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Half-joints degradation: analysis of some case studies

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Abstract

Existing Reinforced Concrete (RC) bridges, due to their age, are very often affected by significant deterioration phenomena, also intensified by lack of maintenance, which strongly reduces their strength with respect to the design load combinations.
In particular, half-joints were widely used in the RC bridge typology until the end of the 20th century. As well known, due to the static scheme adopted, and recurrent failure due to fragile mechanisms, to date these elements are recognized as critical, since their strength is particularly affected by degradation frequently provoked by erosion caused by rainwater infiltration from the roadway. This phenomenon, definitively, leads to a marked concrete cover reduction and corrosion of the reinforcing bars.
This paper deals with the analysis of certain types of half-joints employed in existing reinforced concrete bridges. To this scope, some case studies are illustrated and discussed to highlight weakness points of the typologies analyzed and causes of defects observed.

Keywords: reinforced concrete bridges; half-joints; deterioration; structural defect.

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1. Introduction

Gerber beam bridges represent one of the bridge typologies massively adopted Italy since 1960, where usually Prestressed Concrete Beams (PCBs) are also present. In this typology, applied for the first time by engineer Gottfried Heinrich Gerber in the 19th century, deck continuous beams are subdivided in several hinged parts, making some of them simply supported beams connected to cantilever beams. With this solution, a deck with a statically determined behavior is obtained (i.e. isostatic), not influenced by any foundation settlement or thermal distortion, permitting also to build bridge with a considerable span. Moreover, the bridge deck over the suspended span may be constructed off-site, improving its quality, and reducing construction time and related costs.

In Gerber beam bridges a crucial role is played by hinge connection, realized at each beam end by means of a half-joint (also commonly indicated as Gerber saddle, or dapped-end), coupled with the one of adjacent beam. The name ‘half-joint’ stems from the fact that coupling is made by a pair of inverted corbels protruding at the end beams (usually also indicated as a nib) for a length of approximately half of the overall girder as shown in Fig. 1 (Desnerck, Valerio, et al., 2018). Moreover, half-joint can be classified into two different typologies, namely short half- and slender half-joints, lying the difference in the nibs protruding length (MIT, 2020).

To date it is largely recognized that half-joint is difficult to be maintained and inspected. This is mainly due to its geometric configuration, making impossible to have an internal access within the joint, that is however the most vulnerable part to deterioration. Water seepage from the roadbed platform, containing also deicing salts in the winter, may deteriorate concrete and corrode reinforcing bars, accelerated also by water stagnation. Under these conditions, half-joint integrity may rapidly decrease leading to brittle collapses, too.

To this it should be added that specific standards with provisions on half-joint correct design were completely missing in the past. Moreover, it has been demonstrated that half-joints failure behavior with the related cracks pattern is strictly dependent on the steel reinforcement layout (Desnerck, Lees, et al., 2018). Most frequent cracks may occur: horizontally, running along the top and bottom reinforcement or within the nibs; vertically, owing to bending moment or along corroded stirrups; diagonally, due to shear.

Owing to these disadvantages, attention of scientific community and managers in studying and monitoring half-joints is increasing more and more. Recently, Ministerial Decree 17/12/2020 no. 578 issued by the Ministry of Infrastructure and Transport (MIT, 2020), “*Italian Guidelines for risk classification and management, safety assessment and monitoring of existing bridges*”, recognizes half-joints as critical elements to which pay particular attention. Therefore, accurate visual inspections become essential for monitoring the current deterioration status of these elements, followed by special inspections for detecting any possible inner defect that visual inspection may not reveal.

In order to improve knowledge of existing half-joints, in this study several case studies are analyzed and commented. In particular, a sample of no. 15 existing Reinforced Concrete (RC) Italian bridges are taken into account focusing on the current state of their half-joints. The investigated sample includes bridges of different construction typology and strategic relevance, belonging to different geographical areas and built in different historical periods.

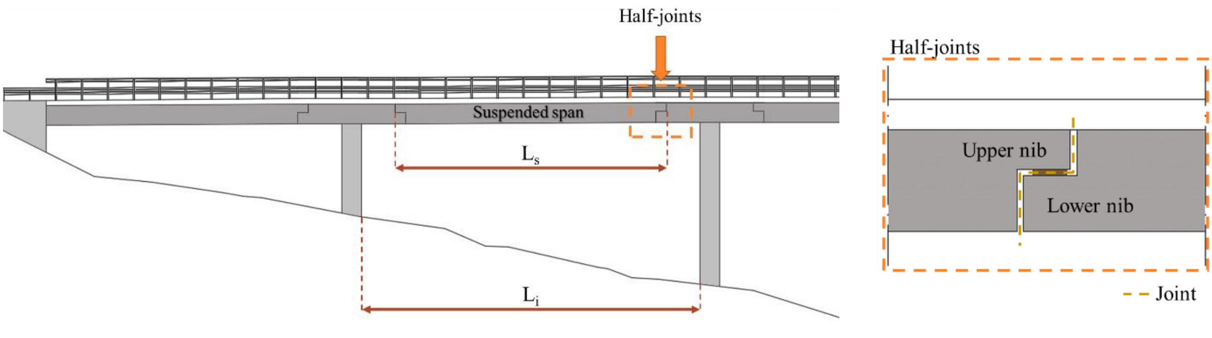

Fig. 1. Reinforced Concrete half-joints and relevant details.

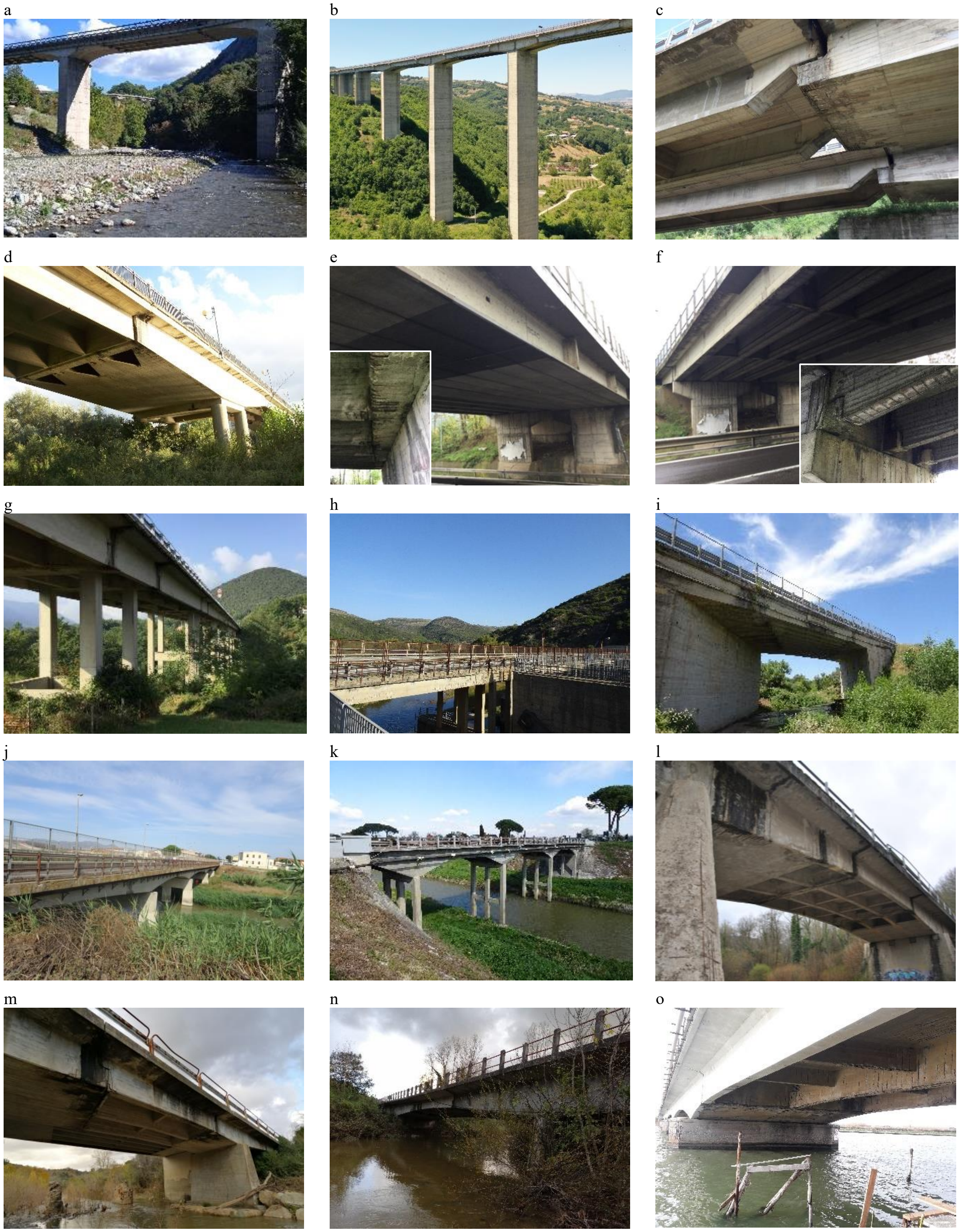

Fig. 2. (a) – (o) Bridges considered in this study.

At first, the bridges sample is briefly described by highlighting similarities and differences between the various bridges, classifying them by serving road, design year, and construction typology. Following this, defects detected on half-joints of these bridges are identified and grouped, and their occurrence on the sample considered is estimated.

Finally, possible causes triggering the defects detected are evaluated in order to identify priorities and to plan intervention required.

2. Case studies

This study aims at investigating a half-joints series belonging to a sample of existing RC bridges. In particular, in this study a total of no. 15 Italian bridges serving no. 1 Highway Junctions (HJs – no. 2 bridges), no. 3 State Roads (SRs – no. 4 bridges) and no. 7 Provincial Roads (PRs – no. 9 bridges) and realized between 1960 and 2000 are considered. Some pictures of the bridges considered are reported in Fig. 2.

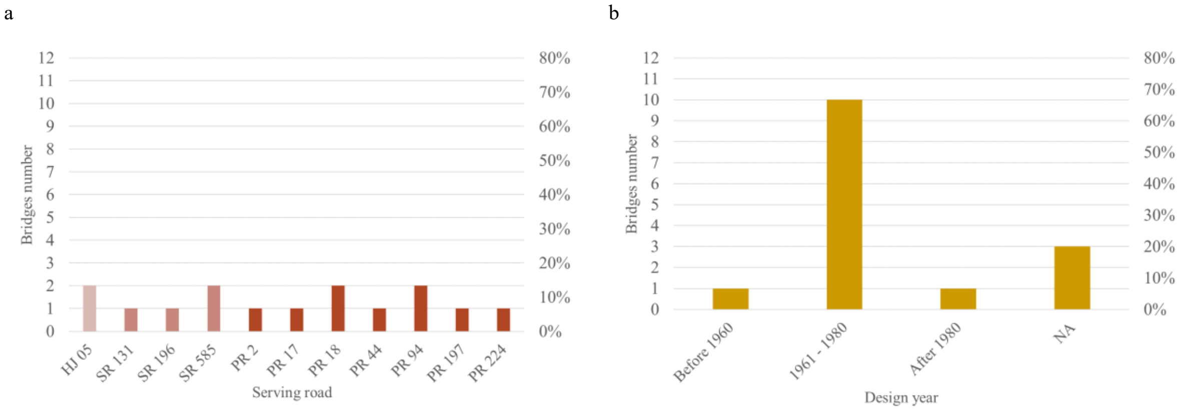

Fig. 3. (a) Bridges number per Highway Junction (HJ), State Road (SR) and Provincial Road (PR); (b) bridges number per several design year ranges.

Table 1. Principal information for the investigated bridges.

Bridge	Bridge spans number	Li (m)	Ls (m)	Deck typology	G5 defect on one or more half-joints
a	7	34	24	Post-tensioned RC beams	No
b	23x2	from 28 to 75	from 30 to 54	Post-tensioned RC beams	Yes
c	3x2	181	42	Post-tensioned RC beams and RC box girders	Yes
d	3	40	21	RC beams	Yes
e	3	8	7,25	RC beams	Yes
f	3	8	7,25	RC beams	Yes
g	9	21	20	RC beams	Yes
h	6	21	19	RC beams	Yes
i	1	29	18	RC beams	Yes
j	5	23	16	RC beams	Yes
k	5	16	8	RC beams	No
l	3	25	12	RC beams	Yes
m	3x2	15	9	RC beams	Yes
n	3	28	10	RC beams	No
o	5	19	13	RC beams	Yes

At first, it is important to describe the main properties of the considered bridges, for better identifying the half-joints typologies under consideration. Details of the studied bridges are reported in Fig. 3 and Table 1. In particular, Fig. 3a reports the serving road, indicative of the bridge strategic importance. While Fig. 3b depicts the bridges number distributed in four design years ranges, that are: before 1960, 1961-1980, after 1980, and Not Available (NA). In the considered sample, no. 10 bridges were mainly designed between 1961 and 1980, corresponding to a value of 67% of the sample examined. According to past Italian standards, they were designed following the Circular of Ministry of Public Works 14/02/1962 no. 384 (M.P.W., 1962). Moreover, in the sample one bridge was designed before 1960 (7%), while the other one after 1980 (7%). As for no. 3 bridges (about 20%), design year is not available.

Table 1 indicates a label assigned to each bridge (from *a* to *o*), bridge spans number, span inner length including simple supported beams with half-joints (L_i, Fig. 1), total length of suspended span (L_s, Fig. 1), deck typology of suspended beams, and presence (if any) of a 'high gravity' (G5) defect on one or more half-joints, in accordance with the Italian Guidelines (MIT, 2020). As it is possible to note all bridges are different for spans number and length (L_i and L_s). Moreover, only no. 3 bridges have suspended beams in PCBs or prestressed box girders with post-tensioned cables (*Bridges a, b, c* - Fig. 2a-c) giving the presence of considerable spans. While the remaining no. 12 bridges have suspended beams in ordinary RC.

As for the cantilevers, except for *Bridges e, f, g* and *h* (Fig. 2e, f, g, h), they have a RC box girder having also, in some case, a section with variable height. In no. 7 bridges, that are *Bridges* from *a* to *d* and *i, l,* and *n* (Fig. 2a-d, i, l, n) the considerable bridge span lengths is covered by long RC cantilevers (≥ 5 m). While, in the remaining bridges, *Bridges e-h, j, k, m, o* (Fig. 2 *e-h, j, k, m, o*), RC cantilevers have a short length (< 5 m).

As far as the half-joints' typology, in all bridges analyzed lower nibs are always connected with a cross-beams, making possible for each bridge the visual inspection only of lower nibs intrados, and of coupled half-joints lateral surfaces on external deck beams. On the contrary, half-joints were fully inspectable only in the case of *Bridge e* (Fig. 2e) where the cross-beam is absent.

Finally, according to Italian Guidelines, only in no. 3 bridges, that are *Bridges a, k, n* (Fig. 2a, k, n) no defect of 'high gravity' G5 was detected on half-joints. While, in the case of remaining ones, G5 defects were found. Details about the defects detected on the half-joints are discussed in the next paragraph.

3. Defects classification

In accordance with Italian Guidelines for existing bridges (MIT, 2020), accurate knowledge of existing bridges is carried out involving 5 analysis levels of increasing complexity and information needs. The first three assessment levels (*Level 0*, *Level 1*, and *Level 2*) permit to obtain a risk ranking at a territorial level. Then, for bridges deserving attention, more refined numerical analyses and monitor plans have to be carried out. *Level 0* consists of bridges census starting from the original documentation available. *Level 1* involves bridge in-situ inspection, for assessing its conservation status and detecting any possible defect, by compiling the inspection forms. *Level 2* classifies bridges providing a risk level (ranging from low to high), indicated as Class of Attention (CoA), by combining Structural and Foundational (SF-CoA), Seismic (S-CoA), Hydraulic (H-CoA) and Landslides (L-CoA) risk levels.

During the inspection phase, it is possible to identify deterioration phenomena and defects on half-joints, to be gathered on a specific form, where defects intensity (*K1*) and extension (*K2*) may be reported. Each defect detected is associated with a G-weight ranging from G1 to G5, where G1 corresponds to the lowest defect gravity and G5 to the highest one. The presence of defects of gravity G5 of any intensity (*K2*) on critical elements such as half-joints, leads to a high structural risk class (High SF-CoA), owing to a high defect level and, consequently, a high SF vulnerability. In addition, independently on the CoA referred to the other risks involved in the methodology (Seismic, Hydraulic, and Landslides), the Overall Class of Attention (O-CoA) to assign to the bridge results High. For this reason, the bridge should be directly subjected to an accurate assessment of Level 4. It is inferred that, during inspection, it is very easy to recognize whether the considered bridge may result or not in a High O-CoA, simply by observing the half-joints' conditions. Level 4 assessment involves refined analysis on the bridge by means of numerical models, requiring also the knowledge improvement through in-situ tests investigating the current conservation status of the bridge elements and their main mechanical properties. In this phase, also more refined investigations on hydraulic and landslides aspects may be conducted (if required).

As for the defects detected on half-joints, in this study they are identified and grouped, as illustrated in Table 2. In detail, the defects reported are in accordance with the Italian Guidelines classification, reporting only those detected on the examined half-joints. Whereas, groups proposed refer to material and degradation cause. A preliminary sub-division may be the following: *steel deterioration*, c*oncrete deterioration*, s*teel* c*lear integrity loss* and *concrete clear integrity loss*.

Table 2. Detected defects and defects group proposed.

	Defect detected	Defects group
	• Exposed and oxidized stirrups • Oxidized and/or corroded bars	Steel deterioration
	• Stirrups rupture	Steel clear integrity loss
	• Concrete cover detachment • Active humidity stains • Washed out and degraded concrete • Passive humidity stains • Drip marks • Washed out/degraded concrete beam end section • Water stagnation • Cracks at the stirrups	Concrete deterioration
	• Diagonal cracks	Concrete clear integrity loss

In Fig. 4 the defects percentages found on half-joints are plotted. They are calculated in the following way. At first, since the inspection forms of all bridges are available, half-joints defects found in all bridges are identified. In this way a sample of no. 101 defects (records) corresponding to the ones indicated in the Italian Guidelines forms is obtained. Then, in order to evaluate their recurrence coincident defects are counted. The defects found and their recurrence is plotted in the histogram of Fig. 4a. Once defects are identified, they are grouped according to material (steel and concrete) and degradation cause, as previously mentioned. Fig. 4b shows the groups percentage obtained. It should be noted that all percentages reported in Fig. 4 are calculated by referring to no. 101 defects found.

As it is possible to note in Fig. 4a, the main defects occurred with the related gravity of defect (MIT, 2020) are: *exposed and oxidized stirrups* (G3) with 14%; *concrete cover detachment* (G2), *active humidity stains* (G3) and w*ashed out and degraded concrete* (G3) with 13%*; oxidized and/or corroded bars* (G5) with 12%; *passive humidity stains* (G1) and *drip marks* (G3) with 11%. Note that most of detected defects are mainly due to water infiltration (defects from no. 1 to no. 9 of Fig. 4a, having in total a percentage of 95%.

As for the groups division, Fig. 4b shows that defects group owing to *concrete deterioration* is the most frequent one in the cases analyzed with a percentage of 71%, following by *steel deterioration* with 26%, *steel clear integrity loss* with 2% and *concrete clear integrity loss* with 1%.

a b

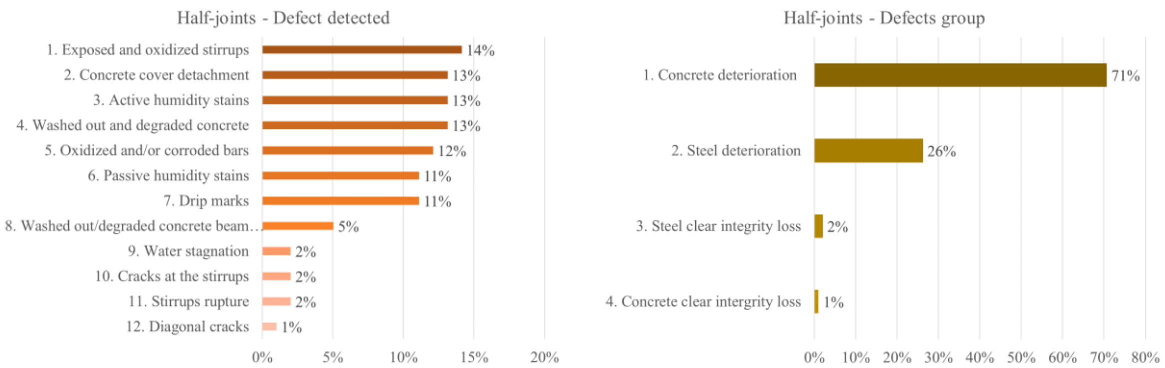

Fig. 4. Recurring defect percentages for half-joints: (a) defects detected; (b) defects group.

More in detail, Fig. 5 depicts pictures of the current status of some half-joints, having a marked deterioration. In particular, those reported from Fig. 5a to Fig. 5d are mostly affected by water infiltration from the expansion joints, but they differ in the defect extension. In fact, Fig. 5a reports defects due to water action with also *diagonal cracks* probably due to traffic loads. On the other hand, Fig. 5b, Fig. 5c and Fig. 5d show half-joints affected by *oxidized and/or corroded bars*, *exposed and oxidized stirrups*, *drip marks* and *active/passive humidity stains* propagating along the entire upper and lower nibs length. It is pointed out that half-joint in Fig. 5d also reports the *water stagnation* defect, since biological patina proliferates along the whole joint. Fig. 5e and Fig. 5f report *stirrups rupture*, as well as a general degradation of concrete and reinforcement. Finally, Fig. 5f shows concrete cover detachment principally located on the half-joint lower nib edge.

It is important to note that all the defects reported in Fig. 5 lead to defects of gravity G5, coherently with the Italian Guidelines for existing bridges (MIT, 2020), and consequently, to High defect level, since half-joints are defined as 'critical elements'. Definitively, this implies a high SF vulnerability, and a High Overall Class of Attention (O-CoA) independently on other risks involved in the methodology (Seismic, Hydraulic, and Landslides). In the cases analyzed, 80% (Table 1) of the existing RC bridges analyzed have a defects of gravity G5, and therefore an O-CoA.

a b c d e f

Fig. 5. Half-joint defect on: (a) *Bridge b*; (b) *Bridge f*; (c) *Bridge g*; (d) *Bridge l*; (e) *Bridge h*; (f) *Bridge j*.

4. Conclusions

In this work defects surveyed on half-joints belonging to a sample of no. 15 Italian RC bridges serving Highway Junctions (HJs), State Roads (SRs) and Provincial Roads (PRs) have been analyzed and commented.

Defect analysis carried out has permitted to identify the most recurrent defects detected, classified according to Italian Guidelines for existing bridges, and to divide them into defects groups. Owing to the defects detected, the study carried out confirms that the half-joints are critical elements as defined by Italian Guidelines, showing always a significant defect status mainly provoked by water infiltration, accelerating steel and concrete deterioration. This leads to assign a defect of gravity G5 to half-joints and, therefore, to obtain a High Overall Class of Attention (O-CoA) independently on other risks taken into account by Italian Guidelines.

However, it should be noted that in-situ visual defect analysis of each half-joint is frequently not complete, since it may be conducted mainly on the visible surfaces of the lower nib. This may definitively lead also to extremely conservative, and therefore uneconomical, evaluations because the overall defect level assigned should depend also by the inner status of half-joints, that is very often inaccessible. Therefore, defects analysis of half-joint should be carefully conducted in order to evaluate the bridge defect level, from which its Overall Class of Attention (O-CoA) depends on. This may imply more refined evaluation through special inspections, such as, for instance, concrete drillings with endoscopies or, if necessary, also by a deck lifting requiring a traffic interruption.

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