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Full-scale load test of a PRC bridge beam after 60 years of service life

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Abstract

The safety assessment of existing infrastructure is a matter of significant concern for infrastructure management authorities. Specifically, in Italy, numerous 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 current load-bearing capacity given the long service time. This study focuses on the experimental examination of the ultimate performance of a PRC bridge beam taken from a bridge deck constructed in the 1960s. The bridge in question, known as the Mollere viaduct, was situated near the town of Ceva (Italy), along the Torino-Savona highway A6. The PRC beam was characterized by a simple supported static scheme with semi-articulated end connections having a total span of 34.60 meters. The beam had been prestressed using post-tensioning techniques. This paper presents an overview of the critical aspects related to the planning of the experimental campaign and, in conclusion, highlights the preliminary findings with respect to structural safety and monitoring.

Keywords: Full-scale; ultimate behavior; prestressing; existing bridge.

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1. Introduction

In the field of large-scale infrastructure management, the focus on ensuring the structural integrity of existing bridges is paramount (Troisi and Arena (2022), Troisi and Alfano (2023), Troisi and Alfano (2021), Medina et al. (2022)). Engineering firms specializing in this domain are entrusted with devising strategies to mitigate potential risks associated with future adverse events involving bridges and related infrastructures (Santarsiero et al. (2021), Miluccio et al. (2021)). Moreover, their efforts contribute to the formulation of plans and regulations by national authorities, aimed at minimizing risks (Linee guida per la classificazione e gestione del rischio, la valutazione della sicurezza ed il monitoraggio dei ponti esistenti (2021), DM 17/12/2020 n. 578 (2020)). A central challenge concerning many existing bridges is their proximity to or reaching of their design working life. This underscores the necessity of assessing their safety status and actively monitoring factors such as vehicular overloads and environmental degradation (Gino et al. (2019), Natali et al. (2023), Miceli and Castaldo (2023)) including also detailed evaluation of the related structural behaviour (Ferrara et al. (2024), Gino et al. (2024)). Recent research has delved into understanding how bridge systems respond to seismic activity through small-scale experimental tests conducted using a shaking table Shoushtari et al. (2021). Similarly, experiments on prestressed reinforced concrete (PRC) beams have been undertaken by Botte et al. (2021), although not directly related to bridge systems. Experiments has been also proposed on RC bridges beams but without prestressing technology as presented by Darò et al. (2023). These experiments, while insightful, do not fully replicate the authentic behavior of bridge beams constituted by PRC members under traffic loads.

This study presents preliminary findings from a full-scale experimental investigation conducted on a PRC beam spanning 34.60 meters. The beam, post-tensioned over 60 years ago, was originally part of the Mollere viaduct along the Torino-Savona highway in Italy (Darò et al. (2023)) but was intentionally removed during dismantling work. It was subsequently relocated and supported by two separate RC footing foundations within an appropriately prepared testing area. The load test involved applying prescribed displacements at two central supports located 5.02 meters apart across the midspan, using hydraulic jacks with a maximum capacity of 2000 kN (200 tons) each. The PRC beam was tested up to a maximum deflection displacement of approximately 50 cm without experiencing catastrophic failure but exhibiting a progressive bending failure mode with significant ductility. This paper further discusses the test setup configuration and preliminary outcomes.

2. Overview of the considered PRC beam

This section presents a thorough examination of the PRC beam, encompassing its geometric features, material attributes derived from initial design records, and its present state, inclusive of damage identification. Positioned as the pivotal element within a girder bridge deck constituted by six primary beams, the beam measures an overall height of 190 cm and displays a symmetrical cross-sectional configuration, as illustrated in Figure 1(c) based on available documentation and on-site surveys.

The cross-sectional setup entails an in-situ cast concrete slab with a thickness of 20 cm and a prefabricated main PRC beam in precast concrete. Despite the longitudinal separation from the original deck, remnants of the in-situ cast concrete crossbeams endure at the supports and midspan. Complemented by bonded prestressing main reinforcement facilitated through post-tensioning with injected mortar, the beam features nine tendons, each comprising 18 wires with a 7 mm diameter, following a parabolic trajectory, as depicted in Figures 1(a)-(d). The arrangement of parabolic tendons is delineated in Figure 1(d), while Figure 1(a) illustrates the longitudinal profile of the PRC beam. Figure 2 portrays the assessment of the structural member's degradation level through preliminary inspections, revealing a corrosive process in the web stirrups and reinforcements near the drainage device holes in the deck. Additionally, longitudinal cracks along the alignment of the post-tensioning tendons near the anchorage heads, ascribed to the "bursting" phenomenon, were noted, potentially present even during post-tensioning. Remarkably, despite 60 years of service, no significant degradation was discerned. Information pertaining to the condition of the prestressing tendons, including the quality of the original mortar injection within the sheaths, remained elusive prior to testing.

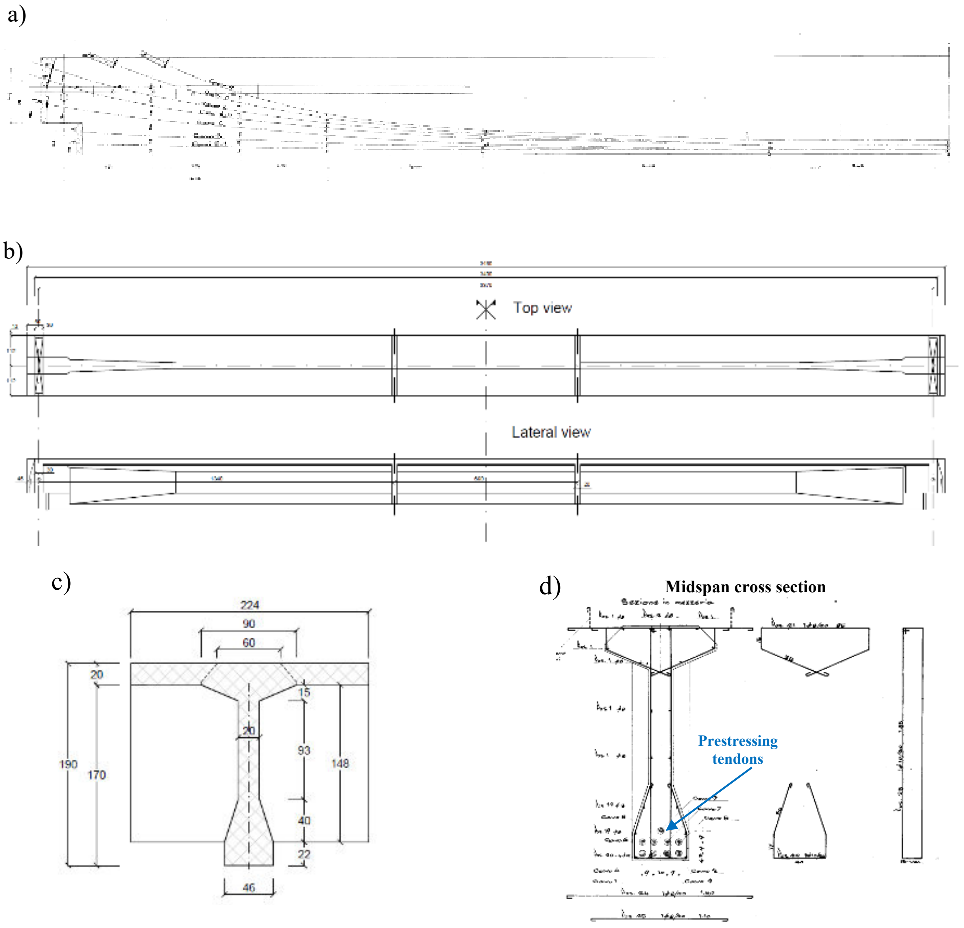

Fig. 1. Arrangement of the prestressing tendons longitudinally in (a). The longitudinal configuration of the beam is illustrated in (b). At the midspan, a cross-sectional perspective of the precast concrete beam and the top slab is depicted in (c), shows the reinforcement layout and placement of the prestressing tendons in (d). All measurements are presented in centimeters.

Mechanical properties for concrete, sourced from initial design reports, include R_{ck}=25MPa for cast in-situ and R_{ck}=35MPa for precast concretes. Furthermore, ordinary reinforcements are represented by Feb44k with f_{yk}=440MPa. In formulating the experimental test to estimate its ultimate capacity, consideration was given to the prestressing reinforcement steel, characterized by $f_{p(0.1)k}$=1558 MPa and a declared tensioning stress level of 1150 MPa.

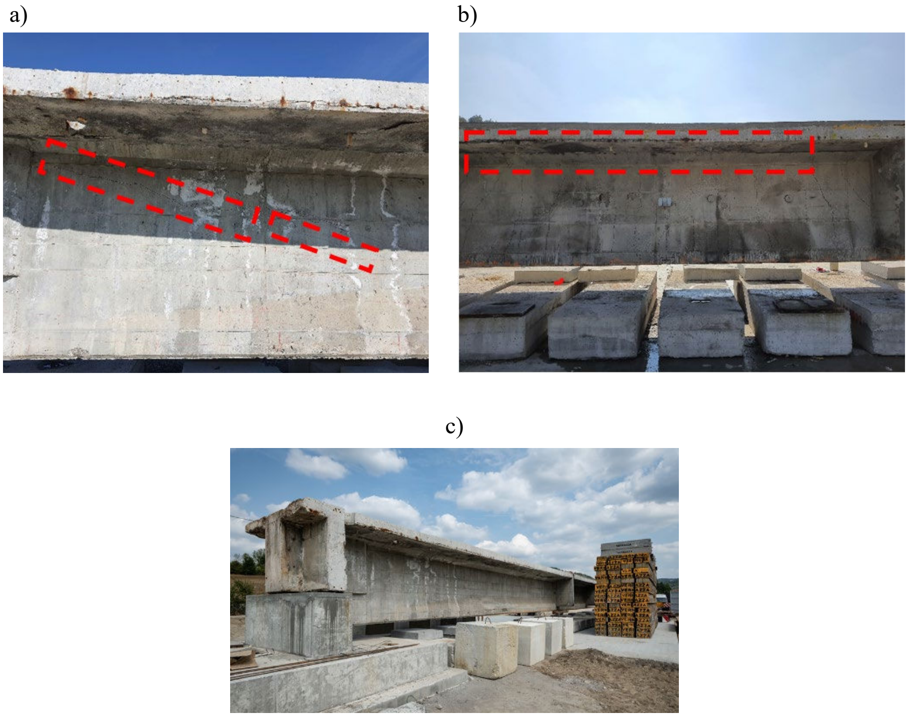

Fig. 2. Cracking along the longitudinal direction near the path of post-tensioning tendons close to the anchorages. (a). Longitudinal cracking of the slab (b). General view of the beam (c).

3. Planning of the experimental test

Detailing the test setup configuration, loading procedure, and monitoring is the focus of this section.

3.1. Testing procedures

The positioning of the PRC beam within the test area adheres to the arrangement depicted in Figure 3 (a)-(b). Supported by two specifically casted in situ RC footings labeled as support A and B, the beam is situated accordingly. Underneath the beam, an RC slab footing measuring 20x22x0.5m has been erected to offer a clean and stable surface for accommodating the loading devices, totaling 3000 kN in weight, as illustrated in Figure 3 (b). Strategically placed concrete blocks beneath the span ensure a clearance of 50 cm, corresponding to the maximum midspan displacements achievable during the test, as shown in Figure 3 (a). Positioned 5.02m apart across the midspan, two jacks (A and B) are situated on the top slab, positioned as close as feasible to the original transverse beams. Each jack has a capacity of 2000 kN (equivalent to 200 tons). Figure 3 (b) offers a visual depiction of the test setup, showing the counteracting structure constructed using Azobè wood walls, steel beams, and iron ballasts. The mobilization of heavy materials within the testing area was facilitated by a mobile crane.

The load test entailed applying controlled displacements at two jacks, A and B, as depicted in Figure 4. Using geometric and mechanical data acquired from a historical survey and visual inspection of the RC beam spanning 34.60 meters, a resisting bending moment of 17750 kNm was computed following EN 1992-1-1 guidelines. It's essential to emphasize that this resisting moment value was determined utilizing mean values of material mechanical properties derived from known characteristic values (from design reports), per EN 1992-1-1.

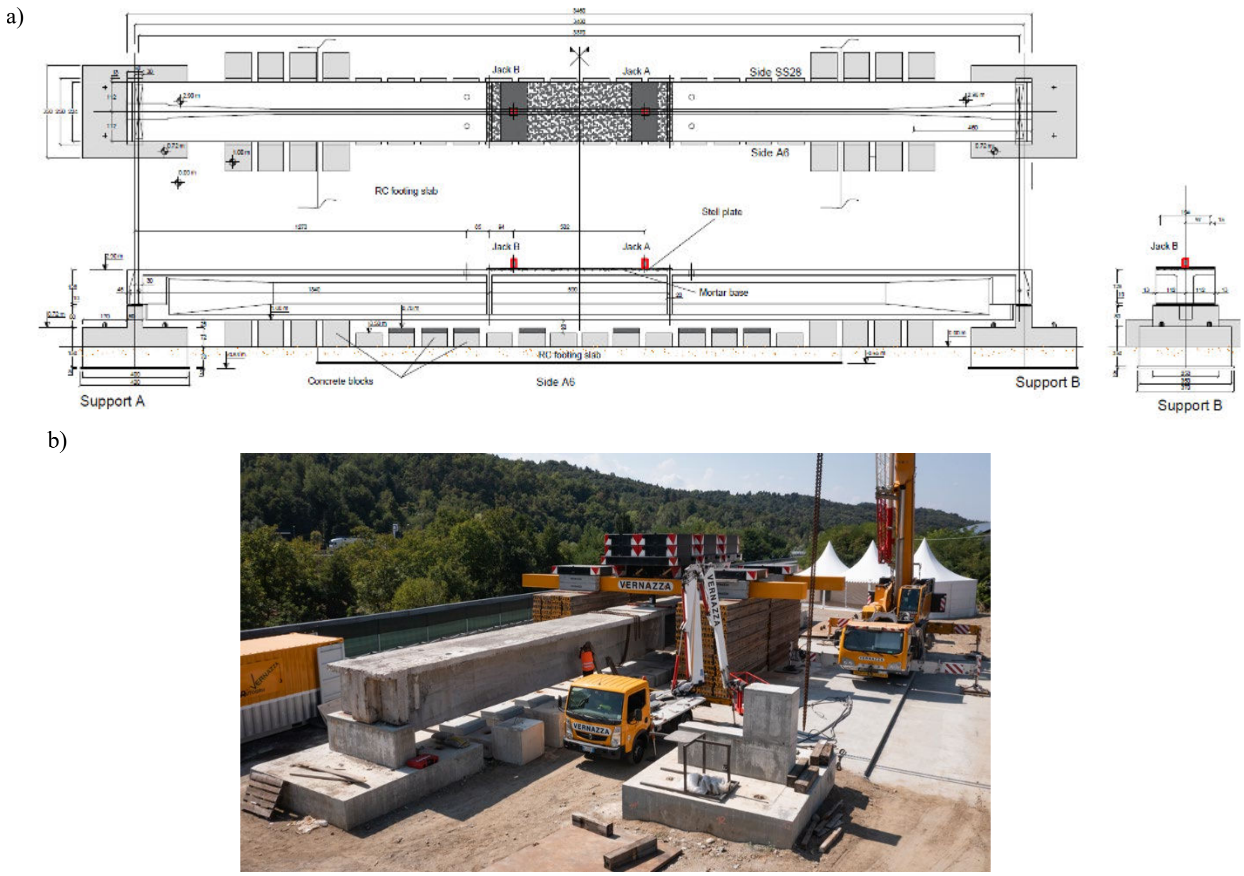

Fig.3. The testing layout is depicted in (a), with measurements in centimeters. (b) provides a general view of the testing area.

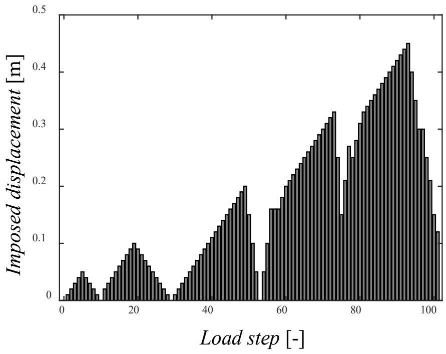

Fig.4. The imposed displacement at jacks A and B during the execution of the test is illustrated.

To achieve the estimated resisting moment, the total counterweight on the counteracting steel structure (depicted in Figure 3(b)), comprising the iron ballasts and the structure's self-weight, amounted to 3000 kN (300 tons). This configuration ensured that each of the two load points could apply a maximum force of 1500 kN (150 tons) to the beam, maintaining a sufficient margin for conducting the test. The jack displacements were incrementally increased at a slow pace between each step, with the reacting force measured and recorded upon reaching the desired displacement level.

3.2. Instrumentation for test monitoring

Outlined in this section is the arrangement of instruments along the beam to monitor the relevant response parameters. Various instruments have been utilized and integrated for this purpose:

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

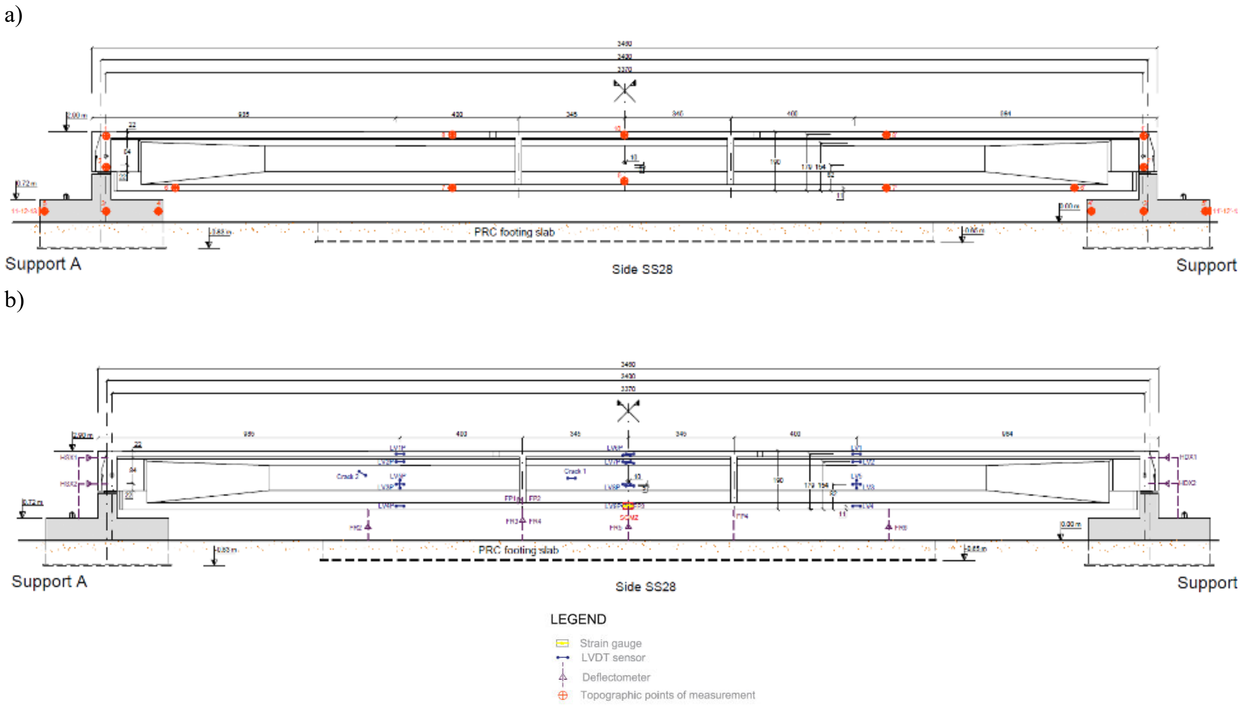

Fig.5. (a) Topographic monitoring points. (b) Placement of deflectometers, strain gauges, and LVDT sensors.

Figure 5(a)-(b) provides a detailed representation of the disposition of the measurement devices.

4. Initial findings from the experimental examination

This section presents preliminary findings from our experimental investigation. Notably, the sensor data underwent numerical processing and fitting (Darò et al. (2023)). Throughout the test's entirety, within each scheduled loading phase, the beam experienced simple bending and shear in the vertical plane, resulting in a bending-deformation response within that specific plane.

a)

b)

Fig.6. (b) provides a view of the deflection of the PRC beam under the maximum load. (c) shows the crack pattern of shear cracks close to the support.

The test concluded upon the beam exhibiting a mid-span deflection of approximately 46 cm, corresponding to a total load transmitted by the jacks of 1836 kN. Across the beam axis, the neutral axis consistently extended beyond the upper slab thickness in every investigated section, leading to continuous compression of the slab. The observed crack pattern (Figure 6(b)) aligns with that of a structure fixed at both ends with simple supports and loaded by two concentrated forces straddling the midpoint. In the central zone with a constant moment (between the two jacks), cracks appeared nearly vertical due to minimal interference between bending and shear stress. However, as one moves toward the supports where shear stress intensifies, cracks tend to incline, with a minimum angle of around 30 degrees, influenced partially by the presence of prestressing force. The maximum midspan deflection measured approximately 46 cm, as evident in Figure 6(a). Upon reaching this displacement level, the test was concluded.

5. Conclusions

This study serves as an initial step in evaluating the structural integrity of existing bridges, with a primary focus on enhancing safety and averting collapses. It delves into key considerations for planning an on-site, full-scale experimental test involving the loading of a 34.60-meter-long simply supported beam. By examining the response of prestressed reinforced concrete beams after more than 60 years of service, the study sheds light on limited observable degradation phenomena. Visual inspections indicate an overall state of healthiness, with preliminary test results reinforcing these observations. The beam demonstrates a typical bending failure mode, with a maximum load of 1836 kN (about 184 tons) applied by the jack, resulting in a maximum mid-span displacement of 46 cm. This underscores a notably ductile response, confirming the beam's satisfactory condition based on initial visual inspections. Ongoing comprehensive investigations will encompass comparing various monitoring approaches and conducting numerical simulations to gain a thorough understanding of the structural response. The outcomes of this research hold significant potential in guiding future interventions and maintenance strategies for outdated bridge decks within major infrastructures.

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