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SAFETY ASSESSMENT OF EXISTING CONCRETE RAILWAY BRIDGES FOR 150-YEAR SERVICE LIFE

Summary: The sustainable rehabilitation of existing reinforced concrete railway bridges is gaining importance as transportation infrastructure approaches the end of its original design life. Reusing existing concrete substructures instead of complete replacement offers substantial environmental and economic benefits but requires robust assessment and targeted strengthening. This contribution presents a performance-based framework for extending the service life of reinforced concrete bridge substructures to 210 years. The framework integrates condition assessment, strengthening of existing piers and foundations, advanced numerical verification, and comprehensive quality management throughout design and construction. The methodology is demonstrated through the Jauntal Bridge in Austria, where approximately 60-year-old reinforced concrete substructures were reused for a new composite steel-concrete railway bridge carrying high-speed traffic. Innovative bearing and damping systems reduce additional forces on the existing structure while ensuring adequate structural performance. The framework provides a practical basis for sustainable rehabilitation, life-cycle extension, and quality-assured reuse of existing bridge infrastructure.

Keywords: composite steel-concrete bridges, bridge rehabilitation, service life extension, structural strengthening, performance-based assessment, sustainable infrastructure

PROCENA SIGURNOSTI POSTOJEĆIH BETONSKIH ŽELEZNIČKIH MOSTOVA ZA EKSPLOATACIONI VEK OD 150 GODINA

Rezime: Održiva sanacija postojećih armiranobetonskih železničkih mostova postaje sve važnija kako se saobraćajna infrastruktura približava kraju svog projektovanog veka. Ponovna upotreba betonskih podkonstrukcija umesto potpune zamene pruža značajne ekološke i ekonomske koristi, ali zahteva robusnu procenu i ciljano ojačanje. Ovaj doprinos predstavlja okvir zasnovan na performansama za produženje eksploatacionog veka armiranobetonskih podkonstrukcija mostova na 210 godina. Okvir integriše procenu stanja, ojačanje stubova i temelja, naprednu numeričku verifikaciju i sveobuhvatno upravljanje kvalitetom tokom projektovanja i izgradnje. Metodologija je demonstrirana na mostu Jauntal u Austriji, gde su podkonstrukcije stare oko 60 godina ponovo korišćene za novi spregnuti čelično-betonski železnički most. Inovativni sistemi ležajeva i prigušenja smanjuju dodatne sile na postojeću konstrukciju i obezbeđuju adekvatno konstruktivno ponašanje. Okvir pruža praktičnu osnovu za održivu sanaciju, produženje životnog ciklusa i ponovnu upotrebu postojeće mostovske infrastrukture.

Ključne reči: spregnuti mostovi, sanacija mostova, produženje eksploatacionog veka, konstruktivno ojačanje, procena zasnovana na performansama, održiva infrastruktura

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1. INTRODUCTION

Railway bridge infrastructure constructed during the second half of the twentieth century is approaching the end of its original design service life in many countries. Increasing traffic demand, axle loads, train speeds and safety requirements require existing structures to perform beyond their original design conditions. Complete replacement often entails high economic costs, environmental impacts and prolonged interruptions of railway operation. Consequently, sustainable rehabilitation and continued use of existing reinforced concrete bridge substructures have become major challenges in modern infrastructure engineering [1–3]. Recent developments in life-cycle engineering indicate that the remaining capacity of existing reinforced concrete bridges can often be utilized more efficiently through performance-based assessment than purely prescriptive code verification. Such approaches combine condition assessment, material characterization, numerical modelling, reliability analysis and durability evaluation to determine structural performance and remaining service life [4,5]. Extending bridge service life to approximately 150 years therefore requires an integrated framework addressing structural safety, durability, quality management, inspection and long-term monitoring. This enables infrastructure owners to manage uncertainties while maintaining safety, serviceability and durability throughout the extended operational life [6]. Quality management is particularly important because rehabilitation projects involve uncertainties in material properties, construction details, deterioration and structural behaviour. Systematic inspections, non-destructive testing, material investigations, numerical model validation, independent verification and comprehensive documentation support reliable engineering decisions and long-term asset management. The proposed performance-based workflow, integrating assessment, numerical verification, strengthening, monitoring and asset management, is presented in Figure 1.

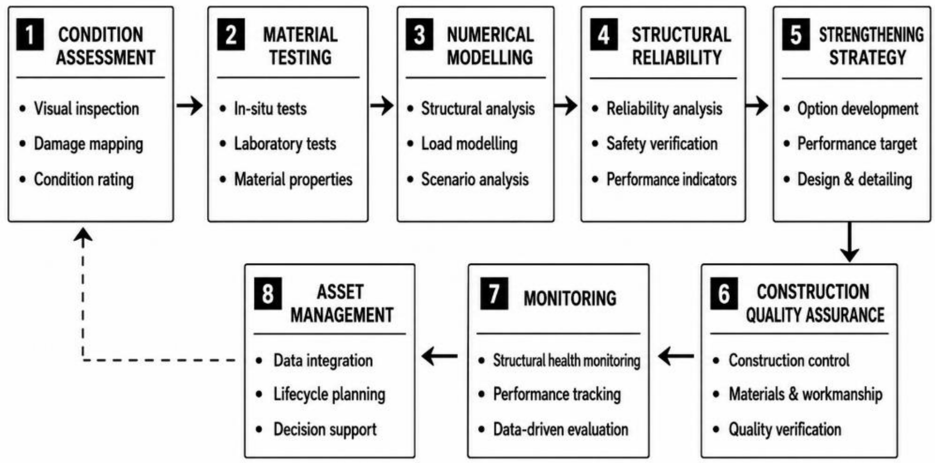

Figure 1: Performance-based assessment and quality management framework for extending the service life of reinforced concrete railway bridges

This contribution presents a performance-based framework for extending the service life of existing reinforced concrete railway bridge substructures to 150 years. The methodology integrates structural assessment, strengthening, advanced numerical verification and quality management throughout the rehabilitation process. Using the Jauntal Bridge as a case study, the paper demonstrates the safe reuse of existing reinforced concrete substructures for modern high-speed railway infrastructure while reducing material consumption, embodied carbon and construction waste. The framework supports sustainable bridge asset management by integrating structural reliability with environmental and economic performance over an extended service life.

2. JAUNTAL RAILWAY BRIDGE ON THE AUSTRIAN KORALM RAILWAY

2.1. DESIGN CONCEPT

The Jauntal Railway Bridge on the Austrian Koralm Railway provides a representative case study for the proposed performance-based rehabilitation methodology. The bridge forms part of the electrified double-track Baltic–Adriatic TEN-T corridor between Graz and Klagenfurt and is designed for train speeds of up to 250 km/h. Located near Aich–Mittlern, it crosses the approximately 100 m deep Drau Valley.

Originally constructed between 1959 and 1962 and commissioned in 1964, the bridge was modernized by replacing its original single-track steel superstructure with a new double-track composite steel–concrete structure. The existing reinforced concrete piers, foundations and abutments were retained and selectively strengthened, significantly reducing material consumption, construction waste and environmental impact. The bridge is 428.26 m long and comprises five continuous spans supported by four reinforced concrete piers, up to 76.85 m high, and two abutments. Valley piers are founded on caissons embedded in phyllite bedrock, while hillside piers are supported on well foundations in dense alluvial gravel.

Although the hollow-box piers provide high vertical load capacity, their relatively low longitudinal stiffness makes them sensitive to thermal actions, braking forces, seismic loading and bridge–track interaction [6]. The new continuous superstructure has an effective thermal expansion length of approximately 215 m, requiring comprehensive reassessment of the bridge system. Nonlinear numerical analyses incorporating bridge–track interaction, thermal effects, braking and acceleration, dynamic train loading and seismic actions confirmed the suitability of the strengthened substructure for long-term operation.

Figure 2: Existing Jauntal Bridge, strengthened reinforced concrete substructure and new composite steel–concrete superstructure

Several Several alternatives were assessed during the feasibility phase, including complete bridge replacement, strengthening of the existing steel superstructure and construction of an additional single-track bridge. The adopted solution replaced the original steel superstructure with a new double-track composite bridge while retaining the existing reinforced concrete substructure. The geometry of the piers, foundations and abutments remained largely unchanged, maximizing reuse of the existing infrastructure. Detailed inspections confirmed the excellent condition of the approximately 60-year-old reinforced concrete elements, while life-cycle and environmental analyses demonstrated substantial reductions in embodied carbon, material consumption and construction waste compared with complete replacement.

A key construction feature was the use of the existing bridge as a temporary launching structure for the new superstructure. Temporary connections between the old and new structures enabled simultaneous incremental launching of the replacement bridge and dismantling of the existing steel superstructure, minimizing interventions to the substructure, construction risks and railway closure periods.

The replacement bridge is a continuous double-track composite steel–concrete structure with constant structural depth. It comprises two parallel steel truss girders connected by transverse cross-frames and composite concrete deck slabs. The upper deck carries the railway tracks, while the lower deck provides inspection access and a maintenance walkway. Welded hollow-box chords and diagonals form the truss, with locally adapted cross-sections. Double-composite regions and orthotropic steel deck plates above the piers increase stiffness, reduce traffic-induced deformations and improve dynamic behaviour. The superstructure is supported beneath the lower chords at the piers and beneath the upper chords at the abutments, improving end rotations and bridge–track interaction. Composite action is provided by welded headed shear studs.

The existing reinforced concrete piers, foundations and abutments were retained following targeted strengthening. Hillside well foundations were strengthened with prestressed permanent ground anchors, while additional reinforced concrete ribs and prestressed anchors reinforced the pier bases. The caisson foundations of the valley piers were considered adequate after local pressure grouting of detected voids. Pier heads were reconstructed with new bearing plinths and prestressed reinforcement to accommodate increased bearing forces. Concrete repairs included a crack-bridging protective coating. The abutments were widened and strengthened for the new superstructure and hydraulic shock transmission units, while reinforced concrete anchor ribs with prestressed anchors provided additional slope stabilization.

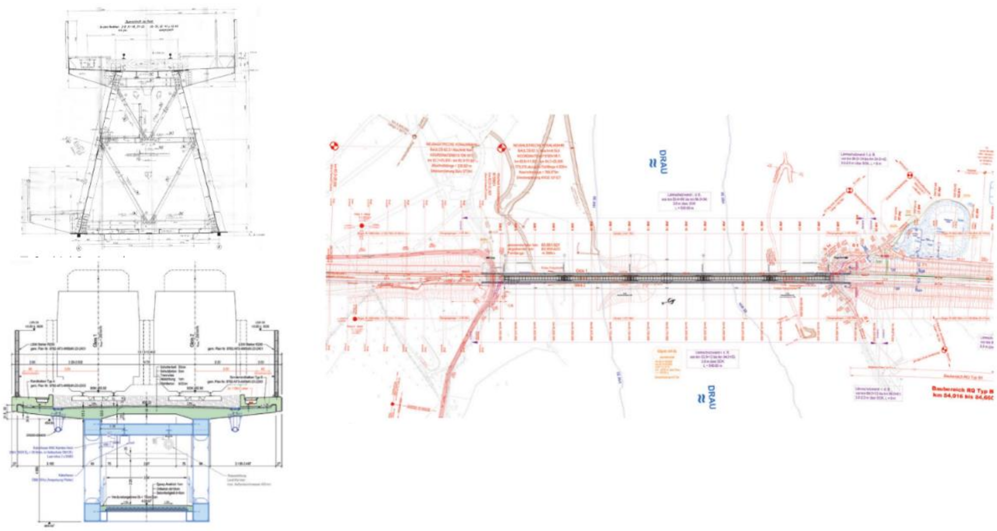

Figure 3: Existing Jauntal Railway Bridge prior to rehabilitation and the new double-track composite steel–concrete bridge solution

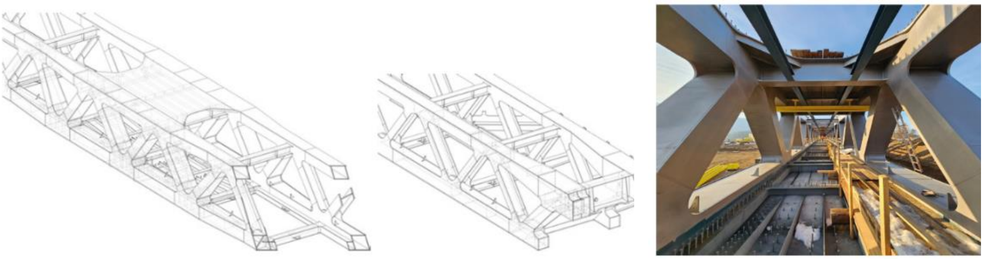

Figure 4: Replacement of the steel superstructure by a new double-track orthotropic two-level composite bridge with steel truss girders

Figure 5: Strengthening and rehabilitation measures applied to the existing reinforced concrete piers, foundations and abutments

The reuse of the existing substructure was achieved primarily by modifying the bridge's longitudinal load-transfer mechanism rather than by extensively increasing the capacity of the slender piers. The new double-track railway bridge generates substantially higher vertical and longitudinal loads from braking, traction and seismic actions. The adaptive system combines self-centring friction pendulum bearings at the pier heads with hydraulic shock transmitters integrated into both abutments. Under normal operating conditions, the bearings permit almost unrestricted thermal movements and minimize temperature-induced restraint forces. During braking or seismic events, the hydraulic shock transmitters activate and transfer longitudinal forces mainly to the considerably stiffer abutments. This largely decouples braking and seismic actions from the existing piers. The friction pendulum bearings were designed for vertical reactions of approximately 50 MN, while spherical bearings with capacities of approximately 20 MN were installed at the abutments. Compared with the hydraulically interconnected damping system of the original bridge, the autonomous hydraulic shock transmitters provide a simpler and more maintenance-efficient solution. This concept enabled the safe reuse of the existing reinforced concrete substructure while meeting current requirements for structural safety, serviceability and seismic performance.

2.2. CONSTRUCTION STATEGY

The construction strategy aimed to preserve the existing reinforced concrete substructure, minimize railway interruptions and avoid temporary supports within the environmentally sensitive Drau Valley. Following contract award in 2021, the piers, foundations and abutments were rehabilitated before erection of the new superstructure. The replacement bridge was prefabricated in three steel segments of approximately 145 m each. During a twelve-month railway possession, the new and existing superstructures were temporarily connected, enabling simultaneous incremental launching of the new bridge and dismantling of the original steel superstructure. Hydraulic strand-jacking was performed in three stages of approximately 65 m, 135 m and 210 m. A specially designed 25 m coupling structure ensured safe transfer of bending moments, shear forces and torsion during launching. After launching, the bridge was lowered onto its permanent bearings, which were subsequently grouted. The composite deck slabs were then cast using two movable formwork systems progressing simultaneously from both abutments toward mid-span. The response of the existing reinforced concrete piers was continuously monitored during construction to verify numerical predictions and ensure structural safety. This approach enabled complete superstructure replacement while retaining the existing substructure and supporting the project's life-cycle sustainability objectives.

Figure 6: Construction sequence for replacing the Jauntal Railway Bridge by incremental launching and sequential construction of the composite concrete deck slabs on the steel truss system

2.3. EXISTING SUBSTRUCTURES

The bridge comprises four hollow reinforced concrete piers, up to 77 m high, and two reinforced concrete abutments. Depending on geological conditions, the piers are supported by either large caisson or well foundations. Their hollow box sections with internal diaphragms provide high vertical load-carrying capacity while maintaining a slender configuration. Consequently, the piers have limited longitudinal stiffness and are sensitive to thermal actions, train braking and seismic loading. Detailed inspections confirmed that the reinforced concrete substructures remained in very good condition after approximately 60 years of service. However, the replacement superstructure and increased railway loading required comprehensive verification of structural performance. A condition assessment was therefore conducted to evaluate the remaining capacity and durability of the existing substructures, including visual inspections, material testing, review of original design documentation, geometric verification and advanced numerical analyses. Particular attention was given to concrete cracking, reinforcement corrosion, carbonation, freeze–thaw damage and potential foundation defects. Nonlinear numerical analyses evaluated the response of the slender piers under increased longitudinal railway loading. The results confirmed that the concrete quality and overall structural condition were suitable for continued service following targeted strengthening. Rehabilitation was therefore identified as the technically, economically and environmentally preferred solution [7,8].

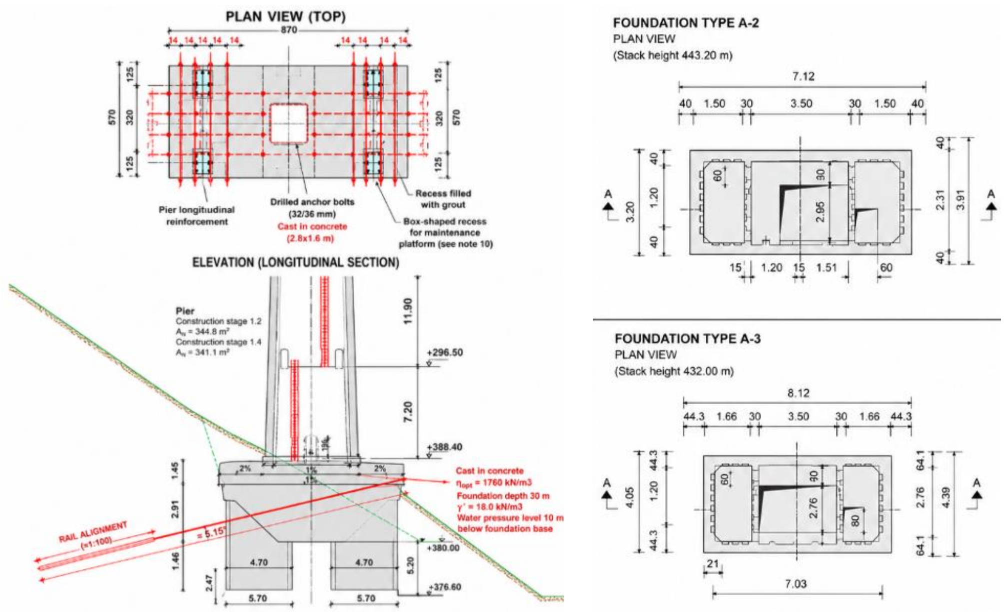

Figure 7: Geometry of the existing reinforced concrete piers and foundations

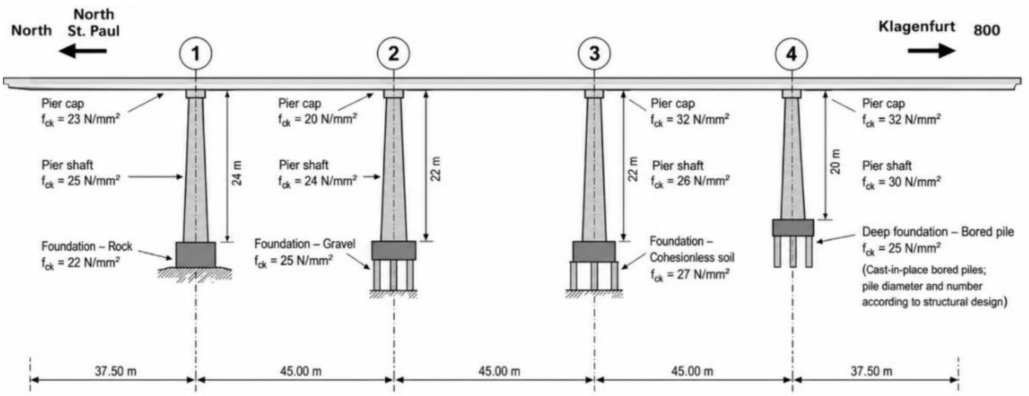

Figure 8: Performance-based condition assessment procedure

Although deterioration was limited, targeted strengthening measures were implemented to meet current design requirements and accommodate high-speed railway operation. This included foundation strengthening using post-tensioned anchors, enlargement of pier bases, reconstruction of pier heads for the new bearing system, installation of new bearing pedestals, reinforcement against splitting forces, concrete repair, crack injection and protective coatings. The abutments were additionally strengthened to accommodate the modified longitudinal load-transfer mechanism. The existing geometry and principal rehabilitation measures are shown in Figures 7 and 9. The rehabilitation strategy followed a performance-based engineering approach rather than relying solely on deterministic code verification. Its objective was to demonstrate that the existing piers, foundations and abutments could safely support a new double-track railway superstructure while satisfying ultimate and serviceability limit states, seismic performance, braking and acceleration loads, robustness and long-term durability.

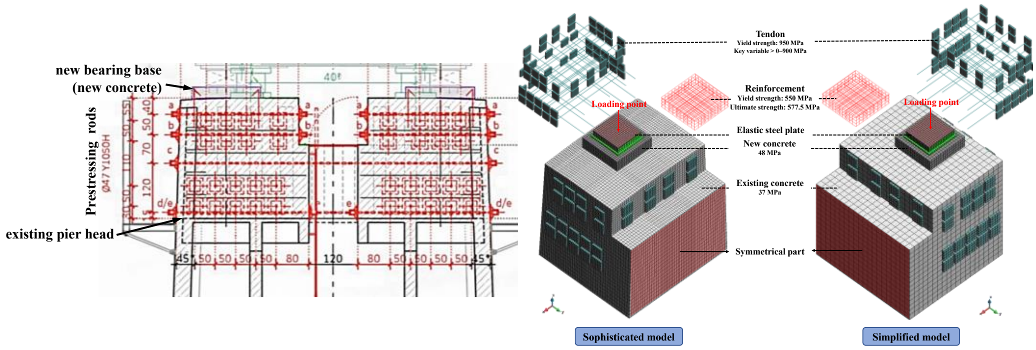

Figure 9: Strengthening measures applied to the reinforced concrete substructures

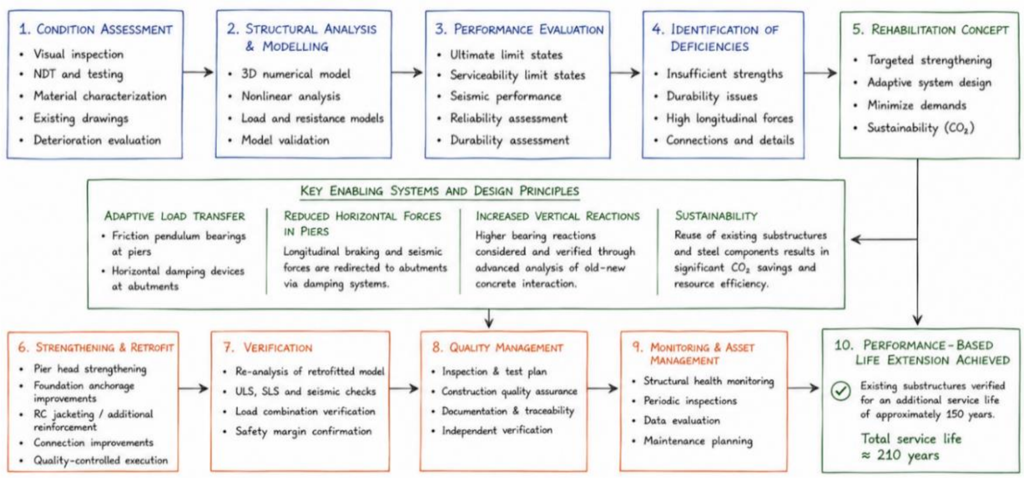

Figure 10: Performance-based life-extension strategy for existing reinforced concrete bridge substructures [9]

The assessment combined inspections, material characterization, nonlinear numerical analyses, structural reliability verification and durability evaluation, as summarized in Figure 8. Particular attention was given to the interaction between existing and newly constructed reinforced concrete elements within the strengthened pier heads and bearing pedestals. Numerical analyses confirmed adequate load redistribution and sufficient safety margins. A key component of the rehabilitation concept was the adaptive load-transfer system comprising friction pendulum bearings at the piers and hydraulic shock transmission units at the abutments. Overall, the methodology demonstrates that performance-based assessment, advanced numerical modelling, adaptive bearing technology, targeted strengthening and rigorous quality management can safely integrate existing reinforced concrete bridge substructures into a new infrastructure life cycle. The overall life-extension strategy is summarized in Figure 10 and provides a transferable framework for the sustainable rehabilitation of aging railway bridges.

3. RELIABILITY-BASED QUALITY MANAGEMENT AND LONG-TERM SERVICE LIFE

The rehabilitation of existing reinforced concrete railway bridges differs fundamentally from the design of new structures because engineering decisions must address uncertainties in structural condition, material properties, construction details and remaining capacity. Quality management therefore extends beyond conventional construction control and forms an integral part of the performance-based engineering process. Consistent with the principles developed by fib Task Group 3.6 "Quality Management", the proposed approach covers the entire life cycle, integrating planning, inspection, structural assessment, design verification, execution, monitoring and long-term asset management. For the Jauntal Railway Bridge, quality management began with a comprehensive assessment of the approximately 60-year-old reinforced concrete substructure. Historical documentation, inspections, geometric surveys, material characterization and non-destructive investigations were combined with advanced numerical analyses to determine the actual structural condition and remaining load-carrying capacity. This provided the basis for performance-based assessment rather than reliance solely on conservative code assumptions [10].

Structural verification incorporated nonlinear analyses considering bridge–track interaction, thermal loading, braking and acceleration forces, seismic actions, construction stages and long-term operational behaviour. Calibration against measured structural characteristics and independent engineering review increased confidence in the predicted structural response. Quality assurance continued during foundation strengthening, installation of post-tensioned anchors, pier-head reconstruction, concrete repairs and installation of the adaptive bearing and hydraulic shock transmission systems. Systematic inspections, acceptance criteria and documentation ensured compliance with design assumptions and performance requirements. Final verification included structural monitoring during construction and commissioning, proof-load tests and full-scale braking tests. The agreement between measured and calculated responses confirmed the numerical models, validated the adaptive load-transfer concept and demonstrated compliance with the required safety, serviceability and durability criteria [11]. In accordance with the life-cycle principles of fib Task Group 3.6, quality management continues during operation through periodic inspections, structural health monitoring, maintenance of the adaptive bearing system and continuous updating of structural information. This integrated framework combines condition assessment, numerical modelling, reliability verification, construction quality assurance and asset management to reduce uncertainty and support risk-informed maintenance. For the Jauntal Bridge, it enables the safe reuse of the existing reinforced concrete substructure for an additional service life of approximately 150 years while reducing embodied carbon, construction waste and life-cycle costs [12]. Within the Eurocode reliability framework, structural safety is quantified by the reliability index:

$$\beta = -\Phi^{-1}(P_f) \tag{1}$$

where P_f denotes the probability of failure and Φ^{-1} is the inverse standard normal distribution. The uncertainty of the governing material properties is represented by the coefficient of variation:

$$V_X = \frac{\sigma_X}{\mu_X} \tag{2}$$

where μ_X and σ_X denote the mean value and standard deviation, respectively. Since the coefficient of variation directly influences structural reliability, reducing material variability increases the achievable safety level without changing the deterministic design model. Within the Eurocode semi-probabilistic design concept, the relationship between structural reliability, material partial safety factors and statistical variability may be approximated by:

$$V_X = \frac{\gamma_M - 1}{\alpha_R \beta \gamma_M - k_n} \tag{3}$$

where γ_M is the material partial safety factor, α_R the resistance sensitivity factor and k_n the statistical fractile. Equation (3) illustrates that higher target reliability levels or longer service lives require lower variability of the governing material properties. Recent investigations have demonstrated that conformity and identity testing of structural concrete frequently result in substantially lower coefficients of variation than assumed during the calibration of the Eurocode partial safety factors. For reinforced concrete bridge structures, maintaining $V_X \leq 0.10$ is generally sufficient to achieve the target reliability required for service lives of approximately 150 years while preserving the existing Eurocode safety concept. The coefficient of variation therefore represents a practical quality indicator directly linking construction quality with long-term structural reliability. The rehabilitation of the Jauntal Railway Bridge followed this reliability-based quality management philosophy. Comprehensive inspections, material characterization, non-destructive testing and geometric surveys significantly reduced uncertainties regarding the existing reinforced concrete substructure. These data formed the basis for advanced numerical analyses, while systematic quality assurance during strengthening, construction and installation of the adaptive bearing system ensured compliance with the required performance objectives. Structural monitoring, proof-load testing and full-scale braking tests subsequently confirmed the predicted structural behaviour and validated the numerical models. The proposed methodology demonstrates that quality management is not limited to construction control but represents a continuous reliability-based engineering process integrating uncertainty quantification, structural verification, construction quality assurance and experimental validation. By systematically reducing material variability and epistemic uncertainty, existing reinforced concrete bridge substructures can be safely reused and their service life extended to approximately 150 years while maintaining the target reliability required for critical railway infrastructure.

4. CONCLUSION

The The rehabilitation of the Jauntal Railway Bridge demonstrates that existing reinforced concrete bridge substructures can be adapted for modern double-track high-speed railway operation through an integrated performance-based approach.

A key achievement was the integration of the approximately 60-year-old reinforced concrete substructure with a new composite steel–concrete superstructure. Comprehensive nonlinear analyses, including bridge–track interaction, thermal actions, braking loads, construction stages and seismic effects, confirmed that the existing piers, foundations and abutments could safely accommodate the increased operational demands. The adaptive bearing system, combining friction pendulum bearings with hydraulic shock transmission units, substantially reduced longitudinal forces on the existing piers by transferring braking and seismic actions toward the abutments while permitting thermal movements.

The integrated assessment demonstrated that the existing substructure can safely achieve an additional design service life of approximately **150 years** while satisfying current requirements for structural safety, serviceability and durability.

Beyond the Jauntal Bridge, the proposed methodology provides a transferable framework for sustainable rehabilitation of ageing railway bridges. Combining performance-based assessment, adaptive structural systems and reliability-based quality management enables efficient infrastructure reuse while reducing embodied carbon, material consumption and construction waste compared with complete replacement. Future developments should further integrate probabilistic reliability assessment, structural health monitoring and digital twins into life-cycle asset management to support risk-informed maintenance and long-term infrastructure resilience.

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REFERENCES

[1] CEN. EN 1990: Eurocode – Basis of Structural and Geotechnical Design, European Committee for Standardization, Brussels, Belgium, 2023.

[2] International Organization for Standardization. ISO 13822: Bases for Design of Structures – Assessment of Existing Structures, ISO, Geneva, Switzerland, 2024.

[3] Fédération internationale du béton (fib). fib Model Code for Concrete Structures 2020, fib, Lausanne, Switzerland, 2020.

[4] Zambon I, Vidović A, Strauss A, Matos J. Condition prediction of existing concrete bridges as a combination of visual inspection and analytical models of deterioration, Applied Sciences, 9 (1), 2019, Article 148.

[5] Zambon I, Vidović A, Strauss A, Matos J, Friedl N. Prediction of the remaining service life of existing concrete bridges in infrastructural networks based on carbonation and chloride ingress, Smart Structures and Systems, 2022.

[6] Frangopol D. M, Strauss A, Kim S. Bridge reliability assessment based on monitoring, Journal of Bridge Engineering, 13 (3), 2008, 258-270.

[7] Strauss A, Spyridis P, Zambon I, Sattler F, Apostolidi E. Quality control method for the service life and reliability of concrete structures, Infrastructures, 7 (2), 2022, Article 24.

[8] Strauss A, Bergmeister K, Seywald C. Verlängerung der technischen Nutzungsdauer von Infrastrukturbauwerken auf Basis semiprobabilistischer Betrachtungen, Beton- und Stahlbetonbau, 118 (8), 2023, 575-588.

[9] Casas J. R, Gómez J. D. Load rating of highway bridges through proof-load testing, Engineering Structures, 48, 2013, 506-515.

[10] Strauss A, Bergmeister K, Pukl R, Novák D, et al. Monitoring and data-informed approaches for the assessment of existing structures, Structural Concrete, 24 (4), 2023, 4433-4445.

[11] fib Task Group 3.6. Quality management of concrete structures, fib Bulletin, forthcoming.

[12] Frangopol D. M. Bridge management based on life-cycle performance, Structure and Infrastructure Engineering.

[13] International Organization for Standardization. ISO 15686: Buildings and Constructed Assets – Service Life Planning, ISO, Geneva, Switzerland.

[14] Fédération internationale du béton (fib). fib Bulletin 34: Model Code for Service Life Design, fib, Lausanne, Switzerland, 2006.

[15] Novák D, Novák L, Lehký D, Strauss A, Täubling-Fruleux B. Reliability assessment of historical reinforced concrete bridge piers based on nonlinear fracture mechanics modeling and safety formats, 12th International Conference on Fracture Mechanics for Concrete and Concrete Structures, 2025.

[16] Strauss A, Karimi S, Šomodíková M, Lehký D, Novák D, Frangopol D. M. Monitoring based nonlinear system modeling of bridge–continuous welded rail interaction, Engineering Structures, 155, 2018, 25-35.