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Analysis of highway geometric design and effect of speed factor on traffic accidents with virtual reality program

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Highlights

- Speed is an important parameter in the selection of geometric standards
- Minimum distance required for reverse curves poses serious accident risks
- Correct designs on highways will minimize loss of life and property

Abstract

Highway geometry plays an important role in road safety and mobility. A successful or unsuccessful geometric design result directly or indirectly affects the driver, the physical implementation of the design. Therefore, roads should be designed with the driver in mind. Virtual reality programs play an important role in helping road engineers design and evaluate alternative road configurations. Virtual reality programs play an important role in evaluating the geometric design security of roads, intersections of roads and intersections and taking precautions against problematic geometric elements. In this study, the importance of geometric standards in existing highways is confirmed by using Virtual CRASH4, a virtual reality program. In this context, three highways with different design criteria were designed using Virtual CRASH4. Accident risks arising from speed changes and design errors have been identified on the designed roads.

Information

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1. Introduction

Today, transportation is one of the most important factors affecting human life. The traffic density leads to an increase in accidents, fuel consumption, exhaust gases and time loss. In addition, the emission gases released into the air adversely affect both the environment and human life [1-3].

According to the researches, 95.2% of the passenger transportation in our country is carried out by Highway. This rate is 89% in the USA and 79% in EU countries. Highway usage rate in the field of freight transportation is around 76.1% in our country. This rate is 69.5% in the USA and about 45% in EU countries [4].

In this case, it becomes a very important issue to examine traffic accidents and the factors caused by them. General factors that cause traffic accidents can be listed as driver defects, pedestrian defects, passenger defects, road defects and vehicle defects [5].

According to the research conducted by the General Directorate of Highways; the rate of traffic accidents caused by road defects is 0.32% in 2018. On the other hand, the rate of traffic accidents caused by driver defects was determined as 92.65%. The biggest reason for traffic accidents caused by driver errors is the failure to adapt the vehicle speed to the conditions required by the road, air and traffic, with a rate of 41.70%. According these data, it can be said that the majority of accidents are caused by excessive speed [6].

Although the rate of road defects to traffic accidents is around 0.32%, it is undoubtedly that faulty project design

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or faulty application of road geometric designs will increase the accident rate.

Elements forming the road geometric standards; are the geometric values of road elements such as the width of the road, the horizontal and vertical curves radii, the slope, the transverse and the neck slope, the view length. Certain factors are kept in the foreground when choosing geometric standards. The most important of these factors are the road class and project speed values [7].

Unfortunately, there are some problems in the planning and construction phases of urban roads in underdeveloped and developing countries, including our country. Unplanned, irregular and dysfunctional roads can be built as a result of both the lack of knowledge and inexperience of the planners and the political behavior of the decision makers [8, 9].

The two main objectives of transportation engineering are to provide comfort and safety. For this reason, public institutions are working intensively to reduce traffic density and traffic accidents. At this stage, it is extremely important to estimate the efficiency of planning or regulation. It is of great importance to analyze traffic networks in different transport modes in order to facilitate and predict these studies [2,3].

Traffic simulations are safe, cheap and easy to apply. Alternative solutions can be analyzed effectively with these models. In recent years, researchers have been using virtual reality programs and micro-simulation modeling intensively to evaluate and compare the application performance of design alternatives [2,3]. Felez et al. [10] in their paper made an application of virtual reality techniques to traffic accident analysis. Physical models used to define the real behavior of the objects involved in the accident were described. A specific collision model was presented. The model reproduced the forces that appear in a traffic accident [10]. Yang et al. [11] based on the virtual simulation theory, used three-dimensional modeling software to build modeling road facilities for simulating the accident environment, and by using OpenGL technology, achieved reading, displaying and controlling the three-dimensional models [11].

In this study, three different ways were designed using Virtual Crash 4, a virtual reality program. Accident risks arising from speed changes on the designed roads have been investigated. In the first design, a single curve standard road with a project speed of 100 km/h was used. In the second design, 60m minimum distance between two opposite curves and curves is used. In the final design, the design was repeated without leaving a minimum superelevation application distance between the curves. Thus, the risks arising from road design errors and speed changes were tried to be determined.

2. Material

Three designs are made in this study. The first is a road with a single curve, the second is the road where the distance between two reverse curves is 60 m, and the third is the roads where the distance between the reverse curves is 0 m. The behavior of a particular vehicle at different speeds on these designed roads was examined.

2.1. Common Features of Designed Roads

Three different road designs have been made to use in analysis. At this stage, design and application flaws and the risks that may arise as a result of speed changes were tried to be determined. There are no vertical curves in road designs. Common features for all roads designed for analysis are presented in Table 1.

Table 1. Common Feature of Roads Used in Design

Feature of the Road	Value
Project speed (Vp) (Km/ h)	100
Number of lanes	2x2
Strip width (m)	3.5
Banquet width (cm)	50

2.1.1. Road design with a single curve

The road consists of 3 sections. These sections are 100 m alignment, a curve with a radius of 400 m and a length of 100 m, and then a 100 m alignment. The road is divided by barriers. There are also barriers on the sides of the road. Side barriers are 50 cm wide, 80 cm high and 40 kg/m in weight. The barrier in the middle of the road is 1.5 m wide, 80 cm high and 120 kg/m in weight (Figure 1).

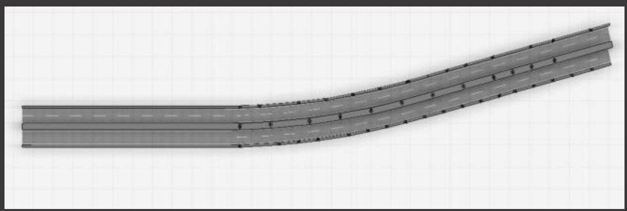


Figure 1. Road design with a single curve

2.1.2. Road design with 60m distance between two reverse curves:

The road consists of 5 sections. These sections are 100 m alignment, a curve with a radius of 400 m and a length of 100 m, 60 m alignment, a reverse curve with a radius of 400 m and a length of 100 m, and then a 100 m alignment. The road is divided by barriers. There are also barriers on the sides of the road. Side barriers are 50 cm wide, 80 cm high and 40 kg/m in weight. The barrier in the middle of the road is 1.5 m wide, 80 cm high and 120 kg/m in weight (Figure 2).

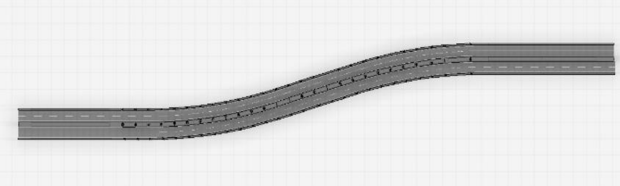


Figure 2. Road design with 60m distance between two reverse curves.

2.1.3. Road design with 0 m between two reverse curves

The road consists of 4 sections. These sections are 100 m alignment, a curve with a radius of 400 m and a length of 100 m, a reverse curve with a radius of 400 m and a length of 100 m, and then a 100 m alignment. Alignment is not left between both curves. The road is divided by barriers. There are also barriers on the sides of the road. Side barriers are 50 cm wide, 80 cm high and 40 kg / m in weight. The barrier in the median is 1.5 m wide by 80 cm high and its weight is 120 kg / m (Figure 3).

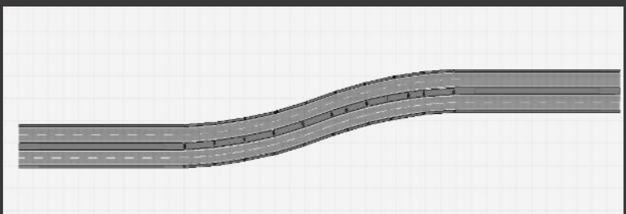


Figure 3. Road design with 0 m between two reverse curves.

2.2. Information on the vehicle selected to be used in analysis

In the analysis, BMW brand vehicle with all features given in Table 2, was used with the thought that it will perform well at high speeds.

Table 2. Features of the vehicle used in the analysis

Vehicle Features	Value
Brand / Model	BMW M5 F90
Class	D
Horsepower (cm^3)	4941
Engine power (kW)	294
Mass (kg)	1837
Length (m)	4.78
Height (m)	1.43
Width (m)	1.8
Sprocket distance to front axle (m)	1.36
Number of Axles	2
Distance between front two tires (m)	1.51
Distance between two tires (m)	1.53
Wheelbase (m)	2.83
Front overhang length (m)	0.83
Rear overhang length (m)	1.11

3. Method

3.1. Simulation Programs

In this study, Virtual Crash 4 program was used as a virtual reality program. Apart from this, there are also programs used for different analyzes in the world. These programs can be summarized as follows. ISSD VISSIM; It is a micro-scale simulation software that combines all road users such as private vehicle traffic, logistics services, public transportation, pedestrians and cyclists and their interactions in a single model [12]. ISSD VISUM; It is software used for network and demand modeling, analysis of expected traffic flow, planning public transportation services, and developing transportation strategies and solutions [13]. ISSD VISTRO is the software with the ability to determine the intersection service level, signal time optimization, traffic impact analysis, manage multiple scenarios and generate comprehensive reports [14]. VISWALK is software that models the interaction between pedestrians and vehicles and works in integration with PTV Vissim. It realistically and reliably analyzes pedestrian movements by simulating places such as pedestrian zones, subway stations [15]. PTV Optima is a software system that can monitor traffic in real time and make short-term traffic estimation (flow, speed and density) [16]. AUTODESK INFRAWORKS, Autodesk InfraWorks is pre-design software that combines and connects data to create, view, analyze, share and manage information to make the right design decisions [17]. Another simulation program is AnyLogic simulation modeling. This program provides a road traffic library that enables traffic flow simulation that has the power to deliver efficient road traffic engineering and design. The freedom to experiment with traffic simulation software and the ability to optimize the right models provide the best platform for success in road traffic planning and engineering [18].

3.2. Virtual CRASH 4

It was especially preferred due to its ability to access the Virtual Crash 4 program and its ease of use. In addition, the fact that this program was preferred more worldwide than other programs and the possibility of obtaining more detailed data was also effective. Virtual Crash program is used to simulate even the most difficult accidents.

• In Virtual CRASH 4, it is integrated into the Google Earth user interface. It provides the opportunity to find the coordinates of the region where the accident occurred and upload it directly to the program using Easy Surface Builder.

• With the road animation tool, you can create animated motion sequences in Virtual CRASH 4 without using the simulation engine to control vehicle movement. It automatically interpolates in Virtual CRASH 4 when you specify key positions and directions along vehicle trajectories.

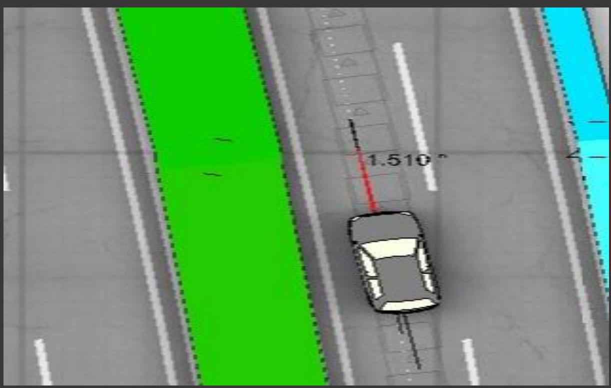
• It is a simulation program that we can determine our own lighting, road geometries, vehicle characteristics, and speed of vehicles, environmental conditions, human reaction times and many more [19].

4. Research Findings

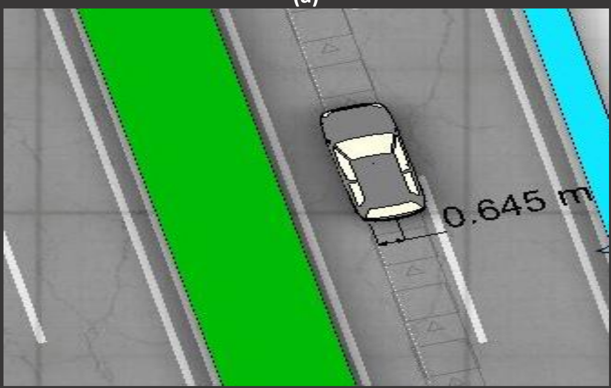
4.1. Analysis results on the road with a single curve

The first analyzes were made on the single curved road, the feature of which is defined in other sections. The slip angles and horizontal displacements occurring in the vehicle traveling at the project speed (Vp: 100 km/h) and above this speed (between 110-220 km/h) on the designed road were determined.

The data obtained from the Virtual CRASH 4 program, which is a virtual reality program for the determination of shear angles and horizontal displacement values, are presented in Figure 4-6. In addition, the slip angles and horizontal displacement distances that occur in the vehicle as a result of the speed change on the designed road are presented in Table 3 for all speed values. When the results are examined, it will be seen that no slip angle and horizontal displacement were detected at the project speed of 100 km/h and 110 km/h.



(a)



(b)

Figure 4. Maximum slip angle at 120 km/h (a), Maximum displacement at 120 km/h (b)

The maximum slip angle was determined as 1.51° at a distance of 48.8 m from the start of the curve, at a distance of 0+148.4 m from the starting point of the road while the vehicle was traveling on a single curve with a speed of 120 km/h (Figure 4a). The vehicle is 0+208.5 m from the starting point of the road; it performed a maximum horizontal displacement of 8.5 m after the end of the curve. It was calculated that it slid from its initial position of 0.645 m (Figure 4b).

While the vehicle is traveling on a road with a single curve at 170 km/h, the maximum slip angle at 0+149.22 m from the starting point of the road is 3.819°. The maximum slip angle occurred at a distance of 49.22 m from the beginning of the curve (Figure 5a). The maximum displacement distance of the vehicle at the same speed at a distance of 0+218.68 m from the starting point of the road is 2.357 m. The maximum displacement distance has been determined 18.68 m from the curve's end point (Figure 5b).

(a)

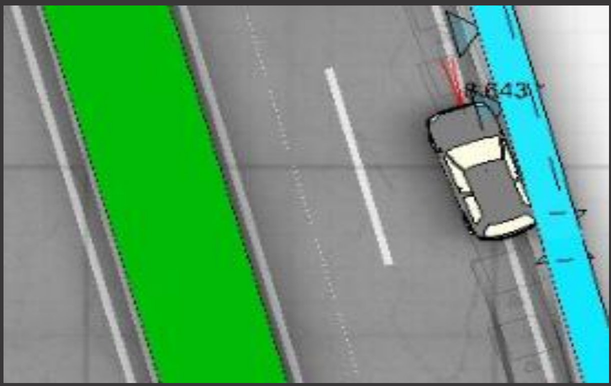
(b)

Figure 5. Maximum slip angle at 170 km/h (a), Maximum displacement at 170 km/h (b)

While the vehicle was traveling on a road with a single curve with a speed of 220 km/h, it was determined as 0+208.6 m from the starting point of the road and 8.6 m from the end of the curve as a maximum slip angle of 8.643° (Figure 6a). The vehicle is 0+231.58 m from the starting point of the road; it has performed a maximum displacement 31.58 m after the end of the curve and it is calculated that it has shifted from its initial position of 4.369 m (Figure 6b).

In order to determine the critical slip angle and displacement distances that may cause accidents in the same road design, separate analyzes were made for each 10 km/h where the speed changes. The data obtained are presented in Table 3.

When the table is examined, it is observed that the stability of the vehicle can vary in different parts of the road according to the speed condition, and despite the 8% max thrust slope applied on the road, deviation angles and displacement situations arise with the effect of centrifugal force.



(a)

(b)

Figure 6. Maximum slip angle at 220 km/h (a), Maximum displacement at 220 km/h (b)

Table 3. Analysis results for different speed values for single curb road design

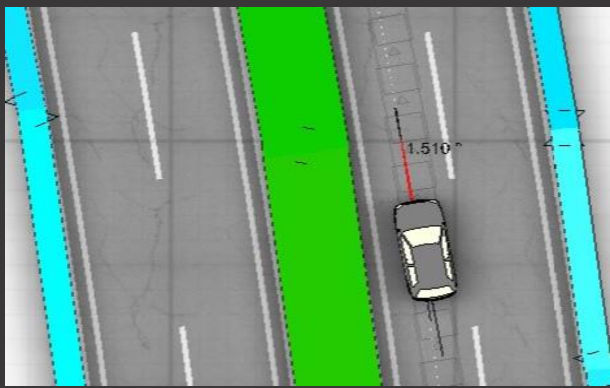
Speed (Km/h)	Maximum Slip Angle		Maximum Displacement Distance	
	°	From the Beginning of the Road (m)	m	From the Beginning of the Road (m)
100	-	-	-	-
110	-	-	-	-
120	1.51	148.4	0.645	208.5
130	1.743	151.92	0.895	214.28
140	2.063	147.11	1.173	218.28
150	2.873	107.33	1.42	205.79
160	3.122	155.06	1.737	217.92
170	3.819	149.22	2.357	218.68
180	3.692	151.45	2.612	220.05
190	4.927	153.055	1.522	224.045
200	5.406	150.55	3.573	229.888
210	4.254	145.71	4.369	231.58
220	8.643	208.6	4.667	208.6

4.2. Results of the analysis made in the design of the road with 60m between two reverse curves

In the previous section, road design features were defined and there is 60 m distance between curves on the road consisting of two reverse curves. The slip angles and displacements occurring in the vehicle traveling at project speed and above (100-220 km/h) on the designed road were determined with the help of the virtual reality program. The slip angles and displacement distances obtained at different speeds are presented in Figure 7-10.

In addition, for curves with designed inverted curves and the minimum distance between these two curves, which is a 60 m rotational application distance, the changes in the vehicle as a result of the change in speed are examined separately for both curves. Analysis results for all speed values are presented in Table 4.

The vehicle traveling in the first of the two reverse coupes with a speed of 120 km/h, the maximum slip angle at 0+148.4 m from the starting point of the road is 1,510 °. The maximum slip angle occurs at a distance of 48.4 m from the start of the first curve. (Figure 7a). The vehicle entering the second curve at the same speed reaches the maximum slip angle of 2,107° at a distance of 0+300.9 m from the starting point of the road. The maximum slip angle occurs 40.9m ahead of the start of the second curve (Figure 7b).

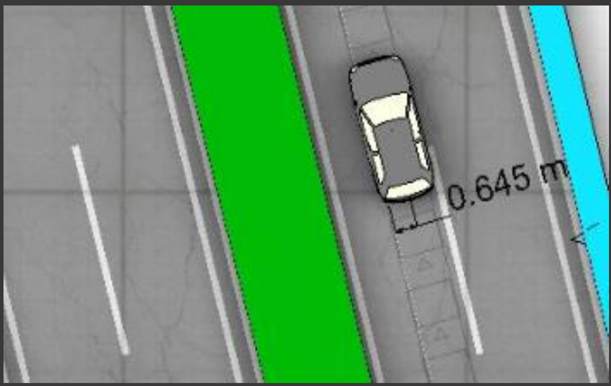


(a)

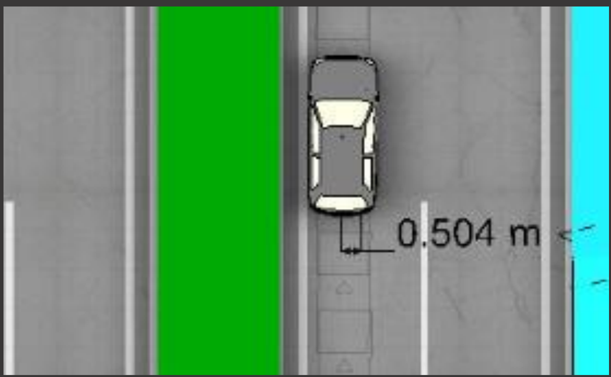
(b)

Figure 7. Maximum slip angle at 120 km/h (1st curve) (a), Maximum slip angle at 120 km/h (2nd curve) (b)

The maximum displacement distance is 0.645 m at a distance of 0+208.5 m from the starting point of the road while the vehicle is traveling on a road with two reverse curves at 120 km/h. The maximum displacement distance was determined 8.5 m ahead of the end point of the first curve (Figure 8a). The vehicle, whose speed did not change, entered the second curve of the same road and the maximum displacement distance was 0+368.27 m from the starting point of the road was 0.504 m. The maximum displacement distance is 8.5 m ahead of the end point of the second curve (Figure 8b).



(a)



(b)

Figure 8. Maximum displacement at 120 km/h (1st curve) (a), Maximum displacement at 120 km/h (2nd curve) (b)

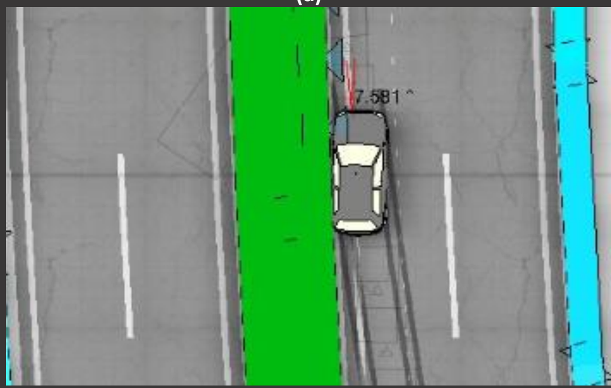
When the speed of 220 km/h is reached, the vehicle tries to enter the second curve after rubbing the right barriers in the first curve, but due to the speed, the vehicle cannot provide stability and leaves the road by rolling. For this reason, the deflection angle and displacement distance for 220 km/h could not be calculated in the second curve.

In order to see the maximum deflection angles and displacement distances in both curves, the vehicle's speed changes of 210 km/h are presented.

The maximum slip angle is 4,254° at 0+145.71 m from the starting point of the road while the vehicle is traveling on a road between 210 km/h and 60 m between two reverse curves. The maximum slip angle was formed 45.71 m ahead of the beginning of the curve. (Figure 9a). The maximum slip angle at 0+345.97 m from the starting point is 7,581°. The maximum slip angle was observed 85.97m further from the beginning of the second curve (Figure 9b).

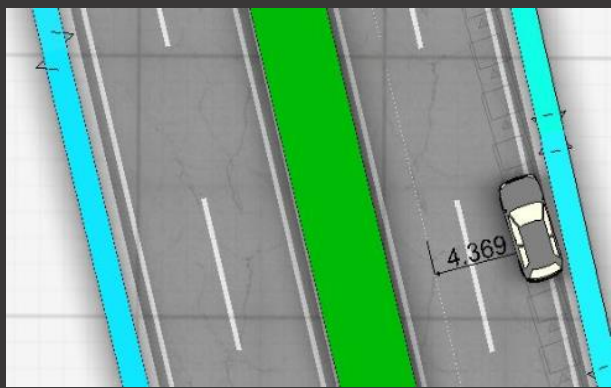
While the vehicle was moving at 210 km/h, the maximum displacement distance was 4.369 m in 0+231.58 m ahead, and the maximum displacement distance was 1.516 m at 0+345.97 m while moving on the second curve (Figure 10).

(a)

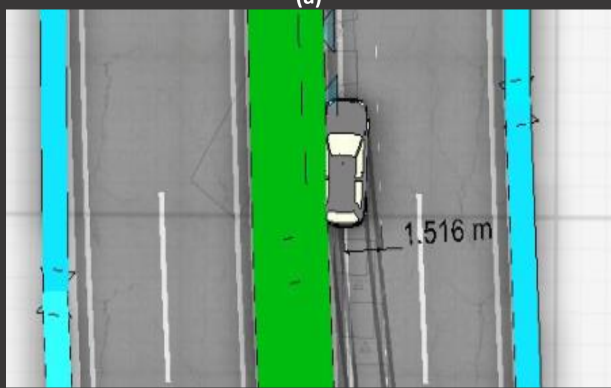


(b)

Figure 9. Maximum slip angle at 210 km/h (1st curve) (a), Maximum slip angle at 210 km/h (2nd curve) (b)



(a)



(b)

Figure 10. Maximum displacement at 210 km/h (1st curve) (a), Maximum displacement at 210 km/h (2nd curve) (b)

All analyses made for different speed values on the road with two reverse curves designed by giving 60m spacing, which is the minimum superelevation application distance, were repeated for both curves and presented in Table 4.

Table 4. Analysis results depending on the speed change for the reverse curve road design with 60m distance between them.

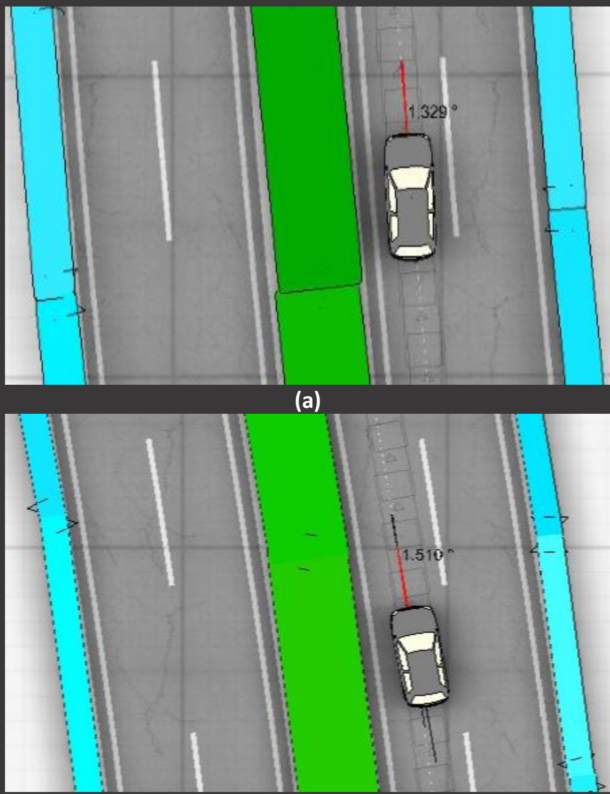
	Speed (Km/h)	Angle °	Distance to start (m)	Max displaceme nt	Distance to start (m)
1. Curve	100	-	-	-	-
	110	-	-	-	-
	120	1.51	148.4	0.645	208.5
	130	1.743	151.92	0.895	214.28
	140	2.063	147.11	1.173	218.28
	150	2.873	107.33	1.42	205.79
	160	3.122	155.06	1.737	217.92
	170	3.819	149.22	2.357	218.68
	180	3.692	151.45	2.612	220.05
	190	4.927	153.055	1.522	224.045
	200	5.406	150.55	3.573	229.888
	210	4.254	145.71	4.369	231.58
	220	8.643	208.6	4.667	208.6
2. Curve	100	-	-	-	-
	110	-	-	-	-
	120	2.107	300.9	0.504	368.27
	130	2.279	313.59	0.751	367.21
	140	2.541	309.75	1.029	362.61
	150	1.862	315.79	1.288	355.92
	160	4.117	341.24	0.851	339.68
	170	3.585	339.9	1.432	339.9
	180	4.687	335	1.469	335
	190	5.524	339.015	1.251	339.015
	200	6.261	340.77	1.323	340.77
	210	7.581	345.97	1.516	345.97
	220	-	-	-	-

4.3. Analysis results on the designed road without leaving superelevation application distance between two reverse curves

In order to determine the risk of accidents that may arise from design or application errors, roads where even the minimum distance between the reverse curves is not used in the road construction specification. The deviations from the road that will occur due to speed changes on these roads were determined at the end of the analysis. Visuals and tables regarding the analysis are presented below.

In Figure 11a, the vehicle reaches the maximum slip angle at a distance of 0+148.4 m from the starting point of the road while traveling on a road with a distance of 120 km/h and 0 m between two reverse curves, and this value is determined to be 1.51°. When the vehicle reached 0 + 264.66 m from the starting point of the road, the maximum slip angle was 1,329°. It was observed that the maximum slip angle occurred 64.66 m further from the starting point of the second curve (Figure 11b).

While the vehicle is traveling on the road between 120 km/h and 0 m between two reverse curves, the maximum slip distance at 0+208.5m from the starting point of the road is 0.645 m. The maximum slip distance occurs at a distance of 8.5 m from the second curve's end point. (Figure 12a)



(b)

Figure 11. Maximum slip angle at 120 km/h (1st curve) (a), Maximum slip angle at 120 km/h (2nd curve) (b)

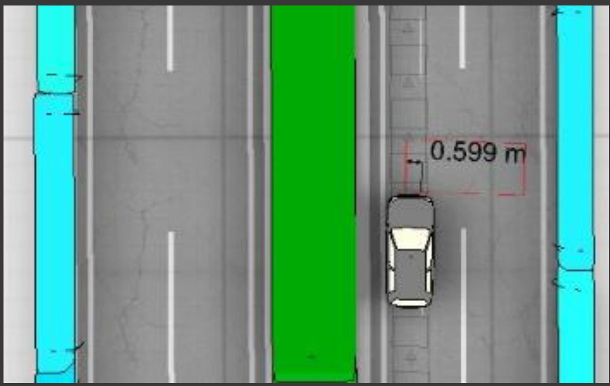
While the vehicle is traveling on a road between 120 km/h and 0 m between two reverse curves, the maximum slip distance is 0.599 m at 0+305.4 m from the starting point of the road. The maximum slip distance occurs at a distance of 5.4 m from the second curve's end point. (Figure 12b)

When the speed of 210 km/h is reached, the vehicle tries to enter the second curve after rubbing the right barriers on the first curve, but due to the speed, the vehicle cannot provide stability and leaves the road by rolling over. For this reason, the deflection angle and displacement distance for 210 km/h and 220 km/h could not be calculated in the second curve.

In order to see the maximum deflection angles and displacement distances in both curves, the changes of the vehicle at a speed of 200 km/h are presented.

While the vehicle is traveling with 200 km/h on the road where there is no rotational application distance between two reverse curves, the maximum slip angle is 5.406° at 0+150.55m from the starting point of the road. The maximum slip angle occurs at a distance of 50.55 m from the starting point of the curve. (Figure 13a). While the vehicle is traveling on the road between 200 km/h and 0 m between two reverse curves, the maximum slip angle is 1,855° at 0+280.5 m from the starting point of the road.

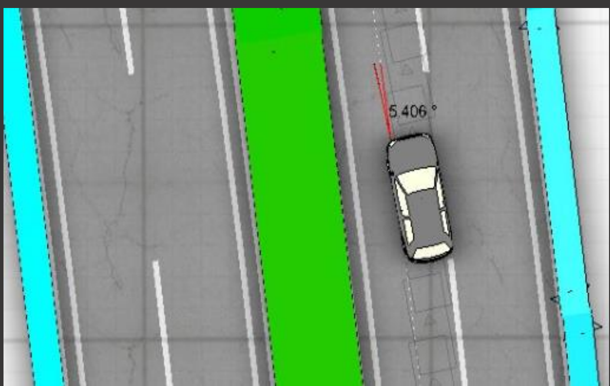
The maximum slip angle occurs at a distance of 80.5 m from the starting point of the second curve (Figure 13b).



(a)

(b)

Figure 12. Maximum displacement at 120 km/h (1st curve) (a), Maximum displacement at 120 km/h (2nd curve) (b)

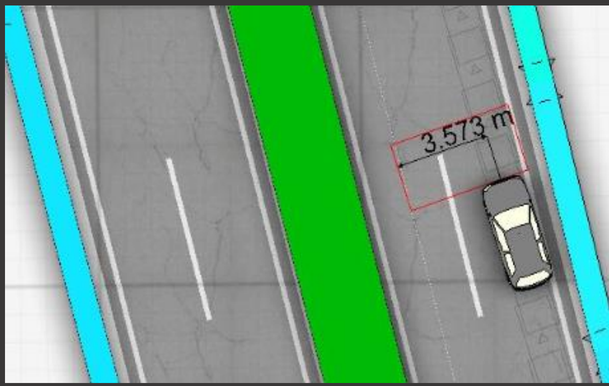


(a)

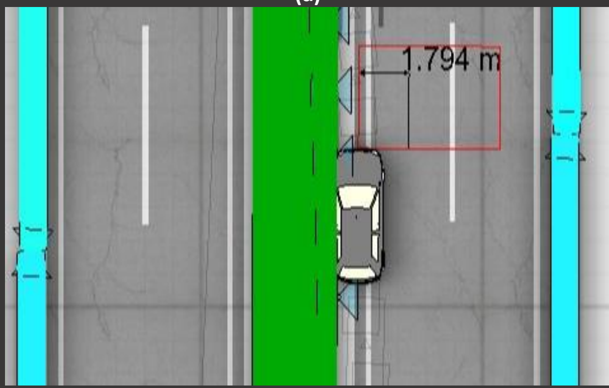
(b)

Figure 13. Maximum slip angle at 200 km/h (1st curve) (a), Maximum slip angle at 200 km/h (2nd curve) (b)

While the vehicle was moving at 200 km/h, the maximum displacement distance was 3.573 m in 0+229.88 m ahead, and the maximum displacement distance was 1.794 m at 0+314.88 m while moving on the second curve (Figure 14).



(a)



(b)

Figure 14. Maximum displacement at 200 km/h (1st curve) (a), Maximum displacement at 200 km/h (2nd curve) (b)

The results of the analysis obtained at the end of these analyses, which were made to investigate the dangers of design-based errors with speed variation and without a minimum superelevation application distance, are presented in Table 5.

When the data in the table is examined, it has been observed that after a certain speed value, the vehicle tends to deviate from the road on the first curve, and when the speed limits are pushed, serious dangers can arise from the friction to the barriers and the vehicle rolling.

5. Results and Suggestions:

In this study, the importance of geometric standards to be preferred in highway design has been revealed. In all of the studies, it has been calculated assuming that the vehicles do not use any brakes. In addition, it has been revealed at the end of all analyses that the biggest factor in accidents is speed.

Table 5. Changes due to the change in speed in reverse curves without deviation application distance between them.

	Speed (Km/h)	Angle °	Distance to start (m)	Max displacement	Distance to start (m)
1. Curve	100	-	-	-	-
	110	-	-	-	-
	120	1.51	148.4	0.645	208.5
	130	1.743	151.92	0.895	214.28
	140	2.063	147.11	1.173	218.28
	150	2.873	107.33	1.42	205.79
	160	3.122	155.06	1.737	217.92
	170	3.819	149.22	2.357	218.68
	180	3.692	151.45	2.612	220.05
	190	4.927	153.055	1.522	224.045
	200	5.406	150.55	3.573	229.888
	210	4.254	145.71	4.369	231.58
	220	8.643	208.6	4.667	208.6
2. Curve	100	-	-	-	-
	110	-	-	-	-
	120	1.329	264.66	0.599	305.4
	130	2.1	247.54	0.576	300.51
	140	1.997	252.93	1.046	312.82
	150	3.305	268.75	1.346	314.875
	160	3.299	262.91	1.514	309.68
	170	2.71	264.208	1.644	310.86
	180	2.576	272.05	1.652	308.2
	190	2.879	272.06	1.69	310.175
	200	1.855	280.5	1.794	314.88
	210	-	-	-	-
	220	-	-	-	-

It can be seen in Table 3-5, the stability of the vehicle in the curve depends directly on the speed and geometric standards of the road. All test results have shown that the risk of accident is at the minimum level at project speed and speed values close to this. Failure to comply with the rules in the road design criteria also poses a risk. When Table 4 and Table 5 are examined, despite the same design, not leaving a distance between the curves causes the risk to increase with the increase in speed.

In the first design of the vehicle with a project speed of In the first design, the vehicle traveling at the project speed or 10% above the project speed did not cause any slipping or displacement problems. These speed values did not pose a risk to the vehicle.

It was determined that vehicle slippage started to occur when the project speed was exceeded by 20%. If the project speed exceeds 40% on the same road, the vehicle slips into the side lane and poses a danger to both itself and another vehicle traveling in the same direction.

When Table 3 is examined, it is seen that the slip angle and horizontal displacement distance increase in direct proportion to the speed while the vehicle is in the curve. In the first road design, for two vehicles traveling in the same direction, while traveling at speeds of 150 km/h and above, the possibility of an accident will be very high if the other driver does not show reflexes. In cases where the speed is 180km/h and above, it is seen that the gain will be inevitable.

When Table 3, Table 4 and Table 5 are compared, the changes in the vehicle in the first design are the same as in the first curve of the other designs. When the roads with two reverse curves are compared, it is clearly seen again that the distance between the curves is important for traffic safety. When the distance between curves decreases, slip angles and displacement distances pose a great risk for traffic.

It was observed that with the increase of the distance between the reverse curves, the stability of the vehicle increased. Thus, it has been observed that the risk of accident arises at higher speeds.

Due to the fact that the vehicle is traveling in the left lane in the simulation, there is not much difference between the max horizontal displacement distances of the vehicles. However, considering the distance covered by the vehicle until reaching its maximum sliding distance, on the second road; in other words, when the distance between the reverse curves is in line with the standards, it has shown that the vehicle is more advantageous than other ways to cross the curve.

It can be seen from the tables that the angle of slip in the second curve increases with the increase of the distance between curves. However, it is also observed that the positions where the maximum slip angles take place go further at the starting point.

Based on these results, it was revealed that speed is an important parameter in the selection of geometric standards. In addition, it has been determined that the minimum distance required for reverse curves poses serious accident risks. Correct design criteria to be carried out on the roads will be able to absorb errors caused by the driver on the road, thus minimizing loss of life and property.

Declaration of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution Statement

S. Serin: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing original draft, Writing review & editing – **Y. E. Açar**: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing original draft, Writing review & editing – **A. K. Açıkgöz**: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Writing original draft – **A. Şahin**: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Writing original draft

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