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Computerized Simulation using Finite Element Method (FEM) for Guardrail Crashes

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ABSTRACT: The rigid structure of the existing w-beam guardrail design leads to numerous death and injuries. Recently, a new prototype was produced by considering the best design while innovating an additional element to the existing w-shape guardrail to create a safer and more practical device. Yet, the behavior of the prototype when subjected to explicit impaction force with proper environment setting was not properly investigated experimentally. By using Ansys Ls-Dyna software, finite element analysis was conducted by subjecting a higher impaction velocity with proper environment setting on both models: (1) the existing w-beam model, and (2) prototype model. The validity of the produced finite element model was ensured by comparing the maximum impaction force of the existing experimental literature. The model deformation in terms of element displacement and scale of force received by both models was observed. The observation showed that the additional element on the prototype reduced the deformation rate onto the beam span under the impaction force of 26.933 kN.

1. INTRODUCTION

The demand for infrastructure development across the globe has grown tremendously. Based on the statistical data from 2000-2020, the total length of the road network around the globe is approximately 64,285,009 km [6], [7]. In Malaysia, the total length of road network available for road users is approximately 237,022.353 km [10].

In essence, a road network is known as a combination of different road corridors that are functioning as a vessel connecting peoples and goods from one place to another place. Its construction depends on the area itself, wherher it is urban or a rural. It also comes together with specific network characteristic elements, such as the number of lanes, speed limit, road alignment, signages, and other road furniture for safety purposes [11].

In highway networks, median barriers are the most important road furniture because it minimizes the rate of impaction that leads to injuries and fatalities of occupants by preventing vehicles from slipping on the shoulder of the road or getting into the opposite lane [12]. Yet, severe injuries and fatalities still cannot be prevented as the impact force during collision is directly channelled towards the occupant vehicles.

2. PROBLEM STATEMENT

The main problem with the existing guardrail is as the rigidity of the system increases, the impact force imposed upon the vehicles is likely to increase because it lacks the abilities to dissipate the force during the collision. Research on fixed-object fatalities revealed that traffic barriers were listed as the third most common cause after tree and utility poles [4]. Most of the safety barriers installed along highways in Malaysia are made of iron. Although the main purpose of the device is to protect road users from any sort of danger throughout driving, during a road accident, w-beam guardrail has higher tendency to be hazardous towards road users, especially motorcyclists, and to cause higher risks of fatal and serious accidents. Therefore, the propriety of the guardrails needs to be reviewed to ensure the safety of road users.

In 2016, a South Korean company introduced new road barrier known as Roller Barrier. During the prohibition period, the data showed that the barrier managed to reduced accident rates significantly by 94%. However, due to the extremely high installation expenses, a newly developed prototype idea was produced by taking into account the best design and innovation of the existing W-shape guardrails to create a safer and more practical device [9].

Hence, a comprehensive study is required to obtain on-site impact test findings and simulation tests on the mentioned prototype which is mounted on an existing road barrier without any extreme modification for cost savings.

3. BACKGROUND

Computerized simulation for vehicle crashes has progressed tremendously. Many researches become more achievable by using the technology, for example full-scale simulation with complex dynamic interaction, nonlinear finite element codes, and material models [1].

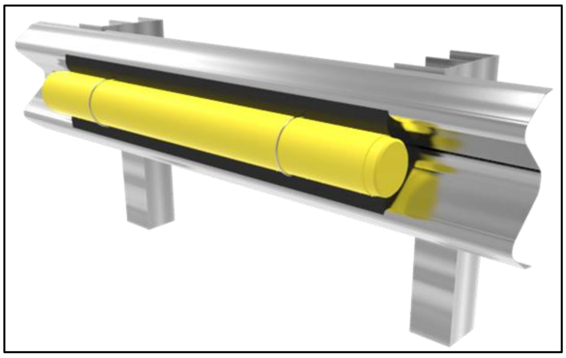

Figure 1: Newly developed guardrail prototype.

The finite element method (FEM) has become popular among researchers due to its reliability in projecting information related to crash test simulations [5]. Moreover, it is inexpensive compared to the real-life crash test.

For this research, Ansys Ls-Dyna was used as the processing tools. The solver is highly accurate, containing all input information needed to ensure that the components and entire system are able to work smoothly in a comparable environmental setting to the real-life events. In other words, it has the ability to simulate the dynamics, strength, vibrations, and stress of a complex model successfully and efficiently.

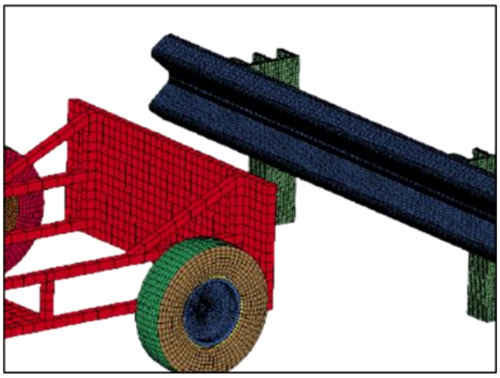

Figure 2: Numerical Analysis Environment Setting.

4. MATERIALS AND BOUNDARY CONDITION

The existing Ls-Dyna reference databases for material models were used.

Table 1 Materials Elastic Behavior [2]

Properties	**Material Selection**			
	W-Beam	Post/ Offset Block	HDPE Pipe	Shredded Rubber
Material Type	Piecewise Linear Plasticity			Blatz-Ko Foam
Element Type	Solid			
Modulus Elasticity (MPa)	200,000	200,000	1,500	2,900
Poisson's Ratio (υ)	0.3	0.3	0.463	0.25
Yield Stress (MPa)	450.0	338.0	29.5	***

***Not required by software.

4.1. Boundary Condition

In order to reduce the computational time, a portion of the guardrail outside of the impaction zone was not modeled. Any remainder of the structure (i.e., end treatments, guardrail beams, and posts) located outside of the study zones was represented as a free end.

The simulation was only conducted at a segment of guardrail with approximately 1500mm span length. In addition to that, all bolt, nuts and welds features were not included as those features were already considered using constraint elements.

5. RESULTS

Preliminary results for the numerical analysis were compared with previous research experimental results for validation purposes.

Based on the finite element theory, the percentage model workability validation for the re-modeled finite element should be less than 30-percent (≤ 30%). However, due to the model complexity, it was hard to stich all the elements together perfectly especially for the prototype model.

Table 2 Finite Element Model Results Comparison

Model	Previous Research	Numerical Analysis	Validation Rate (%)
	Maximum Internal Force (kN)		
Existing W-Beam (Basic)	51.52 kN	47.86 kN	7.10%
Newly Developed Prototype	47.60 kN	47.76 kN	-0.34%
Average Validation Rate (%)			3.37%

Figure 3 and Figure 4 show slightly different graphs for both models possibly due to improper selection of contact, element constraint or even the types of material selection. Further investigation is required as slightly different value can affect the whole structure workability during simulation analysis.

Despite of that, the average validation rate for both finite element models was approximately 3.37%, which was great for preliminary analysis.

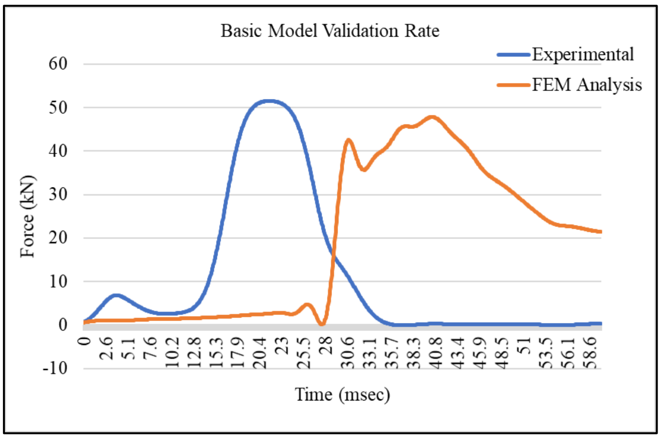

Figure 3: Validation accuracy graph of existing w-beam.

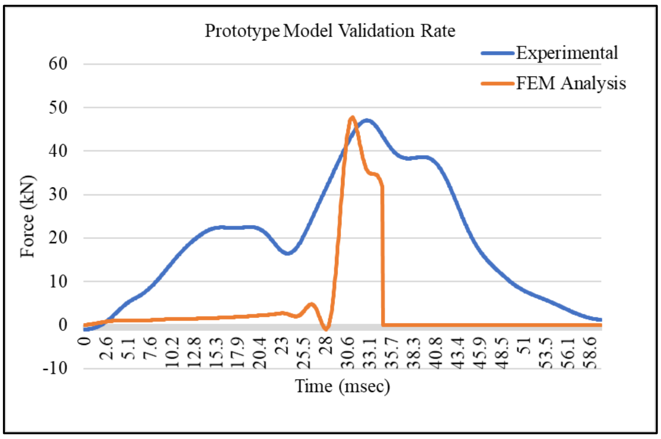

Figure 4: Validation accuracy graph of newly developed prototype.

5.1. Force and Velocity

Every material has the capabilities to absorb a certain amount of dissipated energy conveyed by the impactor during impaction. Figure 5 shows the comparison between both models, existing w-beam and newly developed prototype, when subjected to 90-degree (90˚) angle of impaction with expected initial force of 26.933 kN.

Table 3 Comparison between force and impaction time of numerical analysis models

	Existing W-Beam	Newly Developed Prototype	Percentage Different
Maximum Internal Force	47.86 kN	47.76 kN	0.21%
Maximum Impaction Time	40.3 msec	31.2 msec	22.58%

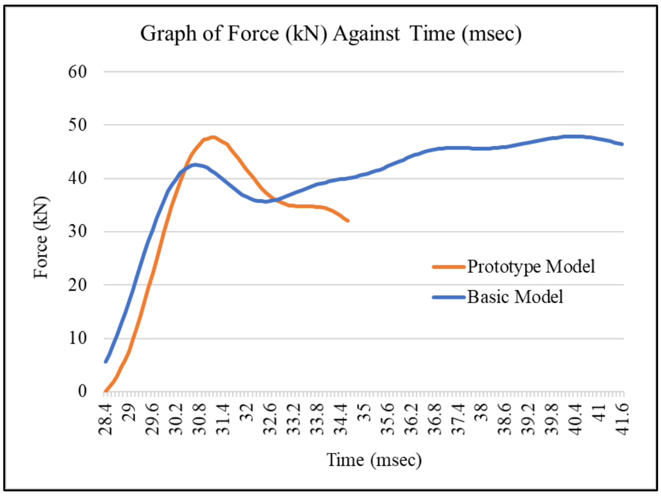

Figure 5: Comparison graph between existing w-beam and newly developed prototype.

The maximum force for both models is different due to the types of materials used during the model development. According to the simulation binary output, the maximum impaction force for the prototype showed an extremely small reduction of 0.1 kN, which was approximately 0.21%.

With the force reduction, the time of impaction indicated an increment of 22.58% which was approximately 9.1 milliseconds faster compared to the existing model. Faster impaction time with lesser maximum-internal energy force illustrates the additional component molecules under a full-restraint set against the intended type of element restraint as in the real-life situation.

5.2. Model Deformation

Model deformation is a steady geometric change distributed onto a subject over a time interval due to parameters action applied to the subject. Holistically, the basic reading scale of model deformation fringe component is readable.

Figure 6 shows that the existing w-beam model has larger shape deformation scale along the w-beam span compared to Figure 7, in which the prototype model still manages to maintain the shape of existing w-beam span when subjected with 26.933 kN of initial force.

Each of the model showed neither any sign of pocketing at the end of beam span nor post undergoing any rotating movement along the local axis. This indicates that the span has an excellent end-treatment while the post is strong enough to withstand an impact. In other words, the post is securely tightened to the ground.

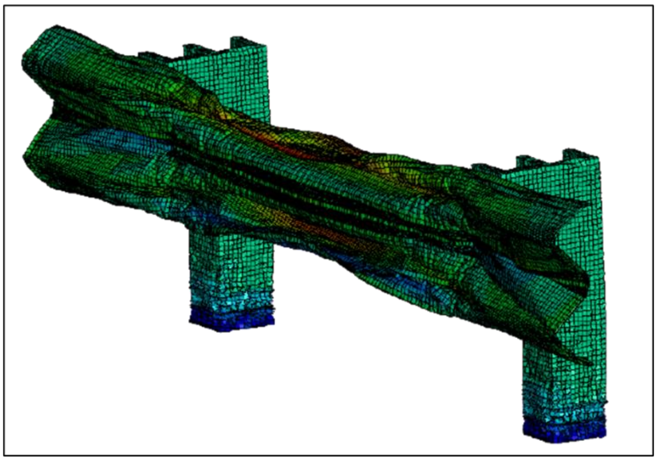

Figure 6: Existing w-beam model deformation.

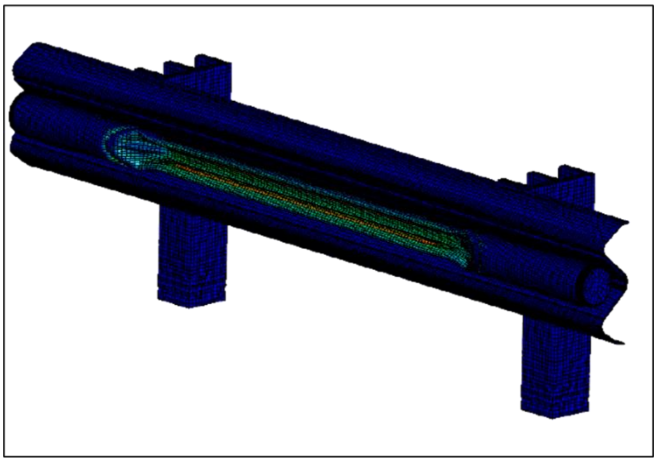

Figure 7: Newly developed prototype model deformation.

5.3. Impaction Momentum

Captured at 279 millisecond (msec) simulation time frame, the figures below show dolly behavior in simulation once contacted with the model.

As presented in Figure 8, the dolly showed no sign of bouncing back to the direction where it initially came. This indicates that the additional structure attached manage to reduce the probability for post-impaction to happen, but at the same time, it shows that the structure is extremely rigid.

Compared to Figure 9, the dolly behaviour showed signs of bouncing once the surface between the dolly and model contacted.

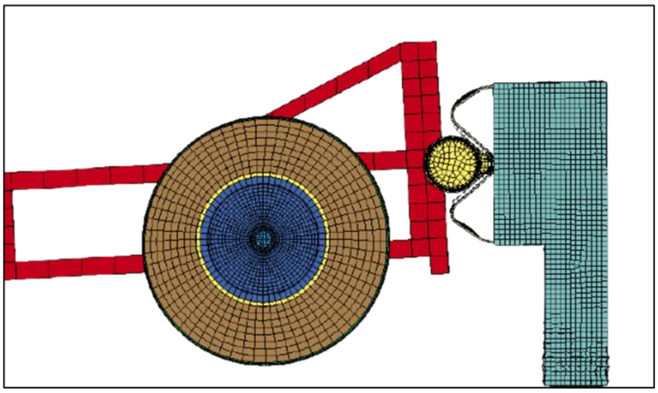

Figure 8: Dolly behaviour when contacted with the prototype model.

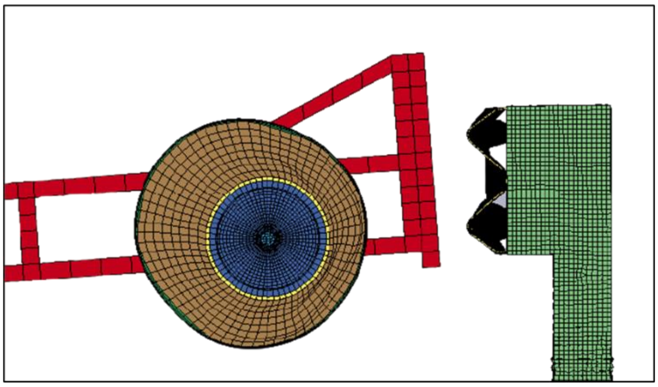

Figure 9: Dolly behavior when contacted with the existing model.

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