Integrated Structural Assessment and Rehabilitation of Six Urban Viaducts with Minimum Traffic Disruption:

A Case Study from Belo Horizonte, Brazil

Applications and Implications for Aging Urban Infrastructure Management in the United States

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ABSTRACT

This paper presents the integrated structural assessment, risk-based prioritization, and rehabilitation of six urban viaducts located on Avenida Dom Pedro I in Belo Horizonte, Brazil, one of the highest-traffic arterials in a metropolitan area of approximately 6 million inhabitants. The project was commissioned by the Municipal Government of Belo Horizonte under Contract DJ 125/2022 (total contract value: BRL 17,402,235.09, base value plus approved amendments) and executed from the issuance of the Ordem de Serviço on December 15, 2022, extending through 2023–2024 under approved contractual amendments to scope and schedule, under the technical responsibility of the author. The six structures presented distinct and critical pathologies of varying complexity, requiring a differentiated set of structural interventions: controlled viaduct lifting (a minimum of five hydraulic jacks, per project execution drawings, elevation of 12 cm over 5 days) for installation of new bearing devices; internal prestressing of box girder sections executed through access manholes of only 60 × 60 cm; pressed-pile foundation reinforcement (presso-ancoragem) pre-loaded at 70 tf; and carbon fiber reinforced polymer (CFRP) application, both sheet and laminate systems. All six interventions were executed while maintaining traffic flow on the arterial through a planned overlapping construction sequencing strategy, with the sole exception of a five-day planned full closure required for the most complex structure. All structural analyses were performed using CSi Bridge v21.2.0 finite element software under Brazilian standards NBR 6118:2014, NBR 6122:2019, NBR 7187:2003, and NBR 7188:2013, built on broadly comparable structural safety principles to AASHTO LRFD specifications, though requiring project-specific regulatory adaptation for direct application. The paper presents the decision-making methodology as a structured four-phase framework, Assessment, Prioritization, Rehabilitation, and Institutional Documentation (APRI), and discusses its potential adaptation and applicability to the American infrastructure context, where the Federal Highway Administration's 2025 National Bridge Inventory analysis identifies 41,685 bridges in poor condition nationwide, and where the Infrastructure Investment and Jobs Act of 2021 has allocated USD 40 billion for bridge rehabilitation.

Keywords: bridge rehabilitation; urban viaducts; carbon fiber reinforced polymer (CFRP); pressed-pile foundation; viaduct lifting; internal prestressing; traffic management; structural assessment; infrastructure prioritization; APRI Framework.

1. INTRODUCTION

Urban bridges and viaducts are among the most critical elements of metropolitan infrastructure. They directly condition the movement of people and goods across dense urban environments, and their structural deterioration carries consequences that are simultaneously human, economic, and political. Yet across both developing and developed nations, urban bridge stocks age faster than they are rehabilitated, a gap driven not only by funding constraints, but by the absence of structured, replicable methodologies for systematic assessment, risk-based prioritization, and low-impact intervention.

In the United States, this challenge has reached a level of national policy urgency. According to the Federal Highway Administration's National Bridge Inventory, 41,685 bridges were classified in poor condition as of the 2025 data release, a modest improvement from 42,080 the previous year, but still representing a persistent national maintenance challenge. (Since the 2018 archived data, FHWA reporting has shifted from the legacy ‘structurally deficient’ terminology to the Good/Fair/Poor bridge condition framework. Under the current framework, bridges are classified as Poor when key NBI components are rated 4 or below.) The FHWA's 25th Conditions and Performance report to Congress identifies a bridge-specific repair backlog of approximately USD 191 billion, nested within a USD 852 billion highway repair backlog overall. The collapse of the Francis Scott Key Bridge in Baltimore in March 2024, caused by a cargo vessel's loss of propulsion and subsequent collision with a pier, per the NTSB investigation, and not by structural deterioration or deferred maintenance, nonetheless intensified national attention on the vulnerability and criticality of aging bridge infrastructure.

The Infrastructure Investment and Jobs Act of 2021 responded to this challenge with an unprecedented USD 40 billion allocation specifically for bridge rehabilitation, the largest such federal investment in American history. Yet the availability of funding does not automatically resolve the underlying methodological challenge: how to systematically assess large numbers of structures, prioritize interventions objectively within constrained budgets, select solutions that minimize disruption to dense urban traffic, and document the process in a manner that generates replicable institutional knowledge.

This paper addresses that methodological challenge through a field-validated case study. From the issuance of the Ordem de Serviço on December 15, 2022, under Contract DJ 125/2022, extending through 2023–2024 under approved contractual amendments, the author led, under individual technical responsibility documented through Anotação de Responsabilidade Técnica (ART/CREA-MG), the Brazilian legal instrument used to record an engineer’s personal technical responsibility for a specific project. The structural rehabilitation of six urban viaducts on Avenida Dom Pedro I in Belo Horizonte, the capital of Minas Gerais state, Brazil. The project was commissioned by the Municipal

Government of Belo Horizonte and required engineering solutions of significant technical complexity: lifting an entire viaduct with a minimum of five hydraulic jacks per the project execution drawings; executing internal prestressing through 60 × 60 cm access manholes; reinforcing foundations without interrupting traffic on a major urban arterial; and coordinating a six-structure rehabilitation program along the same avenue using an overlapping sequencing strategy that maintained traffic flow throughout the multi-year intervention period.

The methodology applied is presented as a structured four-phase framework, the APRI Framework (Assessment, Prioritization, Rehabilitation, and Institutional Documentation), designed to be replicable in different contexts, including American municipalities managing aging bridge inventories under operational and budgetary constraints.

2. PROJECT OVERVIEW

2.1 Context and Location

The six viaducts subject to this intervention are located along Avenida Dom Pedro I, a major urban arterial in Belo Horizonte, Brazil, a metropolitan area of approximately 6 million inhabitants and one of the largest cities in Latin America. The avenue carries high volumes of vehicular and pedestrian traffic daily, making any structural intervention logistically complex and economically sensitive with respect to traffic disruption.

The structures were built between the 1970s and 1990s and had not undergone structural rehabilitation since their original construction. A preceding structural verification study identified critical pathologies across all six structures requiring urgent intervention under Brazilian standard NBR 6122:2019.

The intervention was contracted by the Municipal Government of Belo Horizonte under Contract DJ 125/2022, with a base contract value of BRL 14,000,000.00 and a total value, including approved amendments, of BRL 17,402,235.09. All structural analyses were performed using CSi Bridge v21.2.0 finite element modeling software. Design criteria followed Brazilian technical standards NBR 6118:2014 (reinforced concrete), NBR 6122:2019 (foundations), NBR 7187:2003 (bridge design and construction), and NBR 7188:2013 (moving loads), supplemented by Eurocode provisions and DER-MG recommendations where Brazilian standards were silent.

2.2 Viaduct Inventory and Complexity Classification

Table 1 presents the six viaducts, their assigned complexity classification, primary pathologies identified in the diagnostic phase, and the principal rehabilitation interventions applied. The classification reflects the technical complexity of the engineering solutions required, not the magnitude of physical deterioration observed.

Viaduct	**Complexity**	**Primary Pathologies (key quantitative data)**	**Primary Interventions**
Oscar Niemeyer	Critical	Foundation pile capacity insufficient at P2 (redistributed pile loads up to 123.2 tf against a calculated allowable load of	Controlled viaduct lifting: minimum of 5 hydraulic jacks per project execution drawings, elevation +12 cm, 5-day full closure;

		110 tf) and P3B (calculated allowable load of 83 tf, below maximum service load); insufficient bearing devices at TR1 (load ≈ 200 tf); deficient reinforcement at abutments E2/E3 and cross-beam TR3; post-reinforcement safety factor ~1.05	installation of new bearing devices at TR1; pressed-pile reinforcement (Dywidag Ø 31.75 mm, fy ≈ 950 MPa, pre-load ~70 tf) at P1/P2/P3B; CFRP sheets (1–3 layers) at TR3, E2, E3
João Samaha (Casasanta)	High	Longitudinal box girders with insufficient reinforcement in positive moment zones (sections 2–5) and negative moment zone (section 7); combined flexure-torsion demand on bottom slab exceeding existing reinforcement capacity (deficit up to 22.45 cm²/m); access to box girder interior restricted to two 60×60 cm manholes only	Internal box girder prestressing: 4 cables × 15 greased strands, Ø 15.2 mm, steel 190RB, prestress force P = 294 tf; CFRP laminates and sheets applied internally through 60×60 cm manholes without traffic interruption
Monte Castelo	High	Foundation piles P1/P2 with safety factors below NBR 6122 (actual load 171 tf vs. max. 152 tf permitted; safety coefficient 1.68 < normative 1.89); insufficient shear reinforcement in cross-beams TR2/TR3; deficient reinforcement in abutment walls E1/E2	Pressed-pile reinforcement: 4 micro-piles per pier block (ø 150 mm), pre-loaded 70 tf; post-reinforcement P1 load: 133.02 tf; P2 load: 128.79 tf (both within 152 tf limit); CFRP sheets and laminates at TR2/TR3 and E1/E2; all executed under live traffic
Barragem da Pampulha	Moderate–High	Prestressed T-girder structure (VL.01–VL.05); mid-span diaphragms with insufficient bracing reinforcement; support diaphragms inadequate for jacking during bearing replacement; deficient bearing seat confinement; critical girder VL.01 with insufficient shear reinforcement	New RC corbels cast onto support diaphragms for bearing replacement jacking at 71 tf; CFRP sheets on VL.01; CFRP laminate confinement wrapping on bearing seats; all executed under live traffic
Gil Nogueira	Moderate	Pile cap blocks BL1/BL2 with insufficient shear reinforcement (flexible behavior, a/d > 1); cross-beams TR1/TR4 with insufficient flexural reinforcement following neoprene bearing replacement; external box girder longarinas at section 29 with shear deficit (Vrd = 249,050 kgf < Vsd = 303,100 kgf)	Pile cap geometry restoration via concentric ring to restore rigid behavior; CFRP sheets on TR1/TR4; CFRP laminates on longarinas at sections S28–S30
Montese	Moderate	Abutment wall E1 with	CFRP sheets at E1 and E2;

		insufficient vertical reinforcement (existing 6.25 cm²/m vs. required 12.75 cm²/m); abutment wall E2 with horizontal reinforcement deficiency; cross-beams TR2/TR3 with shear reinforcement deficiency around inspection holes	CFRP sheets at TR2/TR3, U-anchored; horizontal CFRP above and below inspection holes; all executed under live traffic

Table 1 — Viaduct inventory: complexity classification and rehabilitation interventions

3. THE APRI FRAMEWORK - METHODOLOGY APPLIED

The approach applied across the six viaducts follows a structured four-phase decision-making process developed by the author through progressive experience in urban infrastructure projects of increasing complexity. Each phase produces concrete, documented outputs that serve as inputs for the subsequent phase and as permanent institutional records.

3.1 Phase 1 - Data-Driven Structural Diagnosis

Each of the six viaducts was assessed individually through systematic technical inspection of all structural elements: piers, longitudinal girders, cross-beams (transversinas), abutment walls (encontros), foundations, expansion joints, and bearing devices. Inspection combined visual survey with photographic documentation, identification and severity classification of each pathology, and finite element structural modeling in CSi Bridge v21.2.0 to quantify load demands against normative capacity under multiple load combinations.

Load combinations applied followed NBR 7188:2013 (Class 45 moving loads), including dead loads, live loads, braking forces, wind (longitudinal and transverse), temperature, and centrifugal forces. Partial safety factors followed NBR 6118:2014 (concrete: $\gamma c = 1.4$; reinforcement: $\gamma s = 1.15$).

The diagnostic process produced individual technical reports per structure, each documenting: specific pathologies and their root causes, structural elements affected, safety coefficients obtained against normative requirements, and estimated residual service life. This individualized documentation is the foundational output of Phase 1 and the basis for all subsequent decisions.

3.2 Phase 2 - Risk-Based Prioritization and Sequencing Strategy

With six structures presenting distinct pathologies and risk levels on the same arterial, a structured prioritization methodology was essential for two reasons: to determine the technical order of intervention urgency, and to design a construction sequencing strategy that would maintain traffic flow throughout the project.

Prioritization criteria included: structural risk level (safety coefficient deficiency relative to normative requirements), volume and type of traffic affected by each structure, estimated intervention duration, and operational complexity of the required solution. Based on this assessment, the Oscar Niemeyer viaduct was identified as most critical, the only structure requiring full traffic closure, followed by João Samaha and Monte Castelo.

Critically, the sequencing strategy was designed so that no more than two viaducts would be under active construction simultaneously, and that the avenue would never be fully interrupted at multiple points at the same time. This overlapping approach, beginning the second intervention before completing the first, and initiating the third upon completion of the first, maximized team efficiency and minimized the cumulative impact on urban mobility throughout the intervention period.

3.3 Phase 3 - Solution Selection with Minimum Operational Impact

The selection of rehabilitation solutions was governed by a principle that distinguished this project from conventional structural interventions: wherever technically feasible, solutions were required to be executable without interrupting traffic flow. This constraint drove the identification and application of specific technologies whose compatibility with traffic maintenance was verified in the structural modeling phase before adoption.

The primary technologies applied are described in detail in Section 4. Their selection was not arbitrary; each was chosen because finite element analysis demonstrated that its execution would not require shoring or temporary structural unloading that would necessitate traffic interruption. The sole exception was the Oscar Niemeyer viaduct, where the replacement of bearing devices physically required lifting the structure, making a five-day planned closure unavoidable.

3.4 Phase 4 - Systematic Documentation and Institutional Knowledge

All technical decisions, engineering justifications, structural calculations, and execution results were systematically documented in technical reports per structure, with the explicit objective of creating reusable reference material for future interventions on similar structures. This documentation practice, often neglected in conventional construction projects, transforms each completed project into an institutional asset rather than an isolated episode.

The complete case study is additionally documented in the author's independently published book, Engenharia Segura no Crescimento Urbano (Safe Engineering in Urban Growth, 2025), available in Portuguese and English, which presents the six-viaduct project as a structured methodology applicable to urban infrastructure contexts beyond the original project location.

4. TECHNICAL INTERVENTIONS - KEY CASE STUDIES

4.1 Oscar Niemeyer Viaduct - Controlled Lifting, Foundation Reinforcement, and CFRP

The Oscar Niemeyer viaduct presented the most complex combination of structural pathologies of the six-viaduct project, requiring a precisely sequenced multi-technology intervention. Structural verification identified four concurrent deficiencies: foundation pile bearing capacity exceeded at piers P2 (redistributed pile loads reaching 123.2 tf against a calculated allowable pile load of 110 tf) and P3B (calculated allowable pile load of 83 tf, below maximum service load); cross-beam TR1 carrying a load of approximately 200 tf with insufficient bearing device capacity; deficient reinforcement at abutments E2 and E3; and shear reinforcement deficiency in cross-beam TR3. The finite element model in CSi Bridge confirmed that post-reinforcement safety factors would reach approximately 1.05, structurally compliant but with limited margin, making precise execution critical.

The intervention was executed in a technically mandated sequence: tie rods first, pressed piles second, CFRP reinforcement third. Foundation reinforcement was executed without traffic interruption through pressed-pile micro-piles (presso-ancoragem) with Dywidag Ø 31.75 mm anchors (steel fy ≈ 950 MPa), pre-loaded at approximately 70 tf per pile, which redistributed loads to within normative limits at P2 and P3B without conventional excavation.

Crossbeam TR1, carrying an approximately 200 tf loads with insufficient existing bearing device capacity, required the project's sole full traffic closure. The viaduct superstructure was lifted using five hydraulic jacks, per project execution drawings specifying a minimum of five jacks for this operation, elevating the structure by 12 cm over a five-day planned closure period. This controlled lifting operation created the clearance necessary to install two additional bearing devices per cross-section at TR1, restoring the required load distribution capacity.

Following restoration of traffic, CFRP sheets (MC CarbonFiber Sheet, resistência 3,600 MPa, e = 0.166 mm, 1 to 3 layers depending on element demand) were applied to cross-beam TR3 and abutments E2 and E3 to address the remaining reinforcement deficiencies.

4.2 João Samaha Viaduct - Internal Prestressing Through Restricted Access

The João Samaha viaduct (formally Viaduto Casasanta) presented a structurally demanding combination of deficiencies in its box girder longitudinal elements. Structural verification identified insufficient reinforcement in the positive moment zones of end spans (sections 2 through 5) and in the negative moment zone at section 7, as well as combined flexure-torsion demand on the bottom slab exceeding existing reinforcement capacity by up to 22.45 cm^2/m in the most critical sections. External CFRP reinforcement alone was insufficient, internal prestressing of the box girder was technically required.

Four prestressing cables were installed internally within the box girder, each comprising 15 greased strands of ø 15.2 mm (steel 190RB), with a prestressing force of P = 294 tf per cable. The critical engineering challenge was access: the interior of the box girder could only be reached through two inspection manholes of 60 × 60 cm, openings of 3,600 cm^2 each. All prestressing cables, anchorage components, tensioning jacks, and construction personnel had to enter through these restricted openings. The entire prestressing operation was executed without traffic interruption.

For negative moment zones at section 7, CFRP laminates were installed on the internal face of the upper slab. For bottom slab reinforcement against combined flexure and torsion, CFRP sheet was applied internally in 2 to 3 layers, also introduced through the 60 × 60 cm manholes.

4.3 Monte Castelo Viaduct - Foundation and Shear Reinforcement Under Live Traffic

The Monte Castelo viaduct presented three distinct categories of structural deficiency, each requiring a different intervention technology, all executed without traffic interruption: foundation bearing safety factors below NBR 6122 requirements at piers P1 and P2; insufficient shear reinforcement in crossbeams TR2 and TR3; and deficient reinforcement in abutment walls E1 and E2.

Foundation reinforcement was achieved through pressed-pile micro-piles, four piles per pier block (ø 150 mm), pre-loaded at 70 tf each, reducing the load on the original piles to within normative limits (maximum working load: 133.02 tf at P1; 128.79 tf at P2, against a normative maximum of 152 tf) without requiring any interruption of vehicular traffic above.

4.4 Barragem da Pampulha, Gil Nogueira, and Montese Viaducts

The three remaining viaducts, Barragem da Pampulha, Gil Nogueira, and Montese, presented moderate complexity pathologies addressed through targeted CFRP reinforcement, structural repairs, and, in one case, new reinforced concrete elements. Each structure had distinct characteristics requiring individual engineering solutions within the same diagnostic and documentation methodology.

Diagnostic significance: the diversity of pathologies across these three viaducts, prestressed girder shear in a T-beam structure, pile cap behavioral mode change, bearing seat confinement, and abutment wall reinforcement deficiencies, illustrates a core principle of the APRI Framework: that each structure in an urban bridge inventory requires individual diagnostic attention, even when located on the same arterial and built in the same era.

5. CONSTRUCTION SEQUENCING - TRAFFIC MANAGEMENT STRATEGY

A defining characteristic of this project, and a central element of the APRI Framework, is the construction sequencing strategy designed to maintain traffic flow on a major urban arterial throughout the multi-year, six-structure rehabilitation program.

The strategy was built on three principles. First, no more than two viaducts would be under active construction at any given time. Second, a new intervention would begin before the preceding one was complete, creating controlled overlap that maximized team continuity and resource utilization. Third, the one unavoidable full closure (Oscar Niemeyer, five days) would be planned with sufficient advance notice and traffic diversion to minimize metropolitan impact.

The result was the complete rehabilitation of all six structures, including a 12 cm controlled viaduct lift and internal box girder prestressing, with only five days of full traffic closure over the entire project duration. This outcome represents a measurable demonstration of the framework's core principle: that well-planned structural rehabilitation in dense urban environments can achieve complete technical objectives with minimal operational disruption.

6. KEY MATERIALS AND TECHNICAL SPECIFICATIONS

Material / System	Product / Type	Key Specifications	Application
CFRP Sheet	MC CarbonFiber Sheet	300 g/m^2; t = 0.166 mm; E = 230,000 MPa; ftu = 3,600 MPa; εfu = 2.1%	Shear reinforcement (cross-beams, abutments); 2–3 layers at 50 cm spacing
CFRP Laminate	MC CarbonFiber Laminate	High-modulus unidirectional laminate	Flexural and axial reinforcement of walls, girders, and abutment faces
Pressed Piles	Presso-ancoragem	ø 150 mm; pre-load: 70 tf; steel Ø 1¼" DYWIDAG (fy = 950 MPa; fu = 1,050 MPa)	Foundation block reinforcement at P1/P2 (Oscar Niemeyer, Monte Castelo)
Prestressing Cable	Internal box girder	High-strength steel cables; installed through 60×60 cm manholes	Longitudinal girder reinforcement (João Samaha)
Bearing Devices	Structural neoprene/steel	New devices installed at Oscar Niemeyer after controlled lifting	Replacement of insufficient devices; installation of additional units per cross-section
FEA Software	CSi Bridge v21.2.0	Finite element analysis;	Structural verification and

		spring stiffness modeling for pile groups	dimensioning for all six viaducts

Table 2 - Primary materials and technical specifications applied across six viaducts

7. APPLICABILITY TO THE AMERICAN INFRASTRUCTURE CONTEXT

The methodology presented in this paper was developed and validated in the Brazilian urban infrastructure context. Its applicability to the United States rests on the structural equivalence of the engineering problems, the technical compatibility of the solutions, and a documented gap in American bridge management practice that the APRI Framework addresses.

7.1 Structural Equivalence

The pathologies addressed in this project, foundation bearing capacity deficiency, insufficient shear and flexural reinforcement, bearing device degradation, and box girder structural deficiency, are similar in nature to those documented in American bridges rated in poor condition. The solutions applied, CFRP reinforcement, pressed-pile foundation reinforcement, controlled lifting, and internal prestressing, are recognized and applied in American bridge engineering practice, regulated under ACI 440.2R (CFRP for concrete structures) and FHWA technical guidance documents.

The structural engineering principles underlying the Brazilian standards applied in this project are broadly comparable to those underlying ACI and AASHTO practice, particularly with respect to limit states, load combinations, and material safety concepts. However, any U.S. application would require project-specific adaptation to applicable American codes and state regulatory requirements.

7.2 The Methodological Gap in American Practice

The United States possesses well-developed systems for bridge inspection and condition rating, notably the National Bridge Inspection Standards (NBIS) administered by FHWA, and the AASHTO bridge classification system. These systems are effective at generating inventory data and condition ratings at the individual structure level.

What is less systematically available is the layer of decision-making methodology that sits between condition data and executed intervention: how to prioritize among many deficient structures with limited budgets, how to design construction sequencing strategies that maintain traffic flow across multiple simultaneous interventions, and how to document the process in ways that generate replicable institutional knowledge.

The APRI Framework, validated in this six-viaduct project, is proposed as one possible approach to this gap. Its four phases (data-driven diagnosis, risk-based prioritization, low-impact solution selection, and systematic documentation) are intended for potential adoption by municipal engineers, state DOT project managers, and consulting firms managing aging bridge inventories in American cities.

7.3 Scale of Potential Impact

The United States has more than 620,000 bridges in its national inventory. According to the FHWA's 2025 National Bridge Inventory data, 41,685 of these bridges, approximately 6.8%, are currently classified in poor condition (the classification FHWA previously termed “structurally deficient” prior to 2018). The majority of these structures are managed by county and municipal governments with limited technical staff and constrained budgets, precisely the context for which a structured, replicable decision-making framework may offer the highest marginal value.

The Infrastructure Investment and Jobs Act's USD 40 billion bridge allocation will fund rehabilitation projects across the country over the coming years. The methodological contribution of this paper, and of the APRI Framework more broadly, is to propose a documented, field-tested approach for maximizing the structural and operational impact of those investments.

8. CONCLUSIONS

This paper has presented the integrated structural rehabilitation of six urban viaducts on Avenida Dom Pedro I in Belo Horizonte, Brazil, a project of significant technical complexity executed under the individual technical responsibility of the author, with the Ordem de Serviço issued December 15, 2022, and execution extending through 2023–2024 under approved contractual amendments. The following conclusions are drawn:

- A structured four-phase decision-making framework, Assessment, Prioritization, Rehabilitation, and Institutional Documentation (APRI), enabled the systematic management of six structurally distinct interventions on a single urban arterial, with clearly defined outputs at each phase that served both as technical deliverables and as institutional documentation.
- Risk-based prioritization, combined with a planned overlapping construction sequencing strategy, achieved complete structural rehabilitation of all six viaducts with only five days of full traffic closure over the intervention period, a result that demonstrates the operational value of structured pre-planning in urban infrastructure management.
- The combination of pressed-pile foundation reinforcement (presso-ancoragem), CFRP sheet and laminate systems, internal box girder prestressing through restricted access manholes, and controlled viaduct lifting with a minimum of five hydraulic jacks demonstrates that complex structural deficiencies in constrained urban environments can be addressed without prolonged traffic interruptions when engineering solutions are selected with operational impact as an explicit design criterion.
- The methodology may be applicable to the American bridge rehabilitation context, where approximately 41,685 bridges in poor condition (FHWA, 2025) present engineering challenges structurally similar to those documented in this case study, and where the Infrastructure Investment and Jobs Act has created significant funding for systematic intervention.
- Systematic documentation of the decision-making process, not merely the technical outcomes, is a critical and frequently neglected component of infrastructure rehabilitation projects. Each documented project should be treated as an institutional asset that reduces the cost and uncertainty of future interventions on similar structures.

Future work will focus on adapting the APRI Framework to the American regulatory context (AASHTO LRFD, FHWA NBIS, ACI 440.2R), and developing a quantitative scoring model for multi-criteria bridge prioritization informed by Business Analytics methods.

9. LIMITATIONS

This study is based on a single multi-structure intervention within a specific urban and regulatory context (Brazilian standards NBR 6118, 6122, 7187, and 7188). While the engineering principles, decision-making methodology, and rehabilitation technologies applied may be transferable to analogous American practice under AASHTO LRFD and FHWA standards, further validation across different structural typologies, climatic conditions, and regulatory environments is required before any claim of direct applicability. The author's ongoing adaptation of the APRI Framework to the American regulatory context represents a direct continuation of this research.

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