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RESILIENCE ASSESSMENT OF RETROFITTING SOLUTIONS FOR A PRESTRESSED CONCRETE VIADUCT

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Abstract

This paper presents a comprehensive evaluation of strategies for restoring functionality and safety in post-tensioned concrete viaducts, with a focus on the Greece's Polyfytos post-tensioned concrete viaduct. Originally conceptualized by Prof Riccardo Morandi and built in 1972-1975, this structure serves as a representative case for broader applications in aging infrastructure. The study critically assesses the viaduct's structural integrity and long-term performance, considering both safety and technical factors to inform effective rehabilitation strategies. The study investigates various rehabilitation solutions to determine the most suitable option from both resilience and technical perspectives.
A multi-tiered assessment was conducted on the Polyfytos Viaduct to ensure a robust understanding of its current condition. Initial first-level inspections provided preliminary observations, which were subsequently validated and enriched through targeted instrumental investigations. Building upon previous contributions of this research group, this study extends the analysis by including additional retrofitting and strengthening scenarios, evaluated through a resilience-based framework. The assessment considers resilience from both the structural and operational perspectives, namely, the viaduct's capacity to sustain expected performance demands and to maintain transitability under adverse conditions. This approach may provide valuable insights for engineers, policymakers, and infrastructure managers involved in the maintenance and adaptation of post-tensioned concrete viaducts.

Keywords: Post-tensioned, viaduct, retrofit, intervention, resilience.

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1 INTRODUCTION

Aging infrastructure worldwide faces increasing challenges due to long-term material degradation, evolving traffic demands, and climate-related stressors. As critical components of transportation networks, bridges play a vital role in economic stability, regional connectivity, and emergency response, ensuring the continuous movement of people and goods [1,2]. However, exposure to various hazards—ranging from natural deterioration and extreme weather events to human-induced threats—compromises their structural integrity and functionality, leading to severe economic and societal consequences [3]. Recent catastrophic failures, such as the collapse of the Francis Scott Key Bridge in Baltimore, underscore the urgency of proactive assessment and intervention, with economic losses estimated at $15 million per day due to port closures and insurance claims nearing $3 billion [4].

Damage of varying degrees not only impacts direct restoration costs but also affects load-bearing capacity and traffic operability, posing critical risks to regional resilience [5]. Traditional inspection methods relying on manual detection and field surveys become increasingly impractical in inaccessible or high-risk areas, delaying recovery efforts [3]. However, advancements in digital technologies, integrated with resilience science, unlock new possibilities for fast, precise damage assessment, enabling data-driven decision-making and strategically optimized restoration efforts [2,6].

The Polyfytos Viaduct in Western Macedonia, Greece- originally constructed using the balanced cantilever method-has exhibited progressive structural vulnerabilities, driven by prolonged material effects and significantly intensified traffic loads. While various studies have investigated these deterioration mechanisms, a unified resilience-based framework for assessment and mitigation such risks remain underdeveloped. Recent advancements in digital-driven infrastructure assessment, as highlighted in contributions at IABMAS 2024 and FABRE 2024 [7, 8], emphasize the integration of non-invasive technologies and computational tools for improved decision-making. Building on this perspective, the present work introduces a non-invasive resilience-focused methodology that leverages drone-based photogrammetry, laser scanning, and advanced numerical modeling to evaluate the viaduct's structural condition and quantify its long-term performance. This approach aims to support data-informed decision-making by balancing structural performance, service continuity, environmental sustainability, and cost-effectiveness.

Recent investigations, such as Kazantzi et al. (2024) [9], have improved the understanding of the Polyfytos Viaduct's condition by linking observed vertical deflections to internal damage levels—primarily due to tendon corrosion—through a data-driven approach combining numerical modeling and machine learning. This method offers a non-invasive way to support retrofit decisions by interpreting deflection patterns as indicators of structural degradation.

Furthering recent research, such as IABMAS 2024 and FABRE 2024 [7, 8] this study expands the scope by exploring a broader range of retrofitting and strengthening solutions for the Polyfytos Viaduct within a resilience-based assessment framework. By advancing a systematic, resilience-oriented methodology, this work contributes to the development of adaptable, cost-efficient, and scalable solutions for extending the service life of prestressed concrete viaducts. The findings aim to support engineers, policymakers, and infrastructure managers in enhancing the reliability and sustainability of critical transport networks.

2 THE STRUCTURE

The Polyfytos Viaduct, built in 1975 spans the artificial lake of the same name in Western Macedonia, Greece, serving a critical link in the national transportation network and forming a key segment of the E65 Central Greece Highway. A 260-meter segment of the structure, located between piers #22 and #24 (Figure 1), was constructed using the balanced cantilever method and has become the focus of recent concern due to visible deflections and signs of deterioration. Recent inspections have revealed issues such as tendon corrosion and localized concrete damage, prompting the implementation of traffic restrictions to limit further stress on the structure. Due to the viaduct's strategic importance and safety considerations, conventional testing methods—such as destructive sampling or dynamic load testing—were deemed unsuitable by the infrastructure owners. For further technical details on the bridge's design, condition, and inspection findings, the reader is referred to [7, 8, 9].

Figure 1: Polyfytos Viaduct, piers #22 and #24 (Gefyra Polyfytou Servia, by Wikiphysicsgr, originally uploaded on 4 June 2011 to English Wikipedia. Transferred to Wikimedia Commons by Ronhjones. Available at: Wikimedia Commons. Licensed under CC BY-SA 3.0).

2.1 Dual-level assessment

A digital assessment methodology is proposed, leveraging advanced computational tools to facilitate structural diagnostics with minimal intrusion. Unlike conventional sensor-based monitoring systems—often constrained by accuracy and site-specific dependence—the approach prioritizes adaptability, efficiency, and environmental sustainability (see Figure 2). The process begins an initial condition assessment, identifying critical inspection needs, followed by the use of high-resolution, contactless survey technologies such as laser scanning and drone-based photogrammetry [7, 8, 10]. These tools capture key geometric data (e.g., deflections, rotations, and surface cracking), which are subsequently processed into deflection profiles for comparative analysis with analytical and numerical models. Supplemented by available design documentation and literature, the method supports the development of a refined structural model that accounts for long-term effects like creep and shrinkage. Scenario-based simulations help isolate possible causes of observed behavior by matching them against the measured response. Although this approach does not replace exhaustive diagnostic procedures, it provides engineers and decision-makers with valuable, data-driven insights while avoiding disruptive or invasive testing.

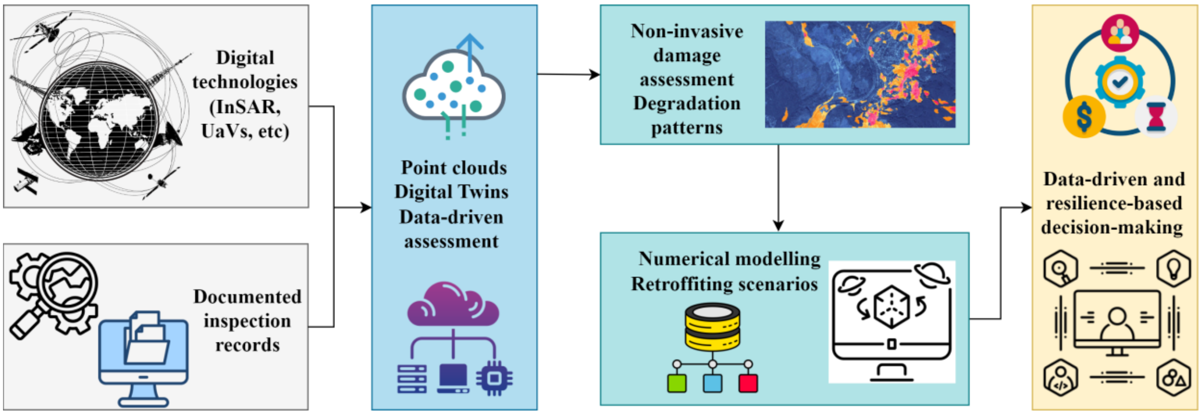

Figure 2: The holistic data-driven methodology for non-invasive damage assessment and decision making for infrastructure recovery.

2.2 Corrosion degradation issues

A detailed analysis of the Polyfytos Viaduct, particularly the deck segments spanning piers #22, #23, and #24, is presented in IABMAS 2024 and FABRE 2024 [7, 8]. These sections, constructed using prestressed concrete technology, feature a combination of balanced cantilever construction and precast beams connected by half-joints. This study provides comprehensive documentation on geometric parameters, material properties, degradation patterns, and analysis assessment techniques. A key advancement of this research is the integration of a high-resolution 3D point cloud model, which captures the current condition of critical structural components, especially the cantilever and half-joint regions.

Notably, the study highlights significant vertical deflections at the free end of the most structurally critical cantilever. Measured deviations from the original design geometry reach 133 mm and 207 mm below the expected elevation, raising serious concerns about internal deterioration. These excessive displacements strongly indicate a potential loss of prestressing force, likely due to progressive tendon corrosion. The magnitude of these observed deformations underscores the urgency of targeted structural evaluation and potential intervention to ensure the long-term safety and functionality of the viaduct.

3 PRELIMINARY RETROFIT SCENARIOS AND RESILIENCE-BASED ASSESSMENT

As an initial step toward defining suitable retrofit strategies for the Polyfytos Viaduct, five intervention scenarios have been identified and preliminarily evaluated in consultation with a professional engineer specializing in bridge rehabilitation. Although these proposals are conceptual at this stage, they are firmly rooted in engineering real-world practices and will be further validated through engagement with a broader panel of experts from both the design and construction sectors.

The aim of this section is to explore the potential effectiveness of these solutions in terms of recovery capacity and service continuity, with a particular focus on the three longest cantilever spans of the viaduct, located between piers #22, #23, and #24. While the proposed retrofit interventions are envisioned for the entire viaduct, this segment is prioritized due to its critical structural and operational vulnerabilities. The assessment is carried out using resilience-based criteria considering both transitability (i.e., how traffic functionality is restored over time) and structural capacity (i.e., the ability of the structure to meet performance demand after intervention).

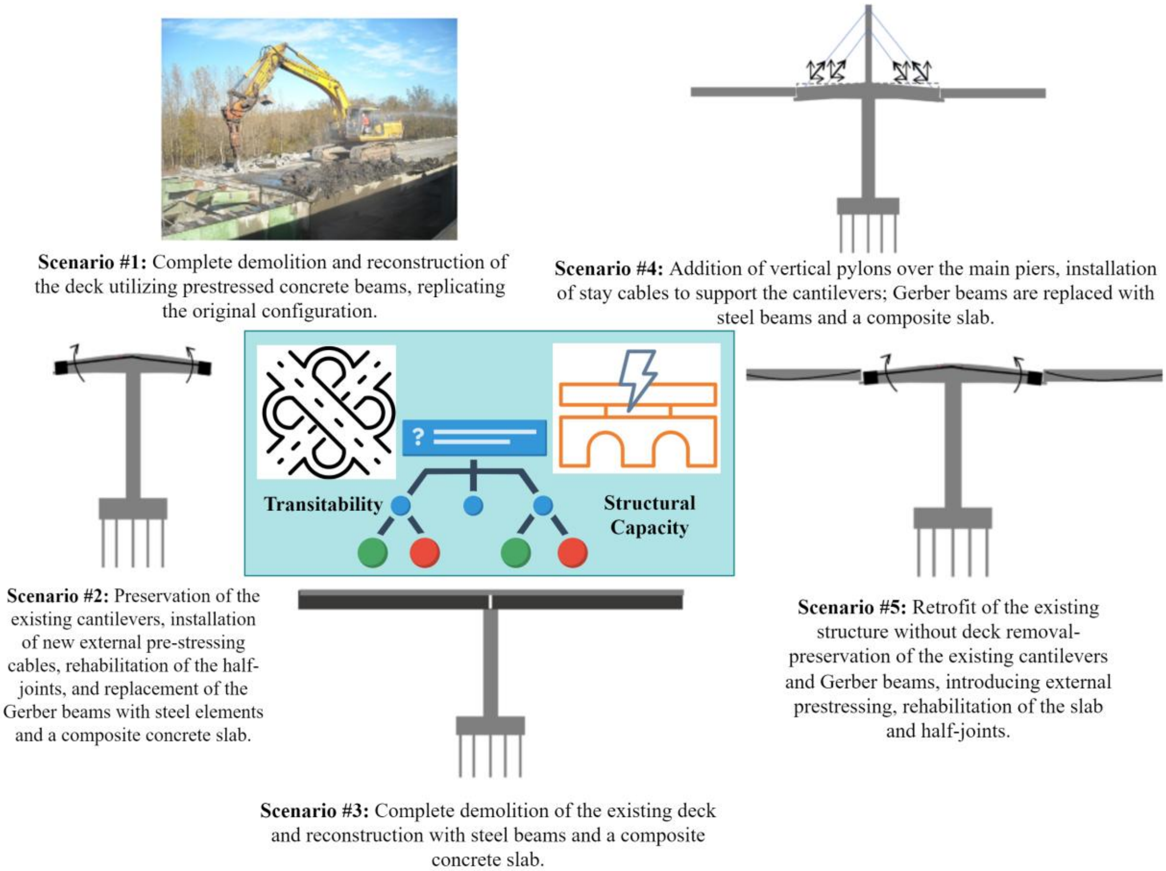

Figure 3: Five intervention scenarios (Wikimedia Commons – File: Demolition of I-84 Sandy River Bridge (9826964494).jpg. Licensed under Creative Commons Attribution 2.0 Generic - CC BY 2.0).

3.1 Description of the intervention scenarios

All five scenarios are designed to preserve the existing piers and foundations, as they remain structurally sound (Figure 3). They differ, however, in the extent of intervention on the superstructure and in the balance between preservation and reconstruction.

- Scenario #1: Complete demolition and reconstruction of the deck utilizing prestressed concrete beams, replicating the original configuration.
- Scenario #2: Preservation of the existing cantilevers, installation of new external prestressing cables, rehabilitation of the half-joints, and replacement of the Gerber beams with steel elements and a composite concrete slab.
- Scenario #3: Complete demolition of the existing deck and reconstruction with steel beams and a composite concrete slab.
- Scenario #4: Addition of vertical pylons over the main piers, installation of stay cables to support the cantilevers; Gerber beams are replaced with steel beams and a composite slab.
- Scenario #5: Retrofit of the existing structure without deck removal- preservation of the existing cantilevers and Gerber beams, introducing external prestressing, rehabilitation of the slab and half-joints.

Among these, Scenario #5 is the only solution that can be implemented without full closure of the viaduct to traffic. Due to the viaduct's configuration as a single carriageway with narrow lateral platforms, it is not feasible to maintain any traffic flow during full or partial deck reconstruction (Scenarios #1–#4).

3.2 Transitability-Based Resilience Analysis

Functionality curves were developed for each preliminary retrofit scenario by simulating the recovery of transitability over time. For Scenarios #1 and #3, explosive demolition is assumed to require approximately 10 days, while controlled demolition of Gerber beams in Scenarios #2 and #4 is expected to take 20 days. In all cases, it is assumed that preparatory work has been completed beforehand to minimize delays.

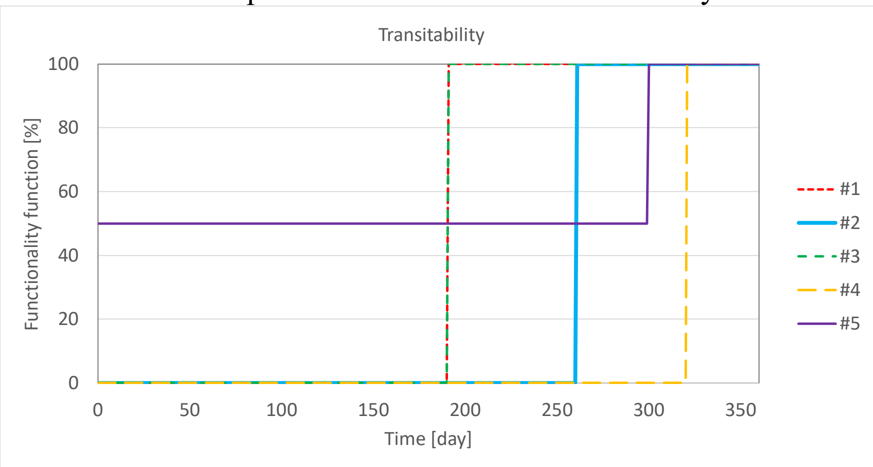

Figure 4: Functionality curves for all five scenarios (transit capability).

Scenario	Resilience
#1	0.47
#2	0.28
#3	0.47
#4	0.11
#5	0.58

Table 1: Resilience values.

The estimated reconstruction durations vary: 90 days for full deck replacement (Scenarios #1 and #3), 150 days for Scenario #2, and 210 days for Scenario #4. Additionally, administrative procedures and final testing are assumed to take 90 days post-construction. Scenario #5, carried out while maintaining 50% traffic capacity, requires about 300 days in total.

Figure 4 illustrates the functionality curves (transit capability) for the five scenarios, while Table 1 reports the computed resilience values.

3.3 Structural Capacity-Based Resilience Analysis

A parallel resilience analysis was conducted focusing solely on the structural capacity restoration, thus omitting administrative delays. The resilience values obtained are reported in Figure 5, while resilience values are in Table 2.

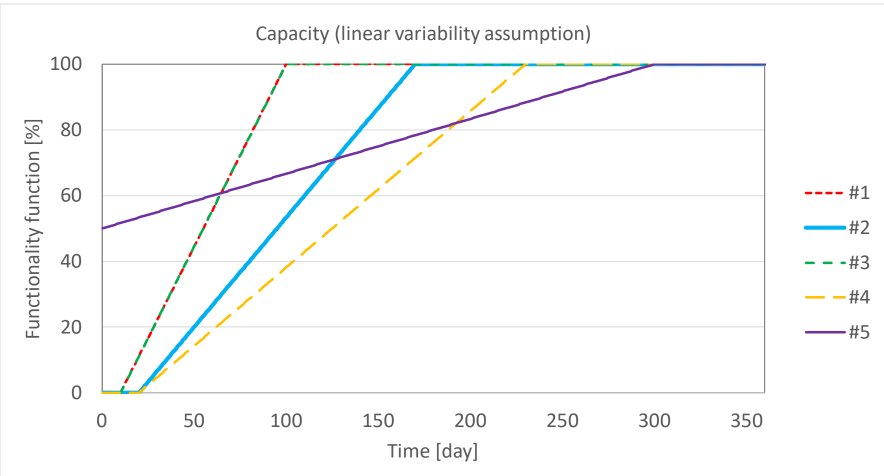

Figure 5: Functionality curves for all five scenarios (structural capacity).

Scenario	Resilience
#1	0.85
#2	0.73
#3	0.85
#4	0.65
#5	0.80

Table 2: Resilience values.

4 CONCLUSIONS

- This study assessed five preliminary retrofit scenarios for the Polyfytos Viaduct using a resilience-based framework, supported by advanced, non-invasive survey tools. Results indicate that while complete deck replacement (Scenarios #1 and #3) ensures high structural capacity, it significantly impacts transitability. In contrast, Scenario #5 emerges as the most balanced solution, enabling partial traffic operation, while achieving strong resilience outcomes.
- The comparison between capacity- and transit-based resilience highlights the significant impact of administrative delays on overall system performance, emphasizing the importance of streamlined approval and testing procedures during rehabilitation projects.
- Future work will expand expert consultations and incorporate a multidimensional evaluation, integrating Life Cycle Assessment (LCA), cost-analysis, and durability considerations to guide sustainable and well-informed decision-making.

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