Research on the Feasibility of Chao Tianmen Cross-River Tunnel Project in Chongqing

Liu Xinrong¹, Zhong Zuliang¹, Qian Qihu¹, Zhang Yongxin¹

¹College of Civil Engineering, Chongqing University, P.R.China

ABSTRACT

The existing construction of cross-river tunnel in home and its superiority is discussed in this paper. When it comes to the inconvenient traffic condition of the metropolitan economic circle in Chongqing City, a plan is put forward to build cross-river tunnel in Chao Tianmen, Chongqing. By analyzing the feasibility of geology condition, economic benefit and technology of construction and operation of tunnel, a conclusion is drawn that it is necessary to build a cross-river tunnel in Chao Tianmen. The project not only satisfies the continual development and national defence, but also plays an important role in economic development and environment protection.

1. GENERAL SITUATION OF DOMESTIC TUNNEL CONSTRUCTION

Since the 1980s, the development of ship industry is serious restricted by the low vertical clearance of the bridge. Especially in recent years, due to abundant rain throughout the country, the flood prevention situation becomes austere, with the result that the warning line of water is exceeded on many occasions. In order to prevent the ships collide the pier of bridge, the routeways under the bridges are always closed down by the ship department. The disadvantage of navigation vertical clearance shortage of the bridge is obvious both in the way of long term planning of shipping and the economic or social benefit. Furthermore, going with the enhancement of people's awareness of national defense, the cross-river project tends to be plan of cross-river tunnel.

Since the 1970s, many cross-river tunnels have been built or been under construction. For example, there are more than 6 cross-river tunnels built by the method of shield technology in shanghai(Jiang Tianhua, Liu Lingli, 2002), which are Dapu Road cross-river Tunnel (2.761km), the north line of Yan’an East Road Tunnel(2.261km), the south line of Yanan East Road Tunnel(2.437km), Dalian Road Tunnel (1.27km), the phase II of Pearl Line cross-river tunnel (1.16km), Fuxing East Road cross-river Tunnel (1.21km)( Zhou Song, 2004). Besides, Jiangbei Cross-river gas tunnel in Sichuan province(0.4km), Sanjiangkou cross-river Tunnel (1.992km), the first gas Tunnel crossing the main channel of the Changjiang River in Chongqing (1.062km) and the second cross-river gas tunnel (0.96km), Changjiang River Tunnel in Zhongxian, Chongqing(1.66m), Chongqing urban drainage tunnel (0.925m), Chongming Tunnel in Shanghai (8.95km), Weiqi Road Tunnel in Nanjing (6.16km), Changjiang River Highway cross-river tunnel are also built with this method in Wuhan. Secondly, there are some cross-river tunnel built with the method of immersed tunnelling method, which are Yongjiang tunnel in Ningbo(1.02km), Pearl River Tunnel in Guangzhou (1.238km), the downstream of Huangpu River Tunnel in Shanghai (2.875m), Kuntou to Shengwu island cross-river tunne under construction in Guangzhou(1.18km). In addition, there are 14 cross-river tunnels being built in Shanghai before 2010 year. And the second cross-river tunnel (Weisan Road Tunnel in Nanjing, Qiantang Jiang cross-river tunnel in Hangzhou, Luoxi Island to the City of University cross-river tunnel in Guangzhou) also will be built in recent years. In order to facilitate the traffic between cities, there will be more and more cross-river tunnels project in China.

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2. ADVANTAGE OF BUILDING CAROSS-RIVER TUNNEL

The plan for cross-river routeways mainly adopts the plan of cross-river tunnel or bridge in present. Although the number of bridge is more than that of tunnel at present, the plan of cross-river tunnel or the combined plan of cross-river tunnel and bridge is suggested preferentially by experts in order to reduce the number of bridge. However the building history of cross-river tunnel is more youthful than that of bridge, the plan of cross-river tunnel has more superiority that the plan of bridge can’t compare with:

(1) It won’t take up the headroom of sea-route. In general, according to the general construction of the bridge, the slope is designed by the height of both sides of the bridge. This vertical headroom of the bridge will be subject to certain restrictions. With the deposition of sand and the changing of riverbed, and the increasing about the tonnage, the restrictions on shipping are becoming more and more obviously. But the plan of cross-river tunnel has not such restrictions on shipping.

(2) The tunnel isn’t subject to the natural conditions, such as high winds, rain, snow, fog and others, and has strong resistance against war damage and natural disasters.

(3) There will be no or less demolition on the existing construction in the spot, which can greatly reduce the total cost of the project.

(4) Cross-river tunnel has larger capacity of bearing weight, superior than bridge which is restricted by common vehicle bridge design load. Besides, it has good structural durability; and its maintenance cost on structure is much lower than the bridge.

(5) It will not be affected by the changes of riverbed, and has small influence on surrounding environment.

(6) The cost of construction of cross-river tunnel is lower than that of bridge. Because the construction of cross-river tunnel needs less steel and common steel

(7) One hole can do more use by design to disposal urban water supply, power supply, gas supply and telecommunications facilities, and can be sure to provide a more relatively safe and stable environment.

3. NECESSITY OF CONSTRUCTION OF CROSS-RIVER TUNNEL IN CHAOTIANMEN

The city of Chongqing locates in the southwest of China, lying to the upstream areas of Changjiang River, and it also borders on the province of Hubei, Hunan, Guizhou, Sichuan, Shanxi etc, with a total area of 82,400 square kilometers. Besides it is the economic center of China's southwestern region, water and land transportation hub in the upriver of the Changjiang River, and a major port for foreign economic and technological exchanging. The city centre locating at the meeting of the two rivers is on a narrow peninsula. The population of the city centre is more than 500 thousand with only 9.3 square kilometers. There are some serious problems existing in the metropolitan districts of Chongqing:

(1) "cross-island" is separated by the Changjiang River and Jialingjiang River; Cross-river ways are grossly inadequate. Especially there are less cross-river routeways from Chaotianmen to Nan’an and Jiangbei, which only has cableways and ferry. The cars must make a detour from the Huang Huayuan Bridge and Shi Banpo Bridge to reach Jiangbei and Nanan District. So the economic circle is greatly restricted.

(2) The traffic capacity of roads is insufficient; and the exploitation space for road is shortage. With rapidly growth of urban transport, traffic capacity of the road will endure large pressure in Yuzhong District.

(3) The road joints linking the various levels of elevation are few. Besides, the structure of road net is unbalance, and the grade of road net is unreasonable.

(4) The conflict between rapid developments of city economy and the urban basic facility becomes increasingly acute.

Moreover, Jiefangbei Central Business District (CBD) is being planned in Chongqing, which is consisted of Jiefangbei District, the Nan’an District and Jiangbei District. Beyond completion, the economy of the CBD will highly develop, and the population, materials, transportation will further...
increase, so the existing breachway is far from meeting the traffic needs. Well then, it is emergent to build cross-river breachways in the vicinity of Chaotianmen in order to meet the traffic needs of highly economic development. At present the plan is cross-river Bridge or cross-river tunnel. Taking into account the city's sustainable continuing development, protection of the Yangtze and Jialingjiang River transportation systems and national defense requirements, the plan of cross-river tunnel is preferentially taken into account. There are many successful examples of cross-river tunnel in home. For example, Chongming Island cross-river tunnel in Shanghai, Wuhan Yangtze River Tunnel, Nanjing Yangtze River tunnel, Qingdao Benthal Tunnel, British and French Channel Tunnel, Japan Qinghan Tunnel. These constructions have played a great role in promoting economic development, accelerating the pace of construction between the two sides, and promoting the continuing development of the city.

4. DISCUSSION ABOUT FEASIBILITY OF BUILDING CROSS-RIVER TUNNEL

4.1 Analysis with feasibility of geology

4.1.1 Geological stratum distribution and geological structure in the site of tunnel

The protruding geological strata in the site of cross-river tunnel are the quaternary system all-new artificial filling soil (Q₄ml), residual deposits of soil, (Q₄el+dl) and Jurassic system (J₉s), among which the sand stratum and mudstone stratum of J₉s are the primary strata. The thickness of Sandstone is 9.00~21.00m, exceptionness amounted to 30.00m. The rate between the thickness of sandstone and sand of mudstone in the site is about 1 to 9 (see Fig. 1).

![Fig. 1. Geology cross-section of the site of cross-river tunnel.](image)

The site of tunnel locates in the Sichuan southeast arc-shaped geological structure zone, southeast of Huarongshan Mountain broom drape zone, and the axis and two wings of Jiefangbei syncline. There is no faultage in the site. Altitude of bed is as follows: east wing of Jiefangbei syncline 280~300°<3~6°, west wing of Jiefangbei syncline 130~140°<3~7°. The terrane head line of Nan’an district is 20 degrees from north to east, and the bed inclination is north to west 45°~60°. Yuzhong District and Jiangbei District lie in the axis of Jiefangbei syncline, and the terrane head line is 8°~15°. In a word, geological structure in the site of tunnel is in good condition.
4.1.2 Engineering geological Characteristics of stratum

From the data of cross-river hole, used for drainage in Chongqing, we can infer that the sandstone strata of the site of tunnel mainly consist of soft rock, with the uniaxial anisotropy pressure strength about 21.00-31.00 Mpa. The terranes in the site, with high intensity, symmetrical texture and well self-stability, fit the cross-river tunnel construction in the mine tunneling method, TBM method or shield method.

4.1.3 Discuss of hydrology condition

The character of hydrology in the site of tunnel is definite. The mudstone and sandstone terranes are territorial water insulation course, with aplasia cranny and faintish water permeability. According to the correlative data (Chen Kui, 2004), coefficient of permeability of mudstone terrane in the site is 0.02~0.10m/d; coefficient of permeability of sandstone terrane in the site is 0.10~0.30m/d, and 3.65m/d is the maximum. But there is a possibility that the river water will filter into the tunnel against cranny network when the tunnel is under construction, which will be a noticeable engineering geological problem in the cross-river tunnel construction.

By elementary judged from reconnaissance data, the affluent permeable layer of sandstone interlayer lies in the bank of Ciyun temple zone in Nan’an district. It is feasible to seal water by purdah grouting to decelerate or stop the river water infiltration, because there is a water insulation course between the top and bottom of sandstone terrane. And the thickness of other sandstone, with gently occurrence, is limited, 3.00~10.00m in general. Besides, the buried depth of sandstone is also limited, about 30.00m. In addition, the method of purdah grouting waterstop can be operated in the Yuzhong District in dry season.

4.1.4 Characteristics of crustal stress

According to two-dimensional stress field data of Chongqing drainage cross-river tunnel in geologic reconnaissance; the maximal principal stress direction in the joint area of Changjiang River and Jialing River is north to west 38°~60° and the maximal horizontal value is 1.6~2.3Mpa. From the above description, we can infer that the crustal stress in the site of tunnel is low, which will not affect the construction of cross-river tunnel.

4.1.5 Stability of areal geology

The tunnel address locates in the relative stable zone of geotectonic movement. According to the earthquake record in recent 400 years and modern earthquake observation data, we can infer that the earthquake geological movement is mainly slight earthquake with 3~3.9 degree in the site of tunnel, and it is a relative fallow district in the earthquake movement. Therefore, the site of tunnel locates in a relative stability of areal geology and fallow earthquake movement district, with low horizontal crustal stress, no rupture construction and well self-stability. So each aspect is of great benefit to the tunnel construction.

4.2 Analysis on the feasibility of economy

According to experience of developed countries, when the per capita GDP attains to 1000 dollars, the exploitation of the underground space enters into beginning stage; when the per capita GDP attains to 3000 dollars, the exploitation of the underground space enters into large-scale development stage. While the per capita GDP of economic circle of Chongqing is about 1700 dollars in 2002, furthermore, the per capita GDP of Yuzhong District, Jiulongpo District, Dadukou District etc, approaches 3000 dollars. So the exploitation of underground space in urban areas is coming into “preheated” stage.
4.2.1 Assessment of contribution

For the sake of enhancing communication among YuZhong District, Nan’an District and JiangBei District, cross-river tunnels are programmed to be built in ChaoTianmen. Taking the construction plan and character of geology in the tunnel address into account, both of shield method and mining method will be used in tunnel construction. The cross-river tunnels will be composed of Chaotianmen underground flyover, Jialingjiang Tunnel and WangLongmen Tunnel. The three tunnels will form in the shape of letter “Y”, connecting the YuZhong District, Nan’an District and JiangBei District. Cross-river tunnel are both double hole and bidirectional six driveways, with 9152m long in single hole. The total investment is up to 4 billions Yuan.

4.2.2 Financing plan

The project of Chaotianmen cross-river Tunnel is a large scale cross-river construction, which will spend more than 4 billions Yuan once. In allusion to large investment and difficulty in financing, the financing plan can be referred as follows:

1) The city investment company plays the role of general contractor of the project and finances by itself one billion Yuan (about 25%).
2) The Chaotianmen cross-river Tunnel is the key foundation construction project of Chongqing, which will greatly relieve the traffic pressure and promote the economy development of Chongqing. So the government of Chongqing should invest at least 0.5 billion Yuan.
3) Bank Load. Firstly, we can load one billion Yuan from National Development Bank. The term of the loan is fifteen years and the lending rate is 6.12%; Secondly, we can load one billion Yuan from China Bank. The term of the loan is fifteen years and the lending rate is 6.12%; Thirdly, we can load one billion Yuan from Commercial Bank. The term of the loan is fifteen years and the lending rate is 6.12% most of the financing will spend on the tunnel project, and rest will be used as reserve.

4.2.3 Operating cost

It is forecasted that the operation cost of tunnels is about 7.48 million Yuan every year when the construction finished. The detailed expenses of cost (Zou Yun, Jiang Shuping, 2004), are listed as follows: (Table 1)

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Operating cost</th>
<th>Maintenance cost</th>
<th>Management cost</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Electricity</td>
<td></td>
<td>Personnel fee:</td>
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<tr>
<td>coefficient of ventilation</td>
<td>Ten thousand Yuan/year</td>
<td>72.28</td>
<td>52.5</td>
<td>60</td>
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<tr>
<td>lighting system</td>
<td>Ten thousand Yuan/year</td>
<td>160.8</td>
<td>55.75</td>
<td></td>
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<tr>
<td>Cable bridge</td>
<td>Ten thousand Yuan/year</td>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Power supply</td>
<td>Ten thousand Yuan/year</td>
<td>---</td>
<td>67.15</td>
<td>Transact fee: 50</td>
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<tr>
<td>Supervisory control system</td>
<td>Ten thousand Yuan/year</td>
<td>15.78</td>
<td>213.63</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>Ten thousand Yuan/year</td>
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<td>389.03</td>
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<td>intotal</td>
<td>Ten thousand Yuan/year</td>
<td></td>
<td></td>
<td>748.89</td>
</tr>
</tbody>
</table>
4.2.4 National economic evaluation

(1) Economic benefit calculation
It is planned that the construction period of the cross-river tunnel in Chaotianmen is 4 years. There are three passageways in the cross-river tunnels, with double hole and bidirectional six driveways. It can be assumed that the tunnels will be operated from 6:00 am to 11:00 pm. And the average intervening time between cars is 15 seconds. So the traffic capacity of the tunnels can be estimated using Eq. (1):

\[2 \times 6 \times 17 \times 60 \times 4.5 = 55080 \text{ (cars)} \quad (1)\]

Besides, it can be assumed that ten percent of the cars, containing buses, ambulances, fire engines and execution cars will be free charge. And also it can be assumed that the effective utilization rate of driveways is seventy percent and each car will be charged three Yuan in one time. The total income of the tunnels will be 37.9969 million Yuan each year. As the number of the vehicle increases, the fee of coefficient of ventilation, lighting system and supervisory control system also increases. If 45% of the yearly income is used for operational cost and revenue, the operational cost mentioned above, about 747890 thousand Yuan each year, takes up 43.74% of this cost. Moreover, maintenance costs of drainage system will takes up 15% of total yearly income. Therefore, it can be assured that the net income is more than 15.1988 million Yuan each year.

(2) Conversion of social benefit
Before the cross-river tunnel construction, it takes 72 minutes from Jiefangbei to Nan’an District. The distance is about 36 kilometers, with the stages containing Shibanpo Changjiang Bridge, Nanping District, Shangxinjie Street. In the same way, it takes 58 minutes from Jiefangbei to Jiangbei District. The distance is about 30 kilometers. When the tunnel system completes, it only takes 28 minutes from Jiefangbei to Nan’an District, and the distance is about 16.5 kilometers. In the same way, it only takes 14 minutes from Jiefangbei to Jiangbei District, and the distance is about 9.7 kilometers. The social benefit can be converted such as follows:

1) Economization benefit of transport cost
The benefit is that the transport cost is cut down when the project is put into operation. 
\[B_1 = \text{yearly amount of traffic (cars/year)} \times (\text{transport cost without project- transport cost with project}) \times \text{load lengths within effect} = 30.2787 \text{ (million Yuan)};\]

2) Economization benefit of transport time
The benefit is that the value is produced by saving the time of passengers and goods in the way. It is about 25.1756 million Yuan/year.

3) Benefit attained by shortened distance
The benefit is that the transport cost is cut down by shorten transport distance. It is about 291.58 million Yuan/year.

4) Benefit produced by enhancing traffic security
The benefit is produced due to the construction of the project, which decreases the flow of traffic and reduces traffic accident. It is about 2.69 million Yuan.

(3) Conclusion of economic analysis
Through economic analysis above, a conclusion can be drawn that economic internal rate of return is 14.53 percent, which is more than social discounted cash flow rate of return, 12%. On one side, all of economic analysis is calculated in those sides quantized, which is a conservative calculation. On the other side, the potential economic benefit is imponderable, which is produced by the district development and the increment of the ground in the three districts.

4.3 Feasibility of technology Analysis

The plan of Chaotianmen cross-river Tunnel is designed with the first standard of the city trunk road GBI and designed speed is 50km/h. And the tunnel is designed as double hole and bidirectional six driveways, with the traffic capability of each hole up to 4860 cars per hour. The project is made up of three tunnels and a subterranean bridge ,which recommended by the Jia Lingjiang tunnel linked chao
tianmen to Jiang Bei, the Chang Jiang Tunnel linked Nan An to Dan Zishi, the Wang Longmen Tunnel and the Chao Tianmen subterranean Bridge, as "Y" shaped layout. The single hole is 4576m and the total is 9152m.

According to the current cross-river tunnel technical level of both home and aboard, this project can attain adequate technical support. At present, the successful cases in the world show as follows: the Qing Han Tunnel, which laid two railroads, has been built in Japan, approximately 54 kilometers; the English Channel is 50 kilometers and the Denmark big Channel Tunnel which underwent more difficulty. The construction technology of cross-river tunnel in home has come up with the international forefront. In the first half of this year, province of Xiamen started construction of the first tunnel in the seabed. On the other hand, more than 10 cross-river tunnels have been built in home, such as the eight cross-river tunnels in Shanghai Huangpu River, either completed or under construction. Besides, the Ningbo Yongjiang Tunnel, Guangzhou Zhujiang Tunnel and the main drain tunnel and two cross-river gas tunnels in Chongqing Changjiang River. All of the above project can provide valuable technical information.

Taking into account of the geological conditions, tunnel construction and project cost, the program can be adopted open cut method on the bank of river before deposited water in the Three Gorges Dam (175 meters deep), and shield method or mine tunneling method can be adopted on the section of river. It is unreasonable to use immersed tunneling method before deposited water in the Three Gorges Dam, because the flow speed in immersed tunneling method is less than 5m/s.

5. CONCLUSION

Researching on the three major aspects of feasibility of Chaotianmen cross-river Tunnel, a conclusion can be drawn that the plan is feasible, which is strongly supported by the following aspects:
(1) The site of tunnel locates in a relative stability of areal geology and fallow earthquake movement district, with low horizontal crustal stress, no rupture construction and well self-stability. it is suitable for cross-river tunnel construction.
(2) Through the discussion of raising funds for the program and analysis of operating costs and investment risks, the project can be drawn with considerable economic efficiency.
(3) Through the discussion of the cross-river tunnel construction technology, the construction and operation of Chaotianmen cross-river tunnel can be supported by the mature technology and experience.

The construction of Chaotianmen cross-river Tunnel will be an important traffic hinge linking with Yuzhong District, Jiangbei District and Nan’an District, which will provide traffic facility for Central Business District (CBD) in Jiefangbei. And the transport plan, "one center, two ring roads and eight traffic lights ", will come into a truth. Furthermore, the project of construction has long-term strategic vision, because it will greatly reduce the vehicle emissions of pollution in major urban areas, as to avoid the vertical clearance of the shipping restrictions of bridge. However, the Chaotianmen cross-river Tunnel is the first cross-river tunnel with an underground flyover in the world. And there will be some key technologies to be conquered in the construction and operation.

REFERENCES