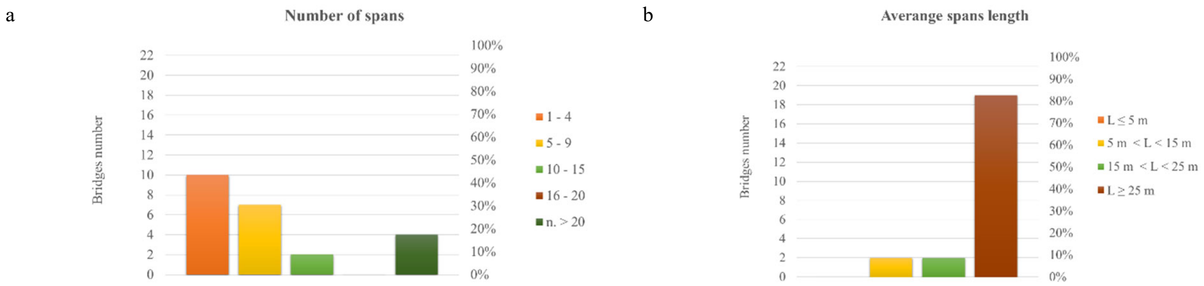

Fig. 3. Bridges classification in terms of: (a) Number of spans; (b) Average length of spans.

As regarding the construction period, it is pointed out that 96% (no. 22) of bridges were constructed from 1960 to 1979, perfectly half-divided into the two reference periods of 1960-1969 and 1970-1979 (Fig. 2a). It is inferred that the reference design standards for the early 1960s and 1970s may probably have been respectively Italian Circular No. 384 of 14/02/1962 and Italian Circular No. 1389 of 28/01/1965. The investigated bridges show also difference in structural system, as reported in Fig. 2b. Approximately 74% (no. 17) are multi-span bridges with simply supported beams, 22% (no. 5) are half-joint beams bridges and the remaining 4% (no. 1) are cable-stayed bridges.

A greater dispersion is observed referring to number and length of spans (Fig. 3a): 43% of the sample consists of 1-4 spans (no. 10 bridges), 30% of 5-9 spans (no. 7 bridges) and 9% of 10-15 spans (no. 2 bridges). 0% of bridges fall in interval 16-20, while 17% (no. 4 bridges) has a spans number higher than 20. As for the average length of spans (Fig. 3b), about 83% (no. 19 bridges) of the bridges examined have span lengths greater than 25 m. In accordance with Italian Guidelines for bridges (MIT, 2020), a span longer than 20 m influences the assessment of structural and foundational vulnerability by leading it to a Medium High or High class, depending on the structural system.

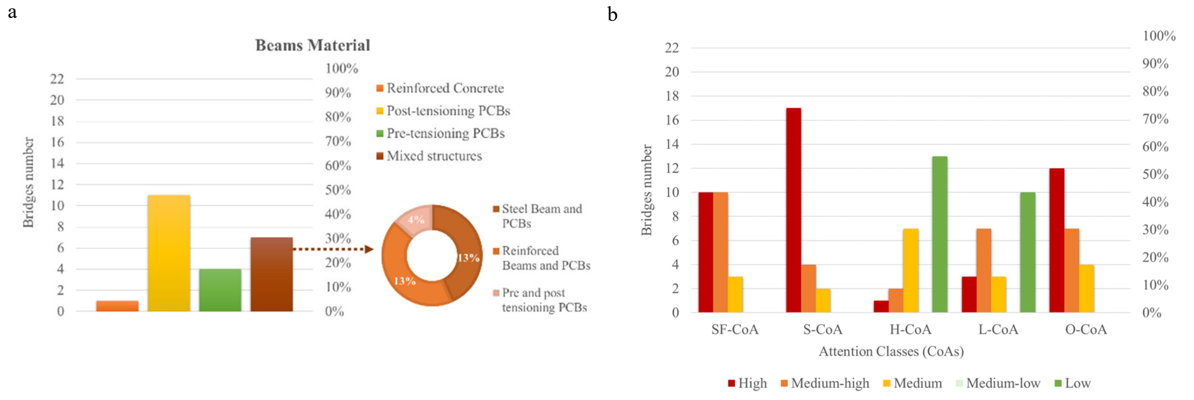

Fig. 4. Bridges classification in terms of: (a) Materials; (b) Classes of Attention (CoAs).

With reference to the beams' material (Fig. 4a), 69% (no. 11 bridges) is composed of Prestressed Concrete Beams (PCBs), with 17% pre-tensioned and the remaining percentage post-tensioned, while 4% is characterized of simple Reinforced Concrete (RC) bridges. Moreover, 30% (no. 7 bridges) is made of more than one construction material: steel and reinforced concrete associated with prestressed concrete.

For the sake of completeness, Fig. 4b reports the resulting Classes of Attention (CoAs) for the bridges sample considered in this work, according to the Italian Guidelines (MIT, 2020). It is worth noting that, in the sample analysed (composed by no. 23 bridges), no. 12 bridges result in High Overall CoA, no. 7 bridges in Medium- High Overall CoA, and the remaining no. 4 in Medium Overall CoA. This is due to the fact that the higher structural-foundational and seismic CoA significantly influence the resulting Overall CoA.

3.1. Territorial context of the bridges sample considered

The analysis of the territorial context of the bridges sample considered is essential for understanding the interaction among the different CoAs for defining the Overall CoA.

The bridges examined fall into no. 9 different geographical areas as indicated in Fig. 5, where also surrounding environment is shown, including hydrographic network and landslide bodies (if any).

Area no. 1 (Fig. 5a) has a small number of landslide bodies and a complex system of main river courses. Nevertheless, bridges do not appear to be affected by the hydrographic network. One bridge is located approximately 100 m far from a landslide body. The bridge in Fig. 5b is located in the Area no. 2, that is an area considered unstable because exposed to landslide bodies (Fig. 6a), and also located near a main river reticulum (Fig. 6b). Into the area no. 3 (Fig. 5c) fall five bridges and it is characterized by an intense hydrographic network. There are no active landslide bodies, but two bridges fall within the landslide risk zone. The bridge located in the Area no. 4 is affected by widespread collapse/overturning and rotational/translational sliding, and is located along a branch of the main hydrographic network (Fig. 5d, Fig. 6c and Fig. 6d). Area no. 5 (Fig. 5e) does not have hydrometeographic and pluviometric stations even though it is close to a branch of the hydrographic network and is not considered a landslide risk area. The viaduct located in area no. 6 (Fig. 5f) is far 700 m and 1000 m from landslide bodies and the central span is crossed by the main course of a river (Fig. 6e). In area no. 7 (Fig. 5g) there are two bridges, one in the north and one in the south of the area. In the north of the area there are overturning failures and to the south of the area, although there are no active landslide bodies, the bridge is considered to be at risk of landslide. Both bridges are located on two branches of the main hydrographic network. Area no. 8 is characterized by a small number of landslide bodies and an articulated hydrographic network affecting the examined bridge (Fig. 5h). Finally, Area no. 9 is an unstable area. In particular the bridge is affected by collapses/tilts, while towards the center it is characterized by a rotational/translational sliding movement (Fig. 5i).

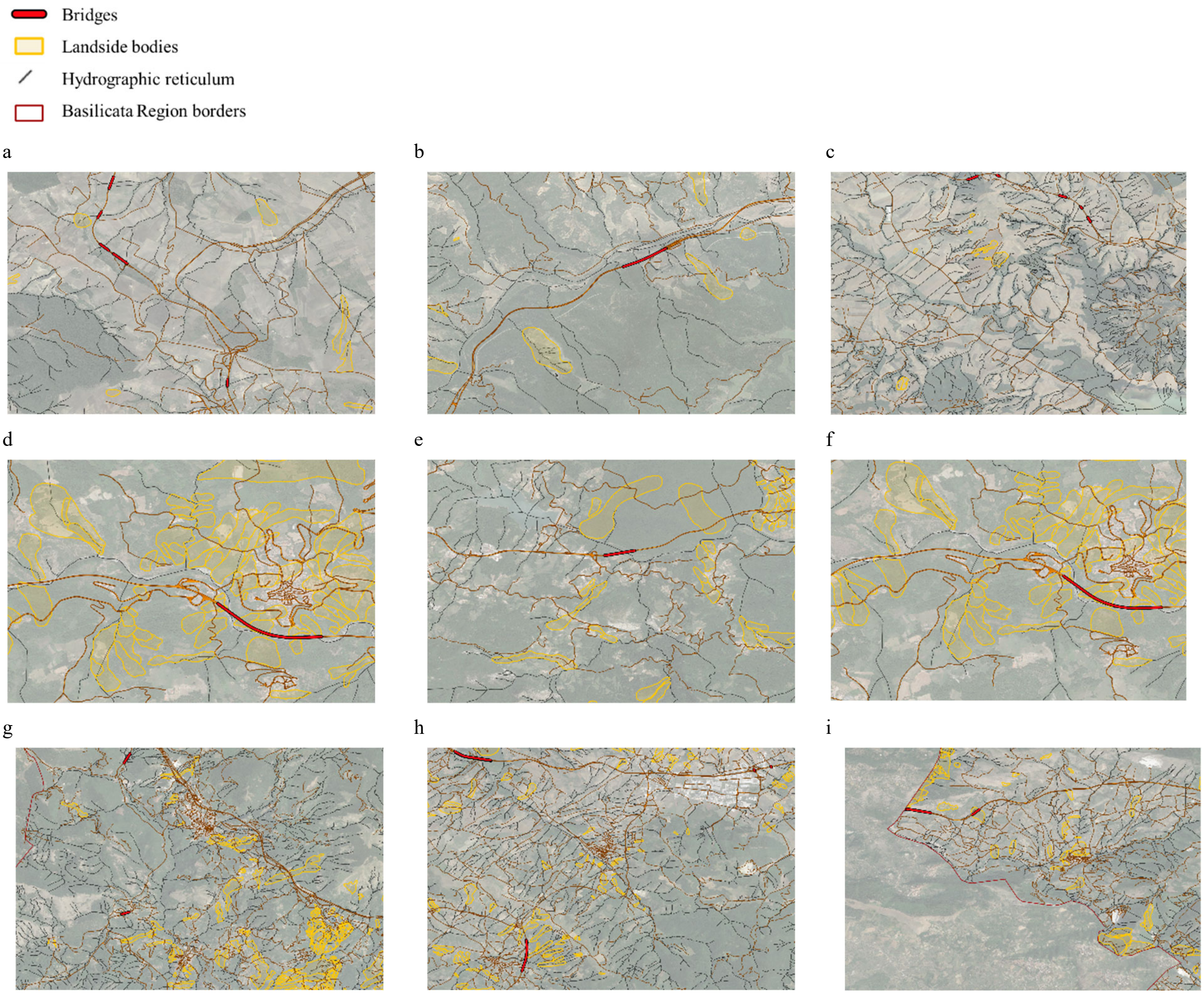

Fig. 5. Geomorphological context of the bridges considered: (a) - (i) show Areas from no. 1 to no. 9.

4. Critical defects analysis

According to Italian Guidelines (MIT, 2020), defect level is a primary parameter for defining vulnerability within the Structural and Foundational Class of Attention (SF-CoA), playing a decisive role for the overall risk (O-CoA). In fact, if a "high defect level" occurs, a "high vulnerability class" must be assigned with a consequent High Structural and Foundational Class of Attention (High SF-CoA), independently on the hazard and exposition classes. Moreover, according to the Guidelines, if a High SF-CoA is obtained, then also the Overall CoA results high (High O-CoA). In a similar way, presence of defects of high or medium-high level significantly impacts the Seismic Class of Attention (S-CoA).

As for the buildings stock considered in this study, defects detected may be classified into the following groups: defects due to wear over time, caused by environmental exposure and traffic loads; defects due to design/construction errors; defects due to bridge interaction with the surrounding environment. For instance, defects due to wear over time is very frequently caused by incorrect rainwater drainage, provoking damage especially on bridge superstructures consisting, in the case of grid decks, of slabs, beams and cross-beams. This damage usually is represented by concrete superficial deterioration and/or defects due to infiltration.

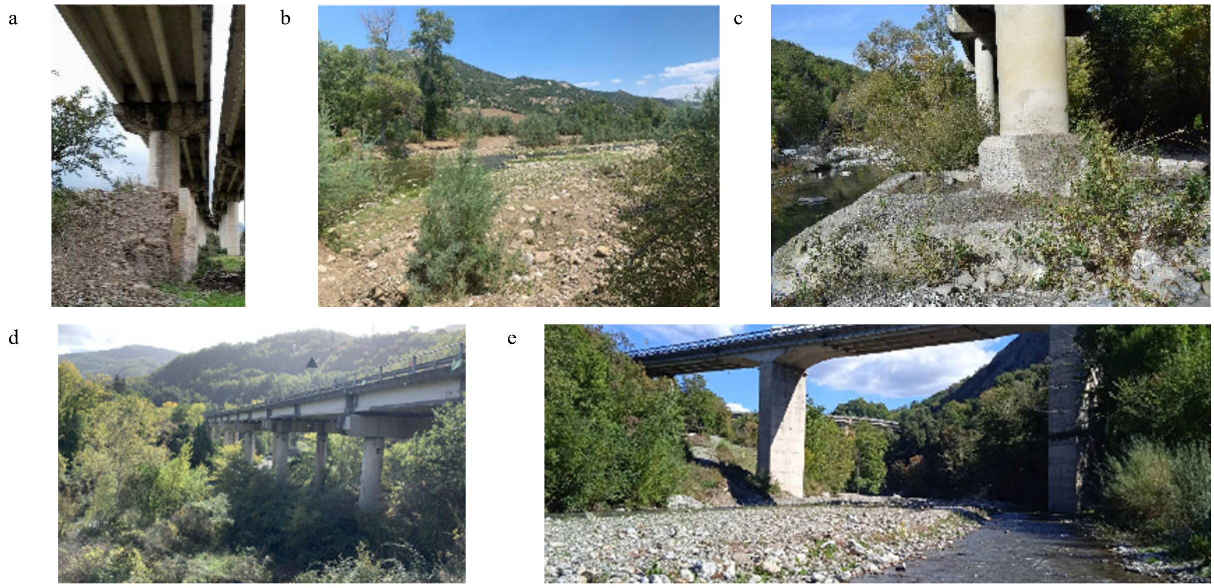

Fig. 6. Some examples of bridges located in areas with: (a), (b), (c) and (e) rivers; (b) and (d) landside bodies.

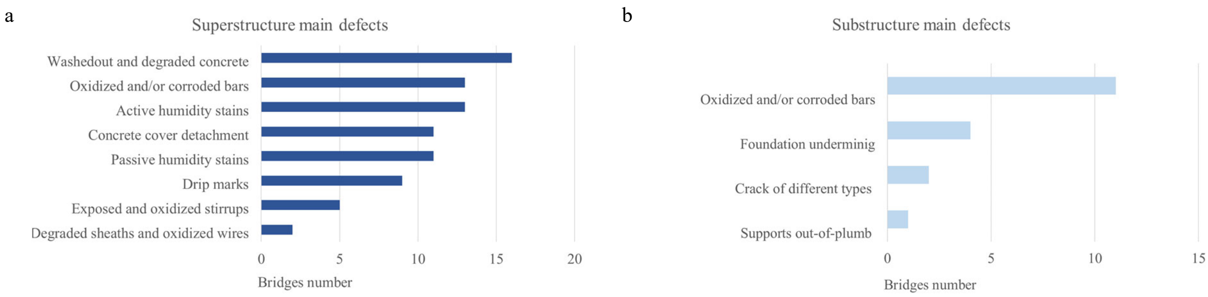

Fig. 7. (a) Superstructure principal defects; (b) Substructure principal defects.

Fig. 7 reports the main defects surveyed and the bridges number where they have been detected, considering the superstructure (Fig. 7a) and substructure elements (Fig. 7b), such as piers, abutments, bridge foundation and supports (ANSFISA, 2022).

In particular, as for the superstructure elements (Fig. 7a), the main defects detected were: washed out and degraded concrete (G3), oxidized and/or corroded bars (G5), active humidity stains (G3), concrete cover detachment (G2), and passive humidity stains (G1). Examples of these defects are reported in Fig. 8. In detail: Fig. 8a and Fig. 8b show corroded bars with reduced section (third-level intensity K2); bars in Fig. 8c and Fig. 8d present only surface oxidation (first-level intensity K2); while in Fig. 8e the oxidation affects the bars cross-section (second-level intensity K2). Finally, Fig. 8f depicts an important, but rarely observed, defect for PCBs consisting of degraded cable sheaths and oxidized wires (G4).

Fig. 9 shows main defects found on the bridge substructures. In particular, it has been detected: corroded and/or oxidized bars (G5, Fig. 9a and Fig. 9b), cracks (G4, Fig. 9c), and foundations scouring (G5, from Fig. 9d to Fig. 9f).

As far as defects on devices are concerned, they may be caused by material aging, such in the case of neoprene (G3 - Fig. 10a), oxidation (G2 - Fig. 10b) and Teflon deterioration (G3 - Fig. 10c), or by traffic loads action, such as neoprene crushing/leakage (G4, Fig. 10a) and permanent pendulum out-of-plumb (G4, Fig. 10b). Moreover, construction details may be source of vulnerability with respect to the seismic action, too. Fig. 10d illustrates small concrete supports and external beams placed near the pier cap perimeter. In these cases, during an earthquake, beams may suffer a loss of support.

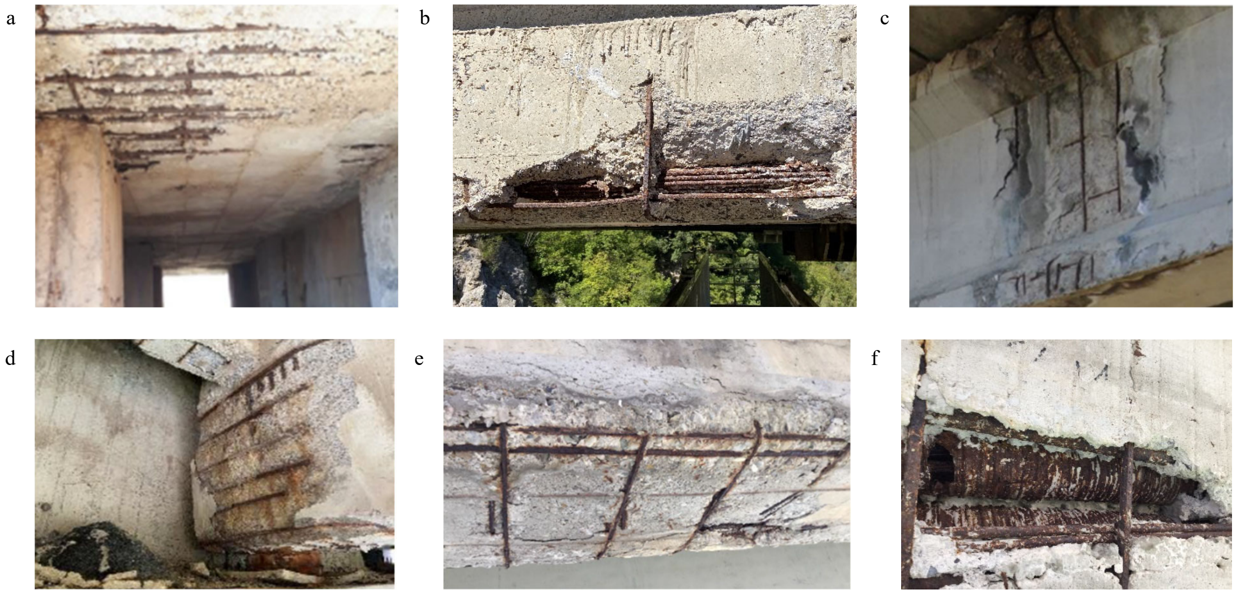

Fig. 8. (a) and (b) corroded bars with reduced section; (c) and (d) only surface oxidation bars; e) oxidation affecting bars surface; f) degraded cable sheaths.

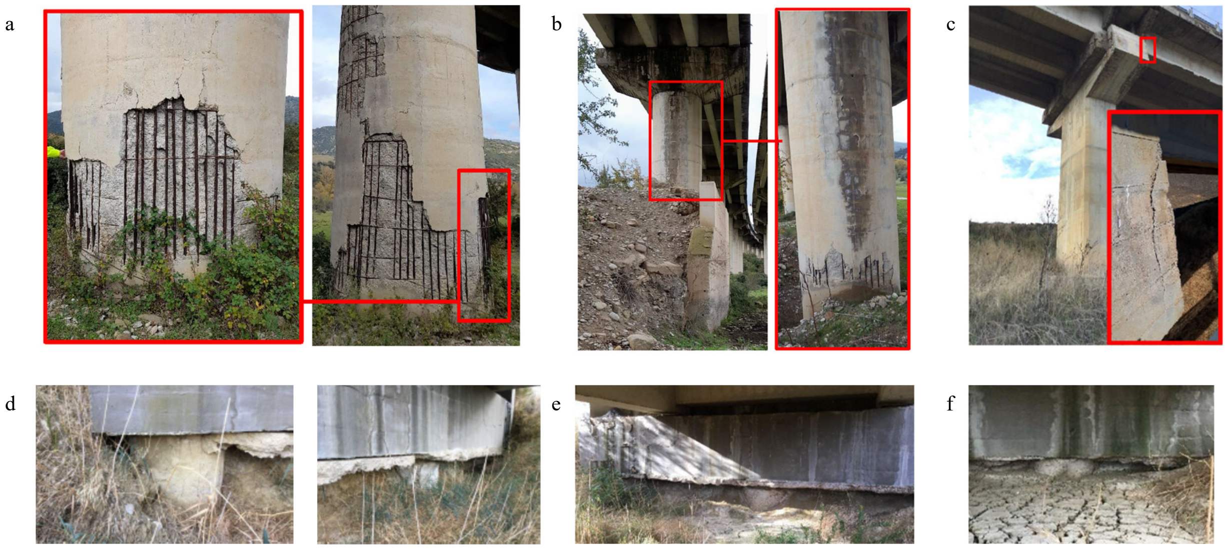

Fig. 9. Defects detected on substructure elements: a)-b) oxidized and/or corroded bars; c) cracks; d), e) and f) foundations scouring.

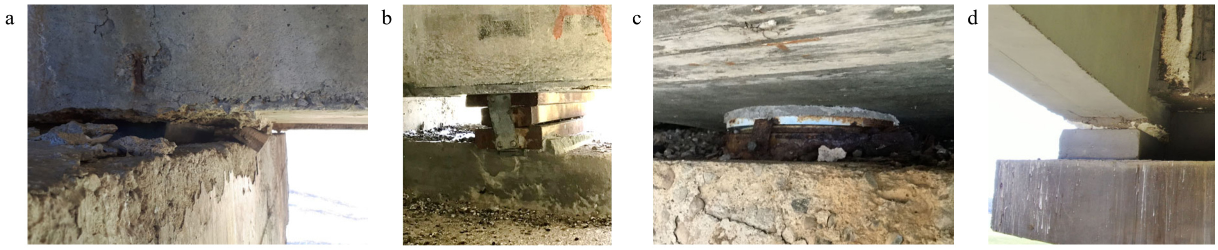

Fig. 10. Supports principal defects: (a) neoprene crushing/leakage; (b) small concrete supports; (c) Teflon deterioration; (d) Out-of-plumb.

4. Conclusion

This work provides a preliminary overview of a bridges stock belonging to a territorial case study. Main defects emerged during the inspections campaign conducted according to Italian Guidelines for Bridges have been shown and commented. Frequent defects surveyed are mainly due to the wear over time, since the bridges examined are really old. These defects during the bridge life time are in many cases pronounced by an incorrect road platform rainwater drainage, that may become important leading the bridge to a "high defect level". However, it has been noted that these defects, if occur, are localized only in few elements, making much easier to define an intervention plan. As for PCBs, where spy defects were detected (such as degraded cable sheaths and oxidized wires), special inspections were also planned. They are necessary for performing, coherently with the Italian Guidelines for bridges, refined evaluations of Level 4, taking also into account the hydro-geological context and the related in-situ tests campaign (if required).

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