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The Impact of the Combination of Circular Curve and Transition Curve on Highway Operation Security

Cao Youlu*
(Department of Road and Railway Engineering, Chongqing Jiaotong University, Chongqing 400074, China)

ABSTRAC
By investigating the accident in 2009 and 2011 of Taijiu Expressway, the study analyzed the relationship between the horizontal curve radiuses, the length of horizontal curve, the length of transition curve and the number of accidents, established the corresponding regression model. The trend of accidents was determined with different length of transition curve and different combination of circular curve according to this model. The results show that the circular curve radius and length of transition curve increase with the decreases of accidents number, the number of accidents decreases with the increase of the ratio of the length of the transition curve and the length of the round curve. When the ratio of the parameters of the transition curve and the radius of the circle is between 0.3-0.6, the accidents are more focused. The bigger change rate of curves is, there are more accidents of flat curve. To evaluate road traffic safety from the perspective of horizontal curve alignment design, these regularities have very important reference.
***Keywords*-**transition curve, circular curve, accident numbers, traffic safety

I. Introduction

The plane curve is a combination of circle curve and transition curve. At all levels of the road regardless size of corner should set up circular curve. Transition curve is set between the straight line and circular curve or a continuous curve between two same direction circular curves which are largely different at radius. The linear that is set up circular curve meet the vehicle turning track so as to make the line smooth, make the horizontal alignment more flexible and improve the linear degree of freedom.There are no stringent design specifications in the combination of transition curve and circle curve. Generally believed that $Ls:Lc:Ls=1:1:1,1/3\le A/R\le 1$, linear can be smooth and beautiful. For this combination is given a range, and is the experience conclusion. So it has important practical significance to explore and quantitative the combinations of circle curve and transition curve.

Perco P investigated the vehicle running track and driving behavior in two lane highway. The results show that the long transition curve has a negative effect on driving behavior, the time making a turn needed to travel the length is the ideal length of transition curve, and calculation model is established for the ideal length of transition curve based on the turning operation time, reduce speed and speed[1-2]. Hasan M's study found that the length of transition curve has no perception influence on circular curve radius for the driver in the horizontal and vertical combination of corners[3]. The influence of spiral length on cornering speed was analyzed by Xu Jin et al., the results show that the spiral will change the relationship between trajectory and horizontal curve cutting bending of the vehicle, with the increases of the bend radius of the curve track, speed also increases, the longer cyclotron lines are the more dramatically effect is[4]. Chen Fujian et al proposed a reliability design method for circular curve radius which in order to solve the problems that the radius is valued by design speed in design specification, his design is based on the lateral slip curve of vehicle as the constraint condition, established the function of the radius of circular curve, then derived the mathematical model to calculate the radius, calculated reliability and reliability index based on Monte Carlo method or analytical method[5].

These studies did not specifically set indicators for transition curve, but have an important reference for the horizontal alignment. This paper combines with the number of traffic accidents, analyzed the relationship between transition curve and circular curve, and quantized the two curves forms. These results make up the vacancy of transition curve design, provides a reference for more in-depth study of transition curve in future.

II. Taijiu expressway accident investigation

Taijiu expressway (Taiyuan to Jiuguan) in Shanxi is 140.7 km, design speed are 100km / h and 60km / h respectively, the expressway through the region of the Loess Plateau and Shanxi Taihang geomorphological zone, across the flat terrain of

Fen River valley plains, crossing the gully development, the along terrain is extremely complex, project conditions are very difficult. Selecting the road for analysis has a representative.

This paper selected 103 corners with transition curve in this highway, collected accident data from 2009 to 2011, the parameters and accidents of the part of the horizontal curve are shown in Table 1.

Table 1 The investigation of section horizontal curved and accident in Taijiu expressway

R/m	Lc/m	Ls/m	A/R	Ls/Lc	CCR/gon·m^{-1}	Number of accidents
299.82	240	90	0.55	0.38	0.150	11
550	212.8	110	0.45	0.52	0.078	9
400	246.6	100	0.5	0.41	0.111	2
400	242.5	100	0.5	0.41	0.111	3
554.09	119.4	120	0.47	1.01	0.069	1
412.45	178.4	100	0.49	0.56	0.102	5
422.88	334.2	100	0.49	0.3	0.110	9
285.14	284.5	80	0.53	0.28	0.165	11
500	130	100	0.45	0.77	0.080	7
446.91	181.2	100	0.47	0.55	0.095	9
565.03	529.2	100	0.42	0.17	0.087	10

$$A / R = \sqrt{LsR} / R = \sqrt{Ls / R} \qquad (1)$$

Where R is the circular curve radius (m), Lc is the circular curve length (m), Ls is the transition curve length (m), A is the transition curve parameters, CCR is the rate curve (gon·m^{-1}).

II. Results of the survey

2.1 Relationship between circular curve radius and the number of accidents

In the design of horizontal curve, the circular curve radius is an important geometric element. Radius is too small, the vehicle traveling on the circular curve is vulnerable to excessive centrifugal force caused by the lateral instability, and thus lead to traffic accidents; whereas in terrain allows, the curve should use a larger radius for driving comfort. Figure 1 shows the relationship between curve radius and the number of accidents. In Figure 1, x、y are the regression variables, R is the correlation coefficient, the same as later.

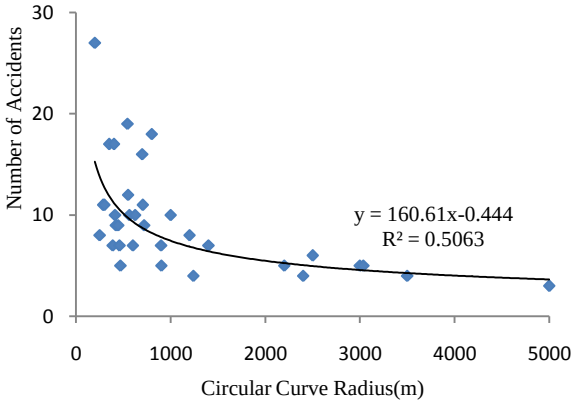

FIGURE 1 The relationship between curve radius and the number of accidents

By preliminary analysis of the data, we can see that the number of accidents is decreasing with increasing radius; accidents are more concentrated in the sections of circle curve radius below 1000m. The regression curve is steeper when the radius is less than 1000m; when the radius is greater than 1000m, the regression curve is moderate. It can be learned that in the permit of terrain and other conditions, excessive curve radius and straight has no much difference, driving comfort will be improved, and the number of accidents will be reduced.

The curve in Figure 1 shows a better decreasing trend, the model of the number of accidents and the circular curve as follows:

$$y = 160.61R^{-0.444} \quad R^2 = 0.506 \quad (2)$$

Where y is the number of accidents, R is the circular curve radius (m).

The F test of the regression model, the results are shown in table 2.

TABLE 2 Model Summary and Parameter Estimates

Equation	Model Summary					Parameter Estimates	
	R^2	F	df1	df2	Sig.	Constant	b1
Power	.506	32.815	1	32	.000	160.61	-.444

In table 2, the sig value is 0.000<0.05, indicating that the relationships between the variables of the regression model is good.

2.2 The relationship between the length of transition curve and the number of accidents

Transition curve has the effect of alleviating the liner, driving, superelevation and widening, but the transition curve must be of sufficient length to avoid centrifugal acceleration and the rapid growth of the driver to turn the steering wheel too fast, so as to ensure the driving comfort and safety. Figure 2 shows the relationship between the number of accidents and the transition curve length.

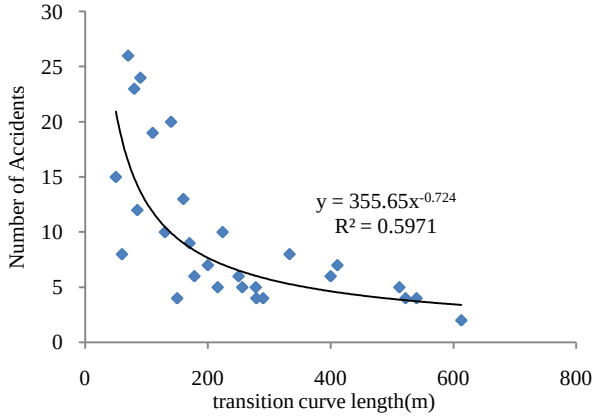

FIGURE 2The relationship between the length of transition curve and the number of accidents

Figure 2 shows the number of accidents, with the length of transition curve showed a decreasing trend , and when the transition curve length is less than 300m, a large number of accidents, the regression curve is steep; When it is more than 300m, the number of accidents are few, the regression curve is gentle. Therefore, the length of transition curve will affect driving behavior and road safety, shorter length is unfavorable to safety. Because of the length of transition curve of road accident in less than 700m, so the too long transition curve affect traffic safety needs further investigation and analysis.

Study analyzed the sample data by linear regression, the model as follows:

$$y = 355.65Ls^{-0.724} \quad R^2 = 0.5971 \quad (3)$$

Where y is the number of accidents, Ls is the transition curve length (m).

The F test of the regression model, the results are shown in table 3.

TABLE 3 Model Summary and Parameter Estimates

Equation	Model Summary					Parameter Estimates	
	R^2	F	df 1	df 2	Sig.	Constant	b1
Power	.597	38.526	1	26	.000	355.65	-.724

Table 3 shows that the sig value is 0.000<0.05, indicating that the relationships between the variablesof the regression model are good, and the length of transition curve significantly affects the accident number.

2.3 The relationship between the parameters of transition curve, curve radius and the number of accidents

The cyclotron parameter A is basedon the requirementsof linear smooth and aesthetic, depending on the size of the curve radius to design, and the provisions value of the A is $R/3 \le A \le R$, then the Ls can be calculated by formula 1.

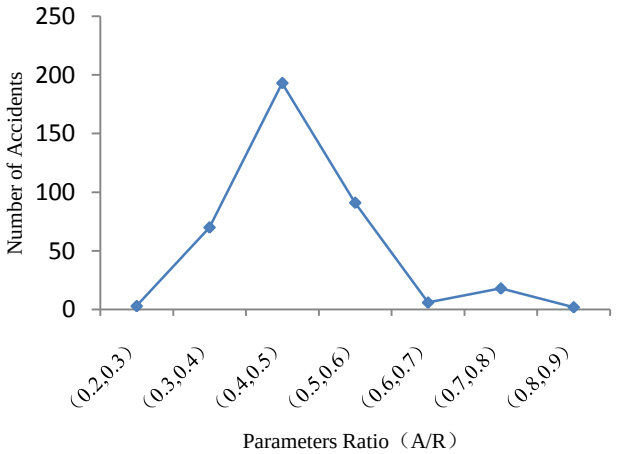

FIGURE 3 The relationship between the parameters of transition curve, curve radius and the number of accidents

As can be seen from figure 3, the design of Taijiu expressway is in accordance with the general requirements, The values of A/R fall in between $1/3 \sim 1$, but this recommendation value belongs to theoretical proposal， the impact of the value in the real range on safety accidents is different. The

accident is concentrated in between $0.3 \sim 0.6$, the number of accidents reached the maximum in the range of $0.4 \sim 0.5$, when the value is less than the range, the number of accidents is increasing with the increasing of A/R; More than this range, the number of accidents is decreased with the increasing of A/R. From the formula 1, A/R can be transformed into the relationship between Ls and R, it is recommended that the value of A/R is $0.6 \sim 1$.

2.4 The relationship between the length of transition, the length of circular curve and the number of accidents

For the minimum length of horizontal curve, the previous experience shows that the minimum curve length is equal to the travel length of 9s, that is Transition Curve: Circular Curve: Transition Curve ≈1: 1: 1, in order to make linear appearance, sleek, and ensure traffic safety and comfort. When the corner of flat curve is less than or equal to 7 °, the driver will often mistake for ends of the curve is straight lines, to avoid this illusion, generally do not choose a small corner of the horizontal curve, when the terrain and other restrictions, the small corner should use a long horizontal curve.

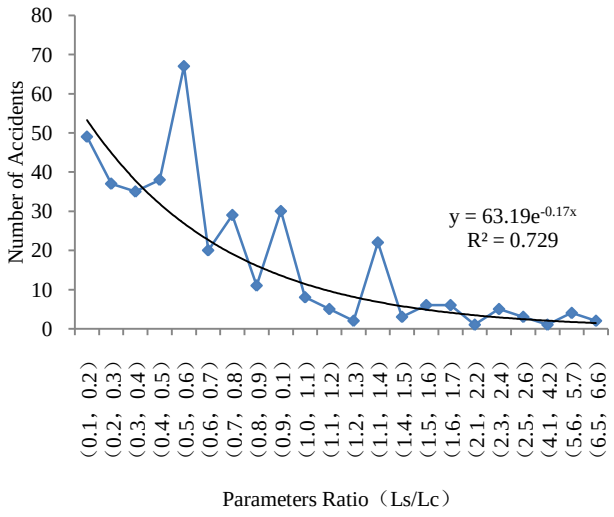

FIGURE 4 The relationship between the length of transition, the length of circular curve and the number of accidents

Figure 4 shows the relationship between the number of accidents and Ls/Lc. The figure shows that the number of accidents increases with Ls/Lc decreases, and has a good negative exponential relationship. When the parameter ratio is less than 1.0, the curve steeper, the Ls is smaller relative to Lc, the number of accidents is higher, and the highest of the number of accidents in (0.5, 0.6). When the parameter ratio is greater than 1.1, the curve is more moderate, the number of traffic accidents is lower, but parameter ratio is relatively large, spiral length is longer than the circular curve length, so linear is coordinate and it is not recommended.

Study analyzed the sample data by linear regression, the model as follows:

$$y = 63.192e^{-0.171(Ls/Lc)} \quad R^2 = 0.7298 \quad (4)$$

Where y is the number of accidents, Lc is the circular curve length (m), Ls is the transition curve length (m).

2.5 The relationship between CCR and the number of accidents.

CCR (Curvature Change Rate) is theflatcurveparameters,CCR value in the plane can be calculated by the length oftransition curveineachplanecurve,the radius of circular curve an d the curve length , as seen in formula 5,the value of CCR can reaction the curvebending and linear coordination.

$$CCR = \frac{180}{\pi L_i}\left[\sum_i \frac{L_{ci}}{R_i} + \sum_j \frac{L_{sj}}{2R_i}\right] \quad (5)$$

Where L_i is the length of horizontal curve, L_{ci} is the length of circular curve I, L_{sj} is the length of Transition Curve j, R_i is the radius of the circular curve i.

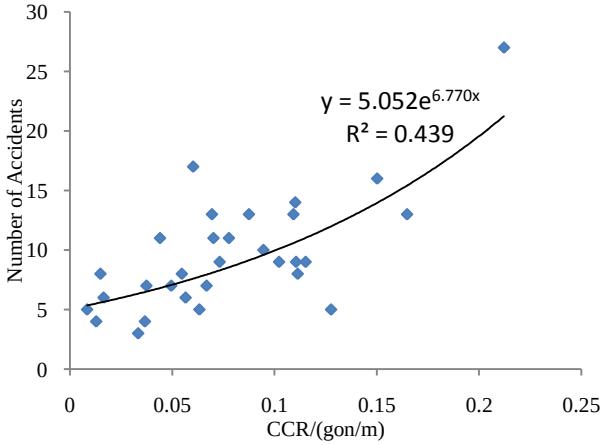

FIGURE 5 The relationship between CCR and the number of accidents

It can be seen from the figure 5 that the number of vehicle accident curves in different sections are closely related to CCR, in general, the change of curve angle is easer, the change of curve rate is smaller, the number of accidents is less ， showing an exponential relationship.The number of accidents concentrates on the CCR value is less than 0.15,and the change trend is small; From the statistical data, road alignment design is less where CCR values greater than 0.15,and the accident was scattered, but the number of accidents is large and the trend curve is large.Study analyzed the sample data by linear regression, the model as follows:

$$y = 5.0523e^{6.7704CCR} \quad R^2 = 0.4391 \quad (6)$$

Where y is the number of accidents, CCRis the curvechangerate.

The F test of the regression model, the results are shown in table 4.

TABLE 4 Model Summary and Parameter Estimates

Equation	Model Summary					Parameter Estimates	
	R^2	F	df 1	df 2	Sig.	Constant	b1
Power	.439	21.920	1	28	.000	5.052	-.770

Table 4 shows that the sig value is 0.000<0.05, indicating that the relationships between the variables of the regression model are good, and the length of transition curve significantly affects the accident number.

III. Conclusion

The geometric alignment of the road is a three dimensional linear which is connected with the straight line and plane curve. Whether the combination of alignment is coordinated directly influences the safety of driving. Because the accident rate of flat curve is high, it is especially important to coordinate the combination of the transition curve and circular curve. It can be seen from the analysis of second section that:

（1）The radius of the circular curve and the length of the transition curve can be analyzed separately. The bigger R and Ls are, the smaller number of accidents is. In the allow of the terrain, R and Ls try to be taken the large value. And for the highway, according to the design speed, the limit value, the average value and the minimum length of the transition curve can often be drawn. The corresponding radius of this section is 700m and 200m, the minimum length of the mitigation curve is 50m, 85m. Correspond to figure 1, 2, the number of accidents are higher, it is not recommended. Therefore, according to the design code values, traffic safety is not good, the study recommends that when the speed of the design is 100km/h, the average value of the circle radius R is 1000m, and the average of the length of the curve Ls is 300m.

(2) When designing horizontal curve, the curve radius R, the length of circle curve Lc and the length of transition curve Ls are the important design indexes., The current specification for the three only for a separate value, both of the combination of data are only to the recommended range of experience, not to apply to the case for analysis and verification. And in this study, the number of accidents decreases with the increases of A/R, when A/R is less than 0.3, although less accidents, the radius of the circle curve and the length of the relaxation curve should be larger.

（3） reflect the coordination of the transition curve length and the circular curve length. When Ls is shorter than Lc , the number of accidents is more. As can be seen, transition curve as the transition part connecting the straight line and the circular curve, the short length gives driver the illusion of linear mutation, correspondingly the number of accidents will be higher; When transition curve is long and circle curve is short, the number of accidents has decreased but the linear appearance and coordination are poor, according to the analysis, the ratio of Ls/Lc is recommended for 1.2 to 1.3.

(4) CCR is a design element that the combination of all the design specifications of the horizontal curve, characterize the continuity of horizontal curve curvature change. The effect of single curve radius and the length of transition curve on traffic safety is low, CCR as the coordination of horizontal curve indicator is the determining factor of the number of traffic accidents. The value of CCR is higher, the number of accidents is more, when the value is lower, accidents aggregation is more significant. According to the number of accidents and linear equalization continuity, CCR value is recommended for less than 0.15gon / m.

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