Progetto DPC-ReLUIS 2022-2024 WP 5

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

Task 5.4 Interventi di miglioramento ed adeguamento di ponti esistenti

Study of the mechanical behavior of half-joints in reinforced concrete bridges: from the assessment to the optimization of the strengthening techniques

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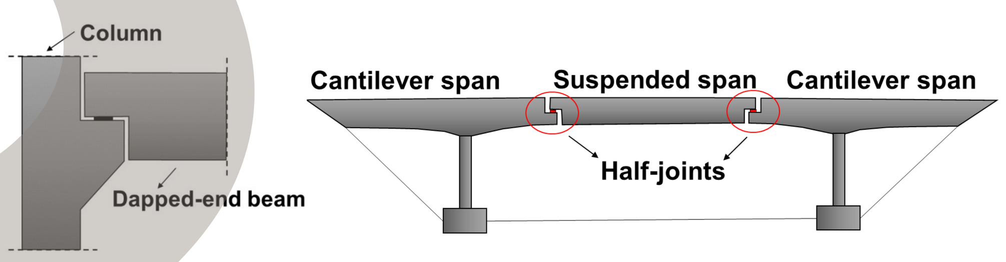
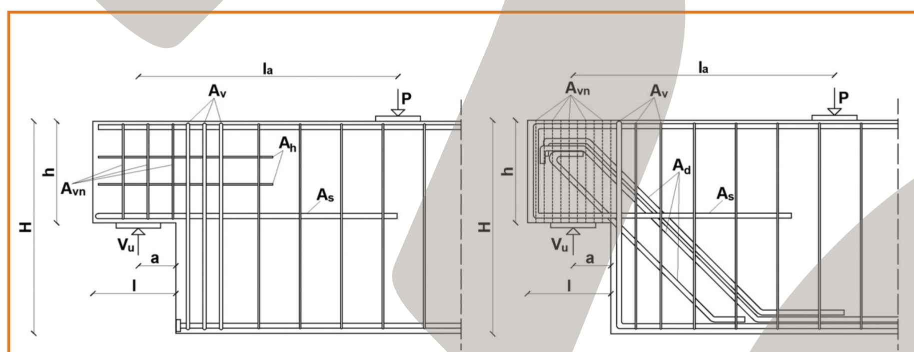
Abstract

The research aims to investigate and deepen the degradation in reinforced concrete bridge structures and the most vulnerable structural components, in order to carry out residual capacity assessments of existing structures and design repair and/or strengthening interventions. The research activity has focused on the study of Gerber saddles (half-joints). These represent the connection elements between the cantilever and the supported spans of a Gerber bridge and, due to their position and configuration, are considered critical points, both in terms of durability and static behaviour. The research was initially conducted through an in-depth analysis of the most commonly used construction details of these elements to deepen their static behaviour under failure conditions. Subsequently, a state-of-the-art review of the main intervention techniques available in the literature, for improving the performance of such elements both during operation and at the ultimate limit state, was carried out. Finally, one of the analysed strengthening techniques was selected to further investigate its performance through the implementation of nonlinear finite element numerical simulations on different case studies.

Half-joints (or dapped-end beams) are widely used for their advantages in terms of construction speed in the horizontal elements, roofs and/or flooring, of prefabricated buildings. In the past, they were extensively employed within cantilever bridges to connect cantilever spans with supported spans, exploiting the benefits associated with using an isostatic rather than a hyperstatic scheme.



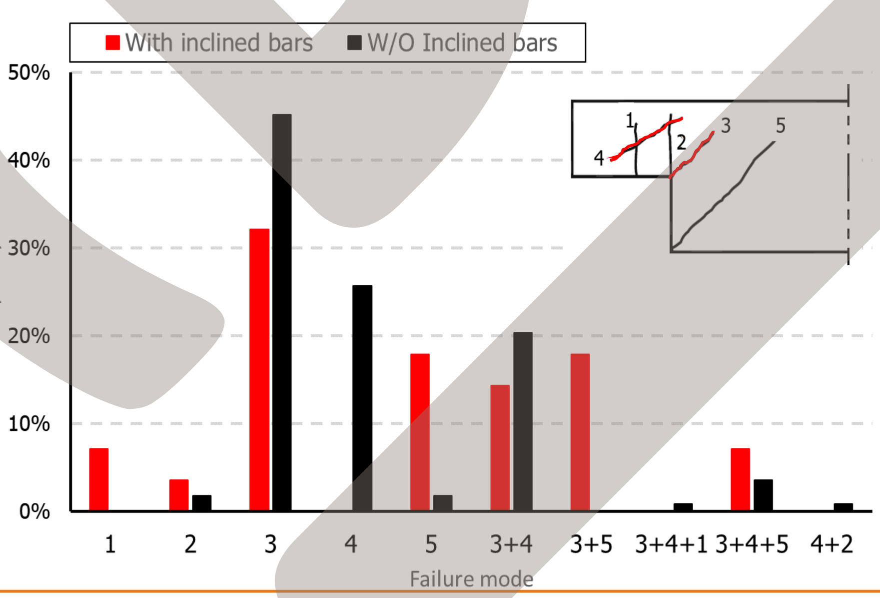


Structural details and failure modes

Due to their geometry, half-joints represent a discontinuity zone from the perspective of stress distribution. Moreover, regarding the construction detail, the arrangement of reinforcements necessary for external load absorption can vary. The most commonly used reinforcement layouts are two: the first is mainly related to building structures, where only vertical and horizontal rebars are used, and the second also involves the presence of inclined reinforcements, which are widely used within the Gerber saddles of existing bridges.

Regarding the ultimate behaviour, it is worth emphasizing that there can be different collapse modes depending on the adopted reinforcement layout. A review of experimental research on half-joints has been conducted, which allowed the collection of 210 experimental tests on dapped-end beams. Regarding the failure mode, it was possible to attribute the collapse to one of the five types indicated in the PCI Design Handbook (2010) or a combination of them.

In the presence of inclined rebars, the most frequent failure mode is associated with a combination of modes 3 and 4, while pure mode 4 is almost absent. In the absence of inclined reinforcements, the tested dapped-ends mostly failed through modes 3 and 4 or a combination of them. Therefore, the presence of inclined reinforcements seems to prevent failure mode 4 related to shear stresses in the nib.



Durability problems

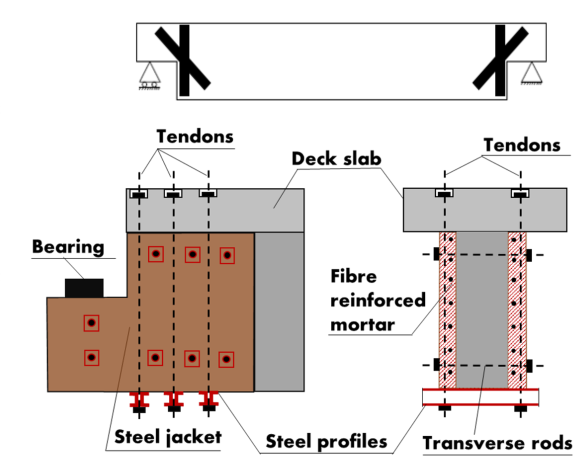
A frequent problem related to this kind of bridge is the malfunctioning of drains, which causes seepage across expansion joints. In particular environmental conditions, the presence of chloride ions may enhance the degradation phenomena leading to reinforcement corrosion and consequent cracking and spalling of concrete.

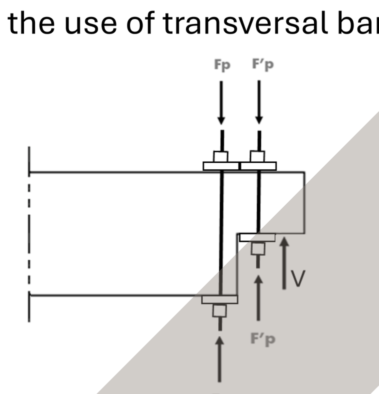
Another issue is related to the very narrow space in correspondence with the joints' position, which causes difficulties in inspections leading to incorrect quantification of degradation.

In the literature, there are cases of bridge collapses related to the half- joint failure. One is related to the Gerber bridge overpass in Annone Brianza (Italy), which collapsed in 2016 following the passage of a 108-ton truck. In that case, the deterioration of the half-joints and damage already present on the bridge coupled with some design and construction flaws were responsible for the collapse.

Strengthening techniques

In the literature, there are intervention techniques developed and tested on the half-joints properly belonging to bridge structures, and techniques more suitable for dapped-end beams often used on the roofs and floor systems of prefabricated buildings. Some techniques are based on the use of composite materials in the form of plates, laminates or fabrics bonded externally to the surfaces of the half-joints. The most commonly used solutions are CFRP or FRP polymer. A technique able to intervene on the deteriorated concrete of the half-joint, provide an increase in strength and, at the same time, provide protection against long-term degrading agents consists in the realisation of a steel jacketing system bonded to the lateral surfaces of the half-joint through the use of transversal bars.

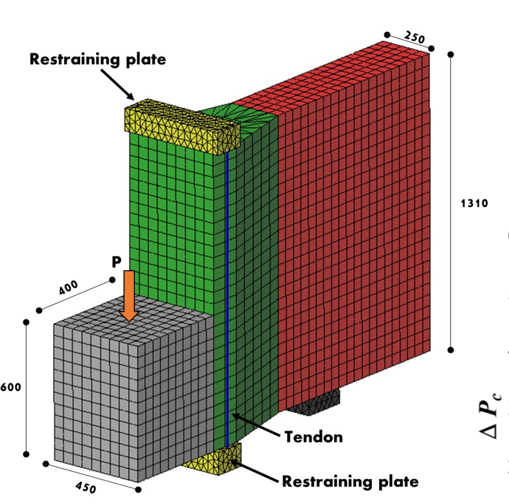


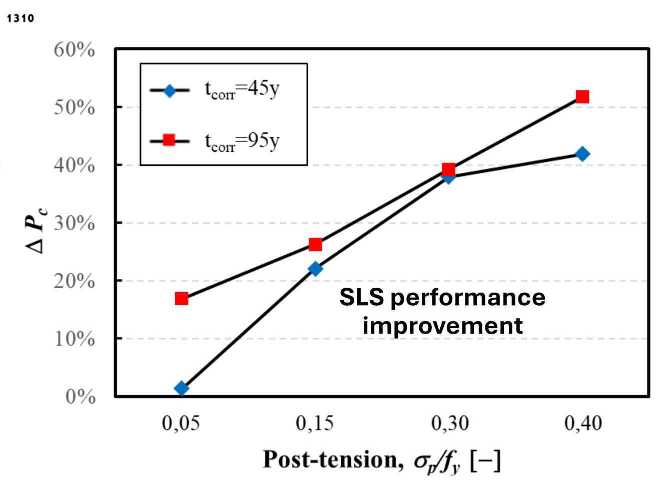


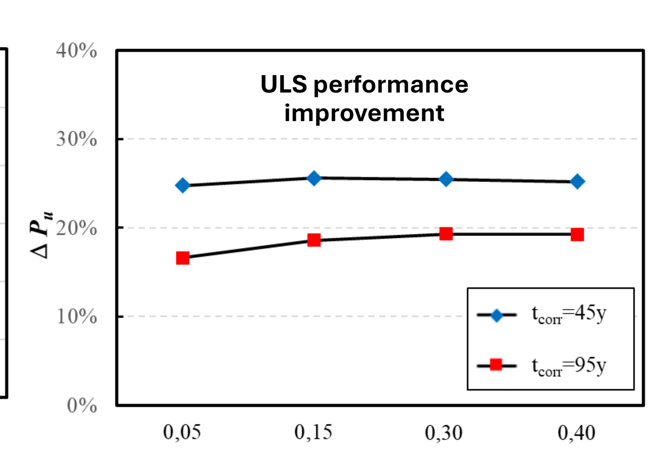
On the other hand, a non-invasive and easy technique consists of the use of high-strength post-tensioned bars installed along the undapped part of the half-joints in a vertical or inclined direction, in order to increase the load-bearing capacity of the half-joint. The only installation operation consists of drilling holes on the side of the joints, through the curb or transverse beam, if present, for the positioning of the bars. The main objective of this technique is to provide an increase in the load-bearing capacity of the half-joint and, in addition, the prestressing action also favours the limitation of cracks during service conditions.

NLFE analyses on a case study bridge

Further numerical analyses were conducted to assess the effectiveness of the intervention technique by simultaneously simulating degradation conditions caused by reinforcement corrosion induced by the presence of chlorides resulting from the use of de-icing salts. In this case, a representative model of one of the half-joints within the deck of the Musmeci Bridge located in Potenza was developed. In this particular bridge, the deck is supported by a double-curvature RC vault designed through a form-finding study devoted to optimising the stress flow and exploiting the concrete ability to support compression stress fields. In addition to considering degradation conditions for different periods, the presence of inclined reinforcements was also accounted for as an additional analysis parameter. In fact, the half-joints of the Musmeci Bridge were designed using inclined reinforcements, whereas in previous cases, the tested specimens were provided with only orthogonal bars. The results of these analyses showed that the intervention is most effective when implemented after 45 years of corrosion development, not only restoring the joint's load-bearing capacity to the as-built condition but also increasing it. Conversely, if the intervention is applied following 95 years of degradation, only the share of strength lost due to corrosion is recovered. Moreover, when the intervention is applied to half-joints designed with diagonal reinforcements, the increase in load-bearing capacity is lower under similar conditions compared to cases without them.

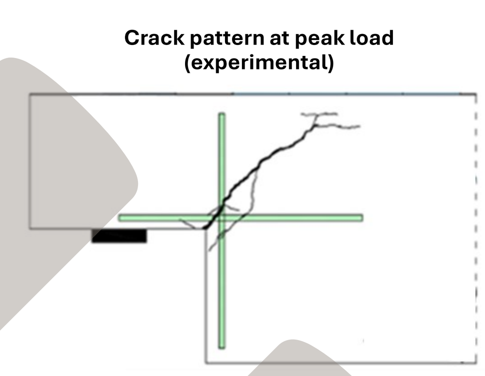


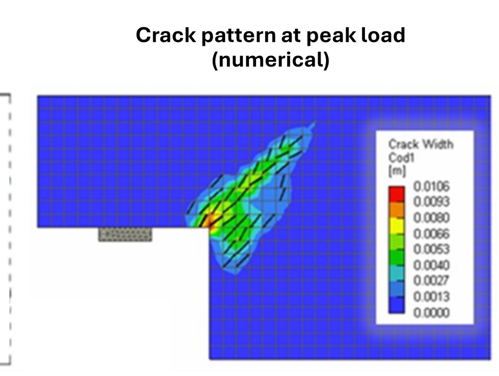




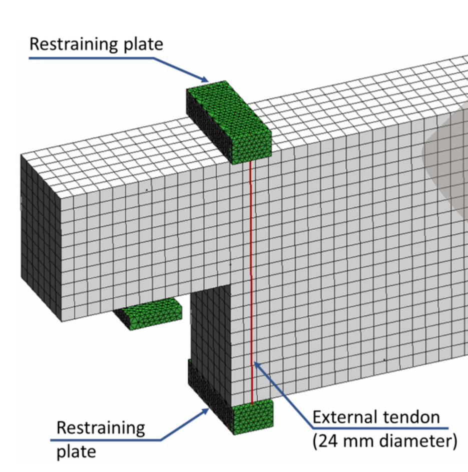
NLFE analyses on tested specimens

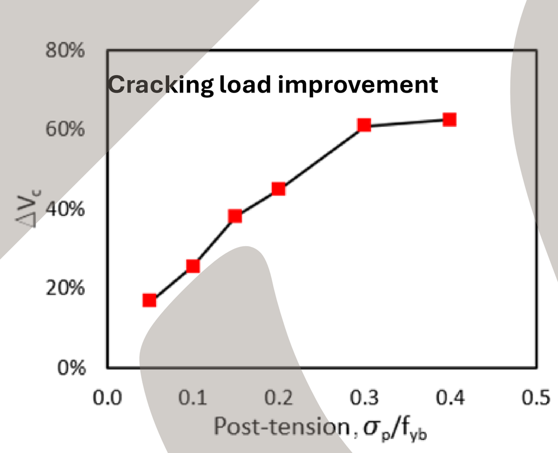
In order to assess the effectiveness of the post-tensioning intervention technique, non-linear finite element analyses were implemented. Specifically, an initial analysis was conducted to calibrate a model based on a literature experimental test on a dapped-end beam. The non-linear model successfully replicated the results of the experimental test, accurately reproducing both the failure load and even the specific cracks' distribution.

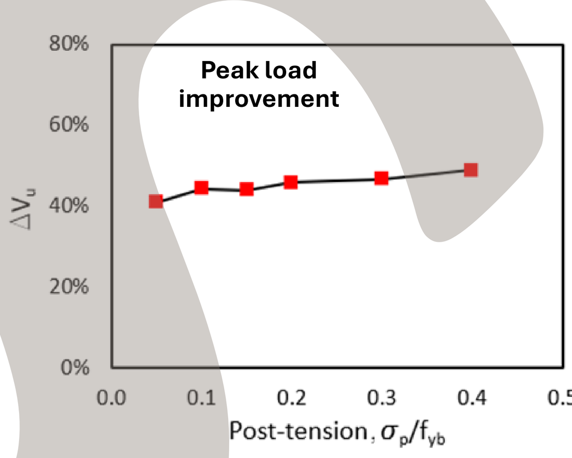




Once the numerical model was validated, the post-tensioning intervention was first designed and then implemented in the model, evaluating the performance enhancement both at the serviceability limit state and at the ultimate limit state by varying the prestress value in the tendons. In terms of results, it is observed that, as the prestress tendon increases, the load at first cracking (V_c) increases almost linearly, while the failure load (V_u) is not greatly affected by the applied prestress value, as nearly the same increment is achieved even for low values of the latter. Furthermore, the analysis of pre- and post-intervention failure modes allowed observing that the application of post-tensioning significantly reduces the crack width and changes their distribution, passing from a failure mode similar to type n°3 to one according to mode 2.

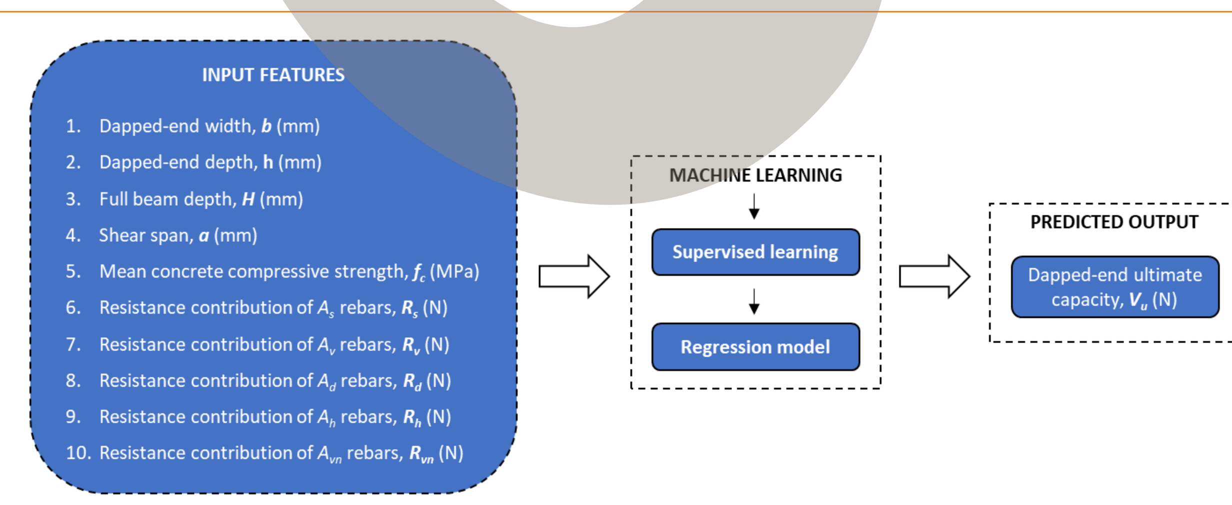






Conclusions and future developments: assessment through Artificial Intelligence

The safety and operation of RC cantilever bridges are strongly dependent on their half-joints. The latter, due to under-designed reinforcement details and degradation phenomena, can act as weak elements. Therefore, they require repair and strengthening interventions to enhance their life span, in order to prevent either traffic limitations or, more importantly, collapses. In this research project, the half-joint structural behaviour has been widely deepened, regarding typical detailing, failure modes, degradation, rehabilitation techniques and, finally, also implementing non-linear numerical analyses. Valuable information related to failure modes, which influence rehabilitation intervention choices, was obtained from a database of experimental tests purposely collected and analysed, allowing the identification of the most frequent ones, depending on the rebars' arrangement. As a further development, the collected database could be also used to train a regression model with Supervised Machine Learning techniques in order to predict the ultimate capacity of dapped-end beams.



Some published papers

- Santarsiero G, Picciano V. **Post-tension retrofitting of RC dapped-end beams: A numerical investigation**. Structural Concrete. 2024. https://doi.org/10.1002/suco.202300207
- Santarsiero, G., & Picciano, V. (2023). **Durability enhancement of half-joints in RC bridges through external prestressed tendons: The Musmeci Bridge's case study**. Case Studies in Construction Materials, 18, e01813. https://doi.org/10.1016/j.cscm.2022.e01813 (Open access).
- Santarsiero, G., Picciano, V. & Masi A. (2023) **Structural rehabilitation of half-joints in RC bridges: a state-of-the-art review**, Structure and Infrastructure Engineering, https://doi.org/10.1080/15732479.2023.2200759
- Picciano V., Santarsiero G., Masi A. & Digrisolo A. **Structural analysis of dapped-end beams through machine learning techniques**. IABMAS Conference 2024. Copenaghen

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