

Design optimization of side impact beam for higher energy absorption characteristics



^{#1}Radha Krishna Nemani, ^{#2}Dr. Rachayya Arakerimath

¹ME Mech Student, Alard College of Engineering and Management, Pune, India

²Guide, G H Raisoni College of Engineering and Management, Pune, India

ABSTRACT

Side impact collisions are the second leading cause of death and injury in the traffic accidents after frontal crashed. Side impact beams are used in the doors to absorb the impact energy and reduce depth of door intrusion, thus help protect the occupant. In a full vehicle test of side impact against a pole, the intrusion characteristics of the complete door assembly are assessed. 'Side impact beams' plays a major role in the behavior of the complete door assembly. In this work, three different cross-sections of the side impact beam are considered. FEA models have been developed to perform three point bend test (quasi-static load test). All investigations are performed using LS-DYNA explicit finite element code. The energy absorption characteristics of different designs are assessed and compared. Optimized parameters are determined by using Taguchi method. Optimal design of 'side impact beam' which is best performing for anti-intrusion is determined.

Keywords— crashworthiness, design optimization, side door beam, side impact, taguchi method.

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I. INTRODUCTION

Traffic accidents are one of the leading causes of mortality in modern society. Car safety becomes the most important issue immediately in the development of the automobile. Injuries due to road accidents are a problem that can be controlled considerably if adequate attention is given to accident and injury prevention strategies. Therefore, car manufactures now incorporate a wide range of passive safety devices and feature into their vehicles, including airbags, energy-absorbing steering columns, side door beams, etc. Notably, side impact collisions are the second leading cause of death and injury in the traffic accidents after front crashes. Unlike a frontal collision, side-impact collisions are particularly dangerous; that is, the space between an occupant and the side of the vehicle is minimal. There are bumpers, engine and so on to help absorb the energy of the impact in a frontal impact. Hence, occupant has very little protection when a vehicle is struck on its side.

To develop a sage and effective passive safety devices are essential for reducing occupant injuries in a side-on crash^[1].

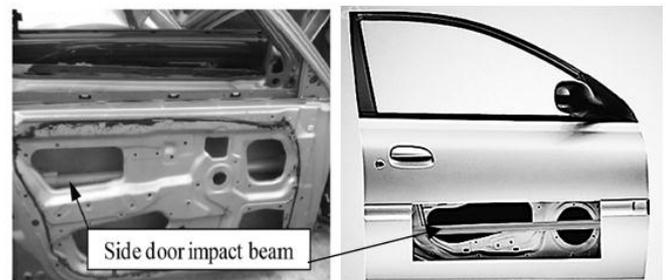


Figure 1: 'Side Door Beam' In Vehicle Front Door^[1]

During the test of side impact against a pole, a car is fixed on the special carriage and is pushed against stationary fixed pole at the speed of 29 km/h. The car with a dummy in driver's seat is directed towards the pole in such way, that it were in one plane with driver's head. The 254 mm diameter pole during the impact intrudes into the car cabin. ^[1, 11]

Vehicles safety is characterized by various tests and regulations, but none of them defines strength characteristics of side doors anti-intrusion beams. To determine the anti-intrusion behaviour of the side door beam, a static load test is to be performed as shown in below image. [1]

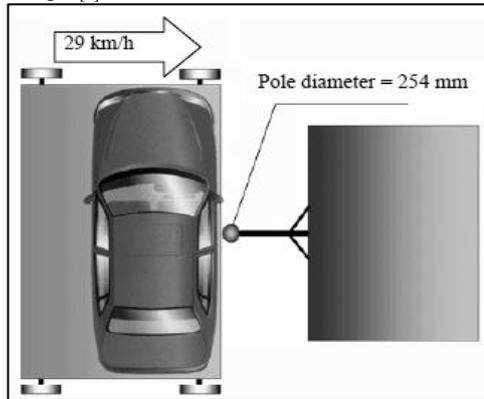


Figure 2: Test Of Side Impact To The Pole, According To Euro-NCAP[1, 11]

A three point bend test of the side-door beam punched with a rigid pole was set up. The numerical simulations were carried out using the software LS-DYNA. The design variables are material and cross section of the side door beam. Attention was focused upon finding an optimum cross- section shape of the beam in order to improve the energy absorption character.[1]

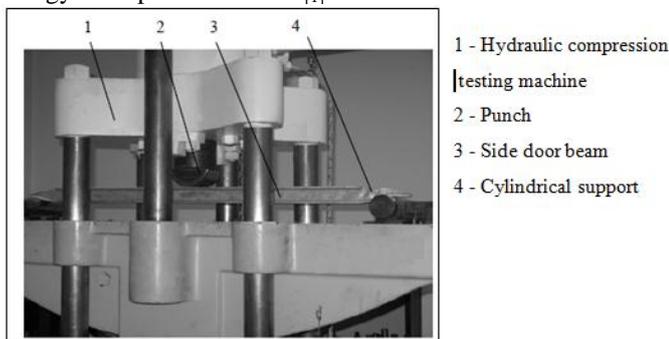


Figure 3: Beam Anti-intrusion Characteristics Testing Equipment[1]

II. PROBLEM STATEMENT

A. Problem Statement:

Occupant has very little protection when a vehicle is struck on its side. Vehicles safety is characterized by various tests and regulations, but none of them define strength characteristics of side doors anti-intrusion beams. Different designs of side door beam exist in current cars, which have different energy absorption characteristics. By performing a three point bend test (static load test), the anti-intrusion behaviour of the different designs is to be assessed and compared. The possibility to design a new side door beam with improved energy absorption characteristics is to be explored with material and cross section as design variables.

B. Objective:

The objective is to perform a three point bend test (static load test) on side door beams with different cross-sections to:

1. Identify the design (cross-section) of side door beam with best specific energy absorption characteristics.
2. Identify the material with higher energy absorption characteristics
3. Identify the sensitivity of the side door beam to magnitude of load and punch location.
4. Design a new side door beam with improved specific energy absorption characteristics.

C. Expected Outcome:

A new side door beam with

1. Minimum Weight
2. Improved Specific Energy Absorption
3. Improved Stiffness

III.METHODOLOGY

D. Taguchi Methods

Dr. Genichi Taguchi is a Japanese statistician and Deming prize winner who pioneered techniques to improve quality through robust design of products and production processes Taguchi describes a continuous Loss Function that increases as a part deviates from the target, or nominal value. The Loss Function stipulates that society's loss due to poorly performing products is proportional to the square of the deviation of the performance characteristic from its target value [13].

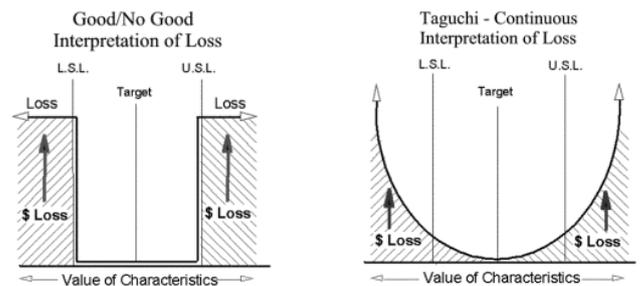


Figure 4: Loss Function, Traditional vs Taguchi[13]

1.) Definition: Taguchi has envisaged a new method of conducting the design of experiments which are based on well-defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameter. [13]

2.) Designing an Experiment by Taguchi Method

The design of an experiment involves the following steps

1. Selection of independent variables
2. Selection of number of level settings for each independent variable
3. Selection of orthogonal array
4. Assigning the independent variables to each column
5. Conducting the experiments
6. Analyzing the data
7. Inference

E. Simulation Setup Overview:

Side impact beam is modelled with 1 order shell elements, element formulation-16 (Fully integrated shell).

The Loadcase set up used in FEA simulation used to determine the anti-intrusion behaviour of the side door beam:

1. The side door beam is supported on 2 rigid cylinder supports of 40 mm diameter. They are constrained in all 6 degrees of freedom.
2. The side door beam is connected to the support cylinders by ‘Extra Node option’, to simulate the welding.
3. A punch of diameter 100 mm is used, which intrudes into the side door beam. It is fully constrained in other 5 degrees of freedom.
4. Surface to Surface Contact is defined between
 1. ‘Punch’ to ‘Side door beam’
 2. ‘Cylinder supports’ to ‘Side door beam’

Uniform punch speed of 2.0 mm/ms

X3 : Location of Load

Three different loading conditions are considered in this evaluation. The location of the intruding ‘Punch’ from one end of the ‘Side door beam’ is varied as listed below.

Profile number and punch distance from one end of ‘Side door beam’		
1	2	3
300 mm	375 mm	450 mm

X4 : Cross-section details

In this evaluation three different cross-sections of the side door beam are considered (Circular, Hat shape, M Shape).

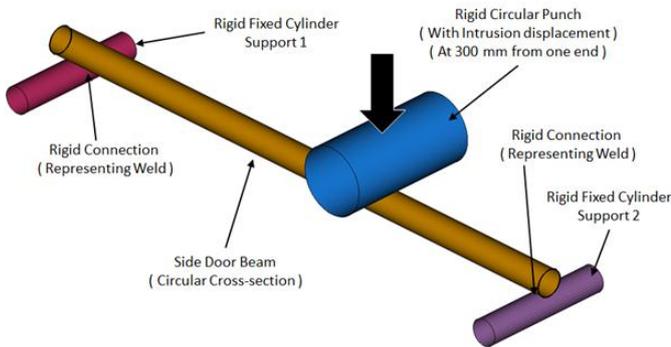


Figure 5: FEA Loadcase to Determine Characteristics of Side Door Beam

Profile number and cross section at centre		
1	2	3
Circular Shape	Hat Shape	M Shape
Thickness is 2 mm in all designs. Column Length is 900mm in all designs		

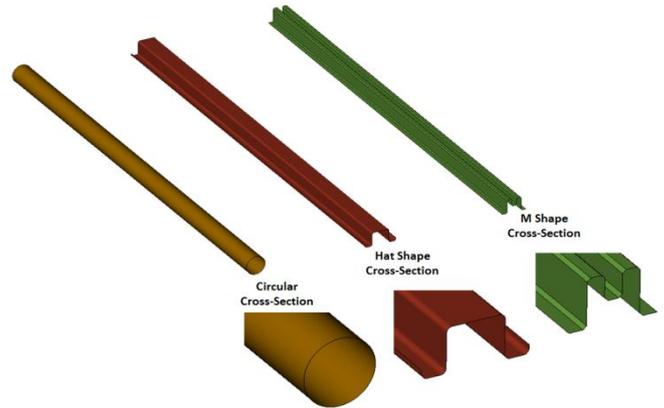


Figure 6: Cross Section Details Of Side door beam

F. Design Parameters :

X1 : Material details

Listed below are the details of the material used for ‘Side door beam’. Ls Dyna material Mat-24 is used (Piecewise Linear Plasticity) is used.

Material Name: AISI 1080	
Young’s Modulus, GPa	205
Poisson’s ratio	0.28
Density, kg/m ³	7860
Tangent modulus, Mpa	5669
Yield Strength, MPa	869

Independent variables considered:

X2 : Magnitude of Load

Listed below are the details of prescribed displacement given to the ‘Punch’ which intrudes into the ‘Side door beam’

Profile number and punch displacement		
1	2	3
100 mm	125 mm	150 mm

G. Variable Parameters overview

The variable design parameters and their levels are listed in table-1.

S No	1	2	3
Independent Variables	Cross-section of beam	Location of Punch (from end of beam)	Punch Displacement
Level 1	Circular	300 mm	100 mm
Level 2	Hat Shape	375 mm	125 mm
Level 3	M Shape	450 mm	150 mm

Table 1: variable design parameters

IV.RESULT & DISCUSSION Simulation Results, Material AISI 1080

Simulation results are listed in Table-2.

L ₉ (3 ³) Orthogonal array								
Exp No	Material	Independent Variables			Output Parameters			
		Variable 1 Beam Cross Section	Variable 2 Location of Punch	Variable 3 Punch Displacement	P1 Weight (KG)	P2 Energy Absorbed (J)	P3 Specific Energy Absorption (J/KG)	P4 Reaction Force (KN)
A1	AISI 1080	1	1	1	3.55	3280	924	75.6
A2	AISI 1080	1	2	2	3.55	5120	1442	99.1
A3	AISI 1080	1	3	3	3.55	7880	2220	124.0
A4	AISI 1080	2	1	2	3.60	7090	1968	131.0
A5	AISI 1080	2	2	3	3.60	9870	2740	148.0
A6	AISI 1080	2	3	1	3.60	3570	991	75.5
A7	AISI 1080	3	1	3	3.65	10600	2904	162.0
A8	AISI 1080	3	2	1	3.65	3600	986	83.0
A9	AISI 1080	3	3	2	3.65	5870	1608	101.0

Table 2: Simulation Results, Material AISI 1080

Von Mises Stress Plot, Circular Beam:

The figure-8 shows the deformation pattern and Von Mises stress of side door impact beam with 'Circular' cross section.

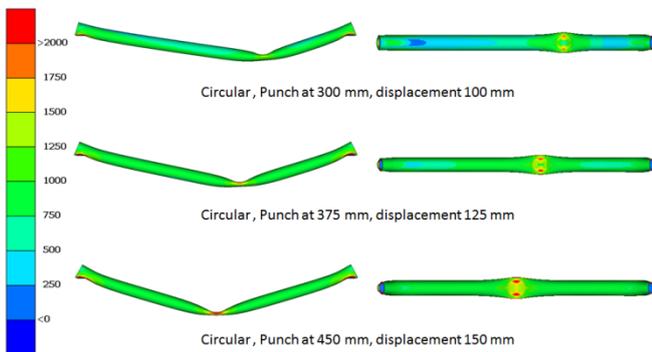


Figure 8: Von Mises stress (MPa), Circular Beam

Von Mises Stress Plot, Hat Shape Beam:

The figure-9 shows the deformation pattern and Von Mises stress of side door impact beam with 'Hat' shape cross section.

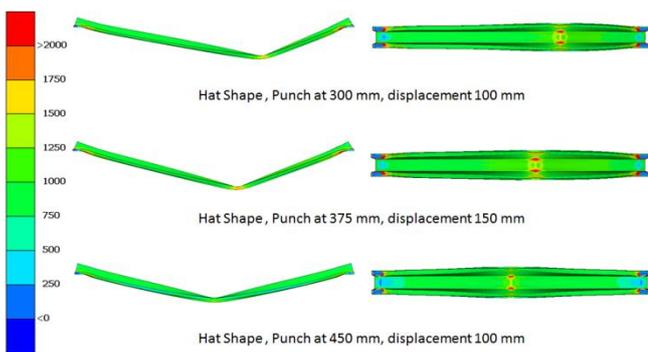


Figure 9: Von Mises stress (MPa), Hat Shape Beam

Von Mises Stress Plot, M Shape Beam:

The figure-10 shows the deformation pattern and Von Mises stress of side door impact beam with 'M' shape cross section.

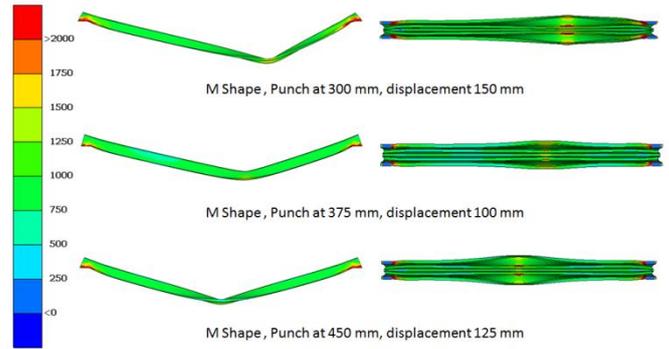


Figure 10: Von Mises stress (MPa), M Shape Beam

Curve Plot of Energy Absorbed:

The figure-11 shows the 'Internal Energy absorbed' in the load cases of circular cross section beam.

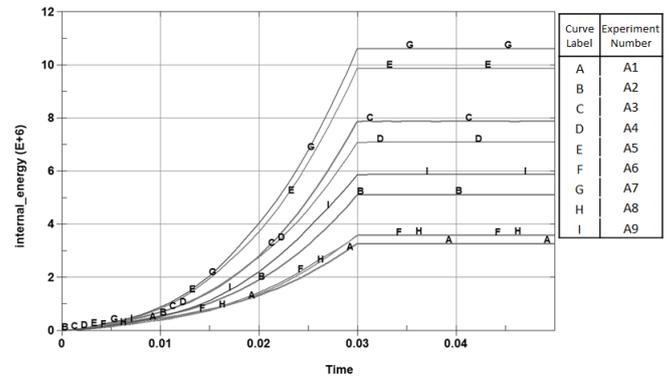


Figure 11: Curve Plot of Internal Energy Absorbed

Calculation of Factor Averages :

$$\text{Average effect of a factor} = \frac{\text{Sum of all results containing the effects of the factor}}{\text{Number of results included in the sum}}$$

Factor averages of the 3 variables are denoted by 'V_{ij}', where
 'i' is variable number
 'j' is variable level

From Table-5, the result P3 for experiments A1 to A9 be denoted by Y1, to Y9

Calculations of 'Variable 1' (beam cross section) factor averages,

$$V_{11} = (Y_1 + Y_2 + Y_3) / 3 = (924 + 1442 + 2220) / 3 = 1529$$

$$V_{12} = (Y_4 + Y_5 + Y_6) / 3 = (1968 + 2740 + 991) / 3 = 1900$$

$$V_{13} = (Y_7 + Y_8 + Y_9) / 3 = (2904 + 986 + 1608) / 3 = 1833$$

Calculations of 'Variable 2' (Location of Punch) factor averages,

$$V_{21} = (Y_1 + Y_4 + Y_7) / 3 = (924 + 1968 + 2904) / 3 = 1932$$

$$V_{22} = (Y_2 + Y_5 + Y_8) / 3 = (1442 + 2740 + 986) / 3 = 1723$$

$$V23 = (Y3 + Y6 + Y9) / 3 = (2220 + 991 + 1608) / 3 = 1606$$

Calculations of 'Variable 3' (Punch Displacement) factor averages,

$$V31 = (Y1 + Y6 + Y8) / 3 = (924 + 991 + 986) / 3 = 967$$

$$V32 = (Y2 + Y4 + Y9) / 3 = (1442 + 1968 + 1608) / 3 = 1673$$

$$V33 = (Y3 + Y5 + Y7) / 3 = (2220 + 2740 + 2904) / 3 = 2621$$

Plot of Factor Average Effects:

The below figure-13 shows the 'Factor average effects' of the three independent variables.

Variable 1 (V1) - Cross-section of beam

Variable 2 (V2) - Location of Punch (from end of beam)

Variable 3 (V3) - Punch Displacement

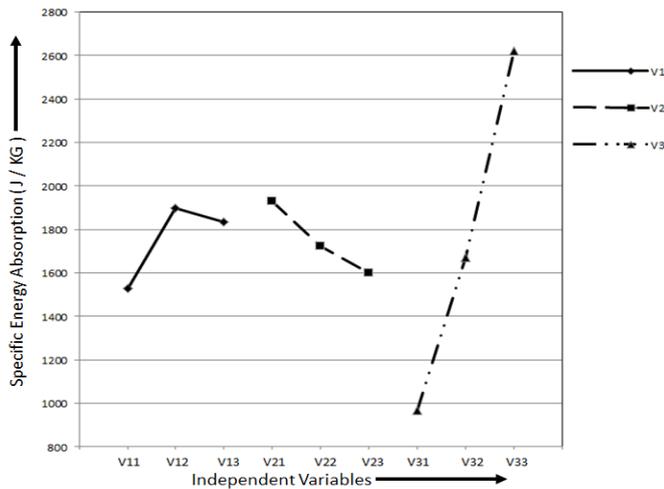


Figure 13: Curve Plot of Factor Average Effects

V. CONCLUSION

From graph shown in figure-11, the following conclusions are made:

1. 'Hat Shape' and 'M Shape' cross section beams have higher 'Specific energy absorption' compared to the traditional used 'Circular' cross section beams.
2. 'Hat Shape' cross section beam has the best energy absorption characteristics.
3. Performance of side door beam is sensitive to location of punch. At punch location of 450 mm, energy absorption is minimal.
4. Performance of side door beam is very highly sensitive to punch displacement. At punch displacement of 100 mm energy absorption is minimal.
5. Minimum absorption of energy by side impact beam is observed in load case with punch located at 450mm from one end, and punch displacement of 100 mm.

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