Guide-way Research for Shanghai Maglev Demonstration Line

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Abstract: Some problems have been confronted with when Shanghai Maglev Demonstration line was designed, such as the control of temperature deformation and the need of too many batter piles in substructures. A new type of guideway with spring joint, which is called "simply supported-continuous guideway", is employed to solve these problems. This new guideway is explained in the paper, also the relative theoretical and experimental research.

1 Introduction

The guideway must be very precise so that the maglev vehicle can run smoothly with high speed. The high precision is required not only in the dimension of the guideway but also in the deformation control under loads and temperature variety. As for the hybrid guideway, the deformation control under static load is relatively easy, but that under moving load and temperature variety is much difficult. Comparing the double span continuous beam with the simply supported beam with the same cross section it can be found that the former gains the advantage when the deformation control under moving load and temperature variety are considered. The midspan deformation of the continuous beam is only 1/3 to 1/4 of that of the simply supported beam. So the double span continuous hybrid guideway is recommended by experts in the early days of construction of Shanghai maglev demonstration line.

But many problems, not only the problems with manufacture, transportation and installation, but also the problems with the control of lateral deformation, which seems very hard to be solved, are encountered when begin designing. When exposed to sunlight the continuous guideway will deform in lateral direction (Y direction). Because there are 3 lateral constraint supports, meanwhile the rigidity of the guideway is very large, temperature variety will cause very large lateral constrained force in substructures. It is found in calculating that this constrained force cause large lateral deformation which reaches more than 60% of that in substructures. For controlling the lateral deformation in substructures large amount batter piles have to be set up. But because the geological condition in Shanghai is disadvantageous and the soil is very soft, the required amount of the latter piles by calculating is too large so that it comes to be unconscionable and unpractical.

If simply supported guideway is adopted the control of deformation under moving load and temperature variety becomes very difficult to meet the demand of the system.

Because the problems of the too large constrained force in substructures with continuous guideways and the too large deformation in simply supported guideways, both kinds of guideways seem unpractical. The design was once in a dilemma in the early days of construction of Shanghai maglev demonstration line. So a new type of guideway, which is called simply supported-continuous guideway, is proposed to solve this problem.

2 Analysis of the Control Target

The deformation of 24.768m-span continuous guideway under vehicle load and temperature variety is compared with that of simply supported guideway with the same span. It can be found by comparing that when the temperature difference is 22℃ in vertical direction and 10℃ in lateral, the deformation of simply supported guideway is 7.051mm in vertical direction, which is 1.54 times of its allowable value, while the value is only 0.9290mm and 20% of its allowable value in double span continuous guideway. But in lateral direction the deformation of the simply supported guideway is 2.518mm and 58% of its allowable value, 4.27mm, though larger than that of the continuous guideway. So it can be deduced:

(1) When comparing the simply supported guideway with the same cross section the continuous guideway is of advantage for deformation control both under vehicle load and temperature difference;

(2) The simply supported hybrid guideway can meet the requirement of deformation limits except for the vertical (Y direction) deformation caused by temperature difference. Measures must be taken to control the vertical temperature deformation.

3 Basic Plan of "Simply Supported-Continuous Guideway"

A kind of guideway has been imagined. In this plan the guideway is divided into several segments and connected in site with post-stressed cables. But this plan is proved on second thoughts to be unpractical because the guideway has to be processed with digital machine tool to get its high precision in dimension and this high precision will be destroyed by the structural deformation caused by the post-stressed cables. So new plan of guideway must be programmed and corresponding design method and construction details must be researched.

Basing on the analysis in paragraph 2 the plan of simply supported-continuous guideway is proposed. This guideway is continuous in vertical direction while simply supported in lateral direction. When manufactured, processed by digital machine tool and transported it can be single span guideway then two single span guideways are connected in site to be continuous only in vertical direction after precisely located. With this plan the problems encountered in the hybrid guideways of Shanghai line mentioned above can be solved.

4 Theoretical Analysis

4.1 Temperature Deformation

A continuous beam with spring joint is illustrated in figure 1. Its midspan deformation under temperature difference is

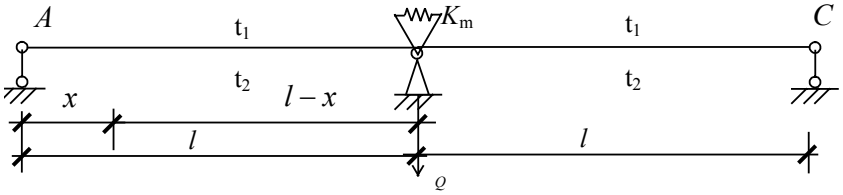

Fig.1 Sketch Map of a Continuous Beam with Spring Joint

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$$\Delta_3 = \frac{l^2}{8}\left(\frac{\alpha\Delta t}{h} + \frac{M_B}{2EI}\right) = \frac{l^2}{8}\frac{\alpha\Delta t}{h}\left(\frac{6i + K_m}{6i + 4K_m}\right)(\uparrow) \tag{1}$$

where: K_m is the bending rigidity of the joint, EI is the section bendind rigidity, $i = EI / l$, h is the height of the cross section, a is the linear expansion coefficient of the material; t_1 and t_2 are the temperature on the upper and lower surface of the beam respectively, supposeing $t_1 > t_2$.

It can be found from equation 1 that the deformation of the beam with spring joint under temperature difference deformation is between that of the simply supported beam and the real continuous beam because the connection rigidity K_m is between that of the simply supported beam and the real continuous beam. The value of Δ_3 is depended on the connection rigidity K_m. By adjusting the joint rigidity in vertical and lateral direction respectively the purpose to make the beam continuous in vertical direction and nearly simply supported in lateral direction can be achieved.

4.2 Parameters Study

To reach the intention of "simply supported-continuous guideway", the parameter K_m must be selected properly.

4.2.1 Analysis of vertical rigidity

To suppose that γ is the ratio of deformation of the beam with spring joint under temperature difference to that of the continuous beam, the relationship of γ to k, which is the relative bending rigidity of the spring joint, $k = k_m / i$, can be obtained by calculation. It can be found that when $k = 10$ γ tends to 1.0 and the varying ratio of γ is very small after $k \geq 10$. That is to say that $k = 10$ is enough. To do this not too much connetion material is needed in enginnering practice.

4.2.2 Parameters Design for connection plates

Two steel connection plates are set up on the upper and lower surface of the hybrid guidway. The purpose to obtain a large enough rigidity in vertical direction and a very small rigidity in lateral direction can be reached easily with this joint detail. It is found that the dimensiom of −800×25 for the connection plates is proper. The connection plates adopted in Shanghai maglev demonstration line is made of steel S355. The dimension of upper plate is $-2100 \times 800 \times 25$ and the lower plate is $-1890 \times 800 \times 25$. The distance between the two plates is $h = 2180mm$ and the gap of the two guideways to be connected is about 470mm. Then the vertical bending rigidity of the joint comes to be $K_m = 2.0734 \times 10^{10} N \cdot m$ and $k = 10.25$.

4.2.3 Analysis of lateral rigidity

Contrarily to the vertical rigidity, the lateral rigidity is expected to be as small as possible. Ideally, when the lateral rigidity is 0 the simply supported-continuous guideway is simply supported in lateral direction and no lateral force will be caused under temperature difference. Certainly, to make the lateral rigidity to be 0 is impossible. When connection plates of −800×25 are adopted the lateral rigidity of the joint is $k_z = K_{mz} / i_{zz} = 0.6632$ and the midspan lateral temperature defomation is $\Delta_3 = 3.08025\Delta_2 = 0.7701\Delta_1$, where Δ_2 and Δ_1 are the midspan temperature defomation of the real continuous beam and that of simply supported beam respectively.

4.3 Load Transmittance

The load transmitting performance of the simply supported-continuous guideway is investigated when subjected to uniformly distributed vertical load. The bending moment of middle support, M_2, is $M_2 = 87.2\%M_1$, where M_1 is the bending moment of middle support in the continuous guideway. That is to say that when subjected to uniformly distributed vertical load the bending moment of middle

support in simply supported-continuous guideway is close to that in the continuous guideway and the difference is no more than 13%. It proves that the simply supported-continuous connection is enough effective when considering the load transmitting performance.

4.4 Dynamic Performance

Similarly with the continuous guideway, there are two groups of vibration modes in the simply supported-continuous guideway, which are symmetric and antisymmetric respectively. The antisymmetric modes and their frequences of the two kinds of guideway are exactly the same. The functions of symmetric modes of them are also the same but the frequences are different. For the simply supported-continuous guideway, when $k = 10.25$, the frequences of symmetric modes are calculated and compared with that of continuous guideway. It can be found that they are very close to each other and the difference is no more than 6%. By comparing the first 10 vibration modes it can be found that their shapes and values are also very close. It proves that the simply supported-continuous connection guideway is enough effective when considering the dynamic performance.

5 Construction Design

It is proved by the theoretical study accomplished hereinbefore that the effect of the simply supported-continuous connection depends on K_m, the bending rigidity of the joint. The joint construction detail adopted in Shanghai maglev demonstration line is illustrated in figure 2. the characteristic of this joint are :

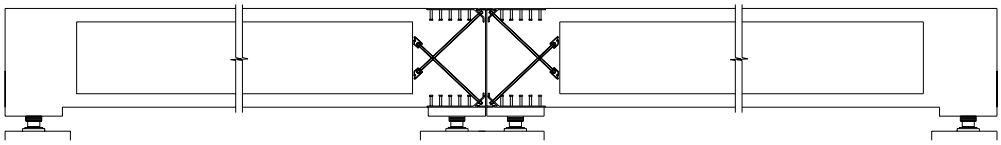

Fig.2 Construction of the simply supported-continuous connection

(1) Embedded steel plates are fixed on one end of the single span guideway;
(2) Anchor pin, horizontal steel bars and diagonal rolled screw anchor are used to ensure the connection;
(3) Attachment of the connection plates to the embedded plates can be with both high strength bolt connection and weld connection.

6 Numerical Analysis

The deformation of the simply supported-continuous hybrid guideway adopted in Shanghai maglev demonstration line under vehicle load and temperature difference is calculated by employing the structure analysis software SOFISTIC. It is compared with that of simply supported guideway and continuous guideway, see table 1.

Table 1. Deformation Analysis

Items	Simply supported	simply supported-continuous	continuous
Under vertical vehicle load	2.232mm	1.303mm	1.052mm
Under vertical temperture difference	7.051mm (temperture difference is 22℃)	3.234mm	2.044mm
	3.205mm (temperture difference is 10℃)	1．470mm	0.929mm
Under lateral vehicle load	0.484mm	0.457mm	0.233mm
Under latera temperture difference	2.518mm	2.329mm	0.783mm
First frequency of free vibration	5.966Hz	6.049Hz	5.807Hz

It can be seen from table 1 that for the simply supported-continuous hybrid guideway adopted in Shanghai maglev demonstration line the vertical deformation is close to that of the continuous guideway and he lateral deformation is close to that of the simply supported guideway. It proves that the intention of "simply supported-continuous" is well reached.

7 Experimental Research

Full-size model experiment is carried out for checking the joint construction and its load bearing performance. Fatigue and load bearing capacity are tested under normal use limit state and load bearing capacity limit state while various phases such as manufacturing, installating and working are taken into account. The test specimen is manufactured exactly according to the blueprint of the 24.768m-span guideway, including the material and so on. These conclusion can be deduced:

(1) The guideway and its joint remain normal after 200 thousands times of repeated load under normal use limit state;
(2) It is found in the test of load bearing capacity limit state that the ultimate load is 1000 kN, which is 2.2 times of the normal use load (450 kN) ;
(3) The joint construction adopted in Shanghai maglev demonstration line can reach the expected effect;
(4) The joint of the simply supported-continuous guideway is practical and safe.

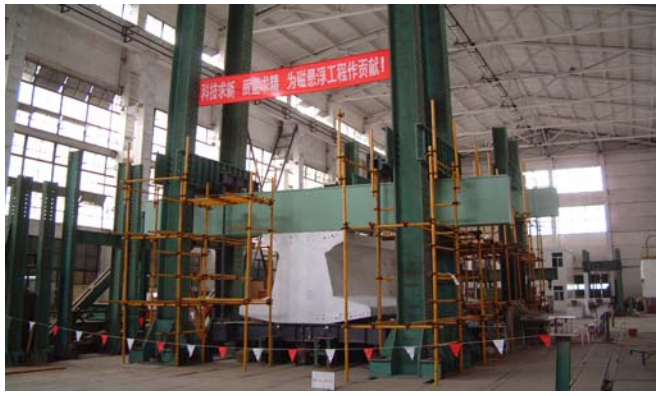

Fig. 3 Scene of test

8 Conclusion

Such conclusions for the simply supported-continuous guideway can be reached by theoretical and experemental research and the engineering practice in Shanghai line:

(1) The temperature deformation of the simply supported guideway is too large and should manage to be controlled;

(2) The structural performance of the simply supported-continuous guideway (guideway with spring joint) is between that of simply supported guideway and continuous guideway. Its deformation is controlled by K_m, the bending rigidity of the joint ;

(3) The idea of "simply supported-continuous guideway", which is to connect two simply supported guideway with spring joint and get a guideway which is continuous in vertical direction and simply supported in lateral direction, is proved to be practical by theory and experiment;

(4) For joint construction of the simply supported-continuous guideway adopted in Shanghai maglev demonstration line, full-size model test proves that the design of diagonal rolled screw anchor, anchor pin and anchor steel bar is proper and reliable; the requirement of bearing long-term static and dynamic load can be reached.

References

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