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Article

Calculation of Reasonable Tension Value for Longitudinal Connecting Reinforcement of CRTSII Slab Ballastless Track

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Abstract: There is a confusion in the original design concept for the tensioning of longitudinally connected reinforcement of CRTSII slab ballastless track. In order to clarify the effect of tension value of longitudinal reinforcement on mechanical characteristics of ballastless track, a three dimensional finite element model considering the nonlinear interaction between the track slab and CA mortar of CRTSII slab ballastless track was established. The mechanical characteristics of the track structure under longitudinal tension load and temperature gradient load of the longitudinal joint were calculated. A method of applying pre-stress to post-pouring concrete was proposed according to the concept of pre-stress loss of pretensioning pre-stressed concrete, reasonable tensile force value was proposed after the crack width and the reinforcement stress of the ballastless track in the operation stage were checked and calculated according to the concrete design principle. When the tension force is greater than 300 kN, it's harmful to the bonding between the slab and mortar layer, which is prone to interlayer damage. In order to adding pre-stress to concrete of wide joints to ensure the longitudinal stability of ballastless track and the reinforcement stress and crack width to meet the design requirements. It is suggested that the tension force value should be 230 kN, and the temperature difference between reinforcement and concrete should be 30 °C before the initial curdle of wide joint concrete.

Keywords: Tension force; Interface damage; CRTSII slab ballastless track; Concrete crack; pre-stress

1. Introduction

Ballastless track which is suitable to the high speed railway for the reason that it has high smoothness and stability of the railway line and has the advantages of high structural stability, good stiffness uniformity, long service life and small maintenance work compared with conventional ballast-track [1,2]. Figure 1 shows the CRTSII slab track and its components. The primary components of the slab track system are the rails, rail pads, track slab, cement emulsified asphalt (CA) mortar layer, and concrete base. CRTSII slab ballastless track is connected longitudinally between track slabs by tensioning the longitudinal connecting reinforcement between track slabs and casting wide and narrow joint concrete [3]. The tensioning of longitudinal reinforcement plays a role in ensuring the longitudinal connection reliable of ballastless track and limiting the crack width at wide and narrow joints. According to the original design concept [4], the tensioning of longitudinal reinforcement generates 300kN prepressure which can effectively reduce the crack width and the stress of the connecting reinforcement on the wide and narrow joint concrete. The

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wide and narrow joint is an important link in the longitudinal system of CRTSII slab ballastless track.

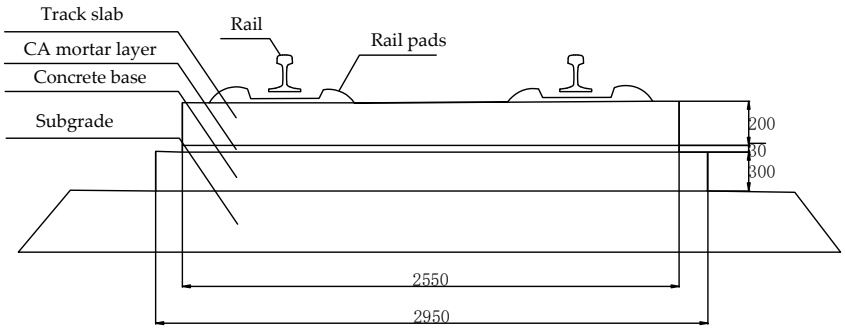

Figure 1. CRTSII slab ballastless track

Although the slab track has gained successful improvements and applications in high-speed railway lines compared with traditional ballasted tracks, slab track still represent some structural damage caused by train load and temperature load in the operation process. In practice, it is found that the wide and narrow joint between the track slabs has appeared diseases like concrete falling off and damage, cracking at joints (shown in Figure 2) and arch etc. in recent years. The longitudinal continuity and stability of ballastless track are seriously weakened by the damage of the wide and narrow joint position. Therefore, it is necessary to study the mechanism of wide and narrow joint disease and provide solutions for the maintenance and repair of wide and narrow joint.

Figure 2. Cracking at wide and narrow joints

At present, most of the researches on wide and narrow joints of ballastless track mainly focus on the generation of cracks and static and dynamic characteristics of wide and narrow joints under temperature load and train load. However, it cannot be effectively combined with the construction process. The influence of wide and narrow joints damage on the force and deformation of seamless line in temperature rise and continuous high temperature load based on the finite element theory is studied in reference [5]. The author thinks that there are some problems in the original design concept that longitudinal connecting reinforcement do not provide pre-pressure on wide joints concrete. Reference [6] investigated the influence of temperature load, interlayer state and material quality on the damage of concrete at wide joints using the plastic damage constitutive model of concrete and analyzed the causes of wide joints damage. Finite element simulation analysis on the effect of different tension-drawing processes on the force exerted on the rail structure is carried out in reference [7]. It was concluded that the tension-drawing of the longitudinal reinforcement do not exert great pre-pressure on the narrow joint concrete, and its effect on temperature resistance is not obvious. It can be seen that there is a problem of wrong design concept in the longitudinal

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connection of ballastless track. However, so far very few studies have been published on the damage caused by tensioning of longitudinal reinforcement in the construction stage, also there is no research on fixing this wrong design concept.

Based on the above analysis, this paper is divided into two parts (construction stage and operation stage) to study the tensile properties of longitudinal reinforcement. Firstly, the construction sequence of CRTSII slab ballastless track in wide and narrow joint position and the tensioning sequence of longitudinal reinforcement are briefly introduced in section 1. In section 2, the simulation model in the construction stage is introduced. The interface model parameters are determined through experimental data. The comparison between numerical results and experimental measurements is also reported. In section 3, different tension forces are selected as initial conditions to analyze the stress and deformation of the track structure after tensioning. Also, the influence of temperature gradient load on the failure of track structure after tensioning is analyzed according to the environmental changes before the casting of wide joint. In section 4, a method of applying pre-stress to wide joint concrete is put forward to fixing the error of original design concept. Reasonable tension force is proposed after the stress of reinforcement and crack width of concrete at the joint are checked and calculated according to the concrete design principle [8].

2. Longitudinal joint construction of CRTSII slab ballastless track

2.1 Construction sequence of ballastless track

The construction sequence of ballastless track is shown in the Figure 3 after casting the concrete base.

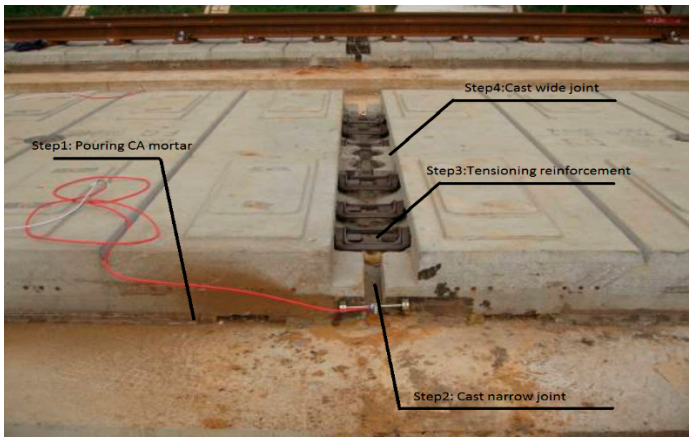

Figure 3. Construction sequence of ballastless track

Step1: Pouring CA mortar

Check the status of the track slab to make sure that its position meets the design requirements and prewet the concrete base before the CA mortar is poured. CA mortar is perfused through the perfusion holes in the middle of the track slab. The CA mortar for each track slab shall be perfused once for all.

Step2: Cast narrow joint concrete

The pouring of narrow joint should be carried out after CA mortar perfusion is completed and its strength reaches 7MPa. The narrow joint height is controlled at the 6 cm below the up edge of the track slab.

Step3: Tensioning longitudinal reinforcement

The tensioning process of reinforcement should be carried out after the strength of CA mortar reaches 9MPa and the strength of narrow joint concrete reaches 20MPa, the specific tensioning sequence is detailed in section 1.2.

Step4: Cast wide joint concrete

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The concrete should be poured in time after the longitudinal reinforcement is connected. Re-check the tension force value before casting. After the casting is completed, it should be vibrated and compacted and make the concrete surface flush with the surface of the track slab.

2.2 Tensioning sequence of longitudinal reinforcement

Each wide and narrow joint is provided with 6 tension locks, First, tension the middle of the two locks (inside locks), and then tension two locks near the middle locks(middle locks), at last, the two locks on the outermost side (outside locks) are tensioned. A total tension force of 300kN is applied to 6 longitudinal reinforcement for each longitudinal reinforcement tension force is 50kN.

Tensioning sequence:

Step1:

Tension the inside locks of two joints.

Step2:

Symmetrically tensioning the two inside locks near the two joints that have been stretched. Tensioning step is carried out with two joints step by step.

Step3:

The middle locks of the two middle joints was tensioned after six inside locks were stretched.

Step4:

Continue symmetrically tensioning the two inside locks near the joints that have been stretched and at the same time tensioning the two middle locks near the joints that have been stretched.

Step5:

The outside locks of the two middle joints was tensioned after six middle locks were stretched.

Longitudinal reinforcement is tensioned in this order until the completion of a construction section. The tensioning sequence is shown in the Figure 4.

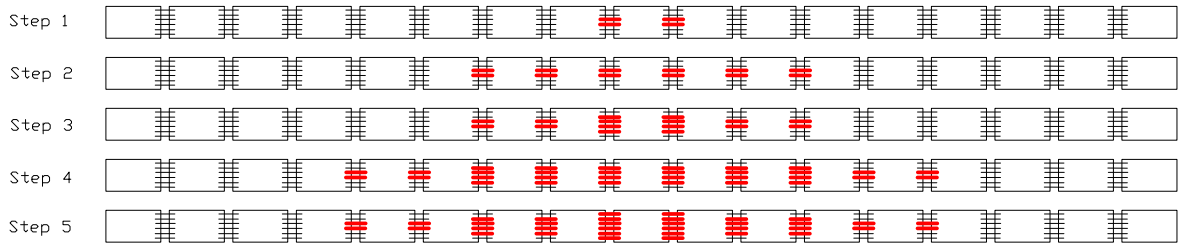

Figure 4. Tensioning sequence of longitudinal reinforcement

3. Calculation model and experimental verification

3.1 Cohesive zone model

Cohesive zone model (CZM) was introduced by Dugdale and Barrenblatt in 1960 and 1962 respectively [9-11]. CZM has been used for the fracture process analysis of most materials since the CZM overcomes the inconsistency of the crack tip stress in classical fracture mechanics and can simply characterize the initiation and propagation of cracks [12-18].

In this paper, the CZM is used to simulate the bonding characteristics between the track slab and the mortar layer. It is assumed that the relationship between the stress of each tiny region of the cohesive zone and the open displacement (τ-δ) is defined as the bilinear relationship as shown in Figure 5. This model is suitable for numerical simulation of finite element method.

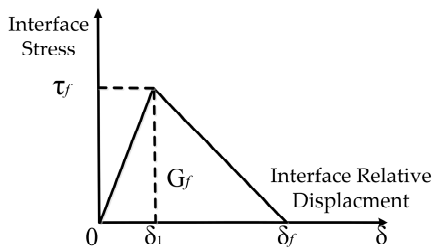

Figure 5. Models of binding-slippage

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The model is divided into 3 stages. Stage1: Elastic stage. The ultimate bonding strength of the interface is τ_f, and the corresponding displacement is δ_1. The interface stress increases linearly before it reaches the ultimate bonding strength τ_f. Stage2: Softening stage. The interface stress decreases linearly when the relative displacement is greater than δ_1. The relative displacement reaches δ_f when the bonding strength drops to zero. Stage3: Failure stage. The model starts to fail when the relative displacement is greater than δ_f. G_f is defined as the fracture energy which its value is the area enclosed by the triangle.

The maximum stress criterion is used to describe the initial damage of the interface element. The damage begins when any nominal stress ratio reaches 1.

$$\max\left\{\frac{\langle \tau_n \rangle}{\tau_n^0}, \frac{\tau_s}{\tau_s^0}, \frac{\tau_t}{\tau_t^0}\right\} = 1 \tag{1}$$

Where τ_n^0, τ_s^0, τ_t^0 respectively represent the bonding strength of the normal stress, the first shear stress, and the second shear stress. τ_n, τ_s, τ_t respectively represents the normal stress and two shear stresses in the mixed stress mode. Where the brackets <> means that the compressive stress does not contribute to the initial failure of the structure.

The damage value D, proposed by Camanho and Davila [19], is defined as:

$$D = \frac{\delta_m^f(\delta_m^{\max} - \delta_m^0)}{\delta_m^{\max}(\delta_m^f - \delta_m^0)} \tag{2}$$

Where δ_m^0 is the effective displacement of the element node when the failure starts. δ_m^f is the effective displacement of the node when the damage value D reaches 1. $\delta_m^{\max}$ is the maximum displacement of nodes in the load history. $0<D<1$ means that the interface element is in the softening area, and when the D value is 1, it means that the interface element is broken.

3.2 Finite element model and model parameters

In order to study the influence of tension value on the track slab and interface between track slab and CA mortar, a three dimensional finite element model of CRTSII slab ballastless track is built according to the actual size of ballastless track based on the commercial software ABAQUS, as shown in Figure 6. The track slab, mortar layer and concrete base are all simulated by solid elements, and the longitudinal reinforcement which is constrained by the joint with the track slab concrete is simulated by truss element. The cohesive element described in the above section is disposed on the bonding layer between the concrete of the track slab and the mortar layer, the debonding of interface is simulated by the failure of bonding layer element. Tie constraints are applied between the mortar layer and the concrete base and all the displacements of the nodes at the bottom of the slab track system are restricted. The model has a total length of 39 m (six track slab) and the parameters are shown in Table 1.

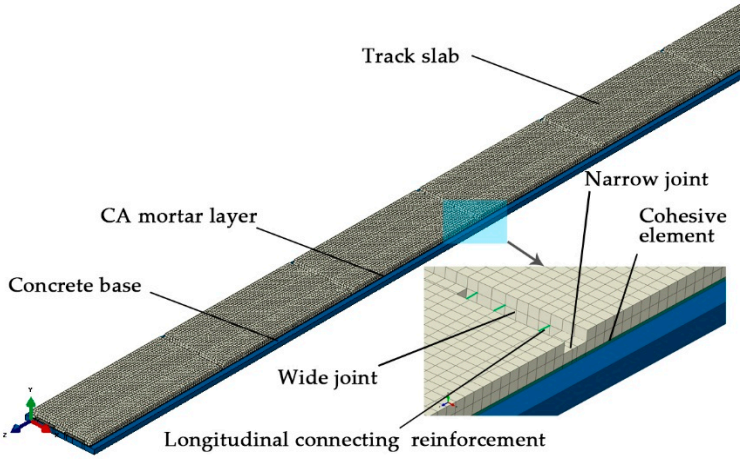

Figure 6. Finite element model

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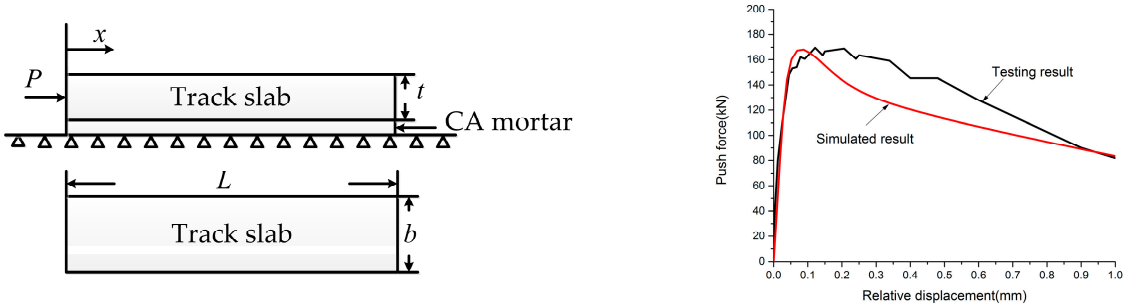
Table 1. Parameters of slab ballastless track model

Components	Young's modulus (Pa)	Poisson ratio	Thermal expansion coefficient (℃-1)
Track slab	3.25E+10	0.2	1E-5
CA mortar	8E+9	0.2	-
Concrete base	2.55E+10	0.2	-

Load-displacement curve of the interface is obtained by slab push test on single rail pads carried out by China Academy of Railway Sciences Corporation Limited (CARS). In order to get the parameters of the interface element, a three-dimensional finite element model is established according to the actual size and constraint mode of the single rail pads push slab test (shown in Figure 7a). L=2.55m，b=0.65m，t=0.2m. Loading method is simulated by gradually increasing the displacement of the track slab end.

This paper assumes that the normal stress strength is the same as the shear stress strength, for the reason that the normal stress value is much smaller than the shear stress value in the process of pushing test and the normal stress strength is slightly greater than the shear strength based on the interface experiment [20], which result in a conservative result.

Figure 7b shows the simulation results, the simulated load-displacement curve is most consistent with the experimental results with τ_f=0.075MPa, δ_1=0.1mm, δ_f=2mm. It can be seen that the established model agrees well with the experimental results in the ascending phase, while the push force is slightly smaller than the test results in the descending phase. But overall, there is a good consistency for the fitting result, which proves that cohesive parameters are reasonable and credible.



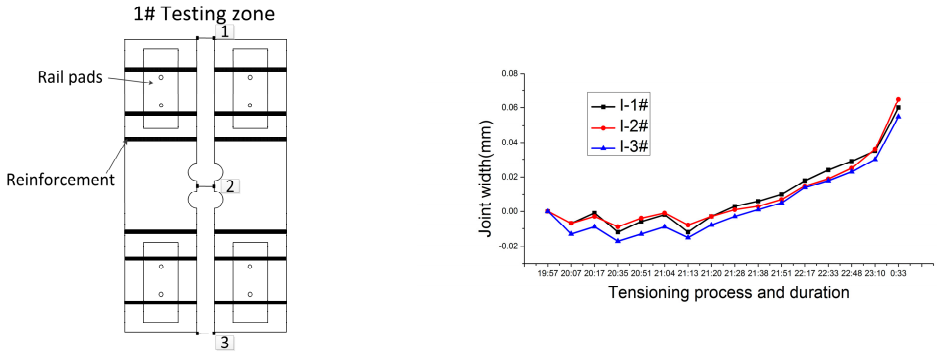
(a) Push test on single rail pad

(b) Testing and simulated result of push test

Figure 7. Push test on single rail pad and its result

3.3 Experimental verification

Tensile test is carried out on the end joint of rail plate by the CARS [20]. The measuring point location and measurement results are shown in Figure 8.



(a) Measuring point of tensioning of longitudinal connecting reinforcement

(b) Testing result of tensioning of longitudinal connecting reinforcement

Figure 8. Tension points and test results of longitudinal reinforcement

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The tension of reinforcement in the measured track can cause the joint compression at the end of the plate (the point of break in the figure). The total compression amount of the joint for 1# and 2# measurement area after tension of reinforcement is -0.026mm and -0.020mm respectively. The shrinkage of track structure after reinforcement tensed in the condition of temperature reduction causes the joint of slab end expand obviously. The maximum extension of track slab joint is closed to 0.08 mm when the temperature drop 5℃ in the actual measurement period from 21:00 to 1:00(the end of Figure 8(b) curve).

The longitudinal connected reinforcement at the slab end is tensioned in the tensile order. The calculated tensile displacement of the three measuring points are 0.021mm, 0.028mm and 0.021mm respectively for the simulation model , which is very close to the measurement result. In addition, the track slab is applied -5℃ cooling load after longitudinal connected reinforcement tensioned, the opening displacement at the end of the track slab was 0.07mm, which was close to the measured results, and proved the reliability of the model.

4. Mechanical analysis in tensioning process

Each longitudinal connecting reinforcement provides 50kN tension force when the longitudinal connecting reinforcement of ballastless track is stretched. Tension force is simulated by dropping temperature, the equivalent formula is:

$$\Delta t = \frac{\Delta l}{la} = \frac{F}{AE\alpha} \quad (3)$$

Where Δt is the scale of drop in temperature, Δl is the length change of wide joint, l is the length of wide joint,α is coefficient of linear expansion, F is the tension value, A is the section area of longitudinal connecting reinforcement, E is the elastic modulus of longitudinal connecting reinforcement.

The ballastless track will be affected by the temperature load after the longitudinal reinforcement is stretched and before the casting of the wide joint, only the temperature gradient load caused by daily temperature change is considered due to the short time interval between casting and stretching. Taking common temperature gradient load into consideration, positive temperature gradient load is 50℃/ m and negative temperature gradient load is -25℃/ m, temperature gradient loads are applied after the longitudinal reinforcement is tensioned. The designed tension load is 300kN, so here four calculation conditions of 100kN, 200kN, 300kN and 400kN are selected to analyze the influence of tension load.

The vertical displacement of the bottom side of the track slab after longitudinal connected reinforcement tensioned is shown in Figure 9. It can be seen that due to the existence of narrow joint, the longitudinal connecting reinforcement makes the track slab under eccentric compression after stretching. The narrow joint position is under compression, the track slab tends to arch upward. The arch displacement of the track slab is increasing from the position of the slab edge to the position 0.7m away from the slab edge. The arch displacement of the track slab begins to decrease gradually and then tends to be very small from the position of 0.7m away from the slab edge to the position of 2m away from the slab edge. The larger the tensile force is, the larger the arch displacement is, and the relationship between the arch displacement and tensile force is nearly liner relationship. The arch displacement of the track slab is very small (0.002mm) for ballastless track structure.

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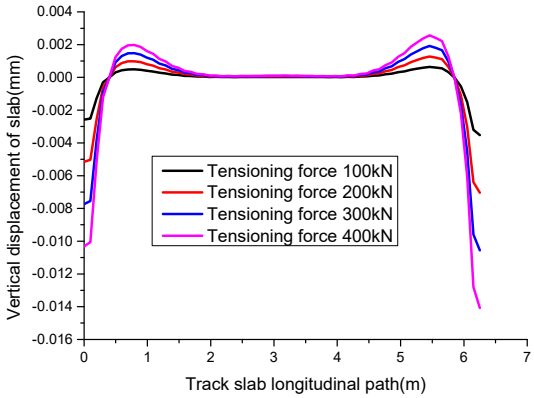
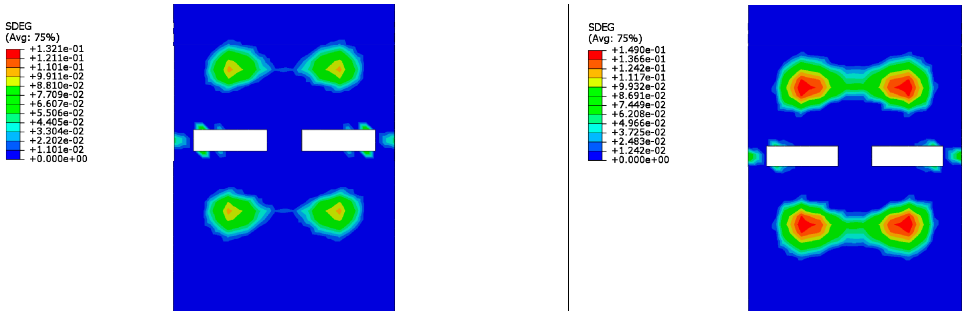


Figure 9. Vertical displacement of track slab after longitudinal connecting reinforcement is tensioned

Figure 10. shows the damage at interface between track slab and CA mortar under the action of positive temperature gradient load with different tensile force values. It can be seen that the position of the interface damage is located 0.7m away from the edge of the track slab and edge of the track slab that corresponds to the outer reinforcement under the action of positive temperature gradient load. Both the damage value and the damage area increase with the increase of the tension force value. The position where the damage first appears is 0.7m away from the edge of the track slab (point B) and the temperature gradient load value when the interface damage occurs is reduced from 46℃/m to 40℃/m when the tension force value increases from 100kN to 300kN(shown in Figure 11). But when the tension force value is 400kN, the first damage area at the edge of the track slab (point A) and the corresponding temperature gradient load value is 20℃/m, which explains that the large tension force value is unfavorable to the interface at the end of the track slab.

The stress condition of the element node at point A and point B are shown in Figure 12 and Figure 13. It is longitudinal shear stress rather than the vertical normal stress and transverse shear stress that is most affected by tension force value. The three-direction stress of the interface element increases linearly with the increase of positive temperature gradient load. The failure mode at point B is mixed failure for its three-direction stress are relatively large. Point A is subjected to 62200Pa of longitudinal shear stress when the tension process ends. When the positive temperature gradient load reach 20℃/m, Point A begins to appear damage under longitudinal shear stress and transverse shear stress, so the failure mode at point A is shear failure.



(a) (b)

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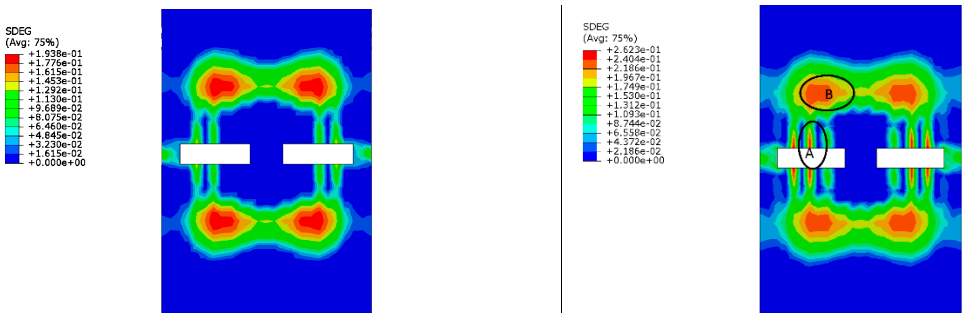

(c) (d)

Figure 10. Damage evolution under positive temperature gradient load with different tension force (a)-(d), 100kN - 400kN.

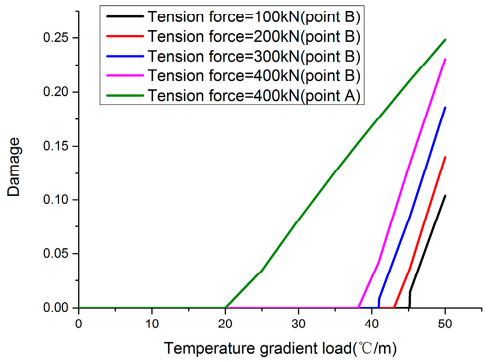

Figure 11. Damage evolution at point A and point B

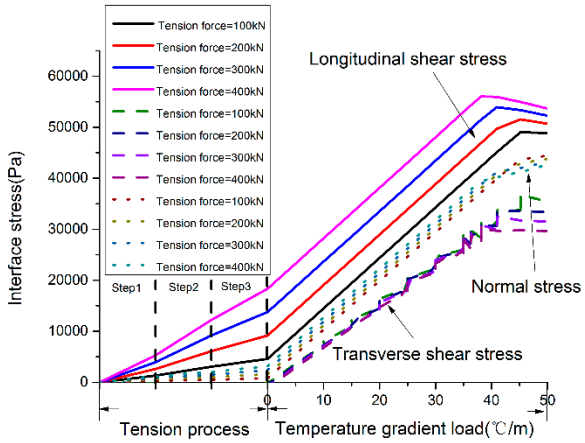

Figure 12. Interface stress evolution at point B

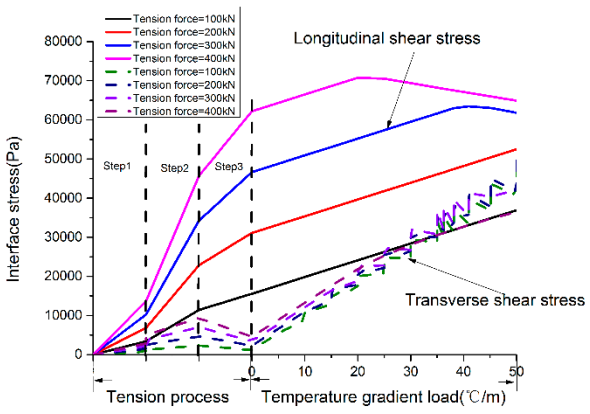

Figure 13. Interface stress evolution at point A

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The interface damage areas shown in Figure 14 are located at the narrow joint position under the action of negative temperature gradient load with different tension force values. The damage value reduced from 0.453 to 0.233 and temperature gradient load value when the interface damage occurs is reduced from -22.5℃/m to -18.5℃/m when the tension force value increases from 100kN to 400kN(as shown in Figure 15). The stresses of the interface in the damaged area are shown in Figure 16. Narrow joint position damage is mainly caused by vertical normal stress. The greater the tension force value is, the greater the buckle pressure to the narrow joint position. So the longitudinal tension of reinforcement can reduce the warping of the track slab corner.

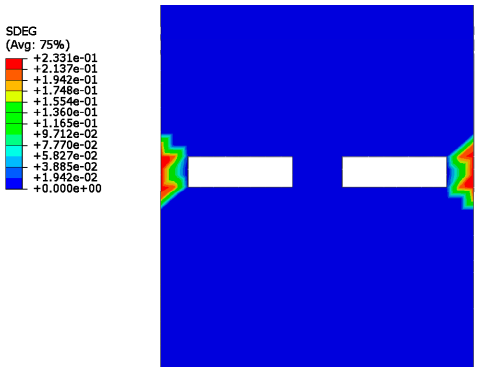

Figure 14. Damage evolution under negative temperature gradient load with 400kN tensile forces

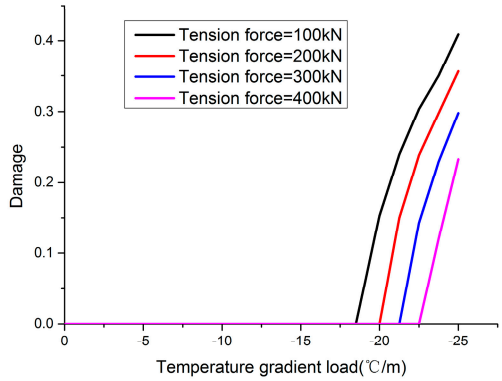

Figure 15. Damage evolution under negative temperature gradient load

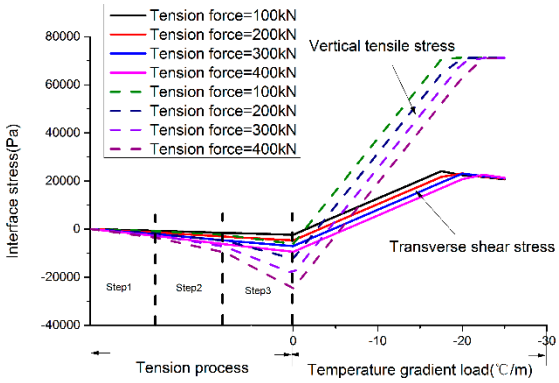

Figure 16. Interface stress evolution at point A

The tension force of the longitudinal reinforcement has little effect on the deformation and stress of the track slab, however, interface damage occurs between the track slab and the mortar layer when subjected to temperature gradient load after the end of tension process. For interface damage, the tension force of the longitudinal reinforcement increases the interface shear stress at the

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edge of the track slab and produces a downward depressing pressure which is possible to increase the ability to resist negative temperature loads, but to reduce the ability to resist positive temperature gradient loads. Therefore, the casting of the wide joint should be carried out at the same time or as soon as possible after the longitudinal reinforcement is stretched to avoid a damage between the layers under large temperature gradient load and ensure a reliable connection between the mortar layer and the track slab.

4. Check and calculation in operating period

4.1 Original design check and calculation

300kN prepressure is applied to the concrete at the wide and narrow joint by applying 300kN longitudinal tension force to the longitudinal reinforcement between the track slabs in the design, and the track slab is considered as continuous in the longitudinal direction. The track slab is considered as the bar fixed in beam end. Therefore, the strain of the track slab under the action of system temperature difference is:

$$\varepsilon_{\Delta t}=\alpha\Delta t \tag{4}$$

The shrinkage deformation considered from 14 days to infinity of concrete is carried out according to the specification [8]. The contraction strain is:

$$\varepsilon_s=-0.23 \tag{5}$$

The stress of the reinforcement under the action of live load is not taken into account but only cooling and concrete shrinkage load are considered in the calculation for the reason that the longitudinal connecting reinforcement of the track slab is placed in the middle of the track slab. The stress of reinforcement is:

$$\sigma_s=E_s\cdot(\varepsilon_{\Delta t}+\varepsilon_s) \tag{6}$$

Where E_s is elastic modulus of reinforcement.

There are only six Φ 20 connecting reinforcement in the joint of the track slabs. The stress of the reinforcement at the joint and the crack width is checked and calculated according to the tensile check result of the reinforcement inside the track slab. The axial force borne by the track slab is as formula (7) under the combined action of cooling load and shrinkage load.

$$N=\sigma_s\cdot A_s \tag{7}$$

Where A_s is cross-sectional area of a single connecting reinforcement.

The stress of reinforcement caused by shrinkage and cooling of concrete in the future should be superimposed on the stress caused by tension of connecting reinforcement for the reason that the tension step occurred before concrete casting step. In addition, the pre-stress of the joint cannot play a role in limiting the crack width due to the fact that the joint concrete is not perfused when the tension force is applied to the connecting reinforcement.

The stress of connecting reinforcement at the wide joint is:

$$\sigma_{s,c}=(N+N_{ten})/A_{s,all} \tag{8}$$

Where $A_{s,all}$ is total cross-sectional area of six reinforcement. N_{ten} is tension force.

The average strain of reinforcement is:

$$\varepsilon_{s,a}=N/E_s/A_{s,all} \tag{9}$$

Crack width is checked and calculated according to the formula below:

$$\omega_{cr}=l_{cr,\max}\cdot(\varepsilon_{s,a}-\varepsilon_{c,a}) \tag{10}$$

Where ω_{cr} is calculated value of crack width, mm. $l_{cr,\max}$ is maximum crack spacing, mm. $\varepsilon_{s,a}$ is average strain of reinforcement. $\varepsilon_{c,a}$ is average strain of concrete.

Take the distance (650mm) between the false seam of track slab as $l_{cr,\max}$. As the strain of concrete is much smaller than that of reinforcement, the average strain of concrete is considered to be 0.

The limiting design value of reinforcement stress is 286MPa and the crack width is 0.5mm according to the design specification [8]. The reinforcement stress is 577.6MPa and crack width is 0.65mm calculated by equations (8) and (10) and both the calculation results are not meet the design requirements.

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It can be seen from formula (8) that the stress value of connecting reinforcement can be reduced by reducing tensile force of connecting reinforcement. In order to reduce the crack width, the effective measures are to reduce the diameter of connecting reinforcement or to apply pre-stress to the wide joint concrete.

4.2 Application of pre-stressed on post-cast concrete

Temperature pre-stress loss can be occured in steam curing causes for pretensioning pre-stressed concrete for the reason that expansion of pre-stressed reinforcement with higher temperature. When the concrete compressive strength reaches a certain strength grade, as 7.5MPa to 10MPa, the reinforcement and concrete are considered as a whole, which can expand and contract together without causing stress loss. But for the wide joint concrete of ballastless track, here we have a design mistake. The pre-stressed reinforcement is not loose after the casting of wide joint concrete which is different with pretensioning pre-stressed concrete, so it is not possible to generate pre-stress on the wide joint concrete.

Here we propose a method of applying pre-stress to the post-pouring concrete between the old concrete reference the concept of pre-stress loss for pretensioning pre-stressed concrete.

After the concrete is casting, electrode heating is applied to connecting reinforcement, which makes the temperature increase for connecting reinforcement. To makes the temperature difference between the pre-tensioned reinforcement and the cast concrete, we can apply thermal insulation material on the surface of the reinforcement. The pre-tensioned reinforcement relaxes to make the tension force decreases. When the concrete compressive strength reaches 7.5MPa to 10MPa, the concrete and tensile reinforcement will deform together. When the concrete and reinforcement resume to its initial temperature, a part of tensile force of the reinforcement will be lost and a part of pre-stress will be generated to the post-pouring concrete which the pre-stress value is equal to the lost tensile force of reinforcement.

4.3 Calculation of reasonable tension value

The pretension loss value is determined by the temperature difference between concrete and reinforcement when the concrete and reinforcement deforms together. The pretension decreases as formula (11) when the temperature difference is Δt.

When the reinforced concrete deforms together:

$$N_{los}=\Delta t\alpha E_s A_{s,all} \tag{11}$$

Pre-stress of concrete $N_{pre}= N_{los}$.

At this time the stress of connecting reinforcement is:

$$\sigma_{s,c}=(N+N_{ten}-N_{los})/A_{s,all} \tag{12}$$

The strain of connecting reinforcement is:

$$\varepsilon_{s,a}=(N-N_{pre})/E_s/A_{s,all} \tag{13}$$

From equations (10), (11) and (13), it can be seen that the crack width is only related to the value of the pre-stress generated at the wide joint, while the pre-stress value is related to the temperature difference Δt inside reinforced concrete. Figure 17 shows the relationship between the crack width and temperature difference value between concrete and reinforcement. It can be seen that reinforcement and concrete temperature difference value should not be less than 29 ℃ to guarantee the crack width is less than 0.5 mm.

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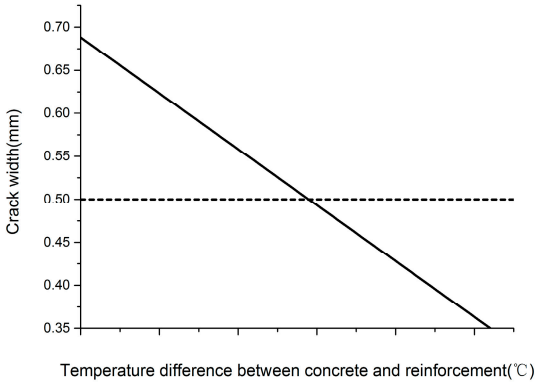

Figure 17. The relationship between crack width and temperature difference between concrete and reinforcement

It can be seen from formula (10) and (12) that the stress of reinforcement is related to tension force and internal temperature difference between concrete and reinforcement. Figure. 18 shows the three-dimensional diagram of stress, tension of reinforcement and temperature difference. It can be seen that stress of reinforcement is directly proportional to tension force and inversely proportional to temperature difference. According to the checked results of crack width, the temperature difference value should be greater than 29 ℃, the three-dimensional figure is mapped to the tension in the Figure 18 - flat surface temperature difference value, under the condition of guaranteeing the crack width and the reinforcement stress meet the design requirements of tension and temperature range, as shown in Figure 19 shaded area.

The maximum tensile force should not exceed 234kN under the condition that the crack width meets the design requirements, maximum tension force linearly increases with the rising of the reinforced concrete temperature difference. The maximum tension force should not exceed 317 kN when reinforced concrete temperature difference value is 50 ℃.

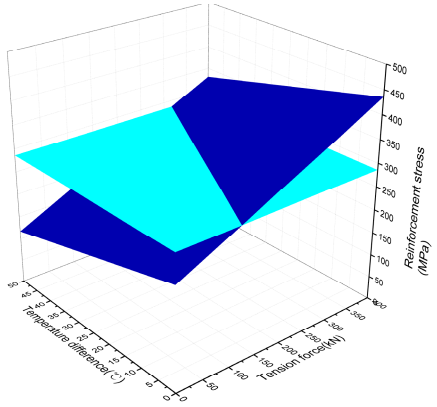

Figure 18. The relationship among reinforcement stress and tension force and temperature difference value

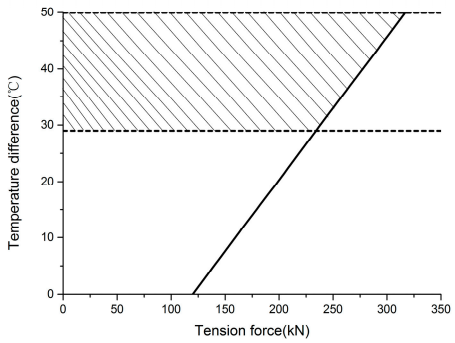

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Figure 19. Temperature and tension force range to guarantee appropriate reinforced stress and crack width

Before the casting of wide-seam concrete, the track slab is in an eccentric compression state after the longitudinal reinforcing bar is stretched due to the existence of narrow joint.

In order to ensure the track slab has a symmetry stress station after the casting of wide-seam concrete, the temperature increment value of the precast reinforcement should be determined according to different tensile values.

The tensile force at this point is

$$N_{ten} = 2N_{los} = 2\Delta t \alpha E_s A_{s,all} \quad (14)$$

Figure 20 shows the relation between tensile force value and temperature increment value of reinforcement under the condition of ensuring that the stress of reinforcement and crack width of concrete meet the requirements and at the same time ensuring the tension force value of track slab under the symmetry pressure condition. It can be seen that tension force range is 229 kN to 240 kN and temperature difference range is 29℃ to 30.3℃ to meet the design requirements and tensile force does not cause interface failure between the track slab and the mortar layer. Due to the range of tension force value and temperature difference of reinforcement is relatively small, so it is suggested that selection of tension force value is 230 kN and temperature difference of reinforcement is 30℃ during construction.

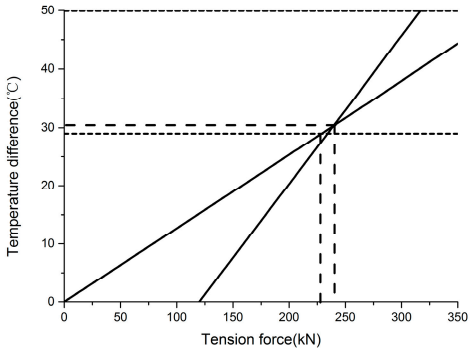

Figure 20. Reasonable tension value and temperature difference value range

5. Conclusions

In this paper, a cohesive zone model is introduced in a three-dimensional finite element model of CRTSII slab track and utilized to investigate the damage or delamination at the interface between track slab and CA mortar layer during the construction stage. The interface stress and damage evolution under the condition of different tension force value and temperature gradient load are analyzed. Simulation results show that interface damage is occurred under temperature gradient load at the end of track slab for large longitudinal shear stress is produced when the tension force is greater than 300kN. A method of applying pre-stress to post-pouring concrete is proposed according to the concept of pre-stress loss of pretensioning pre-stressed concrete, crack width and the reinforcement stress of the ballastless track in the operation stage were checked and calculated according to the concrete design principle. The tension value is suggested in 230 kN, meanwhile, be sure temperature difference between reinforcement and concrete value is 30℃ before initial curdle of concrete.

Future developments of present work will focus on experimental verification activities in terms of applying prestressing on post concrete. A simple construction method is also needed for operating line and conduct on-site experiments and evaluation of this method.

Author Contributions: Long Chen carried out the research work together with Jian-xi Wang, Jin-jie Chen is the head of the chair of Traffic Engineering and provides general support to all the activities of the research staff and provide data support for this research.

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