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Effects of Various Reinforcements in Oblique Loading of Rectangular Thin Walled Structure using FEA

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***Abstract*— This paper investigates the oblique loading of rectangular hollow box using reinforcements to absorb crash energy. The rectangular hollow rectangular box is a thin walled structure commonly used as crash box in automobiles today. It is loaded from one end with help of rigid mass impactor and other side is fixed. The performance of box in oblique loading is compared with axial loading so that we can estimate the difference in energy absorption, force displacement, stiffness variation, acceleration, specific energy absorption & crush force efficiency characteristics. This calculation is done using FEA Explicit code Pam-Crash which is suitable for dynamic analysis.**

***Keywords*— Frontal crash, Oblique loading, Crushing mechanism, Crashworthiness, Impact Energy absorption, Thin walled structures.**

I. INTRODUCTION

The rectangular thin walled box is loaded with oblique and axial loading to understand the difference in behaviour in both the load cases. The most common crash energy absorbers used today are thin walled rectangular sections in automotive structures which absorb most of the kinetic energy and convert into form of strain energy as internal energy by progressive deformation which is into plastic region of stress strain relationship [1].

II. CRASH BOX PROPOSED MODELS

Fig.1-6 shows total of six variants tested that are designed for oblique loadings. Reinforcements design is such that it helps to maximise energy absorption in oblique loading. The first model is hollow rectangular box having no reinforcement to calculate performance in both axial and oblique loading [2]. Also designs from two to six represent different types of reinforcement designs. In second model reinforcement is a plate diagonal to the rectangle i.e. inclined at an angle to longitudinal axis. In third model reinforcement is provided parallel to longitudinal axis of box.

In fourth box two reinforcements are provided normal to the box in plus sign cross section pattern. In fifth design diagonal plate & normal plate to it is added. In sixth design only one reinforcement id added parallel to longitudinal axis of box [3].

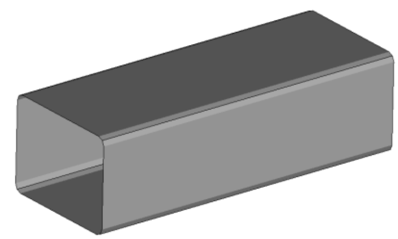

Fig. 1. Design 1

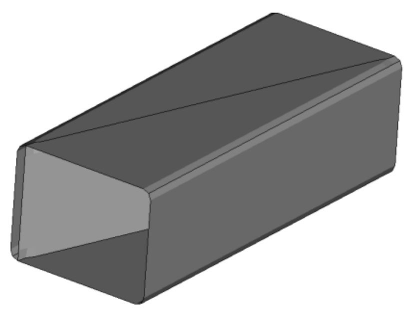

Fig. 2. Design 2

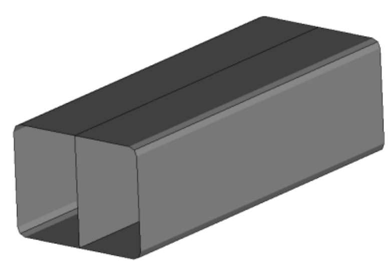

Fig. 3. Design 3

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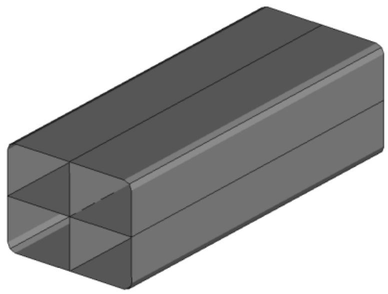

Fig. 4. Design 4

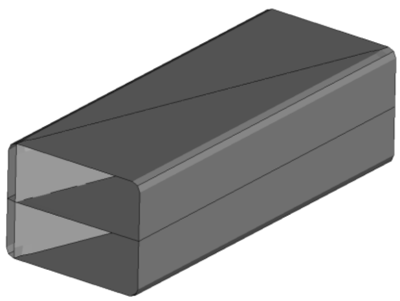

Fig. 5. Design 5

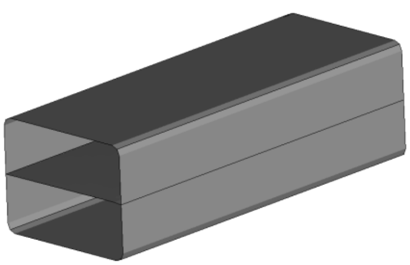

Fig. 6. Design 6

III. Dynamic Finite Element Analysis

Dynamic Explicit FEA Analysis of Box is performed using explicit code Pam-Crash Student version.

A. Loading condition

Model is loaded with axial and oblique loadings with the help of mass impactor which travels at the velocity of 56 kmph which is equal to 15555.5 mmps. The oblique loading is inclined at 30o to the normal axis of box while axial loading is parallel to the normal axis of box. The impactor is having a mass of 125 kg which is of rigid material having applied initial velocity so that it impacts rectangular box [4].

B. Material used

Fig.7 shows the material used is steel which has Yield stress of 350 Mpa and Tensile strength of 650 Mpa with percent elongation at rupture as 30%.The material follows the plastic law with strain hardening effects. Poisson's ratio is 0.3 and density of material is 7.85e-9 T/mm3.Thickness of box is 2mm [5].

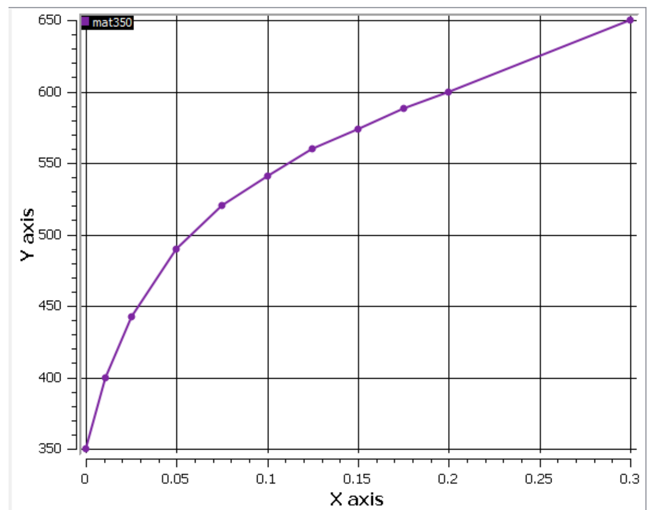

Fig. 7. True stress strain curve for material

C. Analytical Calculation

To calculate the mean crush force we get from

$Pm = 38.27\ M_0\ C^{1/3}\ t^{-1/3}$ where

Pm is the mean/average crush force [6].

$Mo = \sigma_o t^2 / 4$, the fully plastic moment,

σ_o, is the average flow stress ($\sigma_o = (0.9 \text{ to } 0.95)\ \sigma_u$),

σ_u is the ultimate tensile strength of the material,

C = 1/2 (b+d) with b and d being the sides of a rectangular box column,

t its wall thickness

So, for 1st design variant where simple rectangular cross section is undergoing axial normal impact will be

$Pm = 38.27 \times 585 \times 8.36 \times 0.793 = 15735.60695$ N

IV. Results & Discussion

A. Deformation pattern

In Fig. 8-13 shows deformation pattern we can see that in axial loading there is dominance of crushing behavior but in case of oblique loading there is global bending and buckling in all the design models. Design 2 shows good deformation characteristics [7].

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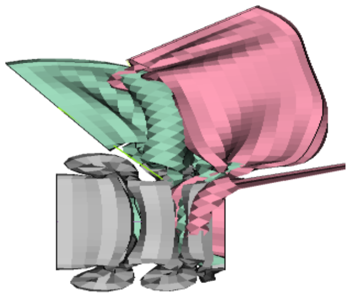

Fig. 8. Design 1 deformation

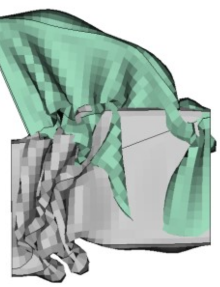

Fig. 9. Design 2 deformation

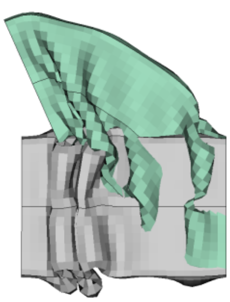

Fig. 10. Design 3 deformation

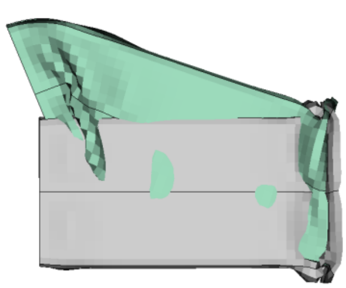

Fig. 11. Design 4 deformation

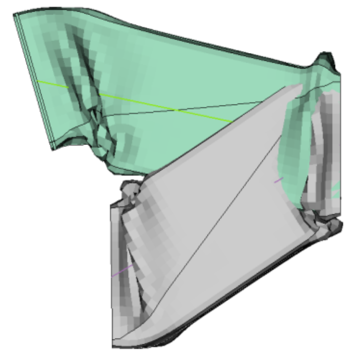

Fig. 12. Design 5 deformation

Fig. 13. Design 6 deformation

B. Force deformation characteristics

Fig. 14-19 shows force and displacement characteristics of the box in axial and oblique loading. Here also design 2 shows better stiffness in both oblique and axial loadings [8].

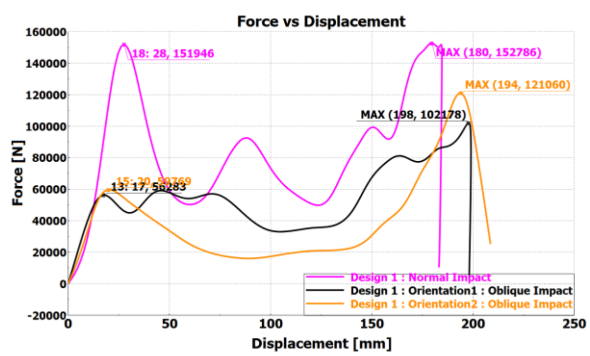

Fig. 14. Design 1 Force vs. deformation

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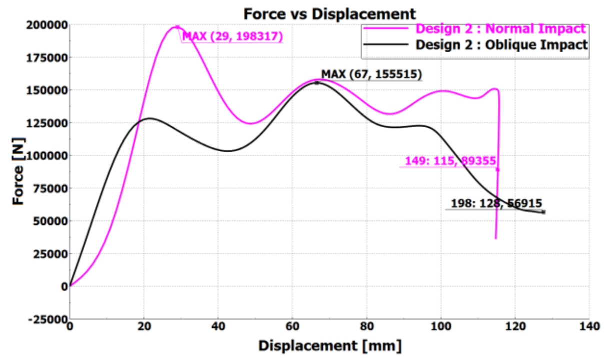

Fig. 15. Design 2 Force vs. deformation

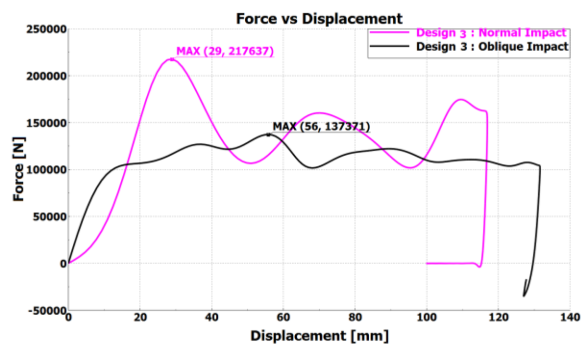

Fig. 16. Design 3 Force vs. deformation

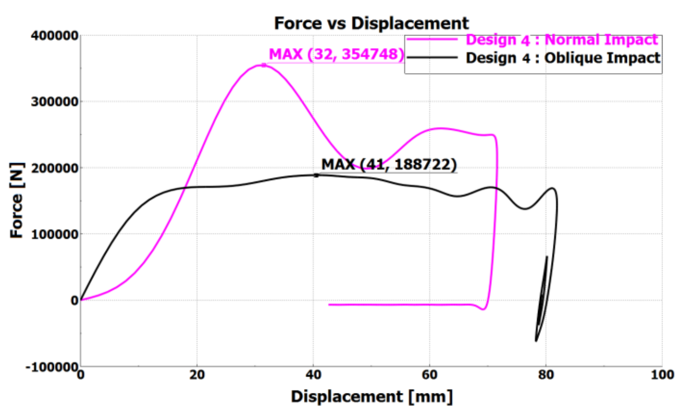

Fig. 17. Design 4 Force vs. deformation

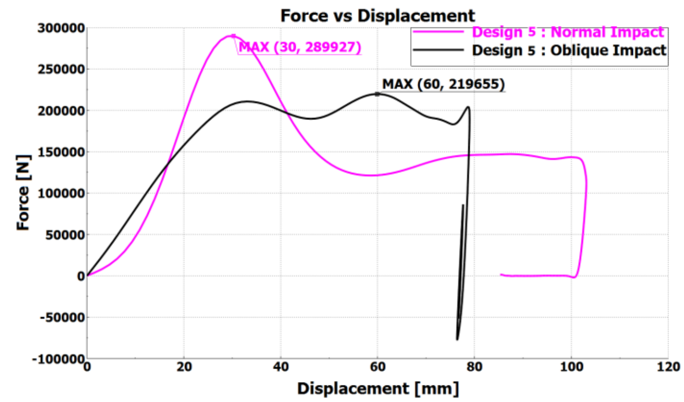

Fig. 18. Design 5 Force vs. deformation

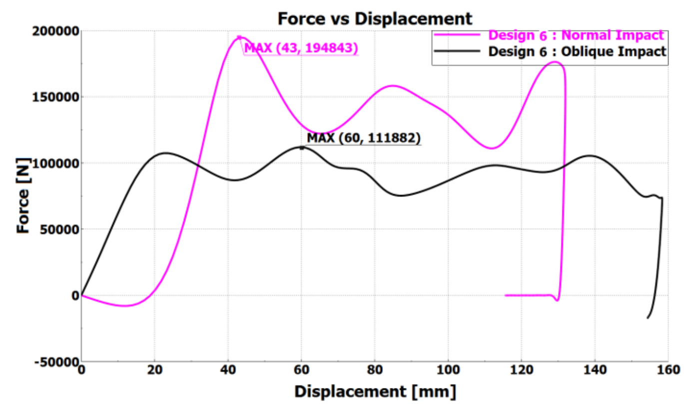

Fig. 19. Design 6 Force vs. deformation

C. Internal Energy absorption

Fig. 20-25 shows energy absorbed by 6 designs where kinetic energy is converted progressively into strain energy due to impact loading. Here also design 2 shows highest energy absorption in oblique load [9].

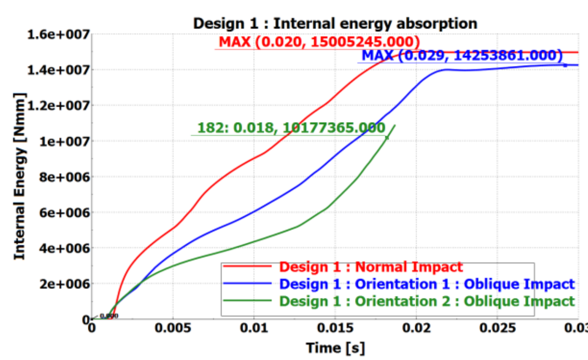

Fig. 20. Design 1 Internal energy

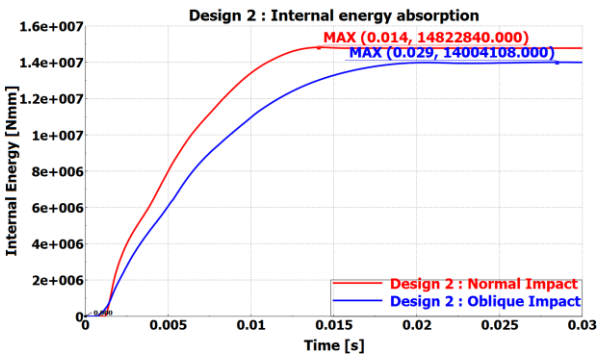

Fig. 21. Design 2 Internal energy

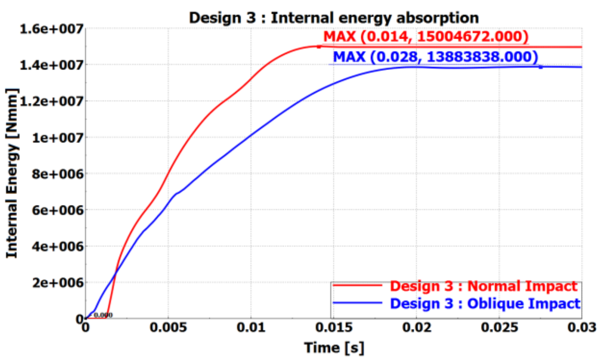

Fig. 22. Design 3 Internal energy

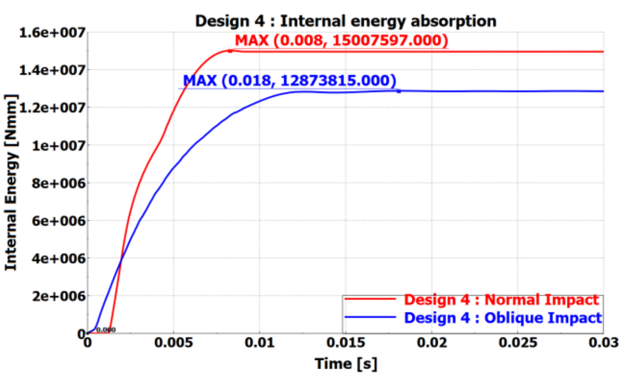

Fig. 23. Design 4 Internal energy

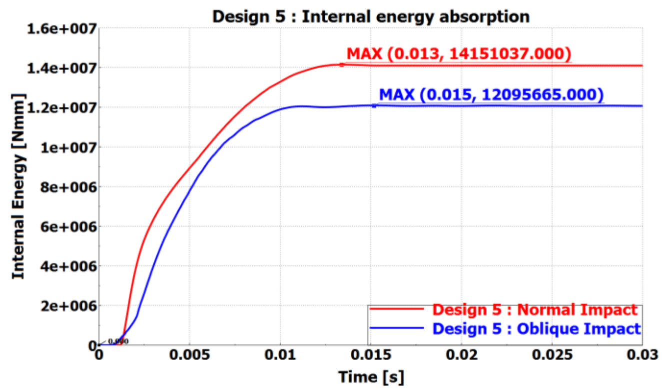

Fig. 24. Design 5 Internal energy

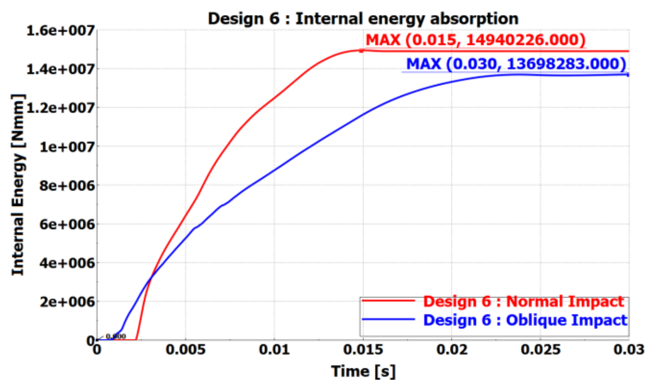

Fig. 25. Design 6 Internal energy

D. Modes of collapse

The mode of collapse is crushing behavior dominant in axial loading however in case of oblique loading it is mix of bending and buckling. So the energy absorbed is always more in the case of axial loading [10].

E. Acceleration pulse

Table 1 show the acceleration obtained in various designs for axial as well as oblique loading. Here we can see that pulse is optimum for design 2 & 3.

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TABLE I
ACCELERATION PULSE

Design	Acceleration pulse (g)	
	Axial Loading	Oblique Loading
Design 1	225	168
Design 2	157	97
Design 3	173	85
Design 4	293	130
Design 5	236	157
Design 6	160	86

F. Specific energy absorption

Table 2 shows SEA for all designs. This is very important factor while analysing the impact behaviour of crash box because this indicates the capacity of mass of body to absorb the kinetic energy by straining in plastic region. That implies that adding mass to the model to increase the energy absorption is not always correct, so it's very essential how the mass is added to the geometry.

For design 1 & 2 it is maximum relatively.

Specific energy absorption is called as,

SEA = maximum energy / weight

TABLE 2
SEA

Design	SEA (N.mm/gm)	
	Axial Loading	Oblique Loading
Design 1	14948	14200
Design 2	11944	11284
Design 3	12215	11303
Design 4	9861	8459
Design 5	9221	7881
Design 6	11515	10558

G. Peak and mean force

Table 3 shows peak and mean force for various designs. High peak force is not desired so design 2 & 1 are best for application.

TABLE 3
PEAK & MEAN FORCE

Design	PEAK & MEAN FORCE (N)	
	Axial Loading	Oblique Loading
Design 1	151946	59769
Design 2	198317	120000
Design 3	217637	110000
Design 4	354748	170000
Design 5	289927	210000
Design 6	194843	110000

H. Crush force efficiency

Table 4 shows CFE for all 6 design iterations. This is also one of the important parameters as it signifies handling of crush force efficiently. It is the ratio of mean load to peak load. Here design 2 & 6 shows better performance.

TABLE 4
CFE

Design	CFE (%)	
	Axial Loading	Oblique Loading
Design 1	62.5	83.6
Design 2	79.6	86.6
Design 3	73.5	80.9
Design 4	70.4	78.2
Design 5	51.7	71.4
Design 6	82.1	80.9

V. CONCLUSION

By analysing the results we can see that design number 2 is best suited for oblique loadings as it absorbs maximum energy. Also the specific energy parameter is high with low acceleration levels which are desired in impact loadings. So we can interpret from the FEA results that design 2 has best performance in all parameters.

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