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A Case Study on the Effect of Geometric Design Consistency on Road Crashes on Narayanghat-Muglin Road Section

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Abstract

Design consistency is overlooked while designing roads, resulting in unsafe road facilities. The safety performance of a highway can be greatly enhanced by detecting and addressing any inconsistencies present on the road. Over time, the application of geometric standards shifted from new road construction to upgrading, which could result in limited design options. Due to the emerging importance of design consistency in geometric design, this research has been initiated to evaluate horizontal curve consistency based on an established operating speed prediction model.

Horizontal curve data of the Narayanghat–Mugling Road section has been collected from the Division Road Office, Bharatpur, and accident data has been obtained from the District Traffic Police, Chitwan. Out of 242 horizontal curves in the Narayanghat-Muglin road section, the design consistency of 223 horizontal curves was evaluated, while 19 horizontal curves with posted speed limits were not considered because these curves are not within the range of design criteria set out in Asian Highways Design Standards (1993).

The average, maximum, and minimum 85th percentile speed was found to be 78, 101, and 32 kmph respectively. Out of 223 horizontal curves evaluated for individual consistency based on operating speed, 75% of the curves were categorized as “poor”, 16% as “fair”, and 9% as “good”. It was found that under successive element consistency evaluation based on operating speed, 22% of horizontal curves were categorized as “poor”, 23% as “fair”, and 55% as “good”. When studied under vehicle stability consistency evaluation criteria, 88% of the curves were classified as “fair” and 12% as “good”. It was found that the predicted accidents caused by geometric design inconsistency and vehicle stability are 5.12% of total accidents per year.

From the safety standpoint, if the condition $|V_{85}-V_d|>20$ is met, critical discrepancies between the design speed and operating speed arise, resulting in unsafe operations. Therefore, it is generally advisable to consider redesigning those road sections.

Keywords: Design Consistency; Safety; Operating Speed; Speed Prediction Model; Accident Prediction.

INTRODUCTION

Significant growth in motorization and highway construction over the past decades has led to increased mobility and economy nationwide. However, this increased mobility has also resulted in hundreds of thousands of deaths and millions of injuries annually, worldwide, due to traffic collisions.

Road accidents are typically influenced by four main factors: the road itself, human error, the vehicle, and the environment. While all of these factors can contribute to accidents, only the road factor can be readily improved by traffic and transportation engineers in order to reduce the frequency and severity of accidents

(Shakya 2020). If a driver encounters an inconsistency on the road that deviates from their expectations, they may respond by adopting an unsuitable speed or maneuver, which could result in accidents (Ng and Sayed 2004). Poor consistency means bad fitting, surprising events, and high-speed variability along different road segments and among different drivers, increasing the likelihood of crashes (Weber & Matena 2005). When the design is consistent with what the driver expects to find, the highway is also consistent thus reducing the possibility of driving errors and unsafe maneuvering (Castro et al. 2015). The use of operating speed as a consistency tool requires the ability to accurately predict speeds as a function of the roadway geometry (Fitzpatrick et al. 2000). An alignment that demands drivers to negotiate high-speed gradients and does not satisfy their expectations, on the other hand, is regarded inconsistent and results in a greater crash frequency (Galante et al. 2021). Geometric design standards, which are formulated on the basis of the design speed concept, constitute one of the primary causes of design inconsistency and have been practiced since the 1930s. The concept's foundation lies in the principles of a vehicle's dynamics as it traverses a horizontal curve of circular shape at a steady speed, as negotiated by a driver (Galante et al. 2021). Previously, in Nepal, road agencies' top goals were connectivity rather than safety. This, together with the country's rugged terrain, became one of the contributing causes of the country's rising number of road crashes. As infrastructure and urbanization progressed, traffic density increased drastically, reducing the effectiveness of the road network and increasing the number of road crashes at an alarming rate. In an effort to enhance the efficiency of road networks, responsible organizations have sought to upgrade existing roads to multilane roads. Despite this, there have been reports of several crashes occurring in newly constructed multilane road sections.

When selecting a route or mode of transportation, speed is a crucial consideration. Road users evaluate the appeal of different highways based on factors such as time, convenience, and cost. The actual speed at which the vehicles travel, known as the operating speed, is typically determined under free-flow conditions and is represented by the 85th percentile speed. To predict operating speed, several factors must be taken into account, including the radius and length of horizontal curves, sight distance, superelevation rate, side friction factor, and pavement conditions. This study explores various methods of predicting operating speed and evaluates consistency across individual geometric elements and successive elements.

RESEARCH OBJECTIVES

The general objective of this study is to evaluate the effect of geometric design consistency on the road crashes of the Narayanghat-Muglin road section in the Gorkha-Narayanghat Highway in Nepal.

MATERIALS AND METHODS

To achieve the objective of the study, the secondary data was extracted from as-built drawings provided by the Department of Roads. The data includes all geometric parameters required to evaluate the geometric consistency. Historical accident data was obtained from the District Traffic Police, Chitwan. The Narayanghat-Muglin road comes under class II as per Asian Highway Classification with 2 lanes and a design speed of 50 kmph ("Annex I Asian Highway Classification and Design Standards," n.d.). Through a review of relevant literature, it has been found that a plethora of models have been created for predicting operating speed. These models can differ significantly in terms of their form and the number of variables incorporated in each one. It is noteworthy that the majority of these models are designed to calculate operating speeds on horizontal curves as shown in Table 1.

Table 1: Speed Prediction Models (Memon et al. 2008)

S.N.	Model	Model Equation for V85	R2
1	Lamm et al. 1990	94.398-3188.656/R	0.79
2	Lamm and Choueiri 1987	95.6-0.0438CCRs	0.82
3	Lamm et al. 1999	Exp (4.561-0.000527CCRs)	0.63
4	Merrall and Talarico 1994	Exp (4.561-0.0058D), D=5729.58/R	0.631
5	TAC 1999	102.45+0.0037LC-(8995+5.73LC)/R	unknown
6	Ottesen and Krammes 2000 (Model 1)	103.66-1.95DC	0.8
7	Ottesen and Krammes 2000 (Model 2)	102.44-1.57DC+0.012LC-0.01DCx LC	0.81

8	Voigt 1996	99.61-2951.37/R+0.014LC-0.131I+71.82e	0.84
9	Kanellaidis et al. 1990	129.88-623.10/R ½	0.78
10	Fitzpatrick (2000)	for -9%<G<-4%, V_{85} = 102.10 -3077.13/R for -4%<G<0%, V_{85} = 105.98-3709.90/R for 0%<G<4%, V_{85} = 104.82-3574.51/R for 4%<G<9%, V_{85} = 96.61-2752.19/R	0.58 0.76 0.76 0.76

where,

CCRs = curve change rate in gons per kilometer (1 gon = 0.90) = [63700(Lc11/2R + Lcr/R + Lc12/2R)]/L

DC=Degree of Curve = 1746.38/R

e = Super elevation rate in m/m

I = deflection angle of horizontal curve in degrees

L = Lc11 + Lcr + Lc12 in m

Lc11 = Length of the spiral curve in m

Lc12 = Length of the spiral curve out in m

Lcr = Length of the circular curve in m

LC = Length of the horizontal curve in m

R = Radius of the horizontal curve in m

The model developed by Fitzpatrick has been used in this research since the methodology has been validated in multiple research projects and has been accepted by FHWA as the basis for examining design consistency on two-lane rural roadways in the IHSDM.

A statistically significant road safety model was used to predict the number of road traffic accidents (Ng & Sayed 2004). The model relies on horizontal curve data only with three design consistency measures that are statistically significant ($|V_{85}-V_d|$, ΔV_{85}, and Δf_R). This model simplified the safety evaluation of highway alignment based on design consistency:

Accidents per 5 years = $\exp(-3.369) \times L^{0.8859} \times V^{0.5841} \times \exp[0.0049(V_{85}-V_d) + 0.0253\Delta V_{85} - 1.177\Delta f_R]$

where,

L=Section length in km

V=Annual average daily traffic in vehicles per day

$V_{85}-V_d$ =Difference between operating and design speed in km/hr

$\Delta V_{85} = |V_{85i}-V_{85i+1}|$, where V_{85i} and V_{85i+1} are operating speeds on elements i and i+1 respectively

$\Delta f_R = f_R - f_{RD}$, where f_R is side friction assumed and f_{RD} is side friction demanded on the element.

RESULTS and DISCUSSIONS

The information related to the geometric alignment of the study road was collected from the Road Division Office, Bharatpur. The details of the horizontal curve are presented in Table 2. Out of 242 curves 19 curves with radius less than 50m are not considered for consistency evaluation because these curves are not within the range of design criteria set out in Asian Highways Design Standards (1993) and the speed limit has been posted at these sections.

Table 2: Horizontal curve summary

Total no. of Horizontal Curves	242
Minimum Radius of Curve in alignment	15 m
Maximum Radius of Curve in alignment	1000 m
No. of Curve with Radius Greater than or equal to 50 m	223
No. of Curve with Radius less than 50 m	19

85^{th} percentile speed of 223 number of curves are calculated based on the model developed by Fitzpatrick (Fitzpatrick et al. 2000). The summary of 85^{th} percentile speed calculation is presented in Table 3.

Table 3: 85^{th} Percentile Speed Summary based on Fitzpatrick

Design Speed	50 km/hr
Maximum 85^{th} percentile Speed	101 km/hr
Minimum 85^{th} percentile Speed	32 km/hr
Average Operating Speed	78 km/hr

The average 85^{th} percentile speed of the study road was 78 kmph which indicated that average speed of the free-flowing passenger car on the study road is 78kmph. The maximum 85^{th} percentile speed of the study road was 101 kmph which exists at three horizontal curves with a radius of 1000m. The minimum 85^{th} percentile speed of the study road was 32 kmph which exists at four horizontal curves with a radius of 50m.

The prevailing method for assessing the consistency of highway design typically relies on operating speed as the primary criterion. For a single geometric element, with reference to threshold values of Lamm et al. (1999) (Fitzpatrick et al. 2000), the horizontal curves with $|V85-Vd|<=10$ were under the "good" category and there are 21 horizontal curves in this road. The curves with $10<|V85-Vd|<=20$ were under the "fair" category; there are 35 horizontal curves under this category in this road. The curves with $|V85-Vd|>20$ were under a "poor" category; there are 167 horizontal curves under this category in this road as shown in Figure 1.

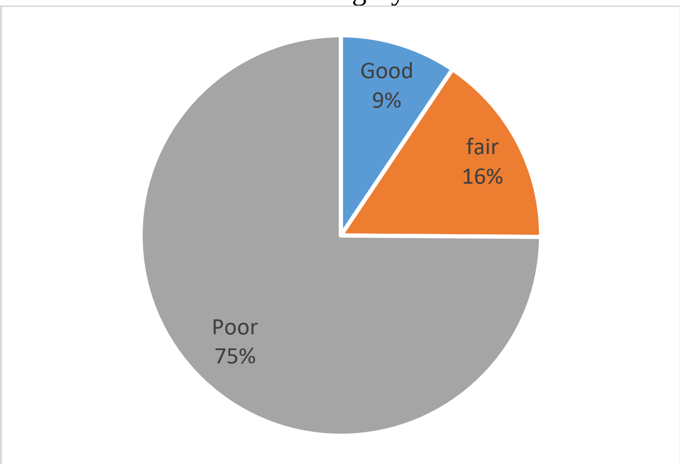

Figure 1: Individual horizontal curve consistency

Similarly for consistency evaluation of successive horizontal curves in the Narayanghat-Muglin road, a comparison of the operating speed of successive curves was carried out. For i^{th} and $i+1^{th}$ successive curves, curves with $|V_{85i}-V_{85i+1}|<=10$ were under the "good" category (123 curves). Similarly, curves with $10<|V_{85i}-V_{85i+1}|<=20$ were under the "fair" category (51 curves), and the curves with $|V_{85i}-V_{85i+1}|>20$ were under the "poor" category (49 curves), as presented in Figure 2.

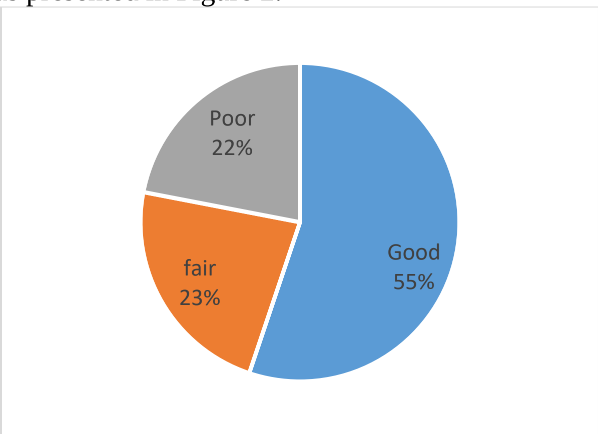

Figure 2: Successive horizontal curve consistency

For consistency evaluation of horizontal curves based on vehicle stability the discrepancy in the side friction assumed vs. demanded at each horizontal curve was calculated. Curves with $\Delta f_r >= 0.01$ were under the "good" category and there are 27 curves with the "good" category in the study road. Similarly curves with $0.01 > \Delta f_r >= -0.04$ were under "fair" category and there were 196 curves with fair category in the study road. The curves with $\Delta f_r < -0.04$ were under the "poor" category and there was no curve under the "poor" category in this road as shown in Figure 3.

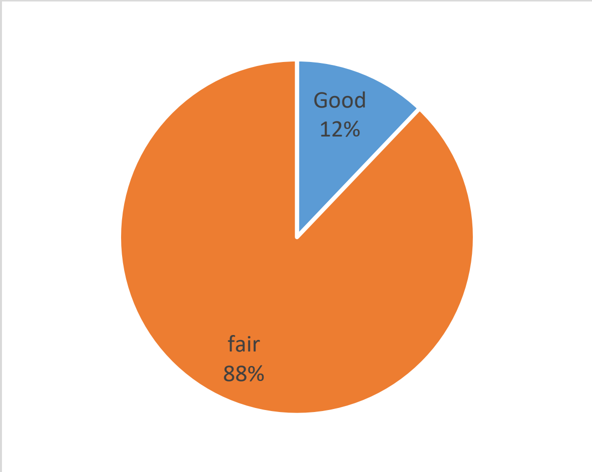

Figure 3: Consistency evaluation based on vehicle stability

The graph has been plotted with Cumulative distance on the horizontal axis and operating speed on the vertical axis to generate a speed profile along the road length. The speed profile is presented in Figure 4. The speed profile shows that there are 18 curves (8%) have an operating speed less than the design speed and the remaining 205 curves (92%) have an operating speed greater than the design speed.

The statistically significant model based on curve data and consistency measure (Ng & Sayed 2004) was used to predict the accidents per 5 years and the result is presented in Table 4. For the prediction of accidents, Average Annual Daily Traffic (AADT) has been taken for the year 2018 (Ojha & Ojha 2018).

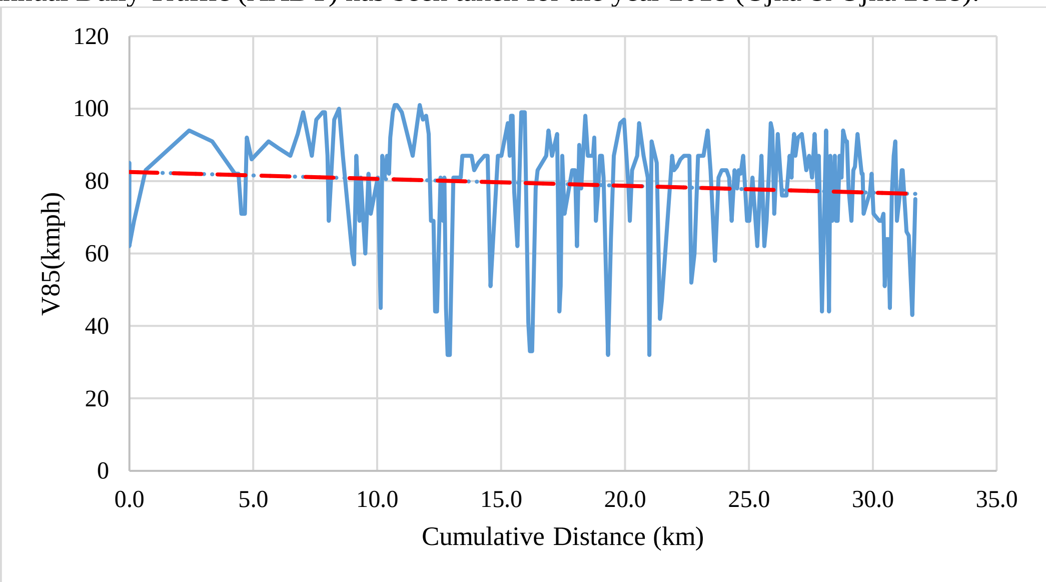

Figure 4: Operating Speed Profile

Table 4: Accident prediction summary

No. of accidents predicted per 5 years	66
No. of accidents predicted per year	13
Total Accident recorded by Traffic Police	254

	(from May 2021 to May 2022)

It has been observed from the traffic police accident record; at the period of 1 year (from May 2021 to May 2022) the total number of accidents in the study area is 254. There may be several causes of accidents among which this study shows that 5.12% of the accidents are attributed to the geometric inconsistency and vehicle stability. The predicted accident percentage of 5.12 in this study area is in compliance with the study performed by Reddy & Shashidher (2018) which shows the total no. of accidents in curve sections is 4.54%.

CONCLUSIONS

This study was aimed to find the effect of geometric design consistency on road accidents. From the results and discussion, it can be concluded that: On average, the 85th percentile speed was 28 kmph greater than the design speed. The speed profile shows there are 18 curves that have an operating speed less than the design speed and the remaining 205 curves have an operating speed greater than the design speed. Among the 223 horizontal curves, there are no curves that satisfy all 3 consistency criteria under the “good” category; 11 (5%) curves that satisfy all 3 consistency criteria under the “fair” category. There were no curves that satisfied all 3 consistency criteria under the “poor” category. There were 22 (10%) curves that satisfied 2 consistency criteria under the “good” category, 53 (24%) curves satisfy 2 consistency criteria under the “fair” category, and 25 (11%) curves satisfy 2 consistency criteria under the “poor” category. Based on the accident prediction model on the basis of geometric design consistency, the total number of accidents predicted per year is 13, which is 5.12% of the total accidents that occurred from May 2021 to May 2022.

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