INFLUENCE OF SPEED VARIATION ON HUMAN BEHAVIOR WHILE NEGOTIATING THE HORIZONTAL CURVE

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Abstract: Coinciding horizontal and vertical curve leads to an undesirable situation for road users controlling the vehicles and increases the potential for skidding and roll over of a moving vehicle. As the results, these regions are prone to be among the blackspots. Therefore, for these region evolution of safety condition of moving vehicle is very essential. There are various factors which affects the vehicle safety requirements at the curves, from which effects of lateral acceleration on human behavior with varying speed of vehicle is addressed in the study. Selection of the location for the defined problem must be concise and factual, therefore Kotarpur horizontal curve is used for the study which is the biggest curve of Ahmedabad city. Study shows the effects of speed variation on lateral force acceleration and human behavior as in heartbeat rate count per minute, which ultimately gives the general idea about driver's physical and psychological situation while negotiating the curve, which may lead to accidents and indirectly increases the risk or crash factor of the curve and calls for the check of safety requirements at the horizontal curve.

***IndexTerms*- Horizontal curve, Lateral acceleration, Human behavior, Heartbeat rate count, Variation in speed of vehicle.**

I. INTRODUCTION

1.1 General

Horizontal curves are a necessary part of any highway system, yet they can present significant safety concerns. In general, curves represent only a small fraction of most state highway systems, but a disproportional number of serious crashes occur at these locations. Research shows that curves are associated with more crashes because of their decreasing radius or speeds on the roadway increase. The collision rates on such curves are between 1.5 and 4 times greater than on similar straight section. For instance, the Green Book (AASHTO 2011) considers a point-mass model for the basic curve equation. Horizontal curves designed in accordance with Green Book criteria have been generally shown to provide substantial margins of safety with respect to vehicle skidding and rollover, for both passenger cars and trucks. The design speed is the one of the most important factors on which geometric design of road depends.

Design speed affects various aspects of highway alignment including radius of horizontal curve, rate of super-elevation, extra widening of pavement at horizontal curves and most importantly lateral acceleration. The main objective or aim of the study is to find the effects of lateral acceleration on human behaviour while negotiating the curve to get the general idea about treacherous condition and its effects on driver, blackspots and how dangerous and uncomfortable situation a defined horizontal curve can create for the driver. First phase of the study gives the classification of vehicle with PCU values at peak hours, Second phase covers the generation of acceleration values on 50 meter radius curve with varying speed, while last phase covers the heartbeat rate count of the driver with respective speeds and its effects on driver's behaviour on the curve.

To calculate the lateral acceleration and side friction three axis accelerometer and ball-back indicator were addressed by Professor J. F. Morrall & R. J. Talarico in March 2015. The factors considered were swerving and increased steering effort required at the horizontal curve. They took linear continuity as one of the basic requirement of highway alignment, who puts number of different research models and quantitative evaluation methodology. Road alignment index considered to find the relation between theoretical and actual operating speed which includes curve radius, vertical slope, horizontal angle, curve length, slope length, super-elevation, cross slope, number of lane, width of lane and various other factors by integrated transportation system in July 2010. Faisal Awadullah derived that sudden variation in acceleration value results in failures like skid and roll-over.

II. LITERATURE REVIEW

2.1 Prof. J. F. Morrall et. al. 2015 In this paper to calculate lateral acceleration and side friction three axis accelerometer and ball-back indicator were used by attaching the equipment in different types of vehicles. Among them all maximum value of side friction factor required were determined and used for calculating the mode of safety for particular horizontal curve should be provided at different speeds.

Other two important factors which are mostly ignored by other authors were considered in this paper. The factors were swerving and increased steering effort required at the horizontal curve. According to the paper, the actual ball-back reading is the

total sum of centrifugal force and body roll angle subtracting the value of super-elevation, which ultimately provides the actual value of centrifugal force acting on a vehicle using calculated safe side friction factor value combined with radius of curve and varying acceleration rate and average safe speed. The aim of the study was to determine the actual side friction value required at the study area location and side friction provided at the curve. Point mass formula was used to find the side friction value at the study area and finally to find the average safe speed for the drivers to negotiate the curve with pleasant safe condition.

2.2 Zhonggin Guo et. al. 2010 Main focus in this paper was given to the linear continuity in speed in all the aspects of highway. The authors addressed that alignment design and evaluation based on operating speed is an effective way to solve safety design problems. In this paper the relation between the road alignment index and current operating speed was analysed and the actual required operating speed prediction was established.

Model generated in the process was highly reliable on observed values as well as predicted values. Road alignment index was considered to find the relation between theoretical and actual operating speed. At the end minimum difference between observed and predicted values were about 20% after all the calculations done at the desired study area, and resulted difference is significant according to AASHTO guideline.

2.3 Faisal Awadullah et. al. 2005 The literature derived that for horizontal curves if radius is greater than allowable limit than there's no need to provide the maximum super-elevation rate. As far as side friction is concerned, according to the literature side friction demand is negative when super-elevation does exists & speed is lower than the threshold limit at the considered study area or location and another thing considered that if radius is larger than required limit, than after summing this all factors ultimately means comparatively less side friction factor is required. If side friction demand is greater than supplied friction which means if demand is greater than one, than it determines that speed of the vehicle, radius of the curve and super-elevation are impossible for safe driving situation.

According to the literature addressing fact is side friction supply and demand mainly depends on two types of failures which are skid and roll over. The method in the paper provides thoroughly consistent design with known safety factor in terms of speed and margin of safety before the start of detection of lateral acceleration.

2.4 Kimberley Musey et. al. 2016 According to the studies 25% of fatal crushes occurs on horizontal curves. Highways friction surface treatments have the potential to greatly contribute to the safety and overall traffic safety goal with the modest cost, schedule and environmental impact.

This research involves identification of crash data to identify correlation between Skid number, Roadway curvature, Crash rate and Crash severity. Need of this research on horizontal curve as an alignment and how it will assist in reaching safety aspects or goals on roadways. Research shows how correlation between this data can be used to develop CMF (crash modification factor). Main aim of the research is to conduct a review of crash data and identify correlation between crash severities, crash type and pavement skid number. High friction surface treatments are less costly, requires low schedule and provides sustainable means of improving road safety.

2.5 Alan Nicholson et. al. 2010 In this paper main focus or more attention was given to the grater consistency in highway design to minimize the frequency and extent of violations of driver's expectancy. Main objective or aim was to have reasonably large safety margin which does not vary much from curve to curve.

Two sources of inconsistency were addressed in road alignment design using either speed-environment or speed-profile method to ensure design speed for each curve. Another main concern of the paper was margin of safety and improve road safety. Paper shows the accident rate increases proportionally with the decrease in radius of horizontal curve, while the accident rate for small radius horizontal curves generally being less or decreases as the frequency of curve increases. The literature works on two basic principles, first is all curves within a section of road should be designed for the same speed and second principle is the design speed should reflect uniform speed at which higher percentage pf drivers desire to operate. Main aim was to eliminate two source of inconsistency, first was the choice of design speed, second was the choice of side friction factor and super-elevation when curve exceeds minimum required limiting radius.

III. STUDY AREA

3.1 Briefing of the Location

The study area must be in such way that it could define the problem in the objective of the study. The kotarpur is the area located in the Ahmedabad city of the Gujarat state. Ahmedabad is seventh largest metropolis city in India and largest city in Gujarat. Ahmedabad is the commercial capital of the state and is also known as the textile capital of India. Ahmedabad has excellent connectivity through Air, Road, Rail lines with Mumbai and Delhi. Historically Ahmedabad has been one of the most important centre of trade and commerce in western India. Where in the Kotarpur area located in Ahmedabad city has the biggest horizontal curve of the city.

The road inventory details of the location is given below in the tabular forms.

Table 3.1 Road Inventory Primary Data

Name of Location	Land use		Terrain Condition	Curve	Drainage Condition
	Left	Right			
Kotarpur	Village & Industrial area	Sardar Vallabhbhai Patel Airport	Plain Terrain	Horizontal Curve	Covered Drain

The curve is considered as densely traffic populated and one of the major accident prone zone or blackspots of the city. The curve matches the criteria for the study area selection. Kotarpur horizontal curve is located in the vicinity of the Sardar Vallabhbhai Patel airport Ahmedabad, Gujarat, India (23°05'34.6"N 72°38'54.5"E).

Table 3.2 Road Inventory Secondary Data

Curve Section		Shoulder			Carriageway			Formation width (m)	Median (m)	Side walk (m)
		Type	Width (m)	Condition	Type	Width(m)	Condition			
Straight	Outer edge	BT-Bitumen	nil	G-Good	BT-Bitumen	11.7	F-Fair	11.7	Width 1.27	Width 1.32
	Inner edge		nil			6.8		9.88		
Circular	Outer edge		3.85			11.6		15.45		
	Inner edge		7.42			13.2		20.62	Height 0.38	Height 0.17
Straight	Outer edge		3.68			10.25		13.93		
	Inner edge		3.7			11.15		14.85		

Type: BT = Bituminous CC = Cement Concrete GR = Gravel ER= Earthen
Condition G = Good F = Fair P = Poor VP = Very Poor
Terrain: P- Plain, R- Rolling, M- Mountainous, S- Steep
Road Side Drain: CD- Cover Drain, LD- Lined Drain, UD- Uncovered Drain

IV. DATA COLLECTION

4.1 Classified Volume Count - CVC

One of the fundamental measures of traffic on a road system is the volume of traffic using the road in a given interval of time. It is also termed as a flow and expressed in vehicle per hour or vehicle per day. Vehicles are classified comprising of smaller vehicles: Motorised two-wheeler, motorised three-wheeler, Light commercial vehicles (LCV), Bus, Truck & Tractors. Various type of sedan or four wheelers considered as a single unit i.e. car, jeep & van, while all types of trucks & tractors whether they are single axle, double axle or three axle & tractor trailer unit are considered as a single classified volume category.

After the data collection, Data extraction was done to carryout mandatory data of the vehicle passing through the curve in defined time interval. The record was carried for the 09:00 am to 11:00 am in the morning and 06:00 pm to 08:00 pm peak hour in the evening.

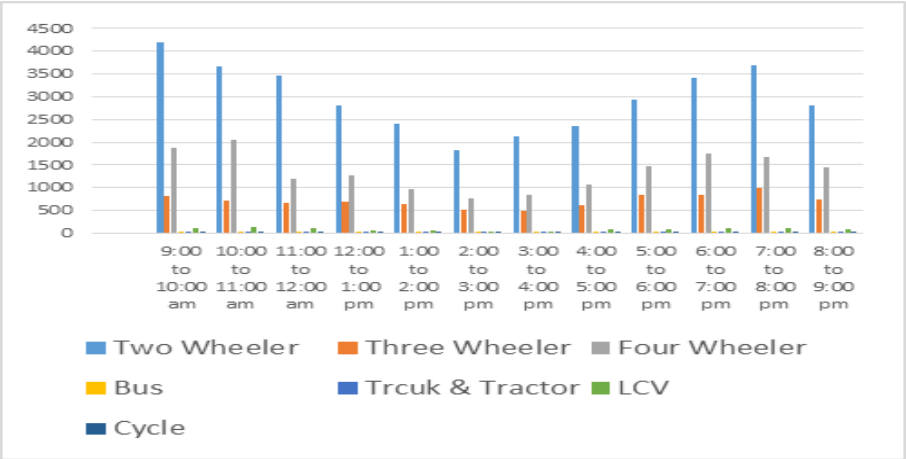

Figure 4.1 Classified Volume Count for the Day

Peak hours at the location was decided by taking the vehicle count for the whole day with the same videography method. A graph for the vehicle count for the day is given in the following figure. After collecting the video footage at the location, further analysis was done in the office by replaying all the video data on the PC monitor.

Table 4.1 CVC for the Peak Hour 9:00 to 11:00 am

Kotarpur Horizontal Curve							
Time Duration(AM)	**Two Wheeler**	**Three Wheeler**	**Four Wheeler**	**Bus**	**Truck & tractor**	**LCV**	**Cycle**
09:00 to 09:15	947	215	376	5	4	18	5
09:15 to 09:30	1016	252	412	1	5	29	6
09:30 to 09:45	1178	182	498	4	3	24	4
09:45 to 10:00	1050	161	586	2	2	31	5
10.00 to 10.15	1019	152	592	4	2	37	3
10:15 to 10:30	846	185	543	3	3	25	4
10:30 to 10:45	975	173	486	5	2	39	3
10.45 to 11:00	817	198	437	3	2	33	3
Sub Total	7848	1518	3930	27	23	236	33
PCU value	**0.5**	**0.8**	**1.0**	**3.5**	**3.5**	**2.2**	**0.2**
PCU	3924	1215	3930	95	81	519	6.6
Total PCU	**9769**						

CVC survey was taken at the location for the whole day, the volume count for the different classified vehicles was taken by replaying the video footage and counting each type of vehicle separately. The counting result addressed that peak hours for the decided or selected curves were 9 to 11 am at morning and 6 to 8 pm for the evening. The graphical representation of the data is plotted in the chart 1. As shown in the chart maximum quantity of vehicle type in PCU are four wheelers and two wheelers.

Table 4.2 CVC for the peak hour 6:00 to 08:00 pm

Kotarpur Horizontal Curve							
Time Duration(PM)	**Two Wheeler**	**Three Wheeler**	**Four Wheeler**	**Bus**	**Truck & Tractor**	**LCV**	**Cycle**
06:00 to 06:15	768	227	419	4	1	23	2
06:15 to 06:30	894	213	395	3	1	21	2
06:30 to 06:45	866	204	467	6	0	29	1
06:45 to 07:00	888	190	459	4	2	35	1
07:00 to 07:15	892	263	437	2	2	33	5
07:15 to 07:30	917	291	458	3	3	35	6
07:30 to 07:45	927	213	398	2	1	22	7
07:45 to 08:00	952	222	375	3	1	21	4
Sub Total	7104	1823	3408	27	11	219	28

PCU Value	0.5	0.8	1.0	3.5	3.5	2.2	0.2
PCU	3552	1459	3408	95	39	482	6
Total PCU	**9039**						

4.1.1 Result

The results of the CVC counts shows that maximum number of vehicles passing through the curve at peak hours are two and four wheelers. Though as far as axle load is concerned four wheelers has far more axle load compared to two wheelers, therefore it has more influence on drivers behavior with the negotiation of curve. Therefore four wheelers are given priority in this study to carry out the acceleration with different speed levels and to derive the heartbeat rate count of the driver respective to the variation in speed level.

4.2 Radius of the Curve

The radius of the horizontal curve is an important design aspect of the geometric design. The maximum comfortable speed on a horizontal curve depends on the radius of the curve. Although it is possible to design the curve with maximum superelevation and coefficient of friction, it is not desirable because re-alignment would be required if the design speed is increased in future. Therefore, a ruling minimum radius can be derived by assuming maximum superelevation and coefficient of friction.

$$R_{\text{ruling}} = \frac{v^2}{g(e+f)} \quad (1)$$

To calculate the radius of the curve for the study Google Earth software is used. The radius of the horizontal curve is approximately 40 meters. The derivation of the radius on the Google Earth software is given in the fig.2. If the radius of the curve is greater than limiting value, than vehicles can operate at better speed without any discomfort felt by the driver at the curve. But if radius of the curve is less than specified limit, than curve has to be verified for the super-elevation and lateral friction rate.

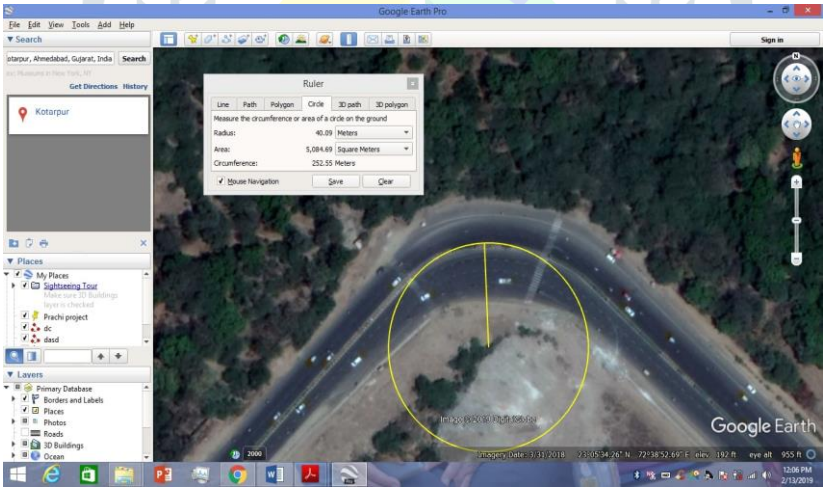

Figure 4.2 Radius of the curve using Google Earth

4.3 Lateral Acceleration and Effects on Human Behaviour

The acceleration capacity of vehicle is dependent on its mass, the resistance to motion and available power. Heavier vehicles have lower rates of acceleration than passenger cars. Variation in acceleration values effects the human behaviour, which increases the risk factor of the location affecting physical as well as psychological characteristics of the driver. That is why the most common sensor in a crash test dummy is the accelerometer. Extreme acceleration can lead to death. Acceleration/deceleration behaviour of vehicles is important for various application like length of yellow light at intersection, determination of sight distance on curves, determination of length of acceleration/deceleration lanes, lane design, traffic simulation modelling, vehicular emission modelling, horizontal curve parameters, etc. The speed at which maximum acceleration rate occurs is referred as critical speed, which varies with vehicle type. This shows acceleration has a strong relationship with speed in all types of vehicles.

For continuing the further calculation process required acceleration data is collected with the help of the accelerometer android application which gives the variation in the acceleration rate in the outward direction with different speed generated while negotiating the curve. Different speed measurements are taken while running the passenger car on the selected curve, and according to those different speed measurements acceleration value counts at every acquired change or variation in the speed.

Table 4.3 Data Extraction of Acceleration and Heartbeat Rate

Acceleration & Heartbeat count Rate					
Project: Redesign of horizontal curve considering the influence of friction factor at Kotarpur using MX Road software					
Name of Road: Kotarpur village Road			**Date : 14 Nov 2018**		
			Time : 03:00 pm		
Outer edge of the Curve			**Inner edge of the Curve**		
Speed (kmph)	**Acceleration (m/s^2)**	**Heartbeat rate (bpm)**	**Speed (kmph)**	**Acceleration (m/s^2)**	**Heartbeat rate (bpm)**
10	0.36	62	10	0.8	63
20	1.01	76	20	1.24	65
30	2.23	77	30	2.03	70
40	3.78	82	40	2.95	76
50	3.89	88	50	5.26	90
55	3.99	99	55	5.51	98
60	4.56	93	60	6.18	96
65	5.6	102	65	6.47	115
70	5.84	116	70	6.63	119

Heartbeat rate count is taken as a major factor to know the affection of the curve to the increasing reaction time of the driver and ultimately causation of accident resulting in a fatal injury or death. To calculate the fluctuation of the heartbeat rate at varying speed stress scan and instant heart rate named applications are used. A driver in this study who drove the car through the curve is having the age of just 22 years. At this young age results of the heartbeat count shows the scary vision of the curve relating to the effects on the driver.

.Although there is no definitive medical advice on when a resting heart rate is too high, but most medical experts agree that a consistent heart rate in the upper level can put too much stress on the heart and other organs. According to AHA (American Heart Association) persons target heart rate zone is between 50 to 85 percent of his or her maximum heart rate. Therefore the target heart rate zone for a 30 year old person would be between percent of his or her maximum heart rate. For a 30 year old person target heart rate zone is calculated as 50 percent: 190 x 0.50 = 95 bpm. Same as for 40 and 50 year old drivers target heart rate zone would be around 85 to 80 bpm respectively and the count will further be reducing with increasing age for safe driving condition.

V. CONCLUSION

The increasing speed, acceleration rate and Heartbeat rate found in the study gives the idea about hazardous condition of the curve. The heartbeat fluctuation kept on increasing with the speed at a very high rate, which could result into very tedious condition for the middle or old age driver. As per results selected location proves to be unpleasant even for the young age drivers as it affects physical and psychological characteristics like reaction time of the driver, fatigue, attentiveness, fear, superstition, etc. The acceleration rate found with the different speed variation could be useful for the friction value formula generation. Results shows that heartbeat rate is proportional to the speed variation. With increasing speed heartbeat rate counts continuously found to be in an increasing manner for the young age drivers, which shows that how dangerous the curve could be for the middle range and over age drivers. The risk factor or crash frequency seeks the attention towards the super-elevation and lateral friction factor values at the curve. In the future scope the friction and super-elevation values must be checked and revised to solve the problem addressed in the paper.

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REFERENCES

- **Papers**

[1] Professor J. F. Morrall & R. J. Talarico 2015, Side friction demanded and margin of safety on horizontal curves published in journal of the Transportation Research Record. ISSN: 0361-1981.
[2] Zhonggin Guo, Xiaohuan ZHOV, Yin YAN 2010, Operating speed prediction based on highway alignment special geometric properties At key laboratory of Road and Traffic Engineering of the ministry of education, published by Integrated Transportation System.
[3] Faisal Awadullah, Theoretical analysis for horizontal curves based on actual discomfort felt with the speed published by Journal of Transportation Engineering, ISSN: 2473-2907.
[4] Kimberley Musey, Seri Park, Ph. D. 2016, Exploring friction modification to improve the safety of horizontal curve roadways published by highway & Transportation research & development, ISSN: 2095-6215.

- **IRC Codes**

[1] Guidelines for Design of Horizontal curves for Highway and Design tables IRC 38:1988
[2] A Policy on Geometric Design of Highway and Streets AASHTO 2004, ISBN: 1-56051-263-6

- **Books**

[1] Kadyali, L. R. and Lal, N. B. 2007, Traffic Engineering and Transport Planning, Khanna Publishers, New Delhi-110006
[2] S. K. Khanna, C. E. G. Justo, A. Veeraragavan, Highway Engineering, Nem Chand & Bros., Roorkee 247667, India, ISBN 978-81-85240-80-0