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Review and analysis of RC bridge half-joints strengthening techniques

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Abstract

In the past, the extensive use of the Gerber scheme in the construction of existing bridges has been justified by the advantages in terms of reduced stresses of the statically determined scheme and rapid execution. On the other hand, the presence of junction elements at the ends of the beams has over time led to a series of issues, especially related to their durability. In fact, the half-joints' geometric configuration leads to the accumulation of degradation due to platform water seepage, resulting in the initiation of reinforcement corrosion, especially in the presence of chlorides derived from de-icing salts used in the winter season. Furthermore, these elements have been designed for lower loads than those specified in current regulations, and therefore, they may be in critical conditions where the strength reduction, due to existing degradation, can lead to failure. For these reasons, local repairs and/or strengthening interventions are necessary to ensure adequate levels of safety. Within this study, the topic of reinforcing half-joints is addressed, first by describing the currently available intervention techniques in the literature, and then by deepening an intervention technique based on the use of external post-tensioned bars, applied to a case study bridge through nonlinear numerical simulations. These analyses allow quantifying the performance improvements of this technique under both service conditions and ultimate loads, considering various parameters, including the pre-stress value applied to the external tendons and different scenarios of chloride-induced corrosion.

Keywords: Bridge; Half-Joint; Repair; Rehabilitation; Degradation; Finite Element Analysis

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1. Introduction

Gerber saddles, also known in the literature as half-joints or dapped-end beams, are extensively used in roofs and flooring for prefabricated buildings and, in the past, were also used to connect the cantilever and the suspended spans of a Gerber bridge due to the advantages of having a statically determinate scheme rather than a continuous one. On the other hand, due to their position and configuration, they are considered critical points both in terms of durability and static behaviour (Kun et al. 2015).

The Italian Guidelines for the classification and management of risk, safety assessment, and monitoring of existing bridges (Ministry of Infrastructure, CSLP 2020) acknowledge Gerber saddles as critical elements since they are particularly susceptible to degradation especially in harsh climates, due to the use of de-icing salts (Bernal et al. 2016), or in coastal areas, due to sea waves or spray in the splash zone (Kim et al. 2020). The accumulation of degradation over time coupled with the difficulties in inspections, due to the narrow space between the two parts of the joint, may cause reinforcement corrosion (Fig. 1) and thus reductions of strength (Desnerck et al. 2018), especially in those bridges designed according to old codes which result under-designed respect to the current ones, up to failure in severe cases (Deng et al. 2016; Choudhury and Hasnat 2015).

Fig. 1. Accumulation of degradation on an RC bridge’s half-joint.

Additionally, due to their geometric shape, half-joints represent discontinuity elements in terms of stress distribution, leading to stress concentrations and high strength requirements (Mattock 2012). This latter is a fundamental aspect in the half-joints’ assessment within existing bridges, as it is necessary to understand past design methods and identify commonly used reinforcement details to deepen their static behaviour at failure. This is crucial for simulated design when project documentation is unavailable or incomplete.

For example, the structural behaviour at failure may depend on the particular reinforcement layout adopted. This is also highlighted in the study of Santarsiero et al. (2023) in which a literature review for the construction of a database of dapped-ends experimental tests has been conducted. Information gathered on geometric characteristics, material properties used in experimentation, details of reinforcements, mode of failure, and recorded individual specimen load-bearing capacity has allowed comprehensive behavioural analyses. These analyses have helped identify primary failure modes and correlate them with the specific reinforcement layout, differentiating the structural behaviour of half-joints with and without inclined reinforcements.

In the literature, two cases of bridge failures are linked to issues with half-joints. The initial incident involved the collapse of the de la Concorde overpass in 2006, located in Laval (Canada). The investigation committee attributed the collapse to a combination of deficiencies in design and construction, along with reinforcement corrosion triggered by degradation due to freeze-thaw cycles (Johnson et al. 2007; Mitchell et al. 2011). The second case pertains to the collapse of the Gerber bridge overpass in Annone Brianza (Italy) in 2016, caused by the passage of a 108-ton truck. Similarly, the deterioration of the half-joints and pre-existing damage on the bridge, coupled with design flaws, contributed to this collapse (Di Prisco et al. 2023).

Consequently, neglecting the degradation of half-joints inevitably leads to a reduction in the overall safety of the bridge. For this reason, it is imperative to execute local repairs and/or strengthening interventions to ensure adequate safety levels. Therefore, within this study, the intervention techniques currently available in the literature are initially briefly described, outlining their main advantages and disadvantages. Subsequently, a critical analysis is proposed concerning feasibility in the field and in terms of intervention costs. Following this, through nonlinear finite element numerical analyses, the application of a technique based on the use of externally anchored post-tensioned bars to an existing saddle is presented. The numerical analyses enable the quantification of performance enhancements of the half-joint under both operational conditions and the ultimate limit state, considering various parameters, including the pre-stress applied to the external bars and accounting for different scenarios of chloride-induced corrosion.

In this way, it is possible to provide useful information regarding the choice of the optimal value of post-tension according to the performance objectives to be achieved.

2. Repairing and strengthening half-joints

For the issues previously mentioned, addressing existing half-joints through repair and strengthening techniques is a crucial aspect for ensuring the safety levels established by the regulations across the entire road network. In this regard, a literature review has allowed the identification of currently available strengthening techniques related to half-joints, which are subsequently outlined. In particular, some techniques have been specifically studied for saddles within bridge structures, while others have been developed for dapped-ends within precast buildings. Moreover, these techniques may vary based on the materials used or the specific issue they address, which can differ depending on the cases under consideration.

One of the simpler and rather invasive techniques involves repairing the deteriorated parts of concrete through partial or total demolition of the half-joint, replacing corroded reinforcements, and reconstructing it using concrete suitable for aggressive environmental conditions (Kun et al. 2015; Smith 2005). This intervention necessitates the closure of the bridge to road traffic as the lifting of the suspended span is required to allow for the repair operations.

Another highly invasive technique involves making the cantilever and the suspended spans integral by completely removing the joint zone. This operation is carried out by connecting the upper and the lower half-joints using high-strength horizontal bars anchored to the existing concrete surfaces. The intervention, patented by Fukuoka (1999), implies a complete modification of the bridge's static scheme, transitioning from an isostatic to a continuous system. Consequently, it is necessary to design and install new bearing devices to absorb additional stresses arising from thermal deformations of the deck. This operation, in addition to increasing the invasiveness of the technique, also amplifies its costs.

A solution that simultaneously protects concrete surfaces from degradation due to external agents and enhances the performance of the half-joint involves coating the lateral concrete surfaces with a steel jacketing system anchored using transverse bars. This jacket protects the surfaces from deterioration, and by employing vertically post-tensioned bars anchored both above and below the saddle, it enhances its strength (Fig. 2a). Such an intervention was implemented on the Generale Franco Romano Viaduct in the Piedmont region (Italy) (Lafranconi et al. 2018).

The use of composite materials in the form of plates, fibres or fabrics represents a highly advantageous technique for reinforcing half-joints. These materials occupy a very low volume for the same increase in strength compared to other materials and adapt well to the confined spaces in the joint areas. The most commonly used materials are carbon fibre-reinforced polymer (CFRP) or fibre-reinforced polymer (FRP), which are bonded to lateral surfaces in various configurations, as illustrated in Fig. 2b. Taher (2005) and Nagy-György et al. (2012) experimentally tested dapped-end beams using these reinforcement materials applied in different forms and in various configurations depending on the inclination relative to the beam axis, achieving an increase in strength in the range of 17-42%. However, these relatively expensive materials cannot always be installed due to geometric limitations in cases where the lateral surfaces of the half-joint are not accessible.

The technique based on the use of external high-strength post-tensioned bars anchored both above and below the half-joint through suitable plates represents a solution that is easy to implement, cost-effective, and adaptable to any geometric configuration. Unlike previous techniques, it does not rely on the use of lateral surfaces, which may not always be accessible. Instead, the external bars can be installed and appropriately anchored simply by drilling holes in the existing concrete. This solution has been implemented on the saddles of some existing Italian bridges, such as the Scafa Bridge located in Fiumicino and the PRC Gerber Bridge near the town of Pieve Porto Morone (Alessandrini and Burba 1994; Di Prisco 2019). Furthermore, it has been experimentally tested. In particular, the use of external bars in various configurations (Fig. 3) was studied by Atta and Taman (2016) to investigate the increase in strength, resulting in a capacity enhancement ranging from 65% to 83% depending on the configuration used.

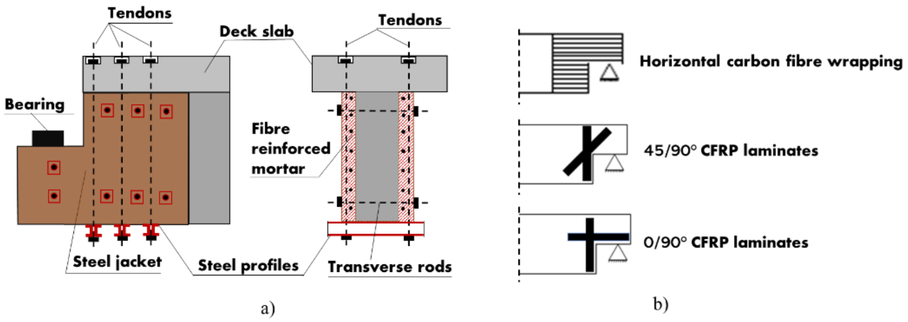


Fig. 2. (a) Jacketing system, adapted from Lafranconi et al. (2018); (b) example of externally bonded composites configurations.

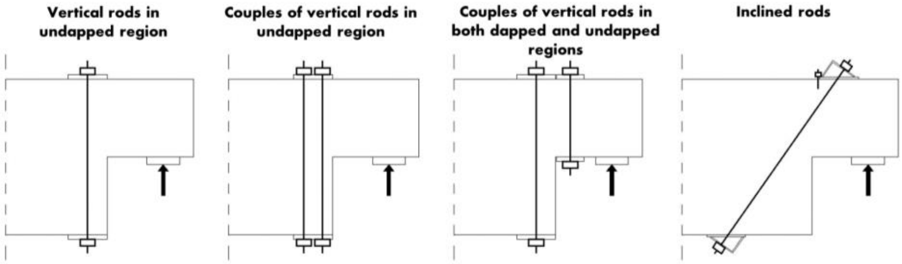


Fig. 3. Different post-tensioned solutions tested by Atta and Taman (2016).

The analysis of the advantages and disadvantages of each of the described techniques, along with the results of experimental tests conducted in the literature, enables the identification of a logical path for choosing the optimal technique. This decision can be based on the expected failure mode, desired performance level (such as crack width limitation or increased ultimate capacity), and applicability and/or invasiveness concerning the geometric configuration of the deck (Santarsiero et al. 2023).

Concerning the latter aspect, a substantial difference in the applicability of techniques is noted based on whether the half-joints at the ends of the longitudinal beams of a bridge deck are connected by a corbel or a transverse beam. This distinction affects the use of techniques along the lateral surfaces. Other techniques, such as the use of post-tensioned bars anchored to the upper and lower surfaces of the half-joints through appropriate plates, exhibit greater simplicity and adaptability to different geometric configurations.

Moreover, the need for preliminary local repairs (e.g., demolition and reconstruction of deteriorated concrete parts) involves lifting the deck portion supported by cantilever spans, resulting in longer construction times, traffic closure, and increased inconvenience to vehicle circulation. Quantifying these inconveniences allows the evaluation of both the cost associated with the intervention and the costs related to the bridge closure, considering that using alternative paths by private and commercial vehicles increases fuel consumption and travel delays.

In Santarsiero et al. (2023) these costs are computed and described in detail. For instance, analysing intervention costs reveals that the sole deck lifting operations account for approximately 30% of the total, with costs increasing based on the length of the deck to be raised~~.~~.

On the other hand, closure-related costs increase with the length of the alternative paths taken. Short deviations (5 km) may cost 1.5 times more than the intervention, while longer deviations (15 km) could be five times more expensive. Cost reduction is achieved by considering an intervention based on post-tensioning, which not only proves effective in enhancing performance but is also economical and straightforward to implement.

The comparison between the total intervention costs, considering a scenario where the deck lifting is necessary for preliminary repair operations and a second scenario where half-joints are strengthened using post-tensioned external bars, is illustrated in Fig. 4, for a Gerber bridge assuming different span lengths (20, 30, 40 m) and a carriageway width of 8.5 m. The Figure depicts costs as a function of the suspended span length (L) and as a function of the deviation length undertaken by vehicles (ΔL).

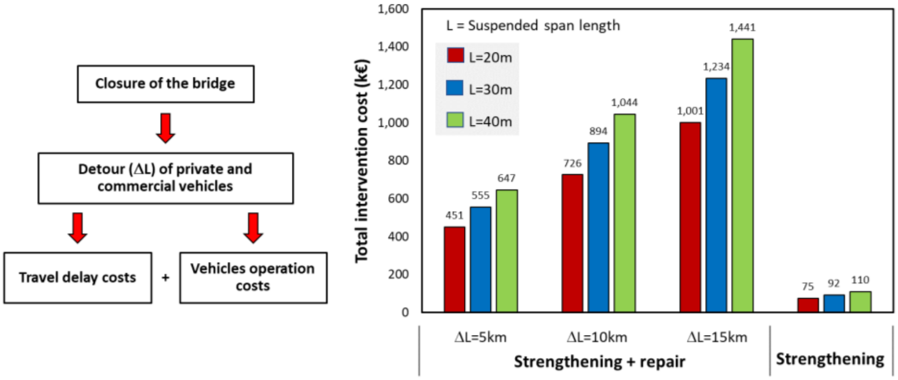


Fig. 4. Computation of the total intervention cost and comparison between two different scenarios (Santarsiero et al. 2023).

3. Numerical investigation of a post-tension intervention

In this section, an application of the intervention technique based on the use of post-tensioned external bars is presented through nonlinear numerical simulations. A refined finite element model of a half-joint of the Musmeci Bridge (Marmo et al. 2019) located in Potenza (Southern Italy) has been implemented to assess its structural behaviour following the intervention. The performance improvements provided by such a technique have already been discussed in the literature without considering some aspects, such as different responses when certain parameters vary. Based on this latter, the presented analyses have evaluated the performance improvements at both serviceability and ultimate limit state considering the external bars' prestress applied and different chloride-induced corrosion scenarios as parameters of the study.

3.1. Finite element modelling

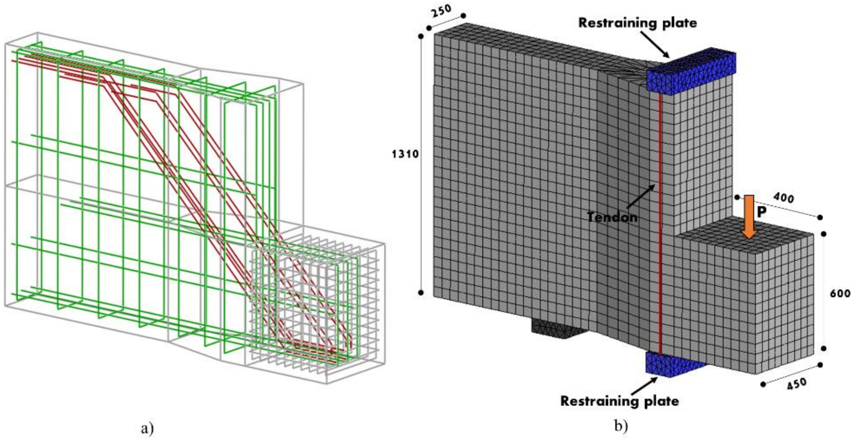
The software employed for finite element analyses is ATENA (Červenka et al. 2021), wherein the nonlinear fracture mechanics theory (Bazant and Oh 1983) is utilized to accurately reproduce the reinforced concrete behaviour under both compressive and tensile stress. Further details regarding the constitutive models adopted for steel and concrete materials are provided in Santarsiero et al. (2021).

Furthermore, the software allows for the simulation of reinforcement corrosion induced by chlorides through a mechano-chemical model based on the 1D chloride diffusion process within concrete as described by the second law of Fick (Zhang et al. 2010). The model is governed by three key parameters: the surface chloride concentration, the chloride diffusion coefficient, and the critical chloride concentration. Careful selection of values for these parameters has enabled the simulation of an aggressive chloride attack condition relevant to the use of de-icing salts on road bridges in harsh climates (Hájková et al. 2018; Angst 2019; Bertolini et al. 2004; Van der Wegen et al. 2012).

The modelling phases have been extensively described in Santarsiero and Picciano (2023) and are briefly summarized here. Concerning the nonlinear behaviour of concrete, the design compressive strength is equal to $f_{cd} = -17.24$ MPa, the design tensile strength is $f_{ctd} = 1.59$ MPa, the elastic modulus $E = 29{,}253.88$ MPa, and the fracture energy $G_F = 1.31\text{E-}4$ MN/m. The reinforcement layout of the half-joint is illustrated in Fig. 5a, comprising longitudinal and inclined bars with a diameter of 30 mm and stirrups with a diameter of 10 mm. The yielding strength of the bars is $f_{yd} = 375$ MPa, the ultimate strength is $f_{td} = 460$ MPa, and the failure strain ε_t is set to 18%.

Fig. 5b depicts the finite element model of the retrofitted half-joint. The intervention is made using 2 high-strength Dywidag external tendons with a diameter of 26.5 mm. These tendons have a yielding strength of $f_y = 950$ MPa and a failure stress $f_t = 1050$ MPa. They are constrained both above and below the half-joint through two plates with plan dimensions of 500x150 mm and thickness equal to 100 mm made of S275JR ordinary steel (EN 1993-1-1 2005; Ministry of Infrastructure 2018).

The structural behaviour of the retrofitted model was studied considering four different values of prestress applied to the external bars, specifically set at 5%, 15%, 30%, and 40% of the yielding strength (f_y = 950 MPa). The intervention impact was examined following two distinct corrosion development scenarios: an initial 45-year corrosion period (the current age of the bridge) and a subsequent 95-year period (additional 50 years of corrosion development). Therefore, 11 nonlinear analyses were conducted, each distinguishing the following intervals: application of permanent structural and non-structural loads; simulation of chloride ingress and corrosion development; implementation of the intervention; displacement-controlled analysis until reaching the ultimate capacity of the saddle.



a) b)

Fig. 5. (a) Half-joints' reinforcement layout; (b) FEM model with intervention (dimension in mm).

3.2. Results and discussion

The results of the numerical analyses allowed for the quantification of performance improvements of the strengthened half-joint in terms of increased cracking load and ultimate capacity based on the aforementioned parameters. Specifically, the cracking load is defined as the load at which a crack width of 0.2 mm is reached, representing the limit for serviceability conditions according to Italian regulations (Ministry of Infrastructure 2018).

Fig. 6a illustrates the increase in the cracking load of the retrofitted half-joint compared to the degraded conditions. The cracking load increases with the prestress in the external rods in an almost linear trend, especially for prestress values exceeding 15% of the yielding stress. Moreover, the increase is more pronounced after 95 years of corrosion development compared to the intervention applied after 45 years of degradation. The post-tensioning effect allows for the limitation of cracking under operational conditions, preserving the durability of the structure.

The increase in the peak load is depicted in Fig. 6b. In this case, there is no significant effect of the applied prestress, as the increment remains constant and significantly high even for low values. Additionally, the increase is higher when the intervention is carried out after 45 years of corrosion development. Specifically, the peak load value increases by approximately 25% compared to the degraded conditions over 45 years, in contrast to an increment of about 18% following 95 years of corrosion. In the latter case, the extensive corrosion developed on the half-joint reinforcement prevents further enhancement of the ultimate load even with the intervention.

In general, the application of post-tensioning significantly improves the half-joint's conditions both in operational condition and in load-bearing capacity. The intervention enhances the durability of the structure by recovering the lost strength due to 95 years of reinforcement corrosion, bringing the peak load of the post-tensioned half-joint back to the same value as the as-built conditions (before the onset of corrosion). When comparing the peak load in the initial conditions with the post-intervention load after 45 years of degradation, the effect is even more beneficial. Not only the strength lost due to corrosion is recovered, but the load-bearing capacity is further increased.

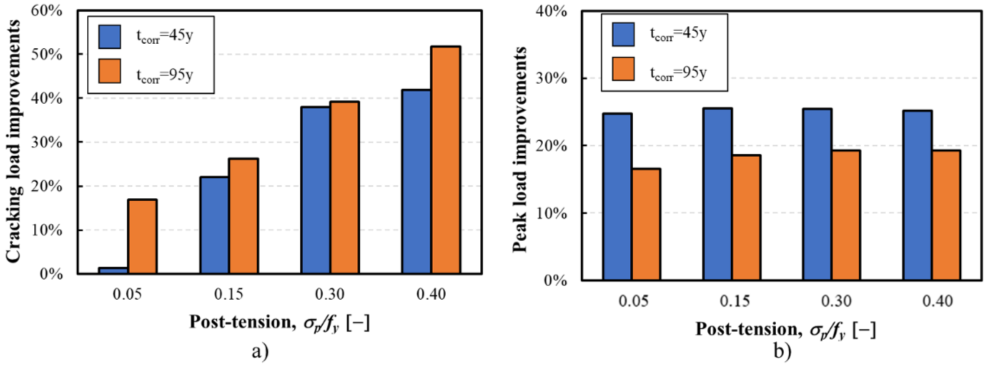


Fig. 6. (a) Cracking load improvements and (b) peak load improvements for corroded conditions after 45 and 95 years, as a function of the applied prestress values.

4. Conclusions

This article discusses the need for repairing and strengthening existing half-joints. Initially, commonly used intervention techniques available in the literature were outlined, evaluating their main advantages and disadvantages and analysing their applicability in practice. The comparison identified post-tensioning as a technique that is easy to implement, widely applicable, and cost-effective. Subsequently, through nonlinear numerical analyses, the post-tensioning technique was deepened, evaluating the performance improvements on a half-joint belonging to an existing bridge based on the prestress applied to the external bars. The analysis also considered the application of the intervention following two different scenarios simulating the corrosion development. The numerical analyses revealed that the use of post-tensioned bars increases the cracking load of the half-joint, with a more significant effect for higher prestress levels, showing an almost linear trend. Furthermore, the prestressing effect helps limiting the crack formation under operational conditions, preserving the concrete durability. The performance increase under ultimate conditions is not dependent on the prestress applied to the bars, as even for low values, a significant capacity increase is achieved. Finally, it was highlighted that the performance increase also depends on when the intervention is applied during the structure's service life. Indeed, the post-tensioning effect is greater when the intervention is carried out after 45 years of corrosion development rather than after 95 years. In the latter case, the more heavier reinforcement corrosion limits the post-tensioning effect.

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References

Alessandrini, F., Burba, P., 1994. Il degrado strutturale degli appoggi. Rassegna tecnica del Friuli-Venezia-Giulia. N.4/1994, Anno XLIV (in Italian).

Angst, U. M., 2019. Predicting the time to corrosion initiation in reinforced concrete structures exposed to chlorides. Cement and Concrete Research, 115, 559-567.

Atta, A., Taman, M., 2016. Innovative method for strengthening dapped-end beams using an ex-ternal prestressing technique. Materials and Structures, 49(8), 3005-3019.

Bazant, Z. P., Oh, B. H., 1983. Crack Band Theory for Fracture of Concrete. Materials and Structures, 16(3), 155-177.

Bernal, J., Fenaux, M., Moragues, A., Reyes, E., Gálvez, J. C., 2016. Study of chloride penetration in concretes exposed to high-mountain weather conditions with presence of de-icing salts. Con-str. Build. Mater., 127, 971-983.

Bertolini, L., Elsener, B., Pedeferri, P., Polder, R. B., Polder, R., 2004. Corrosion of Steel in Concrete: Prevention, Diagnosis, Repair. John Wiley & Sons.

Červenka, V., Jendele, L., Jan Červenka, J., 2021. ATENA Program Documentation, Part 1, ATENA Theory Manual, 2000-2021.

Choudhury, J. R., Hasnat, A., 2015. Bridge collapses around the world: Causes and mechanisms. In IABSE-JSCE joint conference on advances in bridge engineering-III (p. 34).

Deng, L., Wang, W., Yu, Y., 2016. State-of-the-art review on the causes and mechanisms of bridge collapse. Journal of Performance of Constructed Facilities, 30(2), 04015005.

Desnerck, P., Lees, J. M., Valerio, P., Loudon, N., Morley, C. T., 2018. Inspection of RC half-joint bridges in England: analysis of current practice. In Proceedings of the Institution of Civil Engineers-Bridge Engineering (Vol. 171, No. 4, pp. 290-302). Thomas Telford Ltd.

Di Prisco, M., 2019. Critical infrastructures in Italy: State of the art, case studies, rational approaches to select the intervention priorities. In fib Symposium 2019: Concrete-Innovations in Materials, Design and Structures (pp. 49-58). International Federation for Structural Concrete.

Di Prisco, M., Colombo, M., Martinelli, P., 2023. Structural Aspects of the Collapse of a RC Half-Joint Bridge: Case of the Annone Overpass. Journal of Bridge Engineering, 28(11), 05023007.

EN 1993-1-1, 2005. Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC]

Fukuoka, K., 1999. Reinforcing Structure For Henge Section Of Gerber Bridge (Patent Number: 5,893,187). Unites States patent, Date of Patent: Apr. 13, 1999.

Hájková, K., Šmilauer, V., Jendele, L., Červenka, J., 2018. Prediction of reinforcement corrosion due to chloride ingress and its effects on serviceability. Engineering Structures, 174, 768-777.

Johnson, P. M., Couture, A., Nicolet, R., 2007. Report of the Commission of inquiry into the collapse of a portion of the de la Concorde overpass. Government of Quebec.

Kim, C., Choe, D. E., Castro-Borges, P., Castaneda, H., 2020. Probabilistic Corrosion Initiation Model for Coastal Concrete Structures. Corrosion and Materials Degradation, 1(3), 328-344.

Kun, S., Vogt, R., Leuenberger, O., 2015. Rehabilitation of reinforced concrete gerber bridges. Proceedings of the Third Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures, SMAR 2015, Antalya, 7-9 September 2015, Turkey.

Lafranconi, L., Massone, G., Pasqualato, G., 2018. Analysis and rehabilitation of the Generale Franco Romano viaduct. Italian Concrete Days 2018, CTE Conference Milano/Lecco 13-16 Giugno 2018.

Marmo, F., Demartino, C., Candela, G., Sulpizio, C., Briseghella, B., Spagnuolo, R., Xiao, Y., Vanzi, I., Rosati, L., 2019. On the form of the Musmeci's bridge over the Basento river. Engineering Structures, 191, 658-673.

Mattock, A. H., 2012. Strut-and-tie models for dapped-end beams. Concrete International, 34(2), 35–40.

Ministry of Infrastructure, CSLP, 2020. Guidelines on Risk Classification and Management, Safety Assessment and Monitoring of Existing Bridges. Ministry of Infrastructure: Rome, Italy, 2020 (in Italian).

Ministry of Infrastructure, 2018. Aggiornamento delle Norme tecniche per le costruzioni. Ministry of Infrastructure, DM 17 gennaio 2018, Suppl. or. n.30 alla G.U. n.29 del 4/2/2008. (in Italian).

Mitchell, D., Marchand, J., Croteau, P., Cook, W. D., 2011. Concorde overpass collapse: structural aspects. Journal of performance of constructed facilities, 25(6), 545-553.

Nagy-György, T., Sas, G., Dăescu, A. C., Barros, J. A., Stoian, V., 2012. Experimental and numerical assessment of the effectiveness of FRP-based strengthening configurations for dapped-end RC beams. Engineering structures, 44, 291-303.

Santarsiero, G., Masi, A., Picciano, V., 2021. Durability of Gerber saddles in RC bridges: Analyses and applications (Musmeci Bridge, Italy). Infrastructures, 6(2), 25.

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.

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, 1-24.

Smith, D. A., 2005. Refurbishment of the old Medway bridge, UK. In Proceedings of the Institution of Civil Engineers-Bridge Engineering (Vol. 158, No. 3, pp. 129-139). Thomas Telford Ltd.

Taher, S. D., 2005. Strengthening of critically designed girders with dapped ends. Proceedings of the Institution of Civil Engineers-Structures and Buildings, 158(2), 141-152.

Van der Wegen, G., Polder, R. B., van Breugel, K., 2012. Guideline for service life design of structural concrete–a performance based approach with regard to chloride induced corrosion. Heron, 57(3), 153-168.

Zhang, J., Wang, J., Kong, D., 2010. Chloride diffusivity analysis of existing concrete based on Fick's second law. Journal of Wuhan University of Technology-Mater. Sci. Ed., 25(1), 142-146.