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Analysis and Research on Interchange and Expansion options of Expressway

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Abstract: China's road network consists of numerous older expressways experiencing high traffic volumes and severe congestion, necessitating urgent reconstruction and expansion efforts. This study discusses the reconstruction and expansion project of the Yinkun Expressway's Chongqing High-tech Zone to Rongchang District section, with a detailed exploration of the entire design process. Through a comprehensive analysis, the strengths and weaknesses of different plans are examined, so as to determine the optimal plan. The design chosen saves costs while effectively addressing traffic demands. Additionally, the study summarizes the valuable design insights gained from this interchange transformation, aiming to provide valuable reference for similar interchange projects in the future.

Keywords: Expressway; Comparison and selection of expressway interchange reconstruction and expansion designs

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1. Introduction

G85, G93 Chongqing High-tech Zone to Rongchang District (Sichuan-Chongqing boundary) section (hereinafter referred to as "Chengdu Expressway Chongqing Section") belongs to the National Expressway Network G93 Chengdu-Chongqing Area Ring Expressway and G85 Yinkun Expressway, and is the pioneer in the expressway network planning of Chongqing's "Three Rings, Eighteen Radius and Multiple Lines." The Chengdu-Chongqing Expressway is the main channel connecting the main city of Chongqing, Yongchuan, Rongchang, Neijiang, Ziyang, Chengdu, and other major economic nodes between Chengdu and Chongqing. Since its completion and opening to traffic, the Chongqing section of the Chengdu-Chongqing Expressway has undertaken a large amount of long-distance transit traffic, providing strong support for the country´s economic and social development, and driving the comprehensive development of the socioeconomy of the multi-node cities along the line.

The Chengdu-Chongqing Expressway from Hangu to Sangjiapo is 100.9 km long, with a design speed of 60-80 km/h, 2-way 4-lane, and the width of the roadbed is 24.12 m. According to traffic volume statistics over the years, in 2019, the traffic volume of the Chengdu-Chongqing Expressway from Hangu to Ring Expressway was 68, 145 pcu/d, which was at the sixth-level service level, showing a normal congestion state; the traffic volume of the Jinyunshan tunnel section was 42, 663 pcu/d, which was at the fourth-level service level; the traffic volume of the section from Bishan South to Yongchuan was about 32, 034-38, 040 pcu/d, which was at the third-level service level. According to the "Design Rules for Expressway Reconstruction and Expansion," expressway reconstruction and expansion should be

implemented before the service level drops to the below third-level service level, so it is the right time to execute this project[1-4].

The reconstruction plan sets up a total of 16 interchanges along the entire line, including 6 hub interchanges and 10 general interchanges.

Among them, the Zouma Interchange serves as a comprehensive junction situated within Zouma Town. It connects Chongqing' s High-Tech Zone with the main urban artery, Jinma Road, extending all the way to a secondary garbage transfer station. Its primary objective is to facilitate the traffic transition between Zouma Town and the interchange (Figure 1).

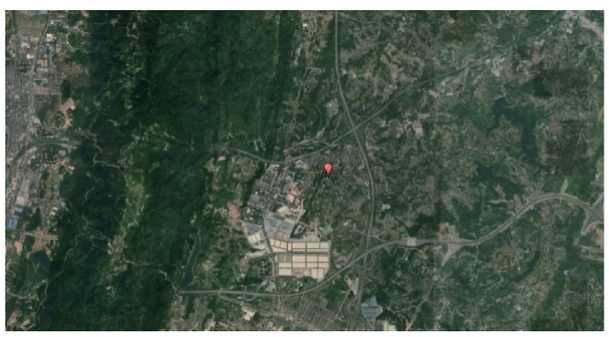

Figure 1 Geographical location map of Zouma Town

2. Current situation and intechange analysis

There are 14 interchanges (excluding the Hangu interchange) in the Hangu-Yongchuan Xiaokan section of the Chengdu-Chongqing Expressway, including 4 hub interchanges and 10 general interchanges (Table 1).

2. 1. The status quo of Zouma interchange

The existing Zouma Interchange features an A-type single-trumpet interchange along with two ramps of the secondary garbage transfer station. The ramps span over the Chengdu-Chongqing Expressway, and the upper-span bridge does not allow for an 8-lane widening. The minimum radius of the main line within the interchange range is 600 m, and the maximum longitudinal slope is 3. 8%. The radius of the ramp is relatively small, with a minimum radius is 30 m, design speed of 30 km/h, and a ramp width of 9 m-11. 5 m. This interchange is a one-lane entrance and exit. There is an auxiliary lane between the interchange with the city ring, which is about 800 m long. However, this lane falls short of the required minimum length for an auxiliary lane at the junction of the 8-lane expressway´s mainline side, and it does not meet the criteria for in-situ reconstruction[3]; the net distance from the Jinyunshan Tunnel is about 1 187 m. On the south side of the interchange is Zouma Town, where there are factories and residential buildings, and it is relatively close to the expressway (Figure 2).

2. 2. Traffic volume analysis of Zouma Interchange

The interchange is designed based on its service function, taking traffic flow into account and considering the terrain and road network layout for selecting its location. The traffic volume analysis for Zouma Interchange: is described below.

The main traffic flow of this interchange is in the direction of Chongqing ⟷ Zouma, the long-term traffic volume (year 2044) will be 682 pcu/h. As for the Chengdu ⟷ Zouma direction, the long-term traffic volume (year 2044) will be 658 pcu/h. The traffic volume of the primary and secondary flows is not much different (Figure 3).

Table 1 List of current Chengdu-Chongqing expressway interchanges

No.	Name	Distance (km)	Shape of interchange	Type of interchange	Road grade	Current situation evaluation
1	Golden Horse Interchange	/	Semi-directional	General interchange	Third class road	The main line overpasses and the indicators of the interchange main line and ramp are good.
2	Raocheng Interchange	24	Diagonal-quadrant double-loop	Hub interchange	Beltway	The main line overpasses, the maximum longitudinal slope of the main line is 4.3%, and the index exceeds the limit. The ramp indicators are better.
3	Zouma Interchange	19	A-type single trumpet	General interchange	Secondary road	The main line passes downwards without widening. The ramp index is too low, the minimum radius is 22.5 m. The minimum distance from the bypass auxiliary lane is 810 m.
4	Bishannan Interchange	71	Diamond	General interchange	Urban secondary road	The main line overpasses, the ramp index is low, and the service capacity is poor. The minimum net distance from the Qinggang service area is 202 m, which is not up to standards.
5	Dingjia Interchange	7.8	B-type single trumpet	General interchange	City main road	The main line passes under, the radius of the circular ramp is only 35m, and the factory buildings are distributed in the southeast direction, so the land use is limited.
6	Xiaokan Hub Interchange	12.6	T-shaped	Hub interchange	Highway	The span of the bridge over the main line is small, limiting widening and reconstruction opportunities.
7	Daan Interchange	2.9	Diamond	General interchange	Municipal roads	The span of the bridge over the main line is small, making expansion and reconstruction limited.
8	Yongchuan Interchange	7.3	B-type single trumpet	General interchange	City main road	The main highway passes underneath, resulting in a suboptimal service level for the interchange. Moreover, the interchange is situated relatively close to the toll station, which hampers expansion and reconstruction possibilities.
9	Shuangshi Interchange	8.5	Single-ring deformed clover leaf	Hub interchange	Third Ring Expressway	The main highway is intersected from below, and the current Chengdu-Chongqing Expressway has a low linear index, which restricts its expansion and reconstruction potential. Additionally, the project is of significant national scale.
10	Youting Interchange	13.5	A-type single trumpet	General interchange	Municipal roads	The main line passes underneath, and the interchange and merging points are in close proximity to the toll station, with numerous nearby buildings, leading to limitations on expansion and reconstruction possibilities.
11	Rongchang East Interchange	11.1	AB clover leaf	General interchange	City main road	The main line passes underneath, the index of the existing interchange ramp is relatively low, and the distance to the existing Rongchang service area is relatively short.
12	Rongchang Interchange	3.1	AB clover leaf	General interchange	City main road	The main line overpasses. The existing interchange is close to Yudai Road. The function of this interchange is limited, so it needs to be rebuilt.
13	Kaiyuan Hub	11.7	Diagonal-quadrant double-ring half cloverleaf	Hub interchange	Tongrong Expressway	The main line overpasses. Upon completion of the mainline expansion in this project, adjustments will be necessary for specific ramps.
14	Ronglong Interchange	1.7	AB clover leaf	General interchange	City main road	The main line overpasses. After the reconstruction and expansion of this project, it is relatively close to the Kaiyuan hub, and the location of the interchange needs to be adjusted to be co-located with the parking area.

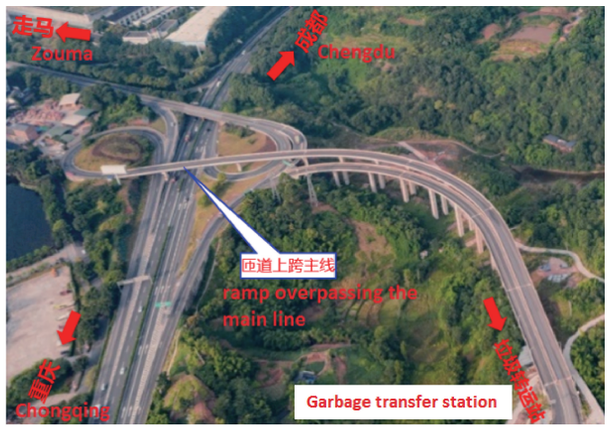

Figure 2　Status quo of the Zouma Interchange

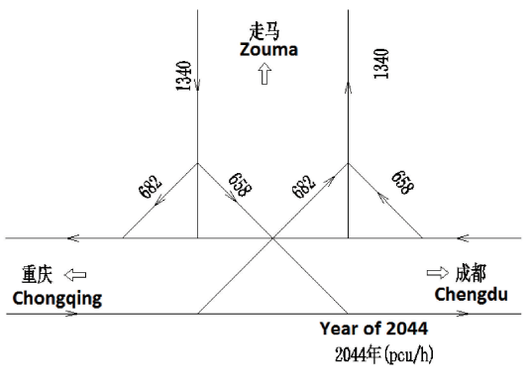

Figure 3　Traffic volume distribution map of Zouma Interchange

According to the traffic volume forecast, the mainstream traffic direction is Chongqing ⟷ Zouma direction, and the traffic volume is predicted to be 682puc/h at the end of the year, and the secondary traffic direction is Yongchuan ⟷ Zouma direction. On the west side, a new building with better indicators will be built for underground communication .

2. 3. Analysis of the construction conditions of Zouma Interchange

(1) Connecting roads

In the short term, this interchange will connect to Jinma Road (Shizheng Road), which is a two-way 5-lane road; in the long-term, it will be connected to seven vertical lines, which will be a 2-way 6-lane road and a 2-way 4-lane auxiliary road.

(2) Terrain and geological conditions

The terrain of the interchange area is structurally denuded and hilly. The overall terrain of the site is high in the middle and low in the east and west. The inclination of the slope is 25-35°, with a maximum of 45-50°. The surface of the slope is mostly covered by quaternary residual slope deposit silty clay, with a thickness of 1-3 m, and the rock-soil interface fluctuates with the terrain. The quaternary residual slope deposit silty clay layer on the surface of the valley at the slope foot is relatively thick, usually 6-10 m. Some areas have been artificially filled, including the former spoil area of the Yin-Kun Expressway and the landfills for construction waste from the Yuxi Water Distribution Project. The interchange area is located on the west wing of the Beibei syncline, and the rock formations are monoclinic, with an occurrence of 100-119°∠34-49°. The developed strata are from the middle Jurassic Shaximiao Formation (J2s) to the lower system Ziliujing Formation (J1zl), and the bedrock lithology includes mudstone, sandstone, shale,

limestone, etc. No landslides, collapses, or debris flows have occurred in this area. The filling area is generally stable, and only some parts have collapsed due to rain erosion.

2.4. Comparative analysis of Zouma Interchange transformation options

Considering the traffic volume, terrain and surrounding constraints, Zouma Interchange is not suitable for *in-situ* reconstruction. The initial design adopts a T-shaped interchange, and the engineering option has been adjusted. The interchange design comprehensively considers the reservation of the seven vertical lines, and forms a T + single trumpet shape with the seven vertical lines in the long run.

The main control elements of the interchange area are as follows: (1) The hub around the city, (2) The existing interchange, (3) Jinyunshan Tunnel, (4) Seven vertical lines (forward); 5. Water pipelines. A total of six options were drawn for comparative analysis.

2.4.1. Option 1

Option 1 adopts B-type single trumpet , and the main line is crossed on the ramp. The range of the main line of the interchange is K11+540–K12+780. The main line of the interchange spans 1 160 m, with a minimum radius of 1 250 m for the main line within the interchange range. The maximum longitudinal slope of the interchange area is 3.95%, and both the horizontal and vertical parameters of the main line meet the requirements for interchange configuration. The design speed of the ramp is 40 km/h, the minimum flat curve radius is 60 m, the maximum longitudinal slope is 4.0 %, and the total length of the ramp is 2 047.4 m. It connects to the auxiliary lane between the Chengdu-Chongqing hub expressway around the city. The length of the auxiliary lane towards Chengdu is 1 067.31 m, and the length of the auxiliary lane towards Chongqing is 1 020.455 m.

The toll station has 5 entries and 5 exits, and the management room covers an area of 6 000 km^2. The connection line adopts the third-class highway standard, with a design speed of 40 km/h. The road width is 8.5 m, the minimum flat curve radius is 60 m, and the maximum longitudinal slope is 6.27%[5-9] (Figure 4).

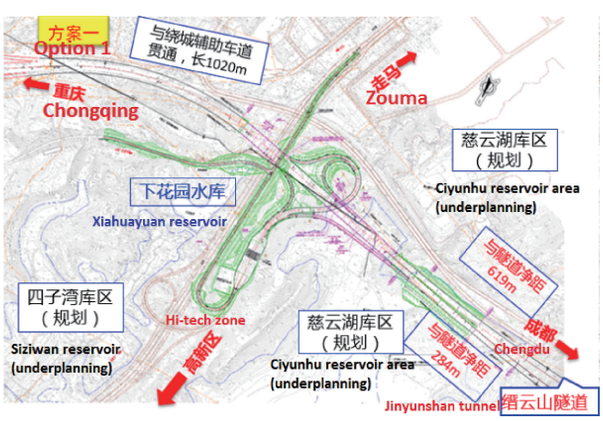

Figure 4 Layout plan of K-line Zouma Interchange (Option 1)

Translation (from top to bottom, left to right): Connected to the auxiliary road of ring expressway, 1020 m long; Clear distance from the tunnel, 619 m; Clear distance from the tunnel, 284 m.

2.4.2. Option 2

T-shape is adopted for Option 2, and the ramp crosses the main line at the top and bottom. The range of the main line of the interchange is K11+540–K12+780. The main line of the interchange range is 1 160 m. The minimum radius of the main line within the interchange range is 1 250 m. The maximum

longitudinal slope of the interchange area is 3.95%. The horizontal and vertical indicators of the main line all meet the interchange setting requirements. The ramp has a design speed of 40 km/h, a minimum flat curve radius of 80 m, a maximum longitudinal slope of 4.6%, and a total length of 2 149.3 m. It connects with the auxiliary lane between the Chengdu-Chongqing hub expressway around the city. The length of the auxiliary lane towards Chengdu is 1 067.507 m, and the length of the auxiliary lane towards Chongqing is 1 021.495 m; the net distance from the Jinyunshan Tunnel towards Chengdu is 517.424 m, and the net distance towards Chongqing is 609.427 m .

The toll station has 5 entries and 5 exits, and the management room covers an area of 9 mu. The connection line adopts the third-class highway standard, with a design speed is 40 km/h, a road width of 8.5 m, a minimum flat curve radius of 60 m, and a maximum longitudinal slope of 6.27% (Figure 5).

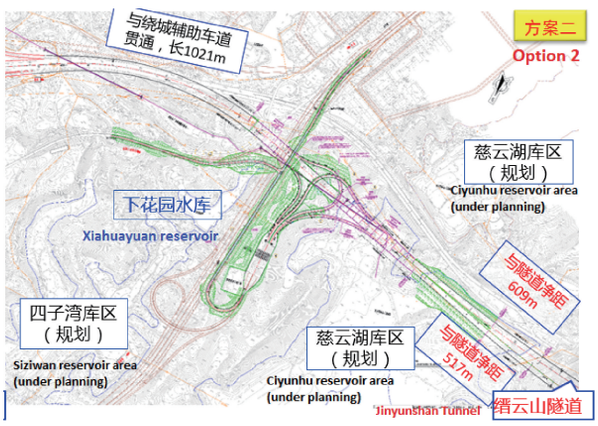

Figure 5 The floor plan of the K-line Zouma Interchange (Option 2)

Translation (from top to bottom, left to right): Connected to the auxiliary road of ring expressway, 1021 m long; Clear distance from the tunnel, 609 m; Clear distance from the tunnel, 517 m.

2.4.3. Option 3 and Option 4

Option 3: A B-type single trumpet is adopted, with the main line crossing the ramp. The short-term and long-term connection with Zouma Town, garbage transfer station, and seven vertical lines is the same as Plan 1. The main difference from Option 1 is that the positions of toll stations and connecting lines have been adjusted (Figure 6).

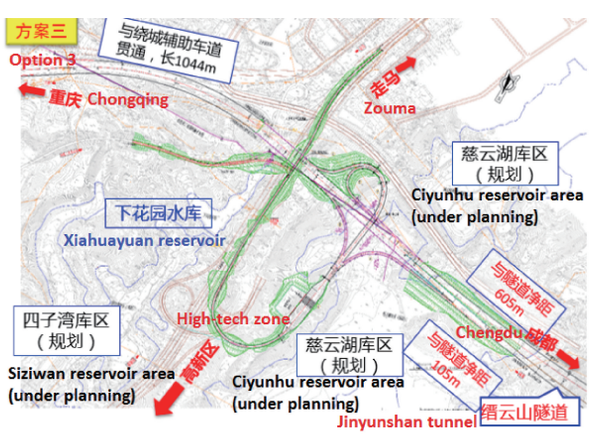

Figure 6 The floor plan of the K-line Zouma Interchange (Option 3)

Translation (from right to left, from top to bottom): Connected to the auxiliary road of ring expressway, 1044 m long; Clear distance from the tunnel, 605 m; Clear distance from the tunnel, 105 m.

Option 4: An A-type single trumpet is adopted, with the main line crossing the ramp. The short-term and long-term plan of Zouma Town, garbage transfer station, and seven vertical lines are the same as Option 1 (Figure 7).

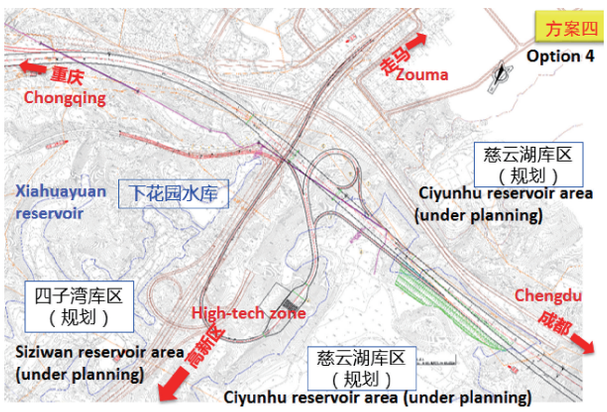

Figure 7 Layout plan of K-line Zouma Interchange (Option 4)

2. 4. 4. Option 5 and Option 6

Given the inconvenience caused by the cancellation of the Qinggang Interchange and the uncertainty surrounding the transfer of the original Chengdu-Chongqing Expressway to local reception, there is a need for further research on an interchange plan that directly connects the original Chengdu-Chongqing Expressway. This will enhance travel convenience for the southern part of Bishan District and the Qinggang area while ensuring effective connection with the seven vertical lines. Additional options to be considered are option five and option six.

Option 5: Double Ts are used to connect the new Chengdu-Chongqing with the old Chengdu-Chongqing. The old Chengdu-Chongqing connects to the municipal road network by crossing the seven vertical lines (Figure 8).

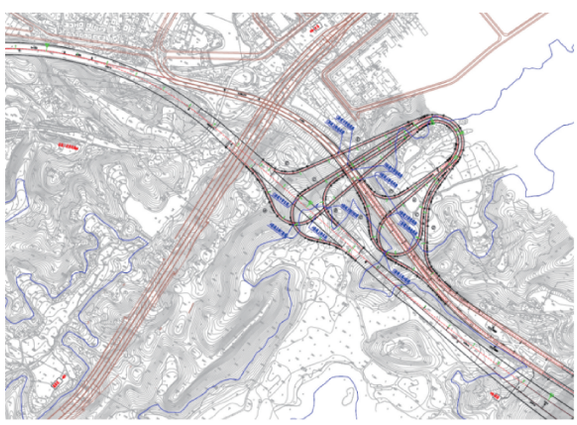

Figure 8 Layout plan of K-line Zouma Interchange (Option 5)

Option 6: The old Chengdu-Chongqing Expressways is connected through a T + A single trumpet interchange. The longitudinal section of the old Chengdu-Chongqing main line is modified to establish a link with the seven vertical lines via a level crossing in the Zouma direction. Additionally, a connection is established to the A-shaped ramp in the direction of Zouma to Chongqing by crossing the seven vertical lines on the ramp (Figure 9).

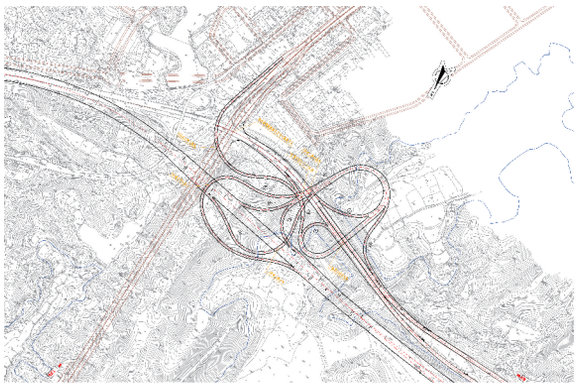

Figure 9 Layout plan of K-line Zouma Interchange (Option 6)

2. 4. 5. Option comparison and selection

(1) Option 1: B-type single trumpet

Advantages: The scale of the bridge is small, and the impact on the Ciyun Lake Reservoir is small.

Disadvantages: The shape of the interchange is irregular, the index of the connecting line in the direction of Zouma is low, and B-type trumpet shape is generally less safe.

(2) Option 2: T-shape

Advantages: Regular-shaped, better driving safety, less impact on Ciyun Lake Reservoir, smaller bridge scale, smaller land occupation.

Disadvantages: The index of the connecting line in the direction of walking is low.

(3) Option 3: Use B-type single trumpet.

Advantages: Relatively regular-shaped, and the index of the connecting line in the direction of Zouma is relatively high.

Disadvantages: The scale of the bridge is larger than that of Options 1 and 2, which will have a greater impact on Ciyun Lake Reservoir.

(4) Option 4: A-type single trumpet

Advantages: The scale of the bridge is smaller than that of Option 3, and A-type trumpet is generally safer. The indicator of the connecting line in the direction of Zouma is higher.

Disadvantages: The shape of the interchange is irregular, the longitudinal slope of the ramp is relatively large, and the longitudinal slope of the ramp bridge from Chengdu to Zouma is too large, about 5. 5%, which has a great impact on Ciyun Lake Reservoir.

After a comprehensive comparison of the four options, it was found that Option 3 has a relatively large bridge scale, while Option 4 has a relatively low ramp index, particularly affecting the drinking water source of Ciyun Lake. Consequently, Options 1 and 2 are chosen for a comparative analysis with equal accuracy for this design.

Comparison between Options 1 and 2 and Options 5 and 6: Option 5 and Option 6 can better solve the inconvenience of traveling from Bishan south to Chongqing and the utilization of the original Chengdu-Chongqing Expressway after the cancellation of Qinggang Interchange. However, Options 5 and 6 involve larger project scales; their connection with the seven vertical lines is weaker. They require converting through local roads to reach the High-Tech Zone, making toll station setup challenging. Currently, the local government has favored using local roads and seems inclined towards Option 1, maintaining a comparison of equal accuracy between Option 1 and Option 2[10].

The comparison between main economic and technical indicators of Options 5 and 6 are listed in

Table 2.

Table 2 Comparison of main economic and technical indicators between Option 5 and Option 6

Project	Work plan	Preliminary plan 1 (single trumpet)	Preliminary plan 2 (T-type)	Preliminary plan 2: work reduction plan
Range of the main line	K11+500-K12+860	K11+5400-K12+800	K11+5400-K12+800	
Length of the main line (m)	1360	1260	1260	-100
Length of the ramp (m)	2807	2047.4	2149.3	-657.7
Connecting line/overpass length (m)	1294	1888.04	1888.04	594.04
Subgrade earthwork/ excavation (m^3)	684424	1421418	1324757	640333
Subgrade earthwork/filling (m^3)	412619	865148	829809	417190
Bridge construction (m/seat)	Main line, 1112/2 Blocks; ramp, 1494/5 blocks; connecting line 661/1 blocks	Main line: 611/2 blocks; ramp: 699.5/3 blocks; connecting line no	Main Line: 633.5/3 Blocks; Ramp: 465/3 Blocks; Connecting Line No	Main line: - 478.7/1 block; ramp: -10295/-2 blocks; connecting line -661
Occupied land (mu)	350.89	389.9 (Added 357.07)	350.14 (325.08 added)	-0.75
Construction fee (RMB)	42457.29	35631.28	33791.70	-8665.59

2.5. Analysis of Zouma traffic management

(1) Step one

(i) The construction of the interchange will not affect the current main line and ramp passage

(ii) Traffic organization will start one year before the completion of the interchange at Jinyun Mountain, and the remaining part should be constructed subsequently.

(iii) The widening segment will be constructed on both the left and right sides between the Ring Interchange and the Zouma Interchange. Simultaneously, the existing portion will be repaired. This involves connecting the newly constructed right mainline to the existing right mainline (Figure 10)[10].

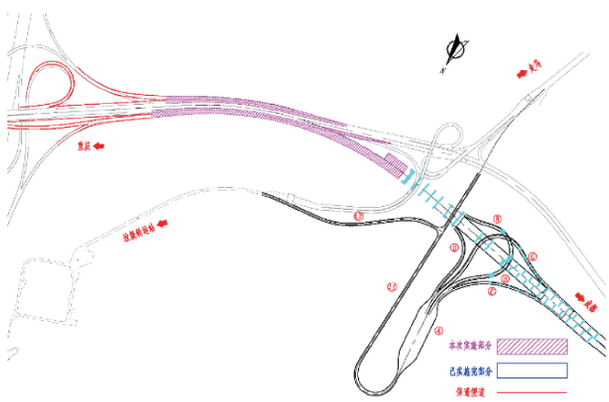

Figure 10 Schematic diagram of the transportation organization of Zouma Interchange
Translation (from right to left, from top to bottom): Zouma, Chongqing, garbage transfer station, Chengdu, in progress, completed part, access road.

(2) Step two

(i) The through traffic will be transitioned to the widened sections on both sides.

(ii) The internal area of the widened sections will be developed and linked with the existing roadway segment.

(3) Step three

(i) The traffic between Chongqing-Zouma and Chengdu-Zouma will be closed, and the traffic in and out of Zouma Town will be transferred to the Three Ring Interchange of Jiuyong Expressway and the Shuangfu North Interchange of Ring Expressway;

(ii) Access Road 1-4 will be constructed

(iii) The traffic from the garbage transfer station will be transferred to Access Road 1-4.

(4) Step four

(i) Bridge Number 1 of the main line of Zouma Interchange will be constructed

(ii) The remaining part of the connecting line to the garbage transfer station will be constructed.

(5) Step five

(i) After the Jinyunshan Tunnel is completed and the main line is opened, a one-way and two-way connection will be created between the hub around the city and the Zouma Interchange;

(ii) Then, the remaining part of the main line will be constructed.

(iii) The existing Chengdu-Chongqing Expressway will be excavated, and the connecting path of the L1 line will be established.

(iv) After the completion of all restoration work, the direct route will be accessible for traffic to Zouma Town, followed by site cleanup.

3. Conclusion

Taking the Chengdu-Chongqing Expressway as an example, this paper introduces the idea of reconstruction and expansion of the interchange, plan research and comparison, and status quo investigation, etc., to provide reference for this type of interchange reconstruction. The main conclusions obtained are summarized below.

(1) The process of interchange reconstruction necessitates a comprehensive assessment of the prevailing factors influencing interchange functionality. A meticulous analysis of the existing interchange's deficiencies, its compatibility with traffic flow, and its operational safety is crucial.

(2) The renovation of an existing interchange is inherently more intricate than constructing a new one, requiring a comparative evaluation of multiple alternatives while accommodating the various stakeholder requirements.

(3) During the formulation of the renovation plan, a holistic approach encompassing traffic management considerations is imperative. This approach ensures that the ongoing highway operations remain undisturbed and that construction activities are conducted in a manner that prioritizes safety and continuity.

Disclosure statement

The author declares no conflict of interest.

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