# Improving Crash Worthiness of a Three Wheeler, by Means of a Mid Crumple Zone.

[1]B.S. Jurangpathy, [1*]S.D. Rasika Perera

[1]Department of Mechanical Engineering, The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka.

*Corresponding Author: email: sdper@ou.ac.lk, Tele: +714421887

***Abstract*** *– Three wheelers have become popular in many developing countries due to lower cost and comparatively high fuel economy. However, due to its poor structural design, alarmed the necessity to improve the safety of three wheelers in many fora. This paper discusses an attempt to incorporate a central-crumple zone to its mid-section using a crush tube to the three wheeler without changing its basic structure. The main structure was modified to accommodate two central crush tubes along the length of its mid-section in an impact. To assess the behaviour of passengers during a collision, human crash dummy models were created based on the dimensions and mass specifications of a 50th Male Hybrid III Anthropometric Test Device. The test was carried out as per the test standard of the New Car Assessment programme criteria for Quadricycles. The analysis revealed severe plastic deformation of the conical Square-type crush tubes that were introduced at the mid-section in an impact. , A 47.2 % reduction of G force for driver and 33% reduction of G force for passengers has been achieved, This indicates that a considerable amount of crash energy has been absorbed by the crush tube during the collision.*

**Keywords**: passenger safety, crush tubes, Automotive Engineering, Crash Worthiness, Transportation

## 1. INTRODUCTION

The need to enhance the Safety of three wheelers has been emphasised repeatedly by WHO 2018 due to its poor structural design, which poses hazards in accidents. Three wheelers have become popular in many developing countries due to comparatively low initial investments, operational cost, and high fuel economy ( Kumarage et.a. 2010).

In contrast to conventional engineering structural design, where the ability of the structure to withstand service loads without yielding or collapsing is considered, the safety criterion of the three wheeler was seemingly ignored at its design stage. Automotive structures are required to be able to plastically deform and absorb energy in a short period during which crash energy is dissipated in a controllable manner during a crash while safeguarding the passengers.

Previous researchers analysed the deformation of a conventional three wheeler in a head-on collision. The solution for head on collision against a rigid barrier at 50 km/h revealed a severe plastic deformation in the front face and mid-structure Jurangpathy & Perera (2023). Among many road accidents, one of the serious accidents is shown in Fig. 1, where a three wheeler crashed into a truck that was stationary at the time of collision, killing two passengers and injuring three other passengers as a result of impact. www.dhakatribune.com.

**Fig.1. Head-on collision of a conventional three wheeler against a rigid barrier (Numan 2022).**

From Numan (2022), and many similar cases, it is evident that current three wheelers lack crash safety. The main reason for fatal injuries during a head-on collision of a three wheeler is due to deficiencies of basic structural features such as lack of a crumple zone, rigid passenger compartment, and restrain systems Jurangpathy & Perera (2023). However, it is practically impossible to incorporate a crumple zone into the front section of a three wheeler due to the limited space surrounding the front wheel and its body shape. Taking into consideration many factors, previous researchers [Jurangpathy & Perera (2023)] have highlighted the necessity to improve the structural crashworthiness of three wheelers taking into consideration the intrusion of the front face and plastic deformation of the mid-section.

The objective of the current study is to enhance the structural crash-worthiness of conventional three wheelers by incorporating a crumple zone that could absorb crash energy during a collision, thus protecting the passenger shell ensuring passenger's safety.

## 2. METHODOLOGY

In this study, an attempt was made to incorporate a central crumple zone by means of a crush tube while keeping the rest of the design as per the analysis carried out by Jurangpathy & Perera (2023). In the design of crumple zones, there are two primary means of absorbing energy, which is also known as collapse modes where the components absorb energy through controlled deformations in two collapse modes. They are;

- Axial mode of collapse
- Bending mode of collapse

Each mode utilises thin wall sheet metal beam-type structures. Real-world accidents are unpredictable, and it is very rare to obtain a purely single mode of collapse in crumple zone structures, thus mixed modes of collapse are often used.

However, in a well-designed and executed energy-absorbing structure, the mixed modes are avoided to ensure predictable performance during crashes Bois, P. D. et al (2004). 2008). For this solution model, an axial mode of collapse-type crumple zone was selected owing to higher energy absorption capacity.

Crush tubes are a common feature in vehicles and absorb energy via axial mode of collapse. It is unique under axial collapse that it produces a unique folding pattern with a degree of regularity which, depends on the structural member's size-to-thickness ratio, geometric stiffness, and shape. An ideal centralized crush tube should be able to handle loads under normal running conditions and collapse only in the event of a frontal collision. The design of crush tubes relies on empirical formulae following the notable works of Wierzbicki & Abramowicz (1983) and Mahmood & Paluszny (1981). The collapse strength of a given section is related to its ratio of width over thickness (t/b) and material properties.

To ensure the stability of the collapse of crush tubes, they should be; considered as a 'compact section' of geometrical cross section with most stability under varying angles of loading.

Compact sections are of t/b ratio exceeding its threshold value where the elastic buckling strength exceeds the material yield strength thus the material strength properties are expected to govern the mode of collapse (Wierzbicki & Abramowicz 1983 and Mahmood & Paluszny 1981). Following the work of Witteman, (1999), who analyzed the stability of crush tube columns of varying cross-sections under the axial collapse of varying degrees, it was found that the most stable geometry is a rectangle in a lying position followed by a square cross-section. When selecting a suitable crush tube it was kept in mind that it should be easily integrated into the base structure without significant changes in cross-section.

In addition, it is essential to include in this design a trigger in the crush tube to initiate the collapse as well as to ensure a stable force level over the entire length. By applying a specific weakness at the right position at the front end of the beam, a stable regular folding process will initiate at that point with a lower initial peak force level to introduce the first fold.

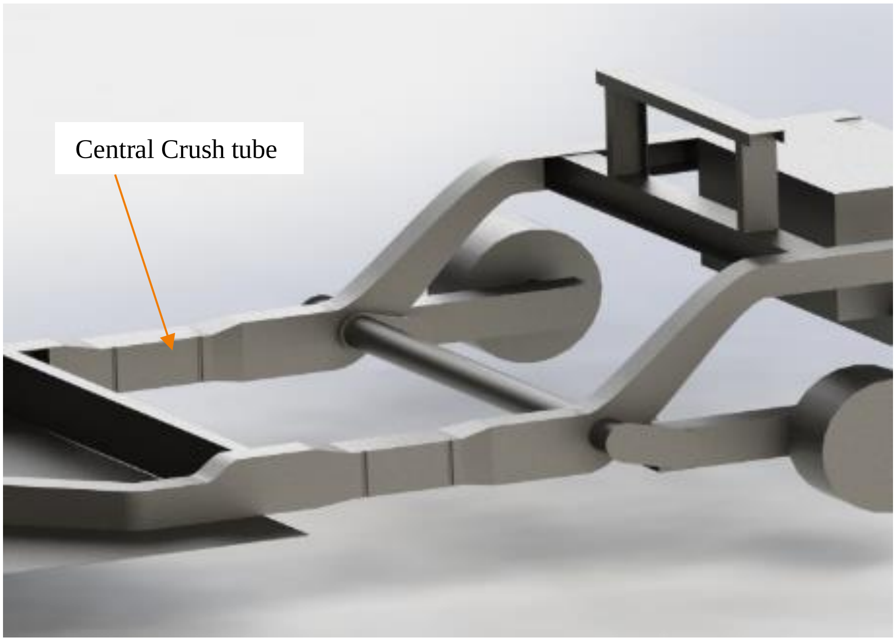


**Fig.2. Structure incorporating the mid crumple zone**

A new passenger shell was designed that incorporated a roof structure with an "A" pillar that will connect to the front face of the three wheeler and its base structure as seen in Fig. 4. Its seating space was modified to be more ergonomic and the floor space was adjusted allowing space for the crush tubes to collapse safely without affecting the passenger space during a severe crash. The main structure was modified to accommodate two central crush tubes along the length of its mid-section as shown in Fig.2 and Fig.3.

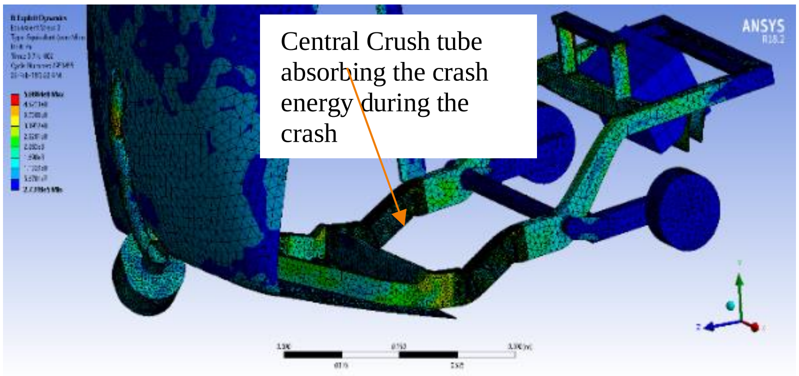


**Fig. 3. Deformation of the crumple zone during a collision.**

The simulation model was created using SolidWorks Software and was solved by exporting the model to ANSYS Software. ANSYS Explicit STR was selected for the analysis utilizing a medium mesh with a total of 215,526 elements.

The Von Mises criteria was used as the failure criterion. Simulation was carried out when the three wheeler hit a rigid barrier at 50 km/h velocity. Full Width Frontal Impact Testing Protocol for Quadri cycles (safety of quadricycles). The barrier, as per the standards was 3 m wide and 1.5 m tall. It was modelled as a rigid object along with a floor to support the motion of the Three Wheeler.

A block mass to represent the engine and transmission and human crash dummy models to represent the driver and passengers were placed in appropriate locations. The barrier, as per the Euro New Car Assessment Programme (NCAP) standard (safety of quadricycles), was 3 m wide and 1.5 m tall. It was modelled as a rigid object along with a floor to support the motion of the three wheeler. The test setup is shown in Fig. 4.

**Fig. 4. Final Setup of the proposed design with Occupants**

As per the requirements extracted from the NCAP Safety of Quadricycles, the analysis was carried out mainly on the following aspects.

1. Full-width frontal Impact Collision with Occupants without the restrain system for the solution model

2. Full-width Frontal Impact Collision with seat belt with occupants with the restrain system for the solution model

All impact tests were carried out at an initial velocity of 50 km/h and the variation of velocity after the crash with time was measured. The human crash dummy model created was based on dimensions and mass specifications of a 50$^{th}$ Male Hybrid III Anthropometric Test Device Safety of Quadricycles. The CAD model of the crash test dummy is shown in Fig. 5.

**Fig. 5. Custom Human Hybrid III 50th Male Model**

The material assigned was a modified Steel 1006 which brought the total mass of the dummy to 88kg. The final setup of a typical crash test dummy is illustrated in Fig. 5.

## 3 RESULTS AND DISCUSSION

Significant plastic deformation was observed on the front face (notably at the 'A-Pillars' which are connected to the roof structure) and the steering column as observed in the original design of the conventional three wheeler 2)Jurangpathy & Perera (2023). However, it was interesting to observe that the Conical Square-type crush tubes underwent collapse as well with severe plastic deformation. This is illustrated in Fig. 7.

The conventional three wheeler does not have a rigid structure to form a passenger shell, and expectedly, a severe deformation to the structure of the conventional three wheeler as shown in Fig.6 has occurred. The proposed design has been able to keep the passenger compartment intact however, a moderate intrusion to the driver compartment can be seen. the FEM model of the proposed design shows a severe plastic deformation at the crush tube location compared to the same area of the conventional three wheeler analyzed by Jurangpathy & Perera (2023).

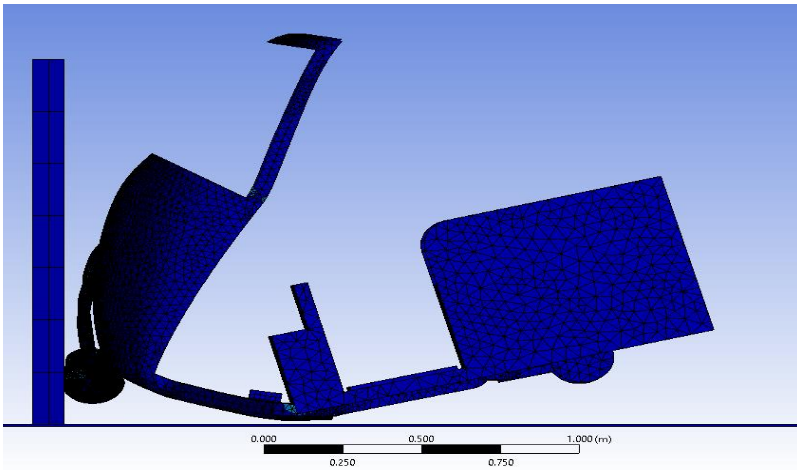


**Fig. 6. Conventional three wheeler at Full Width Frontal Impact Test (from Jurangpathy & Perera 2023)**

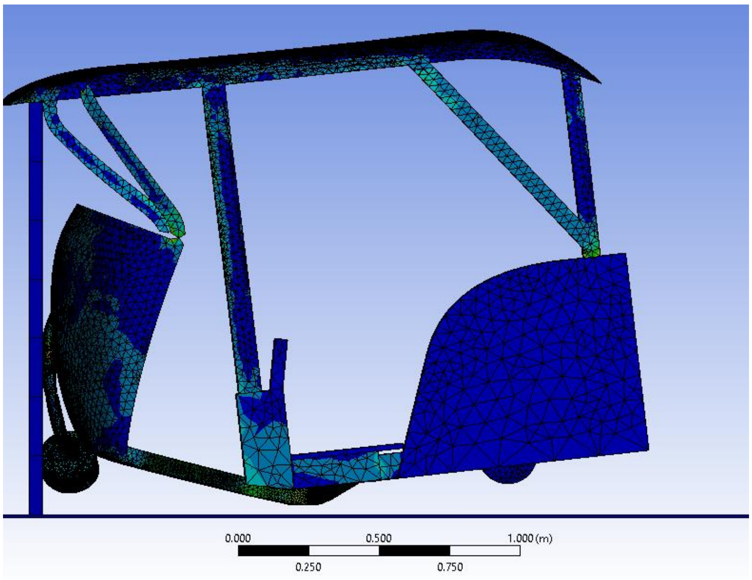


**Fig.7. Proposed design at Full Width Frontal Impact Test**

Fig. 8 depicts the velocity vs time graph of passengers and the driver during the collision without the restrain system for the proposed design.

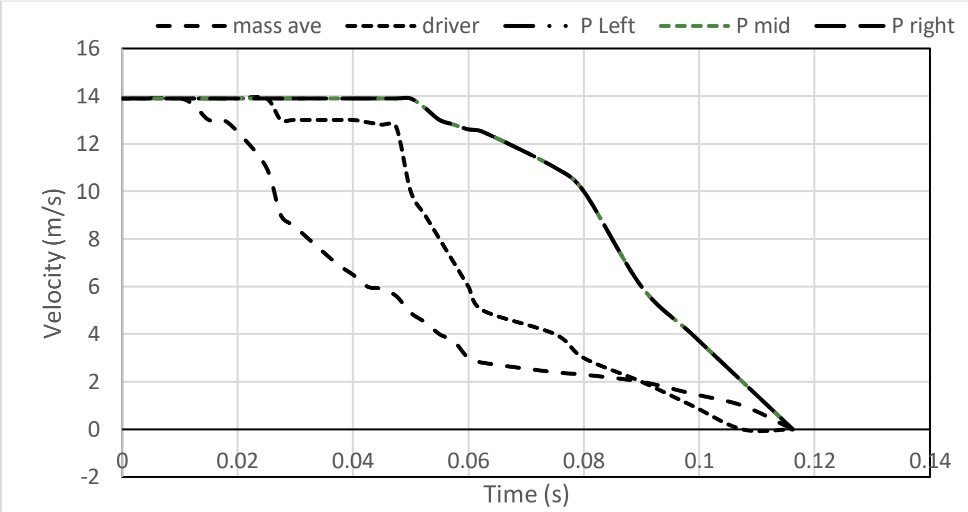


**Fig. 8. Mass Average Velocity signature with passengers and driver for proposed design without restrain system**

The total time for the conventional three wheeler to stall during Full Width Frontal Impact Collision for the conventional three wheeler was 0.09 seconds Jurangpathy & Perera (2023). The analysis of Fig. 8 reveals that the impact time has prolonged up to 0.12 seconds for the solution model. The prolonged time of the proposed three wheeler indicates its shower acceleration three wheeler during the Full Width Frontal Impact Collision This behavior of the proposed model was obtained by subjecting the crush tube to fail by absorbing impact energy during collision. All passengers undergo a lower deceleration than before. A comparison of G force each occupant is subjected to is compared in Table 1 against those obtained for a conventional three wheeler presented by Jurangpathy & Perera (2023).

**Table 1 Occupant Dynamic Motion Data without the restrain system for the conventional design and the proposed design**

| Occupant | Maximum G Force for the conventional three wheeler | Maximum G Force of Proposed model |
|---|---|---|
| Driver | 81 G | 13.3 G |
| Passenger (Left) | 47 G | 20 G |
| Passenger (Mid) | 47 G | 20 G |
| Passenger (Right) | 47 G | 20 G |

This comparison of acceleration for the conventional three wheeler against those for the proposed design reveals that the severity from the collision on occupants in the proposed model has significantly reduced. The acceleration of the driver was 6 times higher in the conventional three-wheeler compared to that of the proposed design. The acceleration of the passengers was 2.35 times higher in the conventional three wheeler compared to those of the proposed design.

Fig 9 Illustrates the velocity vs time graph for the proposed design with seat belts being worn by the passengers and the driver during the collision.

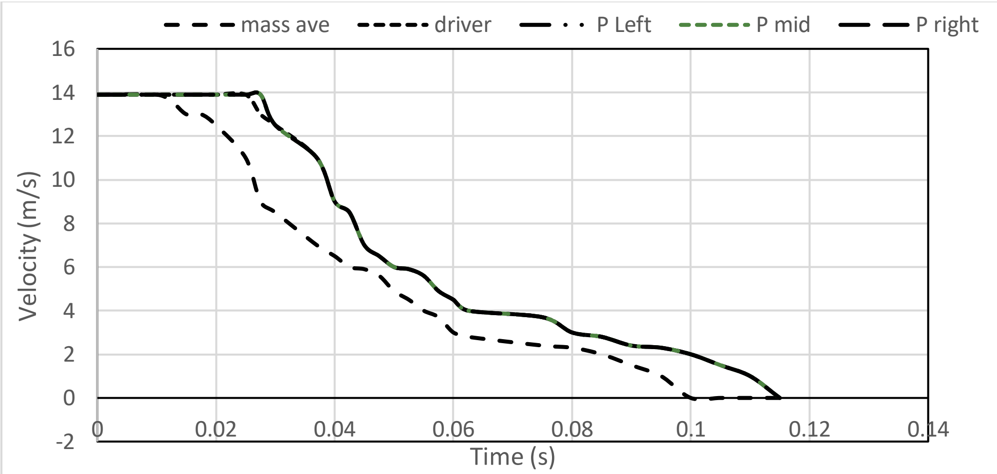


**Fig. 9. Mass Average Velocity signature with passengers and driver for proposed design with restraint system**

Previous findings of Jurangpathy & Perera (2023) on Full Width Frontal Impact Collision for a conventional three wheeler revealed that the maximum G force experienced by the driver as 25 G and 20 G for all passengers with seat belts being worn. Contrary to the above, he analysis of the velocity time signature of the proposed design reveals that the maximum G force experienced by the driver has been reduced to 13.2 G and up to 13.4 G with all passengers. A comparison of the maximum G forces experienced by the driver and passengers for conventional three wheeler and the proposed design is given in Table 2.

**Table 2 Comparison of Occupant Dynamic Motion Data with restrain system for the conventional three wheeler and proposed model**

| **Occupant** | **Maximum G Force of conventional three wheeler from ref 2** | **Maximum G Force of Proposed Model** |
|---|---|---|
| Driver | 25 G | 13.2 G |
| Passenger (Left) | 20 G | 13.4 G |
| Passenger (Mid) | 20 G | 13.4 G |
| Passenger (Right) | 20 G | 13.4 G |

It was a challenging exercise to incorporate a crumple zone without making drastic changes to the existing body shape of three wheelers. Changes to body features in the front would not be acceptable to current users. In order to maintain the exterior features of the three wheeler, a central crumple zone was designed. The design of the crumple zone was developed to attain a sufficiently high threshold to make the central crumple zone feasible, with the design revolving around an axial mode of collapse type comprised mainly of crush tubes. The concept was to replace a portion of the main structure with crush tubes designed to collapse axially and absorb impact energy. A side-by-side comparison of the solution model with the conventional three wheeler showed that the front face deformed far less than the original model and a mixed mode collapse was observed at the crumple zone of the proposed design. Furthermore, it prevented the front face of the model from folding in as much as it did before, reducing the likelihood of fatalities on the driver. With an effective restraint system in place, the survivability of the occupants can be further increased.

## 4 CONCLUSIONS

Conventional three wheelers lack passenger safety. A way of absorbing crash energy while maintaining the integrity of passenger shell is required to enhance safety. The central crumple zone introduced to the conventional three wheeler has been able to enhance crash safety compared to that of the conventional three wheeler.

Compared to results obtained for the conventional three wheeler with seat belts for passengers and the driver by Jurangpaty and Perera, a 47.2 % reduction of G force for the driver and 33% reduction of G force for passengers has been achieved for the proposed design. This suggests that a considerable amount of crash energy has been absorbed by the crush tube during the collision.

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