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Degradation of steel footbridges with neglected inspection and maintenance

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Abstract

Upon representative case studies, the paper illustrates importance of management, maintenance and reconstruction of steel footbridges. Particularly inspection importance for timely discovering imperfections, potentially reducing safety and load carrying capacity are illustrated at effected investigations of actually common structural systems. The paper presents a summary of the findings and conclusions from diagnostic of seven steel footbridges. Focus is paid on the corrosion of structural steel and its influence on overall condition of footbridge structures.

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Keywords: Footbridge; steel suprestructures; diagnostics; corrosion; maintenece.

1. Introduction

Ensuring the safe operation and investment decisions requires a precise and regular inspections of existing bridges, [1]. The frequency and extensity of the control generally depends on the age, transport type and intensity, maintenance, and known defects. An administrator can define the frequency of inspections on the basis of abovementioned factors. One of the main tasks of the supervisory activities is to identify problematic elements and details before the degradation or defects could lead to the requirement of their replacement, [2]. Underestimated monitoring usually results in poor condition of footbridges, requiring major repairs and reconstruction, [3]. The article presents a summary of the findings and conclusions from diagnostic of seven steel footbridges. Only the corrosion as a result of inadequate maintenance

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is the issue in the below chapters. Age of presented footbridges and corrosive environment of their location are very similar in all cases. Though, five footbridges are over rivers and two structures bridge railway lines. Some findings concerning footbridges numbered as #1 and #5 in the study have already been presented in [4].

2. Brief overview of footbridges and their condition

2.1. Two footbridges over railway lines

The first footbridge (#1) cross the railway yard of railway station, Fig. 1a. From the static point of view it is a continuous eight span girder steel superstructure consist on steel piers. The length of spans are 12.20 + 16.00 + 15.10 + 14.45 + 10.50 + 10.20 + 13.30 + 7.80 meters. The superstructure is formed by a pair of main girders connected through crossbeams and horizontal bracings.

Some of piers are affected by uniform corrosion, but without significant losses, Fig 1b. However, in the case of two piers large-scale crevice corrosion formatted due to water penetration into the gap between the plate and rolled sections where improper plug welds was used to create closed cross-section of the pier columns, Fig. 1c. Crevice corrosion is also evident between plates of bearings on the top of nearly all piers.

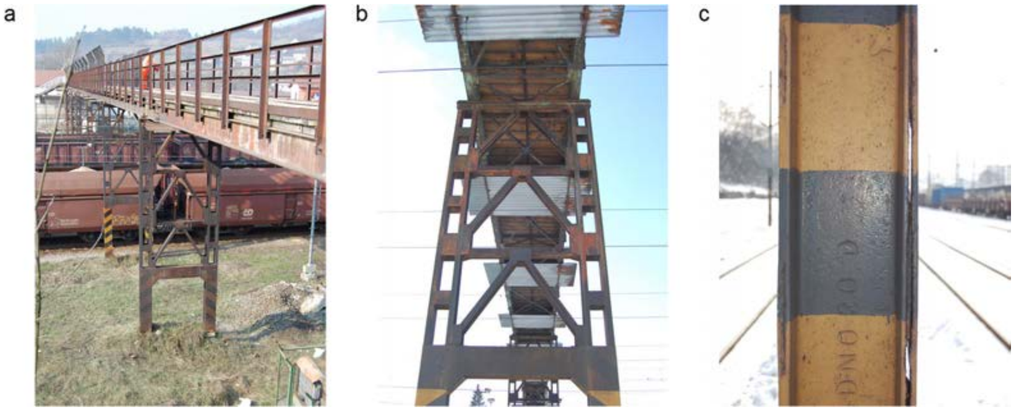

Fig. 1. (a) overall view of the footbridge #1; (b) bottom view; (c) crevice corrosion of the pier columns.

Definitely, the most affected by corrosion are the bridge deck elements, especially in older part of the footbridge. Corrosive losses on the crossbeams are significant and it is only a matter of time when their condition become emergency. Completely degraded by the corrosion are many members of horizontal bracings. Actually, some members are totally destroyed and the rest of them cannot satisfy expected static function, Fig. 2a. Application of road-spreading salt in winter leads to degradation of the individual parts of the side stairway. From the bottom view is evident degradation of steel plates creating stair steps, especially, Fig. 2b.

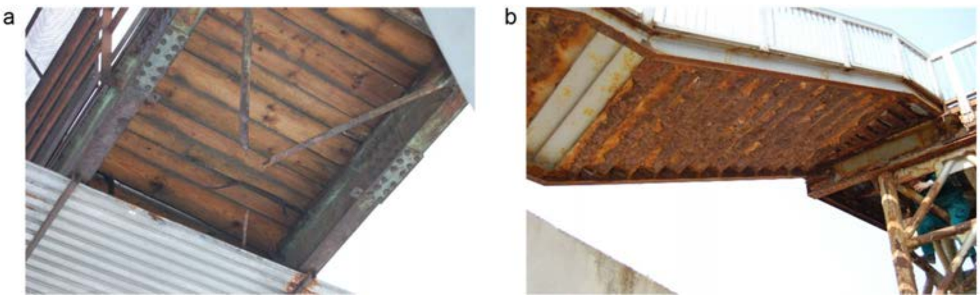

Fig. 2. (a) corrosion of deck members; (b) corroded steps of the staircase.

Also the second footbridge (#2) structure should serve to pedestrians for crossing three railway lines, Fig. 3a. The main superstructure consist of two main plate girders with open deck. The main girders acted as simply supported beams of span 16.80 meters with 2.15 m long cantilevers on both side. One steel pier is fixed in longitudinal direction of the footbridge to the footing foundation, while the second pier is acting as hinged column. On the each side of main structure overhangs are supported steel structures of stairways of similar conception as main superstructure.

Corrosion of main girders is significant only in some typical details, e.g. in the joint of crossbeam or on the top surface of bottom flange from the inner side. As usually, worse condition can be seen at bridge deck elements. The surface of all crossbeams are highly corroded. In some cases, the area of beams' web is reduced more than 50%.

Horizontal bracings of the deck is in emergency condition. Actually, several bracings members are missing and the rest of them are in insufficient condition, Fig. 3b.

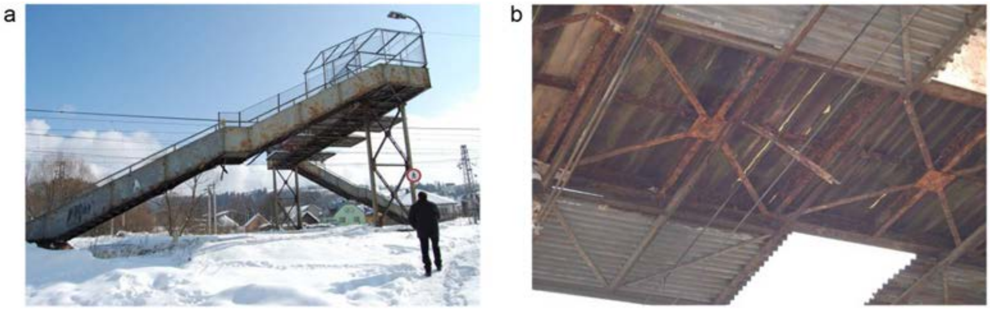

Fig. 3. (a) view of the footbridge #2; (b) corrosion of deck members and damaged horizontal bracing.

Stairway steps and landings are made of steel plates and they are all attacked by corrosion of the highest degree, locally the corrosion progress through whole thickness of steel plates, Fig. 4a. The most important problem is the corrosion of the bottom flange of the stairway main girders. In the most critical place, the corrosive losses reach such a great intension that only about 25% of the flange area remained, Fig. 4b. All horizontal stiffening rods of the stairways are heavily corroded. Some bracing members are already annihilated.

It can be stated that this footbridge is dangerous for pedestrians and for railway traffic underneath, as well.

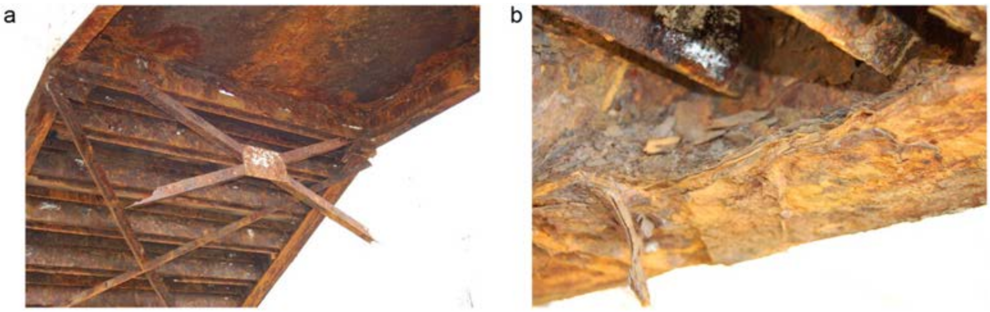

Fig. 4. (a) corroded stairway steps and bracings, (b) bottom flange of stairway girder.

2.2. Two suspension footbridges in town areas

The footbridge #3 is located in small town over local stream to facilitate residents of nearby housing estate reaching town center. The suspension steel structure (see Fig. 5a) was designed with a single pylon on one side and with a main girder with a hinge in the middle of the span. The deck consist of transversal crossbeams and concrete deck casted into corrugated sheets. The five cables with spans 38.40 +17.00 m on both bridge side go through a saddle on the A-shaped steel pylon.

From the top, no obvious mechanical damage or corrosion attacks are visible at the main structural steel members of the bridge. From the bottom, however, significant damages caused by corrosion are evident at the steel parts of bridge deck. Inner side of the bottom flanges of main girders are considerably affected by corrosive action, especially in the connection points of crossbeams and bracing members. The end crossbeam above bearings are highly attacked by corrosion, Fig. 5b. Similarly, the same very bad condition are evident in all intermediate crossbeams, as well. For instance, at the Fig. 6a it is visible a hole in the crossbeam web caused by severe corrosion process.

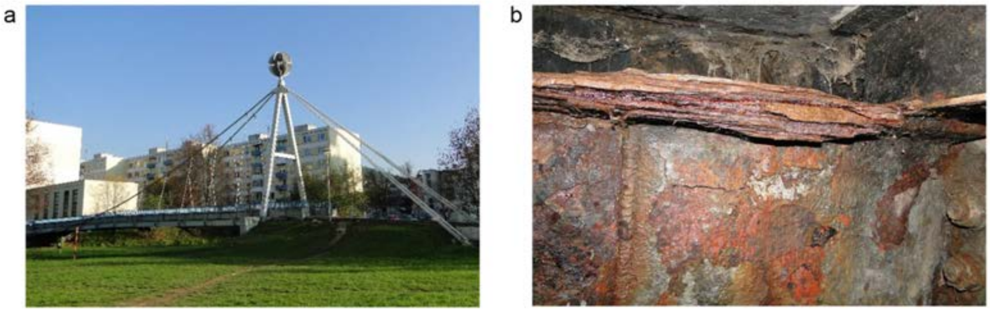

Fig. 5. (a) overall view of the footbridge #3, (b) top flange of end crossbeam.

All corrugated steel sheets are totally destroyed. The thickness of sheets in large areas of the deck is reduced to nearly zero. Actually, in the most places the sheets hang from the deck, Fig. 6b. Very poor condition of the bridge deck is also documented by completely missing ribs of concrete deck, where the steel sheets have already fallen.

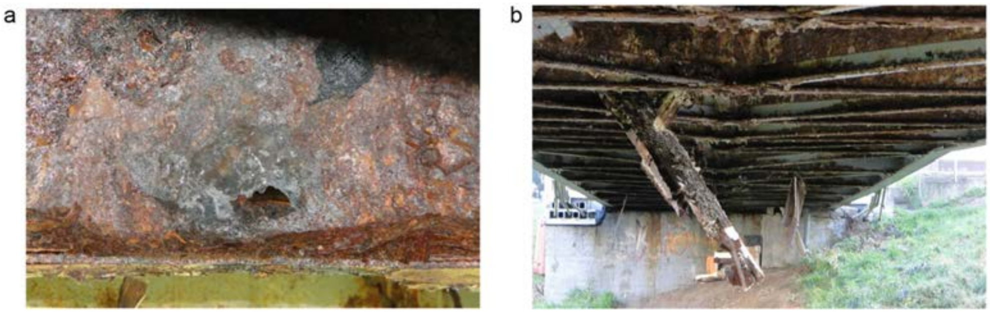

Fig. 6. (a) corroded through, (b) top flange of end crossbeam.

The fourth footbridge (#4) connects the housing estate with the rest of town over middle-wide river. The superstructure is designed as a steel suspension structure with short side spans. To ensure spatial and horizontal stability of the dynamically soft structural type, additional stabilizing collateral cables were applied, Fig. 7a. The substructure consists of anchor blocks carrying cables, pylons and their foundations associated with anchor blocks of stabilizing cables, and by end abutments with short wing walls. From the static point of view, the footbridge is acting as a suspension structure with cables spans of 25.00 + 100.00 + 25.00 m, Fig. 7a. Four parallel main cables went through the steel pylons shaped as upside-down Y-letter. The open member steel deck of three spans with lengths 10.00 + 100.00 + 10.00 m has the mid-span suspended on the main carrying cables thought cross frames in 10 m long distances.

Overall condition of the footbridge is good. At the cables and pylons only slight corrosion can be found in some details, where moisture and dust can accumulate. Because of longitudinal slopes of the deck, water is drained from the deck top surface very quickly. Thus, the members of footbridge deck are in much better condition than in former three footbridges.

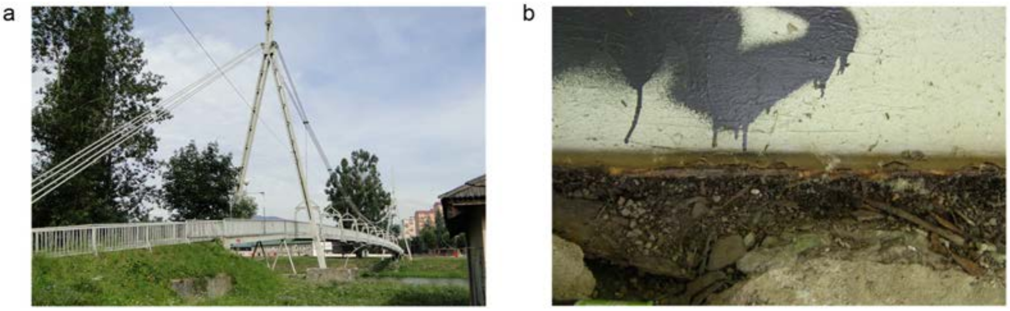

Fig. 7. (a) overall view of the footbridge #4; (b) corrosion of bearing and of bottom flange of support crossbeam.

Local corrosion of middle intension occurs only in details of joints between the deck members. Extensive corrosion occurs at bearings and at parts of end crossbeams above supports, Fig. 7b. The intensive corrosion is caused by very bad solution applied to drainage of support areas of the abutments.

2.3. Three footbridges over local river at village area

Last three footbridges, numbered as #5, #6 and #7 in the presented study are located in the same village in the north of country. They are the typical representatives of conceptions used in Slovakia for crossing small rivers by using steel footbridges.

Thus, the fifth footbridge in this paper is a single span cable-stayed structure with span of 38.95 m. The main girders are made of castellated beams, Fig. 8a.

The sixth structure in the same village consists of two spans. The main span 38.15 m long is again of cable-stayed conception, but with truss main girders, Fig. 9a. The approach span on one side of the bridge has length of 8.90 m with plate main girders stiffed by tie chord.

Finally, in the last one superstructure #7 the same static concept was applied as in the case of smaller span of second mentioned footbridge in this village numbered as #6. The curved I-shaped main girders of span 38.00 meters are stiffed by bottom tie chords, Fig. 10a.

In the case of cable stayed spans, main carrying cables support the main girders in one third of a suspended span. The cables are fixed behind the pylons into anchoring blocks.

The decks are made of hot rolled crossbeams and longitudinal beams, respectively with the steel sheets on their top flanges which serve as walkable surface. Longitudinal horizontal truss bracing stiffs the superstructures.

All three footbridges have some defects caused by floods and the floating debris, but by vandals as well. Nevertheless, from the corrosion point of view, the cables, pylons and main girders are attacked mainly by slight form of corrosion, mostly at local and connection places. In the case of pylons, the corrosion occurs between the plug welds of box cross-section manufactured from two U-profiles and covering steel plates.

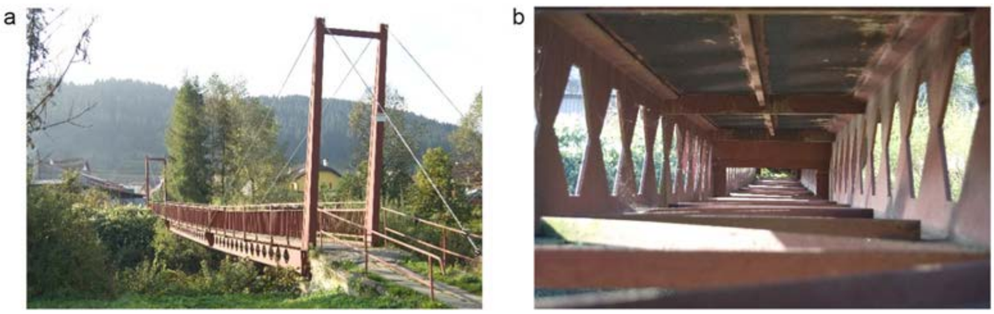

Fig. 8. (a) overall view of the footbridge #5; (b) castellated main girders and deck bracings.

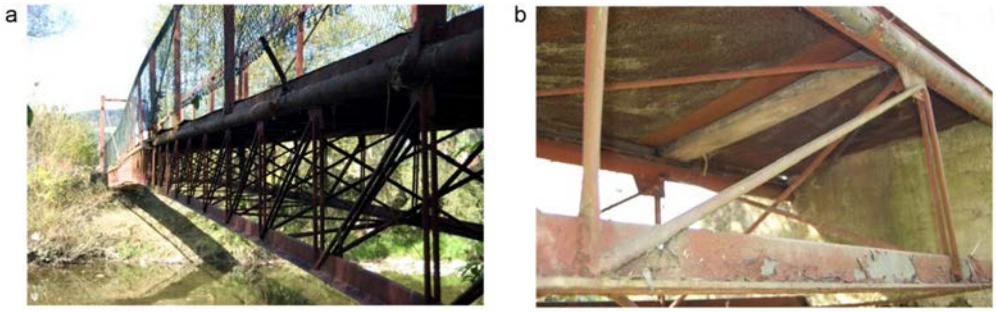

Fig. 9. (a) overall view of the footbridge #6; (b) condition main truss girder and deck plates.

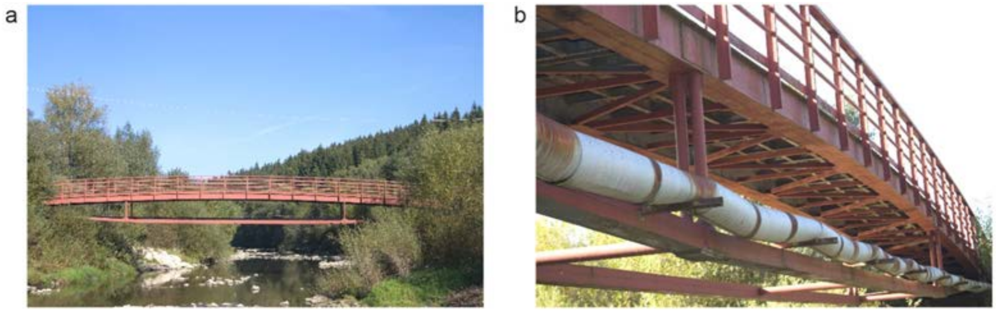

Fig. 10. (a) overall view of the footbridge #7; (b) detailed view of the superstructure.

From the Figs. 8b, 9b and 10b, as well, it is evident that steel sheets creating the deck surface are affected by uniform corrosion from the bottom due to humidity from the water. Similarly, all crossbeams and bracing members are of the same level of corrosion. Visible corrosion are of low intensity without influence on static function. Higher grade of corrosion can be found in support areas at the abutments. It results in higher corrosive losses of bearing in the case of footbridge #5. Within spans, the main girders of both structures are without remarkable impact of corrosion, only paint layers are unstick in some places, Fig. 9b.

3. Summary of corrosion findings

In the Table 1, a brief summarization of footbridges is presented for better identification.

Table 1. Ranking for overall condition, effects of corrosion and inspection level

Footbridge	Locality	Obstacle	Type of main superstructure	Type of deck	Administrator	Age
#1	Town center	Railway station	Plate girder	Member open	Town	49 years
#2	Town	Railway lines	Plate girder	Member	Town	49 years
#3	Town center	Local stream	Suspension + plate girder	Member	Town	42 years
#4	Small town	River	Suspension + plate girder	Member	Town	45 years
#5	Village	Small river	Cable-stayed + castellated girder	Member	Village	45 years
#6	Village	Small river	Cable-stayed + truss girder	Member	Village	40 years
#7	Village	Small river	Plate girder stiffed with tie chord	Member	Village	39 years

To estimate the level of overall technical condition of bridge structures several different approaches can be applied. In the case of presented study, the principles and classification according to guidelines [5, 6] valid in Slovakia were used. For determining the corrosive environment the principles of standards [7] were applied. Except overall assessment, the principles were applied for each type of structural elements, as well. This separation allow administrator to identify the most critical components and to determine priorities, when the budget do not allow complex renovation or even reconstruction of the whole footbridge. For comparison, seven class for overall condition were used. Six intensities for corrosion were applied, while five levels of inspection are recognized, see Table 2.

Table 2. Ranking for overall condition, effects of corrosion and inspection level

Classes for overall condition		Corrosion intensity		Inspection regularity and level	
I	Perfect	1	Negligible	A	Regular expert
II	Very good	2	Low	B	Regular laic + occasional expert
III	Good	3	Moderate	C	Regular laic
IV	Satisfactory	4	Medium	D	Occasional laic
V	Bad	5	Extensive	E	No inspections
VI	Very bad	6	Devastating		
VII	Emergency				

Overview given in Table 3 summarizes the condition of seven above-mentioned superstructures of footbridges from the corrosion degradation point of view. From the comparison it can be seen that very bad and emergency conditions are in coincidence with poor inspection. With the regularity and professionally of inspection performed during exploitation, the probability of early diagnostics of possible defects rises.

Table 3. Comparison of corrosion intensity of individual parts of steel structures

Footbridge identification		**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**
Corrosion atmosphere type		C3	C3	C3	C2 - C3	C2	C2	C2
Corrosion intensity of structural parts	Main girders	3	3	4	2	2	3	3
	Bearings	5	5	5	4	5	-	3
	Piers or Pylons	5	3	3	1	3	3	-
	Cables	-	-	2	2	2	2	-
	Crossbeams	5	6	5	3	3	3	3
	Bracings	6	6	5	-	-	3	4
	Corrugated sheets	3	-	6	-	-	-	-
	Staircase girders	4	6	-	-	-	-	-
	Staircase steps	5	6	-	-	-	-	-
	Deck plates	4	6	-	-	3	3	3
Condition class based on corrosion damage		VI - VII	VII	V-VI	IV	IV	IV	IV
Inspection level		E	E	D	B	C	C	C
Overall condition (not only corrosion)		VI	VII	VI	IV	V	V	V

Different degrees of corrosion on the individual parts of the footbridges are the consequence of bad readiness and inability of the administrator to maintenance, and may be, of his financial capabilities, as well. Bad general practice showed above led to significantly underestimated corrosion protection and emergency condition.

From presented diagnostics it is evident that neglected inspection and maintenance may results into early termination of the exploitation. Consequent reconstruction or even replacement of the structure is much more costly than common and regular maintenance. On the basis of diagnostic survey and the impact of mapped defects to the static functions a plan of maintenance and repair were suggested to footbridges' administrators or owners.

4. Conclusions

On the corrosion defects of seven different footbridge, the importance of periodical inspections and common maintenance is concluded in the article. Systematic management of bridges is still at the beginning in the smaller towns and villages. Of course, the big role played also a fact that most of municipalities has become the owner and administrator of many structures in very bad condition on the basis of government decision.

Described severe and less severe defects will need repair or reconstruction adequately to the age of each structure and underestimated maintenance during service. In the future, administrators have to learn, that only regular periodic inspection and basic routine maintenance can ensure required lifetime and save a lot of money, of course. From the corrosion point of view, even laics can detect problems in their early stages. The activities involving visual control of the paint system and periodical cleaning several critical places and details from litter and vegetation can have significant influence on overall condition of a footbridge structure. The bridge management should be a continuous activity of the administrator to ensure the safety of the public.

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