Safety Evaluation of an Existing PRC Bridge Beam: Preliminary Outcomes of In-Situ Test

(Article begins on next page)

Safety evaluation of an existing PRC bridge beam: preliminary outcomes of in-situ test

Diego Gino[1][0000-0002-8689-0790], Luca Giordano[1] and Paolo Castaldo[1][0000-0002-7956-9392]

[1] Politecnico di Torino, Turin, Corso Duca degli Abruzzi 24, 10129, Italy

Abstract. Assessing the safety of existing infrastructure remains a critical concern for infrastructure management authorities. In Italy, a significant number of reinforced concrete (RC) and prestressed concrete (PRC) bridges were constructed during the 1960s and 1970s. Many of these bridges are still in operation, raising questions about their ultimate resistance after more than 50 years. This study presents preliminary results of the experimental investigation of the ultimate behavior of a PRC bridge beam extracted from a bridge deck built around 1960, specifically the Mollere Viaduct located near the town of Ceva (Italy) along the "Torino-Savona highway - A6". The PRC beam followed a simple support static scheme, with a total span of 34.60m and end half-joints. Post-tensioning was employed as the prestressing technique. The paper outlines the key considerations in planning the experimental campaign and concludes by highlighting some preliminary outcomes of the structural behavior.

Keywords: Full-scale Test, Monitoring, Existing Bridges.

1 Introduction

In today's context, ensuring the structural integrity of existing bridges is of paramount importance for engineering firms specializing in large-scale infrastructure management [1]-[3]. These companies are entrusted with the task of developing strategies to minimize the potential consequences of future adverse events involving existing bridges [4]. Furthermore, these efforts assist national authorities in formulating plans and regulations aimed at reducing risks whose applications depend also on the efficiency of the administrative institutions [5]-[12] at territorial scale. A critical challenge associated with existing bridges is that many of them have either approached or are nearing the end of their design working life. The presence of aging transportation infrastructure emphasizes the need to assess the actual safety status and actively monitor factors such as vehicular overloads and environmental deterioration [13]-[14]. Recently, researchers conducted small-scale experimental tests using a shaking table to explore how a bridge system responds to seismic activity [15]. Additionally, performed full-scale tests on reinforced concrete (RC) and prestressed reinforced concrete (PRC) beams, although not specifically related to bridge systems [16]. While such experiments provide valuable insights [17], they still fall short of accurately replicating the authentic behavior of bridge beams under the influence of traffic loads, particularly in the case of PRC members.

This investigation presents preliminary findings from a comprehensive experimental study conducted on a prestressed reinforced concrete (PRC) beam with a span of 34.60 m. The PRC beam, which was constructed more than 60 years ago using post-tensioning prestressing techniques, was deliberately extracted during the disassembly of the Mollere Viaduct along the “Torino-Savona” highway in Italy. Subsequently, the beam was relocated to a specified area and supported by two distinct reinforced concrete (RC) footing foundations. The load test specifically entailed applying of prescribed displacements at two central supports positioned 5.02 meters apart along the midspan. These displacements were induced using two hydraulic jacks. The next sections delve into the configuration of the test setup and highlight some preliminary accomplishments.

2 Overview of the properties of the investigated PRC beam

This section provides essential details regarding the PRC beam, covering its geometry, material properties sourced from the original design, and its current condition, including identified damages.

The beam serves as the central member of a girder bridge deck, part of a structure consisting of six main beams. It stands at an overall height of 190 cm, featuring a symmetrical cross-sectional profile. The profile includes an in-situ cast concrete slab with a 20 cm thickness and a prefabricated main PRC beam in precast concrete.

The beam is characterized by a bonded prestressing main reinforcement, achieved through post-tensioning with injected mortar. This reinforcement comprises 9 strands, each composed of 18 wires with a diameter of 7 mm, following a parabolic path. Figure 1 (a-b) illustrate the primary geometric features of the cross section, based on existing documentation and on-site geometric surveys. Figure 1 (c) outlines the arrangement of the parabolic tendons, while Figure 1 (d) illustrates the shape in longitudinal direction of the PRC beam.

Based on data extracted from the original design reports, the mechanical properties of concrete were determined, revealing mean values of R_{ck}=25MPa for cast in-situ and R_{ck}=35MPa for precast concretes. Additionally, the ordinary reinforcements featured Feb44k with f_{yk}=440MPa. The prestressing reinforcement steel exhibited $f_{p(0.1)k}$=1558 MPa, with a declared tensioning stress level at 1150 MPa.

These data were utilized to design the experimental test, estimating its ultimate capacity.

To assess the degradation level of the structural member, preliminary inspections were conducted.

These inspections unveiled a corrosive process affecting the web stirrups and reinforcements near the holes in the deck intended for drainage devices for rainwater. Furthermore, longitudinal cracks were identified along the alignment of the post-tensioning tendons near the anchorage heads. This type of cracking, attributed to the "bursting" phenomenon, likely existed in the beam even at the time of its post-tensioning.

Notably, no significant degradation phenomena were recognized, even after 60 years of service.

Unfortunately, no information about the state of the prestressing tendons was available before the test, including details about the quality of the original injection of mortar.

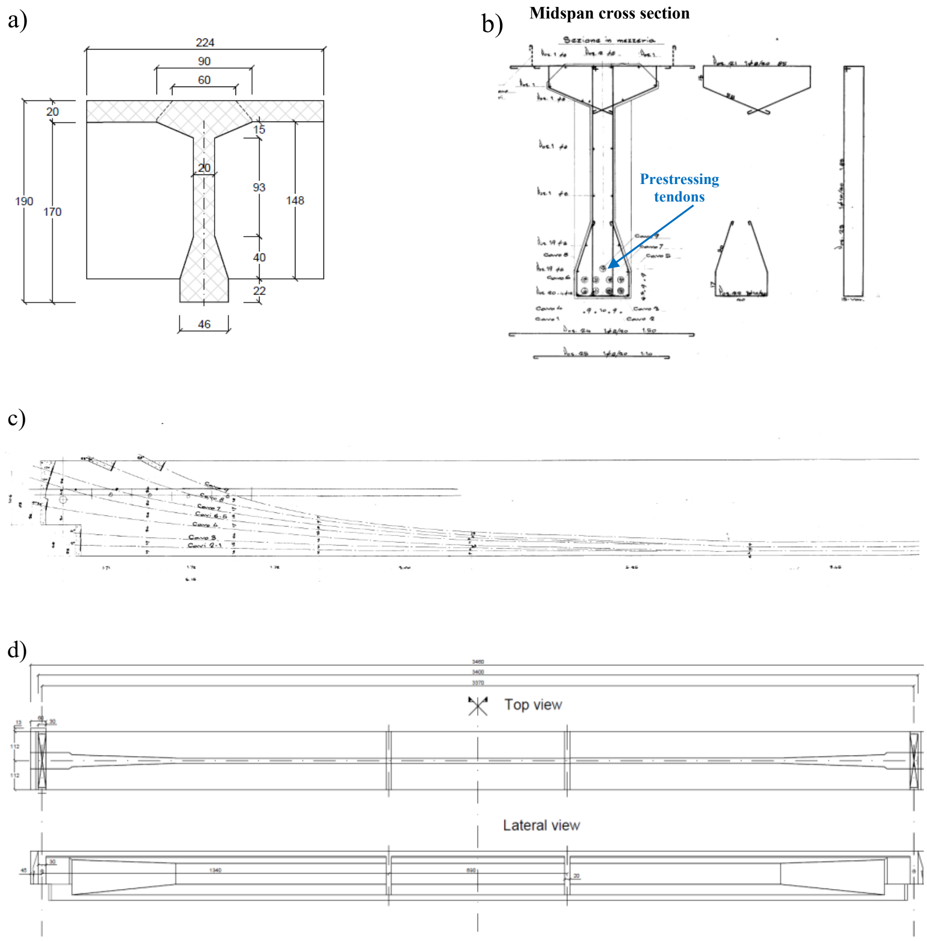

Fig. 1. Cross-sectional perspective at the midpoint of the precast concrete beam and the upper slab (a), along with the associated reinforcement arrangement and placement of the prestressing tendons (b), and the arrangement of the prestressing tendons in the longitudinal direction (c). The longitudinal structure of the beam is illustrated in (d). All measurements are in centimeters.

a) b)

Fig. 2. Visual representation of predominant degradation types: (a) Longitudinal cracks adjacent to the path of post-tensioning tendons in proximity to the anchorages; (b) Indications of corrosion on the stirrups near the apertures in the deck designed for rainfall drainage.

3 Configuration of the test set, loading and monitoring

The positioning of the PRC beam within the testing area is illustrated in the configuration presented in Figure 3. With half-joint terminations, the beam is upheld by two footings, denoted as Support A and B, specially engineered for this application. Below the beam, a substantial RC slab footing measuring 20x22x0.5m has been constructed to provide a level surface capable of accommodating the loading apparatus with a combined weight of 3000 kN, as depicted in Figure 3. Under the beam, multiple concrete blocks have been placed along the span, maintaining a clearance of 50 cm (i.e., maximum midspan displacements achievable during the test), as illustrated in Figure 3. Two jacks (A and B) have been positioned on the top slab at 5.02m across the mid-span, as close as possible to the original transverse beams.

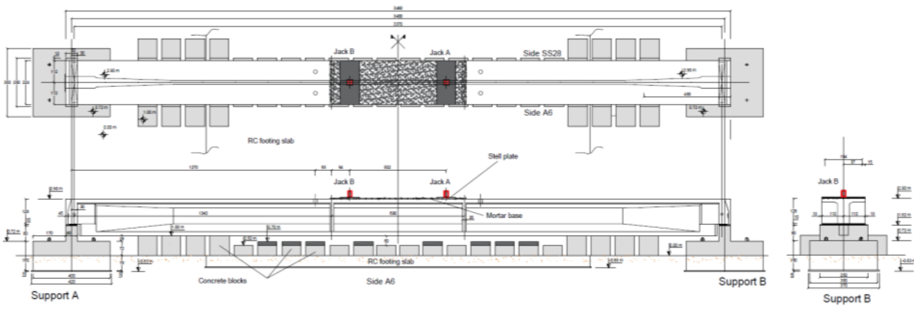

Fig. 3. Configuration of the loading scheme and of the test set.

The image in Figure 4 depicts the configuration of the test setup and the counteracting structure created using Azobè wood walls, steel beams, and iron ballasts.

The movement of the heavy materials within the testing area was facilitated by a mobile crane.

Fig. 4. Ultimate test layout arrangement featuring the 3000 kN counteracting structure.

The load test involved applying displacements at two points aligned with the beam's web on the deck, spanning 5.02 meters at the midspan. Hydraulic jacks (labeled A and B in Figure 3, each with a capacity of 2000 kN (equivalent to 200 tons), were positioned at these load points.

Using geometrical and mechanical data obtained from the historical survey and visual inspection of the 34.60-meter RC beam, a resisting bending moment of around 18000 kNm was calculated following [18]-[20].

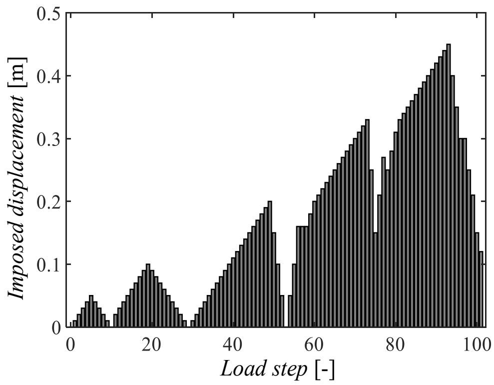

Fig. 5. Procedure for the load test in terms of imposed displacement at the jacks.

It is important to note that this resisting moment value was derived using the mean material mechanical properties from known characteristic values (from the design reports) according to [18]-[20]. To achieve the estimated resisting moment, the total counterweight on the counteracting steel structure (Figure 4), including iron ballasts and the self-weight of the structure, was set at 3000 kN (300 tons). This setup ensured that each of the two load points could apply a maximum force of 1500 kN (150 tons) to the beam while maintaining an adequate safety margin. The testing procedure involved applying incremental displacements simultaneously to each jack, as illustrated in Figure 5. The displacements of the jack were gradually increased at a slow rate between each step, and at each reached displacement level, the corresponding reaction force was measured.

A monitoring system has been deployed along the beam to monitor key response parameters. The following array of distinct instruments has been employed and integrated:

- Topographical survey for horizontal and vertical displacements;
- Deflectometer survey for horizontal and vertical displacements;
- Strain measurement using LVDT (Linear Variable Differential Transformer) sensors and strain gauges.

4 Main outcomes of the experimental examination

This section presents preliminary findings from the experimental investigation. It is important to note that the data from the sensors underwent numerical processing and fitting [17]. Throughout the entire test duration, corresponding to each planned loading phase, the beam exhibited simple bending and shear [21] in the vertical plane, demonstrating a bending-deformation response within that plane.

The test was halted when the beam showed a midspan deflection of approximately 46 cm (Figure 7). The neutral axis consistently exhibited a depth beyond the upper slab thickness for each investigated section along the beam axis, causing the slab to remain consistently compressed with deformation values below 0.1%. In the central zone with a constant moment (i.e., the portion of the beam between the two jacks), cracks appear to be nearly vertical due to the absence of interference between bending and shear stress.

Fig. 7. View o of the PRC beam with around 50cm of deflection in midspan.

5 Conclusions

This examination provides insights into the behavior of 34.60-meter-long simply supported prestressed reinforced concrete beams after more than 60 years of service. The inspected beam exhibited limited observable degradation phenomena, and visual inspections indicated its overall health. Preliminary test results supported these observations, with the beam displaying a typical bending failure mode, reaching a maximum midspan displacement of 46 cm. This suggests a notably ductile response, affirming the beam's good health based on preliminary visual inspections. A more comprehensive investigation is in progress, involving a comparison of diverse monitoring approaches and numerical simulations to fully comprehend the structural response. The findings from this research can be pivotal in planning future interventions and maintenance for aged bridge decks on major infrastructures.

Acknowledgements

This study was carried out within the Ministerial Decree no. 1062/2021 and received funding from the FSE REACT-EU - PON Ricerca e Innovazione 2014-2020. This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

This work is part of the collaboration "Safety assessment of Structures and Infrastructures - Valutazione della sicurezza di strutture e infrastrutture in cemento armato" with SINA S.p.A. and Autostrada dei Fiori S.p.a..

This work is part of the research activities performed within "RELUIS-BRIDGE".

This work is also part of the research activities performed within PRIN 2023-2025 "Data fusion based digital twins for structural safety assessment".

This work is also part of the research activities performed within PRIN 2018-2021 "Life-long optimized structural assessment and proactive maintenance with pervasive sensing techniques".

References

1. Santarsiero, G., Masi, A., Picciano, V. and Digrisolo, A. 2021. "The Italian Guidelines on Risk Classification and Management of Bridges: Applications and Remarks on Large Scale Risk Assessments. "*Infrastructures*, 6, 111. https://doi.org/10.3390/infrastructures6080111
2. Castaldo, P., Miceli, E. "Optimal single concave sliding device properties for isolated multi-span continuous deck bridges depending on the ground motion characteristics". *Soil Dynamics and Earthquake Engineering*, 173, 108128 (2023).
3. Troisi, R., Arena, L.: Organizational Aspects of Sustainable Infrastructure Safety Planning by Means of Alert Maps. Sustainability (Switzerland), 14(4), 2335 (2022).
4. Miluccio, G., Losanno, D., Parisi, F., and Cosenza, E. 2021. "Traffic-load fragility models for prestressed concrete girder decks of existing Italian highway bridges." *Engineering Structures*, 249, 113367

5. Troisi, R.: Illegal land use by Italian firms: An empirical analysis through the lens of isomorphism. Land Use Policy, 121, 106321 (2022).
6. Troisi, R., Alfano, G.: The re-election of corrupt mayors: context, relational leadership and level of corruption. Local Government Studies, 49(1), 204–225 (2023).
7. Troisi, R., Alfano, G.: Proximity and inter-firm corruption: A transaction cost approach. Small Business Economics, 60(3), 1105–1120 (2023).
8. Troisi, R., Alfano, G.: Firms' crimes and land use in Italy: An exploratory data analysis. Smart Innovation, Systems and Technologies, 178, 749–758 (2021).
9. Troisi, R., Nese, A., Blanco-Gregory, R., Giovanniello, M.A.: The Effects of Corruption and Innovation on Sustainability: A Firm-Level Analysis, Sustainability (Switzerland), 15(3), 1848 (2023).
10. Troisi, R., De Simone, S., Vargas, M., Franco, M.: The other side of the crisis: organizational flexibility in balancing Covid-19 and non-Covid-19 health-care services, BMC Health Services Research, 22(1), 1096 (2022).
11. Troisi, R., Alfano, G.: Is "justice hurried actually justice buried"? An organisational perspective of the Italian criminal justice. International Journal of Public Sector Management, 36(1), 94–109, (2023).
12. Troisi, R., De Simone, S., Franco, M.: Illegal firm behaviour and environmental hazard: The case of waste disposal, European Management Review, (2023).
13. Gino, D., Castaldo, P., Bertagnoli, G., Giordano, L. and Mancini G. 2019. "Partial factor methods for existing structures according to fib Bulletin 80: Assessment of an existing prestressed concrete bridge." *Structural Concrete* ;1‒17. https://doi.org/10.1002/suco.201900231
14. Cardone, D., Giuseppe, P. and Salvatore, S. 2011. "A performance-based adaptive methodology for the seismic evaluation of multi-span simply supported deck bridges." *Bull Earthq Eng* , 9(5):1463–98.
15. Shoushtari, E, Saiidi, Saiid M., Itani A. and Mohamed, M.. 2021. "Seismic performance of a two-span steel girder bridge with ABC connections". *Engineering Structures*, 241
16. Botte, W., Vereecken, E., Taerwe, L. and Caspeele R. 2021. "Assessment of posttensioned concrete beams from the 1940s: Large-scale load testing, numerical analysis and Bayesian assessment of prestressing losses." *Structural Concrete*, 1–23. https://doi.org/10.1002/suco.202000774
17. Darò, P., La Mazza, D., Tetta, E., Lastrico, G., Alovisi, I., Mancini, G., Miceli, E., Gino, D., Amendola, G., Giordano, L., Castaldo, P., Mariscotti, M., Garozzo, M., Deiana, M., and Magrì, B. 2023. "Full-Scale Experimental Testing on a Reinforced Bridge RC Beam: Experimental and SHM Results." *Lecture Notes in Civil Engineering*, 349 LNCE:1827–1836.
18. Linee guida per la classificazione e gestione del rischio, la valutazione della sicurezza ed il monitoraggio dei ponti esistenti. *Italian High Council of Public Works*, Rome, Italy, 2020 (in Italian).
19. DM 17/12/2020, n. 578. Adozione delle linee guida per la gestione del rischio dei ponti esistenti e per la definizione di requisiti ed indicazioni relativi al sistema di monitoraggio dinamico. *Italian Ministry of Infrastructures and Transportation*, Rome, Italy, 2020 (in Italian).
20. CEN. EN 1992-1-1. Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings. Brussels, Belgium: Comit´e Europ´een de Normalisation; 2004.
21. Miceli, E., Castaldo, P. "Robustness improvements for 2D reinforced concrete moment resisting frames: Parametric study by means of NLFE analyses". *Structural Concrete*, (2023).