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Study on Rail Switching System for Railway Curve Operation Based on Finite Element Analysis

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Abstract: To address challenges in railway curve section track replacement operations-including difficulties in longitudinal movement of old rails, limited space for new rail placement, and poor stability of welded rails-this study designs a longitudinal rail relocation system for curved track sections. Through 3D modeling and static simulation, beam element models of 60kg/m rails were established with varying lengths (50m, 75m, 100m, 150m), material properties were configured, and constraints and loads were applied. The analysis revealed support arrangement schemes for each rail length that ensure maximum deformation remains below 32mm. The system incorporates longitudinal rail movement mechanisms, positioning devices, and rapid disassembly components, enabling safe fixation of relocated rails while reducing cutting and secondary welding processes. This innovation enhances operational efficiency, cost-effectiveness, and safety in rail replacement for curved track sections, providing technical support for modern track maintenance practices.

1. Introduction

Seamless tracks are the mainstream track structure in railways, and rail overhaul is a key operation for periodic maintenance to ensure track stability and traffic safety. Among them, curved sections, due to complex stress and uneven wear, require higher construction standards [1]. The practice of China Railway Guangzhou Group (Guangzhou Bureau) is highly exemplary. From 2019 to 2020, they used integrated rail replacement technology to replace 29.5km damaged rails in sections on the main lines of the Beijing-Guangzhou and Guangzhou-Shenzhen-Hong Kong high-speed railways. By combining long rail cars, on-board welding machines, and other equipment, they completed the entire process of rail removal, replacement, and welding within a single window, reducing the workload from traditional methods requiring more than three windows to just one, meeting the high-speed rail requirements of "work completed, materials cleared, safety and punctuality" and providing a replicable operational model [2]. Wang Guangwu from Jinan Track Machinery Section pointed out that there are two core influencing factors in construction on curved sections. The first is the temperature difference of the construction rail: the greater the temperature difference between the long rail to be replaced and the environment the next day, the greater the expansion and contraction, which can easily lead to abnormal locking stress. The second is the shortening of the curve: influenced by the length and radius of the curve, the long rail will shorten, with the upper rail extending in the direction of construction and the lower rail contracting in the opposite direction. At the same time, regulations require that the length of old rails in the center of the track should not exceed 500m in straight sections and 300m in curved sections, necessitating the offset of rail heads and the use of No.8 wire to bind them to sleepers every 50m to prevent displacement. Currently, there are still pain points in curved rail replacement: after the old rail is moved into the center of the track, it cannot be longitudinally moved to release internal stress, so each bureau can only cut it section by section. When reused, it needs to be welded again, which consumes manpower and resources and poses quality risks at the joints, leading to resource waste and constraining the improvement of the cost-effectiveness of overhaul [3].

2. Principle

The longitudinal rail replacement system for curved sections focuses on developing track-lifting structures specifically designed for curved tracks. This allows for free longitudinal expansion when replacing old rails into the track center, effectively releasing internal stresses and preventing cutting. Positioning limit devices at specific intervals counteract train vibrations and prevent rail intrusion. The modular design enables standardized component assembly for 3-minute rapid installation, with self-locking fixtures ensuring structural stability. In emergencies, modular components can be rapidly interlocked as temporary supports to facilitate quick rail replacement and restrict track displacement, meeting both routine maintenance and emergency response requirements [4].

3. Track switching difficulties in curved sections

(1) Limited space for new rail placement: When CRTSII ballastless track is used on curved sections, the narrow width of sleeper edges makes it impossible to position new long rails on the outer side of existing tracks under the conventional 'unload first, then replace' method. This requires additional space coordination, otherwise it may compress signaling facilities or ballast structure [5].

(2) Poor stability of rail welding equipment: When operating on curves with small radii (e.g., 1800m) or large superelevation, the tilting of the mobile rail welding trolley may cause welding misalignment [6]. Additionally, rail displacement under lateral forces during welding can compromise joint quality, particularly affecting the smoothness of flash welding and gas pressure welding joints [7].

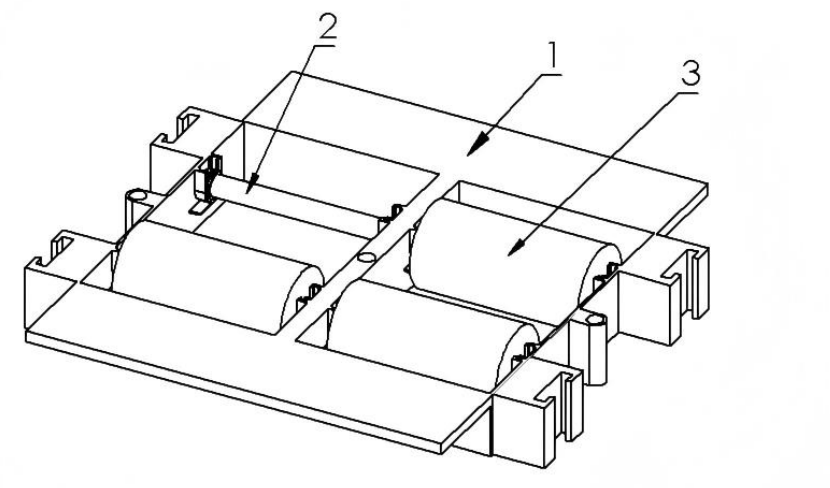
(3) Risks of rail expansion and misalignment: In curved sections, aging rails develop significant expansion due to prolonged stress, particularly under small-radius and large-clearance conditions. When realigning these rails into the track center, lateral movement or jamming often occurs. Manual realignment proves challenging and may damage fastener bolts or rail anti-rotation devices, potentially causing equipment failure or safety incidents [8].

4. Research Content

4.1 Research Content

1) The design of the longitudinal rail-switching system involves 3D modeling (Figure 1) and static simulation analysis to determine structural strength and rail support spacing. This ensures compatibility with tracks of varying curve radii, as well as different types and grades of rails and

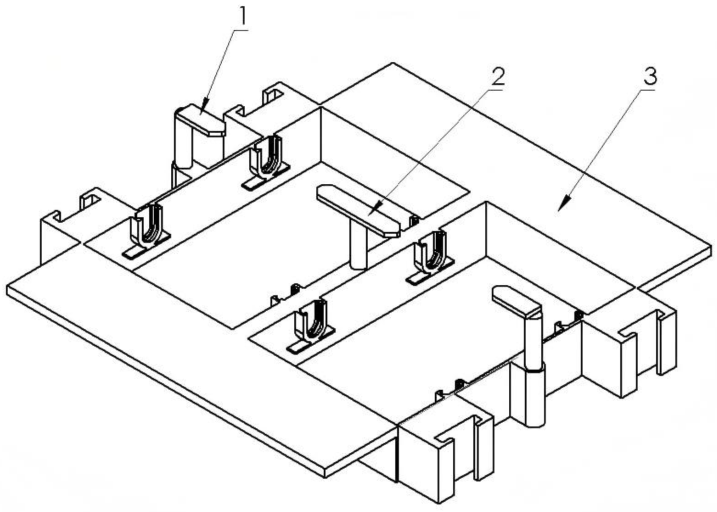
sleepers in terms of material, structure, and dimensions. The system guarantees that when old rails are replaced and inserted into the track center, they should remain straight and capable of free expansion and contraction [9].



1- the main support frame, 2- the bearing, 3- the rolling part

Figure 1: The longitudinal rail system

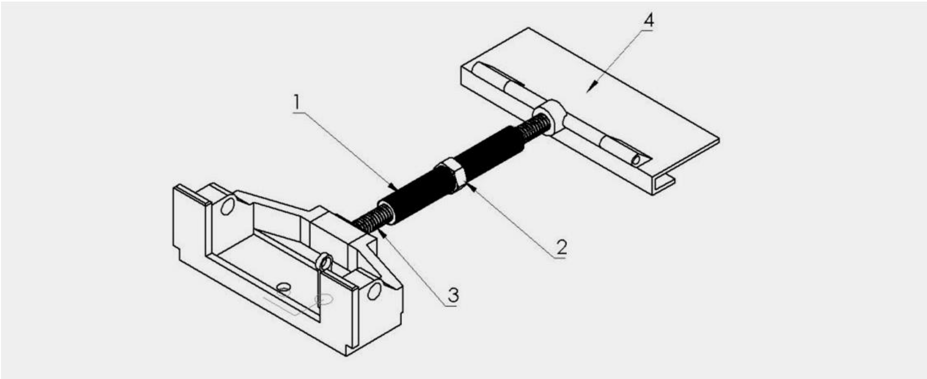
2) The design of the positioning device involves developing a secure arrangement solution for old rails within confined spaces, as illustrated in Figure 2. For seamless tracks, the center-to-center distance between adjacent sleepers is approximately 600mm. After deducting the 220 mm sleeper width, only 380mm remains as longitudinal space. Additionally, the ballast completely fills the subgrade, leaving minimal vertical clearance. When replacing old rails into the track center, the new rail top surface must be no higher than 25 mm above the old rail, with a minimum 300mm clearance between the outer edge of the old rail head and the new rail. Lateral positioning and securing mechanisms should be installed at predetermined intervals [10].



1-the side stop pin, 2-the central stop pin, 3-the main support frame

Figure 2: The limit fixing device

3) Development of rapid disassembly and assembly system: Due to the high labor intensity and limited time of the skylight workers, a rapid disassembly and assembly fixing system [11] was developed to minimize the labor intensity and working time, as shown in Figure 3.

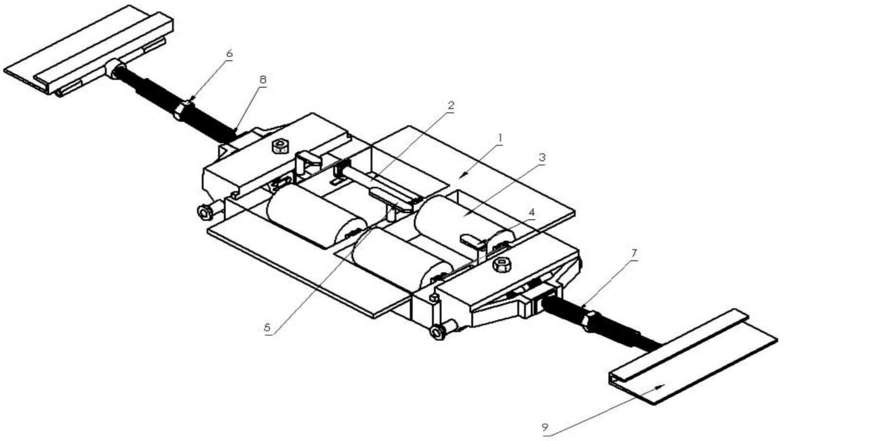


1-the threaded sleeve, 2-the adjusting nut, 3-the threaded inner core column, 4- the clamp

Figure 3: The quick assembly and disassembly system

4.2 Overall Structure Diagram

Figure 4 shows the overall assembly, while Figure 5 illustrates the assembly during operation.



1-the total support frame, 2-the bearing, 3-the rolling part, 4-the side limit pin, 5-the central limit pin, 6-the adjusting nut, 7-the threaded sleeve, 8-the threaded inner core column, 9-the clamp

Figure 4: Overall Assembly Diagram

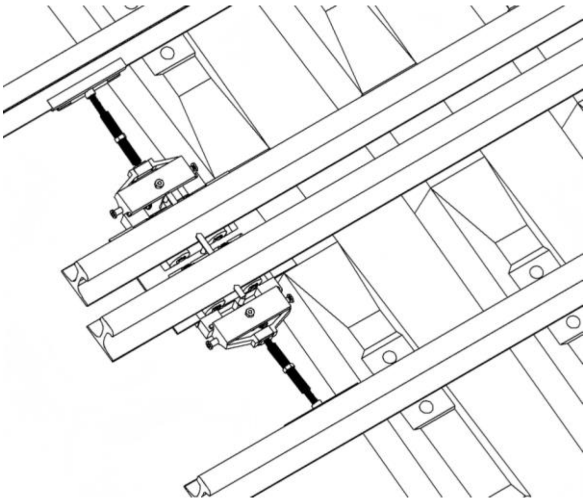


Figure 5: Assembly drawing with rails

5. Finite element analysis

5.1 Geometric Model

Using 60 kg/m rails, the geometric model was simplified. A rail beam element model was established with lengths of 50 m, 75 m, 100 m, and 150 m. The beam cross-section was simplified according to the rail cross-section as shown in Figure 6, with main cross-sectional dimensions listed in Table 1 [12].

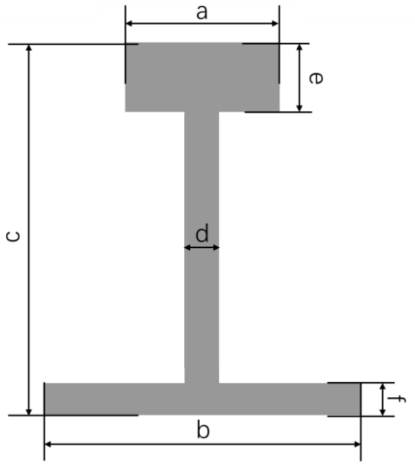


Figure 6: Simplified rail section

Table 1 60 kg/m rail section dimensions

sectional dimension	price /mm
Track width a	73
Track width b	150
Rail height c	176
Railway width d	16.5
Rail thickness e	34
Track bottom thickness f	15.25

5.2 Material Properties

The key properties of 60 kg/m rail material are configured as shown in Table 2.

Table 2 60 kg/m rail material properties

Material Properties	price
density	7850 kg/m^3
modulus of elasticity	210 Gpa
Poisson ratio	0.3

5.3 Constraints and Loads

To simulate the gravitational effect on the rail, a uniformly distributed load is added to the rail beam unit. Given the rail's cross-sectional area A=6860.87 mm^2, density $q = \rho * g * A$, ρ = 7850 kg/m^3, and gravitational acceleration g = 9.81 m/s^2, the uniformly distributed load 527.81 N/m is calculated according to the formula, with its direction perpendicular to the rail plane (as shown at point A in the figure).

The rail beam element is constrained by selecting a corresponding number of support points to simulate the original rail fastening device. All these support points are assigned remote displacement constraints. The far-left rail end (as shown at point B in Figures 7-10) only releases rotational freedom around the z-axis, while the remaining support points are allowed to move along the x-axis and rotate around the z-axis. This configuration simulates the longitudinal movement and axial rotation of the rail relative to the fastening device during gravitational bending deformation.

The constraints for 50m, 75m, 100m, and 150m rails are shown in Figures 7 to 10 respectively.

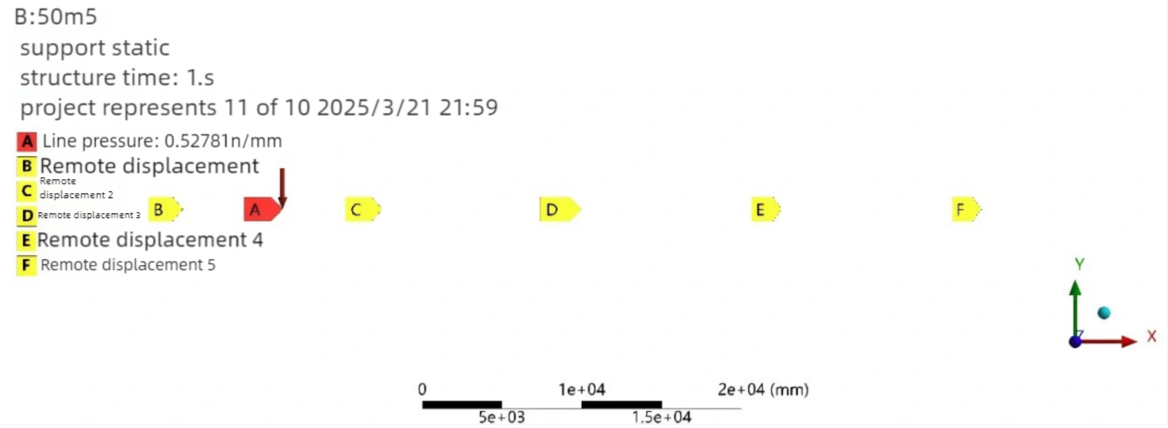


Figure 7: Constraints and loads of 50 m rail

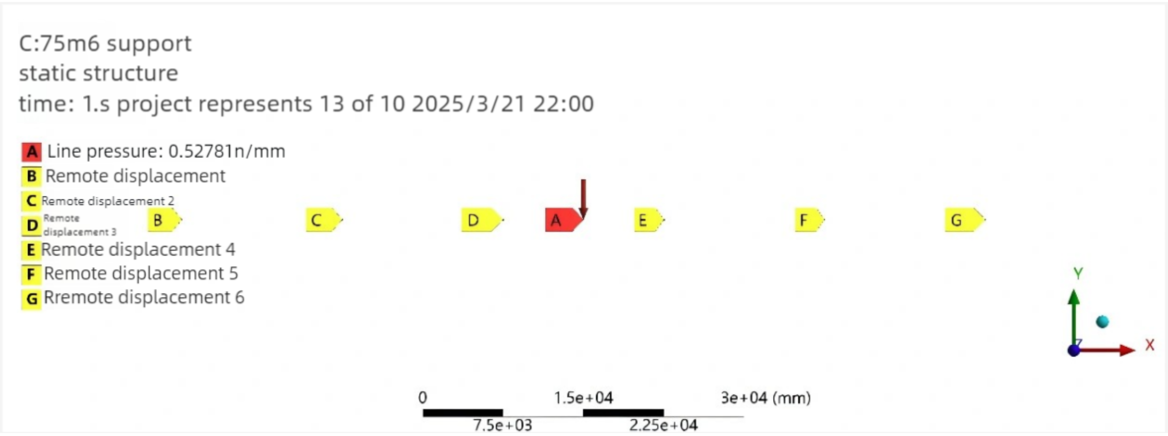


Figure 8: Constraints and loads of 75 m rail

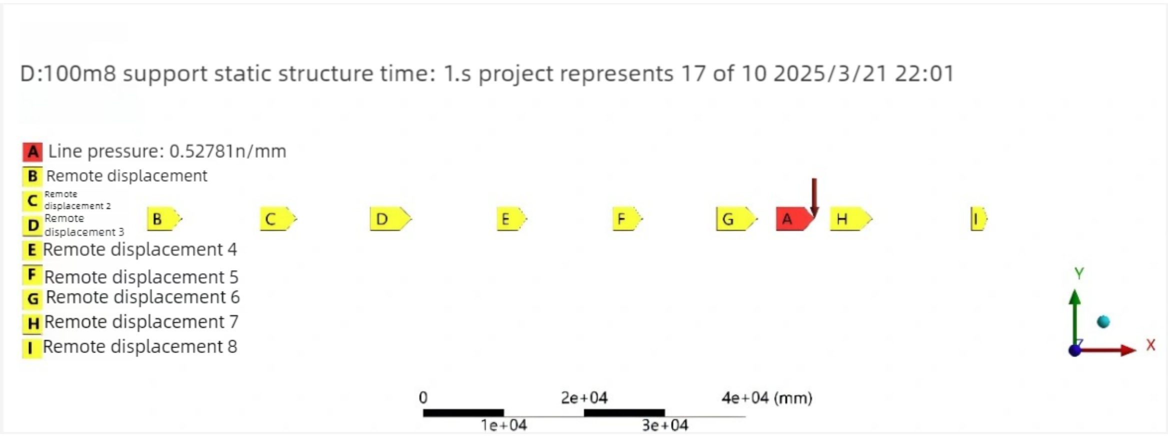


Figure 9: 100 m rail constraints and loads

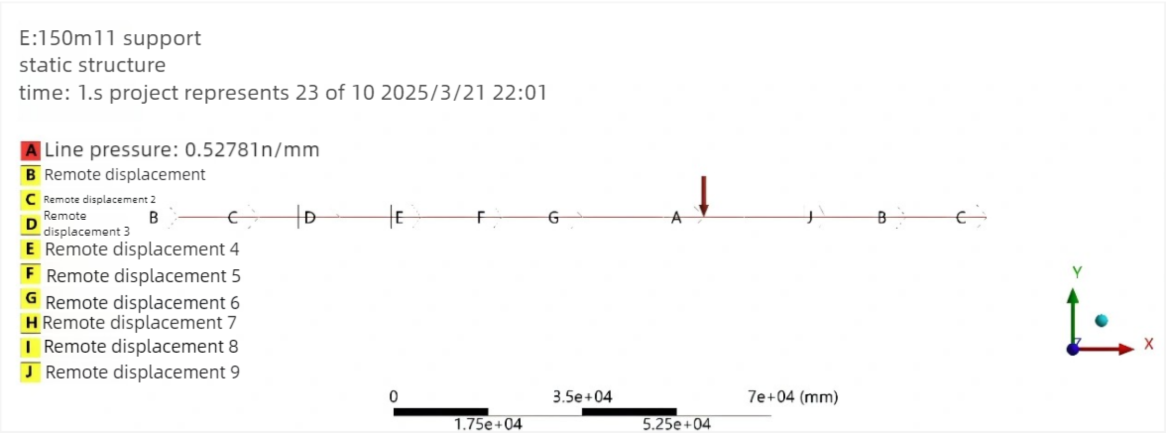


Figure 10: Constraints and loads of 150 m rail

5.4 Simulation Results

Through iterative simulation test of the maximum deformation of rail under the corresponding number of supports, the layout scheme of the fixing device is obtained when the maximum deformation is less than 32 mm, as shown in Table 3.

Table 3 Simulation test results

Rail length (m)	Number of supports (units)	Arrangement distance (m)	Maximum deformation (mm)
50	5	12.5	13.061
75	6	15	27.509
100	8	14.28	27.411
150	11	15	22.56

Figure 11 shows the simulation results of evenly distributing 5 fixing devices on a 50 m rail; Figure 12 displays the results for 6 devices on a 75 m rail; Figure 13 presents the outcomes for 8 devices on a 100 m rail; and Figure 14 illustrates the simulation results for 11 devices on a 150 m rail. To clearly demonstrate rail deformation, all simulation results are magnified 100 times. As shown in Table 3, the maximum deformation values all meet the requirement of being less than 32 mm.

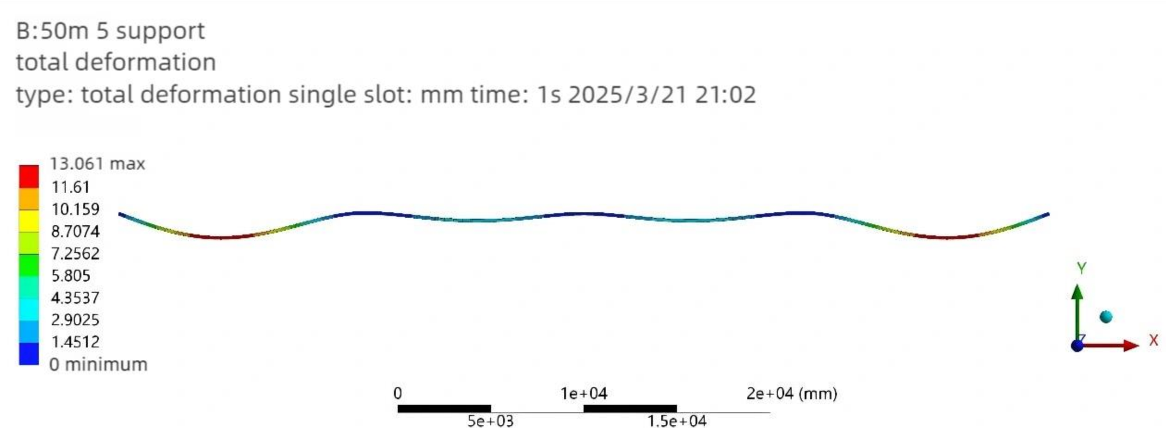


Figure 11: Total deformation of 50m rail

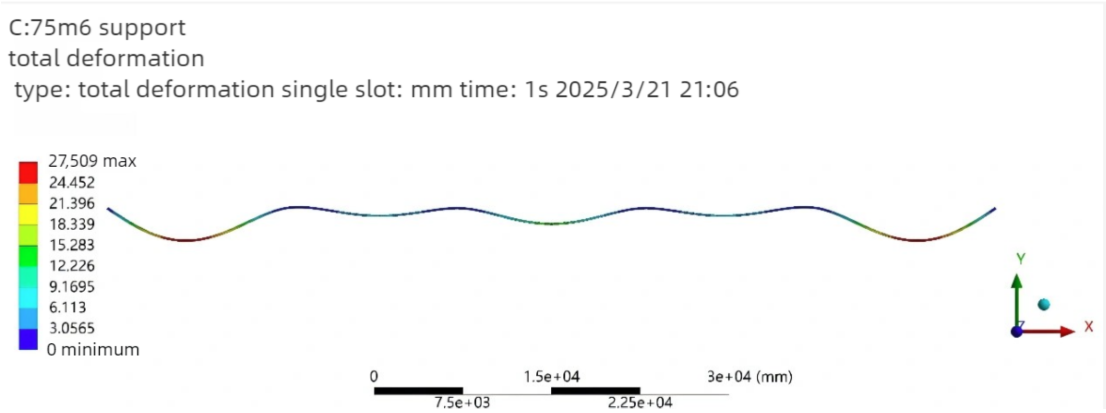


Figure 12: Total deformation of 75m rail

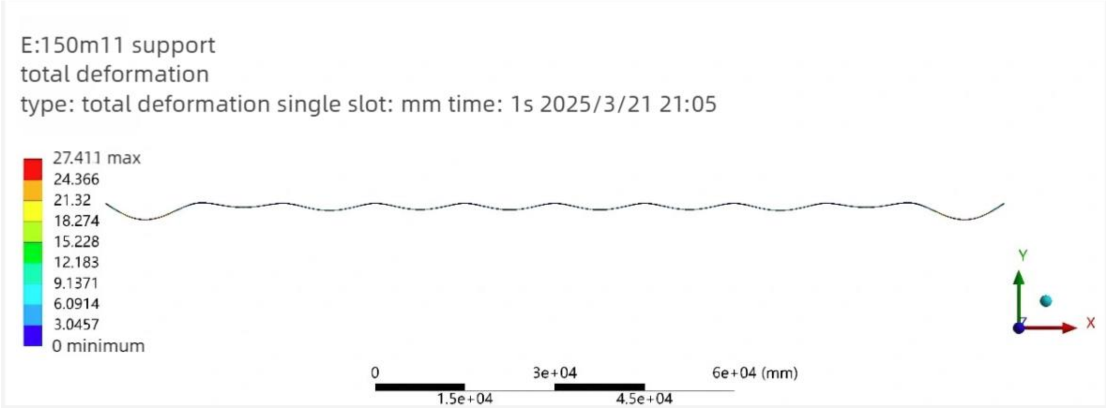


Figure 13: Total deformation of 100m rail

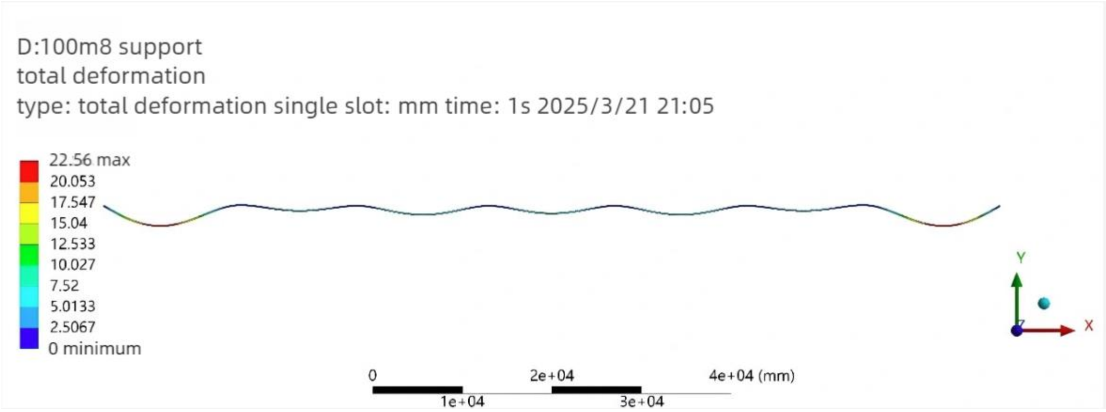


Figure 14: Deformation of 150m rail

6. Conclusion

This study addresses the pain points of railway curve track replacement by designing a longitudinal track-switching system and conducting finite element analysis. For 60 kg/m rails, beam element models with 50 m, 75 m, 100 m, and 150 m spans were established. Static simulation determined the support configuration requiring 5, 6, 8, and 11 support points respectively, with maximum deformation all under 32mm, meeting requirements. The system integrates longitudinal track-switching, positioning, and rapid assembly/disassembly mechanisms, enabling longitudinal expansion-relaxation of old rails to eliminate cutting and secondary welding. The entire process completes in 3 minutes while resolving issues like restricted new rail placement and poor welded rail stability. This enhances track-switching efficiency, cost-effectiveness, and safety of old rail reuse, providing technical support for curve track replacement.

Acknowledgement

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