Parametric Study for the Design of Blast-Resistant Steel Stiffened and Unstiffened Building Panels for Critical Healthcare Infrastructure Protection and Disaster Resilience

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ABSTRACT
Due to an increase in terrorist activities in the world, major attention has been given in the design and construction of important structures under blast loading. Till date, designers have not well understood the effect of blast loading on steel building. Therefore, blast resistance of unstiffened and stiffened steel panels is examined by using ABAQUS.The comparison is also made with stiffened and unstiffened panels having the same thickness. A parametric study is also carried out to study the effect of various parameters like span, panel configuration onthe dynamic response of stiffened and unstiffened panels. The behaviour of the blast resistant panels is measured in terms of ductility ratio and support rotation. The parametric study presented in this paper is compared with permissible performance enlisted in standard literature for blast resistance buildings. Also, optimum stiffener configuration is worked out for each span considering permissible behaviour and cost-effectiveness of each panel configuration.

Keywords: *Steel panel, Blast resistance, Blast Pressure, Stiffened Panel, Cost efficiency.*

I. INTRODUCTION

There is a large scope of study, the way in which structural components behave, while they are subjected to blast loading. It has been a topic of research in the recent past due to increase in various terrorist activities all over the world and fatal industrial accidents. Adequate attention is required against blast loading. In view of these, structural engineers are giving major attention to the design and construction of public buildings, industrial units like refineries, nuclear plants, and thermal power plants, etc. Various approximations and assumptions are made to simplify the structural models to solve the difficulties that arise due to complexity of problem which are time-dependent finite deformations, non-linear elastic behaviorand high strain rates. Complicated structures consisting of several buildings and hinderances capable of changing blast propagation, the blast formation effects can be analyzed from the finite element analysis software like ABAQUS [1], LS-DYNA [2],ANSYS [3],etc. Research work previously carried on civil structures and its parts exposed to blast was restricted to industrial and military applications. The response of unstiffened & stiffened plates subjected to air blast loading was reported by Goel et al.[4]. The corrugated profile blast wall behaviour under different types of loadings was investigated by Sohn and Kim [5]. The results of torsional response and deformation on stiffeners (T-stiffened) and panels was reported by Louca et al. [6], The influence on connection details and overall performance of panels system under different blast loading was worked on by Langdon and Schleyer [7]. By using the historical studies and equations, some guidelines were given on by understanding the explosion phenomena and its loading on the structure by Abdallah and Osman [8].Stiffened plates resistant to high explosion are most commonly used. Stiffeners are located facing toward or away from the blasting loading. A lot of stiffened plates are designed and constructed but the consequence of using stiffeners exposed to blast loading are not understood to the greater extent or in depth by the designers.

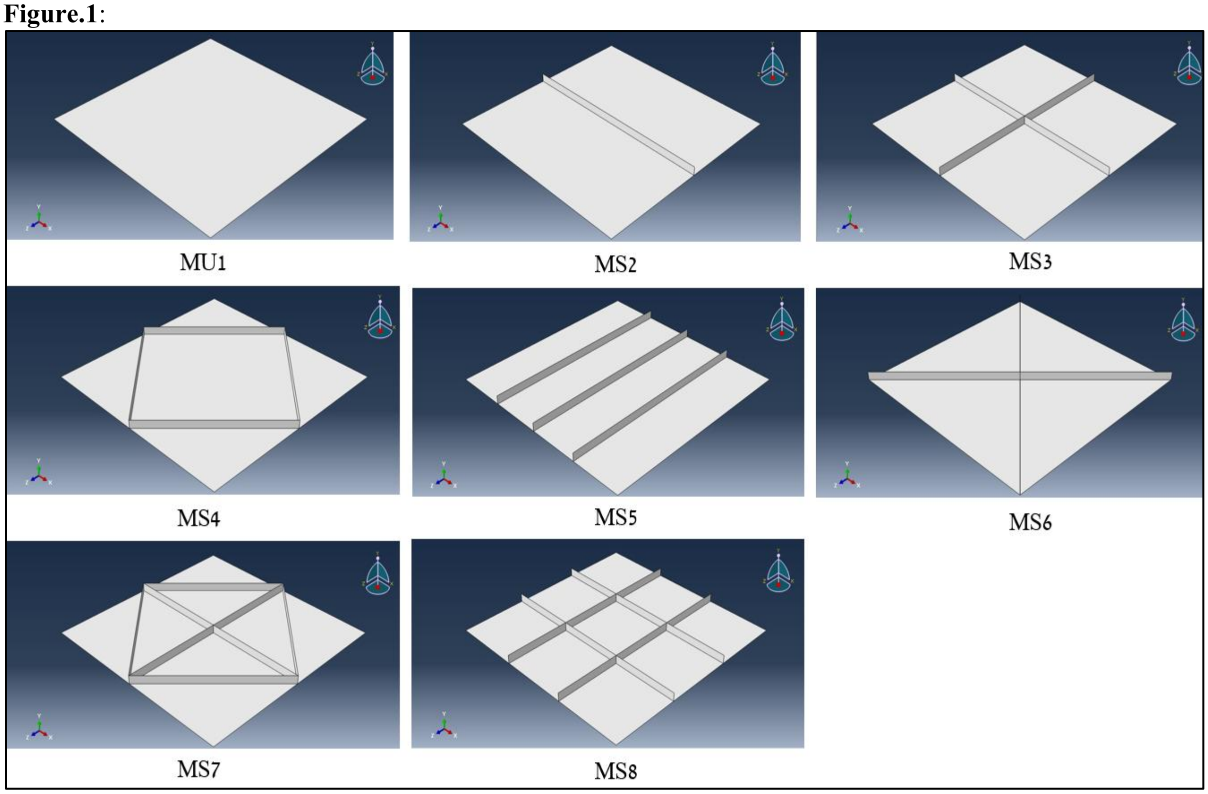
II. DESCRIPTION OF THE PANELS

In this research paper, an unstiffened panel and stiffened panels are used having different sizes namely 1)2 × 2 m^2, 2)2.5 × 2.5 m^2, 3)3 ×3 m^2, 4) 3.5 × 3.5 m^2, 5) 4 × 4 m^2, 6) 4.5× 4.5 m^2, 7) 5× 5 m^2 with thickness of 6 mm. The stiffeners considered are of 0.12m height with a thickness of 6 mmthroughout.Figure.1shows the unstiffened panel and various stiffener configuration panels used in the study.

III. MATERIAL PROPERTIES

Mild steel having Young's modulus(E)= 210 GPa, Poisson's ratio(μ)= 0.3and density(ρ) = 7800 kg/m^{3}is used to model all the panels and stiffeners and the static yield stress of the panel material is 300 MPa. The stress-strain curves are converted into true stress and logarithmic plastic strain, as perthe ABAQUS manual [1]. The unstiffened panel (M1U) and stiffened panels (M2S to M8S) with a different configuration of stiffeners are used in the present study which are shown in Figure.1 and the panels are clamped on all sides. Finite element analysis is done using ABAQUS/Explicit[1] which offersa variety of element library for geometric models. The geometry of panels and stiffeners are modeled by means of quadrilateral shell (S4R) element.

Figure.1:



Unstiffened and stiffened panels configurations

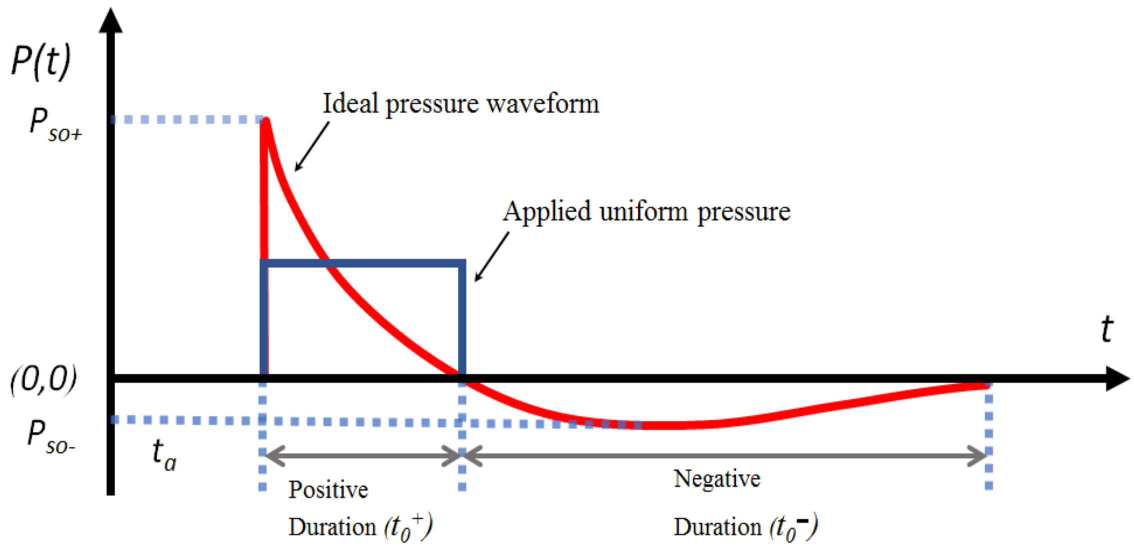
IV. EXPLOSIVE LOADS PROFILE

The application of the explosion loading is completely different as compared to static load which are more often used. The sudden release of energy related to volume expansion is caused by an explosion. The explosion led to an increase in light and temperature, and the pressure is tremendously increased. Glass tone and Dolan [9] and Sartori [10] reviewed the effect on several structures and human body. Figure.2 shows the profile of an ideal waveform generated due to high explosives. Characterization of blast waves is done by an instantaneous increase from the ambient atmosphere pressure (P_0) topeak overpressure (P_{SO}^+) in arrival time (t_a).The peak overpressure deteriorates exponentially with time and comes back to the atmospheric pressure in the positive phase time duration(t_d^+).Negative pressure wave was very small,so it is generally ignored. The modified Friedlander's Equation (1) describes the blast wave profile where,$P(t)$= time-dependent pressure in MPa,P_{S0}^+= peak overpressure in MPa,t_d^+= positive phase time duration inms,t_a= wave arrival time inms.

Formulae:

$$P(t)= P_{S0}^+ \left(1-\frac{t}{t_{d+}}\right) \exp\left(\frac{-b(t-t_a)}{t_{d+}}\right) \quad (1)$$

Figure.2:

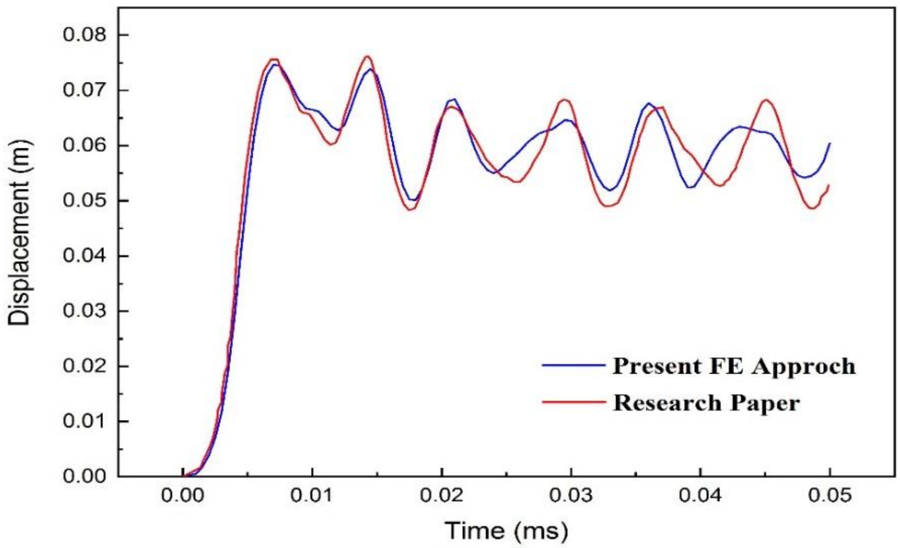


In this research paper, the impulsive blast pressure is replicated for finite element models with the use of applied uniform pressure load of various magnitudes ranging from 3-15 psi and time period of 8.5ms on the panel area,

V. VALIDATION

Using the stiffened plates of 2m × 2m size and thickness of 20mm, and stiffener having height of 100 mm and thickness of 10mm, the finite element (FE) numerical approach was developed and checked against results shown by Goel et al. [4]The modeling of stiffeners and plates was done using the shell element in FEM software ABAQUS/Explicit [1] having similar material properties, blast pressure and edge condition as shown by Goel et al. [4] for validation. The Figure.3 shows the comparison between results of center point displacement reported by Goel et al. [4] and present FE approach.

Figure.3:



Center peak point result comparison

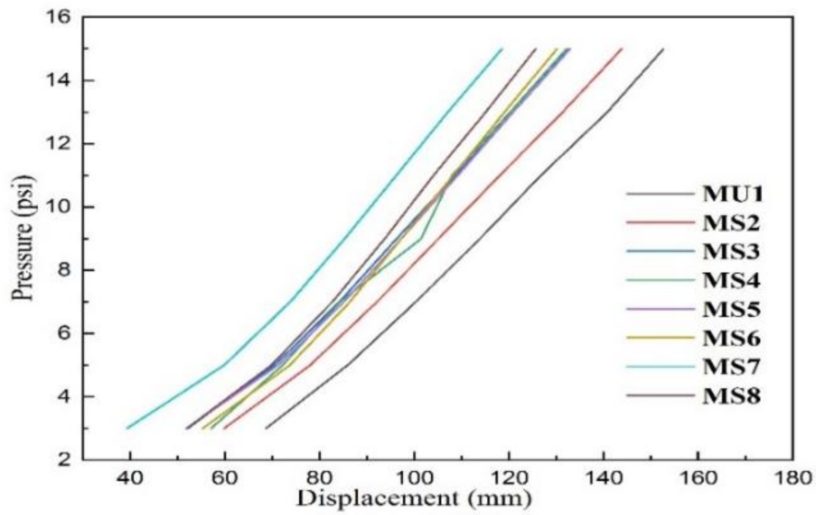
The difference between peak displacement result of the platementioned in theresearch paper and present approach is 2.03%.

VI. RESULT AND DISCUSSIONS

Numerical analysis done in this paper, aims to study (a) Panel span (2-5m) effect over ductility ratio and support rotation under blast pressure, (b) Different blast pressures (3-15 psi) effect over ductility ratio and support rotation using unstiffened and different configuration stiffened panels, (c) Moreover, practical point of consideration, focuses on cost-efficient configuration of stiffened panel under different span and under different blast pressures.

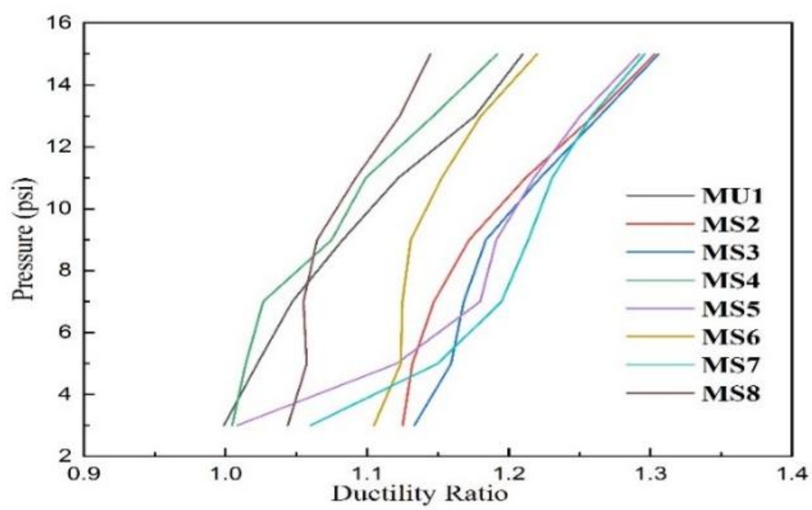
Various numerical simulations are performed, with the use of unstiffened and stiffened panels having a span of 3.5m. Effects of blast pressure on different eight test panel models (MU1, MS2 to MS8)are observed.Figure.4 shows the peak central point displacement for span 3.5m. The peak central point displacement increases as blast pressure increases. The maximum and minimum peak displacement observed in MU1 unstiffened is 152.7 mm at 15psiandin MS7 stiffened panel is39.28 mm at 3psi blast pressure respectively. As per ASCE[11], the maximum acceptable values for ductility ratio and support rotationare5 and 3 for the lower response,10 and 6 for the medium response, and 20 and 12 for high response respectively. Ductility ratio and support rotation variation under different blast pressure are observed inFigure.5 &6. The measured ductility ratio and support rotation values are varying under safe limit for lower blast pressure. Panel configuration MS7 and MS8givelowestand second lowest values of peak maximum displacement and support rotation.

Figure.4:



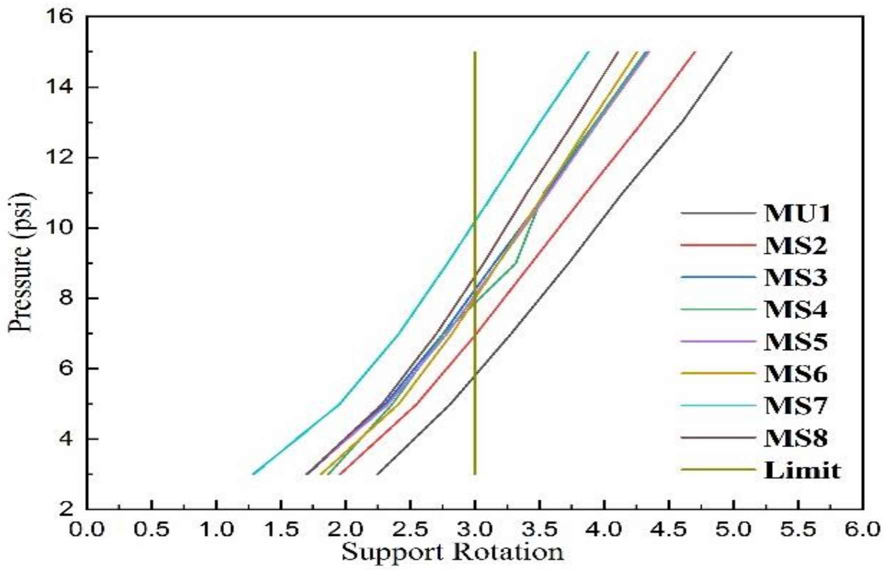
Peak central point displacement having span of 3.5m.

Figure.5:



Ductility ratio values at different blast pressures for all the panels having span of 3.5m

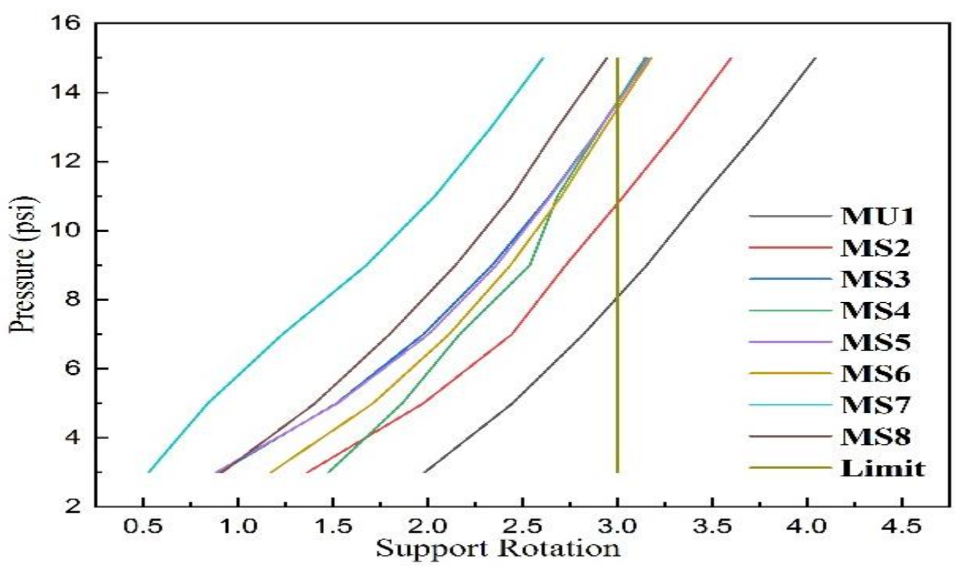
Figure.6:



Support Rotation values at different blast pressures for all the panels having span of 3.5m

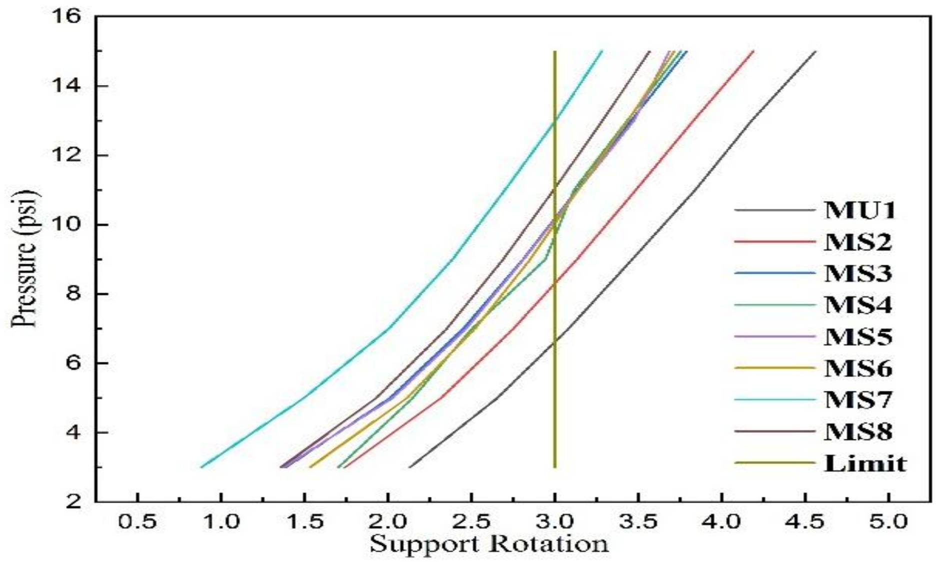
Now, same numerical simulations are performed overa span less than 3.5m i.e.2m, 2.5m, 3m. It is noticed that ductility ratio for these panels are in safe limit under all blast pressures, but support rotation values for the span of 2.0 m is under safe limit for blast pressure up to 13 psi. and support rotation values for span2.5m and 3 m unstiffened and stiffened panels are under safe for blast pressure of 9 psi and 11 psi respectively. Figure. 7(a)& 7(b) represent support rotation values are varying under safe limit for lower blast pressure.

Figure.7(a):



Support Rotation values at different blast pressures for all the panels having span of 2.5m

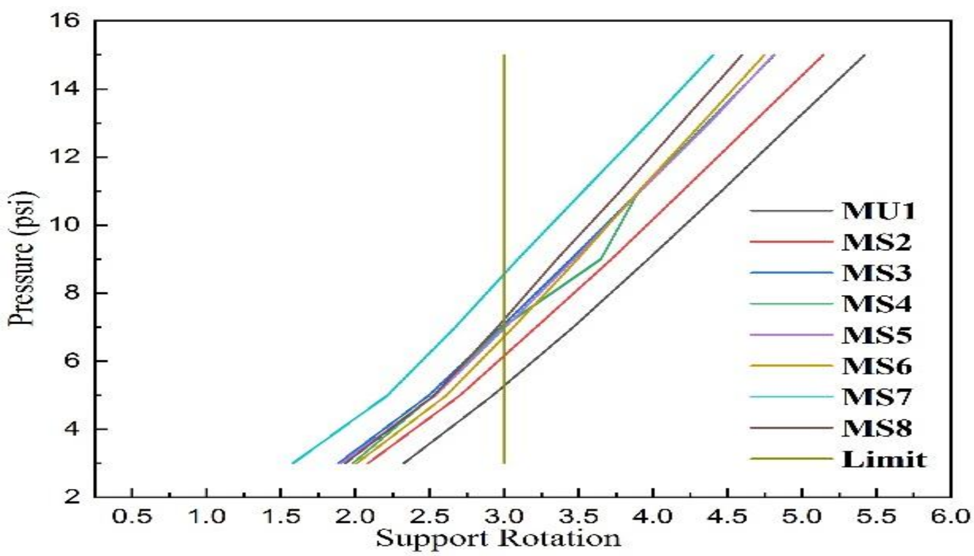
Figure.7(b):



Support Rotation values at different blast pressures for all the panels having span of 3m

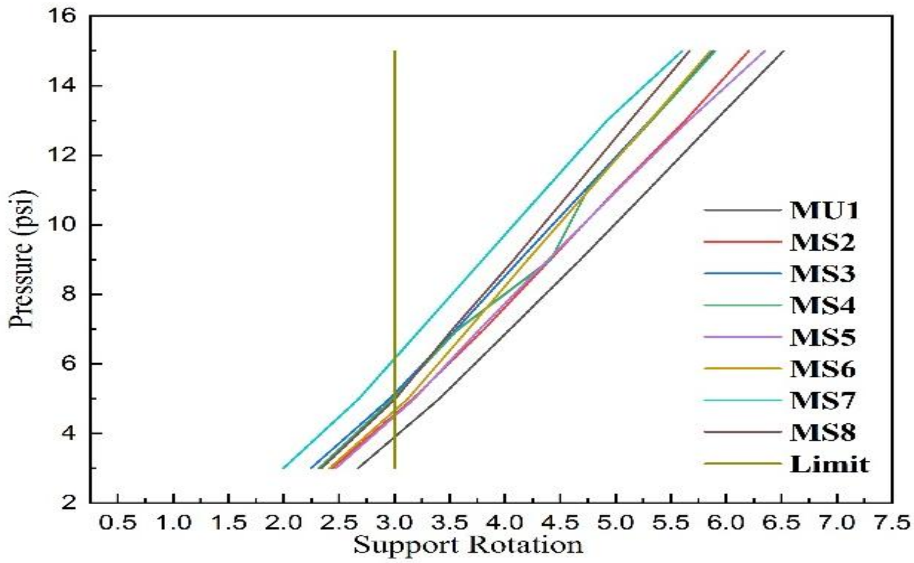
Numerical simulations for span more than 3.5 m unstiffened and stiffened panel i.e. 4m, 4.5m, 5m are performed.It is observed that ductility ratio is inthe safe limit, but support rotation values for the span of 4m isin safe limit for blast pressure up to 5 psi. and support rotation values for span 4.5m and 5m unstiffened and stiffened panels are under safe for lower blast pressure of 3psi only. Figure. 8(a)& 8(b) represent support rotation values are varying under safe limit for lower blast pressure.

Figure.8(a):



Support Rotation values at different blast pressures for all the panels having span of 4m

Figure.8(b):



Support Rotation values at different blast pressures for all the panels having span of 4.5m

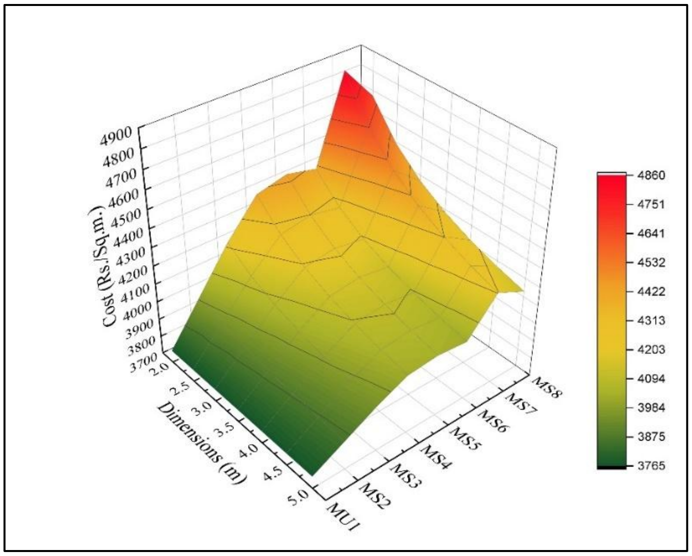
Cost evaluation of unstiffened panel MU1 and stiffened panels of MS2, MS3, MS4, MS5, MS6, MS7, and MS8 with different span considerations (2m, 2.5m, 3m, 3.5m, 4m, 4.5m, 5m) subjected to 3-15 psi blast pressure is carried out.

Tables:

Table.1 Panels costing (Rs. / Sq.m.) for different configurations and for different spans

Span (m)	MU1	MS2	MS3	MS4	MS5	MS6	MS7	MS8
2	3768	3994	4220	4407	4446	4407	4860	4672
2.5	3768	3949	4130	4280	4311	4280	4641	4491
3	3768	3919	4069	4194	4220	4194	4496	4371
3.5	3768	3897	4026	4133	4156	4133	4392	4285
4	3768	3881	3994	4088	4107	4088	4314	4220
4.5	3768	3868	3969	4052	4069	4052	4253	4170
5	3768	3858	3949	4024	4039	4024	4205	4130

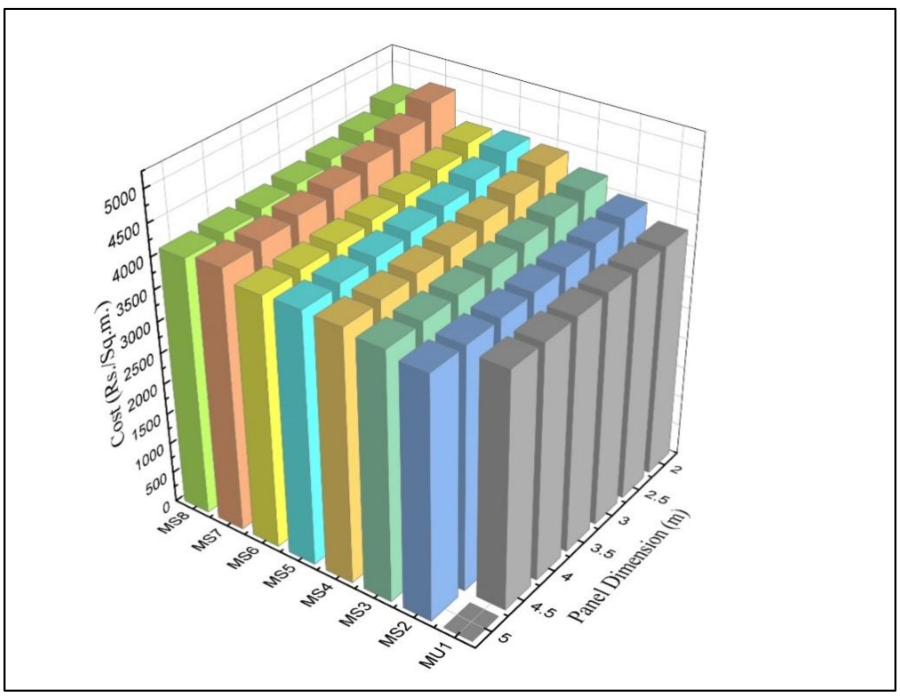
Figure.9:



Cost evaluation graph

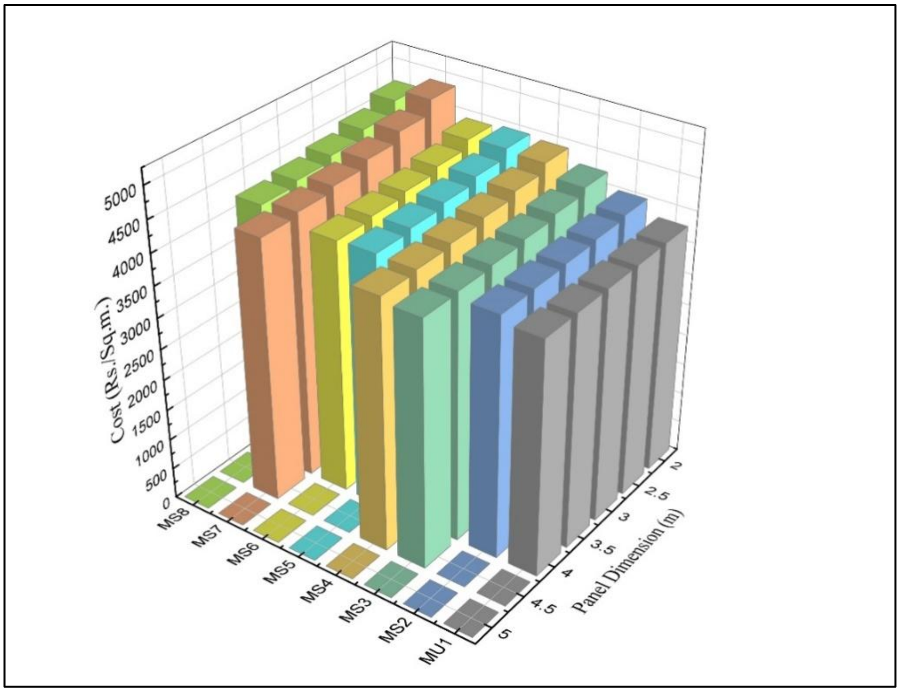
Table.1show costing of the panels considering price of steel atRs. 80 per kg including welding, colour, and placing. Figure.9 exhibits the graphical representation of costing of different spans panel with different configurations. MS7 configuration represents the peak value of graph which is Rs. 4860/sq.m. and configuration with MU1 shows a uniform rate.

Figure.10(a):



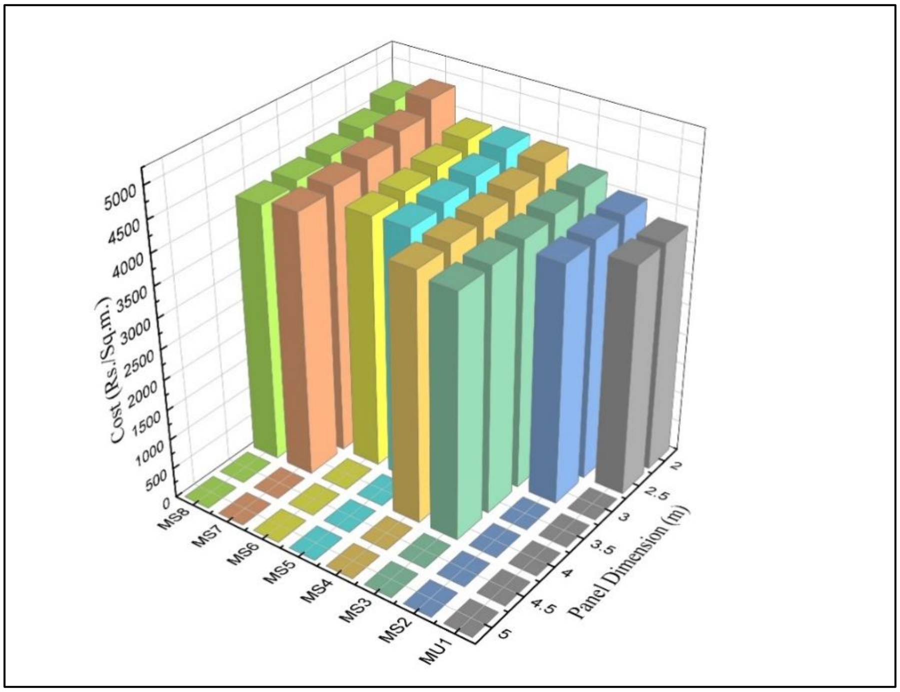
Comparison of safe panels vs. cost per square meter for blast pressure 3 psi

Figure.10(b):



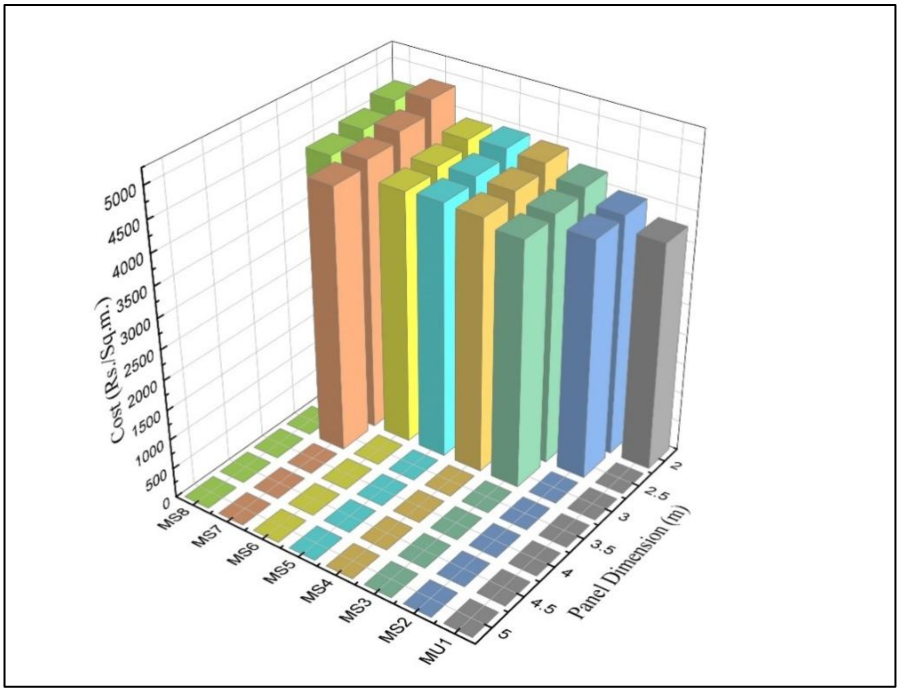
Comparison of safe panels vs. cost per square meter for blast pressure 5psi

Figure.11(a):



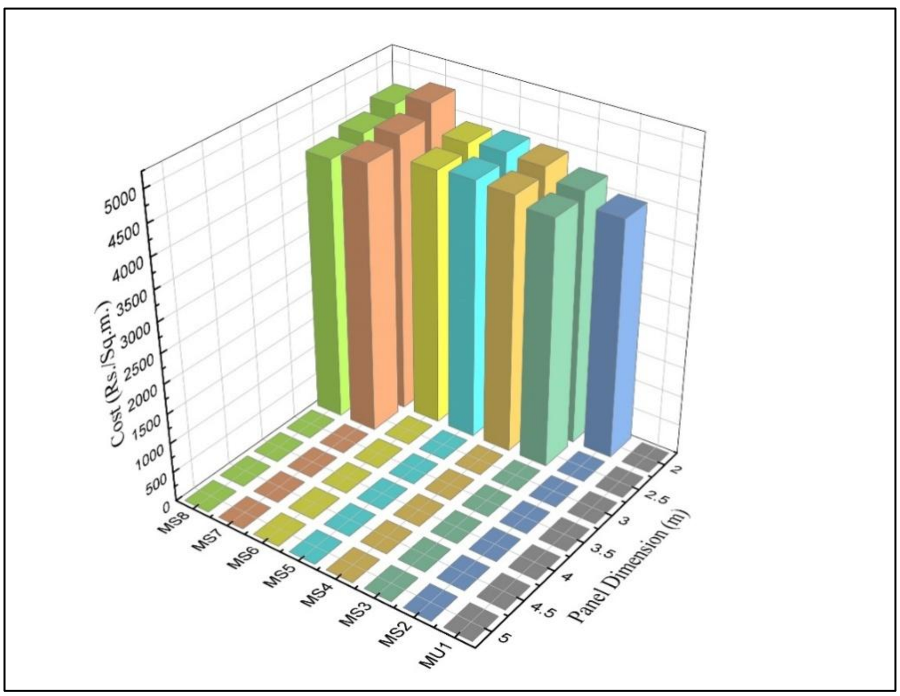
Comparison of safe panels vs. cost per square meter for blast pressure 7 psi

Figure.11(b):



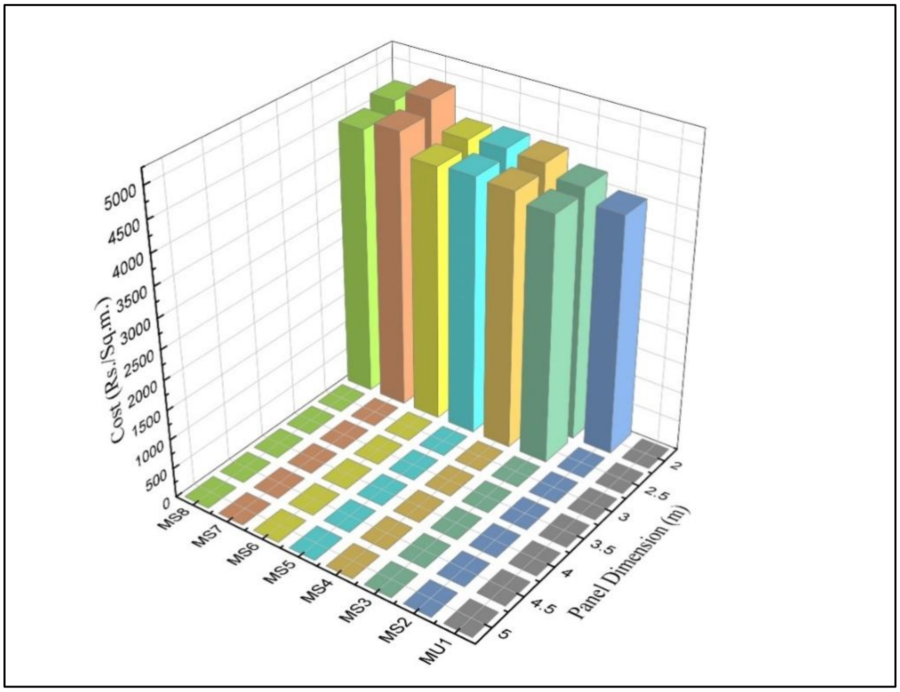
Comparison of safe panels vs. cost per square meter for blast pressure 9 psi

Figure.12(a):



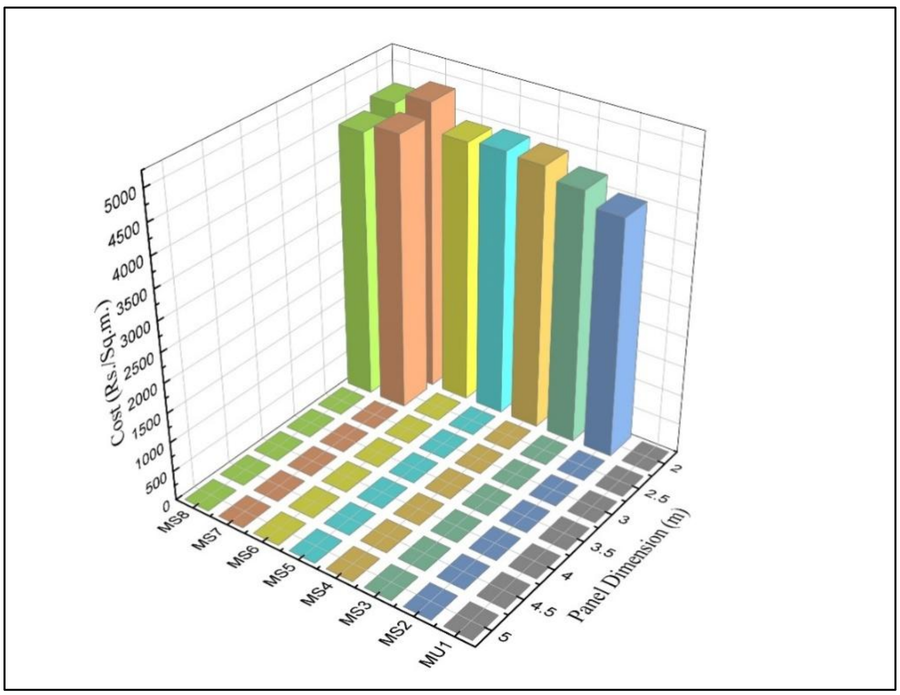
Comparison of safe panels vs. cost per square meter for blast pressure 11 psi

Figure.12(b):



Comparison of safe panels vs. cost per square meter for blast pressure 13 psi

Figure.13:



Comparison of safe panels vs. cost per square meter for blast pressure 15psi

Configuration of MU1 show cost efficiency with panels of all sizes and pressures. With the increase in pressure the safe limit of panels gets exceeded along with the increase in panel span. Table.2 shows the cost efficiency of panels with respect to pressure and span.

Tables

Table.2 Cost efficient panel

		Pressure (psi)						
		3	**5**	**7**	**9**	**11**	**13**	**15**
Span (m)	**2**	MU1	MU1	MU1	MU1	MS2	MS2	MS2
	2.5	MU1	MU1	MU1	MS2	MS3	MS3	MS8
	3	MU1	MU1	MS2	MS3	MS8	-	-
	3.5	MU1	MU1	MS3	MS7	-	-	-
	4	MU1	MU1	MS3	-	-	-	-
	4.5	MU1	MS3	-	-	-	-	-
	5	MS2	-	-	-	-	-	-

It is observed that unstiffened panel MU1 with span of up to 4m is safe up to blast pressure of 5psi and it is exceeding its safe limit of support rotation. So, it is not beneficial to use MU1 where structure is subjected to high pressure, and it is also noticed that some panels performed well under higher pressure of more than 9 psi and percentage ofcost (Rs. per sq. m.) variation between them plays a major role. The higher pressure viz, 15 psi most of the panels with the span more than 2.5m exceeds their safe limit for support rotation. So, it can be inferred that for the span of the 2m panel with different stiffener configurations is safe and cost varies for unstiffened panel MU1 and stiffened panel MS2 to MS8 in ascending order respectively from 6% to 24%. Hence, 2m panels of MS2 are the cost-efficient panel with a costing of Rs. 3994 per square meter which is the lowest pricing as compared to the all other stiffened panels. Whereas MS7 panel is safer in support rotation and it has pricing of Rs. 4860 per square meter for 2m span and Rs. 4641 per square meter for 2.5m span and both were safe under 15 psi high blast pressure. Panels having span up to 3 m can be used for blast pressure of 9 psi and 11 psi whereas for lower blast pressures such as 5 to 7 psi panels of span up to 4 m can be used.Figure.10,11,12 and 13 shows graphical representation of the span of panel which were under safe limit of support rotation and ductility ratio along with costing per square meter of the panel. It can be seen from the graph that panel used under higher blast pressure (9psi -15psi) are less as compared to lower blast pressure (3 psi -7 psi).

VII. CONCLUSIONS

1. With the increase in span and pressure on different configuration panels, the ductility ratio remains in the safe limit, but the support rotation exceeds the safe limits. MS3, MS7 and MS8 are the safest with the increase in the pressure and panel dimension.
2. The most cost-efficient panels in the study are identified with various panel spans which are dependent on stiffeners configuration.MU1 is the safest and most cost efficient up to 7 psi but MS3 is a safe even in higher pressures.
3. The optimum stiffener configuration is stiffened MS7 panel.

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