Brief design and numerical calculations for a secondary road

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Abstract. Based on the traffic volume survey, the standard traffic volume conversion is considered, and then the road traffic volume is predicted. Through the calculation, the maximum annual average daily traffic volume in the design life is obtained, and then the road grade and design speed of the design road are determined. The Annual Average Daily Traffic (AADT) is converted into Directional Design-Hour Volume (DDHV), and then the number of lanes of the road is determined. Collect the terrain data of the route area through the field survey, and then carry on the interior design. The route schemes are compared and the optimal route scheme is selected. AUTOCAD and a professional road design software were used to assist in the design of road line selection, horizontal curve design, vertical section design, cross section design and drainage design. Through the calculation, the design parameters such as the maximum synthetic slope, the average slope and the minimum length of superelevation transition section are obtained. Afterwards, the parameters in horizontal curve, vertical curve and superelevation-widening were checked manually.

1. Introduction
With the rapid development of economy and society, China’s transportation system has gradually developed into a transportation system where multiple modes of transportation coexist. Road traffic is one of the basic industries of the national economy. It is an irresistible trend and inevitable trend to improve the accessibility and speed of the road network among different regions in China. It is very urgent to build more highways between the counties, towns and villages in the undeveloped areas where some farmers have large amounts of agricultural products which are their main resources of income. According to the “13th Five-Year Plan” of the Ministry of Communications, by the end of 2020, the country will basically realize the connection between villages. Here is a brief introduction to the design of the new secondary highway from Beiyuan Town to Lugou Village, Sihui City, Guangdong Province.

2. Traffic situation
Sihui city, located in the south of the Tropic of Cancer, has a subtropical monsoon climate with an annual average temperature of 21.3°C. The extreme maximum temperature was 38.5°C, and the extreme minimum temperature was -1.2°C. The average annual rainfall is 1803.6mm, the maximum daily rainfall is 253.5mm, the average annual sunshine is 1702.3h, and the average annual thunderstorm days are 89. The project site in Lugou village, Beiyuan Town, Sihui city. The terrain of the place is the valley
intermontane basin plain to roughly the smooth terrain, the elevation difference is not big, and highway natural level division belongs to IV area (southeast of hot and humid area).

According to the investigation, it can be seen that the average daily traffic volume of the road from Beiyuan Town to Lugou Village in the initial stage is shown in Table 1.

| Car models | Daily traffic volume (vehicles/d) |
|------------|----------------------------------|
| Dongfeng   | 803                              |
| Mazda      | 523                              |
| Hyundai    | 226                              |
| Toyota     | 209                              |
| CHANGAN    | 809                              |

TABLE 1. Average daily road traffic in the initial stage

According to the "Highway Engineering Technical Standards" (JTG B01-2014)\(^{(1)}\) under different categories of models and different vehicle conversion coefficient, the traffic volume of different models is converted. The conversion results are shown in Table 2.

| Car models | Daily traffic volume (vehicles/d) | Load (KN) | Conversion coefficient | Converted traffic volume (vehicles/d) |
|------------|----------------------------------|-----------|------------------------|--------------------------------------|
| Dongfeng   | 803                              | 50        | 1.5                    | 1205                                 |
| Mazda      | 523                              | 82.6      | 2                      | 1046                                 |
| Hyundai    | 226                              | 100       | 2                      | 452                                  |
| Toyota     | 209                              | 100       | 2                      | 418                                  |
| CHANGAN    | 809                              | 152       | 3                      | 2427                                 |

Convert traffic totals 5548

When \( N_0 = 5548 \) veh/d, \( \lambda = 5\% \), and \( n = 15 \), the designed average daily traffic volume per year is as follows:

\[
N_d = N_0 \times (1 + \lambda)^{n-1} = 10985 \text{(veh/d)}.
\] (1)

According to the average annual daily traffic volume of the vision design, 10,985 (vehicles/day) is located between 5000 and 15000 (vehicles/day), which can be known that it adapts to the traffic volume of secondary highways.

When Annual Average Daily Traffic(AADT) is 10,985 pcu/d, the directional non-uniformity coefficient D is 0.53, and the traffic volume coefficient K is 0.16, the Directional Design-Hour Volume(DDHV) is calculated as follows:

\[
DDHV = AADT \times D \times K = 931.528 \text{(pcu/h)}.
\] (2)

This highway is a secondary highway, with a design speed of 60km/h and a design width of 3.5m for a single lane. Looking up the Table 3, it can be found that the basic capacity of a single lane is 1400 pcu/h.

TABLE 3. Design capacity of secondary highway section

| Highway classification | Design speed | Basic capacity (pcu/h) | Proportion of areas not allowed to overtake (%) | V/C | Design capacity (pcu/h) |
|------------------------|-------------|------------------------|-----------------------------------------------|-----|------------------------|
| Secondary highway      | 80          | 2500                   | <30                                           | 0.64| 550                    |
|                        | 60          | 1400                   | 30~70                                          | 0.48| ~                      |
|                        | 40          | 1300                   | >70                                           | 0.42| 1600                   |
When \( C = 1400 \text{ pcu/h} \), the number of lanes is calculated as follows:

\[
N = \frac{DDHV}{C} = \frac{931.528}{1400} = 0.665 \text{ (round up)} = 1.
\]

Therefore, the lane is set as two-way lane.

Taking into account the annual average daily traffic volume and relevant provisions in The Highway Route Design Specification (JTG D20-2017)\(^2\), it was finally determined that the whole road is based on the design standard of the secondary highway with two lanes in both directions, the design speed is 60km/h, and the design life is 15 years.

3. Design of secondary highway

The road should avoid the deep-water fishpond area as far as possible, avoid crossing agricultural fields, and reduce the demolition of buildings, pay attention to the protection of the ecological environment along the line.

According to these requirements, through multi-section and multi-scheme comparison and selection, the optimal line scheme A was finally obtained. The scheme comparison is shown in Table IV, and the scheme roadmap is shown in Figure 1.

3.1. Line plane design

The method used in plane design is as follows: Collect the elevation points, constraint lines, unconstrained lines and other related data of the topographic map, import the horizontal and vertical section data, and build the DTM digital model. A professional road design software is used for auxiliary alignment, the starting point, several intersections and end points of the route are selected, and the topography and geomorphology, hydrogeology, farmland fish ponds and civil facilities along the line are considered comprehensively. Through human input and real-time modification, the circle at the intersection is initially determined. Graphic elements such as the radius of the curve, the radius and the length of the transition curve, and then repeated fine-tuning until it meets the design requirements.

| Compare the project | Plan A | Plan B |
|---------------------|--------|--------|
| Length of the route(m) | 2,946.769 | 3,011.798 |
| Linear (horizontal curve, vertical curve) | The average radius of the circular curve is small, and the route is more suitable to the change of terrain than the second plan. In terms of the vertical curve, the magnitude is balanced. | The average radius of the circular curve is larger, and the route passes through the hills, so a tunnel needs to be built. In terms of the vertical curve, the magnitude is balanced. |
| Number of intersections | 5 | 4 |
| The minimum radius of a horizontal curve(m) | 220 | 210 |
| Maximum longitudinal grade | 4.00% | 3.46% |
| The minimum longitudinal slope | 0.091% | 1.02% |
| Number of slope changing points | seven | six |
| The visual evaluation | good | general |
| Safety evaluation | security | security |
| Demolition situation | The route does not pass through villages and towns, and demolition is not considered. | The route does not pass through villages and towns, and demolition is not considered. |
| Quantities | The amount of earth and stone filled and excavated is 11,983.3 m, and the amount of earth and stone excavated is 10,839 m. The engineering amount is small and the cost is low. | The route is long, and the excavation quantity of earth and stone is not balanced. The filling quantity is 7,396 m and the excavation quantity is 32,169 m, which means that the engineering quantity is large and the cost is high. |
| Average construction Cost (CNY/km) | 2,395,000 | Credited to tunnel cost, approx. 29,006,667 |
| Other | 1. No need to build bridges and excavate | 1. Large amount of work, long construction |
tunnels, the construction period is shorter, and the construction technology is relatively simple; 2. The engineering earthwork is relatively small. The linear index meets the requirements and adapts to terrain changes.

The four corners of the design line are adjacent to the inverted circle curve. Check "Highway Route Design Code", the minimum straight line length (in m) between the inverted circular curves should be no less than 2 times of the design speed (in km/h), namely 120 m, and the maximum limit length should be less than 20v, namely 1,200 m.

![Plan B](Plan_B.png) ![Plan A](Plan_A.png)

Figure 1 Route comparison Diagram

The length of the straight line between the JD1 and the JD2 is 503.285 m; the length of the straight line between the JD2 and the JD3 is 477.805 m; the length of the straight line between the JD3 and the JD4 is 604.278 m; the length of the straight line between the JD4 and the JD5 is 490.022 m; it conforms to the standard after check.

No matter what the size of the plane Angle is, it must be required to set the circular curve. The design radius of the circular curve of the newly-built secondary highway is 230 m, 240 m, 220 m, 235 m and 245 m respectively. The radius of the circular curve is smaller than the minimum radius without super-elevation, and the transition curve should be designed at the junction of the straight line and the circular curve diameter. The minimum length of the transition curve is 36 m.

The results meet the requirements of the specification after check as shown in Table 5.

| The intersection point | Pile number | Tangent length (m) | Radius of circular curve (m) | Length of relaxation curve (m) | Length of circular curve (m) | Exter distance (m) |
|------------------------|-------------|---------------------|-----------------------------|-------------------------------|-----------------------------|-------------------|
| JD1                    | K0 + 534.997| 230.365             | 230                         | 60                            | 269.032                     | 75.538            |
| JD2                    | K0 + 966.584| 145.997             | 240                         | 60                            | 155.640                     | 27.131            |
| JD3                    | K1 + 428.035| 103.044             | 220                         | 60                            | 80.676                      | 12.462            |
| JD4                    | K2 + 026.902| 129.303             | 235                         | 60                            | 127.481                     | 20.714            |
| JD5                    | K2 + 505.799| 235.901             | 245                         | 60                            | 281.878                     | 75.510            |

There are no phenomena such as deep excavation, construction facilities along the route, traffic facilities and woods that obstruct the minimum driving visual distance on the inner side of the road in this design section. In the horizontal curve design, the horizontal curve elements all meet the specification requirements. In the vertical curve element design of the vertical section, the influence of the minimum vertical curve radius on the driving sight distance is considered, and the vertical section design meets the requirements of the Code.
3.2. *Longitudinal section design*

The longitudinal slopes are +0.764%, +4.000%, +2.050%, +0.358%, +4.000%, -1.732%, -4.000% and -0.052%, respectively, which are all less than 6%. After checking, the above longitudinal slope and slope length are in full compliance with the specification requirements.

Maximum resultant slope is
\[ I_{\text{max}} = \sqrt{(-4.0)^2 + (4.0)^2} = 5.656\% . \]  

The designed resultant slope meets the specifications.

Average slope is
\[ I_{\text{AVG}} = \frac{H}{L} = \frac{47.019 - 27.874}{2946.769} = 0.00645. \]

The average longitudinal slope of any continuous 3 km section is not more than 5.5%, which meets the specifications.

3.3. *Cross-sectional design*

According to relevant standards\(^3\) and combined with actual situation analysis, in order to ensure good drainage performance of the road surface, and at the same time, to meet the driver’s safe and comfortable driving experience, the design standard cross section is shown in Figure 2. Integral subgrade is adopted, the total width of the subgrade is 10 m, the width of the traffic lane is 3.50 m, the cross slope of the traffic road arch is 2%, the hard shoulder width is 0.75 m, the cross slope of the hard shoulder is the same as that of the traffic lane, and the soil shoulder width is 0.75 m. The cross slope of the soil shoulder is 3%.

![Figure 2 Standard cross section diagram of subgrade Design (m)](image)

The radius of the circular curve in the highway horizontal curve design meets the widening needs, so the proportional transition method is adopted for the widening design at the circular curve. The professional software adopts the first-class widening standard, carries out the intelligent widening design, and obtains the subgrade and road widening value at any point of the horizontal curve. The radius of the circular curve of all plane lines in the design section is less than 1,500 m, so the circular curve in this design should be set as superelevation, 4% is set as the maximum super elevation of the circular curve, and the superelevation gradient form is linear. The superelevation transition method that rotates around the inner edge of the lane is adopted, and the maximum superelevation gradient rate is 1/125.

When B is 7 m, \( \Delta_i \) is 6% and \( p \) is 1/125, the length of the minimum superelevation transition section of the highway is calculated as:
\[ L_e = \frac{B \Delta_i}{p} = \frac{7 \times 6\%}{1 / 125} = 52.50(\text{m}) < L_e . \]  

Obviously, the transition rate of superelevation meets the requirements. Since \( L_e \) should be taken as an integral multiple of 5 m, the length of superelevation transition section \( L_e \) is the same as that of transition section \( L_e \), both of which are 60 m.
3.4. Pavement material selection
According to the natural primary zone and the Code [4], the newly-built secondary highway located in Sihui City belongs to the zone IV (southeast hot and humid zone). The annual average precipitation is 1,821 mm, which is a hot and rainy area. Based on this, the newly-built secondary highway is planned to adopt cement concrete pavement structure.

3.5. Drainage design
Symmetrical rectangular edge ditch is adopted in this design. The width of the ditch bottom is 0.6 m, and the depth of the ditch is 0.6 m. The longitudinal slope of the ditch bottom is the same as the longitudinal slope of the road.

![Figure 3 Schematic diagram of rectangular edge ditch (m)](image)

Symmetrical trapezoidal drainage ditch is adopted. The inner ditch slope is 1:1, the ditch bottom width is 0.6 m, the ditch depth is 0.6 m, and the longitudinal slope of the ditch bottom is 1%. Slates are used for reinforcement.

![Figure 4 Schematic diagram of trapezoidal drainage ditch (m)](image)

The section of the designed cut intercepting drain is trapezoid, the slope is 1:1, the depth and width of the intercepting drain are both 0.5 m, and the longitudinal slope of the ditch bottom is 0.5%. The intercepting drain of excavation subgrade should be 5 m away from the slope top, and the intercepting drain on the top of filling subgrade should be no less than 2 m away from the bottom of filling slope.

![Figure 5 Schematic diagram of intercepting ditch (m)](image)

In addition, road drainage facilities such as water holding belts, drainage outlets and chutes should be set up [5].
4. Conclusion
The road material type is cement concrete, the length of the road section is 2946.769 m. Based on the needed traffic capacity, the road grade is determined to be a secondary highway with a design speed of 60 km/h, a roadbed width of 10m, a two-way two-lane road, a hard shoulder 2×0.75m, a soil shoulder of 2×0.75m, and traffic lane of 2×3.5 m. This design mainly includes road line selection, horizontal curve design, vertical section design, cross section design and drainage design. This secondary highway has five horizontal curves with radii of 230 m, 240 m, 220 m, 235 m and 245 m. Superelevation and widening are set at the circular curve, and gentle curves are set at the connections between each couple of straight line and the curve. The superelevation gradual change section and widening transition section are set in the easing curve. The vertical section of this secondary highway has 7 slope changing points, the maximum vertical slope is -4.000% and +4.000%, the minimum vertical slope is -0.052%, the maximum slope length is 680.070 m, and the minimum slope length is 200.780 m. It has been verified to meet the specification requirements.

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