

Lifetime extension of existing steel bridges

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Abstract. Prolonging the life of existing steel trusses all over the world is an incoming necessity for all managing authorities wherever these structures have reached a particular state of use. The unsatisfactory behavior of these structures under the current type and increasing number of loads make clearer that innovative solutions are needed. For this purpose, the realization of composite decks is needed, in order to redistribute the common actual load onto a structure conceived with historical codes, characterized by lower design live loads. The possibilities of retrofitting bridges with this solution studied in a recent research program are presented and compared in this study. Increasing traffic density and vehicle weight have been increasing in recent decades. Many existing truss bridges, all over the world, were not designed for the high service loads and the increased number of load cycles that they are exposed to today

1. Introduction

The increasing traffic density and vehicle weight have been increasing in recent decades. Many existing truss bridges, all over the world, were not designed for the high service loads and the increased number of load cycles that they are exposed to today. Some bridges will have to be either strengthened or replaced in the next decades. As late as the 1980s, steel truss bridges in Europe were often constructed with a non-composite concrete slab on top of steel girders. Different alternatives of interventions for truss bridges are presented in this paper, according to the different truss type to be reinforced. Sometimes the bridge should be retrofitted by deck replacing, other times a new structural configuration should be adopted, or in some cases only little interventions are needed in order to strengthen a truss. This paper presents a brief overview of different alternatives to strengthen existing trusses, ever considering the optimization of costs and material savings.

2. Strengthening old truss road bridges

The investigated structure is a two-lane roadway steel bridge truss. The overall bridge length is 120 m through three spans (40 m each one). The superstructure consists of riveted built-up truss members. Lower chords are inverse T-shaped sections, diagonals and upper chords are C-built-up elements with battens (stiffening brackets), while struts are I-section shaped built-up elements composed of four L-shaped elements and a plate. The deck is realized with longitudinal stringers and transverse floor beams. The floor beams have a fixed distance of 4 m, while the stringers are at 1.15 m one to the other. Top and bottom double-L bracings provide adequate stiffening of the structure. Built-up members, realized with plates, L-profiles or C profiles, are connected by hot riveting and connection joints are made of gusset riveted plates. The main structure and the member details have been completely revealed by an on-site geometrical survey. The bridge structure was modeled using the



finite element method (FEM) software Midas (2005), using only beam elements. Rigid links (rigid body) were used to represent eccentricities of the elements. Overall, the entire bridge model consists of about 2000 beam elements. A Young's modulus of 210,000 MPa (N/mm²), Poisson's ratio of 0.3 and a material density value of 7850 kg/m³ (weight density of 76.98 kN/m³) were used for the analyses. All beam member sections were modeled as the as-built structure, as measured during the geometrical survey. The bridge is subjected to permanent loads, such as the self-weight of steel elements and of nonstructural elements and to variable loads such as temperature and traffic. At first, the bridge was checked referring to the Italian Ministerial Decree 09/06/1945, n. 6018 (DM 6018, 1945) and then to current Italian and Eurocode. Historical tests on the bridge have been used to calibrate the FEM model. In this study, retrofit alternatives chosen from the following solutions are considered:

- a. making composite an existing non-composite deck;
- b. building an orthotropic deck;
- c. building a new concrete deck, directly connected to the main trusses.

All these strategies are normally combined with steel- only interventions (including cover-plating, element replacement). The described procedures are finalized to redistribute the live loads adequately onto the deck with a new or modified deck. As can be observed in the following, the beneficial use of a rigid deck is often the best solution able to extend the bridge life adequately. In the case of Italy, the bridge category shifts from the 1st to the 2nd class:

- AD1 Load, 1st category: Load Model 1, EN 1991- 2:2003 or
- AD2 Load, 2nd category: Load Model 1, EN 1991- 2:2003 taking a reduction of 20% for all loads of Lane number 1.

In the present study, the reference retrofit solutions considered are:

- BR00) The existing bridge is calculated with the historical live load, HS-LOAD, without any retrofit intervention;
- BR01) The existing bridge is calculated with the actual code live load, AD1-LOAD, without any retro- fit intervention;
- BR02) The existing bridge is calculated with the actual code live load, AD2-LOAD, without any retro- fit intervention;
- RROOR1-2) The bridge is retrofitted with the introduction of an orthotropic deck laying between stringers, with open ribs considering both the AD1- Load and AD2-Load;
- RROCR1-2) The bridge is retrofitted with the introduction of an orthotropic deck laying between stringers, with closed ribs considering both the AD1- Load and AD2-Load;
- RRA1-2) The bridge is retrofitted with the introduction of a concrete deck considering both the AD1- Load and AD2-Load; welded shear studs are introduced in the bridge to connect the new concrete deck with the stringers (three $\square 20$ mm studs/m along all stringers, except for stringers along sections 1, 9–13, 19–23, 29–31 where six $\square 20$ mm studs/m have been placed); a parametric analysis is developed varying both the concrete deck thickness (with a fixed strength of C40/50) among 10 cm (RRA1, 2–10), 15 cm (RRA1, 2–15), 20 cm (RRA1, 2–20), 25 cm (RRA1, 2–25), 30 cm (RRA1, 2–30) and the deck concrete strength (fixing the deck thickness at the lowest value of 10 cm) among C30/37 (RRA1, 2-R1), C35/45 (RRA1, 2-R2), C40/50 (RRA1, 2-R3), C45/55 (RRA1, 2-R4), C55/67 (RRA1, 2-R5);
- RRA1-2-I) The bridge is retrofitted with the introduction of a concrete deck considering both the AD1- Load and AD2-Load, fixing the concrete strength at C40/50 and the deck thickness at 100 mm; moreover, the steel-to-steel intervention -cover plating- are introduced adopting S355 new members;
- RRB1-2-I) The bridge is retrofitted with the introduction of a concrete deck considering both the AD1- Load and AD2-Load, introducing a UHPC concrete of C90/105 strength class and fixing the deck thickness at 50 mm; moreover, the steel-to-steel intervention -cover plating- are introduced adopting S355 new members;

- **RRC1-2-I)** The bridge is retrofitted with the introduction of a concrete deck considering both the AD1- Load and AD2-Load, introducing a UHPC concrete of C150/160 strength class and fixing the deck thickness at 30 mm; moreover, the steel-to-steel intervention are introduced adopting S355 new members. According to the analysis performed, the optimal solution is represented by the RRB1-I, which has been compared in terms of utilization rate to the main solution described above (maximum ratios E_d/R_d defined as the minimum safety factor of all ultimate limit state-ULS checks).

Figure 1. The road-bridge over the river Adige.

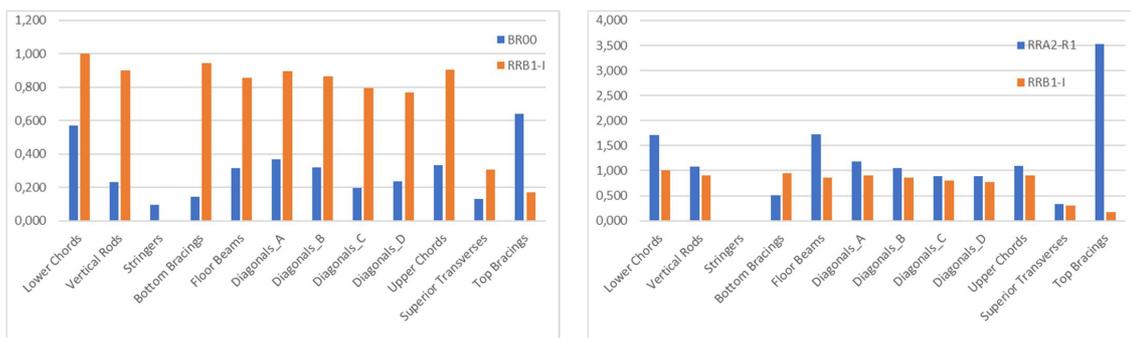
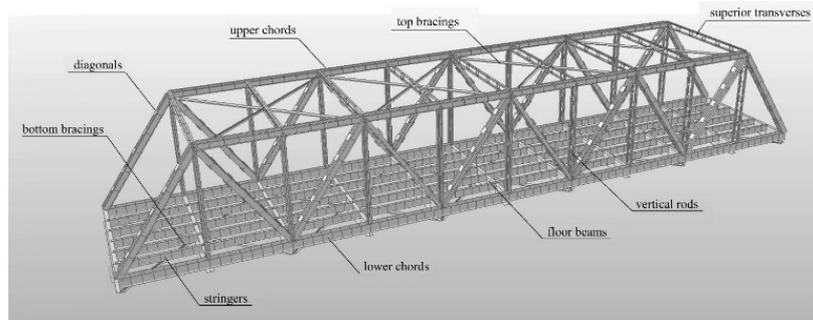


Figure 2: Comparison of B00 vs. RRB1-I model (on left) Comparison of RRA2-R1 vs. RRB1-I (on right)

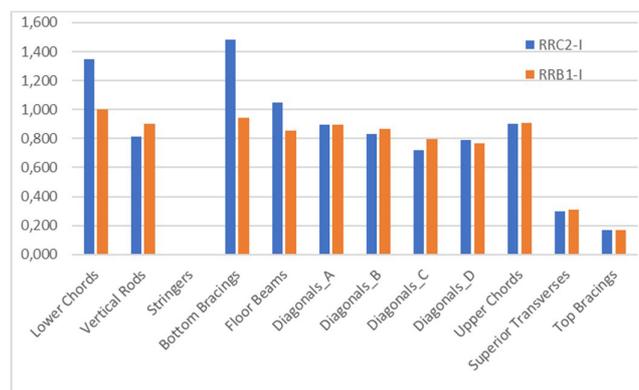


Figure 3: Comparison of RRB1-Ivs. RRB1-I model.

3. Strengthening for fatigue induced damages in trusses: a parametric analysis

Traffic running on bridges produces a stress spectrum that may cause fatigue damage. This stress spectrum depends on the geometry of the vehicles, the axle loads, the vehicle spacing, the composition of the traffic, and its dynamic effects. However, the increasing loads on truss bridges (magnitude and

quantity), both railways and roadways, imply the increasing accumulation of damage in iron or steel member, that could lead to sudden failure. A parametric analysis has been performed onto two existing bridges in Italy, the case study of the par. 2.4 (Br1) and the railway Adige bridge (Br2), in order to check which are the more suitable and effective solution for bridge repair, in order to prolong their fatigue life. After the retrofit solution proposed, all bridges are checked according EN1993-1-9:2005. The following solutions have been considered:

- RRF1: the bridge is retrofitted with the introduction of a concrete deck, made of UHPC concrete; the cover-plating technique is adopted in hot spot fatigue stresses;
- RRF2: the bridge is retrofitted with the introduction of a concrete deck, made of UHPC concrete; hot spot stress truss-nodes are encased in new UHPC nodes;

For every RRF_i (i=1, 2) retrofit solution, a limit of adding no more new material than the 25% of the original weight of the bridge is fixed.

For railway bridges, an unballasted solution is provided for RRF1-RRF2.

A wide number of other parameters are varied in order to analyze the sensitivity of the model to these variations. According to the analysis performed, the optimal solution depends on the bridge type, which has been compared in terms of utilization rate to the main solution described above (maximum ratios E_d/R_d defined as the minimum safety factor of all ultimate limit state-ULS checks).



Figure 4. The railway bridge over the river Adige.

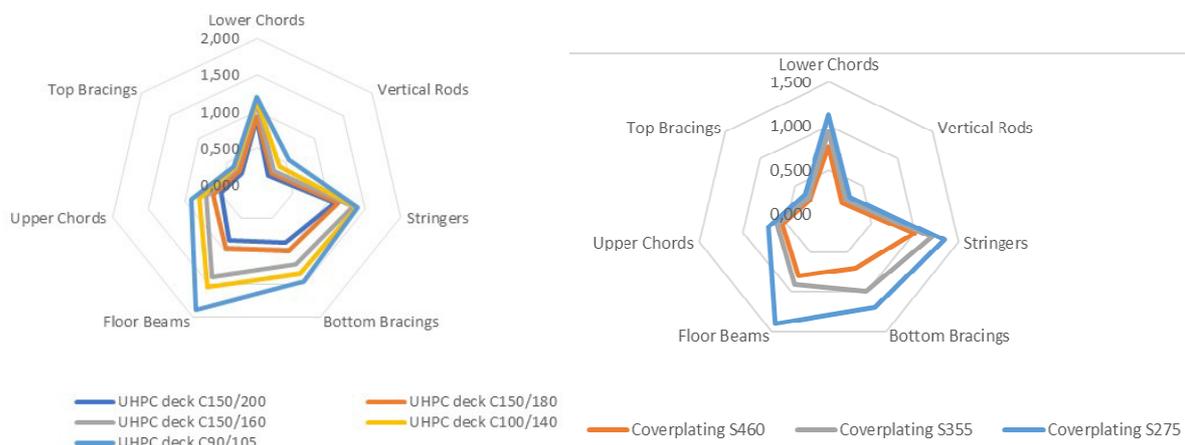


Figure 5: RRF1-Br1 model, E_d/R_d values: variation of the deck UHPC strength class, 50 mm thickness; cover-plating with S275 steel grade (on left), RRF1-Br1 model, E_d/R_d values: variation of the cover plating steel strength class; UHPC deck grade C150/160, 50 mm thickness (on right).

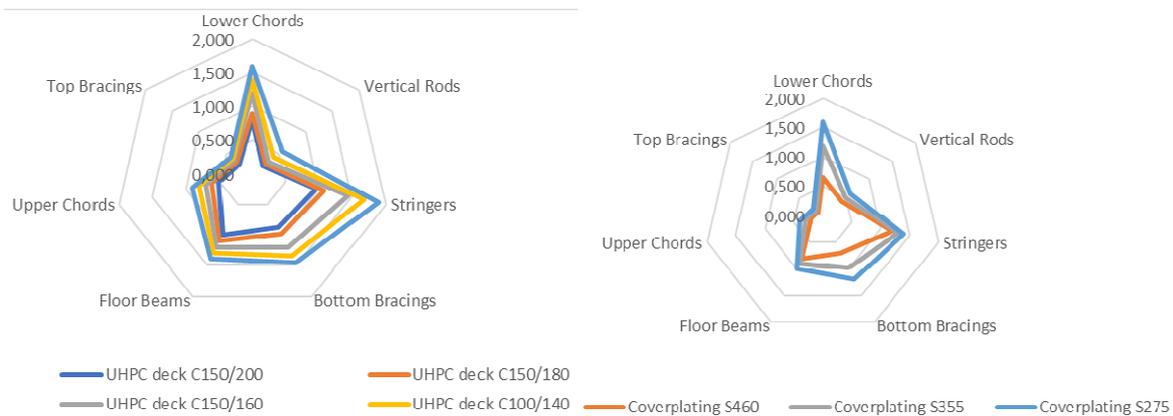


Figure 6: RRF1-Br2 model, Ed/Rd values: variation of the deck UHPC strength class, 80 mm thickness; cover-plating with S275 steel grade (on left), RRF1-Br2 model, Ed/Rd values: variation of the cover plating steel strength class; UHPC deck grade C150/160, 80 mm thickness (on right).

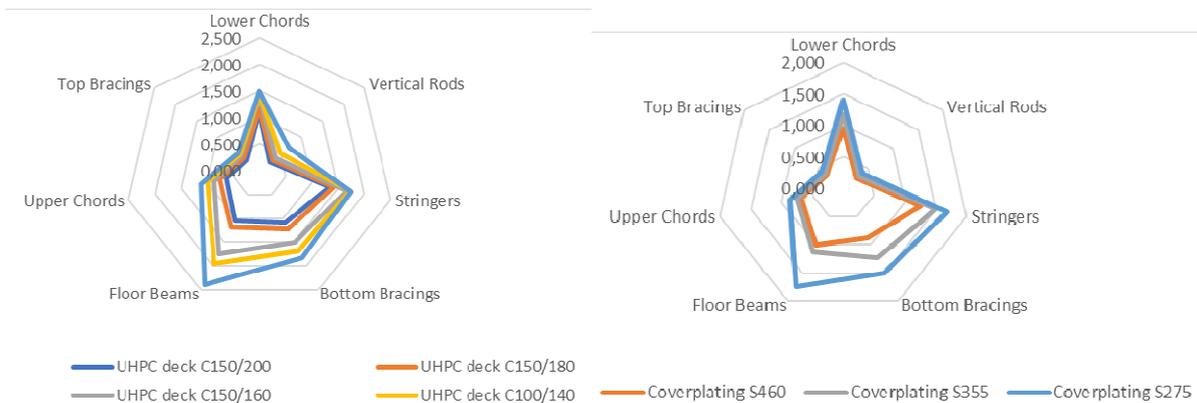


Figure 7: RRF2-Br1 model, Ed/Rd values: variation of the deck UHPC strength class, 50 mm thickness; cover-plating with S275 steel grade (on left), RRF2-Br1 model, Ed/Rd values: variation of the cover plating steel strength class; UHPC deck grade C150/160, 50 mm thickness (on right).

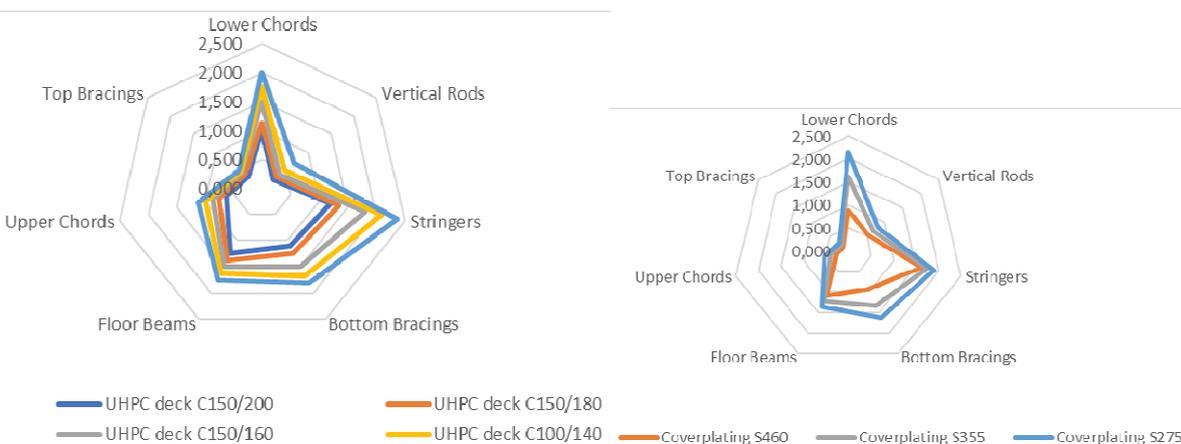


Figure 8: RRF2-Br2 model, Ed/Rd values: variation of the deck UHPC strength class, 80 mm thickness; cover-plating with S275 steel grade (on left), RRF2-Br2 model, Ed/Rd values: variation of the cover plating steel strength class; UHPC deck grade C150/160, 80 mm thickness (on right).

4. Conclusion

In this paper different strategies in order to prolong the lifetime of existing steel truss bridges have been presented. The study presented a parametric analysis to prolong the fatigue strength of existing bridges, to discover the most suitable retrofit solution, and to compare different retrofit techniques. As a matter of fact, the whole solutions presented are finalized to demonstrate that it is possible to prolong the life of existing trusses, with the innovative techniques illustrated herein.

Acknowledgments

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