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Study of Bio-Mechanical Injury Criteria and Side Impact Analysis of A-B-C Pillar

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Abstract— **With the advent of better engines and brakes in the present day automotive, accelerations and decelerations are reaching higher rates than ever before, this call for the better means of pedestrian and passenger safety during vehicle collisions. Through this work, an attempt has been made to collect the data and to understand the various categories of Bio-mechanical injury criteria for different types of accidents. In this work a study has been carried out know the different injury criteria, the descriptions of the injury criteria, the applicability of the same in various situations of vehicle collision. A brief description of the evolution of the methods of gauging the injury criteria and also calculating the same are presented in the work. The various real life obstacles and the effects of the collisions with the same are to be studied for enhancing the occupant safety, for the different types of impacts during a collision, the side impact has been proven to be of higher risk than other modes of impacts. A study has been carried out to know the behavior of the vehicle under side impact of the rigid pole is being simulated using LS-DYNA. The various non-linear deformations under transient dynamic impact loads are simulated for the meshed discretized model. The impact at critical location of the car body, at the A-pillar, B-Pillar and the C-Pillar are the three impact locations under study. The deformation results and its behaviors along length of the vehicle are brought out in terms of resultant contact forces, accelerations, deformations energy plots. The comparison of nature and extent of damage along the vehicle side are presented for the velocity and the obstacle. Finally, the locations of maximum intrusion and its effects on the passengers are discussed.**

Keywords—A-B-C Pillar; Injury Analysis; Impact Analysis

I. INTRODUCTION

The ultimate measure of crashworthiness will be expressed in terms of the resulting injury risk exposure of the occupants & their survival prospects. Injury criteria biomechanics deals with the effect of mechanical loads on the human body in a particular impact loads. In response to mechanical load, a body's specific region will undergo mechanical & physiological changes; this is called the Biomechanical response. It is typically compared with the capacity of the body parts to withstand these forces, mainly the body parts results from contact with the interior of the vehicle. If the contact surface is soft the coupling period is long and if the contact surface is hard the coupling period is short. The velocity at which an occupant impacts the interior surface is called body part velocity differential. Mechanics of Injury in a vehicle collision there are three basic impacts Primary impact is the vehicular collision, secondary Impact is body or body part collision with the vehicle interior. Tertiary Impact is organ collision with in the body i.e., when soft tissue is crushed by the decelerating skeletal structure inside the body. For better understand again the injury is distinguish between blunt injury & penetrating injury. Some of injury criteria, its situations, measurements & developments are

- Head Injury Criteria (HIC)
- Neck Injury Criteria (NIC)
- Chest Injury Criteria (CIC)
- Femur Injury Criteria (FIC)

Aim of the work: The aim of this research is to design, analyze and validate the A-B-C Pillar under the initial velocity of 40kmph, 60kmph & at 80kmph to evaluate the intrusion levels. In this work simulation of the pole impact analysis of a car at the given locations of A-pillar, B-pillar & C-pillar using LS-DYNA and the analysis is performed on a vehicle moving laterally into a 255mm diameter rigid pole at the mentioned locations at a relative velocity of 30 km/h. Due to the impact, crash energy absorption characteristics at the different locations were analyzed and the results were discussed.

II. GEOMETRIC MODELING OF A-B-C PILLAR

Automotive design is a highly experience based process which usually requires a manufacturing practice to design quality parts and it is a tedious and time consuming task. The modeling is done using Catia V5R20 with the help of standard dimensions that we got through the careful review. Figure 1 is the model of the Car assembly with A-B-C-Pillar which is created using the Catia Software.

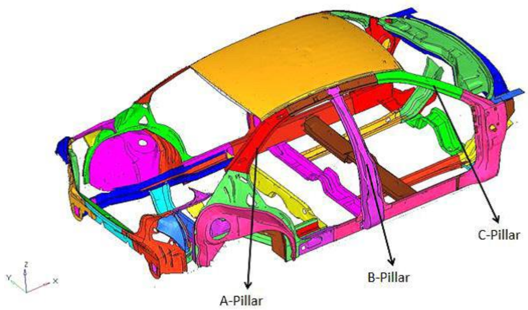

Figure 1 Car assembly model

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III. FINITE ELEMENT MODELING AND PREPROCESSING

The geometric model is converted into a Finite Element Model, selection of element type, assumption of loading and boundary condition are discussed in further coming chapter.

Initially the given meshed model of the car is imported in the HM Environment. Then for the simulation of the side impact analysis rigid pole of diameter 255mm to a length of 2145mm is created using shell elements at the mentioned location as shown in the figure 2.

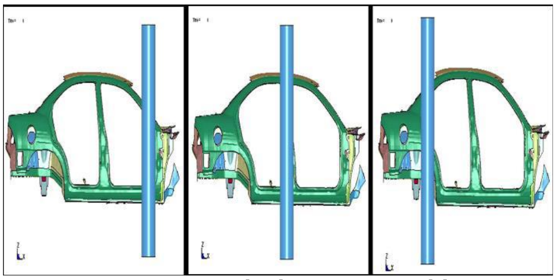

Figure 2 Car and Pole interaction model

IV. DEFINING MATERIAL PROPERTIES AND BOUNDARY CONDITIONS

Material selection: After modeling, the material & its properties are to be assigned for all the components of the car model. Selecting the material is very important step because depends on the material property the behavior of the components can observed. Therefore a linear elastic material MAT20 is updated to the respective components. Similarly MAT24 updated to the rigid pole member &the properties like density, young are modulus, passions ratio, yield stress and etc. are assigned. From the given data set, the material properties of the non-linear range are also updated by inputting the stress-strain values. During side impact, the components undergo deformation. Therefore the deformation pattern is predicated with reference to the stress-strain curve.

Loading condition: A key part of the analysis involves determining the type of loads acting on a structure. In this work, a load collector by a card image as initial velocity is defined to the whole vehicle structure at a speed of 30kmph.

Boundary Conditions: It is very important for the simulation, to check out the behavior of the vehicle, compared with the real world situation. It is the region of interest in which we conduct a simulation. Therefore pole is considered as a rigid, so it is constrained in all degrees of freedoms. Then by contact interface command, defining the contact characteristics of car & pole is assigned in the form of master & slave, by selecting the single surface contact. Then by creating a force collector, an interface force transducer card image is created & assigned to the selected entity sets of the master & salve nodes of the vehicle structure by using box option, recalling the set ID's in the SBOXID & MBOXID.

V. SOLVER AND POST PROCESSOR

For the simulation of the side impact analysis of the car model, initially input deck file i.e., .k file is solved by using LS-DYNA solver. Before solving it writes all the important messages like errors, warnings, failed elements, nodes penetration, contact problems etc.; in the output window & to the D3HSP file. By sense switch controls i.e., SW2 the actual values of the global statistics can be seen in the output window. The behavior observed in the vehicle structure is discussed with the help of graphs shown in next chapter.

In the post processor, the side impact analysis of car model is simulated using LS-DYNA postprocessor. Mainly the solver generates d3plot file, which is imported in study of bio-mechanical injury criteria and side impact analysis of A-B-C pillar the spots to study the simulation of side impact analysis of a car model when it hits to a rigid pole.

VI. DESIGN REQUIREMENTS OF A-B-C PILLAR

This work presents an analytical study of the behavior of the fixture/work piece system under the action of road load conditions. A key aspect of developing a product is the design stage in which ideas for a product must be generated and evaluated. This can be a lengthy, complex, and often iterative affair involving many phases. Concentrate on developing an approach for assisting the unit design phase of fixture design. The aim is to generate complete fixture designs that fully detail the physical structure of the locating/clamping units based upon an understanding of the required function of each unit. The main fixture design considerations are from the graph we can observe that the resultant contact force is very low till 0.05 sec, this is due to the force required to contact Thereafter we can observe an increase in the resultant contact force, this rise in force is due to the resistance offered by the structural components, which causes deformation in the body parts. This process continues till complete deformation takes place.

VII. RESULTS AND DISCUSSIONS

DISCUSION OF A-PILLAR RESULT

Resultant Contact Force

Figure 3 shows the Resultant contact force at A-Pillar vs Time of slave & master over a period of impact. From the graph we can observe that the resultant contact force is very low till 0.05 second, this is due to the force required to contact Thereafter we can observe an increase in the resultant contact force, this rise in force is due to the resistance offered by the structural components, which causes deformation in the body parts. This process continues till complete deformation takes place. The peak resultant force of magnitude of 17.2 KN occurs at 0.026 s. This variation is due to the buckling of car structure when an impact occurs.

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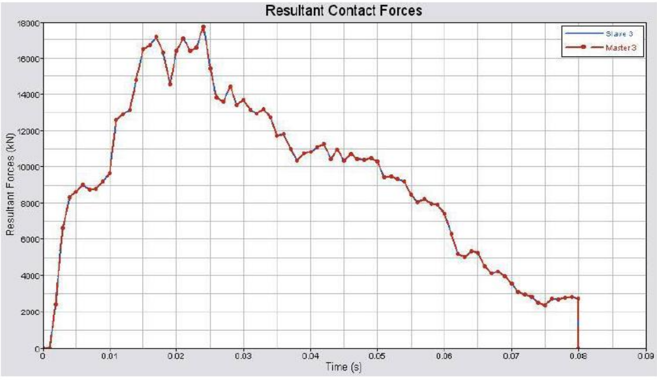

Figure 3 Resultant contact force at A-Pillar vs Time

Resultant Acceleration Force

From the Figure 4 we can see the variation of resultant acceleration of A-pillar over a period of impact and the acceleration force is max at the top side of the A-Pillar which is of magnitude mm/s^2. At the initial impact stages change in rate of velocity is high and hence acceleration is also high. As it reaches peak acceleration the components under deformation beyond its elastic limit, indicates the failure of the outer components. As the deformation progresses, rate of change of velocity decreases with decreases in the acceleration due to absorption of more energy from the internal components & slowly comes to zero when car stops. Hence high priority should be given to reduce the peak acceleration value for the safety of the driver.

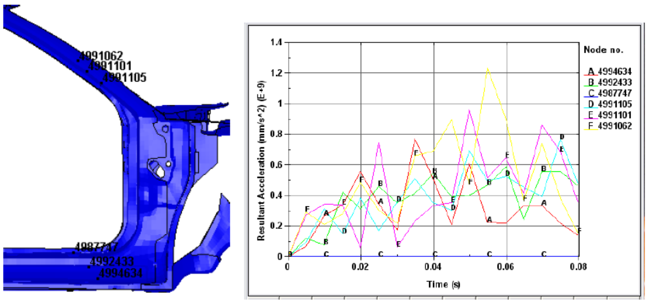

Figure 4 Resultant contact force at A-Pillar vs Time

Displacement along Y-axis

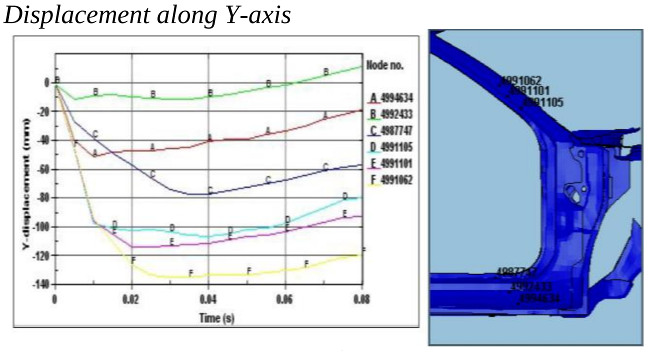

Figure 5 Variation of Y-displacement

Figure 5 shows the variation of Y-displacement at different location. From the intrusion level we can see the maximum deflection at the top of the A-pillar compare to lower location which is of magnitude 140 mm inside the passenger compartment, this cause severe injury to driver in case of side impact. Therefore the intrusion levels should be minimized in order to prevent injuries mainly head injuries.

Displacement along Z-axis

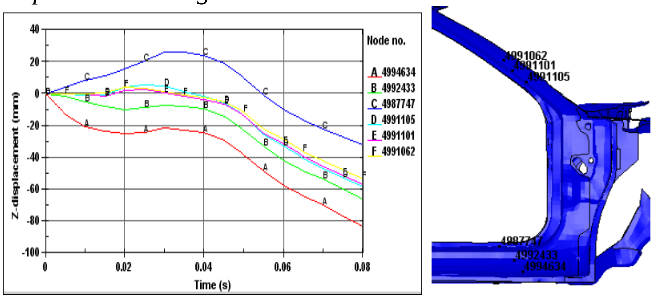

Figure 6 Variation of Z-displacement

From the Figure 6 we can observe the variation of Z-displacement over a period of impact. The intrusion level in this graph s shows the deformation does not cause much more harm to the driver compared to Y-deformation.

Energy Plots

Figure 7 shows the kinetic energy, internal energy & total energy observed & transferred due to the impact. Kinetic energy at the point of contact or impact is high & thereafter as the car under goes on crushing, the kinetic energy goes on reducing. During collision the kinetic energy is converted in to various forms, which is absorbed by the internal components contributing to its internal energy. The total energy in the graph represents the summation of kinetic energy & internal energy. Therefore the components have to be designed in such a way that it absorbs more & more energy during impact.

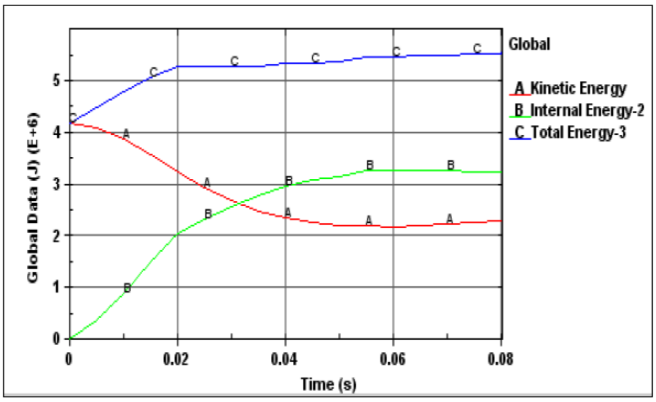

Figure 7 Energy Plot

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DISCUSSION OF B-PILLAR RESULTS

Resultant Contact Force

Figure 8 Resultant contact force at B-Pillar vs Time

Figure 8 shows the resultant contact forces at B-pillar Vs time for the selected slave & master entities over a period of impact. We can observe that the peak resultant forces of magnitude 17.2kN at 0.015ms. Then we can observe the decrease in the resultant contact force in the range of magnitude 10 kN to 14 kN at 0.018ms to 0.078 ms, this is due to the resistance offered by the B-Pillar which causes deformation in the body parts to its elastic limit. This process continues till complete deformation takes place, here forces are not zero as analysis is carried out only for 80 milli-seconds

Resultant Acceleration Force

Figure 9 shows the acceleration Vs time for the B-pillar at selected points. At point 4993085 & 4993210 the acceleration forces are more i.e., 2.2 mm/s^2, this is due to initial impact stage as the change in rate of velocity increase, the acceleration also increases, at peak acceleration, the deformation of the components will be more, as it cross its elastic limit. The relative velocity will also decrease which causes decrease in the acceleration also.

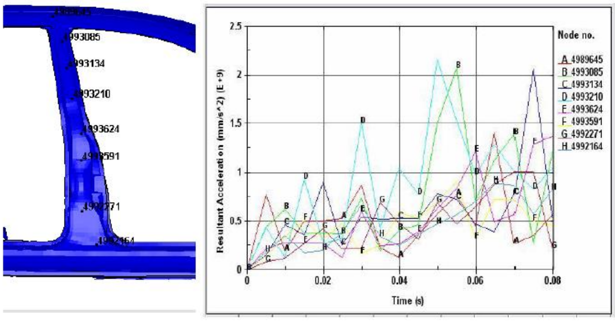

Figure 9 Resultant Acceleration force at B-Pillar vs Time

Displacement along Y-axis

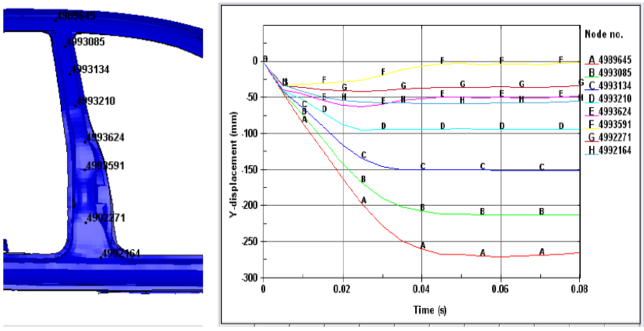

Figure 10 Variation of Y-displacement

Figure 10 shows the Y-displacement Vs. Time at the selected points. At point 4989645 the displacement is maximum of magnitude 275 mm inside the passenger compartment at the top of the B-pillar, which is higher than the A-pillar deflection. This is mainly due to material nonlinearity. The intrusion levels should be minimized in order to prevent injuries mainly head injuries.

Displacement along Z-axis

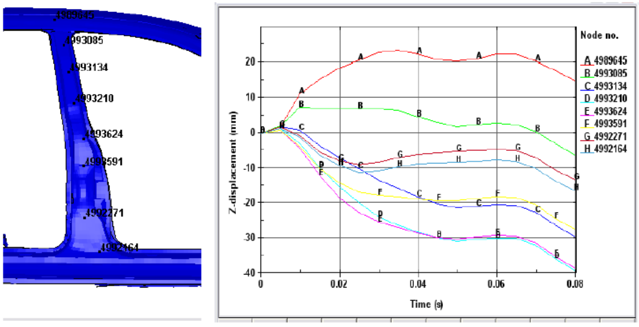

Figure 11 Variation of Z-displacement

Figure 11 shows the Z-displacement Vs. Time over a period of impact. The deformation observed is very less compare to Y-displacement, this is due the force acting in lateral direction i.e., in Y-direction. The intrusion level shows that it does not cause much harm to the occupants

Energy Plot

Figure 12 shows the kinetic energy, internal energy & total energy Vs time over a period of impact. Due to the impact the kinetic energy will be high of magnitude & gradually decreases when the deformation takes place.

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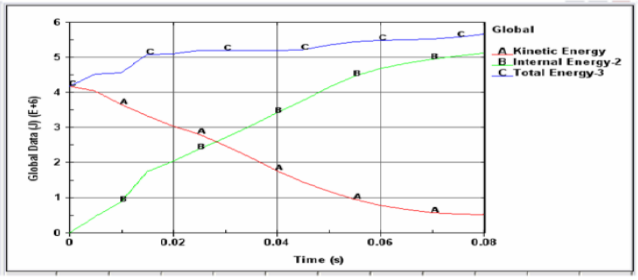

Figure 12 Energy Plots

This is mainly due to the transformation of energy to the internal components, which absorbs & results in the internal energy which is vice versa to the kinetic energy. The total energy from the graph shows the summation of kinetic energy & internal energy.

DISCUSSION OF C-PILLAR RESULTS

Resultant Contact Forces

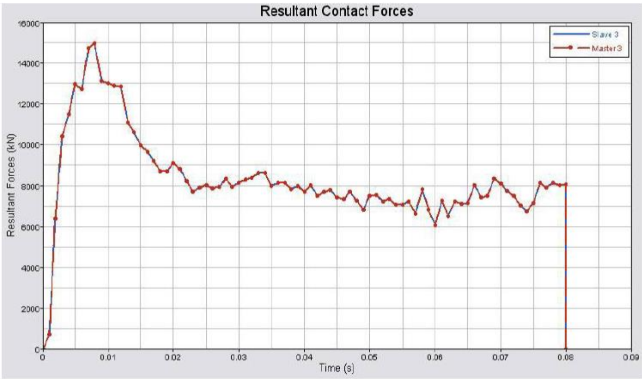

Figure 13 Resultant contact force at C-Pillar vs Time

Figure 13 shows the resultant contact forces at C-pillar Vs. time for the selected slave & master entities over a period of impact. We can observe that the peak resultant forces of magnitude 15 kN at 0.005 ms. Then we can observe sudden decrease in the resultant contact force in the range of magnitude 13 kN to 8 kN at 0.012 ms to 0.08ms, this is due to the resistance offered by the C-pillar which causes deformation in the body parts to its elastic limit. This process continues till complete deformation takes place.

Resultant Acceleration Force

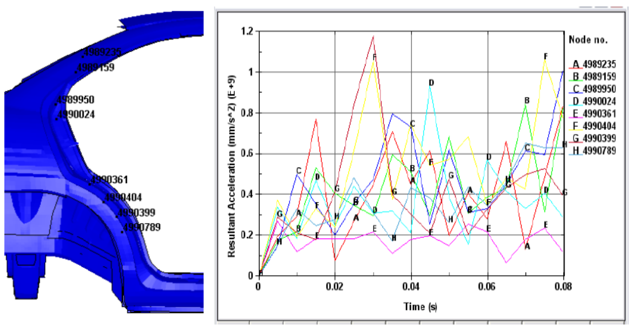

Figure 14 Resultant acceleration force at C-Pillar vs Time

Figure 14 shows the acceleration Vs time for the C-pillar at selected points. At point 4990404 & 4990399 the acceleration forces are more i.e., 1.1 mm/s^2, this is due to initial impact stage as the change in rate of velocity increase, the acceleration also increases, at peak acceleration, the deformation of the components will be more, as it cross its elastic limit. The relative velocity will also decrease which causes decrease in the acceleration also.

Displacement along Y-axis

Figure 15 shows the Y-displacement Vs time at the selected points. At point 4989235 the displacement is the maximum of magnitude 180 mm inside the passenger compartment at the top of the C-pillar, which is higher than the B-pillar deflection. This is mainly due to material nonlinearity.

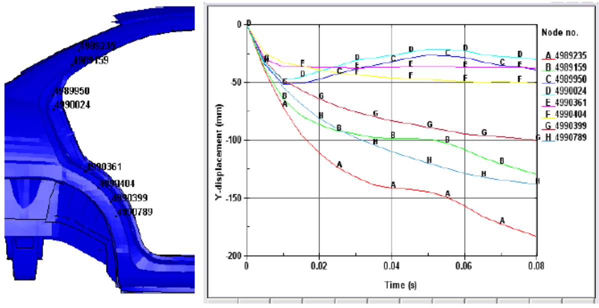

Figure 15 Variation of Y-displacement

Displacement along Z-axis

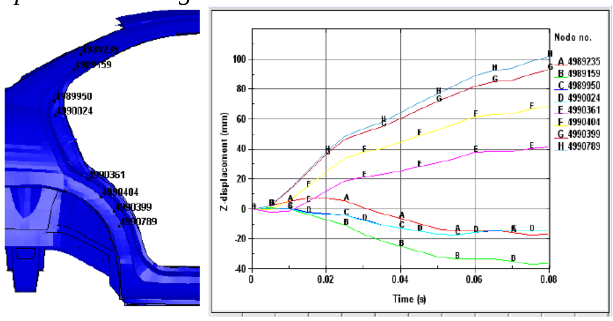

Figure 16 Variation of Z-displacement

Figure 16 the Z-displacement Vs time of C-pillar over a period of impact. The deformation observed is very less compare to Y-displacement, this is due the force acting in lateral direction i.e., in Y-direction. The intrusion level shows that it does not cause much harm to the occupants

Energy Plot

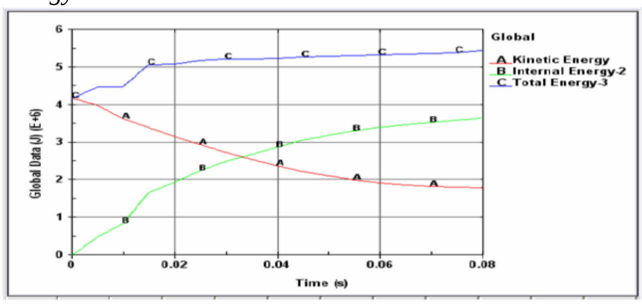

Figure 17 Energy plots

Figure 17 the variation of energy levels of C-pillar over the period of impact. Due to the impact the kinetic energy will be high of magnitude & gradually decreases when the deformation takes place. This is mainly due to the transformation of energy to the internal components, which absorbs & results in the internal energy which is vice versa to the kinetic energy. The total energy from the graph shows the summation of kinetic energy & internal energy.

Intrusion levels of A-B-C Pillars

Table 1 Intrusion levels of A-B-C Pillars

Description	A-Pillar	*B-Pillar*	*C-Pillar*
Resultant contact forces (KN)	17.2	17.2	15
Acceleration (mm/s^2)	1.2x10^9	2.2x10^9	1.1x10^9
Y-Displacement	140	275	180
Z-Displacement	80	40	100
Impact Energy (J)	4.2x10^8	4.2x10^8	4.2x10^8

VIII. CONCLUSION AND SUGGESTIONS

From the above summary of results, it shows that the maximum intrusion level is in B-pillar along Y-direction compare to A-pillar & C-Pillar. Due to the side impact of a B-Pillar, the elongated member extended between the door front end & door rear end in the space frame defined by door outer & door inner panel of the vehicle is being deflected towards the inside of the vehicle at the driver position at one end & to occupant position at the other end. Due to deflection towards the inside causes severe injury to the occupant or to driver, which leads to Head injury, abdominal injuries or pelvis injury. The maximum intrusion allowed into the passenger compartment is 150 mm. since the resultant forces & acceleration for B-pillar is more, which results in the movement of the driver & occupant leads to hit the side wall of the car during collision.

Based upon the results obtained many modifications can be done to overcome the problems caused. Here below some suggestions are listed based upon the above summary of results.

- A detection sensor for the detecting information about the displacement and the displacement speed of the setting area relative to a vehicle body is integrated to minimal the risk injury at the driver & occupant position.
- By providing the side air bags on the roof rails, severity of the injuries can be prevented.
- By providing high Stiffeners & increasing the thickness of the B-pillar can reduce the energy absorption.
- By increasing the free space in the design of passenger compartment along the width side of the vehicle
- By using the alternate composite material, which can absorb more energy compare to other material.
- An acceleration sensor for sensing the lateral acceleration of the vehicle; wherein the determination unit is configured to make a crash determination based on information received from the deriving unit.

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