Feasibility analysis of semi-welded seamless turnout in Yuqomolangma Station of Qinghai-Tibet Railway

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Abstract. It is difficult to lay seamless turnouts on the Qinghai-Tibet Railway, and the large temperature difference between day and night on the plateau railway leads to large changes in the temperature of the turnouts. Aiming at the equipment status of No.1 turnout in the Yuzhufeng station of the Qinghai-Tibet railway, a non-linear finite element calculation model of P60-12 single-open turnout was established. The long rail was calculated and analyzed based on the construction lock rail temperature and the local maximum and minimum rail temperature. The development law of displacement under temperature changes, after comparing the field measured displacement observation data, the model calculation result is correct, and the lateral displacement meets the requirements. Comparing and analyzing on-site rail displacement observation data, the model calculation results meet the engineering accuracy requirements. In the season of the highest rail temperature in the year, strain sensors are installed at the rail waist at different parts of the semi-welded seamless turnout to collect the rail strain increment under the cyclic change of rail temperature. According to the strain increment change rule, displacement observation data and model calculation results, it is concluded that the scheme of laying a semi-welded seamless turnout in Yuqomangma station is feasible, and the rail in the bifurcation area is stable under the action of temperature stress.

1. Introduction

Welding of long rails has replaced ordinary joints of steel rails and has become the main structural form of the main railway line in China. It has increased the stability of trains, improved the quality of the line, saved joint materials, and slowed the accumulation of line deformation. It reduces maintenance workload, reduces maintenance costs, and prolongs the service life of line equipment and rolling stock. It has been widely used in countries all over the world [1]. As an important link in the realization of cross-interval seamless lines, The research on the design, laying, maintenance and other issues of the seamless turnout has increasingly highlighted its importance and necessity.

The stability analysis of seamless turnout has been widely concerned by scholars at home and abroad. Domestic qiu-yi li, xiu-fang Chen, Lou equality on the basis of the analytical model, in the light of different wavelengths, different orbit initial bending, lateral ballast resistance and rail temperature variation on jointless-track's stability and stochastic impact study, establish extremum probability model analysis under different parameter selection, the stability of jointless track, and the stability reliability of stochastic simulation, the influence of different boundary conditions on the calculation results[2-3]. The "unified formula" is frequently used by railway public works departments...
in China to check and calculate the stability of seamless lines, and the calculation results are stable and reliable[4]. W.s. O and G.C.Martin et al. in the United States first proposed the finite element model for stability analysis in 1976 and established the world's first finite element model for the stability of seamless lines[5-6]. In 2003, Dr. Zeng Zhiping regarded sleepers as finite long beams on elastic foundations and conducted force analysis on them by using the Koch method based on elastic theory[7]. In 2001, On the basis of summarizing various theories, Professor Wang Ping of Southwest Jiaotong University applied finite element method to calculate the temperature force and displacement of seamless turnout[8]. In 2006, Yi Jin established the calculation model of seamless turnout by using the finite element method based on variational principle, analyzed the longitudinal temperature additional force and displacement of seamless turnout, and compared it with ballasted turnout, and obtained some conclusions that are useful for engineering practice[9]. Mou Hang et al. [10-11] analyzed the influence degree of vertical settlement on the temperature stress of long rail of seamless line by using the finite element method. Zhou Haiyu et al.[12] studied the impact analysis of track lateral and composite irregularity on the stability of seamless lines. The theory of seamless turnout calculation at home and abroad can be said to have their own advantages, the research results have been verified by practical projects, it shows that the research conclusions are correct. However, there are few literatures about the stability analysis of seamless turnout in the space system, and the permafrost area in The Gela section of qinghai-Tibet Railway is prone to subgrade settlement and other diseases, so it is necessary to consider the influence of track diseases such as the height before and after the line on the stability of seamless turnout. In this paper, based on the Yuqomolangma station of Gra section of Qingzang Railway, a nonlinear finite element calculation model of space bar is established for seamless turnout structure. Combined with the actual displacement observation data, the stability problem of seamless turnout is analyzed, providing a theoretical basis for the research on seamless turnout laying and maintenance of plateau railway.

2. Establishment of seamless turnout model

2.1 Mechanical model
Based on the assumption of small deformation, the rail frame is regarded as a long and thin pressure bar laid in uniform medium, and a 3D model of the frog seamless switch with 12 fixed frog is established. Track frame model with 60 kg/m rails, play a ꟾ type fastener, concrete sleeper ꟾ type, each laying sleeper 1760 km, from your head to bifurcation bifurcation mantissa, a total of 82 bifurcation pillow, roadbed shoulder width is 450 mm. The lateral resistance stiffness of the bed is 1500N/mm, the longitudinal resistance stiffness of the ballast bed is 2500N/mm, and the vertical stiffness is 3200N/mm. The rail and beam elements on each side are rigidly connected and are represented by nonlinear beam elements with twelve degrees of freedom. Double-node spring element is used to simulate the fastener connecting rail and sleeper. The constraint of fastener on rail is elastic constraint, and the fastener is regarded as the spring element without length and mass. The effect of the track bed against the torsion of sleeper is not considered.

A pair of limiter with a limit of +8 and -6mm was set at the heel of the sharp rail. Through calculating the relative displacement of the basic rail and the guide rail at the heel of the sharp rail, the temperature appreciation of the letter block of the limiter was obtained when it was close to each other. After the letter block of the limiter is closely attached, the relationship between its acting force and temperature rise is selected as 14kN/℃ in reference to literature[13], and is added to the model in the form of a pair of nodal forces.

2.2 Solving method of nonlinear finite element
Under the conditions assumed by Kirchhoff, the strain of the beam element of the space beam is composed of linear strain and nonlinear strain. When solving nonlinear problems, the relationship between load and nonlinear displacement can generally be regarded as a series of linear responses.
Generally, Lagrangian column method is used to solve nonlinear finite element problems. A complete iterative step is as follows:

- Measure the irregularity of the line and assign the value according to the measured initial displacement;
- According to linear analysis, the initial value of node displacement is obtained $\{\delta\}_1$;
- Construct element tangent stiffness matrix $[K_T]$ in local coordinate system, and calculate element nodal force $[F]_e$;
- Convert $[K_T]$ and $[F]_e$ to a global coordinate system;
- Repeat steps 3 and 4 for all the elements to generate the structural tangent stiffness matrix $[K_p]_1$ and nodal force vector $[F]_1$;
- Calculate the unbalanced forces:
  \[ \{P\}_1 = \{F\}_1 - \sum e [F]_e \]  
  \[ \{\delta\}_1 = \{\delta\}_1 + \Delta \{\delta\}_1 \]  
- The structural stiffness matrix equation 2 is solved to obtain the displacement increment $\Delta \{\delta\}_1$ of the node;
- Add $\Delta \{\delta\}_1$ to the structure displacement vector $\{\delta\}_1$, namely
  \[ \{\delta\}_2 = \{\delta\}_1 + \Delta \{\delta\}_1 \]  
- Judge the convergence condition, if not satisfied, go back to step 3.

\[ \frac{\sqrt{\Delta \{\delta\}_1^T \cdot \Delta \{\delta\}_1}}{\sqrt{\{\delta\}_1^T \cdot \{\delta\}_1}} \leq e \]  

3. Welding coupon scheme

Seamless turnout is a special turnout form in which all rail joints in turnout are eliminated. Rail joints are connected by cemented joints and welded joints. Field tests and practical applications have proved that frozen joints are superior to cemented joints in many aspects, and 50T tension press is used to test the tensile strength of cemented joints. In order to enhance the integrity of the joint and improve the bending resistance, the frozen joint can be used to improve the shear strength and friction force between the splint and the rail's chin contact surface.

4. The effect of temperature change on displacement

Based on the calculation and analysis of the established rail frame model, the temperature rise of the overall structure of the seamless turnout was 0℃, 10℃, 20℃ and 30℃. The overall structure was cooled by 0℃, -10℃, -20℃, -30℃ and -40℃, and the variation law of its transverse displacement and longitudinal displacement with temperature change was solved.
The change trend of each trajectory of the seamless turnout is similar when the temperature rises. The direction of lateral displacement is from the fork to the fork, with the left side being positive and the right side being negative. The force characteristics of the straight basic rail are more obvious. Under different temperature rise conditions, the transverse displacement trend is shown in Figure 2, and the schematic diagram of the turnout sleepers at each disadvantageous position is shown in Figure 4. From the calculation results of the model, it can be seen that the seamless turnout is produced at the straight basic rail at the switch part No. 6 turnout sleeper, No. 21 turnout sleeper, guide curve part No. 41 turnout sleeper, No. 57 turnout sleeper, and No. 74 turnout sleeper in the switch part. The outer lateral displacement peak, the inner lateral displacement peak of the No. 63 turnout sleeper and the No. 77 turnout sleeper in the switch part, the maximum lateral displacement changes from the turnout center to the end of the wing rail, that is, the No. 63 turnout sleeper, when the temperature is increased by 30°C, Its lateral displacement is approximately 0.6519mm; there is a disconnection at the No. 75 turnout tie, and the displacement has a peak at the No. 74 turnout tie, and then decreases sharply. It can be seen from the temperature rise conditions that the higher the temperature, the greater the lateral displacement of the rail. The maximum increase in displacement at 30°C compared with 0°C is about 90.7%, and the minimum increase is 64.8%. The law of change during cooling is just the opposite of that during heating. Under different temperature drop conditions, the trend of lateral displacement changes is shown in Figure 3.

Figure 5 shows the longitudinal displacement of the curved rail under different temperature rise conditions. Some turnout sleepers are selected for analysis. The calculation results show that as the temperature increases, the longitudinal displacement of the curved track increases continuously. When the temperature is increased by 30°C, the force of the stopper at the heel end of the cusp rail is 36.9kN,
and the tip of the cusp rail (No. 6 turnout tie) produces the maximum longitudinal displacement, and the displacement value is 10.5616mm.

![Figure 5. Longitudinal displacement of curved rail under different temperature rising conditions](image)

According to the measured data on site, the annual construction locked rail temperature of Yuzhufeng Station is 16.8℃ (the designed locked rail temperature is 14±5℃), the annual maximum rail temperature is 26.8℃, and the temperature rise is 10℃, as shown in Figure 5. The maximum longitudinal displacement of the heel end of the tip rail is approximately 3.52mm. The measured data of field displacement observation piles are shown in Table 1. The annual rail temperature of Yuzhufeng Station reached the maximum in August. The longitudinal displacement at the heel end of the turnout rail in Table 1 is -5mm for the left strand and -4mm for the right strand; the data calculated by the model is correct and it is consistent with the measured data on site.

| Displacement observation pile number | Specific location                      | July         | August        | September     |
|-------------------------------------|----------------------------------------|--------------|---------------|---------------|
|                                      |                                        | Left stock   | Right stock   | Left stock    | Right stock   |
| 7-7                                 | Before the fork                        | -3           | -2            | -3            | -3            | -4            | -3            |
| 1-1                                 | The ramp ahead of the turnout           | -3           | -1            | -3            | -3            | -4            | -2            |
| 1-2                                 | At the end of the fork rail             | -3           | -2            | -5            | -4            | -3            | -3            |
| 1-3                                 | The middle of the switch lead           | -1           | -2            | -2            | -3            | -2            | -2            |
| 1-4 5-1                             | Frog of switch follows end              | -1           | -2            | -1            | -2            | 0             | -2            |

### 5. Strain analysis

This article USES the strain gauge to test the rail temperature changes, temperature changes will affect the strain sensing properties of the meter itself, strain gauge type is more, but the resistance strain gauge and vibrating string type sensor is the most commonly used in rail, Bridges, detection, by literature[14], the temperature will be larger influence on the resistance of the strain gauge testing, thereby affect the test results, but for the influence of vibrating wire sensor, temperature can be ignored. Compared with other sensors, vibrating-string strain sensors have the advantages of high measuring accuracy, stable reading and easy to use. They are applied in ship launching trial, dam initial water storage monitoring and long-term monitoring, bridge engineering acceptance, load test and construction control, etc. Vibrating string strain gauge is selected for testing in this paper.

The strain electric measuring method is used to monitor the change of the actual locked track temperature of the seamless line, and the relationship between the stress, strain and the change of track...
temperature generated by the turnout of Yuqomolangma station is measured. Since the daily temperature difference in the high altitude area of the plateau varies greatly, the sunny days with stable rail strain development are selected for continuous observation for 24 hours, and the temperature and strain values of the sensor are read every 2h to observe the strain change characteristics of the vibrating string strain sensor itself under the condition of temperature change without load change. After weld interlocking set, in order to ensure the bifurcation area and a half long rail satisfy low temperature tensile stress state, the use of high temperature compressive requirements, to ensure the safety of line operation, two strain testing point layout rail project components, main check point layout in the straight track and guide curve at the back of the left on the straight and central guide curve left straight shares, tested the rail temperature cycle changes under the condition of rail strain increment value. Zx-212ct vibrating string strain gauge is installed on rail surface at rail, rail in normal zone and rail in bifurcated zone under free state. The measuring range of the vibrating string strain sensor is $\pm 1500 \times 10^{-6}$ and the temperature measurement range is $-20^\circ C \sim 125^\circ C$. The vibrating string strain gauge and vibrating string tester are shown in Figure 6. The vibrating string strain gauge used this time can simultaneously measure temperature and strain, and the measuring accuracy of temperature and strain is $0.1^\circ C$ and $0.1 \times 10^{-6}$ respectively.

Figure 6. Vibrating wire strain gauge

![Figure 6. Vibrating wire strain gauge](image)

The comparison and analysis of the bifurcated straight passage and the normal strain increment are shown in FIG. 6. The measuring points 1 and 2 are located in the normal straight passage, and the measuring points 3 and 4 are located in the left straight strand at the back of the guide curve and the left straight strand at the middle of the guide curve. The initial rail strain observation temperature is $21.8^\circ C$, the rail temperature rises, the rail pressure, the strain increment is positive, the rail temperature decreases, the rail tension, the strain increment is negative. The increment value of rail strain is related to the amplitude of rail temperature change. The greater the increment value of rail strain is, the greater the increment value of rail temperature change is. When the rail goes down from the highest rail temperature $27.6^\circ C$ to $24.3^\circ C$, the strain increment of the direct rail on the frog is slightly less than

Figure 7. Comparative analysis diagram of straight and normal strain increment in bifurcation area

![Figure 7. Comparative analysis diagram of straight and normal strain increment in bifurcation area](image)
that of the normal direct rail. As the rail temperature continues to decline, the strain increment of the middle and rear rail of the guide curve is basically consistent with that of the normal line.

6. Conclusion
According to the increment change law of the rail strain in the bifurcation area and the normal rail length, displacement observation data and model calculation results, the comprehensive analysis shows that the semi-welded seamless bifurcation in the bifurcation area of Yuqomangma station is feasible. The annual average temperature of Yuqomolangma station is relatively low, but due to the high altitude of the station, the rail temperature is susceptible to the influence of climate and has a relatively large fluctuation change. In the course of line operation, it is necessary to strengthen the observation of the long rail displacement in the bifurcation area.

Acknowledgments
The author thanks the tutor and his Science and Technology Research and Development Project of Qinghai-Tibet Group Corporation: Test of semi-welded seamless turnout at Yuzhufeng Station of Gela Section of Qinghai-Tibet Railway (QZ2019-G05) for their help in this article.

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