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MEETING POINT OF THE SCIENCE AND PRACTICE IN THE FIELDS OF CORROSION, MATERIALS AND ENVIRONMENTAL PROTECTION

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The role of drainage systems in the prevention of material degradation of bridge structures

Uloga sistema za odvodnjavanje u prevenciji degradacije materijala konstrukcija mostova

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Abstract

Abstract: The paper gives an illustrative presentation of damage to the material of bridge structures due to failure to maintain the system for drainage of bridges. Damage is caused by mechanical erosion and abrasion or by chemical means, corrosion or a combination of the above. The cause of the damage is related to the retention of salted water on the road and other surfaces of the bridge structure, as well as wetting of the side and ceiling surfaces by flooding due to the non-functionality of the water drainage system from the bridge. The possibility of taking measures to prevent such phenomena and reduce them to a minimum is also considered.
Keywords: *Bridges; Bridge drainage system; Concrete; Steel; Asphalt; Degradation*

Izvod

Izvod: U radu je dat ilustrativni prikaz oštećenja materijala konstrukcija mostova zbog neodržavanja sistema za odvodnjavanje mostova. Oštećenja su izazvana mehanički erozijom i abrazijom ili hemijskim putem, korozijom ili kombinacijom navedenog. Uzrok oštećenja se povezuje sa zadržavanjem osoljene vode na kolovozu i na drugim površinama konstrukcije mosta, kao i kvašenja bočnih i plafonskih površina podlivanjem zbog nefunkcionalnosti sistema za odvođenje vode sa mosta. Razmotrena je i mogućnost preduzimanja mera da se ovakve pojave preventivno spreče i svedu na najmanju moguću meru.
Ključne reči: *Mostovi; Sistem za odvodnjavanje mostova; Beton; Čelik; Asfalt; Degradacija*

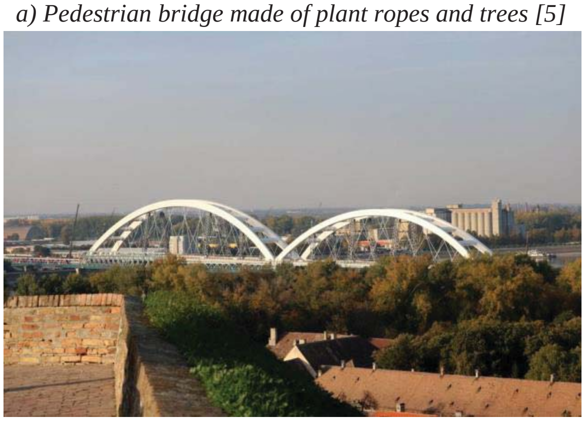
Introduction

Bridges are buildings made of different materials and are used for bridging roads over obstacles, especially over watercourses. They can be pedestrian, bicycle, road, railway or a combination of the above, Fig.1. They differ according to the construction and the type of main building material. For the choice of construction, the conditions of foundation, aesthetic value, the minimum required span, the height of the bridge as well as the anticipated load are important.

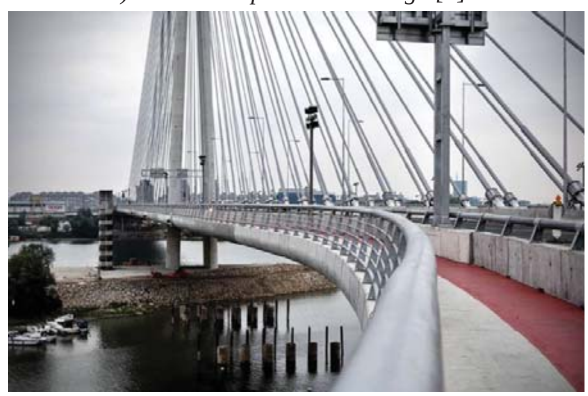
In the current conditions, the most common materials for making bridges are concrete, steel, their combination in the form of reinforced and prestressed concrete, covered with a layer of asphalt. The mentioned layer of asphalt is most exposed to the atmospheres that need to be removed from the bridge by the drainage and sewerage system in the prescribed manner and prevent water retention in any part of the bridge. The main disadvantage of these materials for the construction of bridge structures is the sensitivity to the occurrence of degradation in aggressive environments [1, 2]. The main types of degradation are rot, aging, abrasion, erosion and corrosion. Rotting and corrosion are largely overcome by adequate drainage and regular maintenance of the bridge and its drainage and sewerage system. It can be assumed that the maintenance of bridges costs about 2% of the value of bridge construction per year of operation. These are the experiences of developed western countries where maintaining bridges is a routine thing. Serbia and the countries of the region [3] do not belong to this group and it is only a matter of time before will pay the highest price [4] due to the negligent attitude towards this topic.

a) Pedestrian bridge made of plant ropes and trees [5]

b) Stone road pedestrian bridge [6]



c) Road railway metal concrete bridge [7]



d) Road railway pedestrian bicycle reinforced prestressed concrete bridge with steel ropes [8]

Figure 1. *Bridge constructions of different materials and various applications*

Operational characteristics of bridges from the aspect of corrosion and damage

External influences, which represent the greatest danger to the materials of bridge structures, include: chemical reaction of water-environment and substances dissolved in it, alternating action of temperature change (leading to dilatation changes in the material), alternating wetting and drying of materials and dissolved salts in contaminated water and its evaporation. Exhaust gases on bridges with road traffic also have a influence. In addition to excess air, they contain mainly oxides of carbon, hydrogen and sulfur (carbon monoxide, carbon dioxide, water vapor and sulfur dioxide). Bridges with road traffic are especially exposed to salt in winter, which is used to melt snow and ice on the road. It should be mentioned that the concentration of water vapor above the river is always increased compared to other areas. The presence of water, even uncontaminated, can have a beneficial effect on material degradation. Therefore, it is necessary to remove water in any form from the bridge construction material as soon as possible. This is done by a bridge drainage system. When the drainage system does not work properly, water flows uncontrollably over the bridge structure, degrading the material from which the bridge was made and causing damage to the bridge. Damages can be classified into three categories. The first category is damage to the structure and columns that directly affect the load-bearing capacity and stability of the building as a whole, and these are:

- ✓ damage whose extent is such that the load-bearing capacity of the section is reduced and thus the object as a whole is endangered and
- ✓ damage whose extent does not indicate a reduced load-bearing capacity of the section, but the

progression is significant and accelerated, so it will happen in the foreseeable future.

The second category includes damage and defects in parts of the building and functional elements of the load-bearing structure and columns, which do not directly affect the load-bearing capacity and stability of the building as a whole, but the load-bearing capacity and function of the element are endangered, and these are:

- ✓ damage in which the condition, ascertained by the inspection, indicates reduced bearing capacity or function of the element and
- ✓ damage in which the condition, stated during the inspection, does not indicate a possible reduced load-bearing capacity or function of the element, but the progression of damage is significant, so it will happen in the foreseeable future.

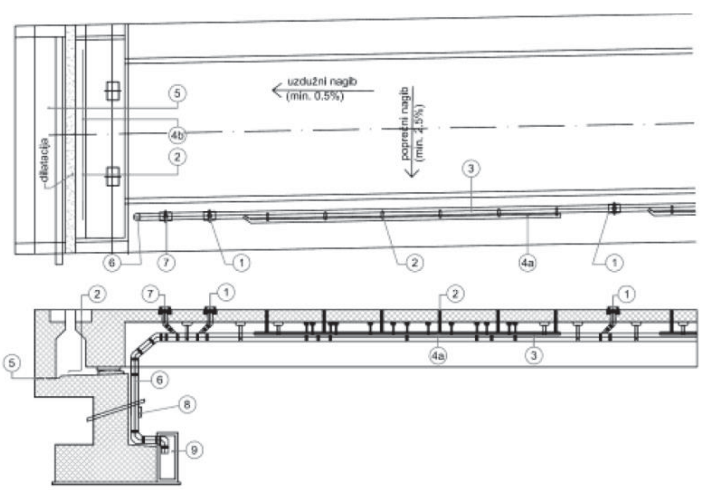
The third category of damages includes damages and deficiencies on the elements of the traffic profile of the bridge that directly affect the safety of traffic participants.

Drainage of bridges

The system of drainage and sewerage of bridges contains all the necessary construction interventions for fast and efficient drainage of surface and leachate from the building [9]. This ensures safe traffic, protection of the bridge structure and environmental protection. Proper functioning of the drainage and sewerage system of bridges is one of the conditions for the projected life of the facilities and reduces maintenance costs. The system of drainage and sewerage of bridges refers to:

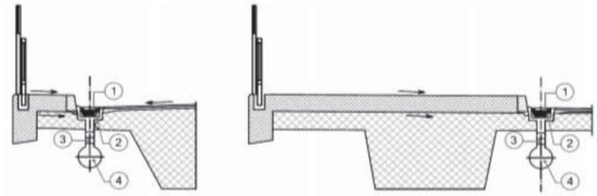
- ✓ drainage of the upper surfaces of bridges,
- ✓ drainage of leachate from insulation surfaces and release of vapor pressures,
- ✓ inlet water drainage and indoor radiation,
- ✓ drainage of bearing surfaces and expansion joints,
- ✓ drainage of the embankment hinterland behind the end pillars,
- ✓ connection of drainage systems to the road sewer and
- ✓ maintenance of the drainage system.

The overall concept of cross-sectional and longitudinal cross-section of the building, and especially the slopes of the level and the cross-slopes of the carriageway must be designed to meet the proper drainage of the building [9]. Figure 2 shows a typical scheme of drainage and sewerage of surface water of the bridge structure. Figures 3a and 3b show the position of the elements in relation to the cross section of the span structure. Cleaning openings with covers at all changes in the direction of the collecting longitudinal or vertical pipe are shown in Fig.3c.



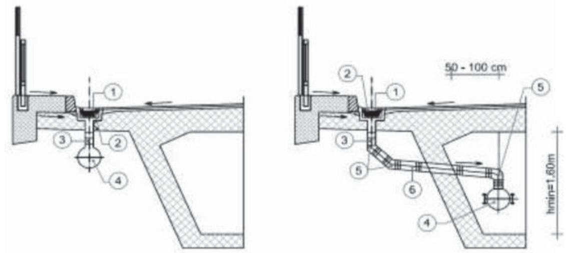
1 –surface water drain
2 – leachate drain pipe with connection to collecting longitudinal leachate line
3 – collecting longitudinal line
4a – collecting longitudinal pipe for draining leachate
4b – collecting transverse pipe for draining leachate in front of expansion joints
5 – drainage of the bearing surface of the end pillars
6 – vertical drain pipe
7 – manhole for cleaning
8 – door cleaning
9 – manhole

Figure 2. *General scheme of drainage and sewerage of the building [9]*



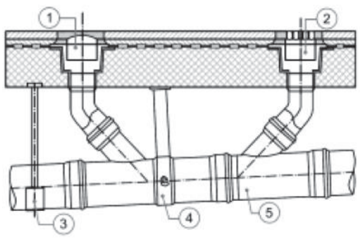
1 – drain
2 – waste collector
3 – vertical drain pipe
4 – collecting longitudinal pipe

a) The position of the drainage elements in relation to the cross section of the building structure



1 – drain
2 – waste collector
3 –transverse pipe for drain connection
4 –collecting drain pipe

b) Position of drainage elements outside and inside the box section



1 – manhole for cleaning
2 – drain
3 – movable fastening
4 – fixed fastening
5 – collecting longitudinal pipe

c) Manhole and cleaning pipe

Figure 3. *Illustrative schemes of drainage, sewerage and cleaning of the bridge structure [9]*

The elements of the drainage system must not enter the load-bearing structures and the area of the prestressing cables and the main load-bearing reinforcement. The facility must have its own separate drainage and sewerage system that connects to the main drainage system via the road sewer or directly to the drain. This does not apply to short objects whose length is less than the required distance between the drains. The dimensions and number of elements of the drainage system are determined on the basis of hydraulic calculation. The input parameters of the hydraulic calculation are meteorological data on the calculated amounts of precipitation at the location of the facility. Corrosion damage in which the load-bearing capacity of the section is reduced, greatly endangers the bridge as a whole. The upstream side of the bridge is more exposed to corrosion due to the water current that causes vapors on the bridge structure [1, 2, 10, 11]. When the drainage of the bridge is bad, water and salt deposits settle inside the bridge with a box solution, which can be catastrophic for the structure.

Examples of drainage system degradation

Due to untimely and inadequate maintenance of the bridge drainage system, the system becomes non-functional and degrades, and indirectly the material from which the bridges are made.
In fig. 4 shows examples of asphalt degradation and bridge drainage systems:

a) *Mesh cracks, porous asphalt and depressions on the road.*
b) *Damage to the pavement in the zone of the expansion joint which is filled with dirt. The space between the combs is filled with dirt on the parts along the protective tape.*
c) *Drain on the tram facility; accumulated dirt around the perimeter of the grille.*
d) *Drains are placed partly in the curb and partly in the road.*
e) *Damaged gutter grate with deposits of garbage and dirt.*
f) *Steel grate across the river.*

g) *Detail of the drain grate.*
h) *Water retention on the footpath.*
i) *Detail on the confrontation of structures.*
j) *Detail of the parapet on the structure at the location of the lighting pole.*
k) *Detail of track fences on the bridge structure.*
l) *Corrosion of the lower part of the drain.*
m) *Corrosion in place of drainage pipes.*
n) *The bottom of the pillar is filled with water with traces of falling water levels on the inner walls of the pillar.*
o) *Appearance of the outer surface and foundation of the pillar with ACP in the form of graffiti and a system for drainage of the bridge that ends in grass.*

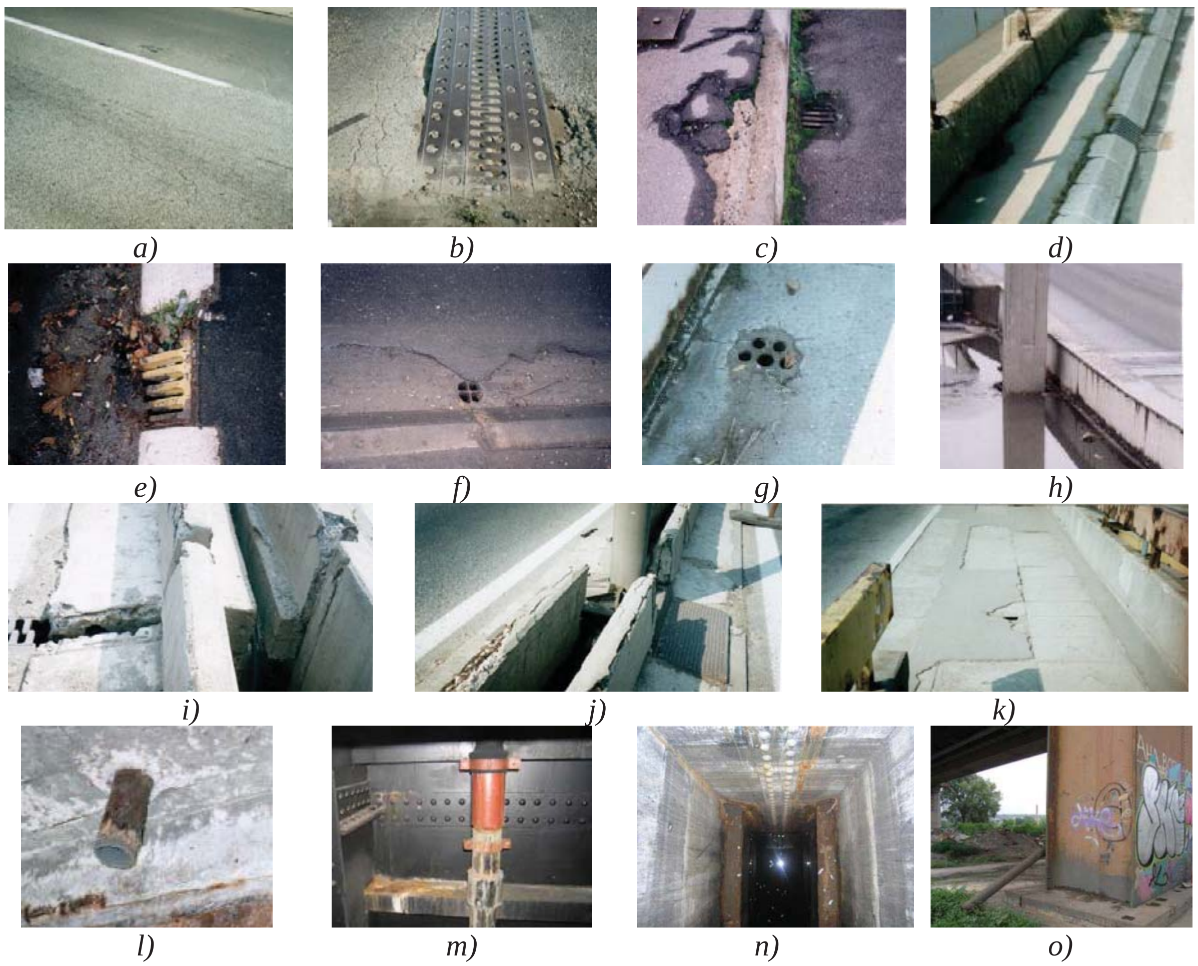


***Figure 4**. Degradation of the drainage system of bridges and materials around it [10, 11]*

Examples of degradation of structural material due to disturbed drainage of bridges

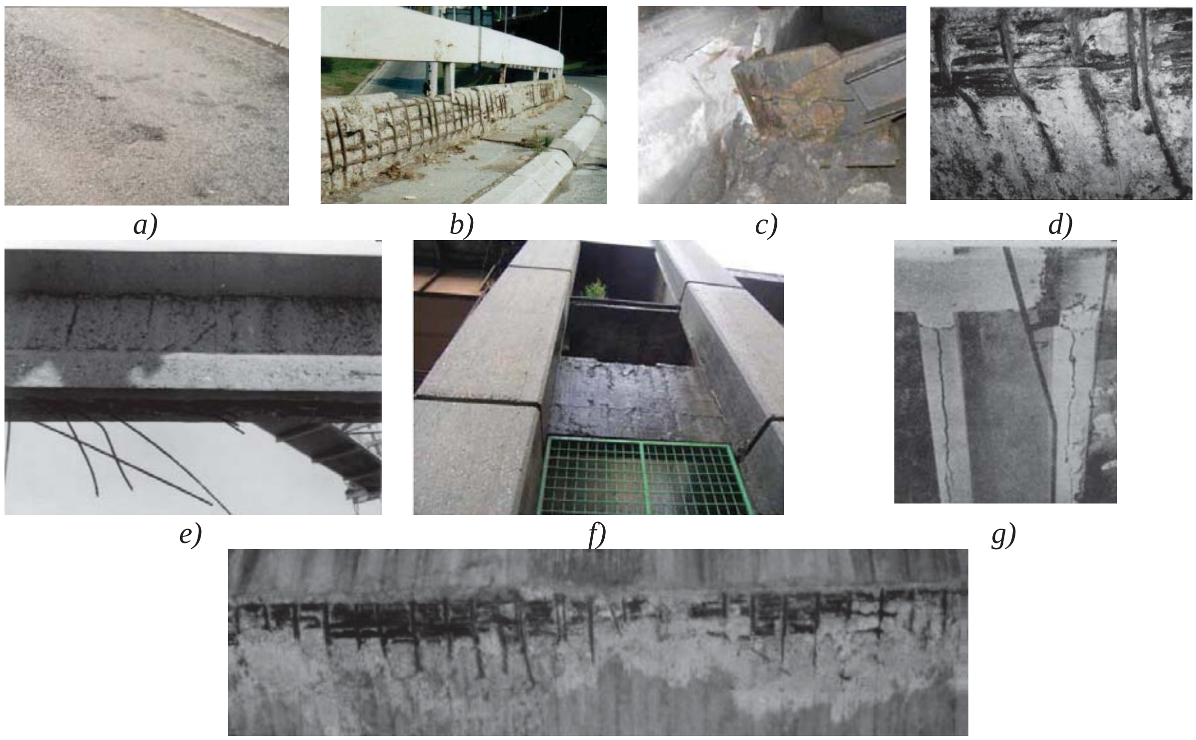
As a consequence of untimely and inadequate maintenance of the bridge drainage system, the material from which the bridges are made degrades. Damage to the load-bearing structure and pillars reaches a level at which the load-bearing capacity of the section is reduced, which endangers the bridge structure as a whole. The practice in Serbia illustrates this very well with examples on the approach concrete prestressed structures and steel structures of the Gazella bridges and the Pančevo bridge.

Corrosion has vitally damaged the building materials of these bridges and put them in direct danger, which can end in disaster.

Degradation of concrete, reinforcement and prestressing cables

In fig. 5 shows examples of degradation of concrete, reinforcement and prestressing cables on the bridge structure caused by non-functioning of the bridge drainage system:

a) *Porous asphalt.*
b) *Initial corrosion of the handrail on the parts of the fence with a coating that is of recent date.*



h)

Figure 5. *Degradation of concrete, reinforcement and prestressing cables [10, 11]*

c) *Pulled out support of the hot water installation.*
d) *Detail of damage to the lower plate of the construction box in the zone of the longitudinal rib.*
e) *Severe damage to the cables as a result of improper protection.*
f) *Exterior appearance of the concrete pillar.*
g) *Wide cracks in monolithic ceiling beams, caused by corrosion of reinforcement.*
h) *Characteristic image of damage to the lower plate of the construction box in the zone of the longitudinal rib.*

Degradation steel structure of the bridge

The anti-corrosion protection on the Gazella steel bridge has been deteriorating for at least 20 years, and this was largely due to inadequate maintenance of the drainage system and, in the end, its complete non-functioning.
In fig. 6 and 7 show examples of degradation of anti-corrosion protection and steel on steel structures of the bridge caused by non-functioning of the bridge drainage system. Fig. 6 represents:

a) *Corrosion of the bottom plate inside the box with salt residue remaining after evaporation of water and visible traces of salted water levels. Peeling of anti-corrosion protection as a consequence of poor preparation before anti-corrosion protection.*
b) *Damage to anti-corrosion protection on the vertical sheet metal of the main girder.*
c) *Characteristic peeling of anti-corrosion protection in the upper belt of the main girder caused by water leakage.*

a) b) c)

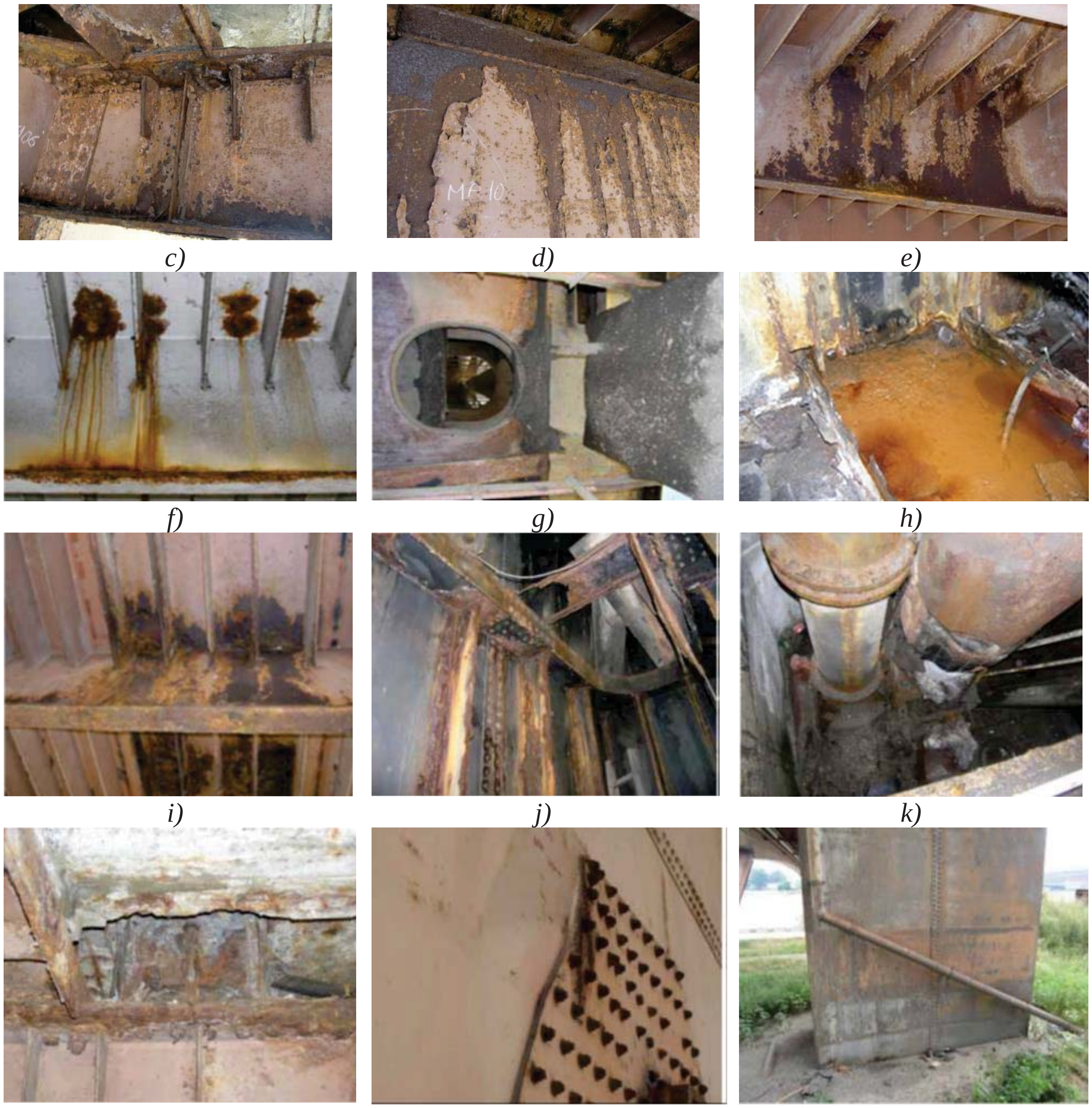
Figure 6. *Degradation of anti-corrosion protection steel parts of the bridge [11]*

Fig. 7 represents:

a) *View of the main girder damaged by corrosion.*
b) *Corrosion of the bottom plate of the main girder.*
c) *Corrosion of the footpath console. Downstream.*
d) *Corrosion damage to the vertical sheet metal and the upper belt of the main girder. Upstream.*
e) *Characteristic corrosion in the dividing strip zone. The middle of the bridge.*
f) *Corrosion of the ortho plate in the zone of the dividing strip.*
g) *Dirt deposits on the inspection track and the fall of the rubber gutter into the expansion space.*
h) *Corrosion of the bottom plate with residue left after evaporation of water with lines showing the level of salted water before evaporation. Inside the bridge.*
i) *Characteristic corrosion in the dividing strip zone. View of the ortho plate in the zone of the dividing strip.*
j) *Rotten climbers and inspection trails with places of corrosion inside the pole.*
k) *Appearance of hot water and plumbing installation and garbage at the bottom of the column.*
l) *Corrosion of the connection between the lighting pole and the pedestrian path console.*
m) *Deformation of the plate reinforcement at the point of support of the inclined pillar on the main girder.*
n) *Exterior appearance of the lower part of the surface of the vertical metal pillar with accumulated dirt and debris at the base of the pillar.*

a) b)

Figure 7. *Degradation of steel structural parts. Examples of corrosion damage of steel bridges [11]*



c) *d)* *e)* *f)* *g)* *h)* *i)* *j)* *k)* *l)* *m)* *n)*

Figure 7. *Degradation of steel structural parts. Examples of corrosion damage of steel bridges [11] (continued)*

Prevention of corrosion degradation of bridge construction materials

From the previous consideration of the danger of corrosion to which parts of the steel structure are exposed due to the action of various attack agents, a number of corrosion protection measures are still in the construction phase: use of clean and uncorroded sheets, profiles and binders after installation, it should be adequately protected on the construction site. In addition, the parts must be protected from the effects of any corrosive agents that may be present on the construction site before installation. Clean wrapping with oily paper or plastic wrap can prevent surface contamination from splashing with aggressive liquids and dust deposits. Conservatives that can be easily removed (oils, fats, non-drying agents) can significantly slow down the access of gaseous attack substances (hydrogen sulfide).

Modern protective epoxy resin coatings adhere very well to the surfaces of parts where cracks do not appear on the elements exposed to tension almost to the limit of their strength. Protective coatings for the protection of bridge construction materials are of exceptional quality and resistant to UV radiation, wear and tear, and extreme temperatures.

Corrosion monitoring in operation

During each inspection of the bridge or during the complaint, the so-called reference surfaces prepared for protection and protected by all details of technical procedures and standards. Work on them is with the constant presence of the responsible person of the contractor and supervision. Their place on the bridge is known and marked.
In addition to proper and timely maintenance, it is necessary to monitor corrosion processes during operation. These processes can be monitored directly or indirectly. Direct monitoring controls the condition of the steel surface and the aggressiveness of the environment surrounding the steel structure of the bridge. Indirect monitoring involves measuring the corrosion effect on coupons made of the same type of material as the steel structure of the bridge. Even during the construction of bridges, it is necessary to install sensors and measuring tapes, to monitor changes in the aggressiveness of the environment, stress and elongation of the responsible bearing parts of the bridge, which would be connected to a computer to process information and make appropriate decisions. Monitoring is very present in the world, especially when monitoring the behavior of dynamically loaded structures, such as bridges, which work in aggressive environments such as large cities. The value of the installed monitoring equipment is negligible in relation to the value of the bridge construction or the value of the undertaken rehabilitation after a number of years of inadequate maintenance.

Regular and extraordinary maintenance

Corrosion protection measures prescribed by numerous technical standards must be applied to all structures, and all this must be monitored over time. High requirements for bridge drainage systems have been set due to the need for high traffic safety and protection of expensive infrastructure. Bridge drainage systems must also meet the special requirements of bridge structures: adaptation to reinforced concrete bridges or the requirements of special structural measures, such as respect for the displacement of the structure of large steel bridges due to expansion joints [12].
In Serbia, the company "Roads of Serbia" is in charge of maintaining and repairing bridges on highways and regional roads, while bridges on railways are under the jurisdiction of the company "Infrastructure of Serbian Railways". The condition of bridges in Serbia is controlled by the Public Company "Roads of Serbia", which is in charge of 2,960 bridges, and "Serbian Railway Infrastructure", which monitors 956 bridges. About ten million euros are allocated annually for periodic maintenance of road bridges in Serbia, which includes major repairs, repairs and reconstructions, while about one million euros are allocated for regular maintenance, while about one million euros are intended for regular maintenance of railway bridges. Bridges are inspected daily, periodically and annually, and a special commission, composed of experts, after determining the complete condition, compiles reports, orders projects for the rehabilitation and repair of certain bridges [13].

Conclusion

Improper maintenance of bridges from the aspect of corrosion protection entails very expensive repairs, so in this regard it is necessary to thoroughly investigate the protection, durability and maintenance of steel bridges and the possibility of monitoring corrosion aggression in operation. In this regard, it is necessary to assess the condition of the bridge endangered by corrosion after longterm use, which should be followed by certain tests by non-destructive methods, in order to determine the actual degree of damage to vital parts of the structure. Control and testing by methods without destroying corroded zones of bearing elements of the bridge structure must follow the process of cleaning by sandblasting during the rehabilitation of the bridge, and immediately after the necessary interventions in terms of changing critical elements, anticorrosion protection follows.

Efficient drainage elements contribute to the rapid evacuation of atmospheric water from the road structure, which statically relieves the bridge structure. Preventing water retention on the road eliminates its penetration into the structural elements and prolongs the durability and service life of the bridge. Violation of the connection between the elements for drainage and waterproofing, leads to leakage and corrosion, which endangers the bridge structure and is subject to frequent repairs. Therefore, for the drainage of bridges, it is necessary to provide elements that are specially designed for a quality connection with waterproofing. Particular care should be taken to ensure that no hazardous substances are spilled in the bridge zone. During the spillage of dangerous substances on the bridge, the collector system is damaged and these substances reach the ground and the watercourse under the bridge. This leads to pollution of groundwater and the surrounding environment [12].

More frequent extraordinary expert inspections of the most frequent bridges in Serbia with a span of pillars longer than 100 meters are needed [13].

Reconstruction of the Gazella Bridge after 40 years of exploitation lasted for almost two years, and began in the summer of 2010. It would be interesting to see the condition of the drainage system on this bridge at the moment.

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