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REHABILITATION OF TWO HISTORICAL BRIDGES IN BAILE HERCULANE ROMANIA

I. BADEA[1] **D. BADEA**[2]

Abstract: *The paper presents the history, the present technical condition and some rehabilitation proposals for two bridges erected in the 19th century in the famous Spa from Baile Herculane near to the Danube.*
The first structure is a steel foot bridge constructed in 1837 made from wrought iron with the span of 32,2 m. The maintenance of the bridge was neglected; the present technical condition is very poor.
The second structure is a masonry arch bridge with 2 spans of 16,5 m and 12,5 m. Some proposals for the rehabilitation of both structures are presented.

Key words: *bridge, arch, iron, stone, rehabilitation.*

1. Introduction

The pedestrian footbridge, known as the “Iron bridge”, is a part of Baile Herculane one of the oldest Spa in Romania, founded during the Roman times.
The metallic pedestrian footbridge crosses the Cerna valley between the streets Cerna and Izvor, in the town of Baile Herculane.

It has a width of 3 m and a length of 32.2 m. The structure was built around the year 1837 and it's an historical monument.
The main resistance structure is made of two truss girder arches with the deck at the upper side. The deck is supported by the vertical members (each – each two angles 50x50x5) covered by ornamental elements.

Fig. 1. *The “Iron Bridge”*

Fig. 2. *The main resistance structure*

[1] Faculty of Civil Engineering , Polytechnic University of Timisoara.
[2] Faculty of Civil Engineering , Polytechnic University of Timisoara.

The upper chord of the arch has a cross section of four angles, similar with the lower chord. The connection is made by lattices. At the lattices intersection ornaments are disposed.

All the joints are riveted, a specific solution from that period. The rivets have a diameter of 19 mm.

Fig. 3. *Ornamental elements*

The bridge crosses the Cerna Valley between Hercules Place and Cerna Street. The bridge has a width of ~10.0 m and a length of ~36.0m. The deck has a small inclination and deserves the car traffic with a restriction of –15 kN – and two footpath, on them is covered.

Fig. 4. *Side view*

The sidewalk situated downstream with a width of 0.5 m has also cast iron ornaments; the upstream sidewalk has a width of 2.5 m and is covered by a wooden roof sustained by vertical cast iron columns with an diameter of 70 mm. At the end of the sidewalks a portal is disposed.

The structure was built around the year 1865, according to the date visible on the bridge.

Fig. 5. *The sidewalk*

The bridge has two spans realized by vaults with spans of 16.5 m, respective 12.5 m. The structure is made by stone and brick and lateral it has two spandrel walls made successively from stone and bricks. The bridge is curved with a Radius of 35 m.

2. Technical Condition of the Bridges

The Iron Bridge Superstructure

The structure had a good behavior in time, although due to poor maintenance to the age several problems appear: numerous corroded elements.

Fig. 6. *The corroded arches*

At the main elements you can find a lot of areas with destroyed anticorrosive protection.

Fig. 7. *Corroded joint and vertical member*

The distance between the rivet at joints was find inadequate (d_{max}= 6d= 6 x 19 mm= 120 mm), causing corrosion between elements.

The wooden floor was severely damaged and some fixing elements were missing.
There are some ornament elements missing.

The Iron Bridge Infrastructure

The infrastructure of the footbridge it's build of soft stone, with a low resistance to erosion.
The connection between the infrastructure and the embankment is partially destroyed. Vegetation growth can be observed.

Fig. 8. *Vegetation growth*

Road bridge Superstructure

The road bridge had a good behavior in time. Some degradation due to a bad maintenance can be observed. Also the impact of the vehicles with the structure destroyed partially some elements of the structure.

- masonry elements are severely damaged;
- water infiltration;
- vegetation;
- damaged soft stone;
- degradations, absence of stone masonry,
- deformations, instabilities, inadequate repairmants and vegetation
- ornaments are missing

Fig. 9. *Vegetation, damaged masonry elements*

Fig.10. *Ornaments are missing*

Road bridge Infrastructure

The bridge infrastructure it's built up of stone masonry and it shows the following problems: erosion, cracks, scouring, and separation. Scoring and missing stone masonry elements can be observed

The riverbed is clogged with different waste and wooden scraps in the zone of the front-breakwaters. The support walls sustaining the riverbed are partially destroyed.

2.1. The Determination of Stress State in the Structure

The arch is parabolic shaped, represents *line of pressure* for uniform distributed loads. The structure is double articulated, this means that the structure is static.

Fig. 11. *The bridge infrastructure*

determinate. The structure design was performed using a automatically computer program (Sofistik) and was verified with manual calculus. The main loads were: self weight of the structure resistance, path weight, human load and temperature action.

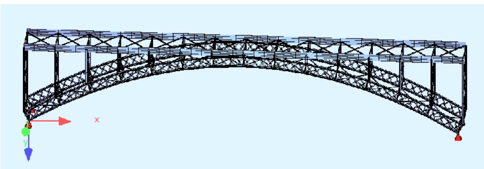

Fig. 12. *Structure design in Sofistik*

Loading cases that were taken into consideration were:
- the load on the entire span
- the load on half span
- temperature load

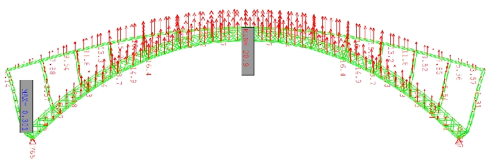

Fig. 13. *Loading case - temperature load*

The verification of the design was made according to limit state method (Eurocode) and also with method allowable stresses (possible for old structures that are still in operation).

Observations:

- The settlement of supports does not introduce efforts into the structure.
- The Euro code Load Modell 4 was considered (5 kN/m²) for the whole structure
- Efforts given by the dead load of the structure give insignificant values.

In the absence of material evidence and taking into account the building year of the structure, the steel used is certainly a puddle steel type (wrought iron); therefore its resistance was reduced by 20 N / mm². In allowable stresses method. Analysis the allowable resistance value was considered equal to 140 N / mm².

In the absence of accurate measurements of the thickness of the elements, and an overall assessment of the state of corrosion, it was considered a 20% reduction in sectional arches. This reduction may, however, be insufficient; it will be verified and confirmed after sandblasting the entire structure.

For the initial unaffected sections the tensions in arch bars are in the permissible state limit. Considering the weakening after corrosion the tensions exceed the limit values. Some problems were found with the slenderness and stability condition of some beams.

At the technical development phase it's is necessary to establish the state of stresses and deformation of the entire structure in accordance with the norms.

3. MEXE Method

The MEXE method (Military Engineering Experimental Establishment) is probably the best known simple method for the load-bearing assessment of historical arch bridges. The method is heavily applied not only in Great Britain (Huges and Blackler 1997), the country of origin, but also in many other countries since it was included in UIC-Codex (1995).

The application of the method is simple and fast. An example will show that. First, the conditions found have to comply with the boundary conditions of the method. The boundary conditions are given in Table 1.

Table 1

Requirements	Example
Span smaller than 20 m Rise greater then ¼ of the clear span Filling above crown is between 30 and 105 cm	10 m ¼ x 10 = 2.5>1.8 m 1.2 - 0.5 = 0.7 m

The load-bearing behavior is the computed with

$$Q_{adm} = Q_p \cdot f \tag{1}$$

with

$$q_{adm} = \frac{Q_{adm}}{1.5m} \tag{2}$$

and

$$f = f_s \cdot f_M \cdot f_j \cdot f_c \cdot f_N \cdot \frac{1}{f_\Phi} \tag{3}$$

The factor f considers a variety of parameters. The first one is the arch shape factor:

$$\frac{r_q}{r_c} = \frac{1.4}{1.8} = 0.78 \rightarrow f_s = 2.3 \cdot \frac{\left(r_c - r_q\right)^{0.6}}{1.40} =$$

$$2.3 \cdot \frac{\left(1.80 - 1.40\right)^{0,6}}{1.40} = 0.95$$

Further factors, which have to be taken from diagrams and tables, are the following:

Material factor $f_m = 1100$

Joint factor $f_j - f_W * f_{mo}$

Joint thickness factor

$f_w = 0.8$ -> *Joint thickness > 12.5mm*

Mortar factor

$f_{mo} = 0.8$ -> *weak, crumblymortar*

Factor for the arch condition

$f_c = 0.85$ -> *Longitudinal cracks, the middle third of the arch*

Factor for the numbers of arches

$f_N = 0.80$ -> *Arch supported by two piers*

And, f can be computed as

$f = 0.95*1.0*0.80*0.90*0.85*0.80*1/1.25 = 0.272$

Using this value, one can read from a diagram (UIC-Codex 1995)

$$Q_p = 425\ kN$$

$$Q_{adm} = 0.425MN * 0.372 = 0.158\ MN$$

$$Q_{adm} = 0.158\ MN / 1.50 = 0.105\ MN/m$$

As shown, the method can be quickly applied. This explains the wide application. However, some authors such as Brencich et al. (2001) have criticized the method that produces unsafe results under some circumstances.

4. Conclusions and Recommendations

The following recommendations are given:

The iron bridge

- For the metallic superstructure:

1. Elimination of actual deck and dismantling of the whole structure, under the terms of the technical project;
2. Transport of the structure into a specialized steel fabrication plant;
3. Sand blasting and thorough inspection of the structure in order to detect any defects;

6. All joints will be executed with rivets to maintain the original character of the structure;
7. Restoration of the deck in a modern and easy solution;
8. Revision, cleaning and repair of bearings and spring connection of the arch;
9. Remounting of the structure in accordance with conditions imposed in the technical project;
10. The final painting of the whole structure; its illumination is recommended to restore the original lighting pillars;

Highway Bridge

For the superstructure:
Taking into account the considerable age of 146 years, special attention will be given to the structure:
- elimination of road layers;
- a repair, rebuilding the vaults in their original form and consistency to ensure lateral stability, uniformity and aesthetics of the bridge;
- cleaning, filling, repair of the bricks at the spandrel, including their protection;
- strengthening the vaults at the extrados or intrados in collaboration with the existing construction.

These operations will be executed based only on the technical rehabilitation project
- Construction of a new path by introducing reinforced concrete slabs;
- a masonry repair, cleaning degraded stone masonry all over the bridge;
- a repair of the ornaments.

5. Proposed Solutions

Solution 1: Besides the usual repairs a repair of the vault at extrados with reinforced concrete C25 / 30 is proposed. Also the replacing of the filling existing over vaults with simple concrete C8 / 10 and the disposal of a plate of reinforced concrete C35 / 45 with the runway role, must be adopted

Solution 2: Also in addition to the recommended repairs, instead of strengthening the upper surface of the vaults, you can choose the consolidation with the intrados side at the vaults by a providing a supplementary reinforced concrete wall. On top of the existing filling will be replaced on the height of approx. 25 cm. Finally a slab of reinforced concrete C35 / 45, similar to the first solution have to be adopted

Repair sidewalks by restoring and replacing only a part of the structure (only highly degraded and corroded elements - a rate of ca. 60% estimated amount) , and subsequently the applying of corrosion protection. In this situation the life of the structure can prolonged by 50 years, in the conditions of a strict maintenance program.

2. Restoring the entire structure while maintaining the strict initial form and its historical features. In this case life is at least 100 years, in the conditions of a strict maintenance program.

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