A Review of Literature on Geometric Design of Highway

Nisha Meena
Research Scholar
nishameena199695@gmail.com

Abstract

The field of geometric design of highways plays a pivotal role in shaping the physical and visible attributes of road infrastructure. This encompasses various elements such as cross-sectional features, sight distances, alignment, curves, and super elevation, all of which contribute to the overall functionality of the road network. With India experiencing a continuous rise in population, there is a corresponding surge in traffic volume. However, the allocation of funds from the government for the development of transportation infrastructure has not been entirely satisfactory.

In light of these challenges, it becomes imperative to proactively plan and design the geometric elements of roads during the initial alignment phase, taking into account the anticipated growth in traffic. The consequences of neglecting this crucial aspect become apparent post-construction, making it not only difficult but also economically unfavorable to modify geometric elements. This can result in unwanted capital investments.

This paper aims to provide a comprehensive review of past research efforts in the realm of highway geometric design, with a specific focus on emphasizing the importance of meticulous planning and designing of these geometric features. While there exist numerous factors influencing highway design, this study underscores the significance of adopting a suitable geometric design that aligns with the objective of achieving optimum efficiency in traffic operation, ensuring contentment and safety measures, all at a reasonable cost.

Keywords: **Review, Geometric design, Super elevation, Cross-sectional elements, Optimum efficiency.**
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1 Introduction:

The geometric design of highways is a critical facet in the development of transportation infrastructure, serving as the architectural blueprint that shapes the physical features of roads. This meticulous process involves the thoughtful consideration of various elements to ensure not only the efficient movement of traffic but also the paramount importance of safety. As we delve into the intricacies of geometric highway design, it becomes evident that this discipline is both an art and a science, requiring a harmonious blend of engineering precision and a deep understanding of human behavior on the road. At the heart of geometric design lies the alignment of the highway, a carefully orchestrated series of horizontal tangents and curves that dictate the road's route. This alignment is not arbitrary; it is a calculated response to the topography of the terrain, traffic patterns, and the overarching goal of facilitating smooth traffic flow. Balancing the need for curves, which can be more aesthetically pleasing and efficient in navigating hilly terrains, with the safety concerns associated with straight stretches is an intricate dance that geometric designers must mas

ter.

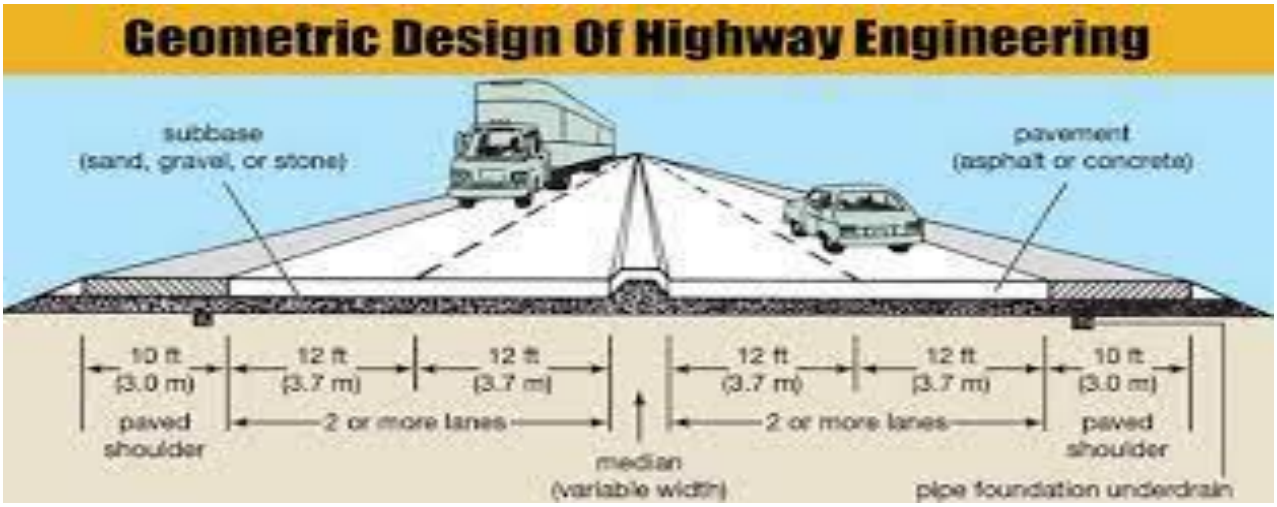

Figure – Gematric Design

The vertical aspect of the road, represented by the profile, is equally crucial. It encompasses crest and sag curves, as well as straight grade lines connecting them. Managing elevation changes ensures that drivers experience a comfortable and safe journey, particularly in regions with varied topography. A well-designed profile not only enhances safety but also contributes to the overall aesthetics of the highway. Cross-sectional elements further add layers of complexity to geometric design. These elements showcase the arrangement of vehicle and bicycle lanes, sidewalks, drainage features, and pavement structures. The cross-section is a holistic view of the road, encompassing not just the immediate path of vehicles but also the surrounding elements that contribute to the road's functionality and safety.

Sight distance, a term deeply embedded in geometric design, refers to the length of roadway visible to a driver. It is a critical factor in ensuring that drivers have adequate visibility to react to changes in the road ahead, thus directly influencing safety. The meticulous consideration of sight distance is emblematic of the overarching commitment to creating roadways that prioritize the well-being of those traversing them.

Horizontal curves introduce a dynamic aspect to geometric design, playing a pivotal role in changing the direction of the road's centerline. The radius of these curves and the speed of vehicles navigating them must be carefully calibrated to prevent accidents caused by centrifugal forces. Transition curves further soften the introduction of superelevation, a design technique that raises the outer edge of the pavement to counteract centrifugal forces during turns.

Superelevation, when applied judiciously, contributes to the prevention of vehicle overturning and lateral skidding. This design element underscores the delicate balance between optimizing traffic efficiency and ensuring safety, a theme that permeates every aspect of geometric design. The intricacies of geometric design become even more apparent when considering specific factors such as pavement widening, cross slope, crest curves, and the relationship between horizontal curves and gradients. Each of these elements requires a nuanced understanding of their impact on safety and traffic flow, emphasizing the interdisciplinary nature of geometric design that draws on principles of engineering, physics, and human behavior.

Technology has become an indispensable ally in the realm of geometric design. Software tools like MX Road have emerged as powerful aids, streamlining the design process and offering default values for various influencing factors. The integration of Geographic Information System (GIS) tools, such as Arc GIS, facilitates the optimization of alignment, contributing to

cost-effective and efficient construction. In the pursuit of safety, researchers and practitioners delve into the study of accident rates, utilizing regression analyses and modeling to identify the influence of various geometric design elements. These studies provide valuable insights into the real-world implications of geometric decisions, guiding future design practices and emphasizing the need for continuous refinement and adaptation.

The geometric design of highways is a nuanced and critical aspect of transportation infrastructure, involving the meticulous planning and shaping of the visible and physical features of roadways. This process encompasses a range of elements, each playing a pivotal role in determining the efficiency, safety, and adaptability of highways. This essay delves into the various geometric elements involved in highway design, highlighting their significance and interplay in creating road networks that not only address current traffic needs but also anticipate and accommodate future growth.

Geometric Elements Defined:

- Alignment: Alignment sets the course for the road, characterized by a series of horizontal tangents and curves. It establishes the overall direction of the roadway, influencing traffic flow and driver experience.
- Profile: The profile addresses the vertical dimension of the road, encompassing crest and sag curves, as well as straight grade lines. It manages elevation changes, impacting the overall topography of the roadway.
- Cross-section: The cross-section provides a holistic view of the road, indicating the position and number of lanes, sidewalks, and their cross slope or banking. Additionally, it incorporates drainage features and pavement structure, extending beyond geometric design considerations.
- Sight Distance: Road geometry significantly affects sight distance, a crucial factor in road design. It refers to the length of roadway visible to the driver, influencing safety and maneuverability.
- Cross Slope: Cross slope dictates the slope of the roadway perpendicular to the centerline, ensuring effective water drainage and maintaining a safe driving surface.
- Crest Curves: Crest vertical curves are upwardly convex curves, influencing visibility and vehicle stability. They are present at hill crests and locations where gradients transition.
- Superelevation: Superelevation involves raising the pavement's outer edge compared to the inner edge, counteracting centrifugal forces during turns and enhancing overall safety.
- Horizontal Curves: Horizontal curves are introduced to alter the direction of the road's centerline. They invoke centrifugal forces during a vehicle's negotiation, dependent on the curve's radius and the vehicle's speed.
- Transition Curve: The transition curve facilitates a gradual introduction of superelevation and centrifugal forces during a horizontal curve, preventing abrupt shifts and ensuring a smoother driving experience.

Understanding and incorporating these geometric elements during the initial stages of highway planning is imperative. Doing so not only ensures optimal traffic efficiency but also minimizes challenges associated with retrofitting geometric features post-construction. This proactive approach leads to more cost-effective and sustainable infrastructure development, aligning with the evolving needs of our dynamic transportation landscape. In navigating the complexities of geometric highway design, the pursuit of safety, efficiency, and adaptability remains paramount for the continued advancement of our road networks.

2 Literature Review

The literature surrounding geometric highway design provides a wealth of knowledge, insights, and empirical findings that contribute to the

enhancement of road infrastructure. This review encompasses various studies and perspectives, shedding light on safety considerations, pavement widening formulas, fuel consumption modeling, software precision, and the impact of geometric factors on accident rates.

Chakole and Wadhai (2018) conducted a comprehensive review comparing geometric design using Civil 3D software with the manual method. The researchers explored the intricacies of design processes and evaluated the efficacy of Civil 3D in enhancing efficiency and precision in geometric design.

In a study by Tougwa (2018), the researcher delved into the geometric design of highways with a specific focus on ensuring road health and safety. The review provided insights into the critical elements influencing road safety and health, offering valuable considerations for future highway designs.

Mandal, Pawade, Sandel, and Infrastructure (2017) contributed to the body of knowledge by investigating the geometric design of highways using Civil 3D. The researchers explored the capabilities of Civil 3D in shaping highway geometry, shedding light on its potential impact on the efficiency and precision of design processes.

Gaikawad and Ghodmare (2018) conducted a comprehensive review focusing on the geometric design of highways with the assistance of AutoCAD Civil 3D. The study provided insights into the application of AutoCAD Civil 3D in geometric design, emphasizing its role in enhancing the overall design process.

In a literature review by Veer, Gupte, and Juremalani (2018), the researchers explored existing knowledge on the geometric design of highways. The review covered a broad spectrum of literature, consolidating information on various factors influencing highway geometry and providing a holistic understanding of the subject.

Aryal (2018) contributed to the field by focusing on the optimization of geometric road design for autonomous vehicles. The researcher explored how geometric design considerations could be tailored to accommodate the unique requirements of autonomous vehicles, contributing to the ongoing discourse on the integration of autonomous technology into highway infrastructure.

Zulfa, Rifai, and Taufik (2018) conducted a case study on the road geometric design using AutoCAD Civil 3D in Jalan Campaka-Wanaraja Garut, Indonesia. The researchers provided valuable insights into the application of AutoCAD Civil 3D in real-world scenarios, emphasizing its effectiveness in addressing specific geographic and design challenges.

In a study by Mandal et al. (2017), the researchers revisited the geometric design of highways using Civil 3D, providing additional perspectives and insights into the software's capabilities. The study reinforced the notion that technology-driven approaches, such as Civil 3D, have the potential to revolutionize traditional highway design methodologies.

Himes, Porter, Hamilton, and Donnell (2017) contributed to the safety evaluation of geometric design criteria, specifically focusing on horizontal curve radius and side friction demand on rural, two-lane highways. The study provided empirical evidence and insights into the crucial relationship between geometric design parameters and safety outcomes on highways.

In a study by Raji, Zava, Jirgba, and Osunkunle (2017), the researchers explored the geometric design of a highway using Autocad Civil 3D. The study contributed to the understanding of the practical application of AutoCAD Civil 3D in highway design, showcasing its potential in real-world engineering projects.

Hameed Aswad Mohammed (2013) - Mohammed emphasizes the critical role of shoulder width in enhancing safety, with wider shoulders (exceeding 2.25m) providing additional safety benefits. His findings underscore that highway curves pose a significantly higher risk of single-vehicle accidents compared to tangents. The combination of horizontal curves with gradients and surfaces featuring low coefficients of

friction amplifies this danger, with crash rates escalating at radii below 1000m. Mohammed's insights underscore the importance of considering multiple factors in geometric design to mitigate risks.

Neeraj and S.S.Kazal (2015) - This study introduces the concept of mechanical widening on horizontal curves to prevent off-tracking. The formula presented, Wm= nl2/2R, defines mechanical widening, where "R" is the mean radius of the curve, "n" is the number of lanes, and "l" is the length of the wheelbase. Additionally, Wps= v/(2.64√R) calculates the pavement widening required at horizontal curves based on design speed. These formulas offer a systematic approach to address off-tracking issues on curves, ensuring a safer roadway.

Min-Wook Kang et al. (2013) - The development of a fuel consumption model based on highway geometric characteristics provides a valuable tool for assessing the environmental impact of road design. Kang et al. consider grades, crest and vertical curve characteristics, speed, and road surface type in their model. The limitations, such as applicability to passenger cars and the absence of considerations for intersections and curved sections, highlight the need for ongoing refinement to encompass a broader range of vehicle types and road scenarios.

Asok Kumar et. al (2015) - advocate for the use of MX ROAD software in geometric design, citing its high precision and time-saving capabilities. The software's efficiency in designing geometric elements underscores the importance of leveraging technological tools for optimal results in highway planning.

Vikas Golakoti (2015) - Golakoti's thesis delves into the geometric factors of roads and their impact on accident rates. This study aims to uncover the relationship between factors such as extra widening, horizontal radius, sight distance, K-value, super elevation, horizontal and vertical arc lengths, and vertical gradient on accident rates. Golakoti's research aims to inform future road designs, emphasizing the need to consider various geometric parameters for safer roads, especially in rural areas.

American Association of State Highway and Transport Officials (2005) - This policy statement by the American Association of State Highway and Transport Officials establishes standards for highway design elements. It encompasses vertical clearance, cross-section, structural capacity of bridges, and considerations about tunnels. The guidelines set forth in this policy serve as a foundational framework for ensuring uniformity and quality in highway design.

Indian Road Congress 73:2005 - The Indian Road Congress 73:2005 stands as a cornerstone, providing specifications for highway geometric elements, terrain classification, design speed, and considerations for different types of highways and design traffic. This comprehensive document serves as a guiding framework for ensuring uniformity and precision in highway design across diverse terrains and traffic conditions in India.

United Nations Highway Safety Information System (1999) - This system offers a fundamental methodology for developing cross-sectional models. By predicting crash rates per kilometer for different road types, it provides a nuanced understanding of safety effects. The use of over-dispersed Poisson models further refines the analysis, allowing for a comprehensive assessment of safety implications across various road classes.

Mohammad A. Hadi et al. (1994) - Hadi's study employs negative binomial regression analysis to estimate the impact of cross-sectional design elements on total fatality and injury crash rates. Results indicate that increasing lane width, median width, and inside shoulder width effectively reduce crashes, emphasizing the role of geometric design in enhancing safety across various types of rural and urban highways.

Abo El-Hassan M. Rahil et al. (2014) - This research introduces three approaches to relate accident rates to geometric characteristics and traffic-related variables, employing Multiple Linear Regression, Poisson Regression, and Negative Binomial Regression. The models are rigorously tested and validated, providing a

comprehensive understanding of the significant factors influencing accident frequency. The study highlights the importance of cautious extrapolation when utilizing these models for future forecasts.

Matthew G. Karlaftis and Ioannis Golias (2001) - Karlaftis and Golias employ a non-parametric statistical methodology to assess the relationship between rural road geometric characteristics, accident rates, and their prediction. Their results reveal that geometric design variables and pavement condition are pivotal factors affecting accident rates, with variations in importance between two-lane and multilane roads.

Ali Aram (2010) - Aram's focus on safety factors on horizontal curves of two-lane highways underscores the higher crash rates on curves compared to straight sections. The study identifies various roadway and geometric features influencing safety, emphasizing the importance of considering factors such as traffic volume, curve features, and pavement friction in geometric design.

Kay Fitzpatrick et al. (2008) - The study by Fitzpatrick et al. aims to develop Accident Modification Factors (AMFs) for median characteristics on urban and rural freeways, as well as rural multilane highways. Negative binomial regression models are utilized to understand the effects of independent variables on crashes, providing valuable insights into the role of median characteristics in safety.

Manoj K. Jha and Paul Schonfeld (2004) - Jha and Schonfeld's work delves into highway alignment optimization, emphasizing the need for a comprehensive formulation of costs sensitive to alignment. Their model integrates a Geographic Information System (GIS) with genetic algorithms, providing a robust approach to cost minimization and alignment selection in constrained spaces.

3 Conclusion

In the realm of highway infrastructure, the geometric design plays a pivotal role in shaping not just the physical aspects of roads but also the efficiency, safety, and overall functionality of transportation networks. As we delve into the conclusions drawn from various sources and past research, a roadmap emerges, highlighting key objectives and considerations essential for achieving optimal geometric highway design. At the forefront of these objectives is the pursuit of optimum efficiency in traffic movement while prioritizing safety, all within the constraints of reasonable cost. Achieving this delicate balance is imperative for ensuring the sustainability and effectiveness of highway infrastructure. This foundational principle underscores the overarching goal of geometric design—to create roadways that not only facilitate seamless traffic flow but also safeguard the lives of commuters at a cost that is justifiable and sustainable. Guidelines serve as the bedrock of effective highway design, with the recommendations of AASHTO and IRC taking precedence. These guidelines, emanating from reputable authorities in the field, provide a standardized framework that aids in the creation of efficient and safe highway systems. While state highway specifications are acknowledged as important, they are seen as supplementary to, rather than a replacement for, these primary guidelines.

In the realm of software tools, MX Road emerges as a preferred and optimistic choice for highway design. Its utilization is recommended due to default values that encompass a myriad of factors influencing the design process. By leveraging such advanced tools, highway engineers can streamline their design processes, ensuring precision and efficiency in their endeavors. To further enhance cost-effectiveness, the optimization of alignment is crucial. Arc GIS software is identified as a strategic tool in this regard, offering a comprehensive approach to alignment planning. This not only contributes to cost savings but also enhances overall construction efficiency, a critical consideration in the ever-evolving landscape of transportation infrastructure.

Careful attention to specific design elements is emphasized, such as the meticulous consideration of super elevation within recommended ranges and the strategic design of pavement widening on horizontal curves. These elements are identified as key

contributors to safety and the overall functionality of highways. The inclusion of a 2.25m wide shoulder is advocated for its potential to provide additional safety, emphasizing the importance of considering not just the main roadway but also its ancillary features. Similarly, the width of medians is recognized as critical, falling within a prescribed range to ensure safety and efficient traffic flow on highways.

The importance of proper sight distance and vertical alignment is not just confined to safety considerations but also extends to fuel efficiency. By reducing propulsive force through thoughtful design, highways can contribute to lower fuel consumption, aligning with environmentally conscious practices. However, amidst these considerations, caution is warranted around horizontal curves at grade separation. These areas are identified as particularly dangerous, contributing to a significant portion of accidents. This underscores the need for heightened caution, strategic planning, and perhaps additional safety measures in these specific locations.

In conclusion, the objectives and considerations outlined above form a comprehensive blueprint for achieving optimal geometric highway design. By integrating these insights into the design process, highway engineers and planners can contribute to the development of safer, more efficient, and cost-effective transportation infrastructure that meets the evolving needs of societies. The journey toward the optimization of geometric design is not merely a technical endeavor; it is a commitment to fostering safer and more sustainable avenues of transportation for the benefit of communities and economies alike.

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