Research on High Speed Maglev Guideway System

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Abstract: In the preliminary study of the potential maglev project, the alignment conditions are mainly divided into two types, underground type and elevated type. As to the former, in order to determine the arrangement of the tunnel and corresponding girders, we should focus on the aero dynamic effects when the maglev train passes through the tunnel, treatment measures to the settlement, emergency plan etc. As to the latter, new practical elevated guideway system should be designed based on the following principles: optimization of the maglev system arrangement, high escape efficiency, economic use of land and better environment protection, etc. The study progress on the above two aspects by Shanghai Maglev Transportation Engineering R&D Center are introduced in this paper.
Key Words: Maglev alignment, Tunnel, Aerodynamic effects, Treatment measures to the settlement, Safe escape, Elevated guideway system

1 INTRODUCTION

Shanghai Maglev Demonstration Line is the first commercial operation line with conventional-conductive maglev technology in the world. Its guideway system is based on the elevated hybrid girder, which ensures the successful construction and safe operation of Shanghai Maglev Demonstration Line. Since the line was open to the public, it has been operated safely and timely for more than 8 years. According to the feedback from the operation & maintenance department, the line is in stable statement. With the development of the research on the potential project, the existed guideway system will not be completely suitable for the complicated condition of potential maglev projects in the future. Therefore, corresponding maglev guideway systems are necessary. Researchers in Shanghai Maglev Transportation Engineering R&D Center have done series of research work on the maglev tunnel and the elevated guideway system according to the requirements of the potential project.

2 RESEARCH ON MAGLEV TUNNEL

In the preliminary study of the project linking two airports in Shanghai, the way to pass through the Huangpu River was designed as underground tunnel, with length of 2.8km, with maximal depth of about 60m, and with designed speed of 250km/h. For the lack of similar experience in maglev tunnels, we carried out series of key researches on the Huangpu River tunnel project. Based on these researches, we optimized the layout, guideway structure, and the engineer treatment of the maglev tunnel project.

The tunnel was designed as double-track tunnel, as shown in Figure 1. The tunnel section is divided into upper and lower space. The upper space is for train operation and equipment installation. The lower space is for evacuation, rescue and the installation & maintenance of some equipment.

The train’s operation space is designed to meet the required clearance envelope limit. The space from the limit to the tunnel lining is for equipments installation. The maintenance power box and wireless control junction box are fixed on the sidewall. The top space of the tunnel is set as the flue partly along the tunnel. The basic and emergency lighting, monitoring camera, speaker, leakage cable and the maglev train special instruments are arranged along the lining. Hydrants (every 50m) and the inspection manholes are arranged between the two tracks.

Under the traffic lane slab, the space between the two tracks is set as the overhaul path along the tunnel to the working wells at two ends. The cable trays, equipment boxes and rainspouts are arranged on the side wall of the overhaul path. The space inside the two apron pieces supporting the tracks is used as the tunnel of traffic cables, and there is an access gate linking with the overhaul path every 100m. Cable channels lie at each side out of the apron pieces, doubling as the gully.
2.1 Research on aerodynamic effect of tunnel

Numerical simulation and scale model test were both carried out to examine the aerodynamic effect when maglev train passing through the tunnel with the speed of 200km/h and 250km/h. The research focused on the train surface pressure, the pressure variation in carriage, the pressure on tunnel and the micro pressure wave at the tunnel opening caused by the train passing through the tunnel or rendezvous in the tunnel. The influence to the aerodynamic effect caused by the tunnel shaft, the tunnel opening buffer structure and the septum (if designed) is also examined.

In simulation, we use FEM sliding mesh to describe the relative movement between the train, the tunnel and the air. The tunnel pressure wave was imitated in ‘One-dimension compressible isentropic flow model’. Loss coefficients of some special structures was got from 3d calculation of the software FLUENT.

In the model test, 1/25.4 scaled models of the train and the tunnel were produced according to the similarity criterion. The test was carried out at the Key Laboratory of Traffic Safety on Track of Central South University in Changsha.

From the simulation and model test, we got some conclusions about the aerodynamic effect of maglev tunnel, which have helped the tunnel project design and optimization.

1) The tunnel buffer structure can evidently reduce the micro pressure wave at the opening, and can reduce the variation of the train surface pressure and the tunnel pressure. For example, when the train runs through the tunnel at the speed of 200km/h, the train surface pressure reduces about 100 Pa, and the tunnel pressure reduces about 150Pa.

2) The shaft can evidently reduce the micro pressure wave of tunnel. When there are buildings near the opening, shaft is necessary to the tunnel.

3) Rendezvous has little effect on the rate and the amplitude of the pressure variation in the train. With speed of 250km/h, the max variation rate is about 322Pa/3s, and the max amplitude is 960pa. If septum is designed, the variation rate becomes 529Pa/3s and the amplitude becomes 1588Pa, and this will make the ride uncomfortable.

4) When the trains run or meet in tunnel with speed of 200km/h~250km/h, the max amplitude of the train surface pressure is from -3500Pa to 2700Pa, which is permitted by the structure.

5) When train runs in tunnel in speed of 250km/h, the max tunnel pressure is about 3200Pa.
6) With the research conclusions, the clearance area value and the blockage ratio of maglev tunnels with different speeds are suggested in Table 1.

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>Clearance Area(m²)</th>
<th>Blockage Ratio</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>52</td>
<td>69.4</td>
<td>0.240</td>
</tr>
<tr>
<td>250</td>
<td>60</td>
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<td>0.208</td>
</tr>
<tr>
<td>300</td>
<td>60</td>
<td>86.1</td>
<td>0.208</td>
</tr>
<tr>
<td>350</td>
<td>70</td>
<td>100</td>
<td>0.178</td>
</tr>
<tr>
<td>400</td>
<td>80</td>
<td>110</td>
<td>0.156</td>
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<tr>
<td>450</td>
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<td>110</td>
<td>0.125</td>
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<td>0.114</td>
</tr>
<tr>
<td>550</td>
<td>120</td>
<td>130</td>
<td>0.104</td>
</tr>
</tbody>
</table>

2.2 Research on tunnel settlement and treatment measures

Due to the soft soil in Shanghai, the tunnel construction method is mainly shield-driven. The longitudinal uneven settlement of the tunnel during long term operation is mainly caused by 6 factors, as follows.

1) The difference in consolidation characteristic of the soil layers lying under the tunnel,
2) Constructions near the tunnel,
3) The addition of ground load above the tunnel,
4) The variation of water level in the tunnel layer,
5) The subversive longitudinal deformation caused by the soil erosion in soil layers under the tunnel, and
6) The differential settlement between the tunnel and the working well.

According to the 2D settlement calculation of the typical tunnel section and the 3D settlement calculation of the total tunnel model, the maximal settlement of the tunnel can be controlled within 50mm, 80 percents of which completed in the construction period. Usually tunnel will not be put into operation until half to one year after shield work done, by when the initial settlement and the consolidation settlement will have almost completed.

Some practical engineer measures are suggested to control the maglev tunnel settlement, as follows.

1) The construction quality control standards are produced to control the longitudinal deformation of the tunnel, so as to meet the requirement of the maglev train operation.
2) With consideration of the tunnel property and the girder arrangement, the short π -shaped hyper beam with span of 12.384m is suggested as the major girder beam used in tunnel.
3) Adjustable bearings are set under the girder ends, which can be adjusted from upward 40mm to downward 20mm, so as to adjust the alignment when necessary.
4) In the operation of long maglev tunnel, some special control measures are suggested:

1) Any construction near the tunnel must be at least 3m away from the tunnel outline.
2) The additional load value to the tunnel wall can’t be more than 30kPa, caused by side building (including foundation basement) or some construction factors like precipitation or grouting, etc.
3) The additional curve radius should be no less than 15000m, caused by the tunnel deformation curve.

2.3 Research on fire protection and rescue escape in maglev tunnels

The fire protection mainly aims at the tunnel fire. Based on the principle of “Rely mainly on prevention, together with extinguishing, and controlled in the tunnel”, reliable disaster proof measurements are taken to provide a safe and economically rational tunnel.

The design is on the assumptions as follows, 1) only one place fires in tunnel at one time, 2) the scale of the fire is no more than 10.5MW, 3) taking the escape efficiency and the reliability of rescue into account.

In maglev tunnel structure design, a layer of 20cm thick in-situ concrete floor is set inside the segments, doubling as the fire proof inner lining of the segments, so as to protect the segment structure when fired.

Figure 5 means of escape in maglev tunnel

The escape plan of maglev passengers in tunnel is designed as, the equipment mainly include escape platform in tunnel (usually used as maintenance platform), escape way in tunnel and the escape stairs set in the working well and the middle well. When got fired, the train stopped at the accident rescue point firstly, then passengers escaped through the
escape platform to the escape way, and then escaped to the nearest working well or middle well, finally passengers escape to the ground through the escape stairs set in the well.

3) The Precise adjustment of the alignment is set to be done on the girder beams, which are mainly short beams successfully designed before such as slab girder beams (as shown in Figure 8) or π-shaped girder beams (as shown Figure 9).

4) Escape measurement is considered in the new system, taking advantage of the train clearance limit space as the escape way in rescue, which doubles the overhaul path in normal times.

5) Override beams are used at the span end, so as to reduce the effect on the alignment by the uneven settlement of the substructures.

6) The integration layout of the system equipments is improved, so as to save the land occupied.

3.1 Girder on bridges system

According to the chosen girder beam type and the functional needs, ‘Slab-beam on bridge’ and ‘π-shaped beam on bridge’ are optimized as the suggested two forms. The major layout is shown in Figure 10. The support bridge is a prestressed concrete box beam. Two tracks are placed on the top surface of the bridge, and on both sides cantilever of the box beam are cast-in-cite short walls on which cable bearers, noise barrier screens and some other equipments can be fixed.
And the detailed schemes are shown in Figure 11 and Figure 12.

### Table 2 Two different types of girder on bridge

<table>
<thead>
<tr>
<th>Item</th>
<th>Slab beams on bridge</th>
<th>π-shaped beam on bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>bridge</td>
<td>Prestressed concrete box beam with span of 24.768m</td>
<td>Prestressed concrete box beam with span of 24.768m</td>
</tr>
<tr>
<td>girder</td>
<td>Slab beams with span of 6.192m</td>
<td>π-shaped Integrated type girder with span of 12.384m</td>
</tr>
<tr>
<td>Straddled beam</td>
<td>π-shaped Integrated type girder with span of 6.192m</td>
<td>π-shaped Integrated type girder with span of 12.384m</td>
</tr>
</tbody>
</table>

Figure 11 Layout of slab beams on bridges

Figure 12 Layout of π-shaped beams on bridges

Figure 13 Layout of trackside switch cabinet on bridges

A new adjustable escape style was put forward for the girder-on-bridge system, which includes escape instruments fixed in the train, escape way on the bridge, and escape stair linking the bridge and the ground. The escape instruments fixed in the train include four parts. The first is a telescopic carriage which can reach out of the train in some distance and keep firm linking. The second is an escape air cushion made of light material (like Nylon, etc) which can be overplayed, can be bloomed to fixed shape, and has balance weight at one end. The third is a set of gas generator which can provide gas for the air cushion quickly. And the last one is an instrument cabinet fixed in the train, where the carriage, the air cushion and the gas generator can be placed when not used.

Figure 14 The escape system of girder on bridge systems

3.2 Research on aerodynamic effect of girder on bridge system

In order to test the technique feasibility of the girder on bridge system, the aerodynamic effect of maglev train running on the bridge is examined with the method of both simulation and scaled model test. The scaled model is made as 1/20.4, and the test was carried out at the Key Laboratory of Traffic Safety on Track in Central South University.

Figure 15 model test for aerodynamic effect

Figure 16 Simulation model for aerodynamic effect

Figure 17 The effect of screen height to the train’s surface pressure
From the model test and the simulation analysis, the aerodynamic effect of the system can be concluded as follows.

1) When the train runs through the barrier screen on bridge, the peak lateral action force appears on the top of the train, the minus peak value appears on the end.

2) The values of the train surface pressure, the barrier screen pressure, the side action force on train, the aerodynamic force on barrier screens, and the longitudinal load on the cable bearers vary proportionately to the square of the speed.

3) Increase of the wall and screen height is beneficial to the outside noise reduction, but will cause small increase of the train surface pressure, the train inside aero pressure and the lateral force on the train.

4) The cable trays on the side wall has seldom effect on the train surface pressure and the aero pressure inside the train, and because of the turbulence effect of the cable trays, the lateral force on train and the pressure on the train and the screen become shortly reduced.

5) The Π-shaped girder bridge is slightly better than slab Girder Bridge on the train surface pressure.

6) The train sets have little effect on the aerodynamic effect of the girder on bridge system.

3.3 Girder-on-bridge system online presentation and noise reduction test

The presentation of girder on bridge system was carried out on the Shanghai Demonstration Line, as shown in Figure 19. The site was chosen at the at-grade part of Shanghai Line, near the Pudong airport. Noise reduction test was also carried out in the presentation, with measuring point arrangement as shown in Figure 20. With the noise test and analysis, the noise reduction effect of the girder on bridge system was estimated. With speed of 300km/h and 400km/h, the noise reduction effects are familiar. The reduction effect is obvious in the sound shadow region of the barrier screens. With 1m high screen on the wall, the maximal noise reduction amplitude is about 5~9dB (A). With 2m high screen on the wall, the maximal noise reduction amplitude is about 8~13dB (A). Outside of the sound shadow region the noise reduction effect is not obvious.

4 CONCLUSIONS

Based on the preliminary study of the potential project, this paper introduced the research of maglev underground tunnel and elevated structures, mainly including the aerodynamic effect of maglev tunnel, rescue measurements in tunnel, settlements of tunnel, and the optimization of elevated guideway system. Suggestions based on the research have been considered in the design.

With the development of modern society, people’s requirement to living surroundings becomes more and more critical. As a new environmental, energy saving, safe and comfortable transportation system, maglev transportation system surely will be used widely in the future. We do believe that the research achievements introduced in this paper will be useful for the further popularization of the maglev transportation system.