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Simulation of Anti-Climbing Mechanism for High-Speed Railways

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Abstract

When a high speed train meets an accident, it has a higher chance of causalities of the passengers and crew members. Every year new high sped trains are introduced, and the speed of trains are increasing day by day. When an accident occur coaches have huge amount of energy in form of kinetic energy, so the coaches climb and crush into one another. Which cause many more deaths. Many research work have been done on the crashworthiness of the train to solve this issue.

This thesis work presents the model of an actual internal frame and the bumpers and anti-climbers. Internal frame were redesigned to absorb huge kinetic energy and anti- climbers are designed to stop the jumping. The results of the newly designed part is compared with the actual model of parts, which are currently used in Indian Railways, to compare the effectiveness of the new parts.

All parts and assemblies are modeled in Solidworks. For simulation of energy absorption the assemblies were imported to Ansys and for simulation of anti-climbers assemblies were imported to Adams View.

Chapter 1. Introduction

Indian Railways is the lifeline of the nation. It traverses the length and breadth of the country providing the required connectivity and integration for balanced regional development. The system never rests, it has been up and working unceasingly for the last several decades. It is an integral part of every Indian's being. It is one of the pillars of the nation. Indian Railways is a great national asset. A single transport network connects far flung areas of the country. It is one of the largest transportation and logistics network of the world which runs 19,000 trains. It runs 12,000 trains to carry over 23 million passengers per day connecting about 8,000 stations spread across the sub-continent.

Safety becomes the major issue for a passengers. An average of 7 rail accidents occur per year, which causes 100-150 deaths every year. Railway accidents may be classified by their effects, e.g.: head-on collisions, rear-end collisions, side collisions, derailments, fires, explosions, etc. They may alternatively be classified by cause, e.g.: driver and signalman error, mechanical failure of rolling stock, tracks and bridges. These are the type of accidents which cannot be predicted.

Figure 1: Utkal Express derails near UP's Muzaffarnagar: 23 dead, 156 injured [Source: The Hindu [1]]

1.1. Motivation

During a rail accident coaches climb over the other and crush into one another. This causes more deaths. Today some of our coaches are equipped with anti-climbers, but they are not good enough. For high speed trains we require more robust design. As the speed increases kinetic energy increases, this requires a more reliable design.

Testing can be done with the help of computer simulations. We can analyze our design at different speeds. If the system fails within the operation region the anti-climbers design can be changed and re-simulated. With the help advanced industrial grade software the design can be simulated for any kind of situations.

1.2. Literature Review

Most of the earlier works done before are focused mainly on the crashworthiness of the railway coaches. Not many people have specifically worked on anti-climbing mechanism for car bodies. In accidents coaches climb each other causing many more causalities and death. Although it cannot be simply said that the previous work were insignificant. They worked upon energy absorbing phenomena. Wang and Tian [2] in their research they experimentally found the effectiveness of aluminium honeycomb. High impact systems were used velocities ranging from 20 to 80 m/s. Xie and Zhou [3] has performed analysis in ANSYS software for passive safety protection during railway vehicle collision. They designed a stage by stage wise energy dissipating system. They saw that total energy dissipation was improved with increased **honeycomb structure plateau stress.** Qiang and Dawei et al. [4] calculated the crushing stress using Simplified Super Folding Element (SSFE) theory of three kinds of the novel honeycombs. Considering the inertia effects finite element simulations of the series full-scale model of honeycombs are conducted by using LS-DYNA software. They found the desirable amount of energy dissipation and progressive folding deformation patterns were developed in all three types of novel honeycomb.

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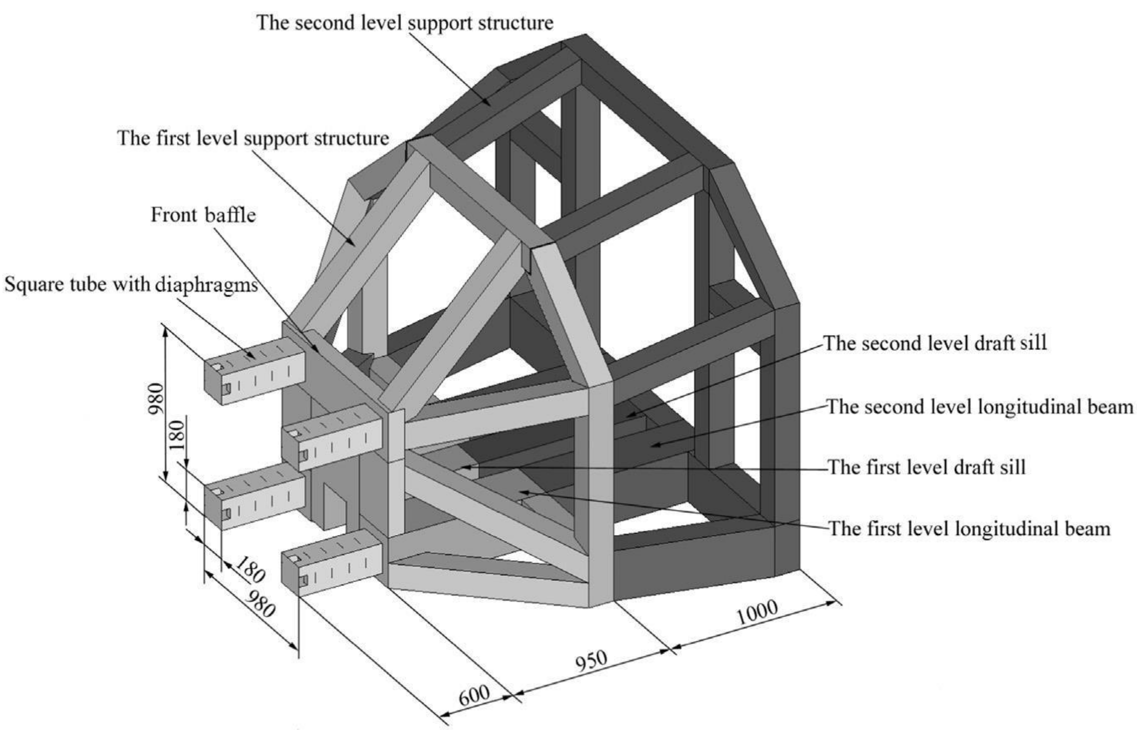

Figure 2: Geometric model of the crashworthy driver's cab. [Source: [4]]

Li et al. [5] presented the crashworthy performance of the structure of railway vehicle driver's cab by simulation and experimental investigations. In the finite element simulation the structure absorbed 2321.13KJ energy.

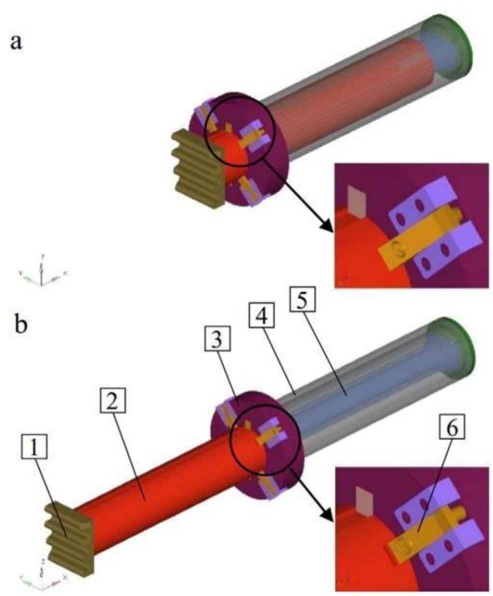

Figure 3: The absorber: (1. anti-climber gear, 2. crush tube, 3. support tool, 4. guide tube, 5. Reversible actuator, 6. Die. [Source: [5]]

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Gao et al. [6] used a new type of energy absorber. The absorber consists of a crush tube, anti-climber gear, die, support tool, guide tube, and reversible actuator. Before collision, the crush tube of the absorber is extended duo to the effect of the reversible actuator, which breaks through the coupler restrictions on the longitudinal dimension of the absorber and significantly increases the deformation stroke of the absorber. During collision, the kinetic energies are dissipated by the cutting of the circular aluminum or steel tube, shear sliding, and friction between the circular tube and the die.

A Scholes et al. [7] build an actual model of the train for crash worthiness testing. The end part near the toilets were modified. It was tested at speed of 40miles/hour and system was absorbing more energy than the theoretical model.

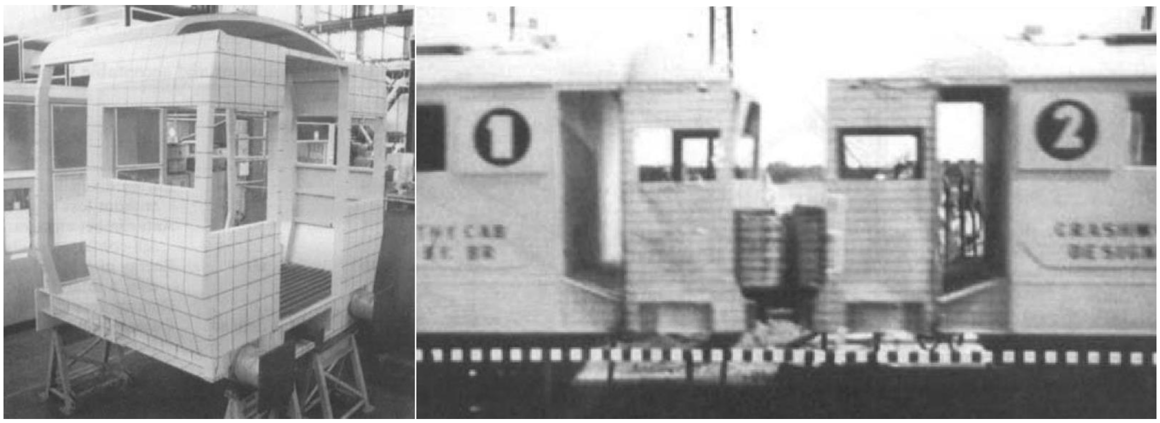

Figure 4: The modified end parts for crashworthiness testing (left). Collision of two coaches is shown (right). [Source: [7]]

Ronald et al. [8] presents information on the design of a rail vehicle crush zone for better occupant protection. The overall design requirements and characteristics is described and the configuration for the various structural subsystems is presented. The paper also includes information on full-scale component tests carried out to support the development of the design, particularly for the primary energy absorbers. Comparisons between test and finite element analysis are presented and there is a discussion of how the test results have affected the design.

As seen from the literature survey, all work which has been done basically on the energy absorbing of the impact. No one has specifically worked on the phenomena of the anti-climbing mechanism, to stop the railway vehicles from climbing over the other. Hence, it is important to build a structure which will prevent the climbing and the impact.

1.3. Objective

1) To develop a mechanism to prevent the climbing of railway vehicles during an accident such as head on collisions, derailments.
2) To absorb the impact energy during an accidents for the safety of the passengers.

1.4. Problem Formulation

- Modeling of each components is done on SolidWorks. A more complex design was made which is comparable with a real coach.
- Testing of the bodies were done from the basic level and the components were added.
- Modification in the design was done to absorb the impact energy.

Chapter 2. Model

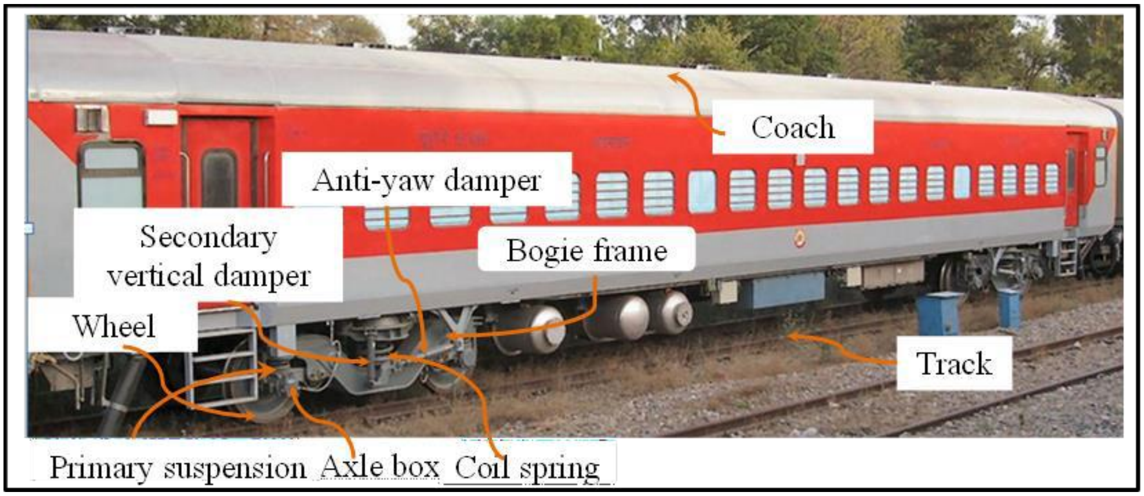

Figure 5: Picture of an actual train showing all the components

The length of an AC 3-tier coach is 23.54m, its width is 3.24m and height is 3.4m. Which means a higher passenger capacity, compared to conventional rakes which is made in US. The tare weight of the AC chair car was weighed as 39.5 tonnes. Based on the original railway coach construction, we have modeled it on the software SolidWorks. All the parts to be modeled is shown in figure 5.

2.1. Internal Frame of the Coaches

This internal frame of a coach is made of rail steel 1020 grade. It has a C-type cross-section. It has a thickness of 5mm. These straight frames connects the round frames shown in the figure 6. All these structure are assembled together and a cage is formed shown in the figure

7. As further design modification was made to absorb the enormous kinetic energy. The train running at 40 m/s has a lot of kinetic energy.

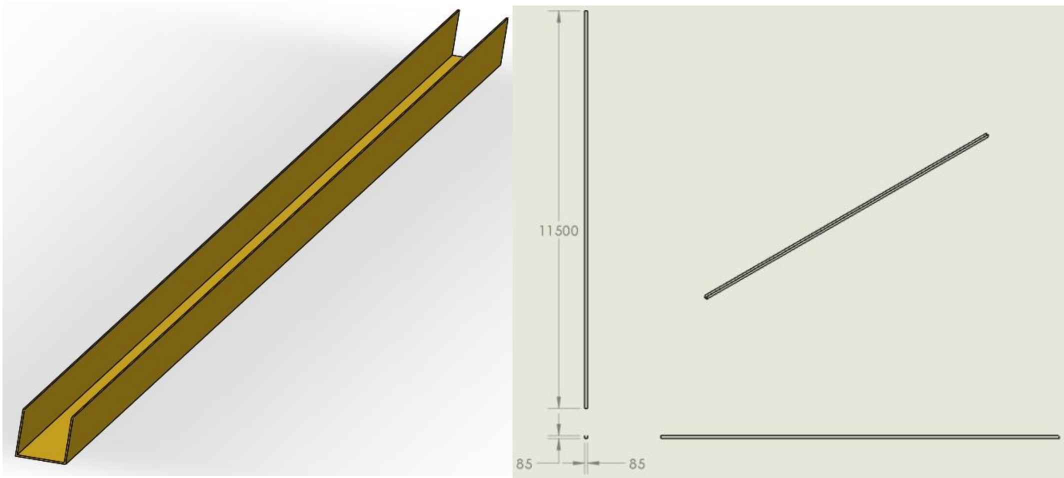

Figure 6 : C-crossction beam is used of horizontal beams (Dimensions in mm)

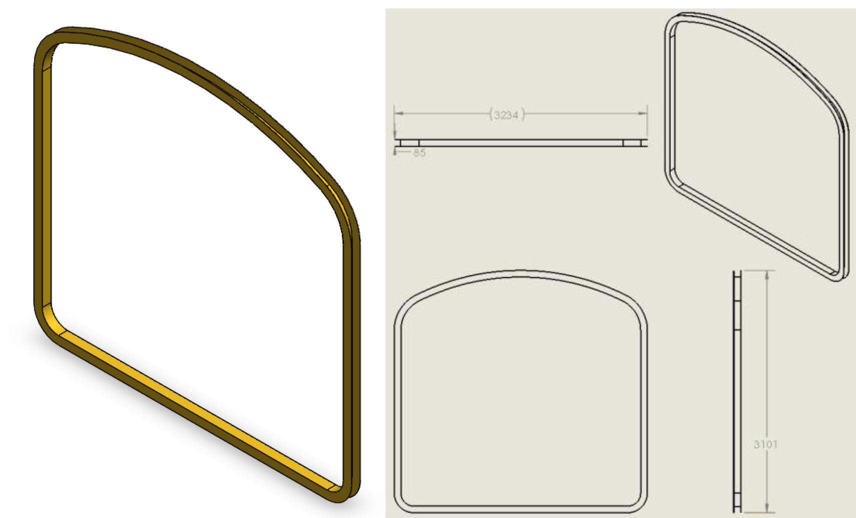

Figure 7: This is the frame of the coach which binds the beam together (Dimensions in mm)

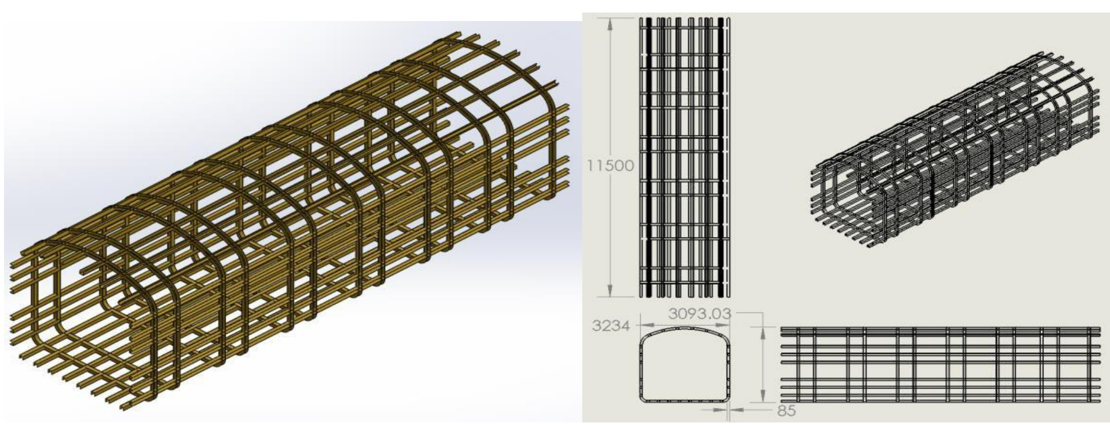

Figure 8: All beams and frames are bind together to form a cage like structure. This is the half frame only. (Dimensions in mm)

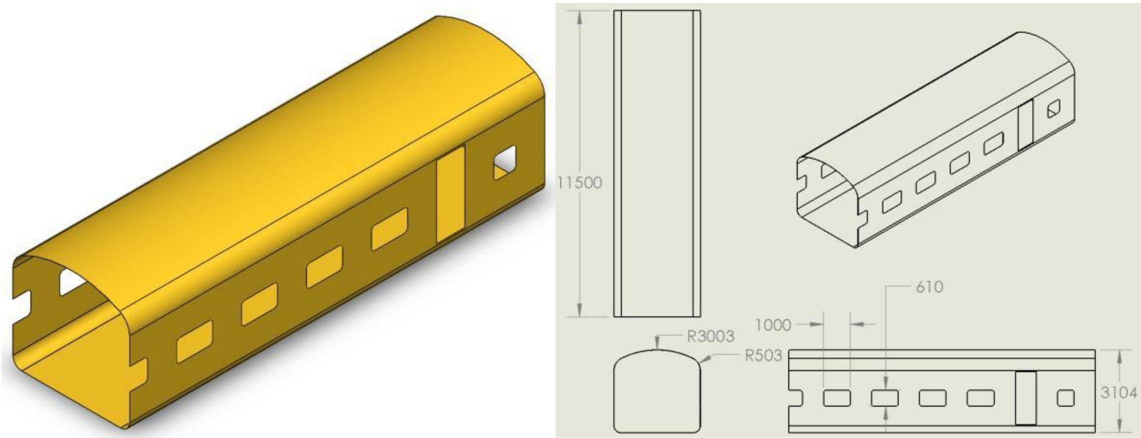

Figure 9: This is the half shell of the coach. Having the cutouts for windows, a door and a toilet window. (Dimensions in mm)

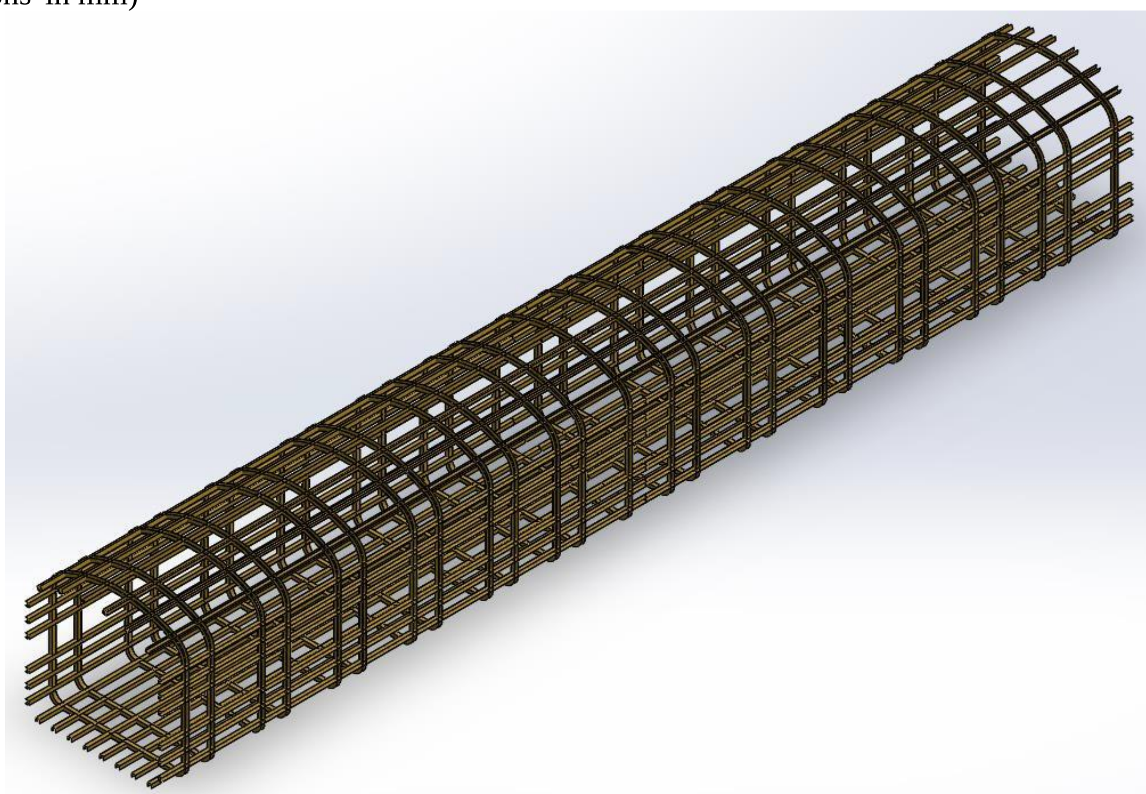

Figure 10: Complete internal frame of a coach

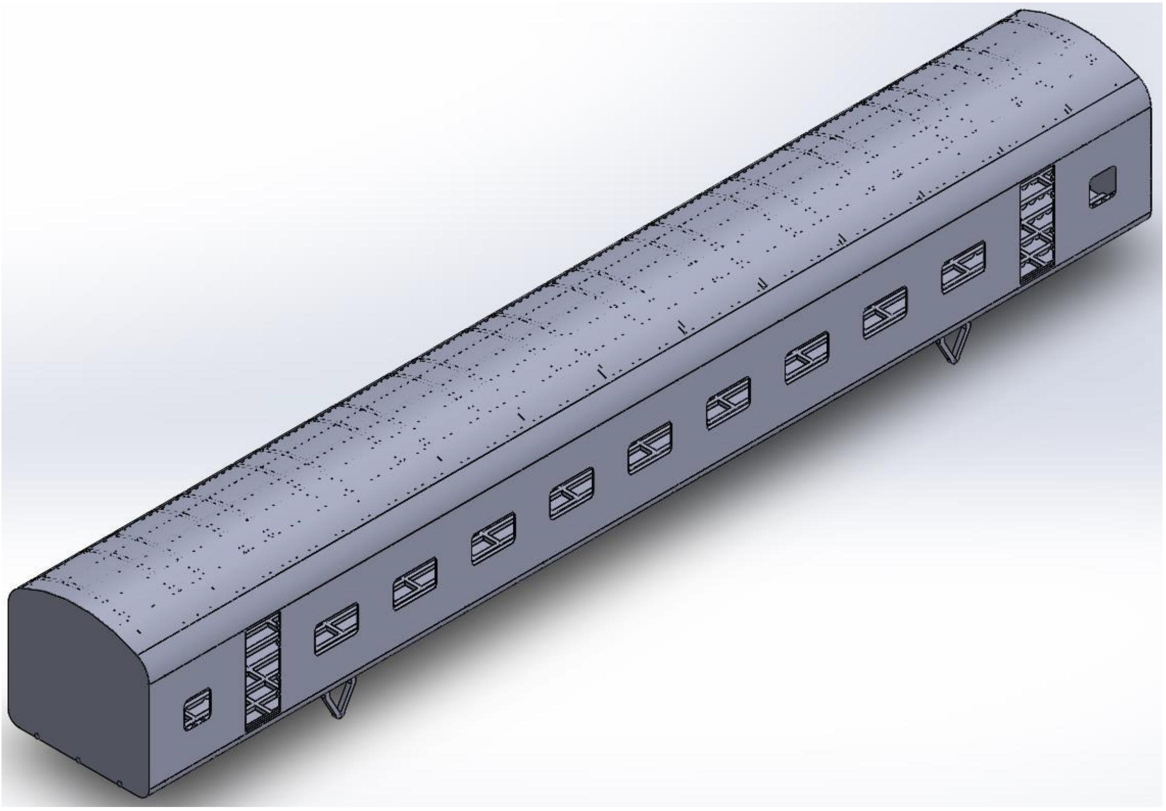

Figure 11: The shell and the Internal Frame are assembled together to form a complete coach.

2.2. Components

2.2.1. Bumpers

Bumpers serve as a shock absorbing device during braking of the train. It is similar to the spring and damper system. During braking, it absorbs very small amount of energy due to impact of coaches. At the time of braking coaches tends to collide each other but that happens at very less speed, so a simple bumper (as shown in the figure 12) serves a good purpose of the same. But at the time of an accident this design is very bad and turns out to dangerous. Due to its round shape bumpers slips over the other and it helps the coaches to jump and climb over the other.

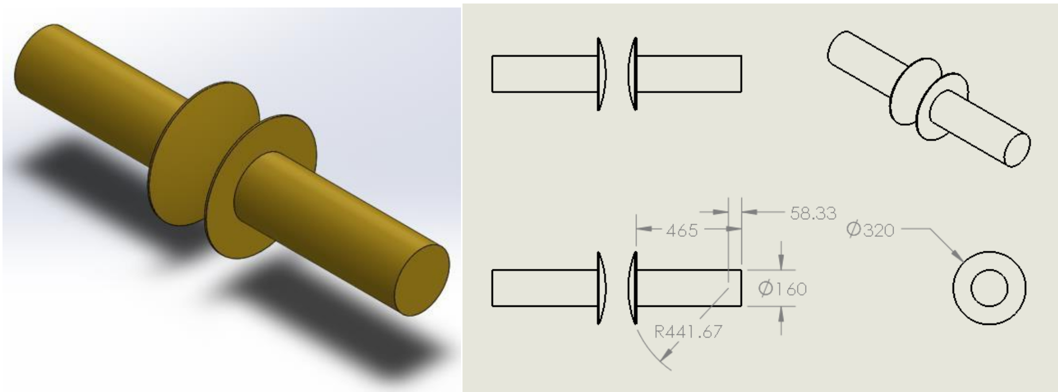

Figure 12: Round faced Straight Bumpers. (Dimensions in mm)

Two other kinds of bumpers are designed to stop the climbing of the coaches, full filing the requirement of reducing jerks at the time of braking and restricting coaches form climbing each other. These kind of bumpers have a locking mechanism (as shown in the figure 13 and 14). Bumpers are placed such as when they collide they locks into one another.

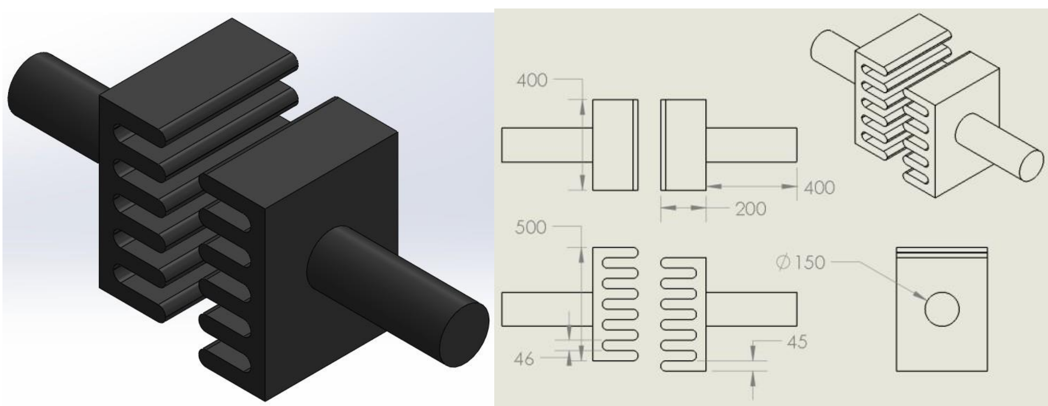

Figure 13: Straight Slots Bumpers. (Dimensions in mm)

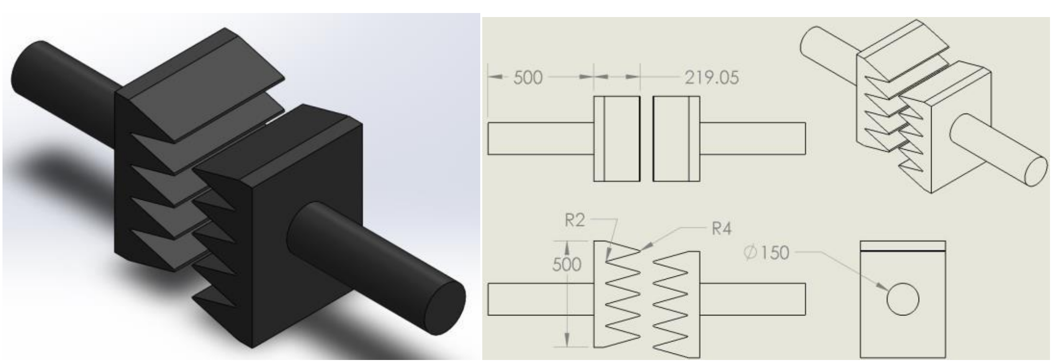

Figure 14: Tapered slot bumpers. (Dimensions in mm)

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2.2.2. Couplers

The modeled couplers just serves the purpose of pulling and binding the coaches when pulled by the engine. These are different than the actual couplers. Modeled couplers are showen in the figure 15.

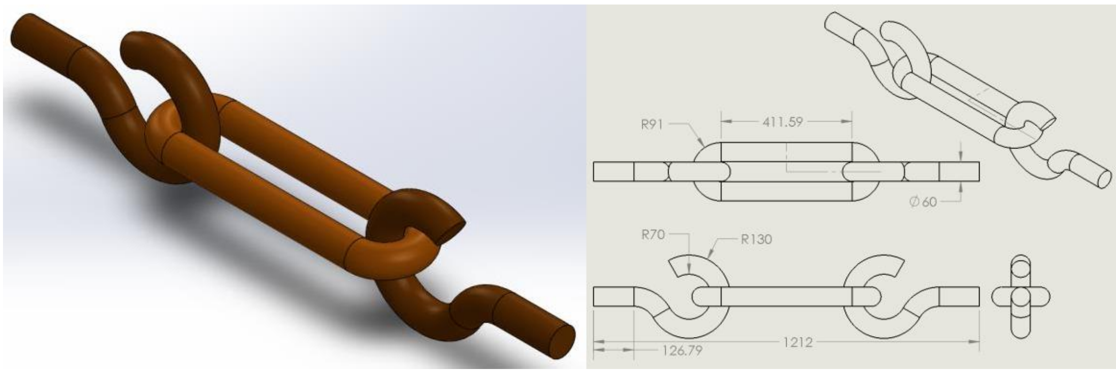

Figure 15: Assembly of the hooks and connector, forms a coupler, which is used to pull other coaches. (Dimensions in mm)

2.2.3. Bogies

Bogies are the part of a coach which holds the rail wheels and suspensions (shown in figure 16). Better bogie technology lets the train have comfortable journey and reach higher speeds. Components of bogies are wheel-sets, axle boxes, suspensions, dampers and brakes.

- Wheel-set is the pair of two wheels and a shaft (shown in the figure 17). Shafts are transition fitted on the shaft and form a rigid body.
- Axle box holds the wheel shaft. It can be of different designs depending on the technology of the bogies it is (shown in the figure 18).
- Dampers play a very important role in the stability of a bogie. More stable bogie means higher speeds can be reached by the trains. Anti-role damper is used in minimizing the hunting effect.
- Bogies have two types of suspensions which are primary suspensions and secondary suspensions. Primary suspension connects wheel axle box to the bogie frame and secondary suspension which sometimes called central suspension connects the bogie to the bolsters. Bolsters are connected to the coaches.

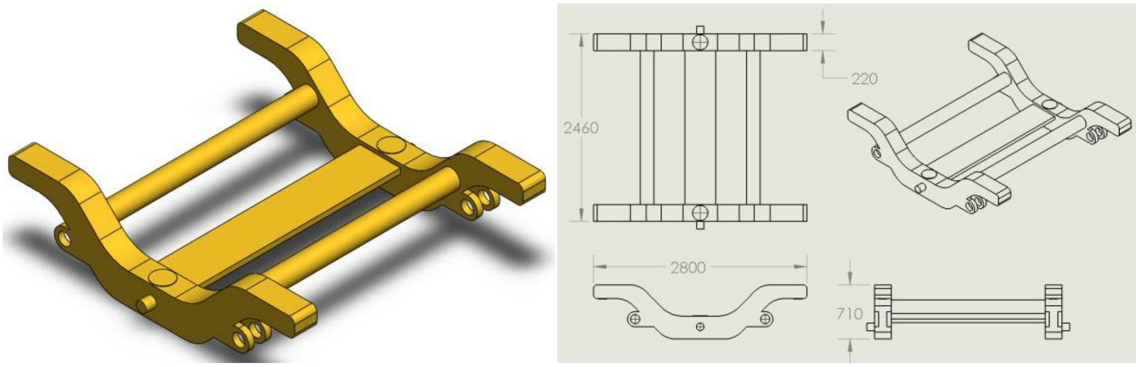

Figure 16: Model of the Bogie. (Dimensions in mm)

2.2.4. Wheel-set

The conicity of the wheels is not defined in this model. So, the wheels are cylindrical. This is done in order to reduce the time of simulation.

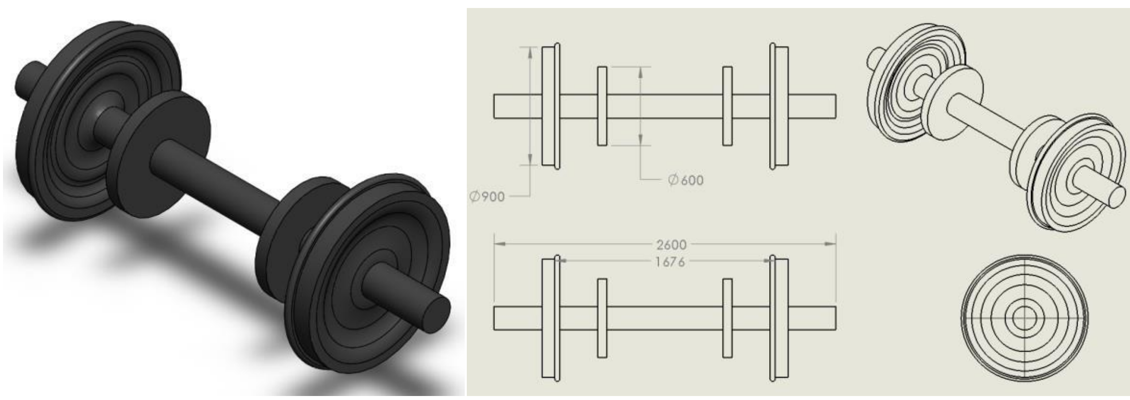

Figure 17: Wheel conicity is not present. (Dimensions in mm)

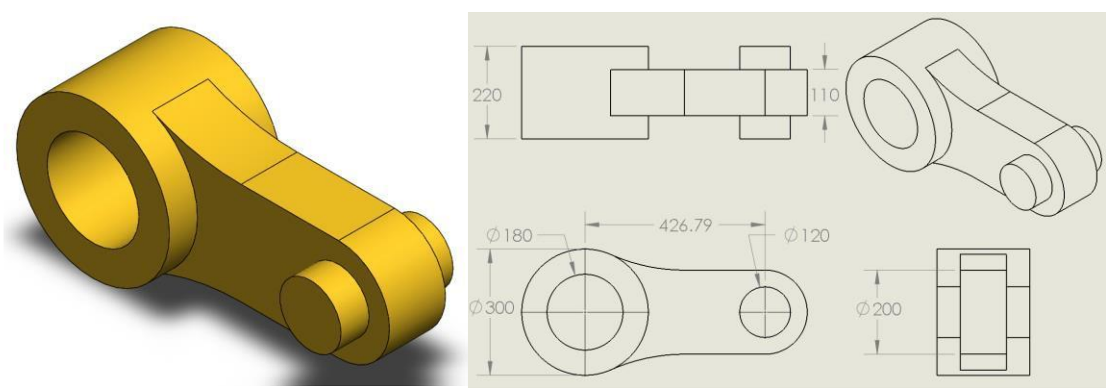

Figure 18: Axlebox is used to connect wheels and bogies. (Dimensions in mm)

Chapter 3. Overview of the currently modeled design

3.1. Assembly setup

SolidWorks is a great tool for designing, modeling and assembling any part. These modeled assemblies (as shown in the figure 19) were imported to Adams software. Adams works best if the assembly is directly imported to its preprocessor. After importing the models or assemblies the joints has to be defined. With the help of joints, properties of an actual coach can be implemented in the modeled virtual coach. Properties of different components is given in the table.

Bodies	Properties	Values
Coach	Weight	32000kg
	Material	Steel
	Elastic Modulus	2e+011 N/m^2
	Poisson's Ratio	0.29
	Shear Modulus	7.7e+010 N/m^2
	Mass Density	7900 kg/m^3
	Tensile Strength	420507000 N/m^2
	Yield Strength	351571000 N/m^2
Primary suspension	Stiffness	3924000 N/m
	Damping	708711 Ns/m
Secondary suspension	Stiffness	7848000 N/m
	Damping	1002270 Ns/m
Anti-yaw damper	Stiffness	2864000 N/m
	Damping	605500 Ns/m

Table 1: Properties of the coach.

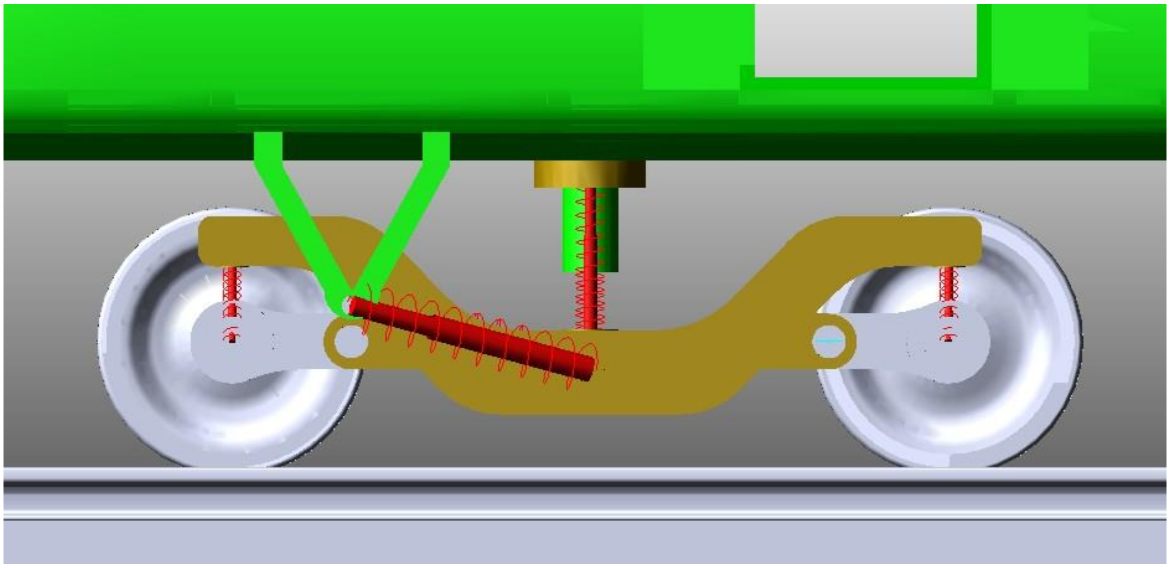

Figure 19: This figure shows all the components attached to the Bogie. View in A dams Software.

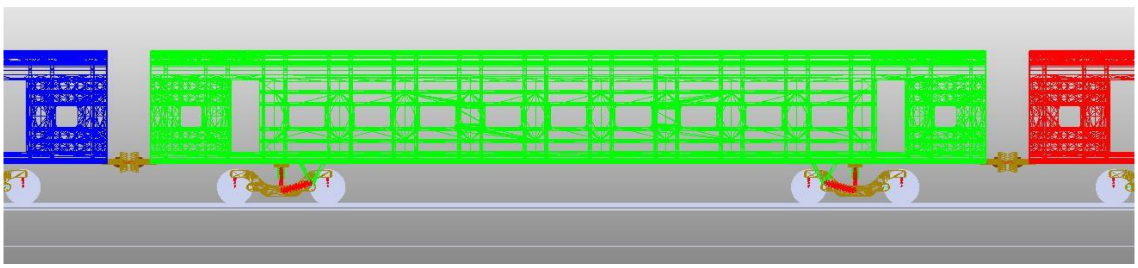

Figure 20: Wire frame view in Adams. It shows coaches, bogies and track all assembled. Red coach is not moving in any simulation.

When a railway accident occur huge amount of kinetic energy is present. This huge energy has to be damped out to reduce damage occurred to the passengers. In this regard, the railway coaches were redesigned to compensate huge energies, these design were again modeled on SolidWorks and imported to Ansys. Notches were created at the ends of the coach near the toilets and rest of the coach is made rigid (as shown in the figure 21). So that the end part will collapse and absorb all the energies.

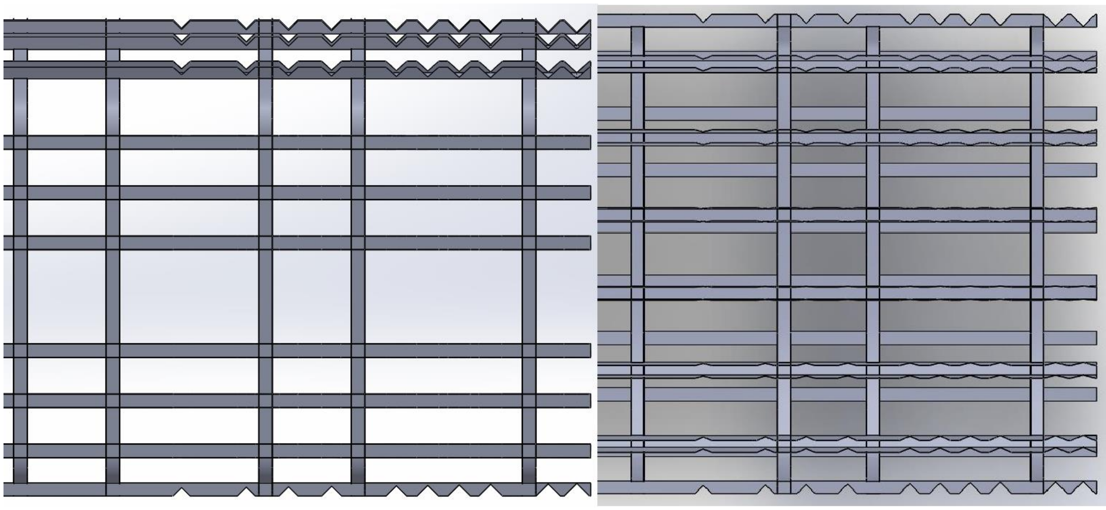

Figure 21: Notches are created at the ends of the frame, so that this frame will collapse and absorb some kinetic energy. Side view (left) and Top view (right).

The assembly for this test is shown in the figure 26. Frame with the only notched part with a solid mass and a wall is assembled. Wall is only 0.1 mm away from the frame.

3.2. Setup for jumping of the coaches

The simulation ran for 5secs in Adams. 3 coaches (Green, blue and yellow) are moving at 40m/s and a red coach is just standing showing the case as it has met an accident and it is stopped. Four bumper design were tested. Starting with the round faced bumpers. Designs are as follows:

- Round faced Bumpers aligned for testing which shows an example of an ideal accident conditions.
- Due to springs and suspensions when accident occur bumpers are never aligned. So in the second case bumpers offset to each other to simulate a worst conditions.
- The third design was then simulated which has straight slots bumpers, which will prevent the coaches from any sliding.
- The last model which a tapered slots was simulated.

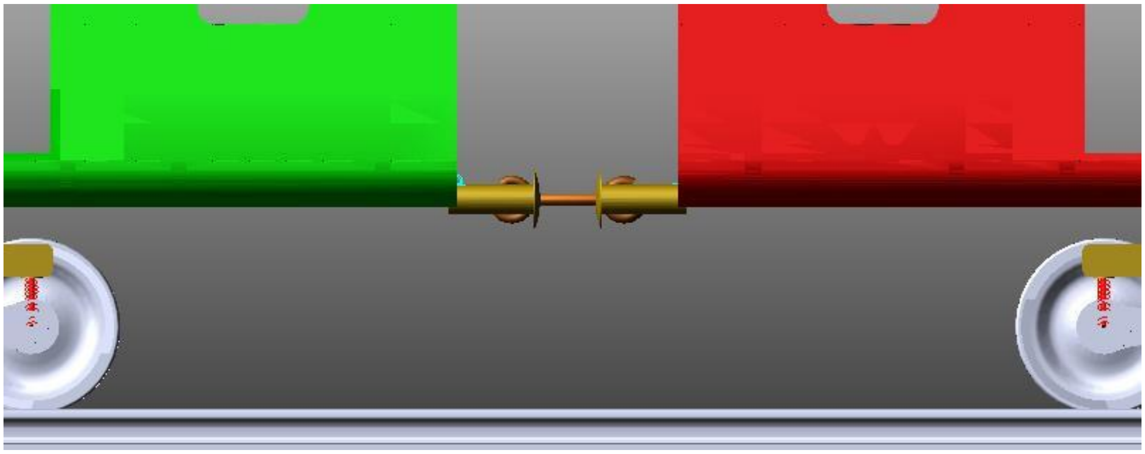

Figure 22: Shows the in-line round faced bumpers.

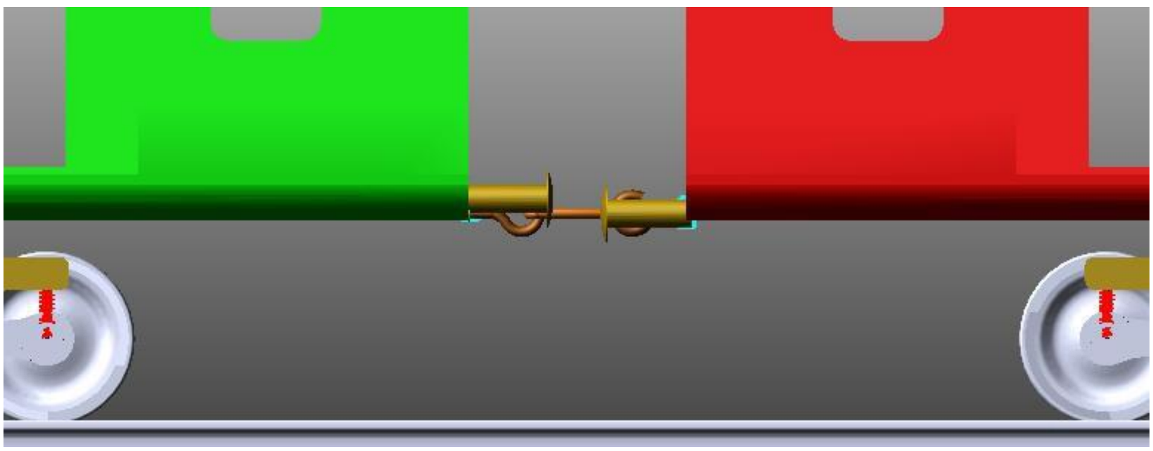

Figure 23: Shows the condition when the bumpers are offset to each other during an accident.

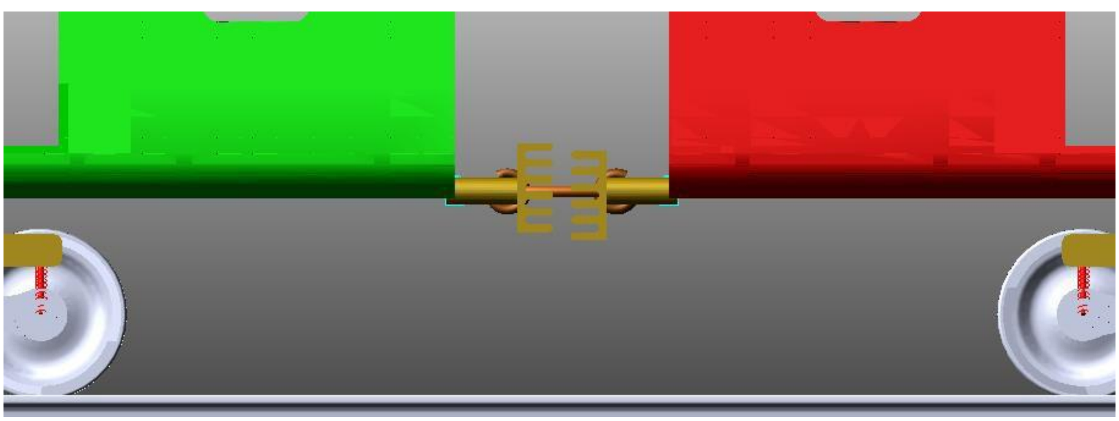

Figure 24: Straight slot bumpers.

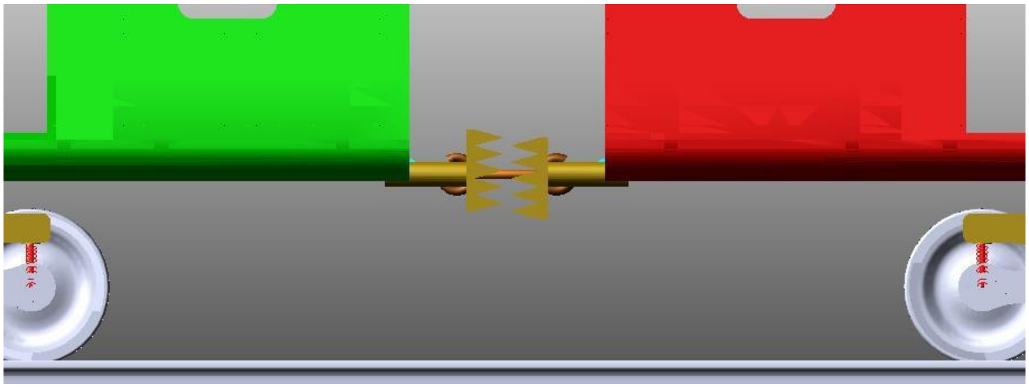

Figure 25: Tapered slot bumpers.

3.3. Setup for energy absorption

A train running at 40m/s has huge amount of energy, if the jumping of coaches has to be stopped this energy has to be damped out. One way to do this is to add a structure which will break and energy will be absorbed. This is done in this simulation. The frame of the train having 32000kg of weight is collided with a static wall in the Ansys workbench. The setup for this simulation is shown in the figure 26 below. To reduce the time of simulation only the toilet part which has the notches is meshed and simulated. The simulation was taking almost 600hrs for simulation of 0.2 sec. So the simulation was run only for 0.01 sec which took around 30+ hrs. Meshing of the frame part is done with the tetrahedral element. Size of the elements was calculated automatically by Ansys depending on the size of notch. For comparison frame with and without notch were simulated.

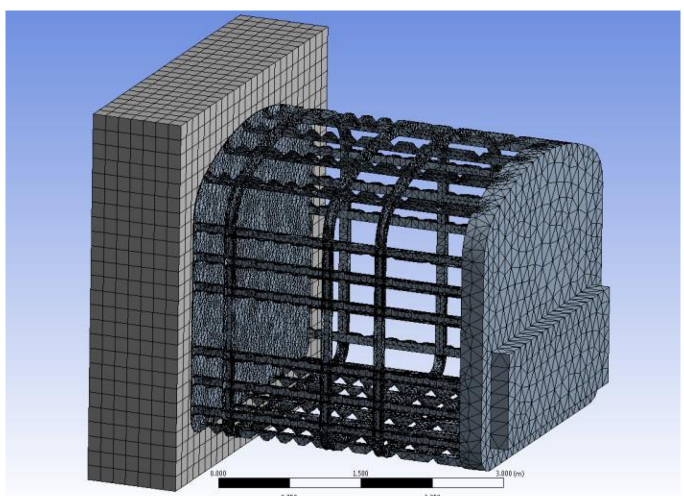

Figure 26: Meshing of the notched end part of the frame is done, which is going to collide with the fixed wall at speed of 40m/s.

Chapter 4. Results and discussions

All simulations were run for 5 sec. The first coach is named as **Coach1** which is red in color. The first coach was standing. Rest 3 coaches were moving in the right direction at 40m/s. The second coach is named as **Coach2** (green) followed by **Coach3** (blue) and **Coach4** (yellow).

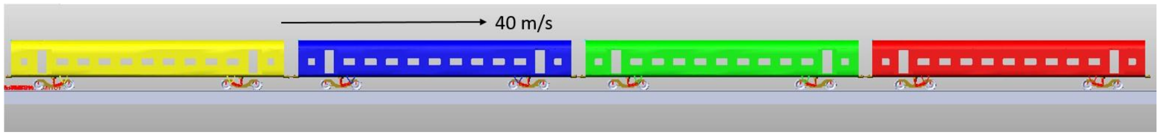

Figure 27: Red coach is the first coach followed by second, third and fourth. Red coach is not moving.

4.1. Simulation for energy absorption

Two frames were simulated. One with actual frame with any deformities and the other is simulated with notches in the frame. A solid mass body is attached at the end of same mass as of a coach. Velocity probes are attached at the corners of the solid mass body. Velocity probe gives the average velocity of four corners.

4.1.1. Frame with no deformities

- At time 6.667 milliseconds the stress are maximum and at this time the frame starts moving backwards.
- Velocity of the solid mass block is reduced to 4 m/s in just 6.667 milliseconds. But all the kinetic energy is stored in the frame. And then solid mass started moving backwards and attains a speed of 41 m/s in just 2 milliseconds.
- The frame behaves as an elastic body, and the solid body bounced back with same speed.

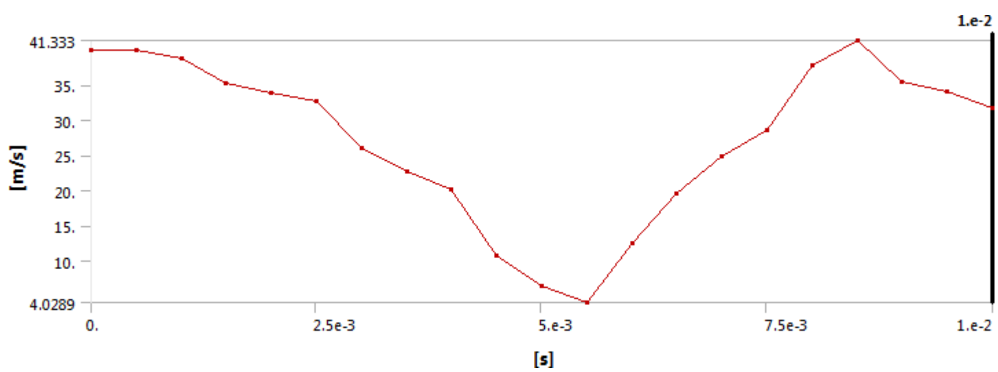

Figure 28: Velocity vs. time graph of the solid mass body attached at the end of the frame without any deformities. (This graph shows the magnitude of the velocities not the direction)

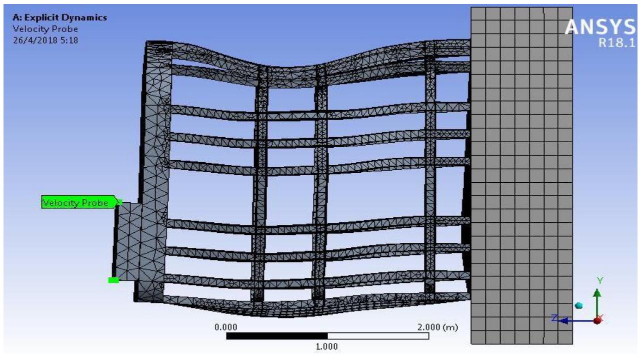

Figure 29: The mass bounces back after the collision with the fixed wall.

4.1.2. Frame with deformities

- At time 7.5 millisecond the speed of the solid mass is reduced from 40 m/s to 16.5 m/s.
- Energy is lost due to the plastic deformation of the notched frame.
- The velocity diagram shows that huge amount of kinetic energy is absorbed due to plastic deformation.

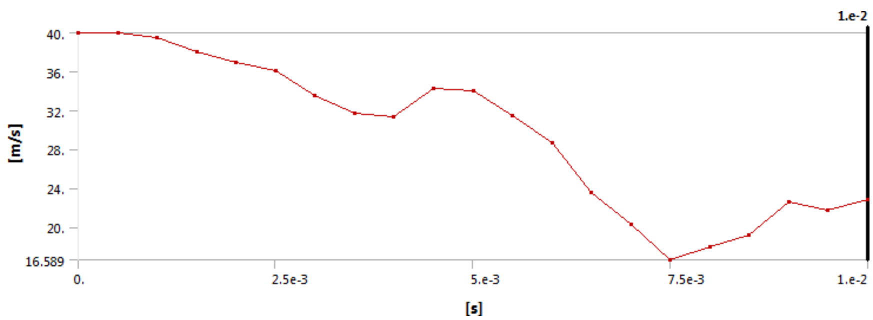

Figure 30: Velocity vs. time graph of the solid mass body attached at the end of the frame with notches. (This graph shows the magnitude of the velocities not the direction)

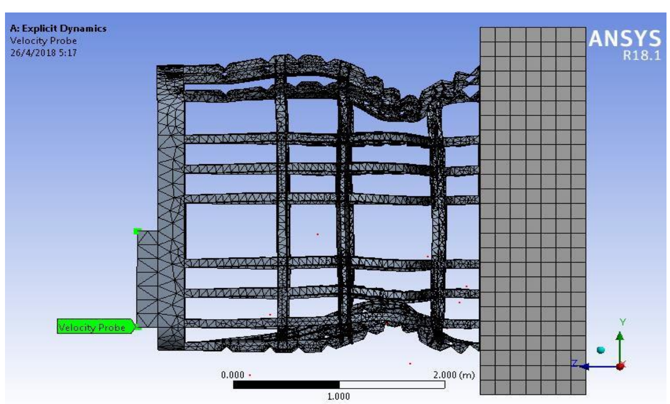

Figure 31: Speed of the solid mass is reduced to 4 m/s due to plastic deformation of the frame.

4.2. Simulation for aligned round bumpers

- First simulation was done for inline round faced bumpers for and ideal case accident. In which the second coach jump was seen to be about than 3meters.
- The velocity of the first coach was increased 42.5 m/s after the first impact. Velocities are damping out slowing. This is happening because the friction between the wheel and ground is taken very less.
- Maximum force due to impact was seen when the coach 2 and coach 3 collided. The magnitude of the force increased to 9th order.

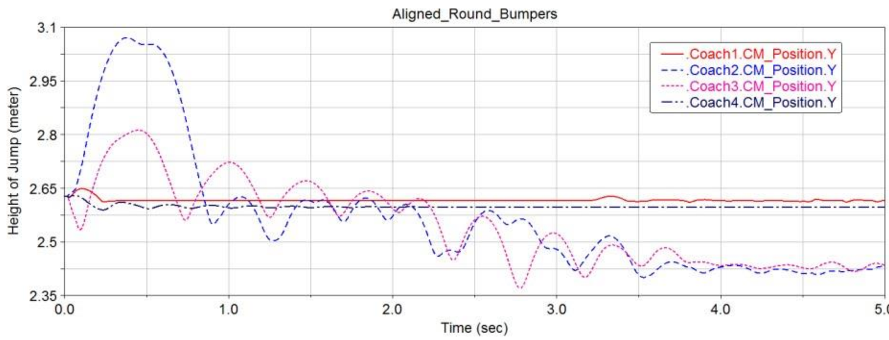

Figure 32: Height vs. time graph of center of mass of coaches for aligned round bumpers.

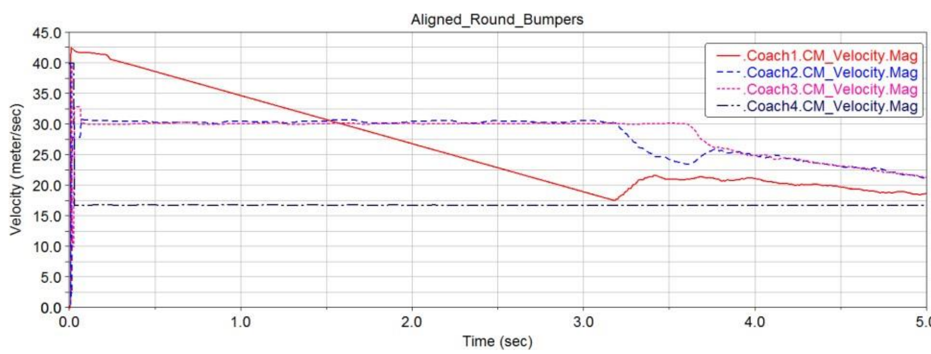

Figure 33: Velocity vs. time graph of center of mass of coaches for aligned round bumpers.

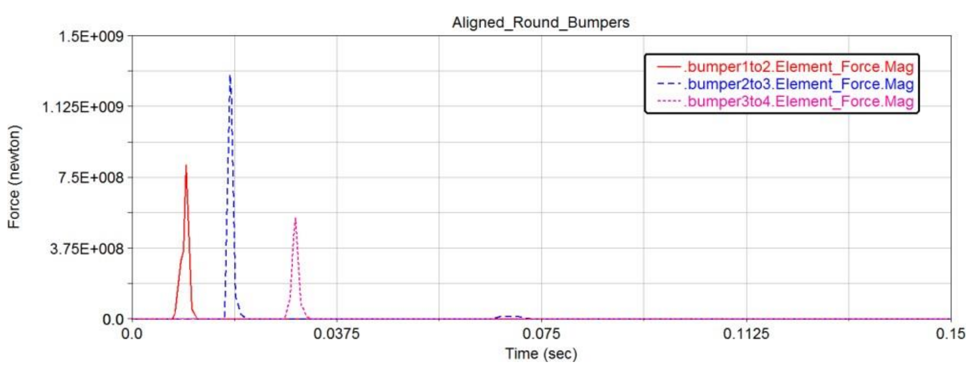

Figure 34: Force vs. time graph of center of mass of coaches for aligned round bumpers.

4.3. Simulation for offset bumpers

- Second simulation was done for offset round faced bumpers which is showing an extreme condition of an accident. Here we a jump of 18m for the second coach and 9m for the first coach was seen.
- Velocity changes is drastic because of many collisions between the coaches and the ground.
- Maximum force induced is of 8th order also only one force component was seen. This is because of jumping. The other bumpers never meet in the time given for the simulation. The force is less here it is because of the interacting geometries. Round faces are offset so it is not a type of head on collision and collision occurs at some angle.

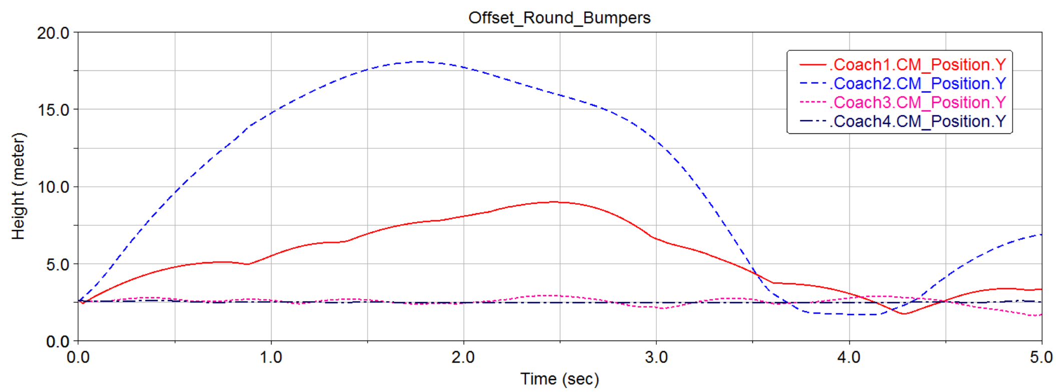

Figure 35: Height vs. time graph of center of mass of coaches for offset round bumpers.

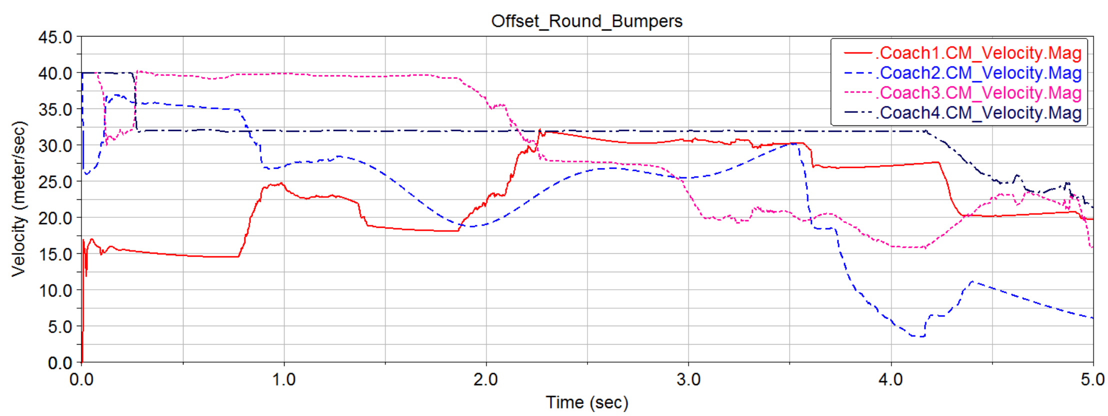

Figure 36: Velocity vs. time graph of center of mass of coaches for offset round bumpers.

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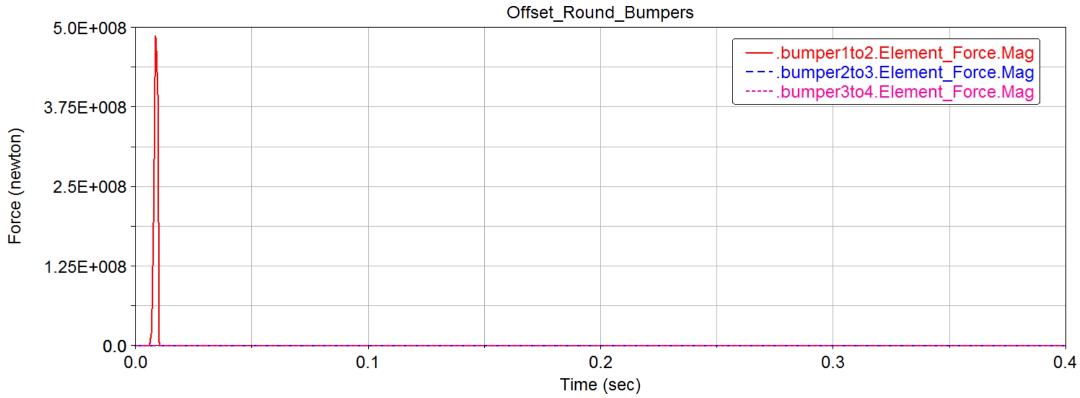

Figure 37: Force vs. time graph of center of mass of coaches for offset round bumpers.

4.4. Simulation for straight slot anti-climbers (bumpers)

- Jump of 3 meter was seen. But in some simulation it was also seen that sometimes straight slot bumpers does not lock because of its geometry.
- Coach 1 is jumping many times that is the reason there is so much fluctuations in the magnitude if total velocities.
- Forces induced are of 9th order which maximum when the first two collided.

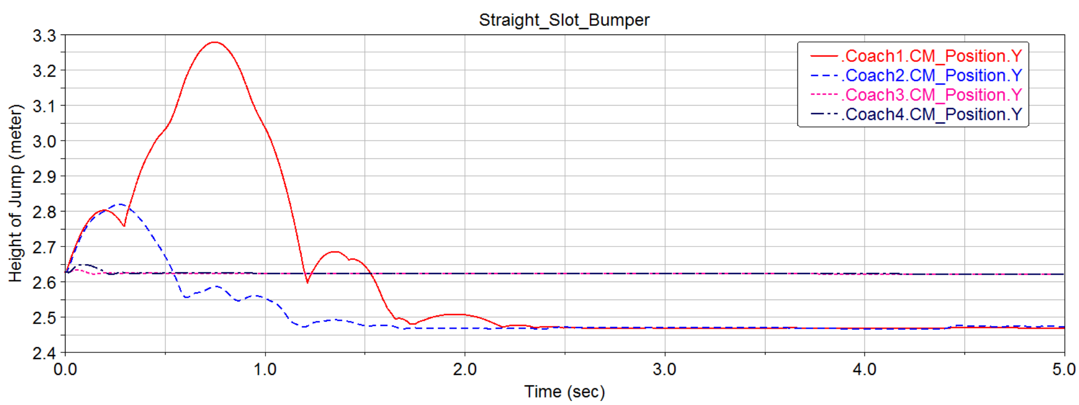

Figure 38: Height vs. time graph of center of mass of coaches for straight slot bumpers.

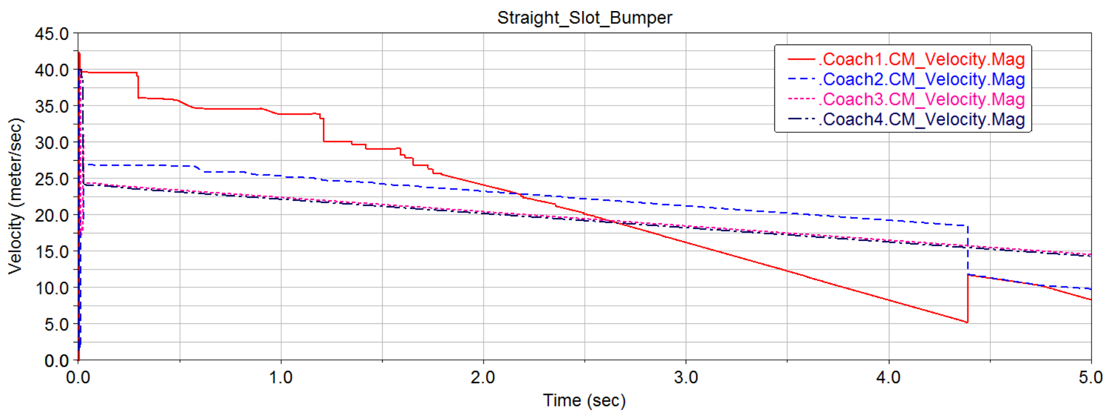

Figure 39: Velocity vs. time graph of center of mass of coaches for straight slot bumpers.

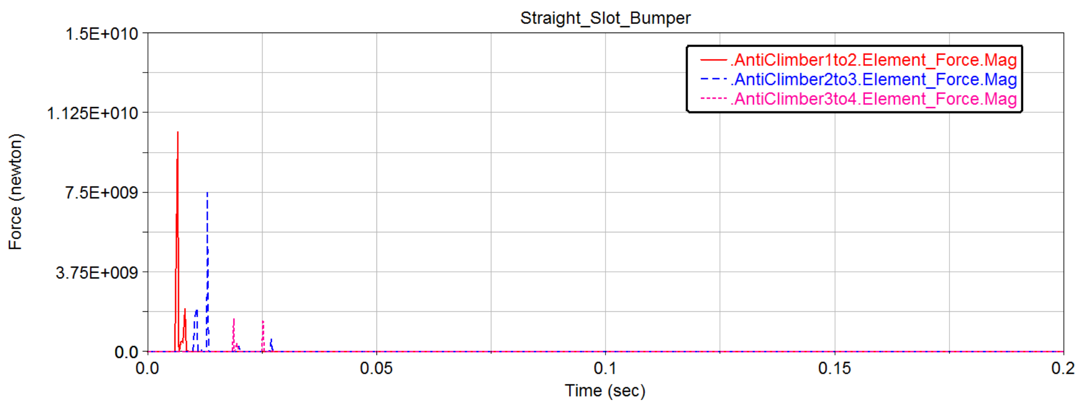

Figure 40: Force vs. time graph of center of mass of coaches for s traight slot bumpers.

4.5. Simulation for tapered slot anti-climbers

- Jump of 6 meters was seen. Due to perfect locking both 1st and 2nd coach jumped together but no climbing was seen.
- Perfect locking can be seen from the velocities graphs. 1st , 2nd and 3rd coaches are moving together with same velocities.
- Forces induced are of 9th order. Also, since the coaches started moving together so such peak force is seen in the collision of 2nd and 3rd coaches and 3rd and 4th coaches.

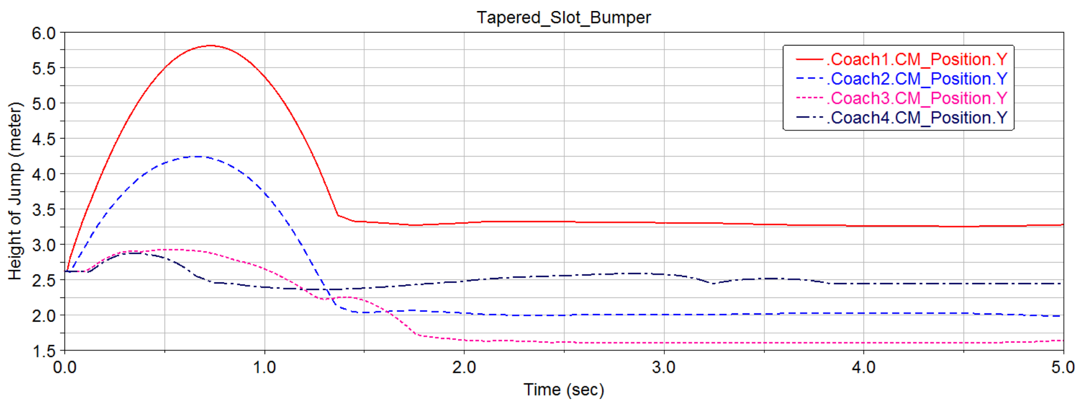

Figure 41: Height vs. time graph of center of mass of coaches for tapered slot bumpers.

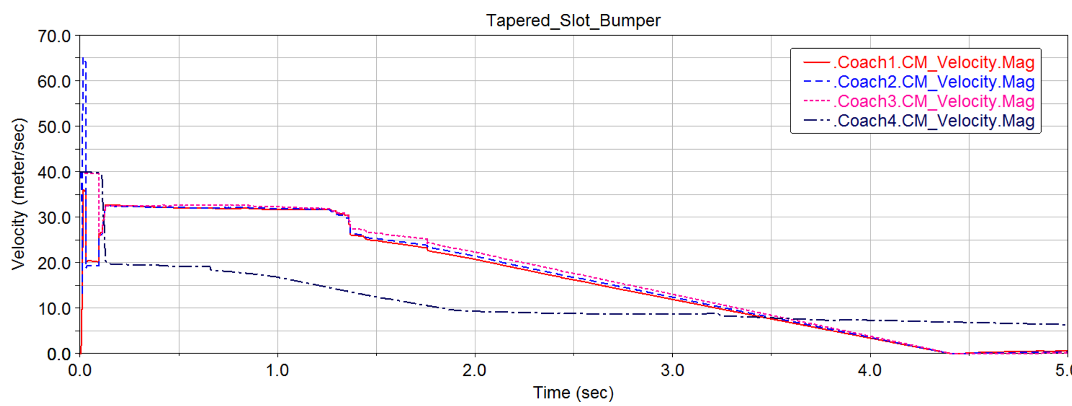

Figure 42: Velocity vs. time graph of center of mass of coaches for tapered slot bumpers.

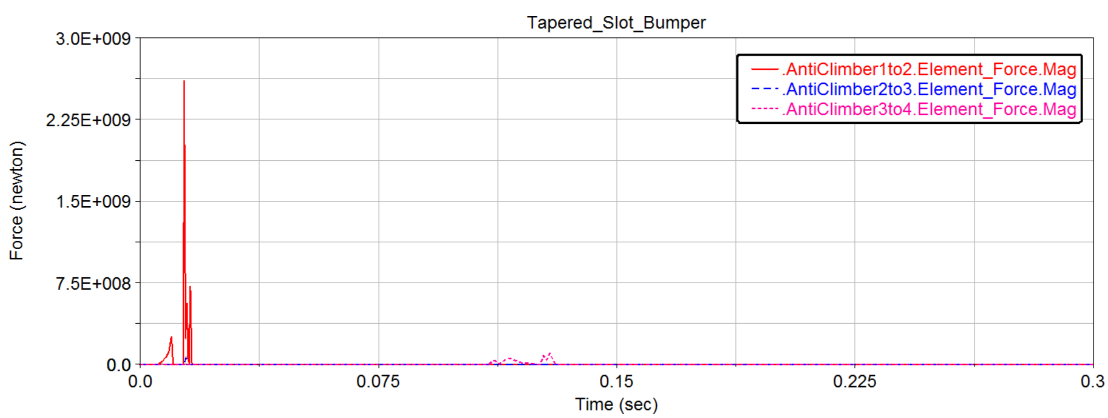

Figure 43: Force vs. time graph of center of mass of coaches for tapered slot bumpers.

Chapter 5. Conclusions

- The simulation for anti-climbers was done only for 4 coaches and for a particular condition where only 3 coaches were moving where the front coach was simply standing. And test was done for energy absorption of the impact and for the anti- climbing mechanism.
- Changes in the frame were done for absorbing energy and bumpers were modified for stopping the coaches from climbing over the other. The energy absorption data was used in Adams view when the coaches were colliding. As a coefficient of restitution.
- When the frame without any deformities collided with the fixed wall it is bounced back with almost same speed showing that the frame is completely elastic and no energy was absorbed in the collision. But, when the frame with notches was used, due to its plastic deformation a lot of kinetic energy was absorbed and the frame was just moving with a velocity of 16 m/s in just 7.5 milliseconds.
- No significant jumping was seen in the aligned round bumpers because bumpers being aligned which will occur only in an ideal condition, which never happens in a collision. Bumpers are always non-aligned due to loading conditions and condition of the wheels and coaches.
- Where as in non-aligned bumpers, which actually happens during a collision, showed the maximum jump. 2nd coach just jumped over the first coach.
- Straight slot bumpers showed good results in some simulation. But in some simulation it did not lock, this happened due to its geometry. Slots of two interfering bumpers did not enters each other. And did not performed as desired.
- The tapered slot bumpers performed well in every conditions. As its geometry was tapered the opening side was very broad as compared to the straight slots bumpers. So the locking was very easy.

Chapter 6. Future Scope

- This works contains only 4 coaches but for better simulations number of coaches can be increased.
- In this simulation only one initial condition was used in which the front coach was not moving and rest coaches were moving at 40 m/s. So, in future other
simulation with different initial conditions can be used like coaches moving in opposite direction towards each other.
- Also one situation can be simulated in which the first coach is derailed and the collision occurred.
- Situation of accidents due to buff and draft is also not discussed.
- Rollover crashworthiness is not discussed in this thesis, which can be done with the same frame design. Further this frame design can be modified according to the boundary conditions.

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