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Comparative analysis of different non-rigid crash barriers: A case study of Nepal

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Abstract

Crash barriers are one of the most important components for traffic safety. Despite their importance, there is no advancement in their tests in Nepal. As a result, the design standards for crash barriers are yet to be updated and further fails to include wire rope barrier system. This study aims to see effectiveness of three different types of non-rigid barriers namely, W-beam, thrie beam and wire rope barrier in context of Nepal analytically using finite element tool Abaqus FEA. The developed analytical model is first validated with a full-scale test from NCHRP report 350. Further, the validated model is used for the simulation of crash using Abaqus/Explicit for each type of barrier system. The behavior of the crash barriers is compared in terms of two major crash parameters: deflection and acceleration severity index (ASI). The results show thrie beam with smallest deflection of 0.871 m and largest ASI of 0.82. Wire rope barrier undergoes largest deflection of 1.408 m but incurs smallest ASI of 0.67 ensuring comparatively higher safety to the passengers. Despite the safety factor of wire rope barrier, location for provision of the barrier must be given utmost care as it requires large clearance beneath the barrier. The comparative analysis of the barriers further assists in formulation of revised design standards in Nepal. Furthermore, the study supports in evaluating the appropriateness of wire rope barrier which has been strictly limited to pilot application in Nepal.

Keywords: Crash barrier; Acceleration Severity Index; Finite Element Modeling; Abaqus

1. Introduction

Road safety is one of the major issues of concern for traffic engineers and officials. Every year road crashes take lives of numerous people around the world. As per global status report on road safety 2018, by World Health Organization [1], the number of deaths caused by road traffic crashes every year is around 1.35 million. Nepal is also a victim of high number of road crashes. In the fiscal year 2017/18, the number of deaths reported due to road crashes was 2,541 with 4,144 serious injuries reported in the same period [2]. Crash barriers play a major role in coping with the effects of such events. With proper choice of location and type of crash barrier, road safety can be significantly enhanced.

Different types of crash barriers are used in roads depending on location and surrounding. The commonly used types are W - beam barrier, thrie beam barrier, wire rope barrier and concrete barrier. Out of these, the former two are classified as semi-rigid barrier, wire rope as flexible barrier and concrete barrier as rigid barrier, classified as per their deflection behavior during crash. The provisions for use and specifications for these different types of crash barriers are provided in guidelines which are formulated by different countries. Different international guidelines have been developed by Indian Road Congress (IRC) [3], American Association of State Highway and Transportation Officials (AASHTO) [4] etc. National guidelines for crash barriers are Road Safety Notes 6 [5], Nepal Road Standard 2070 [6] and Standard Specifications for Road and Bridge Works [7]. Despite the availability of different literature on road safety in Nepal, wire rope barrier hasn't been introduced in any of them. Moreover, as compared to international guidelines, Nepalese guidelines seem less detailed with some shortcomings in each of

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them. This highlights the need for a well-detailed and specific guideline that satisfies the requirements of the present context in Nepal.

Analysis of crash barriers requires full-scale experiments to be conducted. Guidelines for tests are provided by different literature like National Cooperative Highway Research Program (NCHRP) Report 350 [8], Manual for Assessing Safety Hardware (MASH) [9]. Full-scale tests provide visual inspection as well as detailed results about barrier allowing detailed evaluation of the barrier. However, they incur a huge expense and different test runs. Despite the necessity of latest safety guidelines, development of full-scale tests in Nepal is little to none. A suitable alternative to full-scale test is numerical simulation. Vehicle crashes are usually simulated using finite element tools in order to obtain results fast and economically. The most commonly used finite element software is LS-DYNA [10]. One of the first numerical simulations in LS-DYNA was conducted by Ren et. al. [11]. The authors compared the computational results with experimental in order to prove the correctness of the computational model. Borovinssek et. al. [12] simulated vehicle crash conditions for high containment levels using LS-DYNA and found a good agreement between simulation and real crash tests. Besides LS-DYNA, Abaqus FEA [13] is also used for simulation of crash. Latorre et. al. [14] presented a correlation between simulation and full crash test in Abaqus modeling software. Ogamia and Tasel [15] investigated the use of Abaqus/Explicit for simulation of crash and verified the suitability of Abaqus/Explicit from the results. Sigdel [16] used Abaqus FEA to study the impact of vehicle crash on system foundation. The author calibrated the Abaqus model and used the calibrated model to analyze the foundation response.

This work aims to compare the non-rigid crash barriers: W-beam, thrie beam and wire rope barrier, in context of Nepal. As full-scale tests are costly, numerical simulation can be a feasible option for crash barrier analysis for Nepal. Having no such analyses done previously for crash barriers in a detailed manner, this research aims to pioneer numerical simulation studies of crash barrier in context of Nepal. W-beam and thrie beam are commonly used barriers in Nepal, while wire rope barrier is limited to one pilot application. Although concrete barriers are commonly found in Nepal, they require extensive modeling and therefore, are not included within the scope of this research. The barriers are compared based on two major crash parameters namely, deflection and Acceleration Severity Index (ASI). Performance of the crash barriers are evaluated using the above parameters so as to suggest the suitability of each type of barrier. Further, this research intends to provide suggestions for the formulation of latest safety guidelines.

2. Methodology

This research makes use of Abaqus FEA [13] for simulation of vehicle crashes. Different elements of crash barrier and vehicle were modeled in Abaqus CAE and were brought together to form an assembly. The complete FE model was run using Abaqus/Explicit to obtain the results. In the first part of research, the simulation performed was validated against a full-scale test: NCHRP Report 350 Test Level 3 (TL-3) [17]. The validated model was modified as necessary to represent simulation of other non-rigid barriers.

2.1. Finite Element Modeling

The geometry used for the crash barrier in the validation was as per the NCHRP Report 350 TL-3 [17]. The tubular thrie beam and vertical posts of I section were modeled using shell element of respective thickness. The material assigned to the beam and post was steel with properties as indicated in Table 1.

Table 1. Steel properties

Properties	Abaqus Input	
Elastic Modulus (MPa)	200000	
Yield Stress (MPa)	250	
Possion's Ratio	0.26	
Density (Kg/m ³)	7850	
Plastic properties		
Stress (MPa)	250	475
Plastic Strain	0.00	0.20

The steel properties assigned are in compliance with the properties used by Ogamia and Tasel [15]. The W-beam and thrie beam used in the research were in accordance with the specifications of Standard Specifications for Road and Bridge Works [7]. Channel section of 75 mm x 150 mm and 5 mm thickness was used for steel post and spacer for both W-beam and thrie beam both of which were of thickness 3 mm. Both of the barriers were modeled using shell element with steel properties as indicated in Table 1. Wire rope barrier was modeled in accordance with the barrier available in Narayanghat-Muglin section. Cable of 20 mm diameter and hollow post of 140 mm diameter and 5 mm thickness was modeled using solid element with steel properties as earlier.

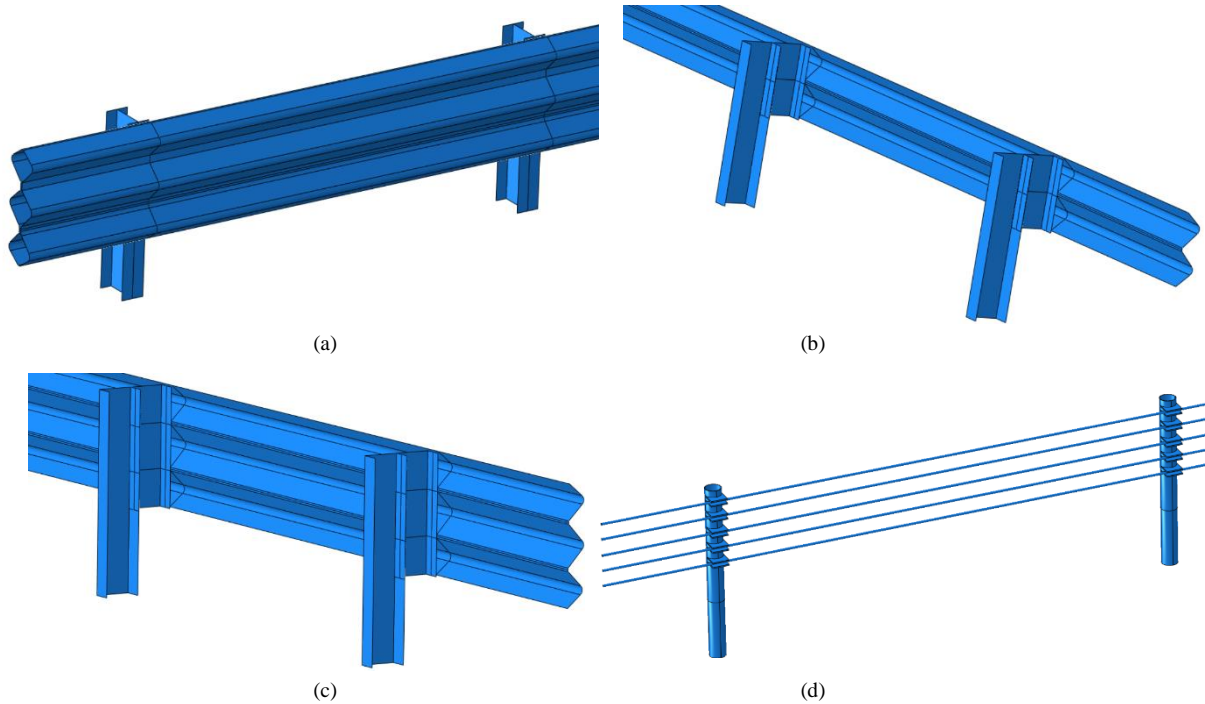


Figure 1: Abaqus model of barriers: (a) Tubular thrie beam (for validation) [17] (b) W-beam (c) Thrie beam (d) Wire rope

A 2000 Chevrolet C2500 pickup truck as described in full scale test, NCHRP Report 350 TL-3 [17] was used for vehicle model. For simplicity, vehicle was modeled as rigid solid element with inertial mass of 2051 kg keeping the dimensions same as that in full scale test as shown in Figure 2. Since the vehicle model is a standard test vehicle, same was used for validation as well as further analysis. The road was also modeled as rigid solid element.

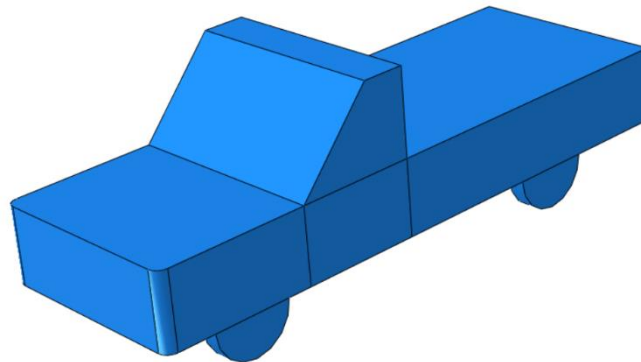


Figure 2: Abaqus model of vehicle

2.2. Interaction and Load

In order to simulate the contact between different surfaces coefficient of friction was set to 0.001 which was based on the report of Ogamia and Tasel [15]. Higher value of friction coefficient caused higher stress in vehicle

tires resulting in deviation from actual behaviour [15,16]. Therefore, a low value was chosen. The posts in each of the barriers except wire rope barrier were fixed at bottom so as to represent the connection of posts to the ground. For the wire rope barrier, the post was pinned on the circumference of the part of the post below the ground. This was done due to low depth of penetration of posts in case of wire rope barrier. The bolt connections between posts and beam were represented using ‘cartesian’ connector available in Abaqus [13]. The stiffness of connector was set very high to a value of 100000000 N/m so as to transfer all the forces and the failure load was adopted from the report of Ogamia and Tasel [15]. As validation was done using the connector with aforementioned property, the use of connectors was justified.

Gravity load was assigned in form of acceleration of value $g = 9.81 \text{ m/s}^2$ acting vertically downwards. The velocity of 100 km/h was assigned to the centre of mass of vehicle by resolving the velocity into lateral and longitudinal direction based on impact angle of 23.8°.

2.3. Validation

Different elements were brought together to form a complete model for validation as shown in Figure 3. The test parameters for validation were kept as follows: A 2051 kg pickup truck hit a tubular beam barrier with a speed of 100 km/h at an angle of 23.8° as indicated in the full-scale test. Since this test corresponds to test level 3 to NCHRP Report 350 [8], same test parameters were adopted for further analyses. The maximum permanent and dynamic deflection of the barrier in full-scale test were 1.69 ft (0.515 m) and 1.91 ft (0.582 m) respectively. The corresponding values from simulation were 0.529 m and 0.563 m respectively which differed by 2.72 % and 3.26% from the real test. The final state of beam in full-scale test and Abaqus simulation are compared in Figure 4. As deflection and ASI are the major parameters to be studied, the close agreement of deflection of barrier validates the use of Abaqus FEA for simulation of vehicle crash.

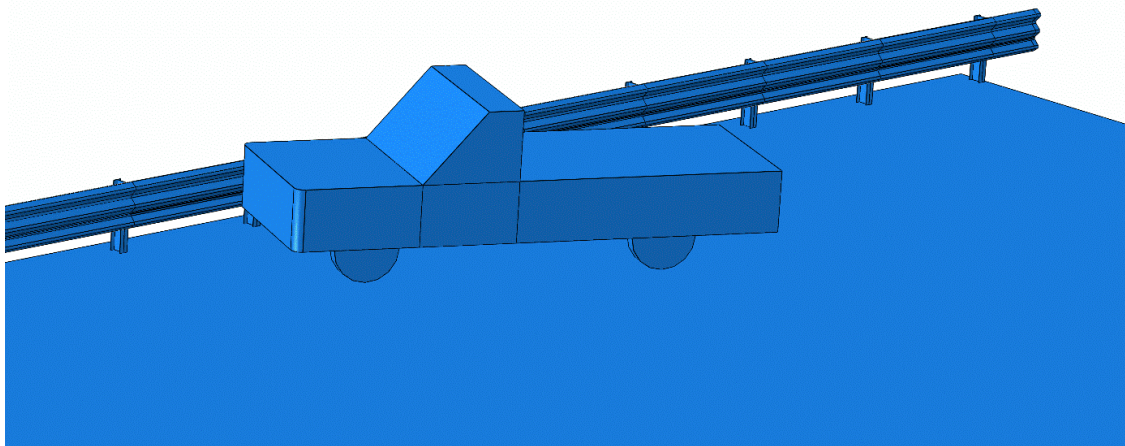
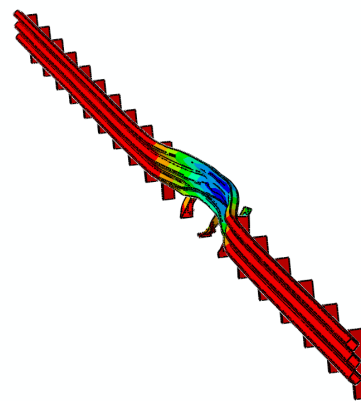


Figure 3. Assembled model for validation



(a)



(b)

Figure 4. Comparison of final state of beam: (a) Full scale test [17] (b) Abaqus model

2.4. Analysis

The validated model was used in analyses of non rigid barriers with modifications as necessary for the barrier. A sample of such model is shown in Figure 5 which represents wire rope barrier. As mentioned earlier, the test parameters were set similar to the ones used for validation purpose. The impact point was set at 0.3 m upstream of 5th post in all the cases. For each of the barrier, the maximum deflection was found from the analysis result. ASI was also calculated for each time using the methodology, which follows EN 1317 [18].

$$ASI(t) = \sqrt{\left(\frac{a_x(t)}{\hat{a}_x}\right)^2 + \left(\frac{a_y(t)}{\hat{a}_y}\right)^2 + \left(\frac{a_z(t)}{\hat{a}_z}\right)^2} \quad (1)$$

Where,

$a_x(t), a_y(t), a_z(t)$: Average 50 ms acceleration in longitudinal, lateral and vertical direction respectively

$\hat{a}_x, \hat{a}_y, \hat{a}_z$: Acceleration limit in longitudinal, lateral and vertical direction respectively

($\hat{a}_x = 12g, \hat{a}_y = 9g, \hat{a}_z = 10g; g = 9.81 \text{ m/s}^2$)

ASI is used to evaluate occupant risk in a vehicle crash. Higher ASI values represent higher risks for occupants and hence, crash barrier becomes more unsafe. Maximum value of ASI should preferably be less than 1 [18]. The results for ASI and deflection are compared for each of the test crash barrier.

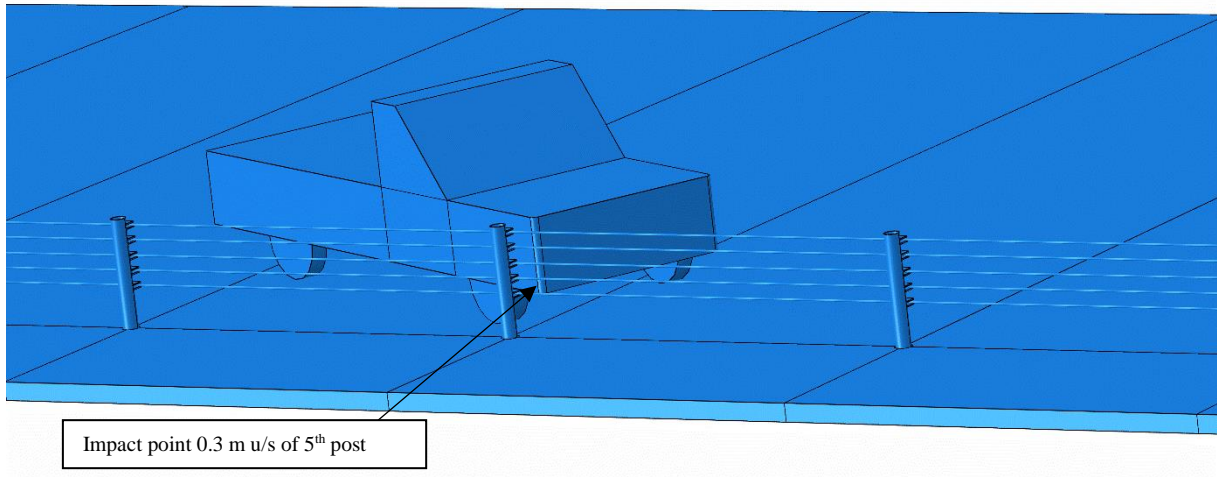


Figure 5. Assembled model for wire rope barrier

3. Results & Discussion

The simulation for each of the crash barrier was run for 0.3 s. Instant of maximum deflection for each of the barrier is presented in Figure 6, 7 and 8. Wire rope barrier experienced the most deflection of all the barrier systems, with maximum deflection of 1.408 m. Second to that is the W - beam barrier with maximum deflection of 1.211 m and lastly, thrie beam with maximum deflection of 0.871 m. A plot of deflection of each barrier at different time values is shown in Figure 9.

ASI values were calculated manually from the data of velocity at centre of mass of the vehicle. Thrie beam was found to have the maximum ASI value of 0.82 among the test barriers. W - beam resulted in ASI value of 0.72, and wire rope barrier had least ASI value of 0.67. Similar to plot of deflection, a plot of ASI at different times is shown in Figure 10.

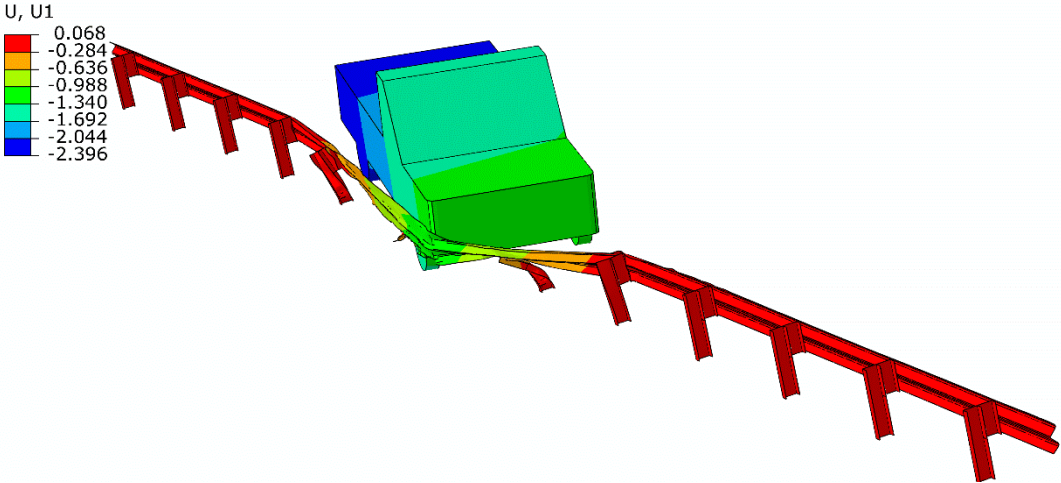


Figure 6. Maximum deflection of W-beam (0.2 sec)

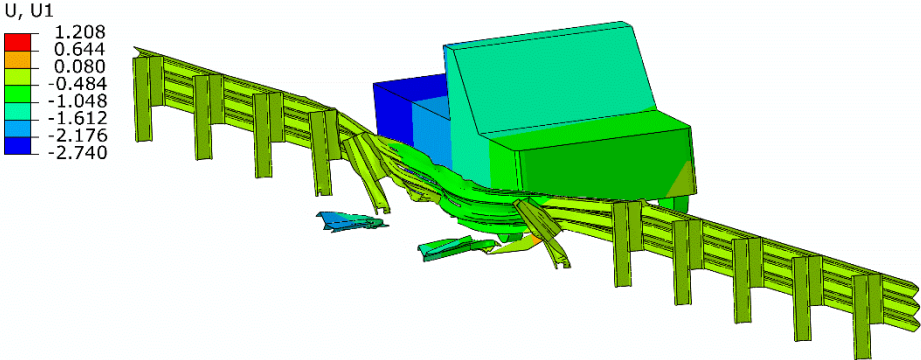


Figure 7. Maximum deflection of thrie beam (0.22 sec)

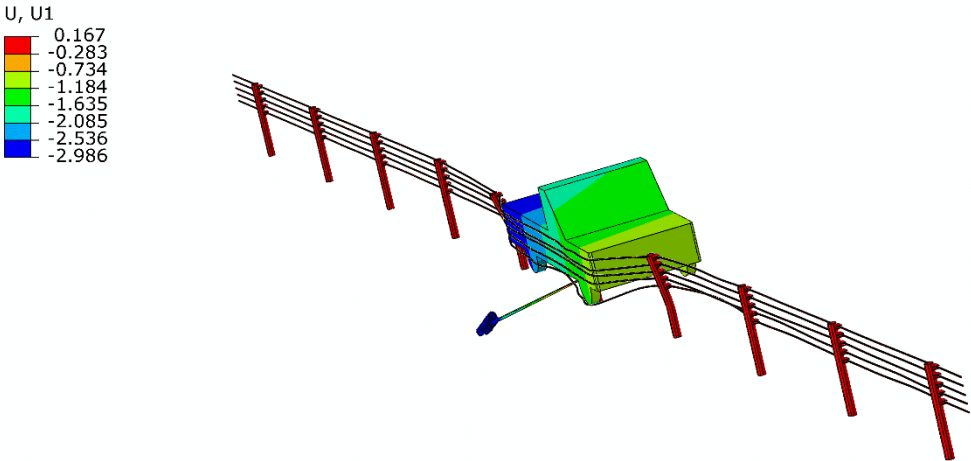


Figure 8. Maximum deflection of wire rope barrier (0.27 sec)

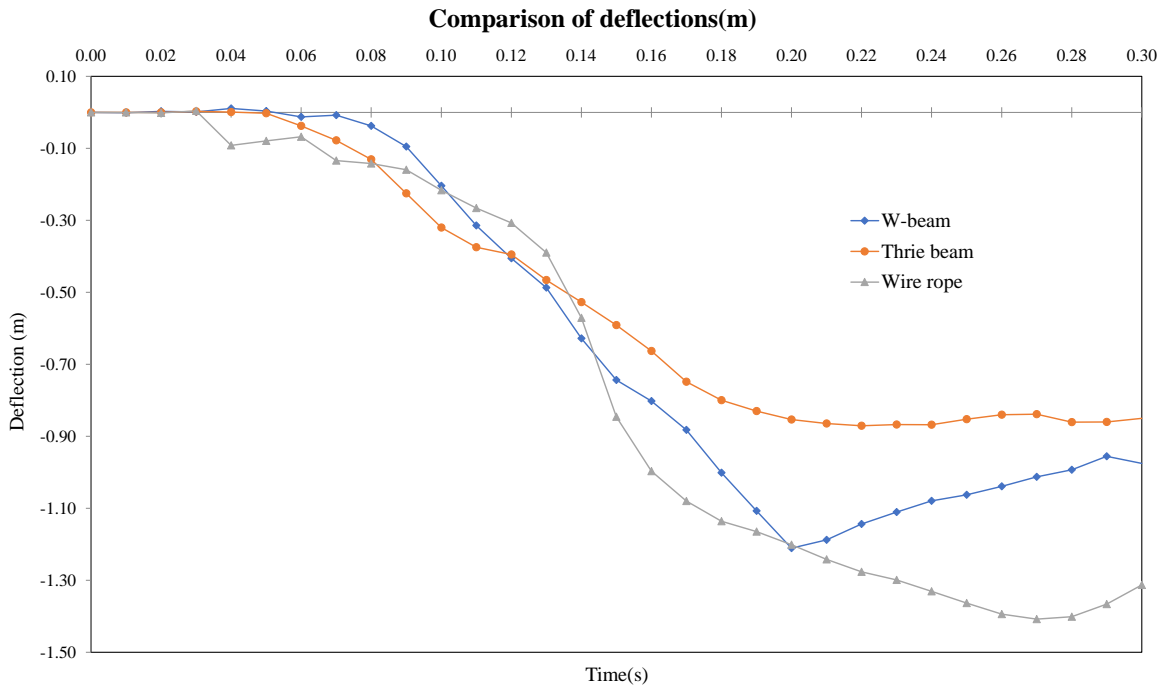


Figure 9. Deflection vs time for different barriers

W - beam and Thrie beam are relatively more rigid than wire rope barrier. This evidently caused them to deflect less than the wire rope barrier. Due to similar reasoning, the higher rigidity caused the vehicle to decelerate faster that eventually led to higher ASI value. Between W - beam and thrie beam, thrie beam offer more rigidity so that thrie beam experiences the lowest deflection and highest ASI.

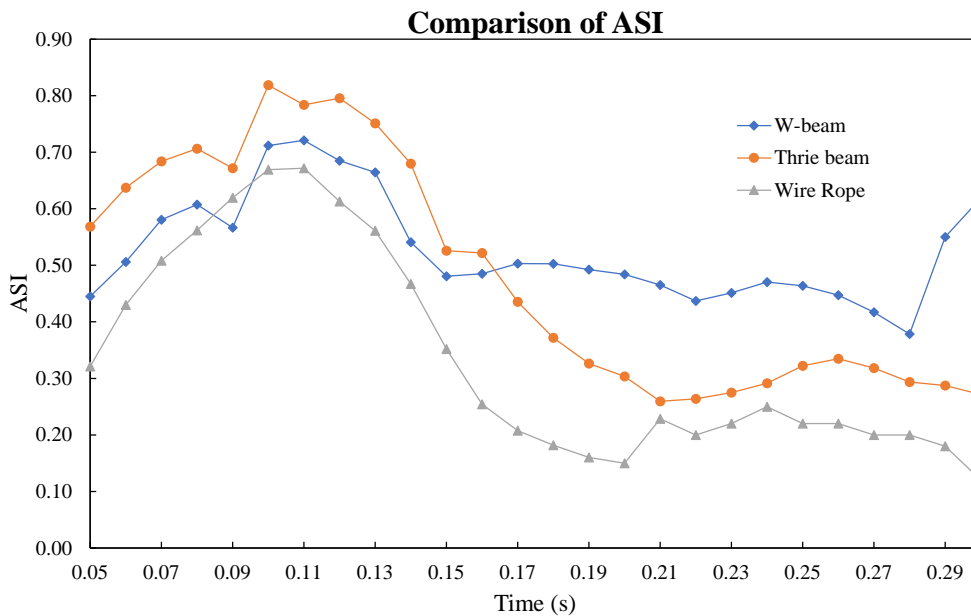


Figure 10. ASI vs time for different barriers

4. Conclusion

This study justifies the wide use of W - beam in roads of Nepal. With deflection less than wire rope barrier and ASI less than thrie beam, W - beam offers a good protection against crash and adequate safety for the passengers.

Thrie beam also forms a good crash barrier system with less damage and hence less maintenance than that of W - beam. Although wire rope barrier offers comparatively higher safety to the passengers, its high deflection limits its use in critical locations. Especially in the hill roads where sufficient clearance can't be ensured beyond the barrier, wire rope barrier may prove to be less effective. However, in roads with sufficient clearance and wide medians, wire rope barrier can prove to be the safest as well as the most economic crash barrier system. For the formulation of latest road safety guidelines, inclusion of the wire rope barrier is a necessity, however, with proper provision and guidelines for the barrier.

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