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RESEARCH ARTICLE **ROAD AND TRANSPORTION ENGINEERING**

The Impact of Roadway Cross-section Elements' Design and Conditions on Road Safety: A Case Study of Alshwarif-Brack Road

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A B S T R A C T

This study assesses the design and physical characteristics of cross-sectional elements on the road links connecting Alshwarif and Bark Alshatti cities and their influence on road safety, aiming to propose solutions by existing standards. Essential factors, including the design aspects of curves, gradients, and drainage systems, are analysed to assess their impact on collision frequency and overall safety. The research examines factors including road surfaces, lane and shoulder widths, guardrails, and lighting conditions. All these factors significantly influence driver behavior and the likelihood of collisions. This study provides evidence-based recommendations for enhanced road design and maintenance methods through field observations, survey work, and the integration of concepts from existing guidelines. The results of this study emphasize the need to repave the road and implement road layers according to the required standards, with a cross slope for lanes of at least 2%. Additionally, it is important to redesign horizontal curves by adding superelevation in accordance with AASHTO standards, along with providing wide shoulders and barriers to prevent off-road collisions, particularly at curves and elevated sections. The study also highlights the importance of properly implementing side drainage to reduce the risk of hydroplaning. The primary objective of these proposals is to enhance the safety of Alshwarif-Barck Alshatti road. This will help in reducing the likelihood of collisions and fatalities. It would also contribute to creating an improved roadway environment for all users.

تأثير تصميم وظروف عناصر المقطع العرضي للطريق على السلامة المرورية: دراسة طريق الشويرف-براك

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الكلمات المفتاحية

السلامة المرورية
سلوك السائقين
عناصر التصميم
المقاطع العرضية
الانحدار

الملخص

تقوم هذه الدراسة بتقييم تصميم و خصائص المقاطع العرضية للطريق الرابط بين مدينتي الشويرف و براك الشاطئ وتأثيرها على السلامة المرورية، بهدف اقتراح حلول وفقاً للمعايير القائمة. الدراسة تهدف الي تحليل عوامل أساسية، بما في ذلك جوانب التصميم المتعلقة بالمنحنيات والانحدارات وأنظمة الصرف، لتقييم تأثيرها على تكرار الحوادث والسلامة العامة على الطريق. كما تسلط الضوء على مجموعة من العوامل المختلفة مثل جودة أسطح الطرق، وعرض الحارات والأكتاف، والحواجز الجانبية، وظروف الإضاءة. كل هذه العوامل تؤثر بشكل كبير على سلوك السائقين و احتمالية وقوع الحوادث. تقدم هذه الدراسة توصيات قائمة على الأدلة لتحسين تصميم الطرق و اساليب الصيانة من خلال الملاحظات الميدانية وأعمال المسح ومقارنة التصميم الحالي بالمعايير و المفاهيم المستخلصة من الادلة الارشادية. وتؤكد نتائج هذه الدراسة على ضرورة اعادة رصف الطريق و تنفيذ طبقات الطرق حسب المعايير المطلوبة مع ميةل للحارات لا يقل عن 2%.كذلك ، اعادة تصميم المنحنيات الافقية مع اضافة superelevation طبقا لاشتراطات AASHTO، بلاضافة الي توفير وأكتاف واسعة، وحواجز لمنع الحوادث على اطراف الطريق خاصة عند المنحنيات , القطاعات المرتفعة للطريق. و تبرز الدراسة ايضاً اهمية تنفيذ صرف جانبي بشكل صحيح لتقليل مخاطر الانزلاق المائي. الهدف الرئيسي من هذه المقترحات هو تحسين السلامة المرورية على طريق الشويرف-براك ، مما سيساهم في تقليل احتمالية الحوادث والوفيات، وكذلك في جعل بيئة الطريق أفضل لجميع المستخدمين.

Introduction

Road safety is a crucial concern in modern transportation infrastructure. One of the main aspects of guaranteeing safe travel is the proper design and implementation of road cross-sections. The geometric depiction of a road's profile is called a cross-section. They provide vital information about the many characteristics present within a road, including its width, slope, and alignment. These factors play a significant role in ensuring road safety. The significance of these aspects on road safety must be considered since they directly influence how drivers navigate and interpret the road environment. Lane width and slope both impacts how well water drains off the surface of the road and how stable and manoeuvrable a vehicle is [1,2].

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Road alignment is another significant feature that influences safety. The curvature of a road determines the driver's sight around curves, which is vital for anticipating potential risks or barriers ahead [3]. Besides geometric elements, cross-sections also incorporate other crucial components such as traffic signs, pavement markings, guardrails, and lighting systems. These components improve visibility for drivers during varied weather situations or at night.

Understanding the impact of each factor present within cross-sections is vital for building safe roadways and avoiding collisions. By examining elements such as suitable lane widths to accommodate different vehicle types, good drainage systems to minimize hydroplaning incidents during rainfall, or deploying proper signs to promote driver awareness, transportation authorities can improve overall road safety.

The intricacy of road cross-sections extends beyond their physical components. The interaction between these components and human behaviour plays a key effect in road safety outcomes. For example, the psychological impact of road design on driver perception and decision-making is a topic of considerable research. Factors such as the visual cues supplied by road markings and the apparent width of lanes can all influence driving behaviour and, consequently, safety.

This study intends to dive more into the impact of these factors discovered in cross sections on road safety. By assessing their separate impacts and understanding their relationship with one another, improved methods can be established for creating safer roads that prevent collisions and ensure optimal travel conditions for all users. This research endeavour is expected to give useful insights into enhancing existing infrastructure as well as assist future planning decisions regarding roads' cross-sectional design toward establishing safer transportation networks.

Literature Review

Numerous research has shed light on how lane width affects traffic safety. Strathman et al., [4] and Potts et al., [5] undertook a comprehensive review of collision data on urban arterials, finding that while wider lanes generally increase safety, the connection is not linear. They noticed that lanes larger than 12 feet (3.7 meters) did not provide substantial additional safety benefits and could potentially increase speeding. Conversely, Manuel et al., [6] focused on rural two-lane roadways, suggesting that increasing lane width from 9 to 12 feet (2.7 to 3.7 meters) could lower collision frequency by up to 40%. This emphasizes the context-dependent nature of lane width impacts.

Horizontal curves are one of the most important features of any road network. In comparison to straight sections of a road, horizontal bends have a collision rate that is 1.5–4 times greater when they are paired with grades and low friction surfaces [7]. Designing and assessing horizontal curves with the proper geometric and safety parameters—such as side friction and superelevation—is crucial. The transverse slope known as superelevation is applied along the length of the horizontal bends in order to oppose the centrifugal force that tries to pull the vehicle outward. Furthermore, side friction is the force that prevents a vehicle from sliding or skidding by acting between the wheels and the pavement [8].

The need for optimum road slope for drainage has been further underlined in recent research. Ghavami et al. [9] applied advanced simulation approaches to model the connection between road cross slope, rainfall intensity, and vehicle hydroplaning risk. Their findings support the continued use of a minimum 2% cross slope for most roadways but imply that higher slopes may be necessary in places prone to excessive rainfall. The possibility for hydroplaning in connection to water depth, as well as a variety of vehicle speeds, tire tread depth, tire pressure, pavement surface roughness, and cross slope, was also computed by Shams et al. [10], highlighting the necessity of routine slope repair to give the best possible safety conditions.

Recent research has provided useful insights into the complex relationship between pavement conditions and traffic safety. Lee et al. [11] studied data from Florida, demonstrating that poor pavement conditions have variable effects on collision severity depending on road type and collision characteristics. Notably, they observed that bad pavement decreased single-vehicle collision severity on low-speed highways but increased it on high-speed highways, while consistently raising multi-vehicle collision severity across all roadway types.

Methodology

Research into the impact of cross-sectional features on road safety typically takes a diverse methodological approach to examine the influence of numerous factors. These factors include road markings, signage, obstacles, and illuminations. This research domain utilizes many approaches to analyze the relationship between these variables and road safety outcomes. The following methodologies are often applied in the field of study.

- Observational Studies: Researchers may undertake observational studies to acquire data on the presence, condition, and usefulness of cross-section elements on roads. This could comprise on-site inspections of road conditions, traffic behavior, and collision hotspots to study the association between different elements and road safety.
- Simulation and Modeling: Utilizing powerful simulation tools or computational models, researchers can simulate diverse scenarios to examine the impact of cross-section elements on road safety. By developing virtual settings and testing alternative configurations, they may examine the potential usefulness of different design initiatives in enhancing safety results.
- Surveys and Questionnaires: Surveys and questionnaires can be used to get input from road users, stakeholders, and experts regarding their perceptions of cross-section aspects and their influence on road safety. These qualitative data provide significant insights into user experiences, preferences, and suggestions for strengthening safety measures.
- Statistical Analysis: Statistical tools like as regression analysis, correlation research, and data mining techniques can be applied to quantify the association between cross-section elements and road safety outcomes. By analyzing vast datasets and identifying key variables, researchers can establish the efficiency of individual aspects in improving road safety.

- Comparative Studies: Researchers can investigate the relative effects of these aspects on road safety with the help of comparative studies using various road segments with different cross-section elements. Researchers can determine the impact of individual components and evaluate how they affect safety metrics by contrasting comparable roads with different design elements.

The methodology for examining the impact of cross-sectional features on road safety is fundamentally interdisciplinary, generally including a combination of observational, analytical, simulative, and statistical approaches. This comprehensive framework provides for understanding of how various cross-sectional features contribute to the overall safety and functionality of road infrastructure.

In the context of the present research, the researchers experienced substantial constraints in accessing collision data for the study area. The given data suffered from severe incompleteness, suggesting it was unsuitable for statistical analysis. This data shortcoming is relatively prevalent in road safety studies, particularly in places where systematic collision reporting, and database administration may be immature or inconsistent.

Consequently, the evaluation reported in this work uses a targeted observational method. This analytical option illustrates an adaptation to limits imposed by data limitations, while yet providing useful insights into the relationship between cross-sectional factors and road safety. By concentrating on observational methodologies, the study uses direct field assessments, and land surveys to analyze the physical characteristics, conditions, and potential safety consequences of various roadway cross-sectional elements.

Highway Survey

A highway survey is a professional sort of land survey conducted during the first stages of a road project. It is a vital element in the planning and design process for new highways or major changes to existing ones. The primary goal is to collect reliable data about the current terrain and features along the proposed route, providing a basis for road design, construction planning, and cost estimation. The survey contains three important elements: topographic assessment, border demarcation, and geometric design considerations.

- **Preliminary Survey**

The goal of a preliminary survey is to acquire crucial physical facts and data regarding the terrain, drainage, and soil. This information is then utilized to analyze several ideas and decide the best alignment for the route. Additionally, the preliminary survey helps estimate the amount of earthwork required and concludes the ideal alignment.

- **Topographic Survey**

A topographic survey plays a significant part in the success of building or engineering projects. It helps identify unsuitable places for building, hence saving costly adverse effects. These unsuitable regions can include spots close to watercourses or drains that are prone to flooding, areas near huge trees that may cause ground swell or root problems, and areas too close to boundaries that may require specific permissions from the authorities. Commissioning a topographic survey at the beginning of a project also assists the setting out engineer. The survey leaves fixed reference markers, such as concrete monuments, on the site. These markers can be used to correctly locate aspects of the new design, such as the alignment center line and foundation of structures.

- **Geometric Design Survey**

Geometric design is a key part of transportation facility planning. It entails designing the cross sections, horizontal and vertical alignments, intersections, and other aspects of the facility. While the specific design guidelines may change based on the mode of transportation and the class of facility, the essential principles of geometric design remain the same. The fundamental goals of geometric design are to promote comfort, safety, and cost-effectiveness while minimizing environmental concerns.

Geometric cross sections are the first in the material presentation order in a road project, and they are followed by junctions, superelevation, vertical and horizontal alignment, and design details. However, for explanation, the order of issues is not necessary. On the other hand, in a normal design project, there is a specific order of work. Establishing a tentative horizontal centerline usually comes before establishing vertical alignment because the elevation of the existing ground along the centerline is a key aspect in determining vertical alignment. To design the vertical alignment, a profile of the existing terrain is plotted, and a tentative horizontal centerline must already be in place for this process.

Highway cross sections comprise the traveled path, shoulders (or parking lanes), and drainage systems. Shoulders primarily serve as a safety element, accommodating stopped vehicles, and emergency circumstances, and providing lateral support for the pavement. Shoulders can be either paved or unpaved. Drainage channels can be ditches (usually grassed swales) or paved shoulders with berms curbs and gutters. A graphic illustration of these highway cross-section elements is shown in Figure 1.

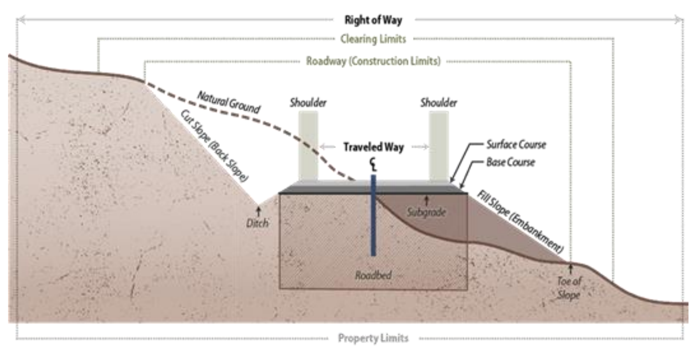

Fig.1: Highway Cross Section

- **Horizontal Alignment**

For linear transportation infrastructure like highways and railways, horizontal alignment comprises horizontal tangents, circular curves, slope, superelevation, and perhaps transition curves, as shown in Figure 2.

- **Vertical Alignment**

A transportation facility's vertical alignment consists of vertical curves and tangent grades, or straight lines in the vertical plane. The profile describes the vertical alignment, indicating elevation on the vertical axis and distance measured in stations along the centerline or another horizontal reference line of the facility. Tangent grades are classified depending on their slopes or grades.

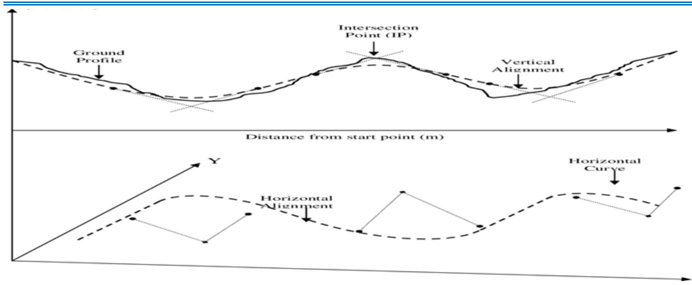

Fig.2: Vertical and horizontal Alignments of Roads

A Case Study of Brack-Alshwarif Road

Brack-Alshwarif road is an important highway that stretches for 280 kilometers through the Libyan Sahara Desert. For a long time, this road has not been adequately cared for or received the necessary maintenance. As a result, the road surface has become highly deteriorated, which has led to more collisions and fatalities. The difficult desert environment and the road's strategic importance make its poor status a matter of significant concern for both local populations and regional transportation networks.

This study focuses on evaluating the roadway cross-sectional conditions of a 70-kilometer length north of Brack City. By evaluating this portion, we want to provide a representative appraisal of the road's current state and its impact on safety. The choice of examining this particular portion enables a detailed examination of how various cross-sectional elements—such as lane width, shoulder conditions, drainage systems, and pavement quality—contribute to the overall safety profile of the road.

- **Embankment**

Brack-Alshwarif road is confronted with serious challenges deriving from its inadequately graded embankment slopes at various parts. These slopes are especially susceptible to erosion and instability, particularly during periods of severe rainfall. The road's geographical location lends it to adverse weather conditions, with water depths sometimes exceeding one meter following heavy rainfall. The survey crew in this study has discovered that certain portions of the road have experienced considerable erosion damage, Figure 3 provides an example. Furthermore, the research team observed that the slope has been eroded in several portions, requiring rapid measures. This deterioration seriously threatens the road's structural integrity and poses considerable risks to anyone traveling on it.

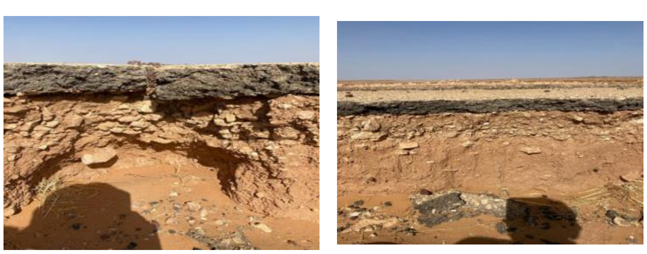

Fig.3: Embankment Deterioration

The American Association of State Highway and Transportation Officials (AASHTO) recommends a slope angle of 2:1 (horizontal: vertical) or flatter for most soil types to guarantee stability. To address the slope erosion, two highly effective alternatives are proposed: stone pitching and Plain Cement Concrete (PCC) reinforcement. Stone pitching includes deliberately putting huge stones in an interlocking pattern along the slope, providing an interlocking protective layer that resists erosion and promotes stability. Figure 4 displays a typical implementation of stone pitching. This approach is extremely successful in dissipating the energy of water runoff. Alternatively, PCC reinforcement comprises laying a layer of cement concrete over the slope, producing an impervious barrier against water infiltration.

Both solutions offer robust protection against the harsh environmental conditions faced by Brack-Alshwarif road, with the potential to greatly increase its resilience and strength. Implementing one of these alternatives will enhance the road's structural integrity and user safety. The decision between these alternatives would depend on individual site characteristics, available resources, and long-term maintenance considerations.

Fig.4: Stone Pitching

- **Superelevation**

The design and safety assessment of horizontal curves should address two parameters: the safety and the comfort of the passengers. These two crucial characteristics are connected to the superelevation and side friction. The survey teams noticed drivers often exceeding design speed limits, a tendency aggravated by the absence of law enforcement and marked speed restrictions. Notably, some horizontal curves were discovered to have no superelevation. This combination of excessive speeds and inadequate curve design considerably enhances the possibility of cars losing control or overturning while navigating horizontal bends. Additionally, the road's safety is further hindered by worsening surface conditions, poorly visible lane markers, and little shoulder space. These elements collectively contribute to a heightened collision frequency along this road, producing a hazardous environment for individuals using it.

Superelevation measurements were made at crucial curves along the road. Based on the survey findings, a new design has been developed to align with the criteria specified by AASHTO. Table 1 represent results from station 44+000 which demonstrates a significant change in road geometry to accommodate a horizontal curve. The present camber is to be replaced with a 3% superelevation, which fits within the suggested range of 3-6% for curved sections. It is vital for enabling vehicles to safely navigate the curve by counteracting centrifugal force. Figure 5 illustrates a graphic representation of the superelevation cross-section of the existing and the suggested design. This redesign objectives provide better water drainage, thus boosting safety during harsh weather conditions.

Table 1. Superelevation for Existing and New Designs

Project: Brack-Alshwarif Road				
Station	Existing Position	New Position	Standard	Remarks
44+000	Camber	Superelevation 3%	3 to 6%	Horizontal Curve

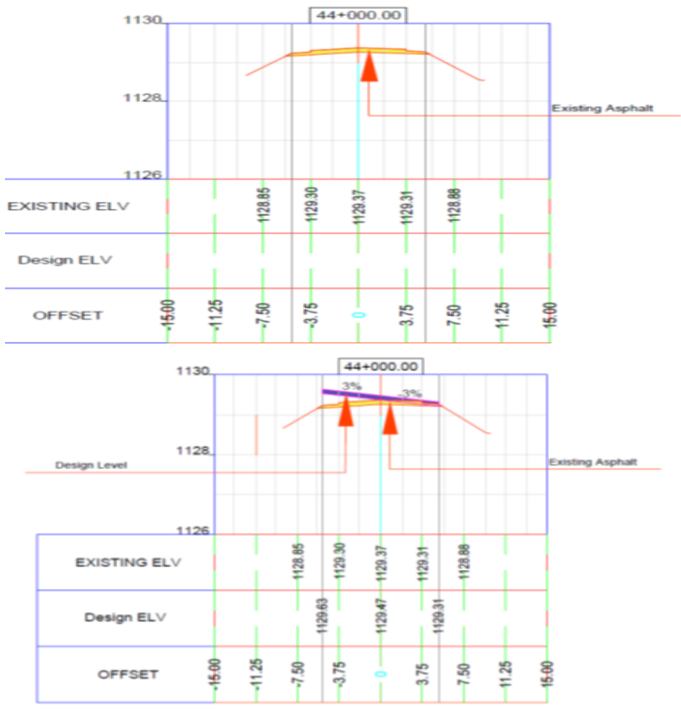

Fig.5: Superelevation at 44+000 Station

- **Shoulders**

The need for a robust and durable road shoulder cannot be emphasized enough for road long life and stability. Brack-Alshwarif Road's original design contained an insufficient half-meter soil shoulder, Figure 6, which fell short of regulations and could have led to damage over time. For rural highways and high-speed urban roadways, AASHTO generally recommends minimum shoulder widths of 1.2. Our new recommended design offers a 1-meter shoulder on Brack-Alshwarif road which is a major improvement over the existing 0.5-meter width, putting it closer to AASHTO's requirements. While it may not match the full width specified for some road conditions, it represents a major advance in road safety and durability.

- **Lane Width and Grades**

The existing condition of Brack-Alshwarif road offers substantial obstacles for drivers and poses considerable safety hazards. The existing road design contains a short width and steep cross-slope, qualities that are particularly problematic considering the road's role as a vital traffic artery in the region. The narrow width constrains vehicle agility, especially for large trucks, while the steep cross-slope amplifies concerns about vehicle stability, particularly during severe weather conditions.

Road grades were checked at several locations uncovered worrisome results. The road has been designed with a total pavement structure width of 10.5 m. This consists of two main traffic lanes measuring 7.5 m in width, complemented by 1.5 m

Fig.6: Shoulders Erosion

paved shoulders on each side. The road width aligns with the recommendations of AASHTO for two-way two-lane roads which it typically between 3 to 3.6 m per lane. Furthermore, many lane slopes were found to be below the criteria set by AASHTO. More alarmingly, some slopes were even negative. This is a severe issue because precise road slopes are crucial for safety and proper water drainage. Negative slopes are particularly dangerous as they can allow water to collect on the road, which may lead to vehicles losing control (hydroplaning) and diminish overall road safety. The fact that both insufficient and negative slopes were identified in various regions hints at a serious fault in how the roads were planned or maintained. This issue needs to be addressed swiftly to ensure road user safety.

Measurement of lane slops at station 0+400 illustrates the existing circumstances on straight parts of the road. From Table 2, the existing camber of 0.50% is being increased to 2%, which coincides with AASHTO standards of 2 to 3% for straight road portions. This improvement will considerably boost drainage, lowering the possibility of water gathering and hydroplaning, therefore improving safety and extending the road's lifespan. The revised 2% camber falls within the recommended range, bringing the road into compliance with design criteria. Figure 7 illustrates a graphic representation of Cross Section at 0+400.00 Station for both the existing and the suggested design

Table 2. Grades for Existing and New Designs

Project: Brack-Alshwarif Road				
Station	Existing Position	New Position	Standard	Remarks
0+400	Camber 0.50	Camber 2%	Camber 2 to 3 %	Straight Road

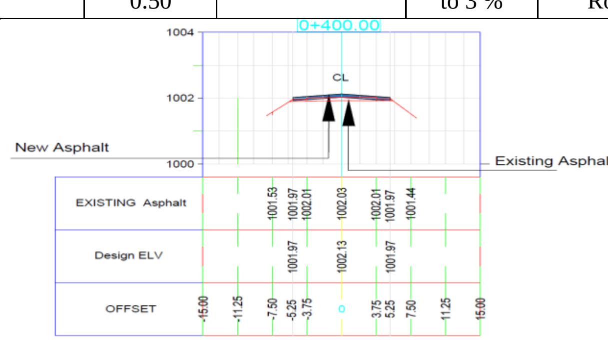

Fig. 7: Cross Section at 0+400.00 Station

- **Guardrails and Blocked Culverts**

Guardrails, known as flexible barriers, presents a safety measures that contributes to reducing both human and material losses in the event of traffic collisions at elevated sections of the roads. Currently guardrails are uninstalled in all elevated areas along Brack-Alshwarif road. Furthermore, the scenario on the Brack-Alshwarif road underlines the crucial need to preserve infrastructure like culverts. An assessment of the road indicated that most culverts under the road were obstructed. Figure 8 shows an illustration of this frequent issue. Blocked culverts pose substantial dangers to road integrity, potentially leading to water collection, embankment penetration, and structural damage. Regular maintenance is vital for preventing blockages, recognizing problems early, and guaranteeing cost-effective management of road networks. By maintaining vigilance in culvert care through routine inspections, debris removal, and prompt repairs, road authorities can extend infrastructure lifespan, enhance public safety, and avoid costly repairs.

Fig.8: Blocked Culverts

Discussion

Road safety is a key concern for transportation companies and governments worldwide. The features found in cross sections of highways can have a considerable impact on road safety, and it is crucial to understand their influence on designing safer roadways. One of the important characteristics observed in cross-sections that influences road safety is the road surface. A smooth, well-maintained surface gives higher traction and decreases the chance of collisions. On the other side, rough or uneven terrain can lead to poorer vehicle control and increase the probability of sliding or loss of control. Another essential aspect present in cross-sections is the presence of curves or bends. Curves can be hard for drivers, especially if they are sharp or poorly built. They demand drivers to slow down and negotiate them carefully to preserve control. Poorly planned curves may have inadequate signs or inappropriate banking, which can lead to collision.

The width of lanes also plays a critical influence on road safety. Narrow lanes decrease manoeuvrability for vehicles, particularly larger ones such as trucks or buses. This raises the likelihood of sideswiping incidents and restricts space for error when drivers meet unexpected impediments on the road. Shoulders are another characteristic found in cross sections that affect road safety. Wide shoulders give a location for vehicles to safely pull off if needed, decreasing potential collisions from disabled vehicles on the roadway itself. Additionally, shoulders serve as a buffer zone between moving traffic lanes and pedestrians or bicycles sharing the highway.

The presence of obstacles along roadsides also affects road safety dramatically. Barriers act as protective measures by keeping errant vehicles from leaving their allocated travel paths and colliding with trees, ditches, embankments, or other hazards beyond roadside slopes. Adequate lighting along roadsides is another crucial component influencing road safety in night-time situations when vision is reduced compared with daylight settings. Last but not least, critical flooding issues should be evaluated when building roads since they represent substantial risks during heavy rains resulting in hydroplaning collisions impacting vehicle stability while traveling at high speeds potentially leading to severe collisions.

Conclusions

In conclusion, several elements present in cross-sections have a potential impact on the safety of Brack-Alshwarif road - including but not limited to Road surfaces (smoothness), Curves/Bends (appropriate signage/design), Lane Widths (accommodate varied types/sizes/weights/classes) Shoulders (width & buffer zones), Barriers (preventing collisions beyond pathway limitations), Lighting Conditions (nighttime visibility enhancement), Flooding concerns (assesses hydroplaning dangers.

This study provides recommendations based on results from observational surveys which offers various advantages including direct assessment, contextual understanding, and detection of potential hazards. Furthermore, they can generate valuable qualitative data that supplement quantitative assessment and drive future study paths. However, it is vital to understand the drawbacks of this approach, which may include a lack of historical trend analysis and potential observer bias. These constraints, in turn, might restrict the application of the findings to other geographic or infrastructural settings. In light of these considerations, the study's findings should be viewed as early insights that can lead to future deeper investigations.

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