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Assessment of Road Safety Through Geometric Design Analysis: The Case of Sagonsongan Diversion Road in Marawi City

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Abstract. This study critically assessed the impact of geometric design on road safety. This assessment was based on a detailed analysis of the case of Sagonsongan Diversion Road in Marawi City, the Philippines. Applying quantitative methods such as a survey using Real-Time Kinematics and software-based road designing using AutoCAD Civil 3D, the study thoroughly analyzed the geometric design elements of the road, such as horizontal alignment, vertical alignment, and superelevation. Thus, the study showed that all geometric features were highly inconsistent with the safety standards. In particular, the high curve radius and slope aspect ratio significantly increase the risk of traffic incidents. The evaluation of two key curve sections has demonstrated that the road's overall geometric design directly affects drivers' ability to keep their cars stable. To eliminate the risk of traffic wretchedness, this study has suggested several corrective measures, including redesigning the road to adjust the geometrical aspects to safe norms, setting accurately calculated speed limits, reinstalling road signs, and conducting continuous safety checks. These measures will help to bring the Sagonsongan Diversion Road's design to the level of established safety standards and decrease possible incidents to the minimum. The study has provided important findings on the relevance of established road designing principles to road safety. This work can be useful for the existing discussion regarding engineering and policy measures that should be considered to enhance road safety, especially in countries with developing economies. This study has also illustrated the importance of continued geometric design assessment in ensuring road safety and adapting the safety requirements to the dynamic needs of road users.

Keywords: Road safety; Geometric design; Curve radius; Slope grade; Marawi City.

1.0 Introduction

Road safety is a vital concern worldwide, impacting policies influencing transportation, urban planning, and engineering practices. The geometric design of the road, including curvature, grade, and alignment, highly impacts vehicular movement and determines the safety and appropriateness of travel being facilitated. Road safety can be evaluated through the Sagonsongan Diversion Road located in Marawi City, Philippines, due to its unique characteristic of showcasing road geometric design and its factors that affect driving conditions. While the road is vital in connecting Marawi City to the respective neighboring municipalities, it has been in the years since its commission faced several traffic incidents, leading to a growing concern about the safety and appropriateness of vehicular motor facilitation. The curvature of the two curve portions on the Sagonsongan Diversion Road has caused concern amid the escalating traffic incidents and emerging transportation congestion. On August 2, 2022, a car crash incident occurred along Sagonsongan Diversion Road, as reported by the Marawi CDRRMO, where two passengers were injured though safely brought to the nearest hospital (One Bangsamoro News). One of the

neighbors residing close to the two curve parts also claimed that motorbike crashes have soared significantly, adding that at least five automobile incidents have occurred along those portions. Additionally, some neighbors living close to the Hillside taste of Asia shared that around five to ten cars had been engaged in car crashes and incidents while driving along the two curve portions—also, the testimony of the barangay secretary of Brgy. Sagonsongan, Marawi City, who shared these events, validated these incidents within the first two years since the road was opened for public use.

Over the years, the correlation between road geometric design and traffic accidents has presented extensive research attention. Research suggests that several geometric design elements, such as horizontal curvature, vertical curvature, slope, curve radius, and superelevation, are critical to traffic safety (AASHTO, 2011). This was proven in the study of Alghafli, A., Mohamad, E., & Ahmed, A. Z. (2021), where they indicated that the road's geometric design elements (curves and slopes) play a critical role in road safety. Hence, vehicle crashes occurring on roads with inadequate geometric designs underscore the necessity of comprehensive assessments to check the design's adherence to safety requirements and guidelines set by the DPWH road safety design manual and the AASHTO Policy on the geometric design of highways and streets. The World Health Organization (WHO) recognizes traffic accidents as a major global health concern due to large-scale estimates of fatalities and injuries. According to the actual statistics of fatal injuries from traffic accidents, traffic accidents account for about 1.25 million deaths, 20 to 50 million critical, and 20 to 50 million permanently injured within one year (WHO, 2013). In order to enhance road design, it is imperative to assess and establish the correlation between road accidents and geometric design elements. Thus, these facts are crucial for evaluating the road safety of a roadway in terms of its geometry (Islam et al., 2019). These needs call for a review of design works with the road, and it is particularly relevant in developing countries. Such nations may lack experience or may disregard specific safety and security standards.

With an abrupt change in the number of vehicles and other road users in the irregular land topography of Sagonsongan Diversion Road, it is important to assess its safety measures for its geometric design. Initial findings and reports from local authorities correspond to the increasing number of car incidents, particularly on the curve. This paper aimed to analyze the Sagonsongan Diversion Road's geometric design and assess its curve radius, slope grade, and superelevation compared to design standards. This paper has suggested areas for improvement and presented a significant contribution to the design criteria critical to safety capacity. Additionally, the paper emphasized the need to adapt the design to modern vehicle and transportation technology demands.

2.0 Methodology

2.1 Research Design

The research design used for this study was descriptive and quantitative. The design assessed the geometric design of the road, particularly the horizontal alignment for curve radius, vertical alignment for its slope grade, and superelevation, to determine the extent to which it complies with road safety standards. This study aimed to identify gaps between current road conditions and safety guidelines and understand their implications for road safety.

2.2 Research Locale

This study was performed on the Sagonsongan Diversion Road in Marawi City, Philippines. This road is an essential passage between Marawi City and its neighboring municipalities since it considerably serves regional mobility and economic functions. The study area focused on two curve sections with a recorded high rate of reported traffic collisions, which raised concerns about their geometric design aspect. The actual survey points is shown in Figure 1.

2.3 Research Instrument

This survey aimed to collect data for the analysis of key geometric design properties, including the horizontal alignment (the radius of the curve), vertical alignment (slope grades are the focus), and superelevation (evaluating the road's banking). The data was collected using Real-Time Kinematics (RTK) surveying equipment to obtain high-precision measurements suitable for assessing the road's geometric design parameters. The data points were collected at discrete intervals along the chosen road section to ascertain features that may contribute to road safety,

such as curve radius, slope grade, and superelevation. RTK surveying was instrumental in collecting the required topographical and geometric data.

Figure 1. The actual survey points

2.4 Data Gathering Procedure

The analytical work was undertaken using AutoCAD Civil 3D, a powerful engineering software tool developed for civil engineering design and analysis. This software analyzes road geometric design within the setting of horizontal and vertical alignment and superelevation, using specific road safety standards, such as curve radius in case of horizontal alignment and slope grade in terms of vertical alignment and superelevation. Specifically, this assessment sought to identify compliance and noncompliance with road safety standards. The evaluation of the road's geometric design is considered through established design standards that were sourced from different authoritative bodies. These standards reflect the standard design of the road design, including horizontal curvature, vertical curvature, slope, curve radius, and superelevation, which are the most contributing factors to traffic safety. Other factors were used to determine whether Sagonsongan Diversion Road complies with safety criteria.

3.0 Results and Discussion

3.1 Horizontal Alignment (Curved Radius)

Using the geometric design of the Sagonsongan Diversion Road, the researchers assessed the actual curve radius and slope grade and reveals that there are huge differences from the ideal standard. The data was plotted in AutoCAD Civil 3D is outlined in Figure 2 to provide a horizontal alignment result as shown in Table 1.

Table 1. Result of the horizontal alignment using AutoCAD Civil 3D

P.I No.	P.I. Sta.	Start Sta.	End Sta.	Length	Radius
1	0+069.002	0+039.76	0+089.67	49.92 m	38.18 m
4	0+755.037	0+722.59	0+780.06	57.47 m	49.59 m

The radius of a horizontal curve is a critical factor in road design. As per Table 1, a greater radius indicates a more gradual curve, which allows cars to travel around it more safely and comfortably at higher speeds. Curve 1 has a curve radius of 38.18 meters, less than Curve 2, which is 49.59 meters. This may imply that Curve 2 is less critical than Curve 1, allowing for more efficient vehicle movement. Also, the length of the curve portion is important; long curves have a smoother transition. The curve radius used in designing a specific road segment to obtain a smoother transition should be higher than the design speed, as cited in the DPWH-DGCS. Also, a study by the European Commission indicates that as the radius of horizontal curves increases, the number of accidents decreases.

The data analysis above indicates that the two horizontal curves on the Sagonsongan diversion route have important implications for vehicle safety. Specifically, improving curve two by increasing its radius and reducing sharpness could enhance navigation safety based on this data. To promote road safety overall, designers must consider larger radii carefully in their curve designs. Research has consistently shown that accidents are more likely to occur along horizontal curves than straight sections due to increased demands placed upon drivers and vehicles, which can result in speed and trajectory misjudgments (Charlton, 2007; Hummer et al., 2010). Traffic crash statistics demonstrate a significantly higher average crash rate on horizontal curves than on tangent sections (NHTSA, 2008). These findings underscore the importance of considering length and radius when designing geometrically sound roads such as those found within the Sagonsongan Diversion Route--an approach that should lead not only to improved car user comfort but also reduced congestion through high-speed operation capabilities made possible by these safer design choices.

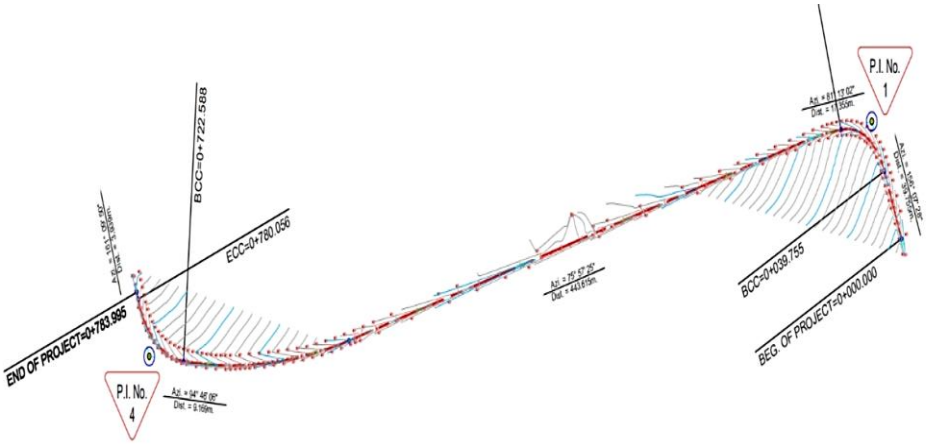

Figure 2. AutoCAD CIVIL 3D projection of horizontal alignment for Sagonsongan diversion road

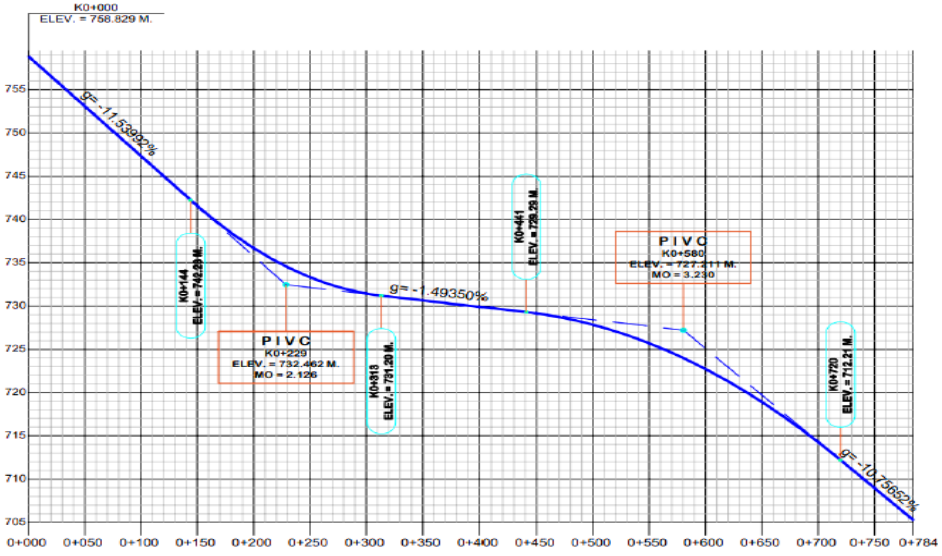

Figure 3. AutoCAD CIVIL 3D projection of vertical alignment for Sagonsongan diversion road

3.2 Vertical Alignment (Slope Grade)

By plotting the data on AutoCAD Civil 3D, as shown in Figure 3, the researchers have arrived at a Vertical Alignment (Slope Grade) result, as shown in Table 2.

Table 2. Result of the vertical alignment using AutoCAD Civil 3D

P.I No.	P.I. Sta.	Start Sta.	End Sta.	Length	Slope Grade
1	0+069.002	0+039.76	0+089.67	49.916m	-11.54%
4	0+755.037	0+722.59	0+780.06	57.468m	-10.76%

The slope of the two-curve segment is displayed in Table 2, where the negative values of the slope grade (-11.54% and -10.76%) denote downward slopes for both curve portions. A road with a negative slope has a declining vertical alignment, which could cause cars to descend more quickly. The DPWH DGCS standards for road design dictate that, because the road was formerly known as Urban Collector Road, the road's vertical alignment fails at a design speed of 60 kph higher. It recommends that passing cars should not travel faster than 50 kph for the safety of other passing cars. In addition, new research has shown how sensitive trucks' operating speeds are to vertical grade on highways; since speeds sharply decrease on improved stretches and rise on downhill segments (Archilla et al., 1996; Morris et al., 2014; Wang et al., 2018).

This implies that the slope grade could be a Hazard to road safety, considering that cars tend to move at high speeds. A steep slope could cause challenges such as decreasing vehicle balance when it leans on one side to prevent overturning, extended braking distances, and a higher probability of rear-end collisions, particularly for large trucks. Additionally, steep slopes may impact how well a road functions properly for the users. It might require cars to work harder to get through the inclining segment of the road, which could hurt efficiency and traffic flow. Steep slopes can also affect vehicle wear and tear and fuel consumption. Thus, it is evident that certain road segments require modifications or enhancements as they do not adhere to the DPWH DGCS design guidelines. The vertical alignment must adhere to the prescribed criteria for road safety and performance. Road authorities may need to take corrective action, such as rebuilding or redesigning the road, considering these findings to bring the slope grades within tolerable bounds. This can entail changing the superelevation, geometry, or other road design features.

3.3 Superelevation

Because the shoulder of the road was covered with grass and other vegetation, the researchers could not arrive at a Superelevation result due to several impediments on the section of Sagonsongan Diversion Road.

Figure 4. The image shows the shoulder covered with grass and other vegetation

Two other opposing impediments were the grass and other vegetation covering the shoulder of the road. These opposing impediments prevented one from being able to measure the borders of the road accurately, and for that reason, one could not accurately determine the road's banking or slope at curves. It also may have been difficult to get accurate data because of the disruption of surveying equipment. It is potentially dangerous to clear the grass

and bushes on the side of the road, especially if the clutter obstructs traffic or should be cleared out in the road's lane. The second opposing impediment exemplifies how not being able to collect superelevation data shows that the sides of the roads need to be taken care of in general. Clear access to the sides of the road is required to accurately measure superelevation because it is evident that the construction of skew superelevation runoff at critical pavement sections, especially in highway rehabilitation and reconstruction projects, has been identified as an effective measure to improve road safety (Aoun et al., 2017).

Superelevation, also known as the transverse slope of a road, is a critical element in road design that enhances road safety by reducing the impact of centrifugal force on vehicles navigating curves. It helps minimize the risk of vehicles overturning or skidding, particularly on curved road sections Pham (2023). Also, superelevation is a fundamental aspect of road design that greatly contributes to road safety by enhancing vehicle stability, reducing the risk of overturning or skidding, and improving driving conditions on curved road sections. Well-designed superelevation facilitates safer navigation of curves and plays a vital role in serious incident prevention and promoting road user safety.

The assessment result on the radius of the two horizontal curves of Sagonsongan Diversion Road proved that it has a direct correlation with the road's superelevation design as far as the safety standard is concerned. The effectiveness of superelevation is more pronounced with decreasing curve radius and increasing superelevation rate, underscoring its importance in controlling vehicle speeds and enhancing safety on curved road sections (Liu et al., 2021).

3.4 Study Recommendations

The differences between the actual and ideal geometric design standards indicate the potential safety risks on Sagonsongan Diversion Road. The sharper curves and steeper slopes indicate an increased chance of incidents, collisions, and crashes, especially for vehicles moving at or above the road's design speed. Such circumstances could contribute to the existing vehicle control challenges, lower braking efficiency, and an elevated risk of skidding and loss of control. To alleviate those safety risks, this study proposed measures that the authority could initiate following actions:

Table 3. Study recommended measures

Adjust Road Geometry	If feasible, the realignment of both curve radius and slope grade to meet the ideal standards as closely as possible can potentially maximize road safety conditions. This action should be the last resort since extensive roadwork would likely be required to regrade the slopes and realign the curves.
Adjust Speed Limit	They are introducing a conspicuous speed limit of 50kph before the curve sections will decrease the chance of incidents due to reduced travel speed. This adjustment may be particularly beneficial when redesigning the geometry is impossible.
Enhance Road Signage	More signage on the road, particularly the warning signs about sharp curves and steep slopes, as well as the advisory speed level notification, would enhance driver education and driving practices.
Continuous Monitoring and Evaluation	Finally, road safety authorities should continually recheck the section of the road for collisions and unfortunate incidents and review the extracted data against the available safety standards.

4.0 Conclusion

The curve radius and slope grade results provide strong evidence for significant safety concerns in the design. This was validated by existing literature highlighting the vital role of geometric design in ensuring road safety. As observed, the curve radius values of 38.180 m and 49.592 m are significantly lower than the recommended standards for safe curve maneuvers by vehicles. For instance, DPWH – DGCS for design speed for urban collector roads and AASHTO (2011) in the policy on geometric design of highways and streets have emphasized that a small curve radius can cause a higher accident rate owing to reduced stability and control of a vehicle while navigating through a curve. This is a major concern in sections designed for 60 kph and above due to the need for the road and vehicle maneuverability to be in close harmony to prevent accidents.

Furthermore, the slope grade observations of -11.53% and -10.75 % exceed the provided standards, affecting vehicle braking and acceleration performances. Fambro, Fitzpatrick, and Koppa (1997), in a study on driver speed behavior about road grade, confirmed that steeper grades often result in inconsistent vehicle speed that increases the likelihood of rear-end collisions and loss of control. Moreover, the risk is exacerbated when other adverse

conditions like wet and slippery pavement exist. The current outcomes are, therefore, consistent with existing literature highlighting the need for the immediate introduction of remedial interventions. The proposed measures, which include accident control and the adjustment of speed limits, are consistent with the findings in existing literature regarding their effectiveness in guaranteeing road user safety. For example, restoring speed limits in critical areas is consistent with the findings of Elvik (2013) in a study that found that a decrease in speed limits results in a sharp reduction in the accident rate. Similarly, the focus on improving signing and service is consistent with Retting, Weinstein, and Solomon's (2003) findings on the effect of improved signs and lane markings on speed and crash rate. Thus, if implemented with stringent monitoring and evaluation, such measures would be significant in aligning Sagonsongan Diversion Road with safety standards. Therefore, the two areas of geometric design observed in this analysis clearly indicate safety threats to road users and must be aligned with the established standards of road safety. Hence, they must be addressed to ensure that they are aligned with safety standards and guarantee safety for all road users in Sagonsongan Diversion Road

Considering the numerous limitations the researchers encounter, future researchers who would like to address a similar topic as this study are advised to conduct a more comprehensive investigation. Additionally, this study may recommend the following to future researchers: (1)propose further research on the curve section of the Sagonsongan diversion road in Marawi City. It should involve the superelevation in connection to the road's horizontal curvature and vertical alignment. These elements are interconnected and affect the road line's viability and necessary safety measures. (2) Another recommendation that the researcher may make is to introduce a 50 kph speed limit. This policy would ensure the safe operation of the two curved sections. Furthermore, one can propose posting speed limits and other traffic signs at least 50 to 150 meters away. Thus, this measure would increase road users' awareness and enable drivers to undertake a safe journey.

5.0 Contributions of Authors

Jalaloden M. Motalib – editing, writing, supervising, data analysis
Nassib U. H. Nasser – writing or encoding, research assistant
Jamshed D. Mangacop – Field assistant and recording
Abdul Warith M. Mamaingco – Field assistant and recording

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7.0 Conflict of Interests

The authors declare no conflicts of interest.

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