INNOVATIVE CRASH BARRIER

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Abstract

Run-off-road vehicle accidents are a major cause of loss and casualties on roads, with such incidents often resulting in serious injuries or fatalities for both the vehicle occupants and other road users. A road safety barrier is designed to safely control and redirect errant vehicles, absorbing the energy from the collision and minimizing harm to both vehicle occupants and other road users. Crash barriers play a critical role in redirecting vehicles, reducing collision severity, and minimizing injuries, fatalities, and property damage. This research focuses on evaluating the effectiveness of various road safety barriers, including cable barriers and W-beam barrier. Although traditional steel barriers are rigid and ineffective at absorbing impacts, cable barriers offer better performance, especially in light vehicle crashes. However, both types of barriers pose safety risks in certain scenarios, particularly with larger vehicles, prompting a need for better designs. Through analysis using STAAD Pro, this study evaluates three barrier configurations of W-Beam, Cable, and combined W-Beam-Cable systems under various impact conditions with cars and pickup trucks. Results show that W-beam barriers perform well at lower speeds, but their performance drops at higher speeds, especially for pickup trucks. Cable barriers, on the other hand, offer consistent protection across a broader speed range. Combining W-beam with cable barriers enhances vehicle

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containment and stability, especially in high-speed situations, making it a valuable option for improving overall safety.

1 Introduction

Crash barriers, also known as guardrails, safety barriers, traffic barriers, or guide rails, are integral components of modern road infrastructure, playing a crucial role in mitigating the severity of vehicle collisions and enhancing overall road safety. Their primary objective is to prevent vehicles from leaving the roadway and entering hazardous areas, such as steep embankments, water bodies, utility poles, trees, oncoming traffic lanes, or sensitive environmental areas. Fig. 1.1 effectively redirecting errant vehicles along their length or safely decelerating them upon impact, crash barriers significantly reduce the likelihood of severe injuries, fatalities, and property damage. These safety devices are strategically deployed along highways, freeways, expressways, bridges, curves, medians, shoulders, and other high-risk locations identified through thorough traffic engineering studies, accident analysis, and risk assessments. They serve as a crucial last line of defence against driver error, including inattention, fatigue, speeding, impairment, and other human factors, as well as adverse weather conditions, mechanical failures, tire blowouts, and other unforeseen events that can lead to loss of vehicle control.

Beyond preventing crossover accidents and run-off-road incidents, crash barriers fulfil several other essential functions that contribute to a safer transportation environment. They provide protection for vulnerable road users, including pedestrians, cyclists, motorcyclists, and construction workers, by creating a physical separation from vehicular traffic, minimizing the risk of direct collisions. In construction zones, work areas, and temporary traffic management schemes, they delineate safe zones for workers, equipment, and construction activities, preventing accidental incursions by passing vehicles and ensuring worker safety. Moreover, in specific applications, crash barriers are employed to safeguard valuable

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infrastructure, such as buildings, utilities, pipelines, and environmentally sensitive areas located adjacent to roadways, protecting them from potential damage in the event of a vehicle collision. The strategic placement, design, installation, and ongoing maintenance of these barriers are paramount for maximizing their effectiveness and ensuring the safety and well-being of all road users and the protection of surrounding assets.

2 2 Types of Crash Barrier

2.1 1 Guardrail Barrier

Guardrail barriers are essential road safety structures designed to prevent vehicles from leaving the roadway and minimize the impact of accidents. They serve as protective barriers that absorb and redirect crash forces, reducing the severity of collisions and safeguarding motorists and pedestrians alike.

2.2 2 Concrete Barrier

Concrete barriers, as outlined in the Indian Road Congress (IRC) codes, serve as durable traffic safety devices designed to minimize vehicle collision impacts. Commonly used in medians, construction zones, and bridge parapets, they effectively prevent crossover incidents by redirecting vehicles. Unlike flexible barriers such as W-beam or cable systems, concrete barriers rely on their rigid structure for impact mitigation. Their design considers factors like roadway speed, traffic volume, and site conditions. The sloping face of these barriers helps lift vehicle tires upon impact, guiding them parallel to the barrier rather than allowing them to vault over.

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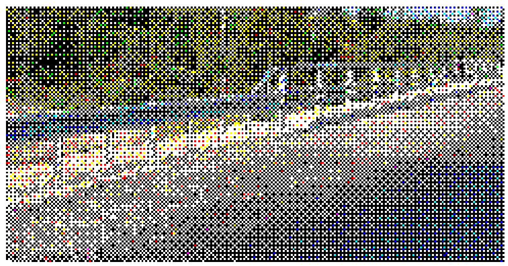

Figure 1: **1.1: Road Crash Barrier (Source: Ž Butāns 2015)**

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2.3 3 Steel Barrier

Steel barriers, as outlined in the Indian Road Congress (IRC) codes, play a crucial role in road safety by effectively absorbing impact energy and redirecting vehicles. IRC:119- 2015 provides detailed specifications for the design, installation, and maintenance of steel barriers, emphasizing their use in high-risk areas. Common types include W-beam barriers, which offer cost-effective protection along highways, and Thrie-beam barriers, which provide enhanced strength for higher-speed environments. These barriers are designed to minimize occupant risk by utilizing plastic deformation, which reduces crash forces.

Figure 2: 1.6: W-Beam Steel Barrier (Source: www.dachugroup.com)

2.4 4 Flexible Barriers

Flexible barriers, as outlined in Indian Road Congress (IRC) guidelines, serve as critical road safety devices by mitigating collision severity. Unlike rigid barriers, they deflect upon impact, absorbing kinetic energy through deformation to reduce occupant injury risks.

Key types include cable barriers, which consist of tensioned high-strength steel cables supported by posts. These barriers prevent crossover accidents on high-speed roads by

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Figure 3: 1.7 Thrie Beam Steel Barrier (Source: www.alpharoofing.com)

laterally redirecting vehicles while minimizing rebound into traffic. The IRC specifies crucial design factors such as cable diameter, post spacing, embedment depth, and tensioning requirements to ensure effectiveness.

Selection of barrier types depends on site-specific conditions, including traffic speed, volume, and median width. Regular inspection and maintenance are essential to ensure proper tensioning, post integrity, and overall functionality. IRC:119 provides detailed specifications for installation, with additional codes addressing road design and material considerations

2.5 5 Rolling Barrier

Rolling barriers, also known as rolling-type guardrails or rotary barriers, represent a relatively newer approach to road safety barrier design. A typically rolling barrier is as shown in Fig. 1.10 Unlike traditional barriers that rely on deflection and plastic deformation to absorb impact energy, rolling barriers utilize rotating cylindrical elements, typically made of high-strength plastic or composite materials, mounted on a steel rail. Upon impact, these rollers rotate, converting a portion of the vehicle's kinetic energy into rotational energy, effectively reducing the impact force and redirecting the vehicle along the barrier. This mechanism aims

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Figure 4: 1.8: Flexible Barrier (Source: www.Safe Direction.com)

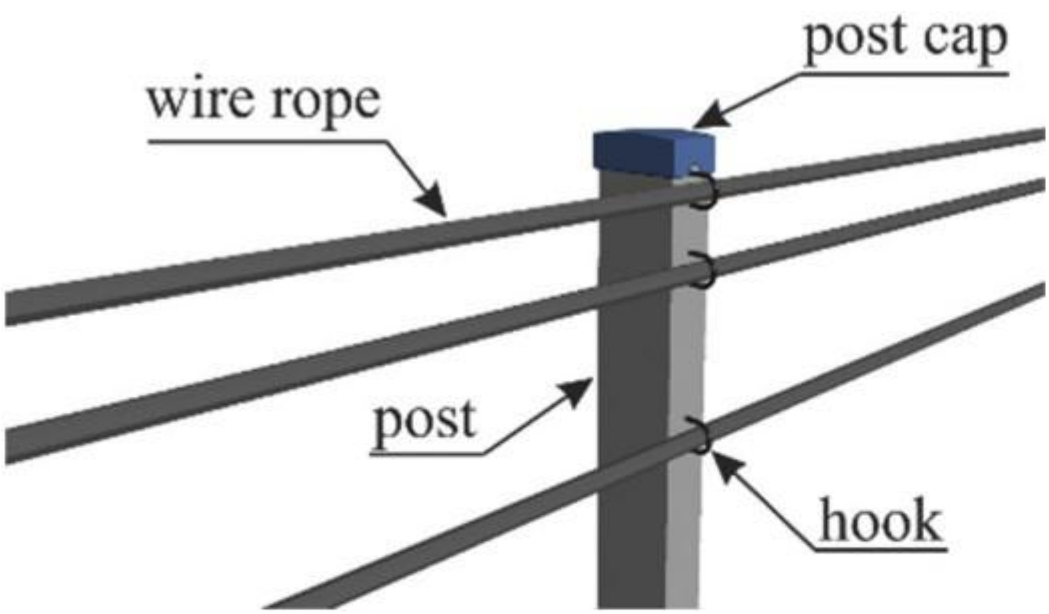

Figure 5: 1.9: Detail of numerical model of post's upper part (source: Dawid Bruski 2019)

to minimize occupant injury by reducing deceleration forces and preventing the vehicle from vaulting or crossing over the barrier. The components of the rolling barrier is as shown in Fig. 1.11. While specific performance criteria and testing procedures for rolling barriers might not be explicitly defined within IRC:119-2015, their evaluation would likely involve similar principles to those used for other barrier types. This could include full-scale crash testing according to established standards to assess their ability to contain and redirect vehicles

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safely, as well as to evaluate occupant risk factors. Rolling barriers offer potential advantages in specific situations, such as high-speed curves, areas with limited space for deflection, and locations prone to frequent accidents. Their ability to reduce impact forces and minimize vehicle damage could also lead to lower repair costs and reduced traffic disruption following collisions. However, their effectiveness and cost-effectiveness compared to more conventional barrier types need to be carefully evaluated on a case-by-case basis.

Figure 6: 1.10: Rolling Barrier (source: www.nikhilinfra.com)

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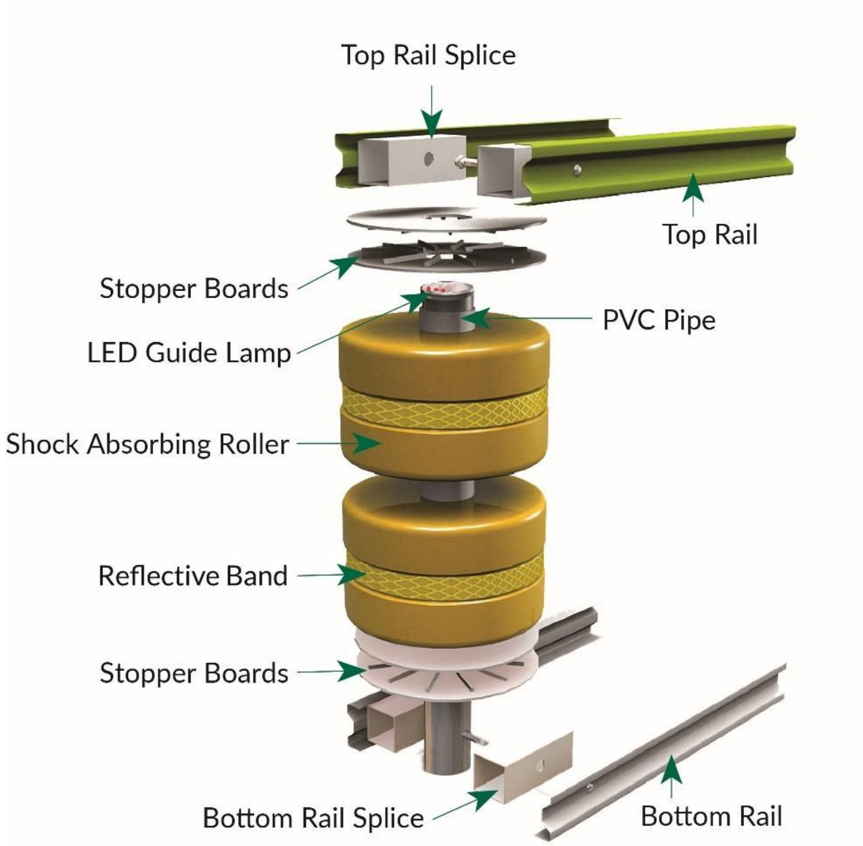

Figure 7: 1.11: Components of rolling barrier system (Source: Vivek Lodhia 2021)

3 LITRATURE REVIEW

The research presented comprehensively explores the effectiveness of various road safety barriers, with a particular focus on cable barriers and innovative designs like rolling barriers. Studies consistently demonstrate the effectiveness of cable median barriers in preventing severe crossover crashes, significantly reducing fatalities and injuries. The Hunter et al. (2001) study, while finding an overall increase in crash rates on treated segments after cable barrier installation, attributed this to the barrier acting as an obstacle. Importantly, the study highlighted a significant reduction in severe crashes, emphasizing the overall safety benefits of these barriers. The research delves into the development and evaluation of advanced barrier systems, such as rolling barriers. Kim and Shin (2004) introduced the Rolling Barrier (RB), an innovative design that utilizes rolling friction to reduce the

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severity of impacts. Initial installations demonstrated a remarkable reduction in accidents, highlighting the potential of this technology. Studies like those by Stolle et al. (2010) and Reid et al. (2010) focused on improving the design and modelling of cable barrier systems, emphasizing the importance of accurate wire rope modelling for predicting vehicle redirection. These studies utilized advanced finite element modelling techniques to simulate crash scenarios and evaluate the performance of different barrier designs. The research also investigates the factors influencing crash severity. Molan et al. (2020) analysed variables such as vehicle type, road conditions, and driver factors. Their findings showed that vehicle type significantly impacts crash severity involving flexible barriers, with cable barriers generally performing better than rigid barriers in light vehicle crashes. However, truck crashes involving guardrails were found to have a higher severity rate, potentially due to the shorter height of guardrails compared to other barrier types. Furthermore, the research emphasizes the importance of ongoing research and development in this field. Studies like those by Cheng et al. (2021) analyse current trends in roadside safety research, identifying key areas for future investigation, such as quantitatively analysing roadside accident probabilities, identifying accident blackspots, and developing more accurate calculation methods for safety design. The research highlights the critical role of effective roadside safety measures in reducing accidents and improving road safety. By implementing effective barrier systems, such as cable barriers and innovative designs like rolling barriers, coupled with ongoing research and development, it is possible to significantly reduce the number of road accidents and save lives. Studies like those by Lekhak et al. (2019) and Bruskia et al. (2019) compare the performance of different barrier types, such as w-beam, thrie beam, and cable barriers, through both experimental crash tests and numerical simulations. These studies demonstrate the superior performance of cable barriers in terms of energy absorption and occupant safety. The research also addresses the importance of considering the social and economic impacts of road accidents. Studies like that by Alluri et al. (2016) highlight the significant reduction in fatal and severe injury crashes achieved through the implementation of cable median

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barriers. This not only saves lives but also reduces the economic burden associated with accidents. Finally, studies like those by Lodhia and Poojari (2021), Suvarna et al. (2022), and Samre et al. (2024) advocate for the widespread adoption of rolling barriers as a cost-effective and efficient solution to enhance road safety. These studies emphasize the need for ongoing research and development to further improve the design and implementation of these innovative safety systems. By combining the findings of these diverse studies, researchers and policymakers can develop and implement more effective and comprehensive road safety strategies, ultimately leading to a significant reduction in road accidents and improved safety for all road users.

4 PROBLEM IDENTIFICATION AND OBJECTIVES

4.1 General

The current roadside crash barriers, especially steel and cable barriers, are causing problems for passengers and vehicles. When a vehicle hits a steel barrier, it can bounce off and hurt the people inside. This is because steel barriers are too rigid and don't absorb the impact well. As a result, the vehicle can crash into other vehicles or objects, causing more damage and injuries. Cable barriers are also dangerous. When a vehicle hits a cable barrier, the cables can whip back and forth, hurting people or damaging other vehicles. Sometimes, these barriers can't stop larger vehicles, leading to serious accidents. Many accidents happen because of these barriers, and people get hurt. The barriers are supposed to keep us safe, but sometimes they make things worse. There's a need for better-designed barriers that can absorb impacts and keep everyone safe. Additionally, the current barriers can also cause damage to vehicles, leading to financial losses. Overall, the current steel and cable barriers are not effective in preventing accidents and injuries, and there is a need for improved designs and technologies to address this issue.

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5 2 Objectives

The objectives of the study are,

Tofindaninnovativecrashbarrierwhichsafeguardthepassengerduring Sevieraccidents.

6 MODELLING

6.1 Modelling of Crash Barrier

6.1.1 STAAD Model with W Beam and Post

The Fig. 4.1: STAAD Model with W Beam and Post depicts a structural model created in STAAD Pro, a structural analysis and design software. The model represents a section of a roadside barrier system, constructed using W-beams and posts. The prominent feature is the horizontal W-beam, which acts as the primary barrier element, depicted by a green mesh or wireframe, indicating it's likely a surface or plate element in the model. This W-beam is supported by vertical posts, shown in blue. These posts are likely modelled as beam elements. The model appears to represent a typical guardrail or crash barrier setup, designed to prevent vehicles from leaving the roadway. The Fig. 4.1: STAAD Model with W Beam and Post Fig. 4.1 shows the geometry of the structure, including the spacing of the posts and the dimensions of the W-beam. The software interface, with tabs like "Geometry," "Properties," "Specifications," "Supports," "Loading," "Analysis," and "Design," indicates that the model is prepared for structural analysis. This analysis would typically involve applying loads representing vehicle impacts to assess the barrier's strength, deflection, and overall performance under crash conditions. The model's purpose is to simulate real-world scenarios and ensure the barrier's design meets safety standards.

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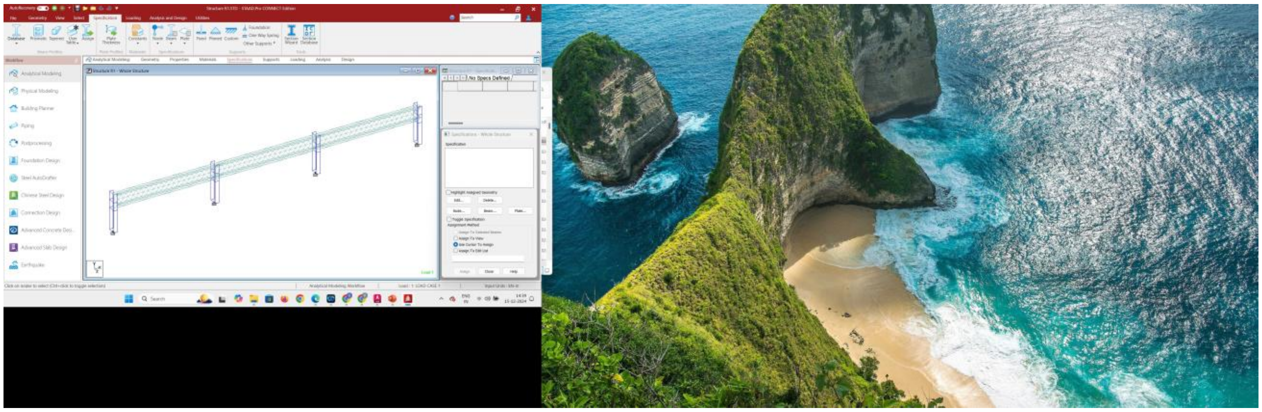

Figure 8: 4.1: STAAD Model with W Beam and Post

6.2 2 STAAD Model with Cable and Post

This Fig. 4.2 shows a structural model created in STAAD Pro, depicting a cable barrier system. The model consists of vertical posts, rendered in a reddish-brown colour, and horizontal cables, shown in light blue, strung between them. The posts are likely modelled as beam elements, providing vertical support for the cables. The cables themselves are likely modelled as tension-only members or cable elements, designed to resist tensile forces. This type of barrier is commonly used as a median barrier on highways to prevent crossover accidents. The STAAD Pro interface, visible with tabs such as "Geometry," "Properties," and "Supports," indicates that the model is being prepared for structural analysis. This analysis would involve tension in the cables, and the overall effectiveness of the system in containing and redirecting vehicles. The model's purpose is to simulate real-world impact scenarios and verify the design's compliance with safety standards.

6.3 3 STAAD Model with Cable, W beam and Post

This is a Fig. 4.3 of a 3D model of a cable barrier system in STAAD Pro. The model consists of vertical posts, rendered in a reddish-brown colour, and horizontal cables, shown in light blue, strung between them. The posts are likely modelled as beam elements, providing vertical support for the cables. The cables themselves are likely modelled as tension-only

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members or cable elements, designed to resist tensile forces. This type of barrier is commonly used as a median barrier on highways to prevent crossover accidents. The STAAD Pro interface, visible with tabs such as Geometry, Properties, and Supports, indicates that the model is being prepared for structural analysis. This analysis would involve applying lateral loads to the cables, simulating vehicle impact, to assess the barrier's deflection, tension in the cables, and the overall effectiveness of the system in containing and redirecting vehicles. The model's purpose is to simulate real-world impact scenarios and verify the design's compliance with safety standards.

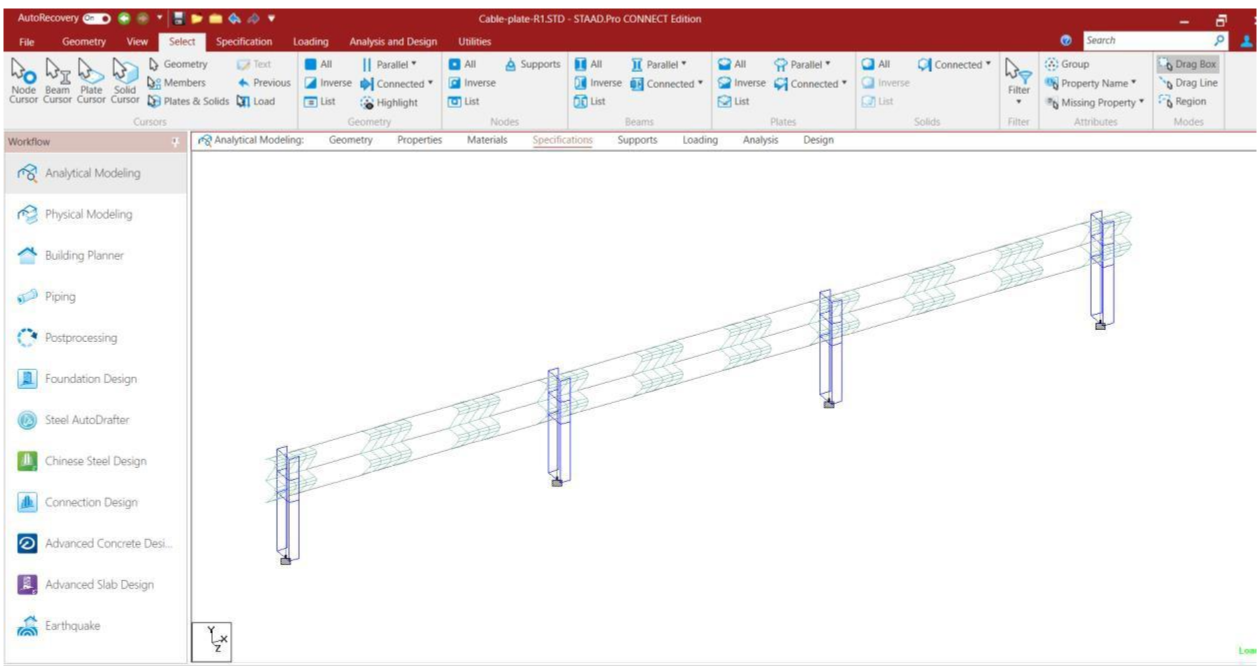

Figure 10: 4.3: STAAD Model with Cable, W beam and Post

7 RESULT AND DISCUSSION

This chapter discusses the results of the analysis conducted on three types of crash barriers discussed in Chapter 5. Detailed models of each barrier type were developed and analysed using STAAD Pro to evaluate their structural performance and effectiveness. This structural analysis aimed to assess the behaviour of the crash barriers under various loading conditions, simulating real-world impact scenarios. The study considered different vehicle types,

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specifically cars and trucks, impacting the barriers at speeds ranging from 50 km/h to 100 km/h. These speed ranges were chosen to represent typical vehicular speeds on highways. The key focus was to observe the structural deformations, stress distributions, and the capacities of the barriers during the collisions. By comparing the performance of the W-Beam, Cable, and combined W-Beam–Cable configurations, valuable insights were gained regarding their suitability for different roadway applications and vehicle categories. This analysis provides essential data for selecting the most effective crash barrier type to enhance road safety and minimize vehicle damage and occupant injuries in the event of a collision.

Case 1: W-Beam Barrier for Car:

The typical yield and ultimate stress values for a W-beam made of structural steel are 250 N/mm2 and 410 N/mm2 respectively. At higher speeds, the deflection of the W-beam barrier increases significantly, reaching 401.988 mm at 100 km/h and reducing to 100.443 mm at 50 km/h. A similar trend is observed in the bending moments, where the value was 254 kN-m at 100 km/h and decreased to 63.5 kN-m at 50 km/h. The stress analysis revealed that at 100 km/h, the stress reached 427 N/mm^2, exceeding the permissible limits, resulting in barrier failure at both 100 km/h and 80 km/h. In contrast, speeds of 60 km/h and 50 km/h produced stress values of 154 N/mm^2 and 107 N/mm^2, respectively, remaining within safe limits and passing the evaluation criteria. In summary, the W-beam barrier fails at higher speeds (80 km/h and above) but effectively mitigates stress and deformation at speeds of 60 km/h and below. The results of the same is shown in Table 5.1

Table 1: Case1 (W-beam for Car)

Speed Km/H	**Deflection mm**	**Moment kN-m**	**Stress N/mm ^{2}**	**Remark**
100	401.988	253.837	426.66	Fail
80	257.139	162.454	273.06	Fail
60	144.644	91.383	153.60	Pass

Case 2: W-beam Barrier for Pickup:

The analysis result is shown in Table 5.2. The analysis of the W-beam barrier for pickup

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trucks reveals significant performance variations at different speeds. At higher speeds, deflection, bending moment, and stress values are substantially higher, leading to structural failures. At 100 km/h, the deflection reaches 829.55 mm, with a moment of 748.83 kN-m and a stress of 1258.663 N/mm^2, causing barrier failure. As the speed decreases, the deflection, moment, and stress values also decrease, but the barrier still fails at 80 km/h, 60 km/h, and 50 km/h due to stress levels remaining above permissible limits. The first acceptable performance is observed at 40 km/h, where the deflection is 132.731 mm, the moment is 119.815 kN-m, and the stress is 201.390 N/mm^2, resulting in a safe condition.

These results indicate that the W-beam barrier is unsuitable for effectively containing and mitigating impacts from pickups at speeds above 40 km/h and requires reinforcement for higher-speed conditions.

Table 2: Case 2 (W-beam for Pick up)

Speed Km/H	**Deflection mm**	**Moment kN-m**	**Stress N/mm ^{2}**	**Remark**
100	829.55	748.830	1258.663	Fail
80	530.914	479.250	805.542	Fail
60	298.641	269.580	453.121	Fail
50	207.386	187.205	314.661	Fail
40	132.731	119.815	201.390	Pass

Case 3: Cable Barrier for Car:

The Table 5.3 presents the results of a simulation or analysis of a cable barrier designed for car impacts. The barrier is tested at different speeds (100, 80, 60, and 50 km/h). For each speed, the deflection of the barrier and the resulting stress are calculated. The yield stress of the cable material is 600 N/mm^2, and the ultimate tensile stress is 1000 N/mm^2. The barrier is considered to pass the test if the calculated stress is less than the yield stress and fails if it exceeds the ultimate tensile stress.

Table 3: Case 3 (Cable for Car)

Speed Km/h	**Deflection mm**	**Stress N/mm ^{2}**	**Remark**
100	41.340	1181.564	Fail
80	25.997	757.390	Pass
60	14.080	422.305	Pass

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50	9.358	290.690	Pass

The analysis of the cable barrier for car impacts shows varying performance at different speeds. At 100 km/h, the deflection reaches 41.340 mm, with a stress value of 1181.564 N/mm^2, leading to failure due to excessive stress. At 80 km/h, the deflection reduces to 25.997 mm, and the stress value decreases to 757.390 N/mm^2, which passes the evaluation criteria. Further reductions in speed to 60 km/h and 50 km/h result in deflections of 14.080 mm and 9.358 mm, respectively, with corresponding stress values of 422.305 N/mm^2 and 290.690 N/mm^2, both remaining within permissible limits. These results indicate that the cable barrier performs effectively at speeds of 80 km/h and below, while it fails at 100 km/h due to stress exceeding the material's capacity.

Case 4: Cable Barrier for Pickup:

The Table 5.4 presents the results of a simulation or analysis of a cable barrier designed for pickup truck impacts. The analysis of the cable barrier for pickup trucks reveals significant variations in performance across different speeds. At 100 km/h, the deflection reaches 86.430 mm, and the stress value is 2462.540 N/mm^2, resulting in barrier failure due to excessive stress. At 80 km/h, the deflection and stress reduce to 54.982 mm and 1572.740 N/mm^2, respectively, but still exceed permissible limits, leading to failure. At 60 km/h, the deflection drops to 30.388 mm with a stress of 800.663 N/mm^2, marking the first instance of safe performance. Further reductions to 50 km/h and 40 km/h yield deflections of 20.700 mm and 12.776 mm, with stress values of 608.924 N/mm^2 and 386.623 N/mm^2, respectively, both remaining within safe limits. These results indicate that the cable barrier is effective for pickups at speeds of 60 km/h and below but fails to handle impacts at 80 km/h and above.

Table 4: Case 4(W-beam for Pick up)

Speed Km/h	Deflection mm	Stress N/mm ^{2}	Remark
100	86.430	2462.540	Fail
80	54.982	1572.740	Fail
60	30.388	800.663	Pass
50	20.700	608.924	Pass

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40	12.776	386.623	Pass

Case 5 and 6: W beam and Cable Barrier:

The analysis of Case 5 (W-Beam + Cable for Car) and Case 6 (W-Beam + Cable for Pickup) indicates that the performance results of these combinations are virtually identical to those observed when the cable barrier is used alone. This suggests that the introduction of the W-beam did not result in any significant improvements in terms of reducing deflection or stress levels when compared to the cable-only configuration. The presence of the W-beam in combination with the cable plays a crucial role in maintaining the integrity of the cable barrier system and preventing vehicles, such as cars and pickups, from passing between the gaps in the cables. While the analysis showed that the performance in terms of deflection and stress values did not significantly improve beyond that of the cable-only system, the W-beam offers an important structural benefit by supporting and stabilizing the cable. In both Case 5 (Car) and Case 6 (Pickup), the W-beam helps to keep the cables taut and in position, ensuring that they remain effective in containing the vehicle within the desired safety zone. The W-beam also acts as a physical barrier to limit the potential for vehicles to pass through gaps between the cable lines. This is particularly important in preventing vehicles from breaching the cable system, which could lead to more severe consequences in the event of a collision.

For the W-beam barrier, the performance is as follows: for cars, the barrier is safe at speeds up to 60 km/h, but it fails at speeds above 80 km/h due to excessive stress and deformation. For pickup trucks, the W-beam barrier is only safe at 40 km/h, as the stress and deflection remain within acceptable limits. At speeds above 40 km/h, the barrier fails due to high stress and deformation. In contrast, the cable barrier performs better at various speeds. For cars, it remains safe at all tested speeds—50 km/h, 60 km/h, 80 km/h, and 100

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km/h—since the stress stays within the material's yield stress (600 N/mm^2) and ultimate tensile stress (1000 N/mm^2). For pickup trucks, the cable barrier is safe at speeds of 60 km/h and below. However, it starts to fail at speeds above 60 km/h due to high stress levels, although it performs safely at 50 km/h and 40 km/h, making it more effective at higher speeds compared to the W-beam barrier.

8 CONCLUSION

The analysis of W-beam and cable crash barriers using STAAD Pro provides valuable insights into their structural behaviour and performance under different impact scenarios. The results reveal that both barrier types exhibit a strong dependence on impact speed and vehicle type.

In conclusion, the W-beam barrier is effective for mitigating impacts at lower speeds, specifically for cars up to 60 km/h and for pickup trucks only at 40 km/h. However, its performance deteriorates at higher speeds, particularly for pickup trucks, where it fails due to excessive stress and deformation. The cable barrier, on the other hand, demonstrates better performance across a wider range of speeds. For cars, it remains effective at all tested speeds, with stress levels staying within safe limits. For pickup trucks, the cable barrier performs safely up to 60 km/h, with a noticeable improvement over the W-beam barrier at higher speeds. Overall, the cable barrier proves to be more suitable for handling impacts from both cars and pickup trucks at a broader range of speeds, especially at higher speeds where the W-beam barrier is less effective.

Overall, the combination of the W-beam and cable barrier system effectively enhances the containment and stability of the cable, preventing vehicles from passing through the gaps between the cables, particularly in high-speed scenarios. While the performance results in terms of stress and deflection did not show significant improvements beyond the cable-only configuration, the W-beam plays a critical role in maintaining the integrity of the system. It ensures that the cables remain taut and in position, providing additional lateral support to contain vehicles, such as cars and pickups, within the safety zone. This structural benefit improves the overall safety of the barrier, despite the lack of major changes in deflection

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and stress values. Therefore, the W-beam and cable combination offers an important enhancement in terms of vehicle containment and barrier stability, even though it may not drastically alter other performance metrics like deflection or stress under the given conditions.

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