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STUDYING THE EFFECT OF SPIRAL CURVES AND INTERSECTION ANGLE ON THE ACCIDENT RATES ON TWO-LANE RURAL HIGHWAYS IN IRAN

ABSTRACT

Safety on highways is one of the most important subjects in Transportation Engineering. The increasing rate of vehicles and the needs to design or geometrically modify the highways has been emphasized in the safe-design of roadways more than before. Between the constructive components of the highway, due to the increasing occurrences of accidents the horizontal curves are of great importance. The US Ministry of Highway and Transportation introduced the IHSDM software, with variant capabilities to predict accidents. In this research, five types of curves (simple circle curve and clothoid-circle-clothoid) at different intersection angles were designed, and based on the standard specifications on each curve accident rates were predicted by using IHSDM. The results have been compared with each other. Finally, by processing the curves of accident rates versus curve types and intersection angle, and comparing them with each other, the necessity of using spiral curves in the highway design is emphasized.

KEY WORDS

highways, safety, horizontal curves, spiral curves, clothoid curves, intersection angle, IHSDM

1. INTRODUCTION

In the past, safety engineering of highways was often about the safety issues, and correcting the accident-prone points, and annually large budget was spent on identifying and modifying these points on roadways. Nowadays, with the advances of science and technology, highway engineers and designers have found methods to predict accidents on roadways. According to this possibility the safety of highways and the accident rates can be investigated before the implementation. New software called IHSDM with the main purpose of safety improvements of highways is being developed and used since the year 1995 in the U.S.A.

Annually, 1,200,000 deaths occur around the world because of accidents. It has been estimated that 60% of these accidents occur on two-lane rural highways, with most of them taking place in curves. Accident rates in horizontal curves are 1.5 to 4 times greater than the accident rates of the connected straight paths [1]. The intensity of accidents is high in the curves and 30% of all accidents occur in the curves [2]. Also, the research has shown that the cause of 34% of accidents is the highway and the environment factors [3]. In this research, three clothoid-circle-clothoid curves and two simple circle curves at different inner intersection angles have been examined by using the IHSDM software to investigate the effect of spiral curves as well as the intersection angles on the curve accidents.

2. INVESTIGATING THE SIGNIFICANCE OF THE SUBJECT

Many believe that the highways geometrical design instructions do not give proper measure in evaluating the level of safety on highways. Lots of authors express their concerns about the inconsideration of safety quantity in the geometrical design instructions. For example:

Feuchtinger and Christoffers said that when a highway is utilized, accident occurrence is the only thing that shows the safety performance of the highway. In the design phase there is no way of expressing the traffic safety [4].

Bitzl said in his research that unlike other engineering fields, in highway design it is almost impossible to determine the highway safety. In other words, instructions do not provide the basic and fundamental values needed to describe the relationship of the highway safety with the design parameters and the traffic conditions, while other engineering fields like structural engineering have safety criteria for designing bridges and buildings [5].

Kerbs and Kloechner said that if the highway design instructions guarantee highway safety, there should be no or few accidents. When an accident takes place only the drivers are blamed. Accidents do not have a uniform distribution along the highway network. The points that have a higher rate of accidents show that other effective parameters besides the driver's mistake interfere [6].

Mackenroth said that when a driver crashes in an accident-prone point, it is often said that driving was the cause of accident. When driver's accident points concentrate at a single point on the highway it will be clear that the problem is not just the drivers, but rather the fundamental geometrical design of the highway related to this subject [6].

Thus, the effective displacements and the traffic safety are substantially under the influence of the highway geometrical properties. By observing the accident-prone points on the maps, the concentration of accidents in the curves, especially the sharp section of the curves, can be understood. Therefore, examining highways, especially the curves, in the perspective of geometrical design conditions seems necessary.

3. IHSDM SOFTWARE AND ITS APPLICATION IN THIS RESEARCH

IHSDM software uses toolboxes to analyze and evaluate the safety performance of the highway geometrical design effects. This software is really an assistant tool to help the designers develop a better design. It will provide the estimation of the highway safety and design performance by the ability to predict accidents, and thus enough investigation about the accident rates and accident-prone parts can be carried out before the implementation phase. Furthermore, with its assistance one can compare the current/proposed highway design with the standard highway design criteria. This software has the capability of providing support in case of changes in the design, by allowing the designer to analyze the main model after changing the necessary parameters, without need to introduce a new model. According to its unique capabilities it can be used by the highway project managers, highway designers and safety and traffic inspectors. From other benefits of this software one can mention its compatibility with the Auto Cad Land software, so that after the highway design one can get the output as .xml and directly import it into IHSDM. This software has currently six capabilities for its users that are:

- Crash prediction;
- Design consistency;
- Intersection review;
- Policy review;
- Traffic analysis;
- Driver/vehicle.

The IHSDM development is coordinated with two related initiatives: the Highway Safety Manual developed by the Transportation Research Board and published by AASHTO; and the Safety Analyst, developed by FHWA and now available as AASHTOWare.

In this research the latest version of the software (version 7.0.1) which was developed by the U.S. Ministry of Highway at the time is used to predict and analyze the accidents.

4. DESCRIPTION AND SIGNIFICANCE OF THE WORK

Because most of the current roads in Iran are two-lane highways, this research has been done on this type of road. To eliminate the vertical highways effects on accidents, the topography conditions are assumed to be smooth. Thus, according to Tables 1 and 2, that were taken from the Iranian standard, the design velocity on two-lane highways in smooth regions has been determined to be 110 km/h [7].

Table 1 - Values of velocity groups in Iranian standard

Design velocity (km/h)			Group name
Maximum	Average	Minimum	
50	40	30	V1
80	70	60	V2
100	90	80	V3
110	110	110	V4
130	130	130	V5

In the current study the highway shoulder is paved and with the width of 1.85 metres and according to the Iranian standard the super elevation value of the curves is taken to be 6%. According to the possible use of this research in the future by the designers, and because the highway designer's approach is a design

Table 2 - Values of velocity groups for road gradation in Iranian standard

Road classes			Highway gradation
Plain	Hill	Mountainous	
V_5	V_4	V_3	Freeway
V_4	V_4	V_3	Highways and detached roads
V_4	V_3	V_2	Main roads
V_3	V_3	V_1	Secondary roads

Table 3 - Capacity of each lane of highways (with multiple lanes) according to traffic volume and design velocity in Iranian standard

Design velocity 100 km/h			Design velocity≥ 110 km/h			Maximum equivalent vehicle density per kilometre in each lane	Level of service
Design capacity MSF	$\frac{V}{C}$	Average speed km/h	Design capacity MSF	$\frac{V}{C}$	Average speed km/h		
650	0.33	≥ 80	700	0.35	≥ 90	8	A
1,000	0.50	≥ 75	1,100	0.55	≥ 85	13	B
1,300	0.65	≥ 70	1,400	0.70	≥ 75	19	C
1,700	0.85	≥ 65	1,700	0.85	≥ 65	26	D
2,000	1	≥ 50	2,000	1	≥ 50	40	E
*	*	< 50	*	*	< 50	More than 40	F
Design velocity 80 km/h			Design velocity 80 km/h			Maximum equivalent vehicle density per kilometre in each lane	Level of service
Design capacity MSF	$\frac{V}{C}$	Average speed km/h	Design capacity MSF	$\frac{V}{C}$	Average speed km/h		
-	-	-	-	-	-	8	A
-	-	-	900	0.47	≥ 70	13	B
-	-	-	1,150	0.6	≥ 60	19	C
1,300	0.68	≥ 50	1,450	0.76	≥ 55	26	D
1,900	1	≥ 45	1,900	1	≥ 45	40	E
*	*	<45	*	*	< 45	More than 40	F

with higher service than now, therefore the "B" service level has been selected. According to *Table 3* that has been taken from the Iranian standard, the maximum number of vehicles per kilometre in each lane is 13. The values of design capacity and the volume-to-capacity rates are taken from the related table and finally, according to the peak hour factor on rural highways, the traffic volume per day is 14,300.

According to *Table 4* which is taken from the Iranian standard, the curve radius will be 565 metres. On the other hand, in accordance with the U.S. standard, the radius of a simple circle curve without the spiral curve is 716 metres [3]. Thus, a simple circle curve with this radius is considered in this study, too.

As shown in *Figure 1* the investigated curves in this research are simple circle curves and clothoid-circle-clothoid curves. In this study the length of the clothoid curve is determined to be 60, 85 and 115 metres that are the minimum length of spiral curve based on the U.S. standard, the minimum length of spiral curve based on the Iranian standard, and the maximum length of spiral curve based on the U.S. standard, respectively. It is necessary to mention that the Iranian standard has no limitation on the maximum length of the clothoid [7]. In addition to the clothoid length and the circle radius that are considered to be variables, the inner angle of the intersection (β) varies from 90 degrees to 160 degrees to make it possible to investigate the inner angle of the intersection effects as well.

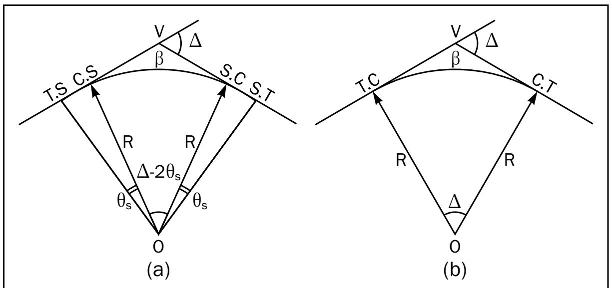

Figure 1 - Characteristics of Clothoid-circle-clothoid curve (a) and simple circle curve (b)

where O, V, Δ, β, R, θ_s, T.S, C.S, S.C, T.C, C.T are centre of circle, intersection point, intersection angle, circle related angle, circle radius, clothoid radius, tangent to spiral, circle to spiral, spiral to circle, spiral to tangent,

tangent to circle and circle to tangent points, respectively. According to the above explanations, five types of curves were selected for the analyses, and these are:

– Simple circle curve with a radius of 565 metres (C565);
– Simple circle curve with a radius of 716 metres (C716);
– Clothoid-circle-clothoid curve with a radius of 565 metres and clothoid length of 60 metres (C565-S60);
– Clothoid-circle-clothoid curve with a radius of 565 metres and clothoid length of 85 metres (C565-S85);
– Clothoid-circle-clothoid curve with a radius of 565 metres and clothoid length of 115 metres (C565-S115).

In order to have the same conditions of the incoming vehicles to the curves there has been an addition of one kilometre of a straight path before and after each curve. Finally, the roads were designed in Auto Cad Land software and after drawing the longitudinal profile, the project line, the cross-section and adjusting the super-elevation settings the output file .xml has been produced. This file has been used as input into IHSDM software and after inserting the traffic characteristics such as the daily traffic and the density, the analysis begins. Accident predictions are done in five-year intervals and based on the HSM default coefficients.

Table 4 - Values of the minimum radius (in metres) for different design velocities and elevations in the Iranian standard

12%	10%	8%	6%	Elevation (%) / Design velocity
25	30	30	35	30
45	50	55	55	40
70	80	75	90	50
105	115	125	135	60
150	165	185	195	70
195	210	230	255	80
255	280	305	340	90
330	360	395	340	100
415	455	505	565	110
540	600	680	760	120
680	740	735	955	130

5. RESULTS

In this study the number of accidents against the length on five types of curves and eight intersection angles has been investigated, with the results shown in *Table 5*. As can be seen, the table columns show the values of accidents per kilometre on the highway in accordance with the inner intersection angle and the table rows show the curve type.

Figure 2 shows the effect of intersection angle on the accident rates per kilometre of highway, according to the curve type. As it can be seen the accident rates per kilometre in curves with clothoid are considerably lower than in the case of simple circle curves, and this difference increases by increasing the inner intersection angle. In simple circle curves, the accident rate per kilometre is increased by increasing the inner intersection angle. This situation can be explained by the driver's mistake in distinguishing the arc curvature

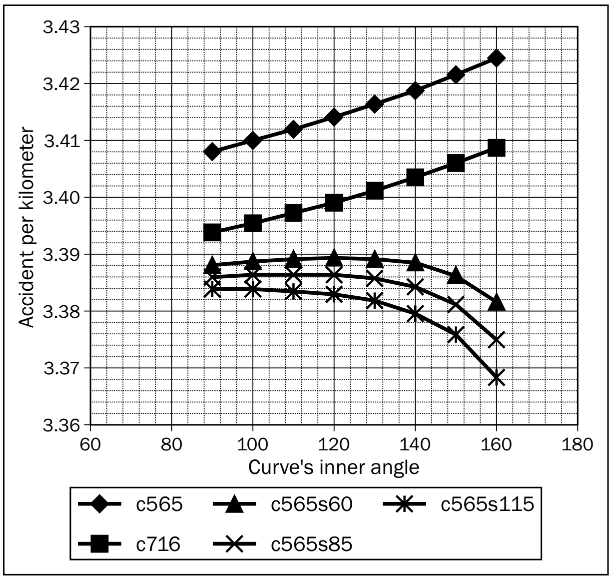

Figure 2 - Relationship between the inner angles of the curve and the accidents per unit length according to the curve type

Table 5 - Accidents per kilometre of the road

Curve type	Intersection angle (degrees)							
	90	100	110	120	130	140	150	160
C565	3.41	3.41	3.41	3.41	3.42	3.42	3.42	3.42
C716	3.39	3.4	3.4	3.4	3.4	3.4	3.41	3.41
C565S60	3.39	3.39	3.39	3.39	3.39	3.39	3.39	3.38
C565S85	3.39	3.39	3.39	3.39	3.39	3.38	3.38	3.37
C565S115	3.38	3.38	3.38	3.38	3.38	3.38	3.38	3.37

and its beginning and end at increased intersection angles and the possibility of the deviation increases. In the case of curves with clothoid due to the gradual increase of the curvature, the driver has enough time to figure out the impending curve, thus reducing the accidents per unit length on highways with spiral curves. Between highways with clothoid curve, and equal inner intersection angle, it is obvious that increasing the clothoid length will result in the reduction of accidents per unit length.

The reduction in accidents per unit length with angles of more than 130 degrees occurs with more intensity, because in case of larger inner angles the likelihood for a driver to make a mistake increases and it is here that the clothoid curves play an important role. The following relations are derived from curve fitting method and show the equations of C565 and C716 curves, respectively:

$$\begin{cases} y = 0.0002\,x + 3.3864 \\ R^2 = 0.9939 \end{cases} \quad (1)$$

$$\begin{cases} y = 0.0002\,x + 3.3744 \\ R^2 = 0.9909 \end{cases} \quad (2)$$

As for the clothoids, the following relations apply to C565S60, C565S85 and C565S115, respectively:

$$\begin{cases} y = -8 \times 10^{-8} x^3 + 2 \times 10^{-5} x^2 - 0.0026\,x + 3.4794 \\ R^2 = 0.9934 \end{cases} \quad (3)$$

$$\begin{cases} y = -9 \times 10^{-8} x^3 + 3 \times 10^{-5} x^2 - 0.0029\,x + 3.4893 \\ R^2 = 0.9968 \end{cases} \quad (4)$$

$$\begin{cases} y = -9 \times 10^{-8} x^3 + 3 \times 10^{-5} x^2 - 0.0032\,x + 3.4961 \\ R^2 = 0.9981 \end{cases} \quad (5)$$

6. CONCLUSION

The results of this research can be described in this way: the existence of spiral curves independent of the intersection angle will considerably reduce the accidents per unit length and this reduction is greater in case of larger inner angles. Increasing the length of the spiral curve will reduce the accidents per unit length and this reduction is not dependent on the variation of the curve inner angle. Increasing the curve radius will decrease the accidents per unit length and increase the length. Accident prediction in such a manner and by using this software was done for the first time in Iran. As consequence of using these software results, the decrease in the accident rates on Iran highways is predicted. According to the aforementioned discussions it is recommended to use the spiral curves in highway design in order to reduce the number of accidents and to increase safety. In the case of using circle curve one should use a curve with a radius that will result in minimum accidents and it is obtained according to the curve length and the number of accidents per unit length. In the end, it is proposed to investigate the effect of super elevation on the accidents, and also the effect of combining different types of curves in order to be able to use the results for the safety design of highways.

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چکیده

بررسی تاثیر قوس‌های پیوندی و زاویه تقاطع بر میزان تصادفات در راه‌های دوخطه برون‌شهری با استفاده از نرم‌افزار IHSDM

ایمنی در راه‌ها یکی از مهمترین مباحثی است که امروزه در حوزه مهندسی حمل و نقل مورد بررسی قرار می‌گیرد. افزایش روزافزون وسایل نقلیه و نیاز به طراحی و یا اصلاح هندسی راه‌ها، موجب شده است طراحی مسیر به صورت ایمن بیش از پیش مورد توجه طراحان قرار گیرد. در بین اجزای تشکیل دهنده‌ی مسیر، قوس‌های افقی به دلیل تعداد بیشتر تصادف رخ داده از اهمیت بالایی برخوردار می‌باشند. وزارت راه و ترابری آمریکا جهت پیش‌بینی تصادفات در راه‌ها نرم افزار IHSDM را با قابلیت‌های متنوع در زمینه پیش‌بینی تصادفات ارائه کرده است. در این پژوهش پنج نوع قوس (دایره ساده و کلوتوئید-دایره-کلوتوئید)، در زاویه‌های تقاطع مختلف طراحی گردیده و میزان تصادفات آنها توسط نرم‌افزار IHSDM با توجه به شرایط ترافیکی آیین نامه پیش‌بینی شده و نتایج با یکدیگر مقایسه شده است. نهایتا با برازش منحنی‌های میزان تصادفات بر حسب نوع قوس و زاویه تقاطع، و مقایسه آنها با یکدیگر لزوم استفاده از قوسهای پیوندی در طراحی راه مورد تاکید قرار گرفته است.

واژه‌های کلیدی

ایمنی، قوس‌های افقی، قوس‌های پیوندی، زاویه تقاطع، نرم‌افزار IHSDM

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