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Procedia Engineering 156 (2016) 164 – 171

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Conference „Bridges in Danube Basin 2016", BDB 2016

Design for Rehabilitation of 7 Steel Railway Bridges in Montenegro

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Abstract

This article summarizes the rehabilitation design of seven steel bridges located along the Railway line Vrbnica – Podgorica. Rehabilitation design had to ensure safety, stability and structural integrity for the designed working life of bridges, whose durability according to the previous national standard, as well as European Norms, is planned to be 100 years. Structural analysis was done according to EN-Eurocodes, and included the verification of structural element resistance for ultimate limit state, serviceability limit state control and fatigue assessment for the remaining working life. Within the rehabilitation design, following elements were covered: the strengthening and rehabilitation of structural elements, corrosion protection, maintenance and monitoring of bridges.

Peer-review under responsibility of the organizing committee of BDB 2016

Keywords: Steel structure, railway bridge, rehabilitation, fatigue assessment, monitoring.

1. INTRODUCTION

The railway line Vrbnica – Bar, as part of the International railway line Belgrade - Bar and Route 4, which connects the Port of Bar with Trans-European corridors VII and X, represents the major traffic route for the economy of Montenegro, as well as the shortest railway link between the southern part of the Adriatic Sea and the Mediterranean Sea with the countries of Central Europe. It is a single-track line, intended for mixed-traffic and its length trough the territory of Montenegro is 167.1 km, along which are located 108 concrete (reinforced concrete and pre-stressed) and 15 steel (steel and composite) bridges.

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1877-7058
Peer-review under responsibility of the organizing committee of BDB 2016
doi:10.1016/j.proeng.2016.08.282

Railway Line Podgorica - Bar with tunnel underneath Sozina Mountain and embankment over Skadar Lake was opened for traffic in 1959, while the Railway Line Vrbnica – Bar was constructed and opened for traffic in 1976. Steel bridge over Moraca River and the bridge “Tanki Rt” over Skadar Lake along the railway line Podgorica – Bar were built between 1950. and 1956., while the remaining steel bridges along the railway line Vrbnica – Podgorica were built between 1970. and 1974.

Despite its enormous importance for the economy and the fact that as part of the International railway line Belgrade – Bar links the Sea routes with the European railway lines, there were no major investments since 1976. Pursuant to Transport Development Strategy and in accordance with the needs for better utilization of the railway potentials and the Port of Bar potentials, in 2009 have begun the works on rehabilitation of railway line Vrbnica - Bar.

Railway infrastructure of Montenegro AD - Podgorica is working on implementation of emergency works at International Main Line Vrbnica - Bar including: (I) overhaul of railway line; (II) rehabilitation of tunnels and bridges; (III) stabilization of slopes and renovation of stations; (IV) placing of signalling and telecommunication equipment; (V) procurement of maintenance machines and regional rolling stock and (VI) overhaul of locomotives etc. Therefore it was planned development of the Main Design for Rehabilitation (Rehabilitation and Anticorrosive Protection) of 15 Steel Bridges on the Railway Line Vrbnica - Bar, Montenegro, whose position is shown on the map below (see Fig. 1).

The Main Design has been prepared based on the contract between the Client - Railway Infrastructure of Montenegro and the consortium - iC consulenten Ziviltechniker GesmbH, Mostprojekt a.d, DB Inzenjering d.o.o. Terms of reference defines basic objectives that design documentation and all necessary testing within the Main Design for Rehabilitation should ensure, in order to provide conditions for:

- Realization of tender procedure;
- Project Implementation;
- Execution of the works (rehabilitation, strengthening, anti-corrosive protection etc.);
- Safe and secure traffic across the bridges under regular velocity;
- Structural integrity of the bridge and its structural elements;
- Extension of the design working life of a steel bridge structures;
- Provision of stationary conditions for maintenance, monitoring of structural integrity after the rehabilitation. It is necessary to ensure stationary conditions for preventive structural monitoring;
- Reducing effect of earthquake at bridge constructions in the zones of increased seismic risk and hazard with implementation of seismic “structural control“.

Within the Terms of Reference are listed activities that a designer needs to implement:

- Review of existing technical documentation and Visual inspection of the bridge in order to determine its actual state;
- Design speed to be used in Main Design for passenger and freight trains on the section Vrbnica - Podgorica is 80km/h;
- On the basis of existing technical documentation and accepted Report on the Bridge State, development of the Main Design in accordance with the following international standards: UIC, EN-Eurocodes, ISO, DIN.

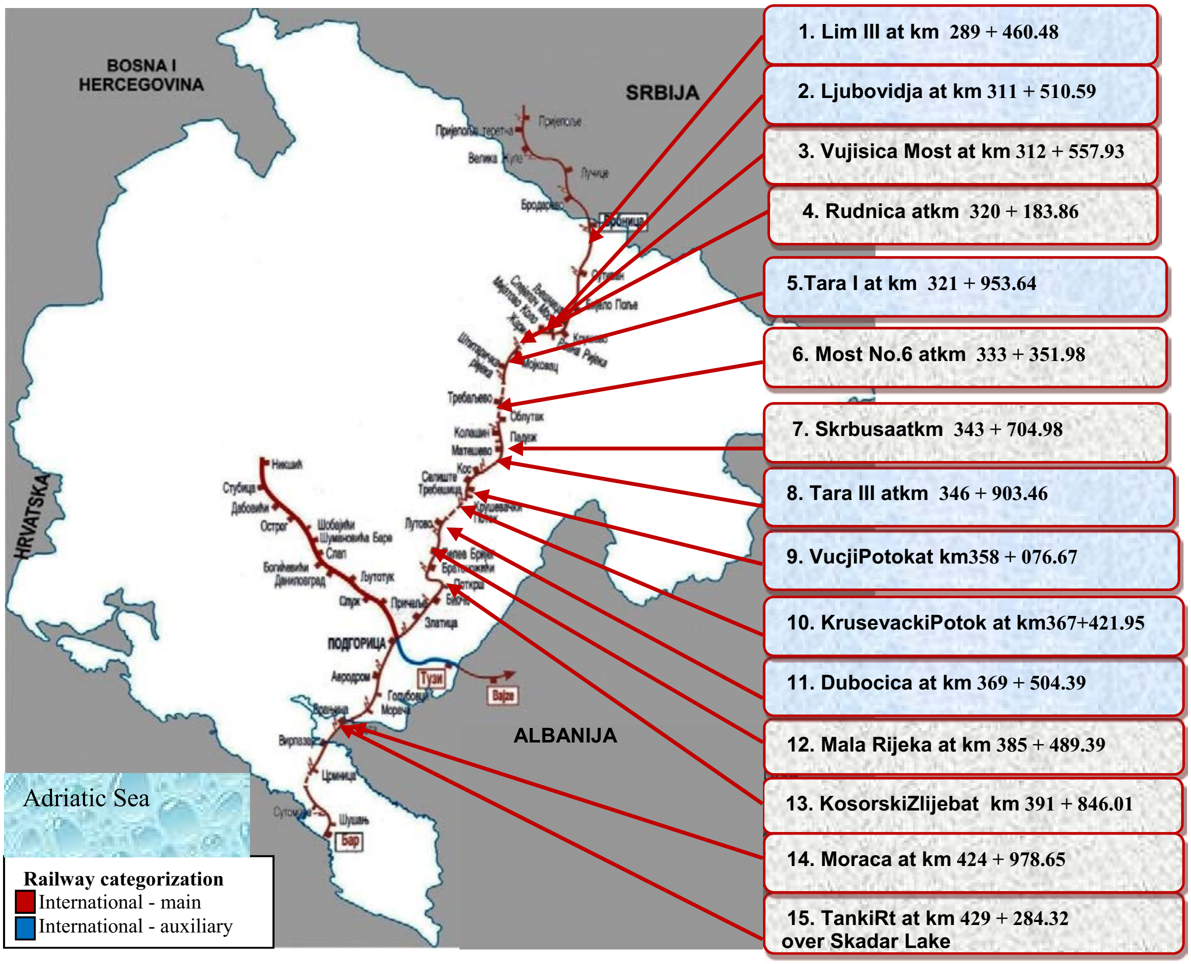

Fig. 1. Map of Steel Bridges on railway line Vrbnica – Bar

2. BASIC INFORMATION ABOUT BRIDGES

This article summarizes the rehabilitation design of seven steel bridges, located in the mountainous area. Bridges were designed and built in the period from 1968 to 1975 according to the Main Design that was created by the Department of Design Community of Yugoslav Railways in Belgrade, and hereinafter will be listed basic information about the aforementioned bridges.

The bridge structure over the river Lim and the main road "Prijepolje - Bijelo Polje" with a total length of 395m, consists of 11 composite simple beams with spans 10x38.5m+28.0m (see Fig.2). Concrete piers and abutments are founded on shallow footings, except the piers in the river bed that are founded on caissons. The railway track on the bridge is horizontal with the axis of the track along the bridge mainly in circular and transition curves.

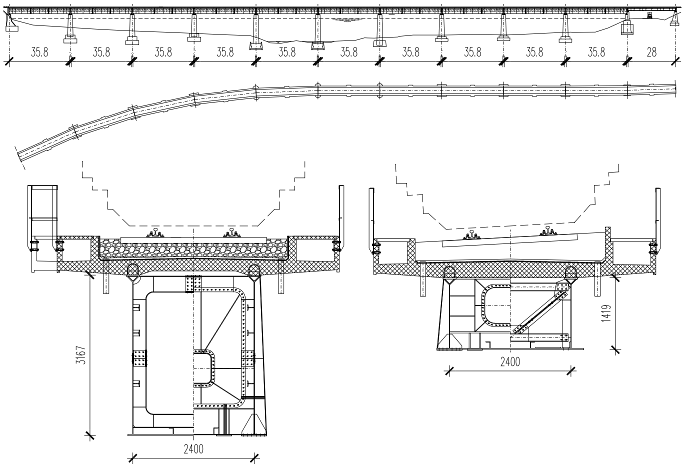

Fig. 2.Layout of the “Lim III” bridge structure

Deep valley of the River “Ljuboviđa” spans the bridge structure with a total length of 454.8m, which consists of steel truss structure in the main span and the composite approach structures (see Fig.3). Truss structure is continuous beam across three spans 90m+126m+90m, while the approach structures are simple beams with span of 36m. The maximum height difference between the railway track and the bottom of the ravine is 98m. In order to reduce the height of the concrete piers, track is on the longitudinal girders which are located above the truss top chord. The longitudinal girders are supported via tangential bearings on the transverse girders that are set in all nodes of the truss top chord. The track is in longitudinal decline of 16.4 ‰, and from a circular curvature through the transition curve goes to the horizontal. Concrete piers are shallow founded.

“Tara I” bridge consists of two simple beam truss structures; with spans 60.0m+60.0m (see Fig.4). Structures are supported on the middle pier founded on reinforced concrete caisson and two massive abutments which are shallow founded. The track on the bridge is open, at the circular curve and is located on the bottom chord.

The bridge structure across the deep valley of the River Tara with a total length 270 m (see Fig.5) is the steel continuous girder over five spans 45.0m+3x60.0m+45.0m. Structure is supported on the concrete piers. Track on a bridge is open, with sleepers which are directly supported by top plate over the box girders web. The railway track on the bridge is horizontal, with straight axis along the most part of bridge length and in the transition curve along the last span.

Canyon “Vuče potok” 105m deep, whose banks are very steep and inaccessible, was bridged with three independent bridge structures with a total length of L=262.0m (see Fig.6). The railway track on the bridge is in the longitudinal decline of 22.3‰,with the axis line going from straight line, through the transition curve, to the circular curve. First structure is a steel box continuous girder over three spans 50.0m+60.0m+50.0 m, whose axis follows the track axis. Next structure is simple beam box girder with 45.0m span, and the last one is continues reinforced concrete structure over three spans 3x19.0m. Concrete piers are shallow founded. Massive concrete pier that supports steel and concrete structures accept the entire braking force from the steel structures.

The bridge structure across the deep valley of “Kruševački potok” with a total length of 83m consists of two simple beam structures with spans equal 41.0m. The railway track on the bridge is in the longitudinal decline of 22.3‰, with the axis line partly straight and partly in the transition curve.

"Dubočica" Bridge is a continuous steel structure over two spans 63.0m+42.0m, with a total length 105.0m, which spans the deep rock scree. Under each railway track, at the axial distance of 4.75m, supporting steel structure was set, whose axis follows a curve of the track. All three structures are supported on common massive concrete piers founded on shallow footings.

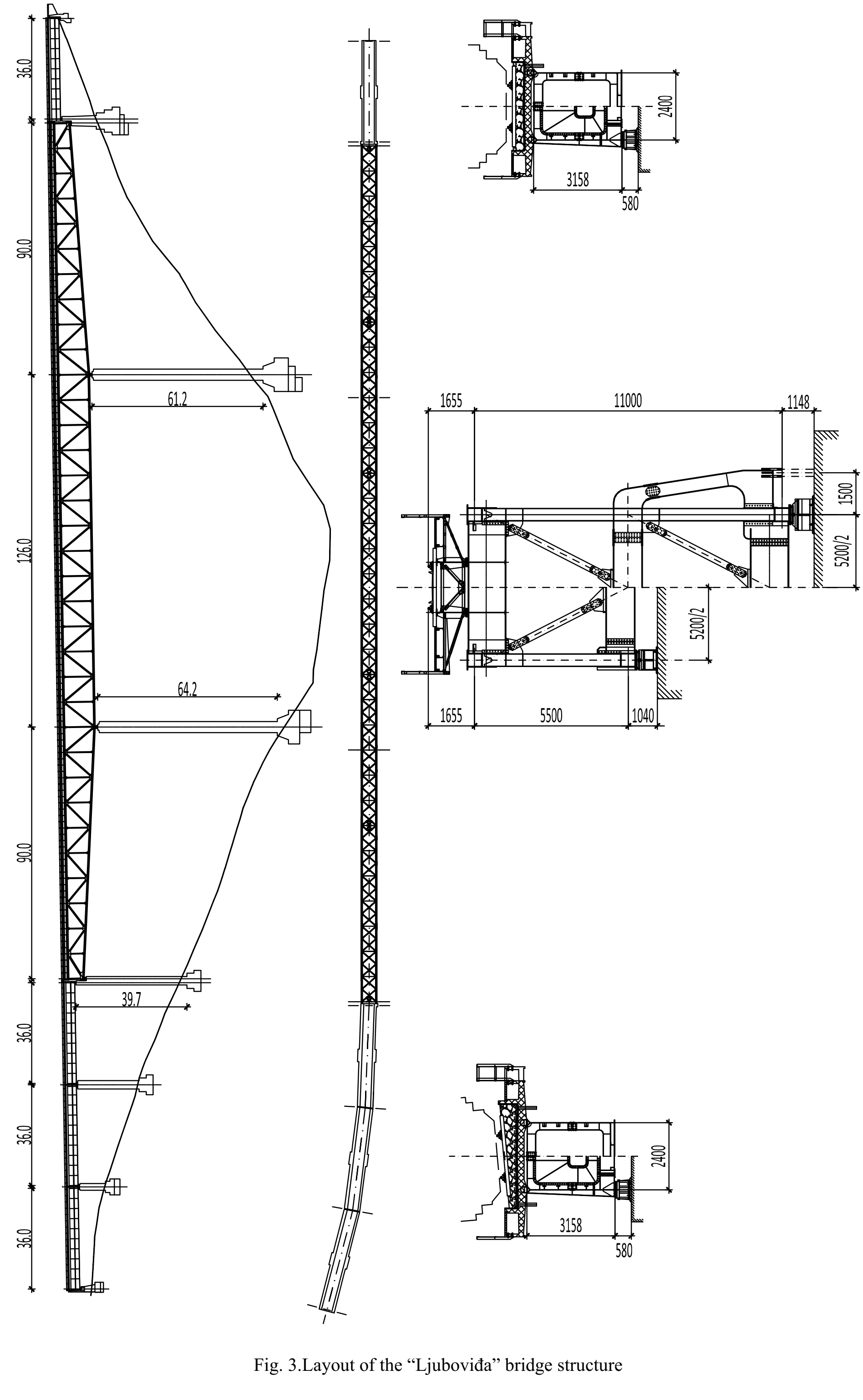

Fig. 3.Layout of the “Ljubovida” bridge structure

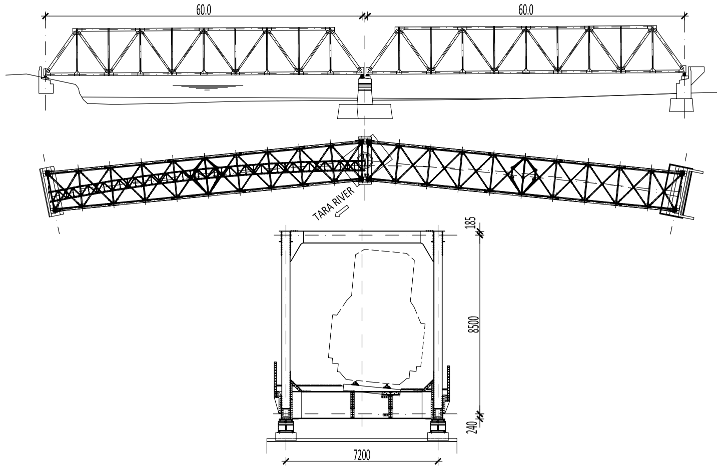

Fig. 4.Layout of the “Tara I” bridge structure

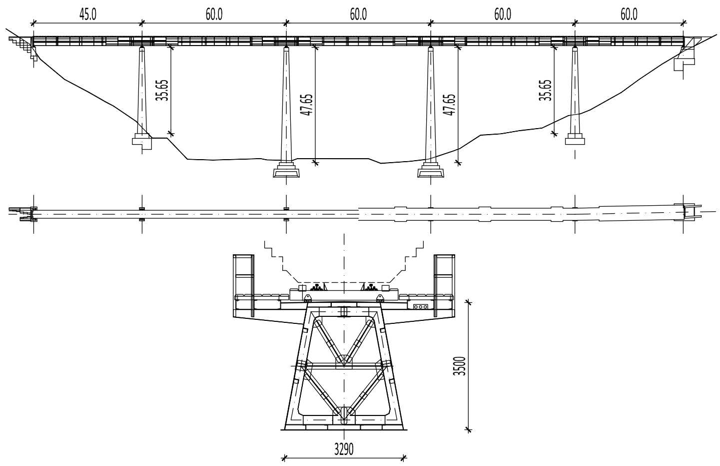

Fig. 5.Layout of the “Tara III” bridge structure

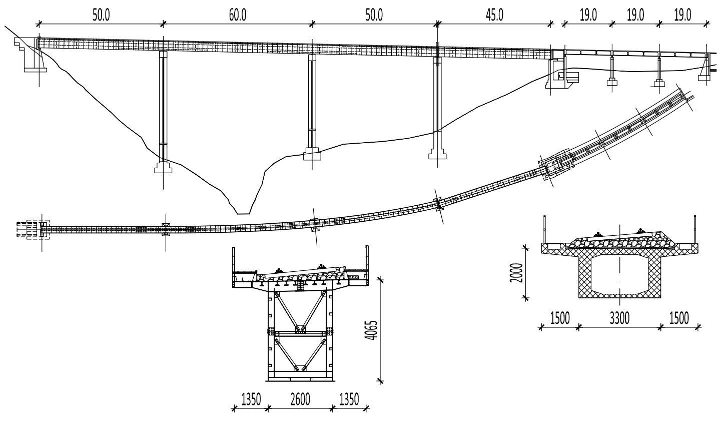

Fig. 6. Layout of the “Vuce Potok” bridge structure

3. STUDY ON BRIDGE CONDITION

Based on the existing technical documentation that has been provided by Montenegro railways (ZICG), all necessary basic data were prepared, and after visiting the sites, the programs for the inspection of a bridge structures were composed. During the inspection of structures, thorough visual inspection was conducted, including photographing and documenting the observed damages. Control compliance of structures with existing technical documentation regarding the spans, the system, cross sections and quality of built-in materials was also made. Observed damages are mainly the result of poor maintenance of bridges, such as: leaking expansion joints, wet concrete zones at the expansion joints, leaking at the location of gullies, corrosion of the main girder, damages of the bearings, damaged concrete cover at the piers and abutments, deterioration of pedestrian sidewalks and railings.

Quality control of built-in material was carried out by non-destructive methods, namely: Brinell test for surface hardness of steel material and examination of concrete surface hardness by Schmidt hammer. Deviations from the vertical position of the rollers at movable bearings were measured. Structure temperature was also observed, in order to determine whether the bearings were placed in the designed position and that they provide sufficient capacity for displacement. During inspection, compliance of a structure with existing technical documentation was compared, and all changes made during construction as well as interventions during exploitation period were registered. Based on that information, technical documentation of the current state of constructions was made.

Within the Study on Bridge Condition, the verification of the adopted structural model and preliminary static analysis were carried out. Bridge structures were modeled by two-dimensional or three-dimensional linear models whose geometrical characteristics corresponded to the geometric characteristics of the structural elements cross-sections. Material properties are entered according to data from the Main Design [1].

During 1976, load testing of structures were carried out. Positions of testing load were adopted so as to create the maximum impact in the observed cross-sections of the structure. Load testing involved measuring the deflection of structures, strain in elements of the structure and dynamic characteristics of structures. In order to verify the adopted structural model, the behavior of the structure under test load was simulated in software package Tower 3D Model Builder. Comparing the calculated and measured values of deformation and strains led to the conclusion that the adopted structural models give acceptable results and information of structures.

Section forces calculated within the preliminary static analysis deviate no more than 3% compared to the same section forces from the Main Design, which indicates that the bridge structures were built according to the Main Design technical documentation [1].

Hereinafter we will give a brief overview of the performed analysis.

Calculation of section forces and natural frequencies were carried out in structural models, which have been verified within the Study of Bridge Condition, as was described in the previous chapter. The calculation was conducted according to the first order linear-elastic analysis.

All loads according to the standards EN 1991-1 and EN 1991-2 were considered. In the analysis of the loads and stresses, erection phases of constructions were taken into account. Load models for railway traffic actions have been adopted based on EN 1991-2, while for the action of real trains, load models C4 and D4 have been used. The input data for the calculation of wind load, snow load, seismic load and temperature were obtained by Institute for Hydrometeorology and Seismology of Montenegro. Load combinations for ultimate limit state and serviceability limit state were formed according to standard EN 1990.

Serviceability limit state included control of natural vertical frequency and horizontal displacement according to the standard EN 1991-2, as well as control of natural horizontal frequencies and deflection of structures according to EN 1990.

Ultimate limit state control and check of structural elements stability indicated a need for strengthening of steel elements, concrete piers and fixed bearings. The differences in the resistances of the sections according to the Main design [1] and the resistances according to the Rehabilitation Design [2] are the result of the changes in partial safety factors for design loads and yield strength reduction. Strengthening of fixed bearings and concrete piers occurred as the result of the fact that the technical regulations, valid at the time when Main Design was made, considered lower values of actions due to traction and braking, as well as for the seismic loads than the ones in the currently valid regulations which are used in Rehabilitation Design.

Fatigue assessment of structural members showed that some steel structure has insufficient fatigue capacity for designed working life. Since, during the visual inspection no cracks were noticed in the critical elements of the bridge, it was concluded that the real traffic on the bridge was not as dense as the Technical Service of Railway Infrastructure of Montenegro had estimated. Within the Bridge Monitoring Concept Design, measuring points were determined, which should be used to observe the behavior of the critical elements of the bridge.

4. THE REHABILITATION DESIGN

Structural analysis within the Rehabilitation Design was carried out in full accordance with the EN-Eurocodes, as specified in the Terms of Reference. Studies on Bridge Condition and static analysis within the rehabilitation design are elements on which was determined the scope of work on the rehabilitation of structures, in order to meet the requirements of the terms of reference.

All the necessary works, needed to bring bridge structures in the condition defined by Terms of Reference, have been included in the Rehabilitation design. At almost every bridge, following works are foreseen: replacement of expansion joints and the rehabilitation of main girders in the zone of expansion joint, rehabilitation of gullies and zones around them, rehabilitation of concrete piers surface and concrete surface protection, repairing or replacing sidewalks and steel railings, corrosion protection of steel parts of structure, servicing or replacement of bearings, additional securing of fixed bearings, making of new ventilation openings at the main box girders.

Structurally, at the bridge Tara III, buckling of vertical webs which are caused by design errors in Basic design, required structural strengthening, by adding new transverse frames as well as longitudinal stiffeners of vertical webs and box girder bottom plate in the zones of middle supports. At the same bridge, strengthening of bearing support plates is also foreseen. Similarly, at the bridge Lim III, the longitudinal and transverse strengthening of vertical ribs is foreseen. All work must be performed under the partial closure of traffic.

5. CONCLUSION

Age of steel bridges on the railway line Vrbnica - Podgorica is 40 years. Works on the rehabilitation and strengthening of Bridge structures emerged as a result of lack of maintenance and due to the changes in Technical regulations.

Rehabilitation design foresees: repair and replacement of damaged parts of the structure; restoration of anti-corrosive protection; stabilization of terrain; straitening of structural elements; establishing maintenance with modern monitoring system; implementation of device for seismic insulation at the bearings of the bridge (“construction control”), in the zone of high seismic hazard and risk. Implementation of Rehabilitation design will ensure safety, stability and structural integrity for the designed working life of bridges.

References

[1] Main Design of Railway Bridges1968-1975: over River Lim; over River Ljubovidja; over River Tara; “Vuce potok”; “Krusevacki potok”; “Dubocica”, Department of Design Community of Yugoslav Railways, Belgrade

[2] Development of the Main Design for Rehabilitation (Rehabilitation and Anticorrosive Protection) of 15 Steel Bridges on the Railway Line Vrbnica – Bar, Montenegro- iC consulenten Ziviltechniker GesmbH, Vienna; Mostprojekt a.d., Belgrade; DB Inzenjering d.o.o, Belgrade