

SUPERSTRUCTURE MODERNIZATION OF THE HEAVY GANTRY CRANE TRACK IN TPP REK BITOLA

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Abstract – This paper presents a comprehensive engineering solution for the rehabilitation and structural modernization of a severely degraded gantry crane track at the Thermal Power Plant (TPP) REK Bitola. The investigated crane, a 383.4-tonne portal structure manufactured by Metalna in 1977, was withdrawn from operation due to significant geometric deterioration of the crane track. Long-term geodetic monitoring and recent levelling surveys identified vertical rail deflections exceeding 30–40 mm, far beyond the permissible operational tolerance of ± 3 to ± 5 mm. The investigation showed that the primary causes of deterioration were the structural decay of the existing wooden sleepers, ballast contamination and inadequate drainage, while the underlying platform exhibited excellent bearing capacity (CBR = 100%) and did not require rehabilitation. The proposed rehabilitation concept focuses on the complete modernization of the track superstructure, utilizing the high-bearing capacity of the existing subgrade. The existing wooden sleepers are replaced with pre-stressed reinforced concrete sleepers (type RAJS-K-B70) tailored for the 1500 mm track gauge, supporting S49 rails via an elastic Vossloh SKL 14 fastening system. Additionally, the configuration features an elevated ballast prism and a newly integrated longitudinal drainage system equipped with perforated Ø100 mm pipes. The structural design was developed in accordance with established railway track design principles to ensure adequate load transfer, improved track stability, efficient drainage and long-term preservation of the track geometry. The proposed solution provides a practical engineering approach for restoring the operational reliability of industrial gantry crane tracks and may serve as a reference for similar rehabilitation projects under comparable operating and environmental conditions.

Keywords – Crane track rehabilitation, Concrete sleepers, Track gauge 1500 mm, Rail S 49, Geodetic levelling, Substructure drainage.

1. INTRODUCTION

Industrial gantry crane tracks in coal-fired thermal power plants are subjected to extreme, concentrated, and cyclic structural loading. Over decades of service, these massive quasi-static forces, together with coal dust buildup and moisture entrapment, trigger severe track degradation and loss of geometric alignment [1][2].

The focus of this paper is the comprehensive reconstruction and geometric stabilization of the degraded heavy gantry crane runway at the Thermal Power Plant (TPP) REK Bitola. This infrastructure supports a 383.4-tonne steel portal crane (manufactured by "Metalna" Maribor in 1977) that performs critical block maintenance on the parallel S49 rail tracks, with dynamic wheel loads of up to 210 kN. After nearly five decades of unmaintained service, advanced biochemical decay of the legacy wooden sleepers and severe ballast fouling led to vertical and horizontal rail deflections of

30–40 mm. Because these distortions violate the crane's safe-operating tolerances of ± 3 to ± 5 mm, the track was officially decommissioned due to derailment risks and structural stress concentrations within the crane's steel portal frame..

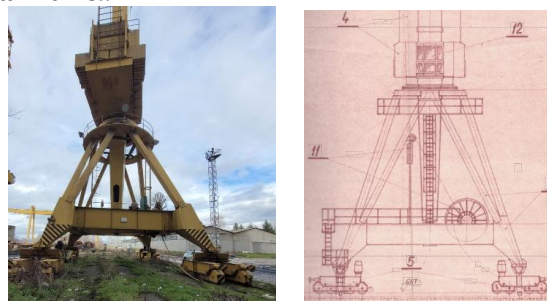


Fig.1. Portal crane at TPP REK Bitola

To engineer a definitive structural solution, a detailed forensic assessment was executed. While typical railway settlement failures are closely linked to subgrade shear

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failure, core-drilling profiles and laboratory testing in accordance with MKC EN 13286-47:2023 revealed a contrasting structural baseline: the underlying platform layers exhibit an exceptionally high bearing capacity, reaching a benchmark CBR value of 100%.

This boundary condition confirms that the systemic deformation was driven exclusively by superstructure degradation rather than by subgrade settlement. Consequently, the modernization design presented in this paper focuses on leveraging this rigid base to optimize construction costs. The engineered solution replaces the decayed timber system with custom pre-stressed reinforced concrete sleepers (type RAJS-K-B70) tailored for the unique 1500 mm track gauge, securing the S49 rails with elastic Vossloh SKL 14 fastening assemblies. The modernized layout elevates the track profile on a clean 35 cm ballast prism placed directly on the rigid subgrade and integrates a high-efficiency subsurface drainage network with perforated Ø100 mm pipes to permanently eliminate the formation of coal-dust slurry.

2. EXISTING CONDITION ASSESSMENT

The gantry crane track at TPP REK Bitola has two parallel runways, each 35 m long, with a center-to-center portal span of 7.50 m and a customized track gauge of 1500 mm [3]. The legacy superstructure used standard S49 rail profiles on wooden sleepers with rigid mechanical joints, and was supported by an aged crushed-stone ballast bed.

Multi-decadal exploitation under intense dynamic concentrations and severe environmental exposure, including coal dust and ash accumulation, triggered accelerated material degradation. Organic decomposition and internal rotting stripped the timber sleepers of their shear capacity, loosening the fastening anchorage and inducing dynamic rail spreading. At the same time, coal particles fully clogged the ballast prism voids. This severe ballast fouling choked the drainage path, leading to moisture retention and a destructive pumping effect under load.



Fig.2. Existing condition of the crane track.

Precise geodetic leveling and diagnostic structural surveys verified critical geometry loss across all parameters. The maximum recorded track gauge deviation reached a critical +44 mm, while localized vertical rail depressions plunged up to 30–40 mm, inducing extensive cross-level non-uniformities and track twist. When traversed by the 383.4-tonne portal crane, these geometric defects induced excessive dynamic impact forces, accelerated wheel-rail flange

friction ("wheel eating"), eccentric loading within the steel portal frame, and an immediate risk of structural derailment. Consequently, complete track reconstruction was mandated.

3. PROPOSED REHABILITATION CONCEPT

To restore structural strength and maintain long-term geometric stability, a complete superstructure modernization was developed based on a 210 kN wheel load envelope. The selected structural components comply with European design standards, using EN 13674-1 for rails [4], RAJS-K-B70 pre-stressed reinforced concrete sleepers [5], and Vossloh SKL 14 elastic fastening systems [6].



Fig.3. Proposed superstructure components: (a) RAJS-K-B70 sleeper; (b) Vossloh SKL 14 fastening; (c) S49 rail.

Given the exceptionally stable subgrade (CBR = 100%), additional granular subbase or artificial stabilization layers were omitted as structurally redundant. Instead, a clean, high-grade crushed-stone ballast prism with a minimum thickness of 35 cm is placed directly onto the existing rigid platform beneath the sleeper seat, preserving structural sufficiency while simplifying the section. This elevated configuration deliberately raises the track profile above the surrounding ground depression, placing it above the concrete perimeter to prevent the accumulation of falling coal dust and ash. To eliminate moisture pooling, a longitudinal subsurface drainage network with a perforated Ø100 mm pipe is embedded parallel to the alignment, combined with a 3% to 4% cross-slope on the platform surface to ensure rapid runoff evacuation.

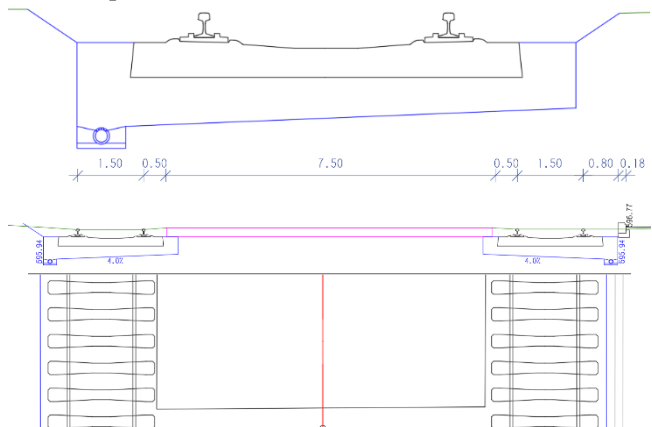


Fig.4. Proposed crane track layout and cross-section.

As illustrated in Fig. 4, the unified superstructure layout integrates continuous S49 rail profiles for smooth wheel transit, secured by elastic Vossloh SKL 14 clip assemblies. Dynamic impacts are attenuated by heavy-stiffness under-rail elastomeric pads that protect the

concrete interface. Finally, custom pre-stressed concrete sleepers (type RAJS-K-B70) permanently lock in the 1500 mm track gauge over an elevated 35 cm ballast prism and a longitudinal Ø100 mm drainage network.

4. TRACK STRUCTURE DESIGN AND ANALYTICAL MODELING

4.1. Input Parameters for the Analytical Model

The structural dimensioning of the modernized superstructure is performed using the classical Zimmermann framework, which treats the rail as an infinitely long beam supported on a continuous elastic Winkler foundation [7]. Based on the geotechnical reference (CBR = 100%), the track bed reaction modulus (C) is set to an elite value of 150 MPa/m ($150 \times 10^3 \text{ kN/m}^3$). The baseline analytical input parameters are:

- Maximum Dynamic Wheel Load (Q): 210kN,
- Rail Profile (S49): $I = 1819 \text{ cm}^4$, $W = 248 \text{ cm}^3$, $E = 2.1 \times 10^5 \text{ MPa}$,
- Sleeper Spacing (a): 0.60m (on-center spacing for RAJS-K-B70 units).

The Winkler model defines the vertical bed reaction force per unit length (p) as directly proportional to the elastic rail deflection (y), expressed as:

$$p = C * y * a \quad (1)$$

where p is the track bed reaction force [kN/m] and y is the vertical elastic deflection of the rail head [m].

4.2. Numerical Analysis and Numerical Results

The characteristic distribution length (L), defining the longitudinal zone of wheel load distribution, is determined via the governing equilibrium equation:

$$L = \sqrt[4]{\frac{4EI}{C}} = \sqrt[4]{\frac{4 * \left(2.1 * \frac{10^8 \text{ kN}}{\text{m}^2}\right) * (1819 * 10^{-8} \text{ m}^4)}{\left(150 * \frac{10^3 \text{ kN}}{\text{m}^3}\right) * 0.60 \text{ m}}} = 0.64 \text{ m} \quad (2)$$

The maximum bending moment ($M_{\max}$) induced directly under the wheel load is derived by incorporating a worst-case dimensionless shape coefficient ($\mu = 1.0$), assuming the wheel rests directly over a single concrete sleeper:

$$M = \frac{QL}{4} \mu = \frac{210 \text{ kN} * 0.642 \text{ m}}{4} 1.0 = 33.71 \text{ kNm} \quad (3)$$

Consequently, the maximum normal bending stress ($\sigma_{\max}$) developed within the extreme fibers of the S49 rail foot is evaluated via equation (4):

$$\sigma = \frac{M}{W} = \frac{33.71 * 10^{-3} \text{ MNm}}{248 * 10^{-6} \text{ m}^3} = 135.92 \text{ MPa} \quad (4)$$

The maximum vertical reaction force ($S_{\max}$) transferred to the custom RAJS-K-B70 pre-stressed concrete sleeper directly beneath the wheel loading is calculated as:

$$S_{\max} = \frac{Q * a}{2 * L} = \frac{210 \text{ kN} * 0.60 \text{ m}}{2 * 0.642 \text{ m}} = 98.13 \text{ kN} \quad (5)$$

Factoring the effective bearing area of the RAJS-K-B70 sleeper foot ($A_{\text{eff}} \sim 0.38 \text{ m}^2$), the maximum

compressive contact stress (σ_b) exerted onto the elevated 35 cm ballast prism is derived as:

$$\sigma_b = \frac{S_{\max}}{A_{\text{eff}}} = \frac{98.13 \text{ kN}}{0.38 \text{ m}^2} = 258.23 \text{ kPa} = 0.258 \text{ MPa} \quad (6)$$

4.3. Limit State Verification

The maximum calculated normal bending stress ($\sigma_{\max} = 135.92 \text{ MPa}$) remains well below the permissible fatigue limit state for the S49 rail steel grade, capped at $\sigma_{\text{perm}} = 225 \text{ MPa}$ according to EN 13674-1. Likewise, the maximum compressive contact stress at the sleeper-ballast interface ($\sigma_b = 0.258 \text{ MPa}$) stays below the critical degradation threshold for crushed stone ballast ($\sigma_{b,\text{perm}} = 0.30 \text{ MPa}$ under EN 13230).

Because the natural subgrade matrix exhibits excellent bearing capacity (CBR = 100%), it accommodates this stress distribution without plastic deformation. The analytical modeling confirms that direct application of the 35-cm-elevated ballast bed over the existing rigid platform satisfies all ultimate and serviceability limit states.

5. CONSTRUCTION METHODOLOGY AND SEQUENTIAL TECHNOLOGY

To achieve the rigorous millimeter-level alignment required by international tolerances (± 3 to $\pm 5 \text{ mm}$), a strict construction sequence is enforced. Geotechnical testing confirmed an exceptionally rigid foundation layer (CBR = 100%), so traditional deep subgrade excavation and subbase installation are entirely omitted. All works are executed directly on the exposed, stable platform. To manage the restricted 35-meter working front without dismantling the 383.4-tonne crane, the work is carried out in two phases: first one half, then the other.

- Stage 1: Site Securing and Temporary Crane Dislocation

Prior to mechanical intervention, the industrial perimeter within the TPP REK Bitola maintenance block is isolated, and high-voltage power lines are decommissioned. To facilitate a continuous workflow within the short 35-meter runway limits, the massive "Metalna" portal crane is systematically moved at minimum speed toward the first designated end half of the alignment. Once positioned safely, the portal structure is mechanically locked, counter-wedged, and anchored. This eliminates the risk of overturning during the reconstruction of the newly exposed adjacent half.

- Stage 2: Rail Cutting, Superstructure Dismantling, and Ballast Scraping

Following crane stabilization, mechanical rail saws make a precise transverse cut through the existing S49 rails at the track midpoint, dividing the runway into two isolated working sections. On the vacant half, unbolt the fasteners, carefully extract and store the preserved S49 rail strings laterally for immediate re-use, and remove and dispose of the degraded wooden sleepers. Excavate the heavily fouled, coal-dust-saturated ballast bed down to the hard gravel-sand platform level (CBR = 100%).

Then thoroughly clean the exposed subgrade surface, high-pressure wash it to remove abrasive slurry accumulations, and geodetically survey it.

- Stage 3: Longitudinal Sub-drainage Infrastructure Integration

To permanently prevent water pooling and the formation of coal-dust mud, integrate the drainage network before laying new ballast. Excavate a shallow longitudinal trench parallel to the track alignment. Grade the subgrade platform to a strict 3%-4% outward cross-slope toward the drainage zone so runoff is directed away from the track. Embed a perforated polyvinyl chloride (PVC) sub-drainage pipe (Ø100 mm) within uniformly graded filter gravel (4-16 mm fraction) to ensure immediate evacuation of surface runoff away from the active track infrastructure.

- Stage 4: Ballast Prism Deposition and Concrete Sleeper Distribution

High-efficiency, sharp-edged crushed stone ballast (Class I, fraction 31.5 to 63 mm) is tipped directly onto the cleaned CBR 100% platform. The lower lift is spread and mechanically compacted with heavy vibratory rollers to a uniform thickness of 20 cm. After base compaction, custom-manufactured pre-stressed reinforced concrete sleepers (type RAJS-K-B70) are distributed over the bed using a hydraulic excavator with a synchronized-spacing lifting beam. The sleepers are aligned at a strict 60 cm on-center longitudinal spacing. Their orientation is verified by laser-guided geodetic positioning to ensure absolute parallelism.

- Stage 5: Rail Re-laying, Continuous Welded Rail (CWR) Welding, and Tamping

The preserved S49 rail strings are re-threaded onto the new concrete sleeper seats over high-stiffness elastomeric under-rail dampening pads. The rails are secured with elastic Vossloh SKL 14 clip assemblies, and the anchoring bolts are mechanically torqued to 220 Nm. Once secured, the rail joints and cut segments are joined via aluminothermy welding. This converts the section into Continuous Welded Rail (CWR), thereby eliminating dynamic mechanical joints.

Finally, top ballast is distributed to fill the sleeper cribs. Final alignment is achieved through sequential passes of mechanical tamping, lining, and leveling equipment until the cross level, longitudinal grade, and 1500 mm track gauge are locked within millimeter operational tolerances. After geodetic verification of this first half, the crane is carefully lowered onto the newly modernized concrete track segment. The sequence from Stage 2 through Stage 5 is then repeated for the remaining half of the runway.

6. CONCLUSION

The engineering approach implemented in this study shifts the paradigm of industrial runway rehabilitation by demonstrating that systemic loss of geometry does not automatically dictate foundation failure. By isolating the true structural root cause—progressive material decay of

legacy timber elements under aggressive exposure to coal dust and moisture—the developed design leverages the exceptional bearing capacity of the existing rigid subgrade platform (CBR = 100%). This eliminates redundant subgrade excavation and granular subbase layers, establishing a highly cost-effective and structurally optimized rehabilitation layout.

The modernized superstructure configuration successfully establishes a uniform, high-stiffness track modulus. Custom pre-stressed concrete sleepers (type RAJS-K-B70) permanently lock in the specialized 1500 mm track gauge, which, when paired with elastic Vossloh SKL 14 fastenings and continuous S49 rail strings, mitigates the risk of gauge spreading under cyclic 210 kN wheel-load envelopes. Simultaneously, intentionally elevating the ballast prism to 35 cm, combined with a 3% to 4% platform cross-slope and a longitudinal subsurface drainage network, eliminates environmental vulnerabilities by preventing water pooling and the formation of coal-dust slurry within the track bed.

Ultimately, the technical feasibility of this project is validated by its sequential execution technology. Slicing the rails at the midpoint and staging the reconstruction in two distinct phases provides a highly practical logistical template for short industrial runways, ensuring that the massive 383.4-tonne portal crane remains safely on-site without interrupting plant operations. Transforming the re-laid rails into Continuous Welded Rail (CWR) successfully eliminates dynamic joint impacts, prevents catastrophic track twist, and restores the heavy gantry crane to certified, long-term operational reliability.

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