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Evaluation of Current Design Practices for Horizontal Curves on Rural Highways Based on Vehicle Stability and Safety

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Abstract: All over the world India bangs the top most position in deaths caused by road crashes. Over 1 lakh people are killed or seriously injured in road crashes in India every year, that is more than the number of people killed in all our wars put together. Sixteen children die on Indian rroads daily and there is at least one death every four minutes. Majority of the crashes are found to take place on rural highways. Rural highways are characterized by a low traffic volume and hence, speed of the vehicles is mainly controlled by the geometry. The topological conditions of India have resulted in very complex curves which include combination of horizontal curve and steep gradients up or down. In such environment, the drivers tend to choose the speeds that they perceive to be comfortable to them based on their perception of the criticality of the road geometrics ahead. Any unexpected road feature in the highway may surprise the drivers and may result in erroneous driving manoeuvres, which in turn, may end up in road crashes. As highways are meant for high speed travel, the impact of any collision that takes place will be grievous or fatal. Hence, the highways have to be designed such that their geometry directs the drivers to choose the operating speed which is in harmony with the environment.

A large number of studies are done to evaluate the effect of geometry on operating speed of rural curves. But only a few researches are done to assess the effect of geometry on the stability of vehicles. Skidding and rollover crashes are increasing dramatically, the first being more common in small vehicles like cars and the latter being more common in heavy commercial vehicles like trucks. The availability of sufficient lateral friction to counteract centrifugal force experienced by a vehicle on curve is least studied, especially in India. The values of lateral friction adopted for design of horizontal curves were developed eighty years ago by Barnett 1936; Moyer and Berry 1940. Since then, vehicle fleet has changed completely and hence the demand for lateral friction may also have changed. But the point mass equation widely used for design of horizontal curve relies on lateral friction values developed by them. Also, the equation ignores the effect of vehicular characteristics or complexity of curve geometry. So, studies focusing on revision of geometric design criteria of horizontal curves based on vehicle stability and assessment of existing margin of safety or in other words, a quantitative assessment of risk involved affecting the stability of vehicles is very important. In this paper an effort has been made to identify the gaps in current design practices and to exhibit current status of study in the field of vehicle stability on rural highways.

Keywords: Skidding, Friction, Vehicle Stability, Rollover.

I. INTRODUCTION

When a vehicle travels along a horizontal circular curve, it experiences centrifugal force outward the centre of the horizontal curve. This centrifugal force is inversely proportional to the radius of horizontal curve. Vehicle stability is achieved by the resistive forces that resist the centrifugal force. These forces include frictional interaction between the tires and pavement, and a component of the vehicle weight that acts parallel to the road surface. The frictional interaction between the tires and pavement depends on road surface side-friction factor, which in turn depends on many other factors, including road surface condition, weather and climatic condition, tire condition, and vehicle kinematics. The component of the vehicle weight that acts parallel to the road surface depends on the side slope of the highway, which is usually termed as superelevation. This approach is usually referred to as the point-mass (PM) model, which is adopted by North American design guides due to its simplicity.

Based on the point-mass model, when a vehicle travels along a vertical curve, there is obviously no centrifugal force, and consequently no potential risk for skidding or rollover. However, for 3D(combined) alignments, where a horizontal curve is superimposed by a vertical alignment, the vertical alignment affects the available side friction. For 3D alignments, traditional design guides (AASHTO 2001; TAC 1999) calculate the minimum radius assuming a side friction on a horizontal plane using the point-mass model, thus ignoring the effect of vertical alignment. This approach simplifies cornering dynamics by reducing the vehicle into a point mass travelling on a 2D horizontal alignment.

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So, the point-mass model, currently used in the design of minimum radius of horizontal curves, although relatively simple, has several limitations. The effect of an overlapping vertical alignment is totally ignored. Also, the point-mass model is not based on any particular set of vehicle characteristics and is theoretically as applicable to trucks as it is to passenger cars (Harwood et al. 1994). However, in light of the differences between passenger cars and trucks in terms of size, number of tires, tire characteristics, and suspension characteristics, the suitability of the point mass assumption for trucks has to be re-examined. It was found that although the friction demands at the four tires of passenger car are approximately equal, the friction demands at various tires of a tractor- trailer truck vary widely (FHWA 1985). The net result of this tire-to-tire variation in side friction demand is that trucks typically demand approximately 10% higher side friction than that required for passenger cars.

The point-mass model does not explicitly consider vehicle rollover thresholds. The rollover threshold for passenger cars is relatively high, so a passenger car will normally skid off a road long before it would rollover (McGee 1981). However, tractor-trailer trucks have relatively higher mass centres and consequently tend to have lower rollover thresholds. Furthermore, because of suspension characteristics, the rollover threshold of these trucks is substantially less than it would be, if a truck was a rigid body. Studies have found that most unstable trucks had rollover threshold of about 0.30 g (Harwood et al. 1990). That is, if a truck travels at a minimum curve radius of 39 m with a design speed of 35 km/h, the lateral acceleration is 0.17 g. Then, this truck could undergo an additional lateral acceleration of only 0.13 g without rolling over.

Another limitation in the point-mass model is that it does not account for vehicle stability on complex alignments, including compound and reverse horizontal curves either individually or combined with vertical alignments. Such curves are commonly used in various highway classifications, especially rural highways. While current design guides provide brief and vague guidelines for the design of compound horizontal curves to have a ratio between the larger and smaller radii not to exceed 1.5, there are no guidelines for the design of reverse curves from the perspective of vehicle stability. In addition, current design guides deal with vehicle stability on compound or reverse curves as two individual curves, each with its own design requirements. Therefore, consistency is lacking in both the individual design of these curves and their 3D nature when they are combined with vertical alignments.

II. STATE OF ART OF THE SUBJECT

A large number of studies are done to evaluate the effect of geometry on operating speed of rural curves. In fact, there are many research findings available for understanding side friction and its characteristics in curve design. However, these studies were made in early days of highway design theory development. Recent research works to assess the effect of geometry on the stability of vehicles are a few in numbers among which most of them relied on computer simulation techniques to analyze the behavior of vehicles on curves. The reason for vehicle stability being least studied may be the difficulty in collecting real time data by conducting large number of experiments using different types of vehicles on highway curves of different nature.

III. DETAILED LITERATURE SURVEY

Considering the alarming rate of increase of road crash, especially in developing countries, United Nations has declared 2011 to 2020 as the Decade of Action for Road Safety (WHO, 2008). In developed countries, road traffic crashes have been reported to be declining by 30%, with the implementation of systems approach to road safety, in which, the design of good roads is given a prime consideration.

To achieve safety-oriented design, engineers and researchers may adopt different techniques. One such technique found suitable for rural highway transportation is to examine the consistency of highway geometric design. Highway consistency can be defined as the conformance of highway geometry with driver expectancy. Inconsistent highway segments can be subjected to improvement on a priority basis. (FHWA,2000)

Fatality and injury crash rates on two-lane rural highways are four to seven times than those on other rural highways (Cleveland et al. 1984). Therefore, research work on geometric design consistency has concentrated mainly on two-lane rural highways. Research work on consistency can be categorized into four main areas (1) Speed considerations; (2) safety considerations; and (3) performance considerations (4) Considerations of alignment indices.

Since change in speed of vehicles is a visible indicator of inconsistency in geometric design (Nicholson, 1998), several interpretations of operating speed as a geometric design consistency measure have been found in the literature. Safety considerations give special attention to the effects of curve geometry, lateral friction and super elevation on vehicle stability. Performance considerations address the effect of design parameters on the driver workload and driver anticipation. General character of alignment changes between segments of roadway is another measure of evaluating consistency using alignment indices.

Even though attractiveness of different highways and route selection mainly depends up on their operating speed, safety against skidding and vehicle rollover should be given prime importance on horizontal curves. Skidding and rollover occurs when the friction available between vehicle tire and pavement is less resulting in driver discomfort while traversing the curve. The interaction between friction demand and supply is the key to understand vehicle stability.

The maximum lateral friction factor used in design should provide comfort, without likelihood of skidding, by the vast majority of drivers. In addition, the maximum side friction factors used in design should be conservative for dry pavements and should provide an ample margin of safety against skidding on pavements that are wet as well as ice or snow covered and against vehicle rollover.

Horizontal curves are not designed based on maximum available side friction, which is basically the point when the vehicle is about to skid (TAC 1999). Instead, side friction values are limited based on driver comfort levels that were established by early researchers (Barnett 1936; Stone x and Noble 1940; Moyer and Berry 1940). Since, lateral skidding occurs at a point much later than when a noticeable side pitch is first detected, it was felt that a sufficient margin of safety against skidding was being provided by limiting side friction in this manner (Barnett 1936). It was assumed that a driver would reduce his or her speed upon feeling discomfort and thus prevent any significant risk of lateral skidding. This assumed margin of safety was meant to account for adverse pavement conditions, environmental and other factors that potentially contribute to destabilizing a vehicle on a horizontal curve.

Current horizontal curve design based on AASHTO Green book uses lateral friction values based on driver comfort levels that were established by earlier researchers (Barnett 1936; Stonex and Noble 1940; Moyer and Berry 1940). Moyer and Berry (1940) found "that a ball bank indicator reading of 10 degrees was the most satisfactory indication of safe speed." They collected data from 48 states and although the effect of body roll was neglected, they concluded that 10 degree reading should still be conservative. A friction factor of 0.14 to 0.15 was found to represent a ball bank indicator reading of 10 degrees. Applying those design values of side friction for today's passenger cars is questionable. In addition, those values were originally developed for passenger cars and their application to today's fleet of trucks is definitely questionable. Vehicle design has changed significantly over the last 150 years resulting in a need to re-examine the driver comfort levels used in AASHTO design policy. This is especially true since the new approach for modern truck design typically tends to provide optimum power/mass ratio for trucks to carry heavier cargo, resulting in higher mass centres and less rollover threshold.

Emmerson (1969) has calculated actual lateral friction factors observed at six horizontal curve sites based on passenger car speed data, and found that at the curve radius range of 196-350 m the average value of lateral friction factors indicated 0.11 with more than 80 % passenger cars having less than0.15. In contrast, in the case of curve radius range of 21-100 m, lateral friction factors were observed to be 0.27 and 0.22 with more than 90 % passenger cars having greater than 0.15.

Fancher et al. (1986) Conducted experiments using different truck tires on dry and wet concrete pavements at 40 mph speeds. The average skidding friction was 0.54 on dry surfaces and 0.47 on wet surfaces. The average peak friction on a dry concrete pavement was 0.76, while the average peak friction on a wet on a wet concrete pavement was0.64.

In western Canada, a number of curves have been examined using various vehicles. It was found that ball bank angles of approximately 10 degrees resulted in side friction factors of 0.16 - 0.17, which correspond to AASHTO values (Morrall et al. 1994). Regression models relating ball bank angles to side friction factors (determined by using the acceleration data collected with the GAnalyst) for each test vehicle at dry and wet conditions were developed. Safe side friction factors for the inside and outside of a given curve were found to be 0.1588 and 0.1790 for dry pavements and 0.187 for wet pavements for all classes of vehicles grouped together. These factors are slightly higher than those found by previous researchers(Morrall et al. 1994). The authors also found that curves flatter than 500 m provide high levels of dynamic driving safety on both wet and dry pavements. Moreover, the value of the side friction factor is a function of length along the curve.

Harwood and Mason (1994) examined the margin of safety provided by the AASHTO (1990) design guide on minimum radius curves with respect to vehicle skidding and rollover. Assuming, vehicles do not exceed the design speed, they found for most situations that an adequate margin of safety does exist. However, under some conditions, skidding and rollover can occur if the vehicle exceeds the design speed even marginally (Harwood et al. 1994). The simulation performed in their analysis examined only 2D horizontal alignments and no study on combined 3D alignments were made.

This indicates that observed side friction factors can be different from theoretical values which questions the consistency of existing highways based on vehicle stability, especially side friction.

To estimate the margin of safety that a curve provides against skidding, the side friction at impending skid conditions and the peak side friction demanded must be known (Morrall et al. 1994). Once these values are known, the margin of safety can be defined as

$$MS_{skid} = Fs_{skid} - Fs_{peak} \quad (1)$$

where MS_{skid} = margin of safety against skidding

Fs_{skid} = side friction factor at impending skid condition at a given speed, and
Fs_{peak} = peak side friction demanded at a given speed.

Vehicle rollover thresholds were also examined by Harwood and Mason (1994). They found that passenger cars have a very high threshold in the order of 1.2 g and that unstable trucks can have thresholds as low as 0.27 g. Since, AASHTO (1990) allows lateral acceleration values as high as 0.17 and given the fact that vehicles typically oversteer along a portion of a curve, the margin of safety for rollover is not great (Harwood et al 1994). It was found that an unstable truck could rollover when exceeding the design speed by as little as 8 km/hr on low design speed horizontal curves and that this is a potentially realistic situation on freeway ramps (Harwood et al. 1994).

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Carlson and Mason (1999) examined lateral acceleration and ball bank indicator readings to determine whether they were actually indicators of driver comfort. They collected data using a mid- size sedan on 5 different curves on the Pennsylvania Transportation Institute test track. Ball bank indicator readings and the unbalanced lateral acceleration were strongly correlated with a coefficient of determination (R^2) value equal to0.924.
The relationship can be expressed mathematically as follows (Carlson et al. 1999):

$$BBI = 1.115 + 52.627(ULA) \qquad (2)$$

Where,

BBI = Ball bank indicator reading (degrees), and

ULA = Unbalanced lateral acceleration or side friction factor

The curves examined in the Felipe and Navin (1999) study was all very small in radius with the largest being only 100 m. Their findings did show that curve radius played a major role in the speed chosen by drivers. Drivers limited their speed on large radii curves based on comfortable lateral acceleration and speed environment while on small radii curves the limiting factor was strictly comfortable lateral acceleration.
Some research work has been conducted in Canada to evaluate side friction under different weather, climatic, and vehicle fleet conditions. A study in Calgary found that while the design values of side friction provided higher margin of safety for passenger cars and pick-up trucks against skidding on dry pavement, the margin of safety on wet and icy conditions was questionable (Morrall and Talarico 1995; Talarico and Morrall1994).
Chang (2001) found that for modern vehicles the key safety issue is rolling rather than lateral skidding. He suggested two methods in which current geometric design standards can address body roll in vehicle dynamics via modifications to the recommended values for horizontal alignment elements. He identified increasing super elevation rates on horizontal curves and increasing minimum curve radii as the most appropriate methods to account for the effect of body roll on vehicle dynamics (Chang2001).
Chang (2001) examined vehicle stability on horizontal alignments taking into account vehicle body roll and found that rollover may be more critical than lateral skidding when considering modern vehicles. He argues that the rollover threshold is actually much lower than what is currently thought correct by the AASHTO (2001) or TAC (1999) guides. He also suggests that the effect of sprung vehicles on minimum horizontal radius be incorporated into current design criteria in order to achieve greater consistency between highway and vehicle design.
Another experimental study has been conducted in New Brunswick using actual five axle semitrailer as a design vehicle with more consideration given to the evaluation of rollover threshold (Garcia et al 2003). The study found that the vehicle carrying less-than-truck-load displayed the highest propensity to rollover with some recorded values of lateral acceleration close to 80 to 90% of the corresponding rollover threshold (when traveling at or below the posted speed limit). Clearly, this raises questions about the adequacy of current design guidelines against rollover.
In fact, there are a few research findings available for understanding lateral friction and its characteristics incurve design. For ex., Meyer (1949), Barnett (HRB 1936), Moyer & Berry (HRB 1940), and Stonex and Noble (HRB 1940) have published their research findings on lateral friction values and vehicle speeds made mostly in the US. Ball bank indicators were used to find lateral acceleration and hence determine safe speed on curves. However, these studies were made in early days of highway design theory development, and it is critical that these research findings, which were based on design speed of 120 km/h at the highest, are not directly applicable to current rural highway design.
For instance, J. Emmerson (1969) has calculated actual side friction factors observed at six horizontal curve sites based on passenger car speed data, and found that at the curve radius range of 196-350 m the average value of side friction factors indicated 0.11 with more than 80 % passenger cars having less than 0.15. In contrast, in the case of curve radius range of 21-100 m, side friction factors were observed to be 0.27 and 0.22 with more than 90 % passenger cars having greater than 0.15. This indicates that observed side friction factors can be different from theoretical values
Essam et al. (1988) studied the limitations of point mass model currently used in the design of minimum radius of horizontal curves. Design aids were then developed to address the recommended solutions to maintain the margin of safety required. Computer software that simulates vehicle behaviour on different geometrical alignments was employed to investigate vehicle stability on complex curves with 3D alignments. It was found that vehicle safety is questionable, especially for larger vehicles on curves associated with vertical alignments.
Garber et al. (1990) investigated the major factors associated with large truck crashes including the effect of highway facility type and highway geometry, and the development of mathematical models relating the factors with crash rates and probability of occurrence.
Easa (2003) in Switzerland, studied on 300 sites and a relationship expressing their pavement conditions and side friction force at different speed levels were developed. Based on the relationship two side friction factor equations, one for the longitudinal direction and another for the side direction, were published.

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McLean in Australia asserted based on his empirical analysis that the side friction values specified in AASHTO design guideline were too low. Then he proposed to increase the current side friction values ranging 0.11-0.19 to0.08-0.35
Meanwhile a group of researchers in Germany including R. Lamm (1999) investigated several European country cases and proposed a new relationship for finding relevant side friction factors in highway curve design as shown in Eqn.

$F_R = 0.27 - 2.19 * 10^{-3} V_D + 5.79 * 10^{-6} V_D^2$ (3)

Where, F_R: Side Friction Factor, V_d: Design Speed (km/h) and the research made an assumption that the model relating side friction factors and design speed would be a logarithmic function.

PinakiMondal et al. (2010) detailed the effect of velocity and road conditions on the roll over behaviour of a popular SUV on Indian road conditions. Road conditions were collected from three crash prone areas of an Indian metropolitan city. The safety critical vehicle dynamics related parameters of a commercial SUV were measured through experiments. These parameters were incorporated within the mathematical modelling and simulations using a multi-body vehicle dynamics software. The sensitivity of critical roll over velocity to the variations in road-tire frictional co-efficient, road side slope and radius of curvature were studied. The findings of the dynamic lateral acceleration threshold indicated that proper side slope and better skid resistance are necessary to improve the roll over stability especially for Indian wet road conditions
Donnell et. al. (2011) provided an analysis of the margin of safety that exists in horizontal curve design policy. This analysis considered various vehicle types, pavement surface types, and operating speed distributions. Comparisons between friction supply, demand, and design side friction factors were made in this paper. It was found that drivers travel at speeds that nearly approximate AASHTO maximum side friction factors on rural highways with high design speeds (i.e., greater than 45 mph). At lower design speeds, however, the observed friction demand of drivers in the present study often exceeded the AASHTO maximum side friction factors used in horizontal curve design. It was found that the observed friction demand, which were based on speeds collected on dry pavement conditions, was generally at least 0.05 below mean friction supply on curves. The friction data were collected using a combination of a portable dynamic friction tester (DF Tester) and circular texture meter (CT meter). The test method produces pavement surface friction properties as a function of speed.
Tang-Hsien Chang (2014) suggests that the relationship between minimum radius, super elevation, side friction, and design speed should be modified to incorporate modern vehicle design in body rolling. This study addressed the limitations of conventional design criteria for horizontal curves. A more appropriate equation was derived as follows
Where,
For passenger cars and trucks, $R = \frac{V^2}{121(0.5e+f)}$ (4)

R is Radius of horizontal curve,
e is super elevation
and f is lateral friction factor
In order to ensure driving safety based on the values obtained from the revised equation, an evaluation of existing highway curves was proposed. This study also suggested that highwayagencies should improve unsatisfactory sections and install speed calming measures at places that cannot be modified.
Morrall et. al. 2013 conducted study to determine the amount of side friction demanded and provided for a range of roadway curvatures, vehicle speeds and types, and pavement surface conditions. A ball bank indicator and a commercial accelerometer (the GAnalyst) were used to measure ball bank readings and corresponding lateral accelerations on the test curves. The friction supply levels measured in the field indicate that friction varies between rural two·lane and multi·lane highways. Their search indicate that passenger cars are more likely to skid before rolling over on horizontal curves, while large trucks are more likely to rollover on horizontal curve before skidding on lows peed roads.
JinXu et al. (2015) conducted an experimental study on lateral acceleration of cars in different environments in Sichuan, Southwest China. The lateral accelerations, speeds, and trajectory curvatures of a passenger car on twelve highways with different design speeds and topographies were obtained. The negative correlation between the lateral acceleration and the curvature was analysed and interpreted. In addition, regression models of the lateral acceleration with the curvature and speed for three different kinds of roads (six-lane road, four-lane road, and two-lane road) were established.

IV. CONCLUSION

The combination of horizontal curves with vertical alignment is a common feature on rural highways in India. It is evident from the literature review that the current geometric design guides do not adequately investigate vehicle stability on such 3D alignments. So, the use of lateral friction values which were developed years back and still used by current design standards may raise safety concerns over vehicles traversing such curves. Inconsistent highways may be resulted as a consequence. Only a few research works are carried out in the field of geometric design consistency on horizontal curves in India. Most of the works evaluate consistency based on speed considerations. Consistency of curves based on margin of safety against skidding and rollover are subjects for only a few researchers. Lateral friction at tire pavement interface and unbalanced lateral acceleration experienced by a vehicle are indicative of their stability. Studies report that the influence of geometry and vehicular characteristics on the stability of vehicles is very high. Knowledge of relationship between different kinds of geometric elements and vehicle stability will help to derive guidelines for designing highway geometric elements with consistency and safety.

REFERENCES

[1]. American Association of State Highway and Transportation Officials. (2001)."A Policy On Geometric Design Of Highways And Streets". AASHTO, Washington, D.C.

[2]. Alan Nicholson et al., "Super elevation, Side Friction, and Roadway Consistency", Journal of Transportation Engineering, American Society of Civil Engineers September/October 1998, 124(5): 411-418

[3]. AlkeshkumarRabari et al., "Analysis of Super elevation and Side Friction Factor on Horizontal Curve", International Research Journal of Engineering and Technology (IRJET), Volume: 05 Issue: 02 | Feb-2018

[4]. Barnett, J. (1936). "Safe Side Friction Factors AndSuperelevation Design". Highway Research Board, Vol. 16, 69-80.

[5]. Carl-GustafWallman and Henrik Åström, "Friction measurement methods and the correlation between road friction and traffic safety. A literature review", Swedish National Road and Transport Research Institute, ISSN 0347-6049, 2001

[6]. Carlson, P.J. and Mason, J.M. (1999). "Relationship Between Ball bank Indicator Readings, Lateral Acceleration Rates and Vehicular Body-Roll Rates". Transportation Research Record 1658, TRB, National Research Council, Washington, D.C., pp. 34-42.

[7]. Chang, Tang-Hsien (2001). "Effect of Vehicle's Suspension on Highway Horizontal Curve Design". Journal of Transportation Engineering, ASCE. Vol. 127, No. 1, pp. 89 – 91.

[8]. Dabbour, E., Easa, S.M. and Abd-El-Halim, A.O. (2003). "Design Guidelines for Horizontal Reverse Curves Combined with Vertical Alignments". Proceedings, CSCE 31st Annual Conference, Moncton, NB.

[9]. Easa, S.M. & Dabbour, E. (2003). "Design Radius Requirements for Simple Horizontal Curves on 3D Alignments". Canadian Journal of Civil Engineering.

[10]. Essam Mohamed S. A. E. A. Dabbour, "Truck Stability on different types of Horizontal Curves Combined with Vertical Alignments", A thesis Presented to Ryerson University, Toronto, Ontario, Canada, 2003

[11]. Eric Donnell et al.,"Use of Side friction in Horizontal Curve Design: A margin of Safety Assessment", 5th International Symposium on Highway Geometric Design, Canada, March 2015

[12]. Federal Highway Administration (2002). "The Interactive Highway Safety Design Model (IHSDM): Making Safety A Priority In Roadway Design". Office of Safety, Research & Development, FHWA, McLean, VA. Internet: www.tfhrc.gov/safety/ihsdm/brief.htm.

[13]. G M Gibreelet al.,"State of the art of Highway design consistency", Journal of Transportation Engineering, American Society of Civil Engineers, August 1999, 125(4): 305-313

[14]. Harwood, D.W. and Mason, J.M. (1994). "Horizontal Curve Design for Passenger Cars And Trucks". Transportation Research Record 1445, TRB, National Research Council, Washington, D.C., pp. 22-33.

[15]. J. F. Morrall and R. J. Talarico, "Side Friction. Demanded and Margins of Safety on Horizontal Curves", TRANSPORTATION RESEARCH RECORD

[16]. Lamm, R., Choueiri, E.M. and Mailaender, T. (1991). "Side Friction Demand Versus Side Friction Assumed for Curve Design on Two-Lane Rural Highways". Transportation ResearchRecord 1303, TRB, National Research Council. Washington, D.C., pp. 11-21.

[17]. PinakiMondal et al. (2010). "Effect of Velocity and Road Conditions on the Roll Over Behaviour of Sports Utility Vehicles", Int. J. Vehicle Structures & Systems, 2(1), 38-44.

[18]. Rebecca Lutz, "A Comparison of Friction Supply, Friction Demand, And Maximum Design Friction on sharp horizontal curves with steep grades", A Thesis Submitted to Pennsylvania State University.

[19]. RuedigerLamm et al., "Side Friction Demand Versus Side Friction Assumed for Curve Design on Two-Lane Rural Highways", Transportation Research Record

[20]. Transportation Association of Canada (1999). "Geometric Design Guide for Canadian Roads". Transportation Association of Canada (TAC), Ottawa, ON, Canada.

[21]. University of Michigan Transportation Research Institute (1998). "Vehicle Dynamics Programs for Roadway and Roadside Studies". Final report. University of Michigan Transportation Research Institute. UMTRI-98-20-1.