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The Temperature Effect Analysis of High-Speed Maglev Transit

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Abstract: The finite element model of the high-speed maglev track beam was established. The temperature field of the track beam was obtained by steady-state heat conduction analysis. The temperature deformation of the maglev track beam under different temperature loads was calculated by thermal-structural coupling analysis method. The calculation results show that the temperature gradient of maglev track beam increases with the increase of temperature difference. Moreover, the vertical or transverse deflection deformation of maglev track beam caused by temperature difference load increases with the increase of temperature difference. However, when the temperature difference load between upper and lower surfaces is greater than 20℃, the vertical deflection of maglev track beam caused by temperature difference exceeds the relevant stipulated limit of high-speed maglev traffic. Therefore, it is necessary to check and analyze the temperature effect of high-speed maglev track beam in the practical engineering.

1. Introduction

Maglev rail transit system is a high-speed non-contact system. Unlike the wheel-rail system, maglev trains need to be levitated at a specific height during operation, which requires that the shape and position of the maglev track function surface should not be changed greatly. Therefore, it is necessary to analyze the deformation of track structure under train load, temperature load and sudden change load to ensure the safety and comfort of Maglev train. At present, there were many studies on the dynamic response of track beams under the load of maglev trains at home and abroad [1-5], but there were few studies on the temperature effect of high-speed maglev track beams. Guo Jian [6] compiled the calculation program and obtained the temperature distribution and stress distribution in the main section of concrete cable-stayed bridge; Yang Wenhua [7] proposed that the non-linear temperature distribution should be considered when the web of concrete box girder cracks; Li Yulei [8] studied the temperature distribution of single-span simply supported track girder under sunshine environment.

Combining with Shanghai High Speed Maglev Demonstration Line Project, this paper calculated the temperature effect of maglev track beam under temperature difference load, and obtained the temperature field distribution of track beam and the track beam deformation temperature variation with temperature difference load. These results can provide reference for the structure design of high-speed maglev track beam.

2. Modeling of high-speed maglev track beam

2.1 Track Beam Model

Taking the track beam of Shanghai Maglev Demonstration Line as an example, a three-dimensional solid model was established according to the existing cross-section form, and the temperature distribution and displacement under different temperature loads were compared. The temperature distribution and the displacement of the track beam were obtained by finite element calculation. The parameters of track beams in all directions are [9]: heat conduction coefficient KXX is 2.34W/(m·℃); density DENS is 2500 kg/m3; specific heat capacity c is 1046 J/(kg·℃); elastic modulus EX is 3.6×1010N/m2; thermal expansion coefficient ALPX is 1.18×105m/℃; and main Poisson's ratio PRXY is 0.2.

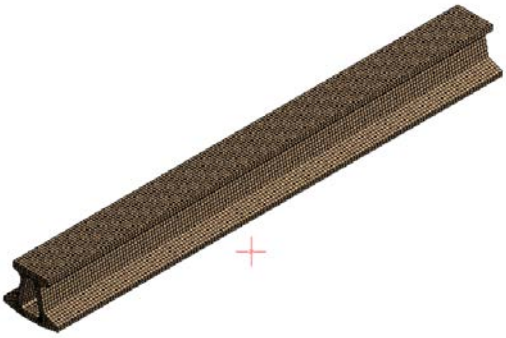

Figure 1. Finite Element Model of High-Speed Maglev Track Beam

2.2 Steady State Analysis of Temperature Load

Under the action of sunshine, the track beam will have obvious temperature changes in vertical and transverse directions, but the longitudinal temperature changes little. Therefore, when simulating the temperature difference load, the temperature difference caused by sunshine can be regarded as along the vertical and transverse distribution.

According to Fourier heat conduction theory, the two-dimensional heat conduction differential equation of bridge structure can be expressed as

$$\rho c\frac{\partial T}{\partial t}=k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{1}$$

In the formula, T is the temperature of a point in the structure at a certain time, which is a function of coordinates x, y and time t; K is the thermal conductivity of the material; ρ is the density of the material; C is the specific heat of the material.

Formula (1) Temperature field changes with time, which belongs to the transient analysis method. It mainly considers the complex heat exchange process in natural environment, such as solar radiation, the position of the structure and other uncertainties. It is also because of these uncertainties that the results of transient thermal analysis are difficult to be universal. Therefore, for the temperature effect of bridge structure, the steady-state thermal analysis method is generally used to analyze [10]. The steady-state thermal analysis does not consider the change of temperature with time at any node of the structure, and its energy balance equation is as follows

$$[K]\{T\}=\{Q\} \tag{2}$$

In the formula, $[K]$ is a conduction matrix, which includes thermal conductivity, convection coefficient, radiation and shape coefficient; $\{T\}$ is node temperature vector; $\{Q\}$ is node heat flux vector.

According to the above analysis, the temperature difference load was applied to the concrete track beam structure, in which the temperature difference load belongs to the first boundary condition.

3. Simulation results of temperature effect

3.1 Vertical Temperature Effect of Track Beam

The temperature distribution of the maglev track beam was calculated by taking the temperature difference between the upper and lower surfaces of the track beam as 10℃, 15℃ and 20℃. Fig. 2 shows the temperature field distribution of the mid-span section of the track beam under the temperature difference load of 20℃. The temperature of the track beam varies monotonously along the vertical direction under the action of vertical temperature difference load. When the temperature difference between the upper and lower surfaces is 10℃ or 15℃, the temperature distribution law of the mid-span section of the track beam is basically the same as that of Fig. 2, which is no longer given.

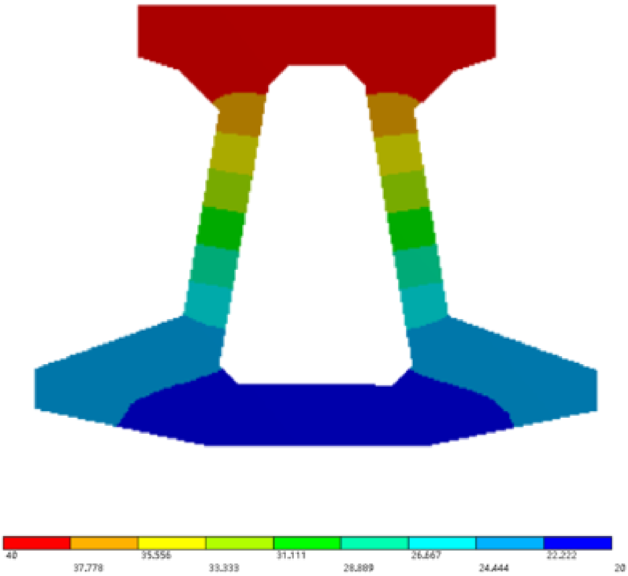

Figure 2. Temperature Distribution of Rail Beam Section at 20℃ Temperature Difference between Upper and Lower Surfaces

By averaging the temperature of all joints at the same height of the mid-span section of the track beam, the distribution curve of the temperature of the track beam along the beam height direction was obtained (Fig. 3). From Figure 3, the temperature distribution of track beams has similar regularity under different surface temperature loads. It was manifested in three stages:

(1) At the height of 0-0.3m, the temperature increases with the height, but the increase is small.

(2) At the height of 0.3-1,8m, the temperature increases with the increase of height, and the increase is larger, but the change is basically linear.

(3) At the height of 1.8-2.2m, the temperature increases with the height, but the increase is small.

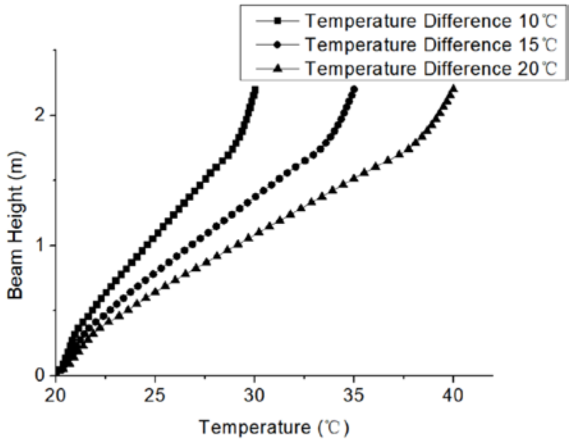

Figure 3. Temperature Distribution along Rail Beam Height

Fig. 4 shows the distribution curve of vertical deflection along the length of track beam when the temperature difference between upper and lower surfaces is 10℃, 25℃ and 20℃. Under the action of vertical temperature difference load, the deflection curve is parabolic, and the maximum deflection increases with the increase of temperature difference. Table l lists the vertical deflection values in mid-span. From Table 1, the maximum vertical deflections of track beams under three different temperature loads were 2.97 *mm*, 4.49 *mm* and 6.00 *mm* respectively. The mid-span deflection increases linearly with the temperature difference.

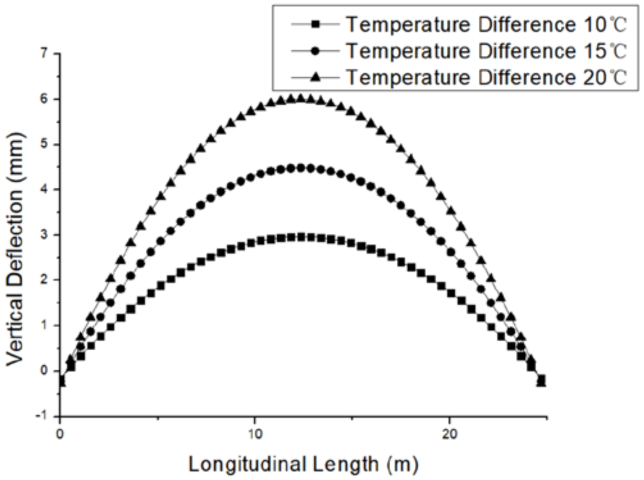

Figure 4. Vertical Deflection Curve of Track Beam under Temperature Difference between Upper and Lower Surfaces

Table 1. Mid-span Deflection Caused by Temperature Difference between Upper and Lower Surfaces

Temperature Difference	10℃	15℃	20℃
Vertical Deflection/mm	2.97	4.49	6.00

3.2 Transverse Temperature Effect

If the temperature difference between the left and right surfaces of the maglev track beam was 5℃, 10℃ and 15℃, the temperature distribution of the maglev track beam was calculated. Fig. 5 was the temperature field distribution of the middle section of the track beam under the action of the temperature difference load of 15℃ on the left and right surfaces. Fig. 5 shows that the temperature inside the track beam increases with the right displacement of the position under the transverse temperature difference load, and the overall change was relatively stable.

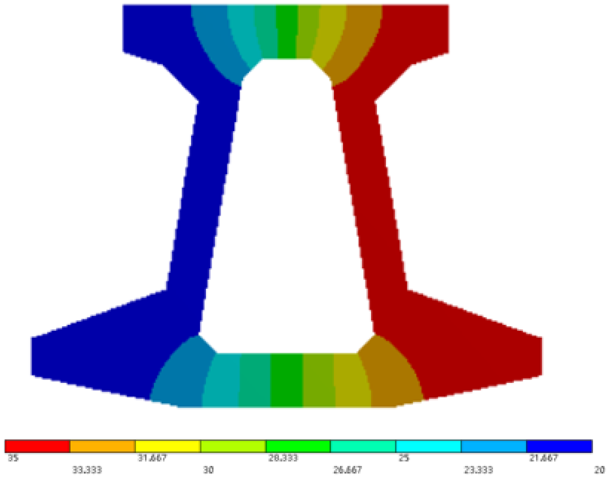

Figure 5. Temperature Distribution of Rail Beam Cross Section at 15℃ Temperature Difference between Left and Right Sides

By averaging the temperatures of all joints at the agreed width of the mid-span section, the temperature distribution curves along the width direction of the track beams at the left and right sides of the beam were obtained when the temperature difference is 5℃, 10℃ and 15℃ respectively (Fig. 6). Figure 6 shows that the temperature distribution curves along the width direction of the track beam are similar under different temperature loads, and the temperature distribution along the transverse direction is not completely linear due to the influence of cross-section shape.

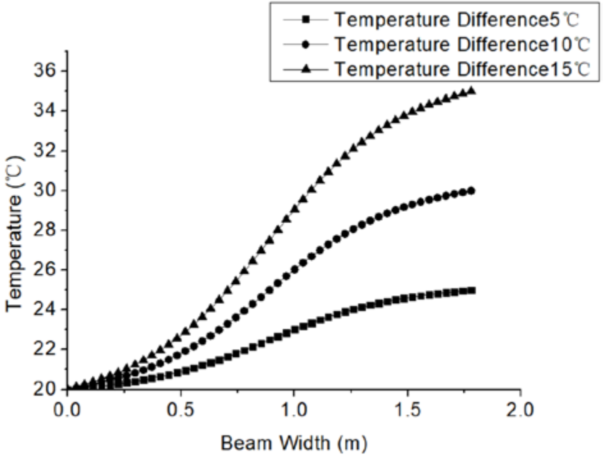

Figure 6. Temperature Distribution along Width Direction of Track Beam

Figure 7 shows the distribution curves of the transverse deflection along the length of the track beam when the temperature difference between the left and right sides is 5℃, 10℃ and 15℃ respectively. The transverse deflection curve of the track beam was also parabolic. Table 2 lists the mid-span lateral deflection of track beams under left and right temperature differential loads. Table 2 shows that the transverse deflections of track beams under three different temperature loads were 1.25 *mm*, 2.47 *mm* and 3.73 *mm* respectively.

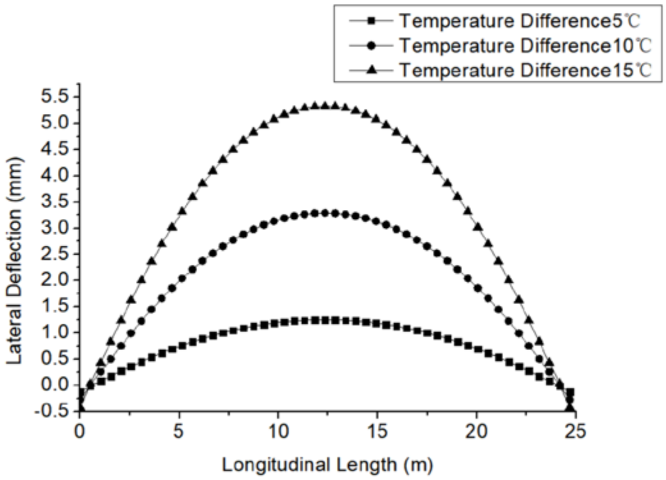

Figure 7. Transverse Deflection Curve of Rail Beam under Temperature Difference between Left and Right Sides

Table 2. Mid-span Deflection Caused by Temperature Difference between Left and Right Sides

Temperature Difference	5℃	10℃	15℃
Lateral Deflection/mm	1.25	2.47	3.73

4. Conclusion

(1) Under the action of temperature difference load on the upper and lower surfaces, the temperature change of the track beam in the height direction can be divided into three parts, that is, the temperature change of the top and bottom plates was not large, but the temperature change on the web was obvious.

(2) The vertical deflection curve of the track beam was parabolic, and increases with the increase of temperature difference load. The maximum vertical displacement of the track beam is 6.00mm under the three different temperature loads in this paper, which exceeds the requirement of vertical temperature deformation control of Shanghai Maglev track structure.

(3) Under the action of temperature difference load on left and right surfaces, the transverse temperature distribution of track beams was relatively smooth, but due to the influence of cross-section shape, the transverse temperature distribution curve of track beams was not completely linear.

(4) The transverse deflection curve of track beams is parabolic, and increases with the increase of temperature difference load. The maximum transverse displacement of the track beam is 3.73mm under three different temperature loads, which meets the requirements of transverse temperature deformation control of Shanghai Maglev track structure.

Acknowledgments

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