# 7 ASSESSING THE STRUCTURAL CRASHWORTHINESS OF A THREE-WHEELER PASSENGER VEHICLE

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Over the last few decades, three wheelers, popularly termed as auto rickshaws, are gaining popularity in the commuting world due to the driving conditions prevailing all over the world. With the traffic increasing every year, esp. in developing countries like India, the proportion of three wheelers on the road is also increasing, in view of their maneuverability, easy drive through narrow lanes and operating cost considerations. Moreover, as the average speed of travel of these vehicles increases, but at the same time, the design objective is for a low cost, light weight and high payload, and greater acceleration capacity three wheelers, makes a concern for safety. Other than some basic safety features, three wheelers are not evaluated for crash worthiness. It may be noted that the crash regulations were mostly for car segment, and as such the regulation for a three wheeler is not in existence.

Primarily, the crashworthiness has been studied by testing, supported by analytical methods that consider simple linear strength of material. Crash worthiness experimentation is very expensive; but, with the advancement of computer hardware and software, several analytical design capabilities have evolved, providing engineers with a variety of tools to design modern vehicle structures that can meet the growing customer demands for better crashworthiness performance. The scope of this paper is to assess the structural crashworthiness of a three wheeler passenger auto rickshaw, considering the frontal and rear impact collision using Hyper works$^{TM}$, Hyper crash$^{TM}$ and Radioss$^{TM}$.

## 1. INTRODUCTION

The need for crash simulations with high degrees of accuracy and robustness is becoming increasingly important for use in parametric studies and early design analysis. The numerical simulation also enables new design concepts to be evaluated where there is a need to establish an optimum design with an interaction between materials and structural forms. In order to reduce the new product development time, it is necessary to apply non-linear finite element (FE) analysis to design and evaluate the crashworthiness of the final product.

With the increase in traffic every year, the proportion of three wheelers on road is also getting increased. Figure 1 shows the data on road accident deaths by type of vehicles (percentage share), of which three-wheeler accidents contributes up to five percentage of the overall road accident deaths.

**Vehicle Crashworthiness:** Crashworthiness is the ability of the vehicle to protect the occupant during an impact. At present, most of the vehicle bodies are built primarily with stamped steel panels and joined by welding and fastening techniques. Vehicle structures, apart from providing protection to the occupants, also control the crash deceleration pulse to a level below the upper limit of human tolerance. A crash deceleration pulse (Energy absorption) with an early peak in time and a gradual decay is more beneficial for protection of a restrained occupant. Generally, vehicle collisions are classified as frontal, side and rear impact, with majority of injuries due to frontal impact, followed by rear impact and side impact.

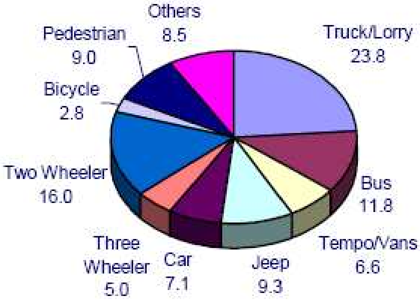

**Figure 1.** Road accidents by type of vehicle.[1]

## 2. SURVEY ON VEHICLE IMPACT

To cope with the increasing demands of the customer, the modern auto rickshaws are driven at higher speed and hence safety is a concern, as accidents can be fatal. In reality, vehicle collisions are unique dynamic events where the vehicle may collide with another vehicle of similar or different shape, stiffness and mass; or it may collide with another stationary object. Some of the three wheeler auto rickshaws collisions are classified and shown below

**Frontal Collision:** A frontal collision is one where the front ends of two vehicles hit each other. This has the potential for the highest crash energy. In the case shown in Figure 2, the vehicle is hit through its front wheel steering system.

**Frontal Offset Impact:** A typical frontal offset impact for an auto rickshaw is shown in the Figure 3. Due to the impact, the front cowl along with the floor has intruded into the driver leg room compartment.

### 2.1. Finite Element Model for an Auto-Rickshaw

The accuracy of any simulation depends on how accurately the modeling work has been carried out. Efforts were taken in constructing the numerical model of a three wheeler as similar as possible to reality. The drive away chassis and all other components in the system were modeled and meshed in order to make a precise model using Hypermesh pre-processor. P1-shell element with average element size of 10–15 is used in the present model. Johnson-Cook type material model Type 2 is used in the analysis. Strain rate sensitivity is accounted for in the model. The material properties used in the analysis for IS513 steel in drawn (D) and deep drawn (DD) conditions are as follows:

| Type | IS 513 D | IS 513 DD |
|---|---|---|
| Density | 7.9E-9 | 7.9E-9 |
| Young modulus | 210000 | 210000 |
| Poisson Ratio | 0.3 | 0.3 |
| Yield stress | 250 | 200 |
| Hardening parameter | 500 | 450 |
| Hardening exponent | 0.5 | 0.5 |
| Failure plastic strain | 1E30 | 1E30 |
| Max stress | 475 | 425 |

All the components were assembled with respect to their respective location in the drive away chassis assembly as shown in Figure 4.

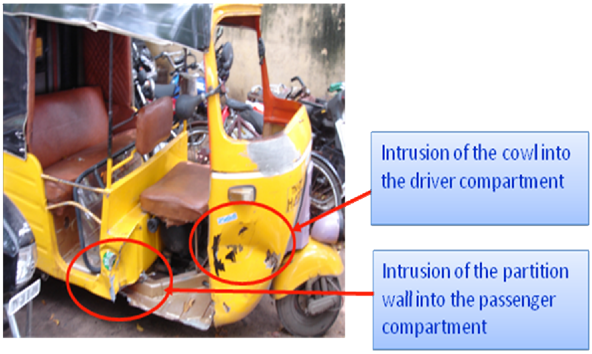

**Figure 2.** Frontal impact.

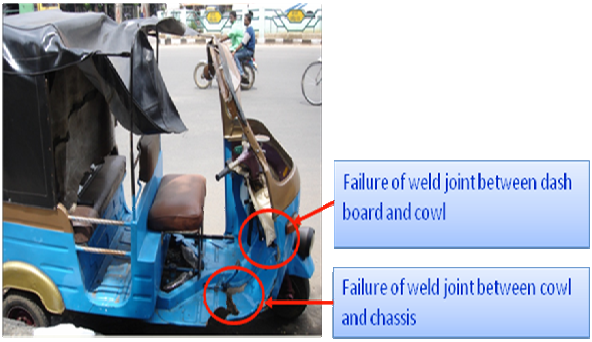

**Figure 3.** Frontal offset impact.

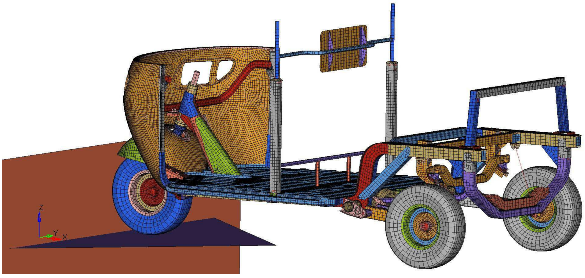

**Figure 4.** Drive away Chassis.

In general autorickshaws are low speed vehicles with a maximum speed of 60 kmph with reasonable acceleration. The international standard for crashworthiness is normally evaluated at 48 kmph. However, at the time of accident, esp. for during frontal impact, the vehicle speed is normally reduced due to the driver braking action, and the instantaneous speed is around 20 kmph. Taking into account the above, the present work considers crashworthiness at two speeds of 20 kmph and 48 kmph.

**Case 1 – Frontal impact:** To simulate the Frontal (Head on) impact, the vehicle is subject to an initial velocity of 20 kmph and 48 kmph along the horizontal direction towards the rigid barrier. A typical

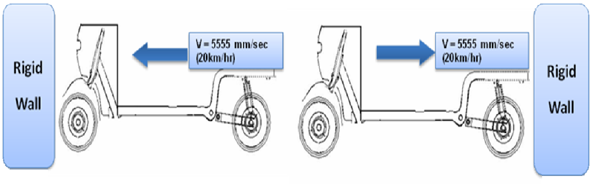

**Figure 5.** Frontal and rear impact.

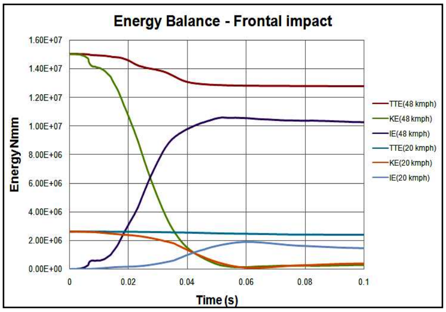

**Figure 6.** Energy balance — frontal impact.

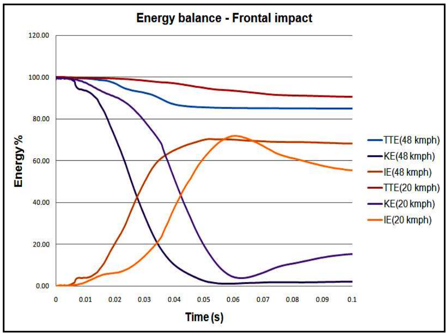

**Figure 7.** Energy balance percentage frontal impact.

schematic boundary condition for the vehicle is shown in the Figure 5.

**Case 2 – Rear impact:** A typical schematic boundary condition for the vehicle is shown in the Figure 5.

## 3. RESULTS: CASE 1 — FRONTAL IMPACT

### 3.1. Energy Balance

The energy balance for a typical run is shown in Figure 6. It can be observed that the total energy remains approximately constant throughout the 100 ms duration for both 20 and 48 kmph. It is also observed that the initial kinetic energy which is high during the start of the impact is slowly getting decayed and converted into internal energy. As the vehicle starts rebounding after the impact, both the KE and IE becomes flat. The energy balance for the frontal impact at 20 and 48kmph is shown in Figure 7 in terms of percentage. It is observed at both the speed of 20 and 48kmph, the trend of the energy curve remain approximately same.

### 3.2. Force Pulse

Figure 8 shows the barrier unfiltered force-time pulse for both 20 kmph and 48 kmph impact. The force pulse data at a speed of 20 kmph shows one peak force at 36 ms.

This peak force is due to the high contact force as the steering column comes in contact with the rigid wall. The initial small raise in the impact forces (20 kmph) is due to the force transfer through tire contact with the rigid wall. It may be noted that during frontal impact at 48 kmph the initial peak force is observed during the initial stage of within 7 ms.This peak force is due to the high contact force as the frontal trailing arm comes in contact with the rigid wall.

### 3.3. Crash Modulus

The crash modulus for the vehicle during frontal impact at 20 kmph is observed to be 0.1 kN/mm, (Figure 9 Force vs Deflection) which is far below the value recommended for four wheelers (1 kN/mm).

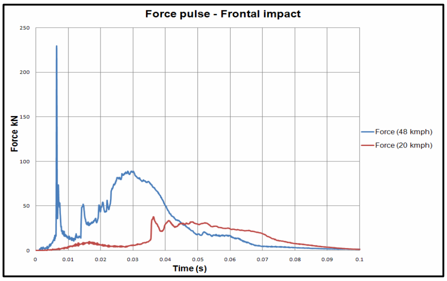

**Figure 8.** Force plus — frontal impact.

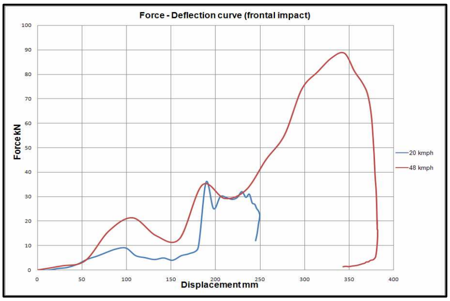

**Figure 9.** Force v$_s$ deflection — frontal impact.

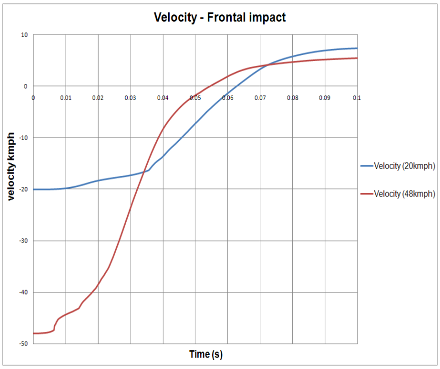

**Figure10.** Internal enegry — frontal impact.

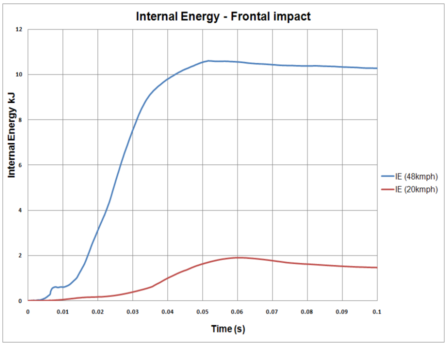

**Figure11.** Vechicle velocity — frontal impact.

The crash modulus for the vehicle at 48 kmph is observed to be 0.2 kN/mm, which is more than the value at 20 kmph. This aspect needs critical examination on occupant safety. It may be noted that the purpose of this study is to assess the structural aspects of crashworthiness for a three wheeler; passenger response during crash has already been studied by researchers at IIT, Delhi.

## 3.4. Internal energy

From Figure 10 we can see that the front end of the vehicle (at 20 kmph) absorbs about 0.45 MN-mm (0.45 KJ) energy in 15ms. During the second slope 0.35MN-mm (0.35 KJ) of energy is absorbed in 20ms, and during the third slope 0.68MNmm (0.68 KJ) of energy is absorbed in 22ms. Beyond this the vehicle starts rebounding. The slope ratio of inner energy versus time corresponds with collision force, that is when the collision force is large the slope ratio is also large. A similar observation has been made by Gao [5].

The energy absorbed during the second stage is less for its time when compared to other stages. During time interval of 45 ms to 67 ms, the long member experiences a bending about the pivot tube. The internal energy during 48 kmph also shows three slopes. During the first slope 0.20 KJ of energy in 06 ms, during second slope 8.3 kJ of energy is absorbed in 24 ms and during the third slope 1.6 kJ of energy is absorbed in 24ms. The energy absorption is low during the initial slope. This is due to the fact that the vehicles frontal wheel is the first contact point during frontal impact.

## 3.5. Vehicle

The vehicle velocity is shown in the Figure 11. During the frontal crash at 20 kmph, the vehicle velocity gets reduced (which in turn gets converted to internal energy) and crosses zero at 62 ms. Beyond this, the vehicle starts rebounding from the rigid wall. The coefficient of restitution is calculated to be 0.36. During the vehicle velocity of 48 kmph the velocity gets reduced and crosses zero at 54 ms. The coefficient of restitution is calculated to be 0.11, which shows that at higher speed there is an increase in the vehicles inelastic behavior.

## 4. CASE 2 — REAR IMPACT

### 4.1. Energy Balance

The energy balance for a typical rear crash is shown in the Figure 12. It can be observed that the total energy remains approximately constant throughout the 100 ms duration at both 20 kmph and 48 kmph. Unlike the frontal impact, here (at 20 kmph) the conversion of KE to IE has happened within 30ms, beyond which the curve remains flat. At 48 kmph, the conversion of KE to IE happened within 35ms, and the vehicle starts rebounding, which is seen through a flat response of data.

The energy balance for the rear impact at 20 and 48kmph is shown in Figure 13 in terms of percentage. It is observed at both the speed of 20 and 48 kmph, the percentage of energy remain approximately the same. Unlike the frontal impact, here in the rear impact the vehicle is in direct impact with the structural member.

### 4.2. Force Pulse

Figure 14 shows the barrier unfiltered force-time pulse. Unlike the frontal impact, in rear impact, (both 20 kmph and 48 kmph) the maximum value of collision force happens at the beginning like a pulse. During the initial time of 15 ms, the whole structure is stable and does not bend down and can withstand large collision force. In the rear impact the collision force completely becomes flat after 50 ms.

### 4.3. Crash Modulus

The crash modulus for the vehicle during rear impact at 20 kmph is absorbed to be 9.5KN/mm (Figure 15) which is quite high compared to the frontal crash modulus. The crash modulus at 48 kmph is absorbed to be 4.7 KN/mm. At higher speed (48 kmph) the crash modulus is half the value as that of lower speed (20 kmph).

### 4.4. Internal Energy

From the Figure 16 we can see that the rear end of the vehicle absorbs (20 kmph) around 1.5E6 Nmm (1.5KJ) energy in the first 10 ms. During the time 10 ms to 20 ms, the vehicle has absorbed around 1.08E6 N-mm (1.08 KJ) of energy and between 20 ms to 30 ms it has absorbed only0.15E6 N-mm

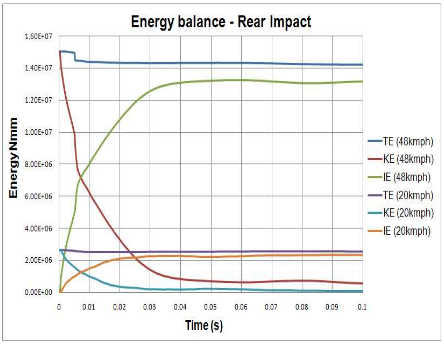

**Figure 12.** Energy balance — Rear impact.

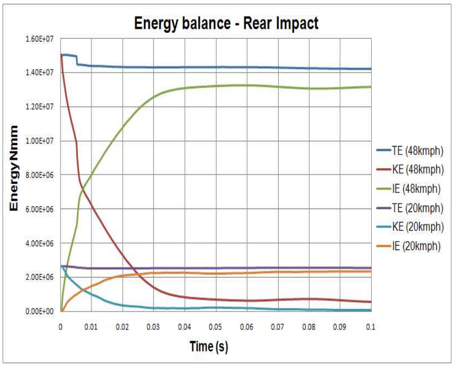

**Figure 13.** Energy balance(%) — Rear impact.

(0.15 KJ) of energy. As such the whole vehicle has absorbed about 2.25E6 N-mm (2.25KJ) of energy. The slope ratio of inner energy versus time corresponds with collision force, that is when the collision force is large the slope ratio is also large [5]. The internal energy during 48 kmph also shows three slopes. During the first slope 5 KJ of energy in 05 ms, during second slope 5.5 kJ of energy is absorbed in 21 ms and during the third slope 0.5 kJ of energy is absorbed in 12 ms. The energy absorption is low during the third slope. This is due to the fact that after 35 ms the vehicle becomes unstable due to bending.

## 4.5. Vehicle Velocity

The vehicles velocity is shown in the Figure 17. During the rear crash, the vehicle velocity gets reduced (which in turn gets converted to internal energy) and crosses zero at approximately 30 ms. Beyond this the vehicle starts rebounding from the rigid wall. The coefficient of restitution is calculated to be 0.1. During the vehicle velocity of 48 kmph the velocity gets reduced and crosses zero at 36 ms. The coefficient of restitution is calculated to be 0.17.

## 5. RESULTS: FRONTAL IMPACT

1. The frontal crash modulus is only 1/10th of the crash modulus for a mid size car segment at 20 kmph. The crash modulus is double at speed of 48 kmph

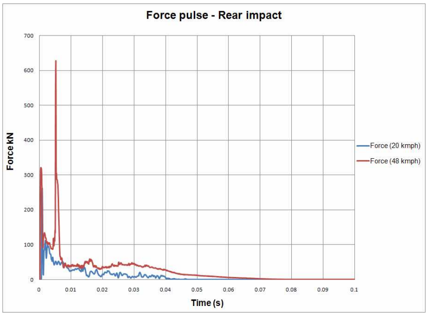

**Figure 14.** Force plus rear impact.

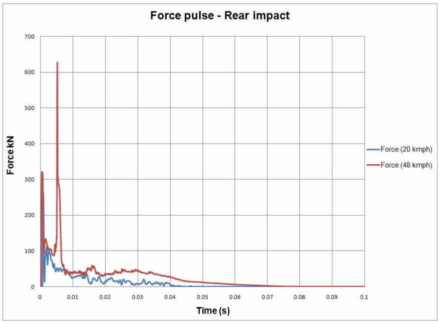

**Figure 15.** Force v$_s$ deflection — rear impact.

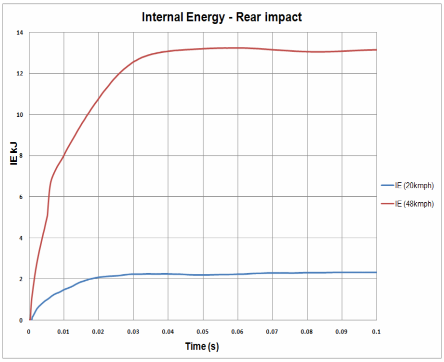

**Figure 16.** Internal energy — rear impact.

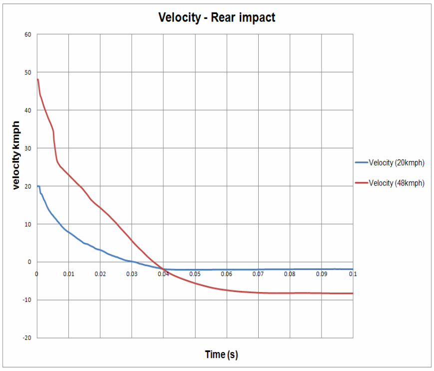

**Figure 17.** Velocity — rear impact.

2. Unlike cars, there is no front bumper for the auto rickshaws and hence no frontal energy absorbing member. This can be improved either by having foam filling in between cowl bottom and reinforcement (closed section) or having a corrugated section inside the long members.
3. To improve the crash worthiness, the initial slope of the force curve has to be high, which in turn gets reflected in the crash modulus
4. The initial force transition has to be increased by providing an energy absorbing zone.
5. The coefficient of restitution for frontal impact is more when compared to rear impact.

## 5.1. Rear Impact

1. The rear crash modulus is much higher than frontal crash.
2. The initial slope is high thereby higher force is absorbed
3. The coefficient of restitution for rear impact is having good inelastic collision when compared to front impact.

## 6. FUTURE WORK

The present work evaluated the crash behavior of a three wheeler drive away chassis by dynamic analysis

- This work can be extended to evaluate the crash behavior for the whole vehicle, including windshield assembly, cabin assembly and soft top assembly i.e. lumped mass analysis can be made to set of independent parts.
- To assess the safety of the vehicle due to fuel tank leakage during rear impact.
- Effect of HAZ (Heat affected zone) due to welding in the crash behavior.
- To verify these results with data obtained from actual testing.

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