Study on traffic organization and work-zone optimization of four-lane freeway reconstruction and expansion

Xuanyu Ye 1, Yazhen Chen 2 and Chen Chen 2
1Jiangxi Ganyue Expressway Co., Ltd., Nanchang 330025, Jiangxi, China
2CCCC Second Highway Consultants Co., Ltd., Wuhan 430052, Hubei, China

Abstract. In this paper, the bi-directional four-lane traffic organization plan and its key factors in the freeway reconstruction and expansion were analyzed. Combined with the actual traffic flow and construction conditions of the freeway network in Chang-zhang Freeway project, the bi-directional four-lane traffic organization plan for the Chang-zhang Freeway reconstruction and expansion were determined, including the construction area length and construction sequence. It systematically summarizes the advantages and disadvantages of the traffic organization and management of the Chang-zhang freeway reconstruction and expansion project. It provides reference cases for the subsequent traffic organization design of freeway reconstruction and expansion similarly.

1. Introduction
With the sustained and rapid development of China's economy, the traffic volume of freeways built in the early days has increased rapidly, with an average annual growth rate of more than 10%, or even more than 20%. The volume has far exceeded the predicted traffic volume during freeway planning. At present, the service level is significantly reduced, which can no longer meet the driving requirements of freeways; at the same time, it cannot meet the needs of rapid socio-economic development. Therefore, the reconstruction and expansion of freeways has become the key development direction of freeway construction in the future. The research on the reconstruction and expansion of freeways under the mode of “construction without interruption of traffic” has become one of the focuses of research on freeway reconstruction and expansion projects. At present, the types of unimpeded plan for freeway expansion and reconstruction mainly include keeping bi-directional two-lane traffic, keeping bi-directional three-lane traffic, and keeping bi-directional four-lane traffic. The selection of the traffic organization plan should be determined according to the specific conditions of the project freeway.

The Nanchang-Zhangshu Freeway (Chang-zhang Freeway) has a total length of 86.545 km. It is an integral part of the Shanghai-Kunming National Freeway in the National Freeway Network (7918). It is also the important section of the main skeleton of the highway network called “three vertical and four horizontals” in Jiangxi Province, connecting the surrounding provinces and strengthening the inter-provincial freeway transportation. It has a very important position in the highway network. In view of the important position of Chang-zhang Freeway in the highway network of Jiangxi Province and the high goals and high requirements for the “expanding and keeping traffic at the same time and both ensuring the quality and the period of the construction”, this project puts forward the traffic organization management measures of freeway reconstruction and expansion as the priority goal [1]. Therefore, it is necessary and significant to make a research of the bi-directional traffic protection during reconstruction. This paper intends to systematically summarize the bi-directional four-lane
traffic organization plan formulation and analysis of the Chang-zhang Freeway. It solves the problems encountered in the actual project and provide reference for the subsequent similar freeway reconstruction and expansion projects.

2. Bi-directional four-lane freeway traffic flow character and construction zone plan

In the bi-directional four-lane traffic organization plan of freeway construction zone, it mainly includes special work sites such as subgrade pavement engineering, bridge engineering, interchange and overpass. This paper focuses on subgrade pavement engineering.

The influencing factors and key problems of the subgrade and pavement reconstruction and expansion have the following four critical points, the length of the construction zone, traffic conversion and safety, road utilization, and emergency room for emergencies. Through analysis and study of the above four influencing factors, the bi-directional four-lane traffic organization plan of construction zone is determined, which not only ensures the safety of driving, but also meets the requirements of construction and guarantees the service level in the project.

2.1 Construction area segment length

The division of the length of the construction zone shall meet the following requirements:

1) Comply with the construction schedule of the project road;
2) Ensure the overall traffic flow stability, safety and efficiency of the entire construction zone as far as possible;
3) Considering the integrity of the road network structure, the boundary of the construction section should be as close as possible to the natural boundary of the road section structure (such as the boundary between the interchange and service areas);
4) The division of the construction section should consider the convenience of subgrade and pavement construction and the saving of construction cost, and minimize the impact of subgrade and pavement construction on the traffic flow along the route;
5) It is not advisable to divide the construction section too much to meet the requirements of reasonable flow construction organization.

2.2 Traffic conversion and safety

The freeway reconstruction and expansion project usually adopt the method of “constructing and keeping traffic at the same time”, which interferes with the construction and keeping traffic, brings great safety risks to the construction zone. In order to more objectively reflect the traffic safety in the construction zone, this paper selects the ratio of the number of conflicts and the cross-kilometer conflicts as the evaluation index (the number of car-kilometer conflicts: under observable conditions, two or more road users are close to each other in space and time, so that if either party does not change its trajectory, a collision will occur. This state is called a traffic conflict. [2]).

\[ f = \frac{TC}{QL} \times 1000 \]  

(1)

Where: \( f \) is the number of vehicle kilometers conflict (times/vehicle-km); \( TC \) is the number of conflicts per hour (times); \( Q \) is the traffic flow (pcu/h); \( L \) is the length of construction area (m);

In summary, a regression model between the segment length (X) of the construction zone and the traffic safety evaluation index (Y) of the construction area is established. First, make the regression equation hypothesis:

\[ y = \alpha + \beta x \]  

(2)

The \( \alpha \) and \( \beta \) in the equation is the undetermined coefficient [3]. From the definition of the regression function, if \( F(x) \) minimizes \( Q[\eta - f(\zeta)]^2 \), then \( F(x) \) is the regression of \( \eta \) and \( \zeta \). Determining \( \alpha \) and \( \beta \) minimizes \( Q[\eta - f(\zeta)]^2 \).

Here \( Q[\eta - f(\zeta)]^2 = \beta^2 \alpha_x^2 - 2 \beta \text{cov}(\zeta, \eta) + \sigma_x^2 + (\alpha_y - \alpha - \beta x)^2 \), it can be seen from the equation that \( Q[\eta - f(\zeta)]^2 \) is the smallest when \( \alpha = \partial \eta - \beta \), \( \beta = \frac{\text{cov}(\eta, \zeta)}{\sigma_x^2} = \frac{\rho \sigma_y}{\sigma_x} \),
Regression equation is as following:

\[
Y = \alpha_y + \left(\frac{\rho \sigma_y}{\sigma_y}\right) \cdot (x - \alpha_x) \tag{3}
\]

\[
X = \alpha_x + \left(\frac{\rho \sigma_x}{\sigma_y}\right) \cdot (x - \alpha_y) \tag{4}
\]

Where \(\frac{\rho \sigma_y}{\sigma_x}\) and \(\frac{\rho \sigma_x}{\sigma_y}\) are regression coefficients. If multiple points were observed, let \(x_1, y_1\), \(x_2, y_2\), \(x_n, y_n\), etc. can be obtained. Using these data to calculate the average and standard deviation of the sample, therefore the regression equation is assumed.

To require a regression equation, the coefficients \(\alpha\) and \(\beta\) must be solved first, and the formula is:

\[
\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \quad (i=1,2,3,...,n) \tag{5}
\]

\[
\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i \quad (i=1,2,3,...,n) \tag{6}
\]

\[
\beta = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \tag{7}
\]

Therefore, the following relationship can be obtained:

\[
y = y - \beta \bar{x} + \beta x = \bar{y} + \beta(x - \bar{x})
\]

2.3 Road utilization rate

Road utilization refers to the ratio of highway that have been used by traffic participants to the total number of roads in the area at a particular time and region. In the process of freeway reconstruction and expansion, the road utilization rate refers specifically to the ratio of the road resources that have been used by the traffic participants to the total resources that can be utilized by the freeway roads (including the expansion parts).

Road utilization rate=Road area already used/Road area that can be used

3. Determination of subgrade and pavement traffic organization plan

This paper takes the southwest Chang hub to the Houtian hub as an example with a lateral width of 0.5m.

Traffic safety evaluation index: number of vehicle kilometers conflict \(f = \frac{TC}{Q \cdot L} \times 1000\)

Length of section of construction zone: 2-8km is selected in this paper (the length of construction zone should be 2-8km to ensure the maximum efficiency)

| Construction zone length (L) km | Traffic flow (Q)pcu/h | Number of conflicts per hour (TC) | Safety evaluation index f |
|--------------------------------|----------------------|----------------------------------|--------------------------|
| 2                              | 537                  | 1310                             | 1.22                     |
| 3                              | 837                  | 2862                             | 1.14                     |
| 4                              | 1128                 | 4331                             | 0.96                     |
| 5                              | 1408                 | 5280                             | 0.75                     |
| 6                              | 1684                 | 7780                             | 0.77                     |
| 7                              | 1983                 | 11243                            | 0.81                     |
| 8                              | 2260                 | 15548                            | 0.86                     |

Table 2 Interweaving area traffic safety clustering center based on VISSIM simulation.

| Grading | Safety | Relatively safe | Safety criticality | Danger |
|---------|--------|-----------------|-------------------|--------|
| \(f(t)\times/vehicle km) | 0.76   | 1.45            | 2.66              | 3.73   |

The length of the construction zone \(X_i\), the safety evaluation index \(Y_i\), and the numerical values of formulas (5) and (6) are calculated by substituting the numerical values, as shown in Table 3.
Table 3 Information on construction zone length and safety evaluation indicators.

| i | $x_i$ (km) | $y_i$ | $x_i - \bar{x}$ | $(x_i - \bar{x})^2$ | $y_i - \bar{y}$ | $(y_i - \bar{y})^2$ | $(x_i - \bar{x})(y_i - \bar{y})$ |
|---|------------|-------|------------------|---------------------|------------------|---------------------|----------------------------------|
| 1 | 2          | 1.22  | -3               | 9                   | 0.29             | 0.0841              | -0.87                            |
| 2 | 3          | 1.14  | -2               | 4                   | 0.21             | 0.0441              | -0.42                            |
| 3 | 4          | 0.96  | -1               | 1                   | 0.03             | 0.0009              | -0.03                            |
| 4 | 5          | 0.75  | 0                | 0                   | -0.18            | 0.0324              | 0                                |
| 5 | 6          | 0.77  | 1                | 1                   | -0.16            | 0.0256              | -0.16                            |
| 6 | 7          | 0.81  | 2                | 4                   | -0.12            | 0.0144              | -0.24                            |
| 7 | 8          | 0.86  | 3                | 9                   | -0.07            | 0.0049              | -0.21                            |

$$\beta = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \approx -0.07$$

$$\alpha = \bar{y} - \beta \bar{x} = 0.93 + 0.07 \times 5 = 0.93 + 0.35 = 1.28$$

Substituting the values of $\alpha$ and $\beta$ into equation (2), the regression equation for the distance between the construction zone and the safety evaluation index can be obtained:

$$y = 1.28 - 0.07x$$

Regression equation error formula:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2} \sum_{i=1}^{n}(y_i - \bar{y})^2} = \approx -0.8029$$

$$|r| = 0.8029$$

In the above, $r$ is the correlation coefficient between $x$ and $y$ in the mathematical method [3]. When the absolute value of $r$ is close to 0, the error is large, and the plan is not desirable. The closer the absolute value of $r$ is to 1, the error is small; when the absolute value is about or equal to 1, the error is 0.

Through the analysis of Table 1, Table 2 and regression equation, the safety evaluation index is better when the section length of the construction zone is 4-8km, and the safety evaluation index is the best when the section length of the construction area is 5-6km. Therefore, the section length of the construction zone of the subgrade and pavement construction zone in the bidirectional four-lane unimpeded plan of Chang-zhang Freeway is selected to be 5-6km. Secondly, combined with the study of road utilization rate in the construction zone, select different construction section lengths in different sections, maximize the road utilization rate in the construction zone, and determine the construction plan of the subgrade and pavement. Through regression analysis, the $r$ value of the regression equation is close to 1, and the error is small, so the plan is feasible.

4. Subgrade pavement traffic organization construction plan

The subgrade pavement traffic organization mainly divides into 2 period. In the first period, the guardrail does not move, while removing the external barrier; the two sides of the extension (7.5m wide on one side) are filled to the top of the roadbed; the vehicle travel in two-way four-lane traffic on the original old road. The illustration is shown in figure 1.

The second period, four sections are divided according to the division of the bid section and the layout of the main structures along the line. The left and right sections of each section are constructed at the same time. The pavement engineering is completed in parallel with the cycle construction in each section. The period includes 4 steps.
In the first step, the old road dirt shoulder and the hard shoulder of the left and right No. 3 construction work area are excavated within 3m, and the roadbed is spliced to construct the pavement on both sides to the flexible base (same level with the old pavement), the new and old pavement Temporary isolation facilities are set up. In this stage, the inner passenger lane should be set to 3.5m to ensure that there is a lateral width of 0.5m on the outside of the two-lane road without the hard shoulder, and the original old road has two-way four-lane traffic.

Step 2: Repeat the first step to excavate the 3m range of the old road dirt shoulder and the hard shoulder of the left and right frame No. 4 construction work area and build the roadbed to the flexible base layer (same level with the old road level).

Step 3: transfer the traffic, two-way four-lane traffic in section 3, renovate the old road in section 1 of the construction operation area, construct the upper surface layer and traffic safety facilities for road subgrade sprouting and pavement overall paving, install temporary water-horse anti-collision facilities between the new and old roads, and one-way two-lane traffic in sections 2 and 4 of the left and right sides; This stage should be at the same time in the left picture of section 2 (or right of section 4) and the left section 4, section 2 (or right) on both sides of the segment joint of median opening, comprehensive factors such as conductor, the speed limit and corner radius set for 150 m to ensure the safety of two-lane traffic transfer passage, half range two-way between the four lanes of traffic and transportation around image transfer place setting temporary anti-collision facilities such as water horse, in order to ensure the safety of driving, opens the mouth to consider using 40 km/h speed limit.
Figure 3. Construction traffic organization in the step 3.

Figure 4. Traffic organization of subgrade pavement construction (cm)

Step 4: Repeat the above steps and cycle forward until the completion of the reconstruction and expansion, forming an eight-lane section.

Figure 5. Traffic organization of subgrade pavement construction in the step 4 (cm)

5. Traffic organization implementation experience and discussion

During the expansion of Chang-zhang Freeway, the traffic organization plan generally followed the traffic organization plan of the project planning. In the actual implementation process, it was adjusted and optimized according to the actual situation. During the implementation process, many valuable experiences were accumulated, and some shortcomings were summarized as follows.

(1) Efficient management organization

The freeway reconstruction and expansion project office innovated the traffic organization management and operation organization and built a highly efficient joint logistics linkage mechanism. It led the establishment of the project office, the provincial safety supervision three, the high-speed traffic police team, the high-speed road administration Yi-chun detachment and other units. The traffic safety organization leading group has an office, the office is deputy director and the deputy director of the traffic police and the road administration department, and the project office is stationed in the
(2) The problem of segmentation

During the design stage of the traffic organization design, factors such as the distribution of structures, the position of the opening in the current situation, and the balance of the workload between the sections are considered. However, during the implementation process, some sections are still insufficient, such as some temporary traffic. The section is divided into an uphill section, which creates a long queue of vehicles and creates a certain traffic congestion.

(3) Highway utilization

The reconstruction and expansion of traffic organization runs through the entire construction process, and the problem of road resource utilization is worthy of attention. The road utilization rate in the construction area is closely related to the traffic capacity. The greater the road utilization rate, the higher the traffic capacity, and vice versa. There are many factors affecting road utilization, including lane width, number of lanes, lateral width, large vehicles, speed limit in construction area, construction intensity, and lane closure form. In order to maximize the use of road resources, it is necessary to design traffic organizations. At the same time, the traffic management should be strengthened.

6. Conclusion

The four-lane guarantee scheme for parallel construction of the left and right sections and sections applied in the reconstruction and expansion of Chang-zhang Freeway fully considers the construction party and the operator, and fully utilizes the road resources of Chang-zhang Freeway to avoid the tolls while ensuring safe operation. The loss, while considering construction safety and efficiency, effectively solved the construction and operation problems. Practice verified that this scheme has good feasibility.

With the acceleration of construction in the central and western regions, the large number of freeways in China are facing renovation and expansion. Due to the low density of road networks in the central and western regions, the traffic along the line during the period of reconstruction and expansion is highly dependent on the roads for reconstruction and expansion. The traffic organization plan and the traffic organization management plan have pioneering significance, and their research results are promoted in Jiangxi Province and across the country, providing mature and learnable experience for other similar road reconstruction and expansion projects.

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