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CASE STUDY ON HEROES' CROSS FROM CARAIMAN

BY

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Abstract. This article presents information on the structural assessments of the historic monument called the Heroes' Cross and the data on the proposed rehabilitation measures. After a brief introduction and a description of the analysed structure, the tests on the materials used are shown as well as the structural analysis and its particularities. Finally, the intervention measures and their effects on the degree of insurance are presented.

Keywords: evaluation; 3D truss beam; monument; consolidation.

1. Introduction

The structure was built between 1926 and 1928 on the Caraiman peak, at an altitude of 2,291 m located in the central area of the Bucegi mountain, by the Bridges Department within the Romanian Railway Association. The monument was realized in the memory of the railway heroes who died on duty in World War I. It was erected at the initiative of Marie of Edinburgh and King Ferdinand of Romania in order to be seen from a large distance.

The designers of the project were the Teofil Revici and Alfred Pilder engineers, meanwhile the site was supervised by Nicu Stănescu. The

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construction was design according to DIN norms (Deutsch Industry Norms) since it was the current code for engineers at that time. Special chapters were considered: DIN 1028 for L-shaped profiles with equal wings and DIN 448 for steel sheets and round steel.

The maximum height of the structure is 39.0 m and the actual height of the cross is 31.0 m. The horizontal arm has a total length of 15.0 m, and it is divided in 2 cantilevers by the main vertical arm, each of 6.45 m long. The structural integrity of the cross is provided by a 3D system of trusses. The cross section is 2.0×2.0 m for the column and 2.0×2.25 m for the cantilever beams.

The monument did not suffer essential changes since the construction, maintaining its structural shape, dimensions, characteristics and the architectural composition (Derer *et al*., 2014).

The article presents data on the structural assessment methodology of the historical monument, the obtained conclusions and the recommendations regarding the necessary intervention measures, considering the restrictions regarding the number of pieces which can be replaced in a historical monument. Consolidation solutions and their implementation methods are presented in the scientific literature such are: (Karbhari *et al*., 2016; Zhao *et al*., 2007; Teng *et al*., 2012).

2. Structural System Description

The structural system of the cross consists of a truss spatial system with flared base (Fig. 1).

Fig. 1 – Heroes Cross during building and today.

All the bars from the structure are made from equal-angle steel cross section with the following dimensions 70 × 70 × 7 mm. The bars can be grouped into elements with one equal angle section (diagonals, struts), elements with two equal angle sections (bottom and top chord, the column edges and the cross arms) and elements with four equal angle sections forming the flares at the base of the monument. The bar connections are made with 17 mm diameter rivets and 10 mm thick sheet gussets. Cross metallic strips are placed in the spaces formed by the struts, with circular hollows in which light bulbs are introduced (Fig. 2).


Fig. 2 – Technical details.

The central pillar rests on the slab, fixed at the intersection of the main beams (Budescu *et al*., 2014). The flared legs rest on the slab, in line with the walls and are anchored in them. The anchoring of the metal legs is well assured, since according to the computation made, if the metal bars would stop in the section below the slab, the cross would not have the required stability. It should also be mentioned that in a description of the construction process it is mentioned that initially the cross was anchored in the rock after which the concrete base was poured.

Even though the cross is not anchored directly into the rock, it was certainly constructed until to a certain extent in the form of a metallic structure rested directly on the ground, after which the base was poured to embed it and ensure its stability. The only plausible hypothesis regarding the execution technique considers that after fixing the base the rest of the monument was assembled. To sustain this hypothesis there are photos showing the base without its crown. The base is made out of simple or weakly reinforced concrete with its weight ensuring the stability requirement. The wall thickness at the base is about 2.0 m wide. The slabs are made of reinforced concrete with beams on both directions.

According to the geotechnical survey from a nearby place, the site's stratification consists of: organic soil until –0.30 m; clay with rock fragments until –0.60 m; and until –2.00 m fragments of limestone with clayey binder.

3. Tests on the Used Materials

In order to obtain information regarding the characteristics of the used materials, samples of metal from the access staircase were taken – an equal-angle $70 \times 70 \times 7$ mm element and a metal bar with of 19 mm diameter.

The metal bar has been tested to tension loads (Fig. 3). The resulting characteristics, such are the breaking stress, flow tension, elongation, cracking, ductility, places the material in the OL37 grade steel category. According to STAS 438-54 for the hot-rolled OL38 steel, the breaking strength should be between 38…47 daN/mm^2 and the yield strength of 22 daN/mm^2.

Fig. 3 – Tension test.

For the tested steel, the breaking strength was slightly inferior to OL38 steel (36 daN/mm^2 instead of 38 daN/mm^2), meanwhile the yield strength was higher (24 daN/mm^2 instead of 22 daN/mm^2). Fig. 4 presents the characteristic stress-strain curve for the used material in the analysed monument. According to STAS 200-52 steel tension test, the obtained value for the tension test place the material in the OL34 quality steel class.

For the design, the considered steel strength was equivalent to the S235. The samples tested for tension were taken from the metallic staircase which is loaded differently than the structural elements. At this stage of the expert's survey, no samples could be taken from the structural elements in order not to damage them, as long as their restoration was uncertain.

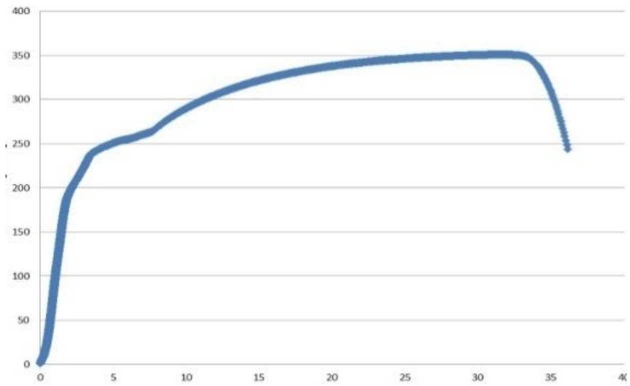

Fig. 4. Stress-Strain curve

It has also to be noted that the steel from which the cross was built is a soft, malleable steel, possibly less sensitive to the fatigue phenomenon.

4. Structural Analysis

The analysis was performed according to P100/3-2008 design code regulations, using the finite element software Axys. Thus, the minimum degree of insurance for each metal bar was computed by the automatic assessment of each element ,,efficiency'' tool from the software. This is in fact the ration between actual and potential internal forces. A spatial model was considered for the computation in both cases – initial and rehabilitated.

Fig. 5 presents the existing profiles from the monument and the composed sections that were found in the survey.

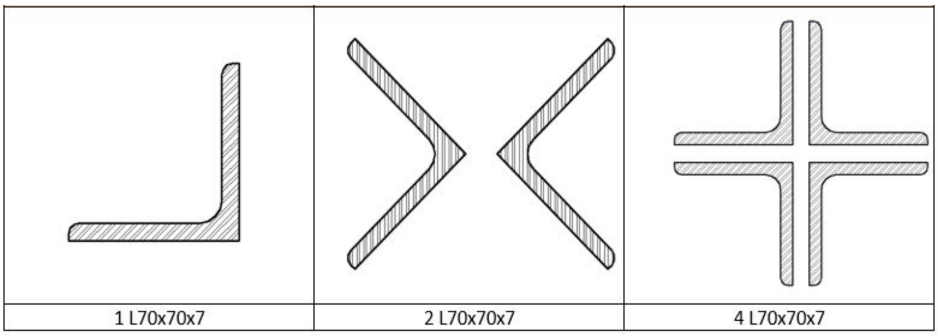

Fig. 5 – Existing cross sections in the structure.

The metal elements were considered in the calculus with the minimum yield strength, f_y = 235 N/mm^2 and an ultimate tensile strength of f_u = = 360 N/mm^2, according to tab.3.1 from SR EN1993-1-1/2006.

The original designers' analysis for wind actions was also based on the Deutsch norms (DIN 1055), in which, the actual wind pressure caused by an obstacle is calculated with $\mathbf{q=v^2/16}$ relation. The maximum wind speed is considered v = 45 m/s, resulting a value for q equal with 130 kg/m^2. The same relation is also given by the first Romanian standard for wind design (STAS 946-50), with the mention that on hills and mountains peaks, the basic dynamic pressure is considered equal to 160 kg/m^2.

The wind speed on site, computed according to current standards (CR1-1-4/2012) is 60 m/s and the dynamic pressure is 200 kg/m^2. These values are amplified by a series of coefficients which consider the real position and the composition of the structure.

The load combination in which maximum internal forces were obtained are those that contain the wind and the ice coating effect. The elements of the 3D truss beam were calculated for tension, compression and buckling. The considered structural model and the wind case are shown in Fig. 6.

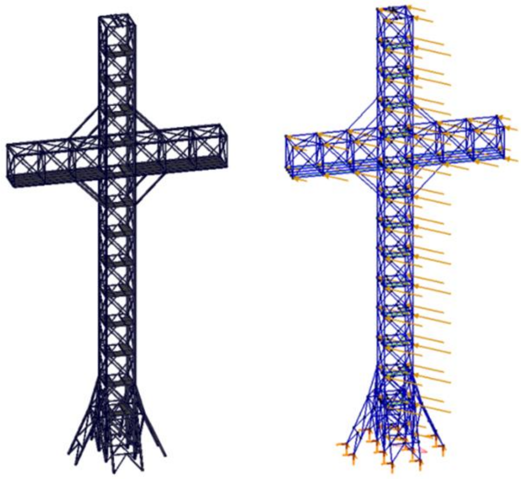

Fig. 6 – Considered numerical model and wind load action.

Fig. 7 shows the axial strain diagram, N_x, from the load case in which the wind is perpendicular to the plane of the cross and the displacement distribution, ey, resulted from static linear analysis.

According to the calculation, the metal structure of the cross does not fulfil the necessary requirements for the insurance degree required to sustain the loads according to current technical regulations. The bars that do not check for both tension and compression are those at the edge of the column, between the section where flaring begins and the section under the diagonals that support the arms of the cross (Fig. 8). The blue bars are the tensioned ones, meanwhile the red ones are the compresses bars.

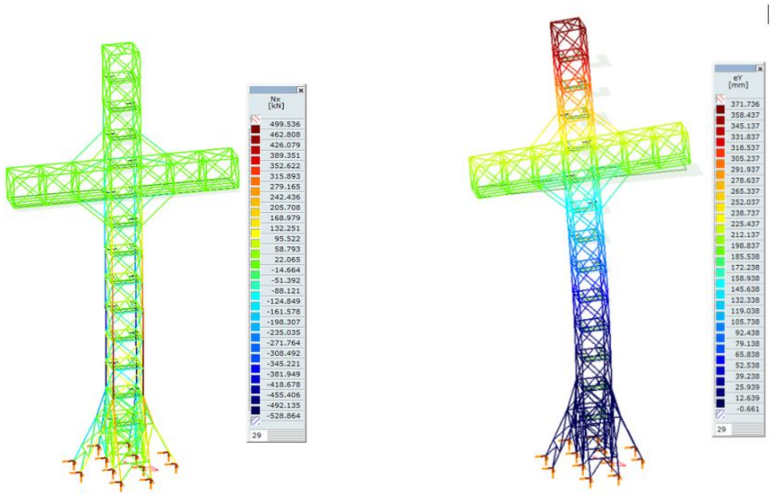

Fig. 7. Axial strain diagram, N_x and displacement distribution, ey.

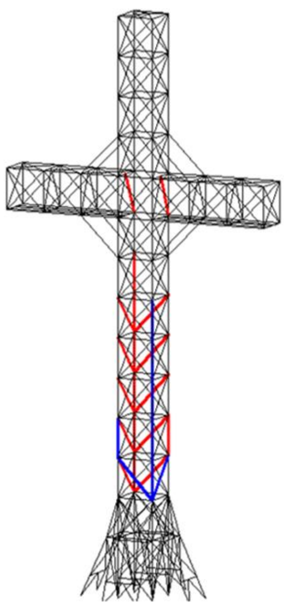

Fig. 8 – Low insurance degree bars distribution
(blue-tension, red-compressed bars).

If the inverse value of the efficiency is regarded as the insurance degree, R_3, then for the most demanded bar a value of 0.4 results. The calculations show that if this bar fails, the other bars can not take over its place and the structure can collapse due a progressive failure of several bars. In this case, it is reasonable to assume the degree of insurance of the whole structure as the degree of insurance for the most demanded bar, although the average of the efficiency for all the bars results significantly smaller.

An insurance degree of $R_3 = 0.40$ places the structure in the second risk class, considering the wind action as the main risk factor, since the maximum internal forces result from the load case in which the wind action is considered.

The overturning of the base has been checked as a ratio between the stability moment given by the self-weight of the structure (base weight included) and the overturning moment given by the maximum load of the wind. Compared to the 1.5 limit value of this ratio, a value of 5.7 was obtained, which is much higher and leading to an insurance degree of $R_3 = 3.8$.

The possibility of detaching the concrete slab from the walls as a result of the overturning of the cross was also checked. In the analysis, it was considered that the legs of the metal structure continue in the concrete structure, these being considered as an equivalent area of reinforcement. In this scenario, the degree of insurance resulted in $R_3 = 1.33$, which indicates a low risk of overturning.

5. Intervention Measures

The proposed solutions for the consolidation of the monument are presented below considering the limitations regarding the substitution interventions on historical monuments (Budescu *et al.*, 2014). The column will be consolidated from the fixed base embedded in the concrete slab to below the bracings which strengthen the cross arms, by increasing the existing cross sections as follows:

– on the inside of the four profiles from the corners, a $70 \times 70 \times 7$ mm profile is added connected to the existing one with screws whose heads are treated similarly to the head of a rivet;

– rigid carbon fibres strips bonded with epoxy resins are also applied on the interior side of the four profiles in order to increase their carrying capacity.

The cross shaped diagonals of the column are also reinforced by applying carbon fibre strip with epoxy resins on the inside of the wing.

The area where the profiles are embedded in the concrete will be exposed and the corrosion status as well as the degree to which the steel section have been decreased will be examined. For these areas it is recommended the wrapped with carbon fibre textile and then concrete to restoration with a special mortar for repairs.

The whole structure will be cleaned by sandblasting and it will be protected against corrosion by painting it with a special paint with guaranteed adhesion.

In the calculus MC-DUR CFK-Lamellen E (MC-Bauchemia manufacturer) carbon strips were considered. Their tensile strength is 2,800 MPa and the modulus of elasticity is 160 GPa. The recommended adhesive for fastening the strips are MC-DUR1280 and can be used with a tensile strength of at least 20 MPa.

By applying this solution, almost all of the bars are brought to a higher insurance degree. From the total number of bars, 5 of them remain at an insurance level close to the unit value and 2 have values less than 1. If the insurance degree for the least efficient bar is considered, a value of 0.7 is obtained which is in fact an admissible level according to current standards ($R_{\min} = 0.6$).

6. Conclusions

Following the restrictions for the rehabilitation process of monuments in general, makes the design of the appropriate solutions a challenging task. The case study presented was a steel structure. Among the applied rehabilitation methods were: adding steel profile in the column corner, increasing strength by carbon strips and corrosion protection.

It was observed that by applying special techniques the insurance degree increased significantly increase. After rehabilitation only 7 bars have values below 1 and neither one of the bars has an insurance degree below the minimum accepted.

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STUDIU DE CAZ PENTRU CRUCEA EROILOR DE PE CARAIMAN

(Rezumat)

Sunt prezentate informații referitoare la evaluarea structurală a monumentului istoric Crucea Eroilor – Caraiman şi date despre măsurile de reabilitare propuse. După o scurtă introducere şi o descriere a structurii analizate se prezintă încercările pe materiale efectuate, calculul structurii şi particularitățile acestuia. In final, se prezintă măsurile de intervenție şi efectele acestora asupra gradului de asigurare.