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A Geometry Elements Based Speed Prediction Model for Interchange Ramps of Mountainous Motorways

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Abstract. The geometric design of motorways in the mountainous area is the top priority of the interchange planning and design. Reasonable ramp geometric design can not only reduce the cost and difficulties of construction of the interchange, but also improve the driving conditions, ensure traffic safety and improve the comfort of driving. Based on the development of foreign geometric alignment design practice, this paper analyze the continuous travel performance of vehicles on mountainous interchange ramps, and then proposes a highway geometric elements design method based on operating speed for practitioners to predict operating speed on ramps. The method will allow the auditors and the designers to proceed operating speed prediction for varied vehicle types for mountainous interchange ramps, which is also expected to give the auditors a good way to evaluate the consistency between driver's expectation and the geometric design of the ramps.

1. Introduction
Many external factors such as the layout, design speed selection, entrance and exit design, sight distance requirements and traffic composition will have influences on the passengers’ perceptions of comfortable and smooth for a ramp geometry, and the ramp geometric design is the core control element. Because the adjacent geometric alignment elements sometimes are lack of consistency, the speed will change sharply which beyond the driver's psychological expectations, the sharp speed changes will lead to frequent accidents on road sections especially on ramps in the interchange. Therefore, in foreign geometric design standards or guidelines, the operating speed is mostly used as the basis of design [1], and the design speed oriented design method adopted by China's current specification [2, 3] is mainly adapted to the condition that the high design speed, the driver complying to the rules, the highway that operating at the design speed, or the poor performance of vehicles, and the driving speed is not high. Nowadays, with the gradual improvement of vehicle performance, the design of the interchange ramp based on the design speed has not been well adapted to the current driving needs of the vehicle, and the continuity of the vehicle driving cannot be guaranteed.

2. Data collection
2.1Survey content
According to previous research experience at home and abroad, one of the most critical constraints on the operating speed of the horizontal curve section is the horizontal curve radius [4, 5]. Although the ramp section also takes the horizontal curve radius into consideration, in the previous researches, the curves considered in the horizontal curve operating speed model are mainly circular curves, the radius is a fixed value, but the radius of the horizontal curve of the road section is continuously changing, and
the radius value of the research object is smaller than that of the previous research object, so the most critical problem in the research process is: firstly, during the model research, the turning angle value and curvature change during the turning of the ramp should be considered as the main influencing factors; secondly, the horizontal alignment index of the road section changes continuously, and it is not a constant value. In the course of the research, the influence of the cumulative variation of the previous section horizontal alignment on the operating speed of the latter section should be taken into consideration.

2.2 Experimental observation plan
For the test observation of horizontal operating speeds, according to the previous ramp design experience, the horizontal curve elements include straight lines, circular curves and spiral curves [6]. Ramps curves can be seen as the combination of various horizontal alignment elements; therefore, it is convenient to simplify the data collection and subsequent analysis in the study. According to the previous operating speed studies, the data acquisition in the circular curve can select each feature point according to the circular curve entrance, the curve midpoint and the exit [7]. However, as the gradual change of the curvature radius of the spiral curve, the vehicle travels on the spiral curve, and the operating speed also changes continuously, so special attention is needed to be paid in selecting the detection point. In the study of the operating speed of the road section of the project, the section observation method is mainly adopted, and the license plate number method is adopted in the horizontal curve test. The schematic diagram of the location of the specific speed observation point is as follows.

![Figure 1. Schematic diagram of the horizontal curve experimental instrument layout](image)

In Figure 1, L1, L2, and L3 are three continuous horizontal curves. The main speed observation points are A, B, C, D, E, F, and G, which are the starting points, the midpoint and the end point of the curve described above.

3. Vehicle traveling features in ramps
According to past experience, the speed of the vehicle on the ramp is gradually changing from high to low and then high. This shifting process is consistent with the alignment of the ramp horizontal. As the horizontal alignment of the ramp, since the radius of the horizontal curve is inconsistent and constantly changing, in the process of studying the operating speed model of the road section, the change of the horizontal curve alone does not reflect the vehicle performance characteristics. In order to find a better description of the geometric alignment change of the road segment, combined with the information obtained from our data acquisition, we introduce curvature as the key research object. In the following, we compare the speed data of a typical road section with the curvature of the ramp horizontal according to the classification of passenger cars and trucks, and obtain the speed-curvature plots of the road section of the road, as shown in Figure 2 and Figure 3 below:
Figure 2. Speed-curvature relationship of the passenger cars

Figure 3. Speed-curvature relationship of trucks

From Figure 2 and Figure 3, we can see the general variation between the velocity and curvature line graphs. In order to get this relationship more intuitively, we added the speed trend curve (blue line in the figure) and the curvature trend curve (red line in the figure), and got the following conclusion: when the curvature of the road section increases, the speed of the vehicle decreases; otherwise, the curvature decreases, the speed of the passenger car is rising. This is consistent with the conventionally summarized ramp speed and horizontal line shape. The vehicle is operating on the ramp, the curvature of the vehicle entering the road section increases, and the operating speed of the vehicle decreases. When the vehicle approaches the midpoint of the ramp, this value continues to decrease until the operating speed reaches the lowest point; when the vehicle passes the midpoint of the ramp, the vehicle accelerates and the operating speed rises until it passes through the ramp exit. The schematic diagram of the operating speed change is shown in Figure 5 below.

Figure 4. Schematic diagram of the change of the operating speed of the road section

4. Relationship between speed and curvature

Through the above analysis of the performance and horizontal curves of the road sections, combined with the horizontal alignment design of the ramp, we study the entrance, midpoint and exit speeds and horizontal curve curvature of the road sections.
Entrance: Regardless of the passenger car or the trucks, the midpoint of entering the ramp entrance to the middle of the road section generally shows that there are different degrees of deceleration, so the curvature increases, and the reduction is larger with respect to the entering speed, as follows.

![Figure 5. Relationship between the midpoint speed and the entering speed increment percentage and curvature of the ramp](image)

(a) passenger cars  (b) trucks

Midpoint: At the midpoint of the road section, the average speed of the passenger car and the truck is reduced with the increase of the curvature without exceeding the expected speed, as shown in the following figure.

![Figure 6. Relationship between speed and curvature of the midpoint of the ramp](image)

(a) passenger cars  (b) trucks

Exit: For passenger cars and trucks, there is usually a certain degree of acceleration relative to the midpoint of the ramp or a slight increase in the midpoint speed of the ramp. The speed of the exit speed of the ramp increases with the curvature decreasing with respect to the midpoint speed of the ramp.

![Figure 7. Relationship between ramp exit speed and midpoint speed increment percentage and radius](image)

(a) passenger cars  (b) trucks

5. Conclusion

Because the speed change of the road section is continuous and the geometric alignment is complex, we not only consider the curvature of the horizontal curve, but also take the length of the ramp, the cumulative change of the turning angle and the operating speed of the ramp curve as the parameters established by the model.
Finally, through the analysis of the actual driving speed of the selected road sections and the horizontal linear indicators of the ramps, the prediction models of the operating speed of the mountainous road sections of passenger cars and trucks are obtained respectively.

Small cars:
\[ V_{ss} = 32.989 - 0.031l - 2.741D + 0.293\Delta + 0.025V_1 \]  
Large cars:
\[ V_{ss} = 36.446 - 0.034l - 72.531D + 0.406\Delta + 0.016V_1 \]  

Where, D-curvature (degree/meter); L-curve length (unit: m); \( \Delta \)-the cumulative value of the angle of rotation (degree); \( V_1 \)-the operating speed of the entering curve (km/h).

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