Fundamental Ideas and Basic Concepts of HSR Route Selection in Complicated Urban Areas

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Abstract: Up till now, no systematic studies on railway route selection in urban areas, HSR route selection in particular, have been taken in China. Based on the Shenzhen Railway Terminal Project and the Shenzhen-Shanwei Railway Project, research on HSR route selection in complicated urban areas has been conducted. An optimal route selection plan is determined after studying the local geological and environmental conditions and the complexity of tunnel construction. The research concludes that there are four major concerns in HSR route selection: the match between the new route and the urban planning, the potential economic return for the massive investment, the likely impacts of land expropriation on social stability, and the best synthesis of multiple controlling factors to meet the HSR standard. Moreover, six principles should be followed in railway route selection in complicated urban areas: the new route should be in alignment with the railway deployment; the route should align with the existing passage as much as possible; extensive analysis and in-depth demonstrations should be done to find the most appropriate combination of open and hidden excavation in tunnel construction; geological conditions and tunnel construction complexities are among the priorities; environmental sensitive sites and environmental vibration noise should be avoided as much as possible; special attention should be paid to the relocation of the power supply, television and communication facilities and the rearrangement of tubes and wires.

Keywords:high speed railway (HSR); complicated urban areas; route selection; railway network layout

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1 Introduction

The publication of a series of national strategies like the *Program of Building National Strength in Transportation* and the *Outline Development Plan for the Guangdong-Hong Kong-Macao Greater Bay Area* has started a new round of development of the high-speed railway (HSR) industry.

In the early stage, only a few HSR stations were built in downtown areas, while most other HSR stations were in suburbs for lower construction costs and less land expropriation and demolishing, as well as for environment protection and city development. But faraway HSR stations are inconvenient for short and medium-distance travelers, and therefore, HSR's fundamental role cannot be fully explored in city clusters. Therefore, bringing HSR into the city center will boost passenger transportation as well as the integration of city clusters.

2 The Current Research on Railway Route Selection in China

The Chinese railway industry has entered a new era in the 21st century and many researches on railway route selection have been launched, among which, researches on route selection in mountainous areas are the most systematic and intensive.

WANG Zhengming[1] sorted out his thinking and concepts of regular railway route selection based on experiences of many railway construction projects; DU Benyu and his colleagues[2] formulated geological principles in railway route selection based on geological explorations and researches in seismic mountainous areas with high intensity of the Chengdu-Lanzhou Railway; LI Wei and his colleagues[3-5] focused on route selection in high mountain areas and established route selection principles prioritized in geological conditions for minimum disasters; HU Ziping[6] concluded the practice of Yichang-Wanzhou Railway and proposed that not only should the route selection in complicated mountainous areas focus on geological conditions and environmental and water preservation, but also should take the technological and economic costs into consideration. ZHU Min[7], after studying the influencing factors in HSR route selection, has put forward a six-pronged route selection principle as follows: geological conditions are the priority; the sites of major projects should be determined first; the route should be planned to minimize the potential impact on the environment; the route should align with the urban planning; the route should make the best of the available resources; the cross-section conditions should also be considered.

As most of the researches are focused on route selection in mountainous areas, a set of systematic principles have been formed accordingly, but for railways in urban areas, HSR in particular, the route selection ideas have not been completely determined and sorted out.

Unlike the intercity railways and regular passenger-and-freight railways, HSR in urban areas have different targeted market, technology standards, track-laying methods and station deployments and so on, and therefore, this paper explores the characteristics of HSR route selection in urban areas and has formed a series of route selection theories and concepts.

3 Characteristics of HSR Route Selection in Urban Areas

Building an HSR in urban areas will not only boost urban development and passenger transportation, but also create new problems, and therefore, we need to find balance in the following four aspects:

(1) Railway should be planned in accordance with the city's overall planning. Since a city's overall planning may lag behind the real urban development, introducing a new railway to the downtown area may bring even bigger challenges. The route should be carefully selected so that it will not split the city. Moreover, for the least interruption of the city's functions, railway should either be elevated or buried, and when a railway comes across an urban high way, a flyover interchange has to be built.

(2) Rational investment and potential economic turnouts. Building an HSR has many promising effects: fast and efficient urban transportation, economic growth, stable employment, and better industrial structure. However, economic gains cannot be collected all at once and the railway development should also abide by the law of development. If an HSR is laid just above ground in the downtown area, the following land expropriation will be massive and expensive. If the railway is planned underground, the shield tunneling method is also costly. Therefore, an urban HSR usually means higher construction economic index and bigger investment. As a result, the potential economic turnouts should be calculated based on the characteristics of the project, the local economic development, the population, transportation demand and so on before determining the proper size of investment for an urban HSR.

(3) Land expropriation and social stability. If an HSR goes through a city, the high speed and the construction standard will make it inevitable for the HSR to go underneath residential buildings, urban facility networks and other means of transportation. Meanwhile, connecting HSR to the urban transportation terminal means massive land expropriation. City residents are very concerned of their neighboring environment and sometimes they may have strong reactions towards a new railway either along the existing passage or through planned land blocks. Therefore, building an HSR in urban areas may impose risks on social stability either going under structures or going above ground after grand land expropriation.

(4) The high technological standards of HSR and other multiple influencing factors. Cities, especially

the first-tier cities like Beijing, Shanghai, Guangzhou and Shenzhen, are characterized by densely-built tall buildings, complicated interchanges, extensive networks and dense pile foundations of all kinds of structures. Compared with subway and intercity express, HSR follows higher technological standards and operates at larger curve radius, and therefore, thorough studies on the many controlling factors of the railway horizontal and longitudinal planes and repeated demonstrations of the designed speed of HSR should be carried out to find the best HSR solution to the city.

4 Ideas and Concepts of Route Selection

4.1 Align with the railway deployment

When connecting the main passenger stations of a terminal city to an HSR line, route selection should be in alignment with the regional railway deployment and match the station's designed functions as well. Moreover, building a HSR should also consider the transfer conveniency to subway and intercity express railway and the connectivity to existing and planned railway stations. The HSR route should be integrated to the national railway network and meet the requirements of train operation.

The current HSR passages in Shenzhen Terminal rely mainly on Guangzhou-Shenzhen-Hongkong HSR and Xiamen-Shenzhen Railway, without direct westwards and northwards HSR routes. The through capacity based on the latest operating train pairs in all sections under management of China Railway Guangzhou Group Co., Ltd., shows that the Guangzhou-Shenzhen-Hongkong HSR is operating at 91% of its designed capacity, almost full, holding back the development of the HSR through passenger transportation in Shenzhen. Xiamen-Shenzhen Railway is also operated at over 80% of its designed capacity, and there is not much room for further growth. Moreover, as a main coastal railway passage, the Xiamen-Shenzhen Railway is under standard, because it's a mixed line, not separated from freight transportation, and the designed speed is only 250 km/h.

The west part of Shenzhen-Shanwei Railway is connected to the Shenzhen-Maoming Railway which is under planning (Shenzhen-Jiangmen Section) at Xili Station and the east part is linked to the Guangzhou-Shanwei HSR, which is in construction, in the Shenzhen-Shanwei Cooperation Zone. This railway will become a new coastal HSR passage of high standard, alleviating the transportation pressure on Xiamen-Shenzhen Railway, providing better costal HSR service eastward of Shenzhen Terminal and meeting the diverse travel demands of passengers. As Shenzhen is a core city in the Guangzhou-Hongkong-Macao Greater Bay Area, the Shenzhen-Shanwei Railway will become an important HSR corridor, facilitating the eastward expansion of the greater bay area. Therefore, the railway access plan of Shenzhen Terminal and the general route selection plan should match the above goals.

4.2 Align with the existing passage as much as possible

In order not to cut through the city and destroy the outlook, and to mitigate the impact on the city's urban development, the HSR route should be chosen in alignment with the existing transportation routes like highways and railways as much as possible and embrace the hilly topography.

Take the Shenzhen-Shanwei Railway as an example. The section from Xili to Pingshan is in the core zone of southern Shenzhen with a high density of buildings. The route selection should take full use of the existing railway passage of Pinghu-Nantou Railway and Xiamen-Shenzhen Railway and the hilly topography in the bordering area.

The existing Pinghu-Nantou Railway is a single-track freight railway and the design standard is too low compared to that of the Shenzhen-Shanwei Railway. Therefore, it is very hard for the two railway lines to share the railway passage. The Xiaman-Shenzhen Railway is a passenger-freight railway with a design speed of 250 km/h, and the paper also studies the plan along the existing Xiamen-Shenzhen Railway (see Fig.1).

The original bordering area between the inside and outside of Shenzhen Pass is hilly, where Luohu District and Qingshuihu region are located in the center. As the city renewal in Luohu District is underway, the district is comprehensively transforming and restructuring the transportation system. To keep up with the city's development, research has been done and the route selection plan along the Qingshuihe River has been formulated which goes through the hilly area in the southern part of Shenzhen with a station planned at the Qingshuihe reconstructed area.

After comparison, the route selection plan along Qingshuihe River is designed with higher standard and speed. This plan is able to facilitate integration of the downtown area in Luohu District in eastern Shenzhen to the concerted development of the Guangdong-Hongkang-Macao Greater Bay Area, meet the HSR travel demands of the residents in the middle and eastern area of Shenzhen, draw in a large number of passengers, and match the city's urban construction and transportation plan. Therefore, it is recommended in this paper.

4.3 Combining open and hidden excavation and intensive studies should be carried out

Open excavation requires a large number of cross-overs. Although building bridges can meet the project's demand, land expropriation will be remarkably expanded and high technical standards like the cross-angles and bridge span will add to the project's complexity. Urban development is very expensive and for big cities in short land supply in particular, open excavation may have a negative impact on the city's overall outlook and the separation of city land blocks may severely threaten social stability.

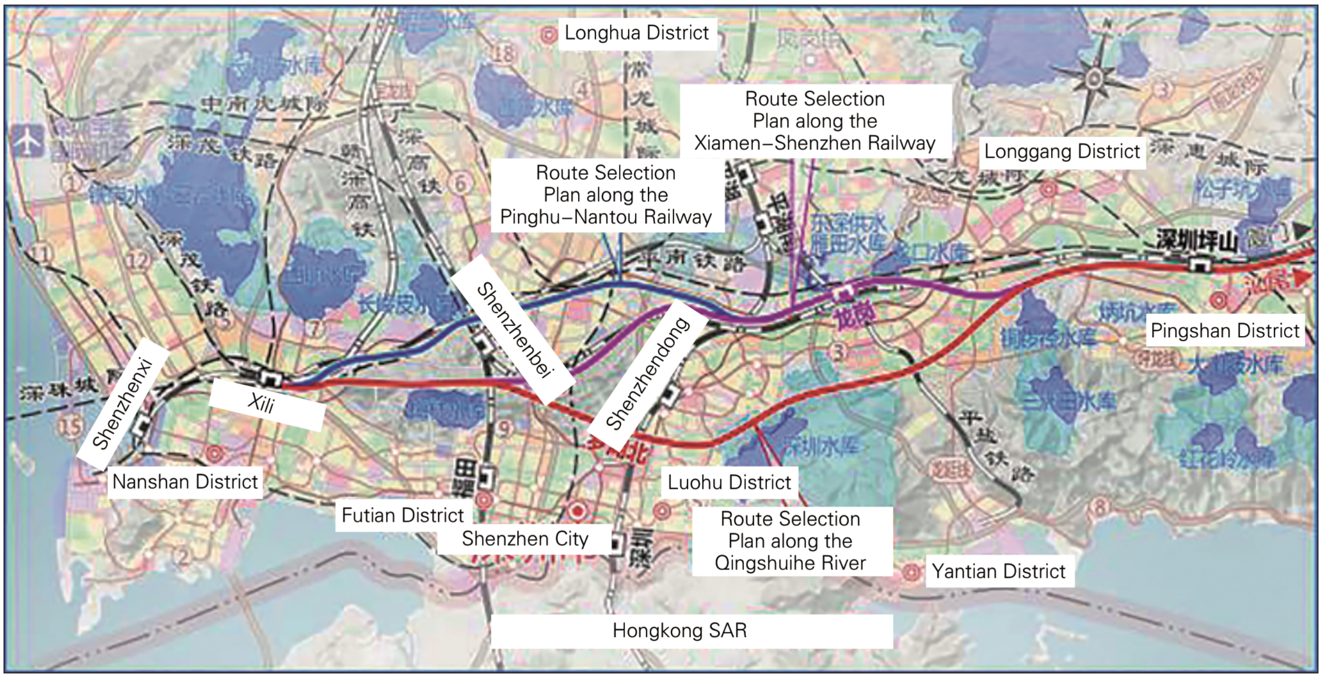

Fig.1 Schematic Diagram of Xili-Pingshan Section

Hidden excavation involves a lot of underpasses. Tunnels can to some extent avoid city separation and when the burial depth is at a desired stratum, land expropriation can be greatly reduced. But in complicated urban areas with high density of buildings, shield tunnelling should be adopted in construction as much as possible which will significantly increase investment. Therefore, route selection plans in urban areas need to be comprehensively discussed and compared in aspects such as rock grading, potential risk in social stability, cost of land expropriation and project investment and so on.

The section in town down Changsha of the Wuhan-Guangzhou HSR was originally planned along the Beijing-Zhuhai Expressway by open excavation. But structures were densely located along the line such as government-built living compounds and a leather market, and problems were hard to solve in flood prevention and control, building urban overpasses, land expropriation, environment protection and city replanning, and as a result, the project met severe resistance in progress. After meticulous reassessing the route plan of the railway section through the city based on both open and hidden excavation through the city, and after analyzing the geological conditions, environmental sensitive points, the construction complexity of going across the Liuyanghe River and the structure positions along the line, the ultimate route selection plan adopted hidden excavation method—building a long tunnel, which lead to better horizontal alignment, less land expropriation of 200 000 km^2 and smaller investment of 4 188 million yuan after examination[8].

The Shenzhen-Shanwei Railway stretches north-eastwards along the hills through Longgang District in Shenzhen city and is connected to Pingshan Station along the Xiamen-Shenzhen Railway. Along the Xiamen-Shenzhen Railway in Longgang District, many key development zones are planned on both sides of the line. For example, the line will go through the Apollo Future Industry City, the PowerLong Science and Technology City and the HSR Newtown in Eastern Shenzhen. The preliminary research adopted a combined excavation plan but further study and analysis has shown that: if the route is built by the open excavation, it will go along with the high voltage power lines. Therefore, a large scale of high voltage power lines may have to be relocated, which will be too difficult to implement. The hidden excavation method is to build a 18.2 km tunnel, with less land expropriation, less interchanged controlling points and less relocation of high voltage powerlines. Weighing all the factors, hidden excavation method is recommended[9].

4.4 Route selection based on geological conditions and tunnel construction complexity

4.4.1 Principles of route selection based on tunnel construction complexity and geological conditions

If HSR lines go through urban areas, geological conditions are still the major consideration. First, regional topography should be intensively studied and the regional geological data and information should be fully analyzed. Route selection should avoid the fault and karst areas as much as possible. Moreover, geological annotation for the major part of the project should also be considered to avoid unfavorable land or special rock and soil.

For long and large tunnels, construction complexity is the major concern. Route selection principles for tunnels through downtown areas should be set based on the local geological conditions. For complicated and difficult horizontal alignment, engineering methodology and construction methods should be comprehensively sorted out and the route alignment should be adjusted dynamically.

When the line has to go underneath dense urban areas, shield tunnelling is usually adopted while the vertical section should be buried deeper at a favorable rock layer. The tunnel should go underneath a structure at the safe clearance distance[10]. If the tunnel goes through the pile foundations of existed bridges or structures, pile foundation replacement and pile cutting should be done before building the tunnel: When approaching the pile foundations, construction isolation should be carried out to protect them.

If the route goes underneath water reservoir or water areas, especially the reservoir for drinking water, horizontal clearance distance, tunnel buried depth and reservoir permeability coefficients should be considered and the vertical section should be adjusted according to the relative positions of the fault, reservoir and the tunnel[11].

4.4.2 Case study of HSR route selection in urban areas

The Shenzhen-Pingshan Section of the Shenzhen-Shanwei Railway goes through a tunnel in parallel to the existing bridge of Xiamen-Shenzhen Railway (see in Fig. 2). Because the parallel passage is very narrow, for the safe operation of Xiamen-Shenzhen Railway, the plane and vertical section has to be stabilized and therefore, the principles of plane arrangement of the Shenzhen-Shanwei Railway close to the existing Xiamen-Shenzhen Railway have been first settled as follows:

(1) Generally, the tunnel will not pass directly under high-rise buildings.

(2) For the route sections where circumstances permitted, the clearance distance between the pile foundations of the tunnel and the bridge should be no less than 22 m, 1.5 times of that of the shield diameter.

(3) For the section where construction is very difficult, shelter pile foundations should be arranged between the tunnel and the bridge and the distance between the shield pile and the pile foundation of the bridge should be at least six times the shield pile diameter. The distance between the tunnel and the shield pile is 0.5 m, and the distance between the tunnel and the pile foundation of the bridge should be at least 7.5 m.

Other than keep the safe distance of side crossing the Xiamen-Shenzhen Railway, after comprehensively analyzing the impacts imposed on both the existing and in-construction high-rise buildings, the tunnel will be constructed on the full-face rock layer, keeping a vertical safe distance from those tall buildings. The tunnel's vertical section will be buried deep (see Fig. 3). Based on different geological conditions, the railway line is divided into regular sections and special sections and is constructed by portal isolation piles and segment grouting respectively.

Fig.2 Plane Graph of the Pingshan-Huizhounan Section of Shenzhen-Shanwei Railway

4.5 Environment protection in route selection

Environment protection in route selection in urban areas focuses on two aspects: route selection at environmental sensitive points and environment vibration noise.

4.5.1 Route selection at environmental sensitive points

The urban passages are usually very narrow and surrounded by many environmental sensitive points, making route selection even more complicated. Apart from the current route selection principles of environment first and source control, environment protection in route selection should also follow the laws and regulations, make reasonable avoidance, and carry out process monitoring and cost-control. In route selection, the route will bypass the environmental sensitive points which must be avoided; for those points that should better be avoided, the route will go around them as much as possible; for those points that could not be avoided in the same plane, the design should be optimized in space and corresponding construction technologies should be adopted to minimize the impact on the environment.

4.5.2 Route selection based on vibration noise

The main influencing factors on the environment of an HSR through complicated downtown areas are environment vibration and secondary structural noise. Buildings for living, medical services, education, culture, scientific research and administration are susceptible to them and therefore, a proper estimating measure should be adopted based on the actual positions and relative positions of the environmental sensitive points as well as construction conditions and planned train operations. Sections in different function zones should meet the vibration standards respectively.

In route selection, the line should be buried deeper and the plane should be optimized to mitigate environment disturbance. When the disturbance is inevitable, sound barriers and sound proof windows should be installed to meet the noise standard. If the noise standard cannot be met, the buildings and structures in the excessive vibration and secondary structure noise zone should be demolished or used for other purposes.

The condition for the connecting line of the Shenzhen-Shanwei Railway and Huizhounan Station are as follows: the west end of the line goes in parallel with Xiamen-Shenzhen Railway and many tall buildings are built along the line; the east end of the line squeezes between the high-rise Agile Garden Community and the Xiamen-Shenzhen Railway; in the middle is the Huizhounan Station which is two floors underground and the buried depth is 25 m.

After estimating and analyzing the vibration noise at the 53 noise sensitive points in the underground section, the daytime VL_{zmax} and the nighttime VL_{zmax} are collected and according to the *GB 10070-88 Standard of Environmental Vibration in Urban Area* (75 db in daytime and 72 db in nighttime), the daytime noises at all the points meet the standard while the nighttime noise at 5 points fail. The secondary structure noise is tested and according the standards set in *JGJ/T170—2009 Limit and Measuring Method of Building Vibration and Secondary Noise Caused by Urban Rail Transit* (41 db for the day and 38 db for the night), the secondary noises at all the points meet the standard in the day while the secondary noise at 5 points fail at night. The estimated noise is listed in Table 1.

Based on the station's plane and deep bury conditions and the limited construction costs, the plane and vertical sections cannot be further adjusted or optimized. After combining the development plan for Huizhounan Station Terminal, the buildings and structures at the noise sensitive points which fail the vibration standard and

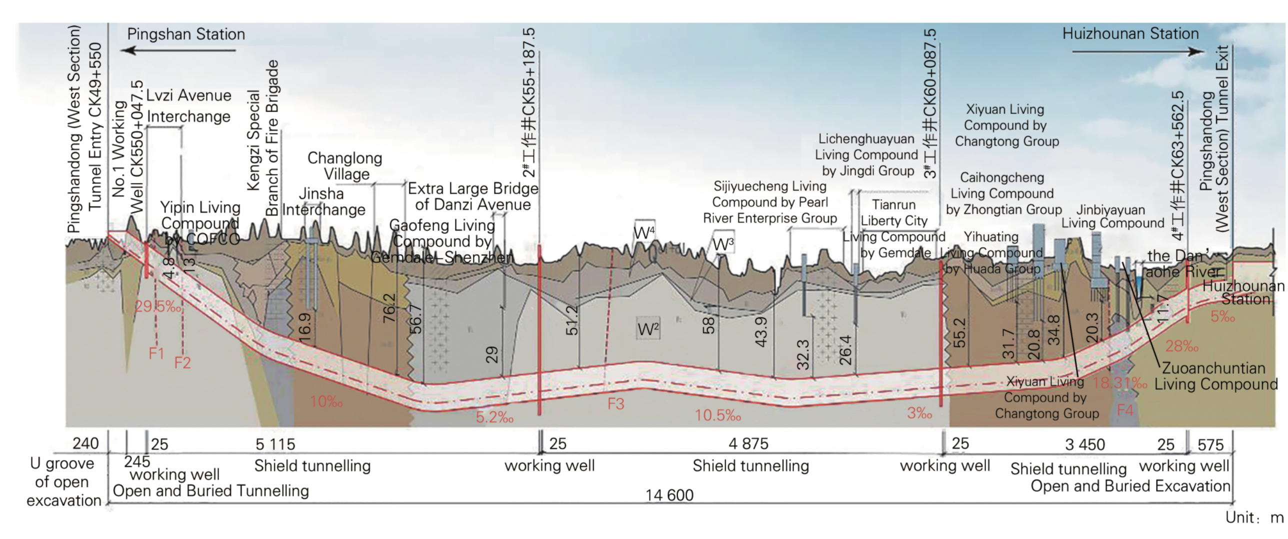

Fig. 3 The Vertical Section of the Pingshan-Shenzhennan Section of Shenzhen-Shanwei Railway

Table1 Estimated Vibration and Secondary Structure Noise at Huizhounan Station

Sensitive points	Locations /m			Estimated vibration / dB(A)		Estimated secondary structure noise /dB(A)		Noise functional zone
	Horizontal distance	Height difference	Forms of route	Daytime	Night	Daytime	Night	
Xinmin Village	12	25	Tunnel	74.4	73.9	41	40	Type 2
Damenbu Village	23	16	Tunnel	74.7	74.2	41	40	Type 2
Zhongwei Village	40	12	Tunnel	74.2	73.7	40	40	Type 2
Qiling Village	24	24	Tunnel	72.8	72.3	39	39	Type 2
Lixing Village	14	25	Tunnel	73.9	73.4	40	40	Type 2

the secondary structure noise standard will be demolished.

4.6 The relocation of television, communication and power facilities and rearrangement of tubes and wires

In complicated urban areas, there are many types of tubes and wires extensively laid and intertwined, and once rearranged or cut off, not only huge reinvestment is needed but also people's lives will be greatly affected.

Route selection should first investigate and collect the information and resources of the power supply facilities, tubes and wires, and with necessary technological methods like geophysical prospecting and NDT, the real conditions can be fully learned. Based on the different grades of the tubes and wires, the complexity of relocation and construction costs should be comprehensively calculated and the potential impacts fully studied.

For those tubes and wires which cannot be rearranged or the relocation might severely hold back construction and impose huge impacts on the society and people's life, the route should be adjusted timely. For those tubes and wires that could be rearranged, the plane and vertical distance should be secured to meet the safety standards and regulations and the rearrangement should not interrupt normal functioning.

The exit section of the Pingshandong Tunnel of the Shenzhen-Shanwei Railway is openly excavated from the tunnel working well to the exit, and there are two triple-loop 500 kV power lines, 2 four-loop 220 kV power lines, and one single-loop 110 kV power line. This openly excavated railway section is very close to high voltage towers. If the towers are to be relocated, the relocation will cost about 130 million yuan and power outage coordination is very difficult. In order to scale down the power relocation project and following *the Implementing Rules of the Regulations of Protection of Power Facilities*, the route plane is adjusted while keeping the minimum distance of 10 m between the tunnel face and the foundation of high voltage towers. The ultimate route meets the requirement for safe distance from Xiamen-Shenzhen Railway and high voltage towers respectively (see in Fig. 4). After route optimization, only one high voltage wire of 110 kV and one of 220 kV need to be relocated which saves not only project investment, but also make construction a lot easier.

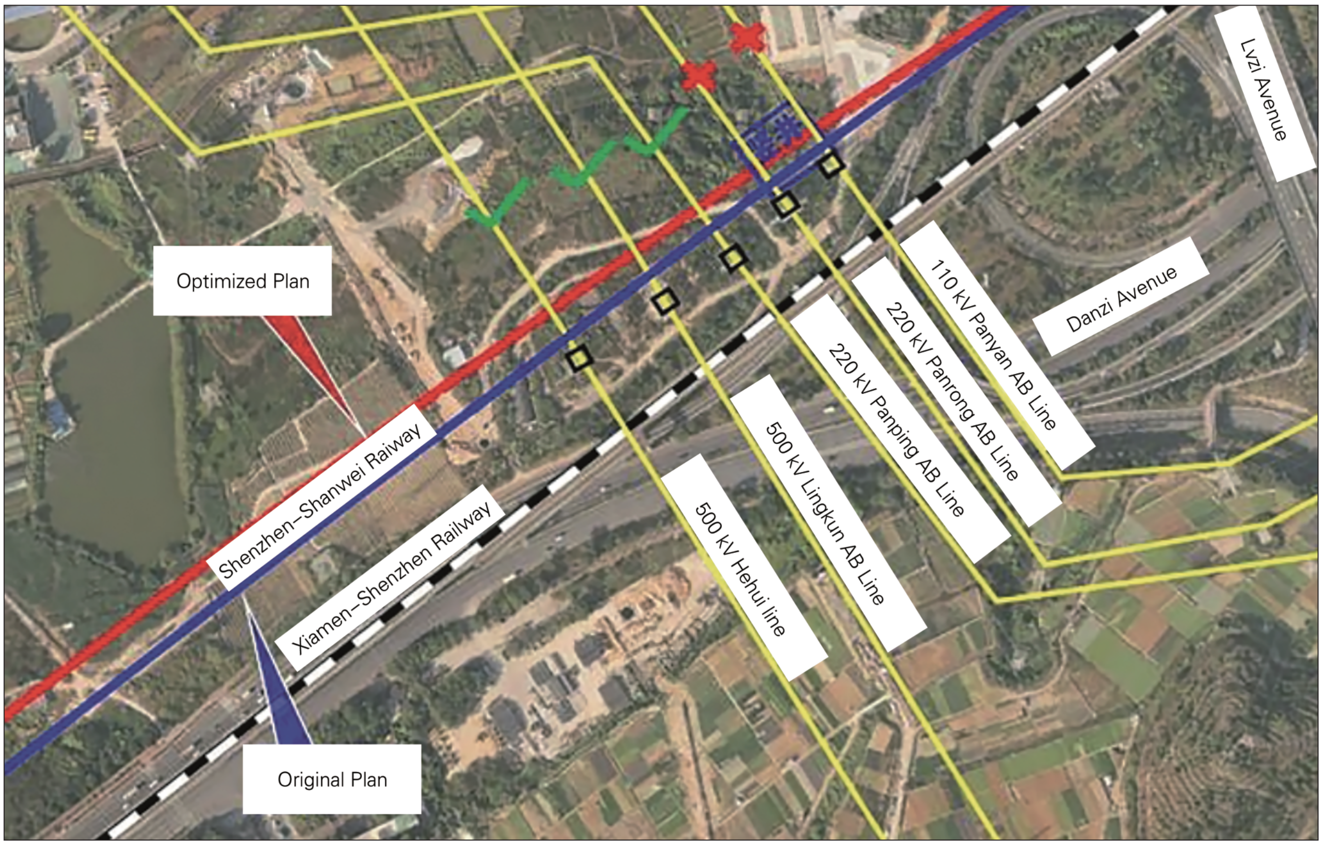

Fig. 4 Plane Diagram of the Pingshandong Tunnel Exit of Shenzhen-Shanwei Railway and High Voltage Towers

5 Conclusions

This paper has studied key elements in HSR route selection in complicated urban areas and analyzed thoughts of HSR route selection in urban areas. Based on the Shenzhen Railway Terminal Project and Shenzhen-Shanwei Railway Project, the paper has determined suitable route selection concepts and feasible construction methods after studying the geological and environmental conditions, tunnel construction complexity and other influencing factors. The following technological suggestions have been made for HSR route selection in cities under new circumstances:

(1) HSR route selection in urban areas should consider the following four factors: integration of the new railway into the city's overall planning, the economic return of the huge investment, the potential impacts of land expropriation on social stability, and synthesizing a large number of controlling factors to meet the high standards of HSR.

(2) Six principles should be strictly followed in HSR route selection in urban areas: conformity to the railway deployment, in alignment with the existing passage as much as possible, calculated combination of open and hidden excavation; geological and tunnel conditions should be prioritized; environmental sensitive points and environmental vibration noise should be taken seriously; the rearrangement of communication, television and power supply facilities and the relocation of cables and wires should be carefully planned.

(Translated by ZHANG Yiran)

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