Contents lists available at **CEPM**

Computational Engineering and Physical Modeling

Journal homepage: www.jcepm.com

Controlling Blast Loading of the Structural System by Cladding Material

K.K. Kiran[1*], J.G. Kori[2]

1. M.Tech, Civil Engineering Department, Government Engineering College Haveri Karnataka India
2. Ph.D. Civil Engineering Department, Government Engineering College Haveri Karnataka India

Corresponding author:*kirankk0202@gmail.com*

https://doi.org/10.22115/CEPM.2018.141294.1038

ARTICLE INFO

Article history:
Received: 01 August 2018
Revised: 02 October 2018
Accepted: 18 February 2019

Keywords:
LCS;
Blast load;
Pressure impulse diagram;
Non dimensional parameters κ and τ.

ABSTRACT

Shelter is one of the main component of the living creature, it should be safe, uneconomical, hygenic and protective. Now a days shelter should be protective from blast load due to terrorist attack, nuclear explosive, chemical reactions occurring inside the building may be internal blast or external blast.A SDOF structural system subjected to blast load on Front wall, rear wall and roof is studied.The response of the structure is determined. The Pressure impulse curve is determined. Pressure impulse curve plays a vital role in determining the damage level of structure subjected to blast load.A LCS model is considered and studied. A LCS model made up of aluminium foam plays a vital role in the protection of structures subjected to blast load. A parameter of non dimensional parameters κ and τ are studied.A non dimensional parameters κ and τ plays a vital role in finding the damage level of the structure.

1. Introduction

More than 2000 years ago world wide across several countries are facing a seviour threat of Terrorism. The places, causes, participants, intensities and a few other financial assets are changing rapidly [1]. Current violence incidents and threats took place in India during

How to cite this article: Kiran KKH, Kori JG. Controlling Blast Loading of the Structural System by Cladding Material. Comput Eng Phys Model 2018;1(3):79–99. https://doi.org/10.22115/cepm.2018.141294.1038

22.02.2016 (in Pampore, Jammu and Kashmir) – unidentified militants killed approximately six people and on 02.01.2016 (in Pathankot airbase, Punjab) -a group of militants infiltrated the air force base and killed at least six military personnel [2].

Numerical investigation of RC member subjected to blast load is studied and is protected by using Foam material [3]. The prominent theoritical approaches are mindlin theory and timoshenko beam model. These strategies are extremely intricate due to inductile, kinked material demeanor, time subordinate dislocations and fickle blast load estimations.Here an attempt is made to study Single Degree of Freedom(SDOF) system[4].

The application of pressure impulse (pi) diagram is used for a damage assessments, for the structure subjected to blast load. During the second world war in UK a bombs dropped leads to the study of different damage levels by pi diagram. The pi diagram is used for predicting structural damage and blast induced human injuries [5]. The main use of pi graph is the reaction of human organs like tympanum, lungs and so on that are revealed to impact load and it is extremely hard to figure the reaction of human organs subjected to impact load [6].The model of load cladding structure is established and the interaction between blast load, the foam cladding and the main structure is considered. The main structure is protected by blast load by using foam cladding of LCS model. From LCS model two non dimensional parameters (κ and τ) is derived [7].For the analysis of the behaviour of RC beam subjected to blast load and is protected by foam of the improved LCS model [8].

Momentarily, the response ofthe blast load on front wall, rear wall and roof side is analyzed.From the past examinations just rooftop divider, raise divider is done and in the coeval work an exertion made to contemplate, the impact load following up on rooftop side is envisaged.The varoius researcher have ploted the pressure impulse curve for the blast load acting on structure member that is RCC slab, beam, column and also RCC panel.In the current work, pressure impulse curve is studied for the structural system of SDOF model. Pressure impulse diagram has been calculated based on energy based concept method.A lot of reaction is diminished by adding cladding material to the basic framework as LCS display and the non dimensional parameters of κ and τ are done.

2. Blast load on SDOF system

The length of the building 12m, width of the building 10m and height of the building 3m, equivalent mass of building 9810N, stiffness $21860*10^3$ N/m and natural circular frequency of $34*10^{-3}$ rad/ms are considered. A 2000kg TNT equivalent bomb is positioned on the earth surface at a distance of 50m from the front wall together withloading of the building is taken as shown in figure1

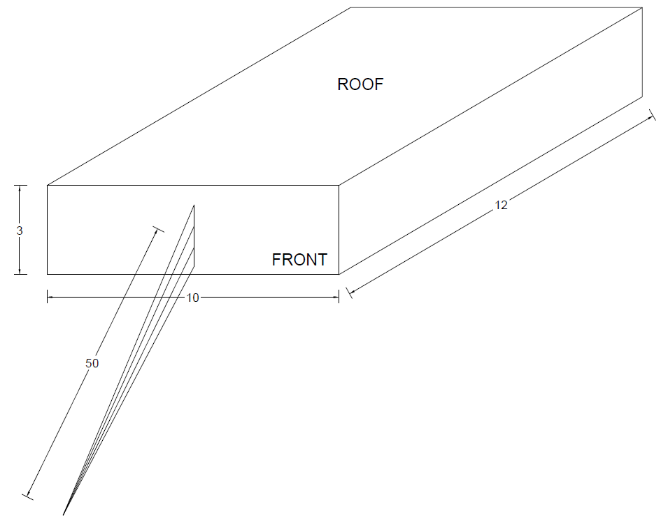


Fig. 1. Blast Load acting in SDOF system model.

The following equations are used to obtain the response of SDOF system are given in Modern Protective Structures [9].

$$M\ddot{y} + C\dot{y} + ky = F(t) \tag{1}$$

Where M- Mass of the structure, $\ddot{y}$ -Acceleration, C- Damping

$\dot{y}$ -Velocity, k- Structural Stiffness, y -Displacement, F(t)- External force.

$$y = C_1 \sin(\omega t) + C_2 \cos(\omega t) \tag{2}$$

Where $C_1 \& C_2$ -Constant, ω -Natural circular frequency

The following procedure shows that blast load acting on front wall, rear wall and roof of the building and design charts given in figure.2

Calculating equivalent TNT load from weight in kg and increase the weight by 20%.

Determining the $Z_g = R_g / W^{1/3}$ Where Z_g - Scaled Distance, R_g - Range and W- weight of the Blast load and by using chart Results are shown below table 1 for 1(front wall) , 2(rear wall) and 3(roof).

1. For Front wall loading

i.Calculate shock front velocity U_s=0.44 m/msec given in chart

ii.Calculate clearing time $t_c = 3S/U_s = \frac{3*3}{0.44} = 20.5\ msec$ where S=3.0m <B/2=5.0m

iii.Finding t_{OF}, from equation $t_{OF} = 2i_s/P_{so}$ =$2 * 1025/74.3$ =27.6msec iv.Finding peak pressure (wind pressure) , reflected pulse duration and finally constructing pressure time curve for front wall.

Table 1
The parameter of the Blast load acting on SDOF Structural System.

Point No	R (m)	Z $(m/kg^{1/3})$	P_{so} (kPa)	t_a (msec)	L_w (m)	t_o (msec)	i_s (kPa-msec)	P_r (kPa)	i_r (kPa-msec)
1	50.0	3.73	74.3	69	12.2	52.2	1025	191.1	2338
2	62.0	4.63	49.5	98	13.9	55.6	-	-	-
3	62.0	4.63	49.5	98	13.9	55.6	-	-	-

2. For rear wall loading to construct pressure time curve the combined applied area is taken into consideration and linear blast load decay is defined by $C_E P_{so}+C_D q_o$.
3. For roof wall loading the following equations are used to calculate pressure time curve

v.Finding free-field pressure at the centre of roof

$$P_o = f\rho c(160)(R/W^{1/3})^n \tag{3}$$

Where P_o - free field pressure, f-Coupling factor, ρc - acoustic impendence, n- attenuation co-efficient, R-range and W-charge weight.

i.Determine the free field pressure decay from the following expression

$$P(t) = P_o e^{-\alpha t/t_d} \tag{4}$$

ii.For equivalent triangular loading pulse, duration is calculated as below

$$t_d = 2I_o/P_o \tag{5}$$

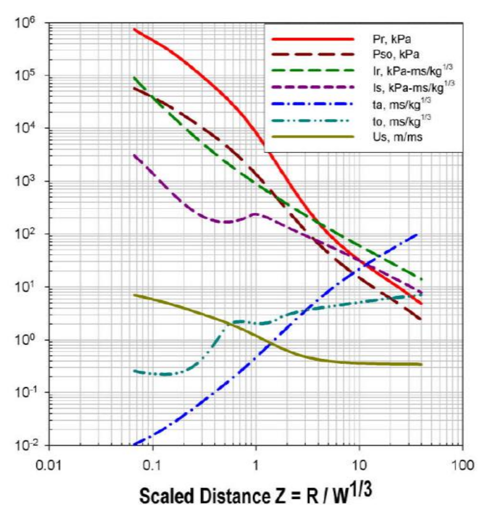


Fig. 2. Hemispherical TNT explosion on the surface at sea level of Blast wave parameters.

Case a: Blast load acting on front wall

The Figure3 reperesents the blast load acting on front wall. The peak pressure occurs at a time of 27.6 msec is 191kPa of a blast load.

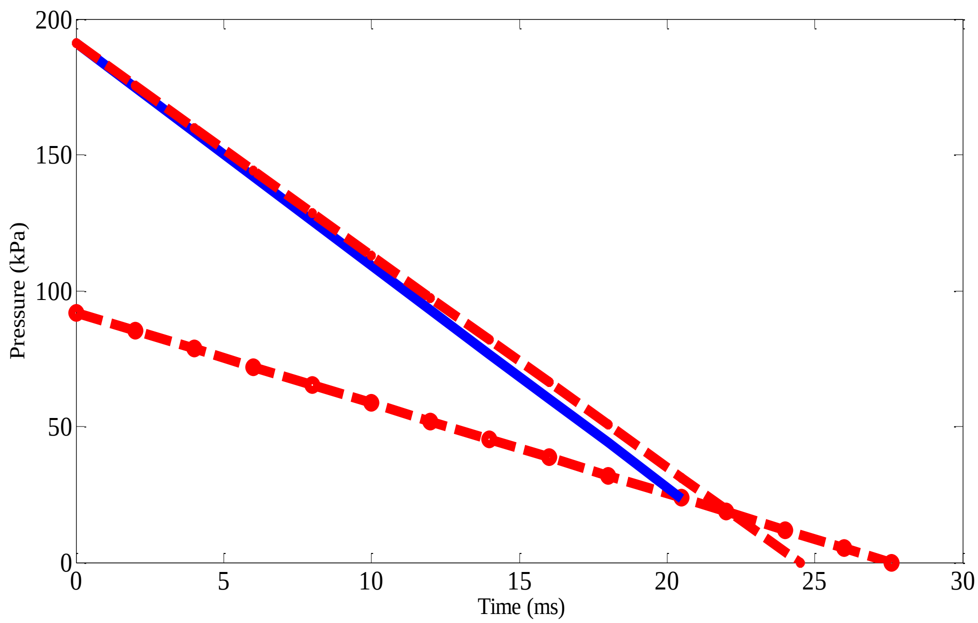
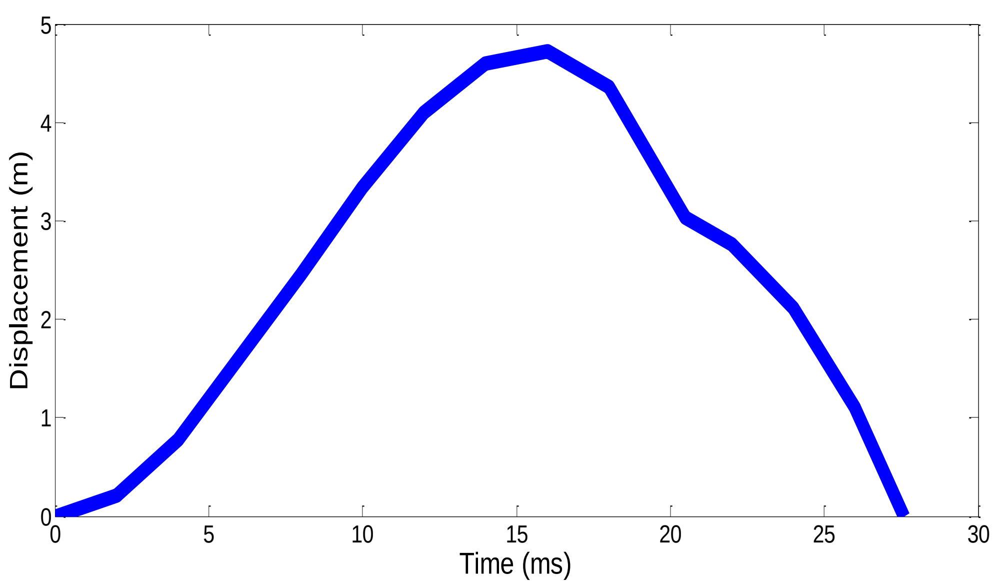
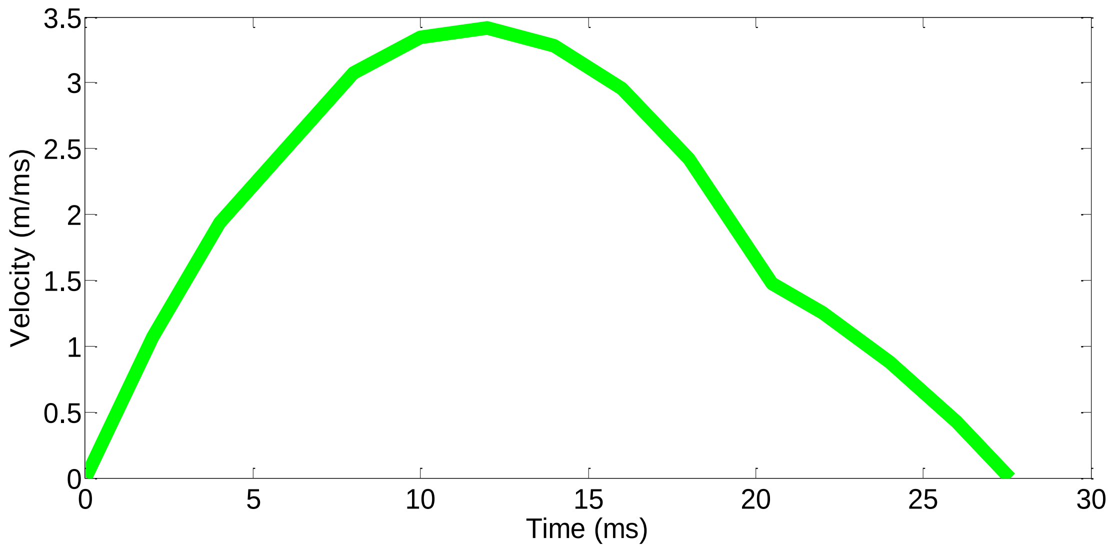


Fig. 3. Pressure time curve for front wall[9].

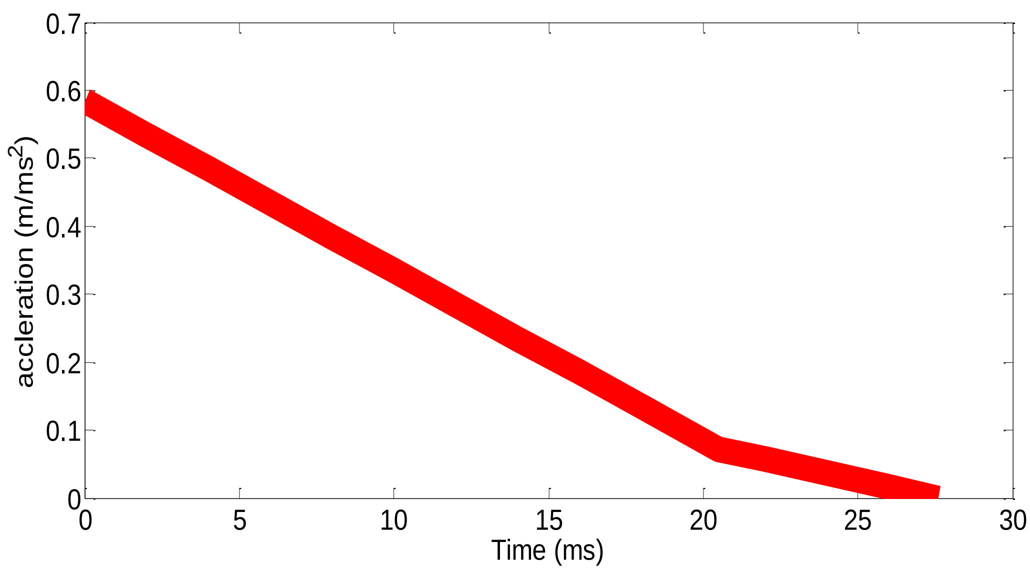
The Figure 4 represents three responses of blast load acting on front wall for the bare SDOF system.



(a): Response of blast load on front wall along Displacement.



(b): Response of blast load on front wall along Velocity.



(c): Response of blast load on front wall along acceleration.

Fig. 4. Response of blast load on front wall with respect to time.

The figure 4 represents the response of blast load acting on front wall are for time duration of 15ms is 4.8m, velocity of 3.48 m/ms at a duration of 13ms and accleration is 0.58m/ms2 at a duration is 1ms.

Case b: Rear wall subjected to blast load

The Figure5 reperesents the blast load acting on rear wall. The peak pressure is 40.7kPa of a blast load.

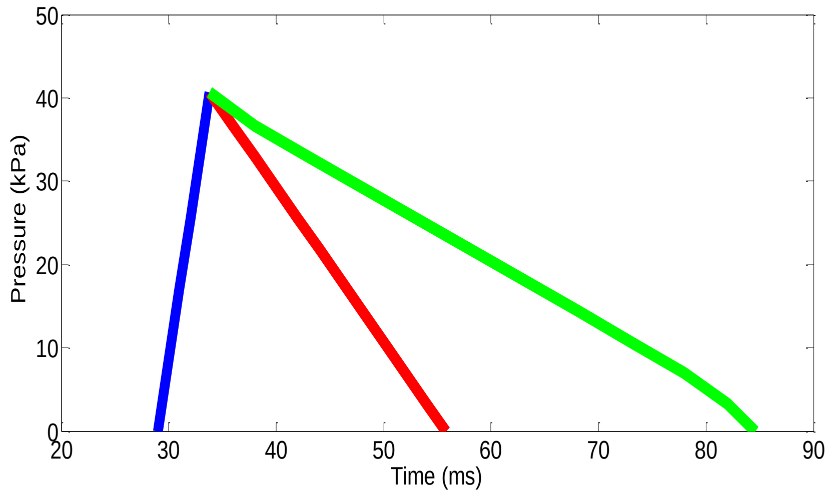
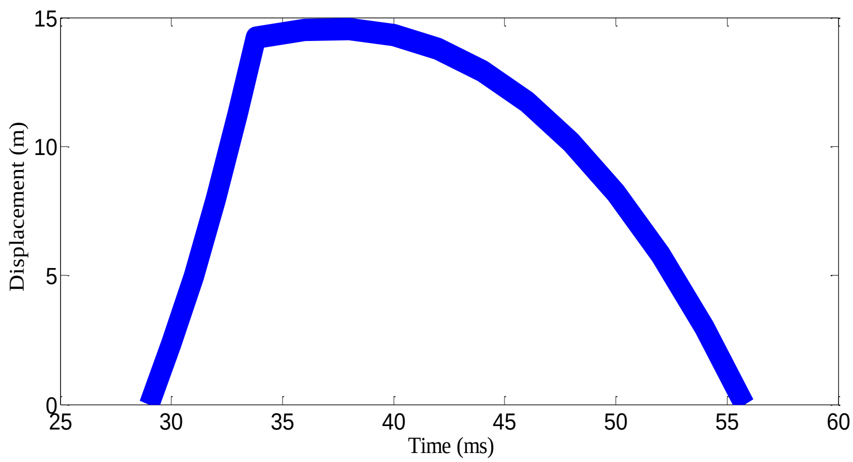
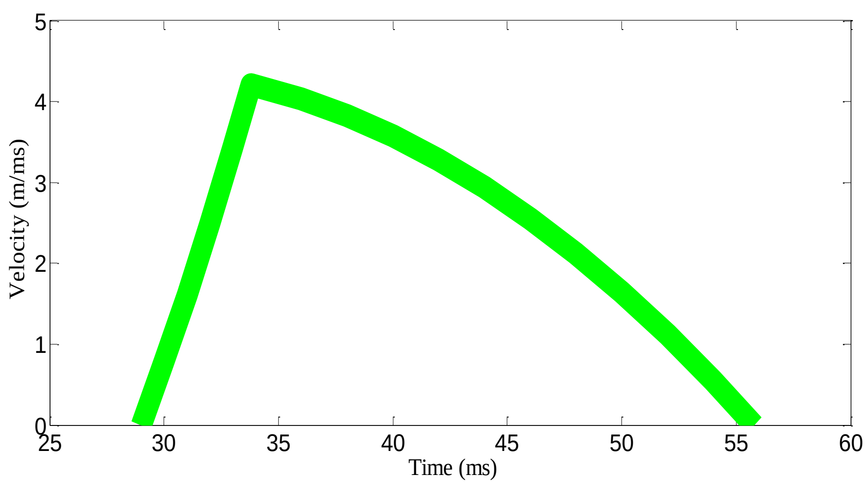


Fig. 5. Pressure time Curves for Rear Wall[9].

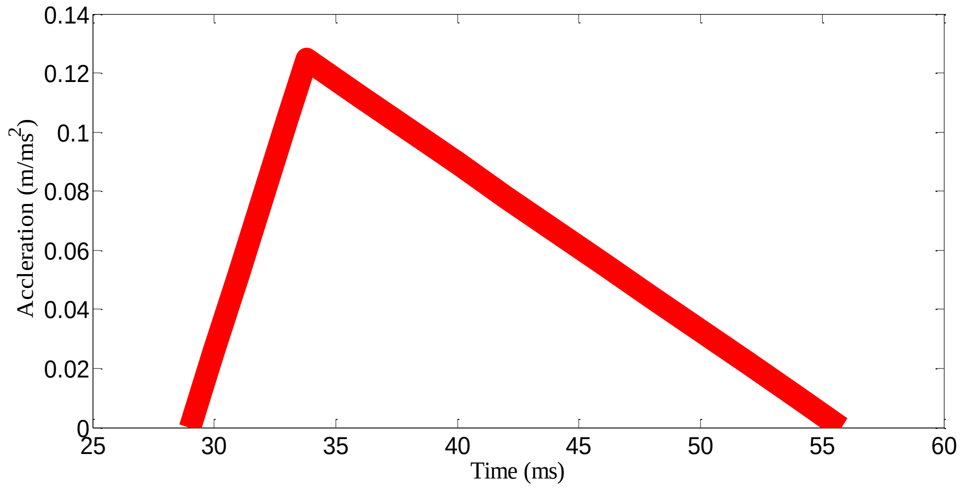
The Figure 5 represents the response of blast load acting on rear wall for bare SDOF system.



(a): Response of blast load on rear wall along displacement.



(b): Response of blast load on rear wall along velocity.



(c): Response of blast load on rear wall along acceleration.

Fig. 6. Response of blast load on rear wall with respect to time.

The figure 6 represents the response of blast load acting on rear wall are for time duration of 38ms is 15m, velocity of 4.3 m/ms at a duration of 35ms and accleration is 0.13m/ms^2 at a duration is 32ms.

Case c: Blast load acting on roof

The Figure7 reperesents the blast load acting on roof. The peak pressure is 37.7kPa and duration of 78.05ms of a blast load.

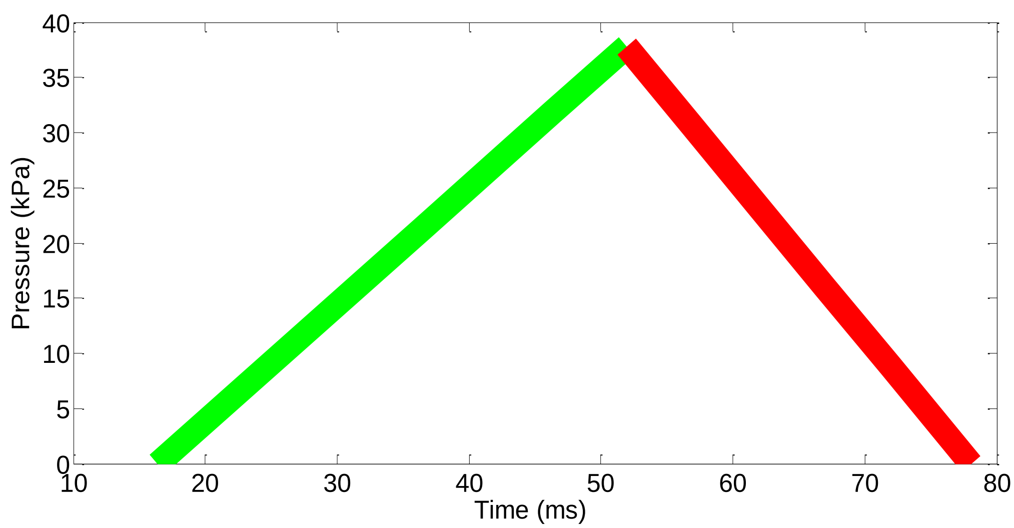
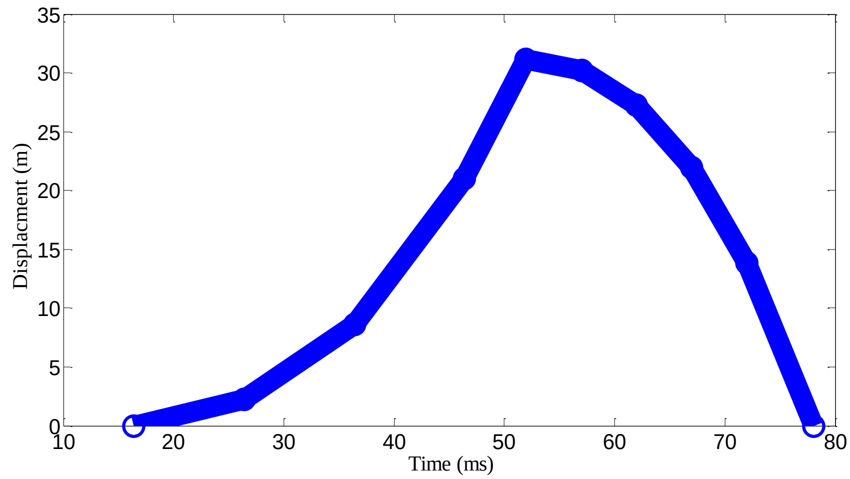
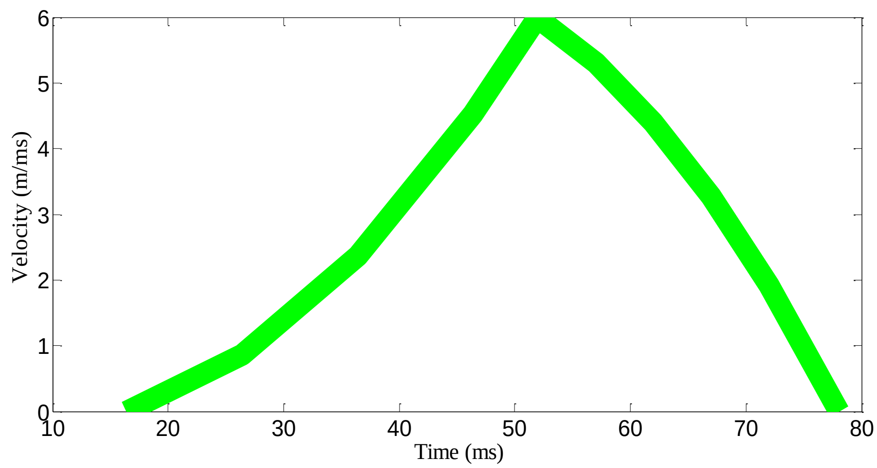


Fig. 7. Pressure time curve for roof wall.

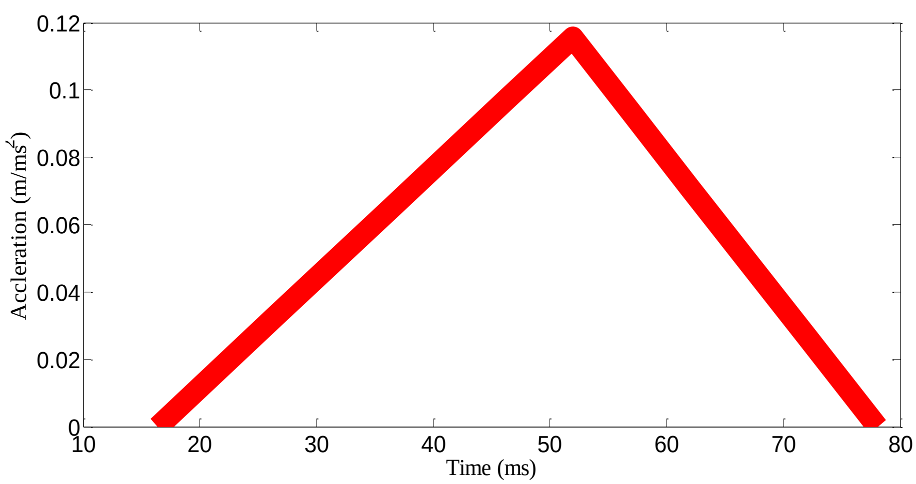
The Figure 8 represents the response of blast load acting on roof side for bare SDOF system.



(a): Response of blast load on roof wall along displacement.



(b): Response of blast load on roof wall along velocity.



(c): Response of blast load on roof wall alongacceleration.

Fig. 8. Response of blast load on roof with respect to time.

The figure 8 represents the response of blast load acting on roof are for time duration of 50ms is 32m, velocity of 6 m/ms at a duration of 52ms and accleration is 0.19m/ms^2 at a duration is 52ms.

3. Pressure impulse diagram of a SDOF system

The pressure impulse (pi) diagram plays a vital role for a structure subjected to blast load because blast load gives pressure verses time curve.The pi diagram is an useful tool in preliminary strength, design and damage assessment.The basic improvement in the field of protective structure, a pressure impulse diagram of energy based approach is used for dynamic loads. The following equations are used for calculation pi diagram. P-I diagram typically energy-based method is a function of mass and impulse defined as the amount of input energy is horizontal axis and energy input rate is plotted in vertical axis. A combination of input energy and its rate a failure criterion or damage indicates above curve. To evaluate the loading hazard from energy point of view the designer will use the convenient tool of pi curve. In the pressure impulse curve failure occur r damage occur when the curve falls to the right and above the curve.

The following equation will use to plot the pi curve

$$E_{input} = \frac{I^2}{2M} \tag{6}$$

Where I-impulse is defined as the area under the load time function

To produce the given response that is maximum displacement is required by actual absorbed energy, U_{max}, is defined as

$$E_{imparted} = \int_0^{U_{max}} kudu \tag{7}$$

Where $E_{imparted}$ - Imparted energy or absorbed energy

$$E_{input\_rate} = \frac{E_{input}}{\beta t_d} \tag{8}$$

Where β is a load pulse shape factor, β=0.5 triangular load.

$$\overline{E} = \frac{E_{input}}{E_{imparted}} = \frac{\frac{I^2}{2M}}{\frac{1}{2}kU_{max}{}^2} = \frac{I^2}{kmU_{max}{}^2} \tag{9}$$

$$\overline{R} = \frac{E_{input\_rate}}{E_{imparted}} = \frac{\frac{(\beta F_o t_d)^2}{2m}\frac{1}{\beta t_d}}{\frac{1}{2}kU_{max}{}^2\omega} = \frac{\beta F_o{}^2 t_d}{k^{\frac{3}{2}}m^{\frac{1}{2}}U_{max}{}^2} \tag{10}$$

Where $\overline{E}$ -Dimensionless input energy ,k- Structural Stiffness, $\overline{R}$ - Dimensionless input energy rate. A typical pi curve is plotted with x axis is $\overline{E}$ and y axis is $\overline{R}$

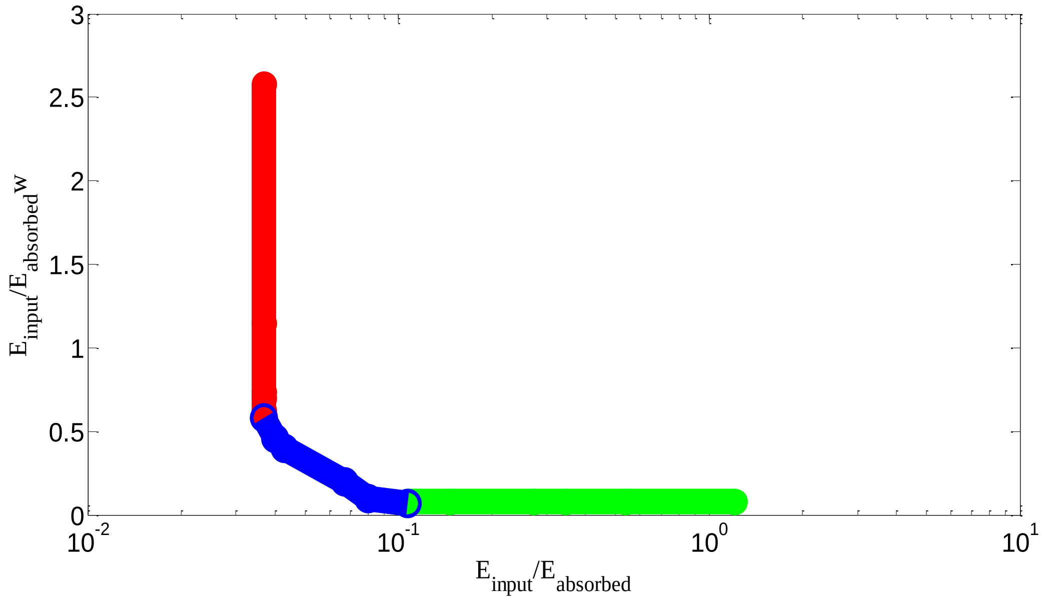


Fig. 9. Pressure impulse curve for SDOF system subjected to blast load on front wall.

The pressure impulse (pi) diagram for SDOF system for blast load acting on front wall is plotted in figure 9. With the consistent drive 0.02 kPams, most extreme pressure of 2.52kPa is taken and with the steady pressure 0.05Pa, the impulse is acquired with the greatest pressure of 1.3kPams.

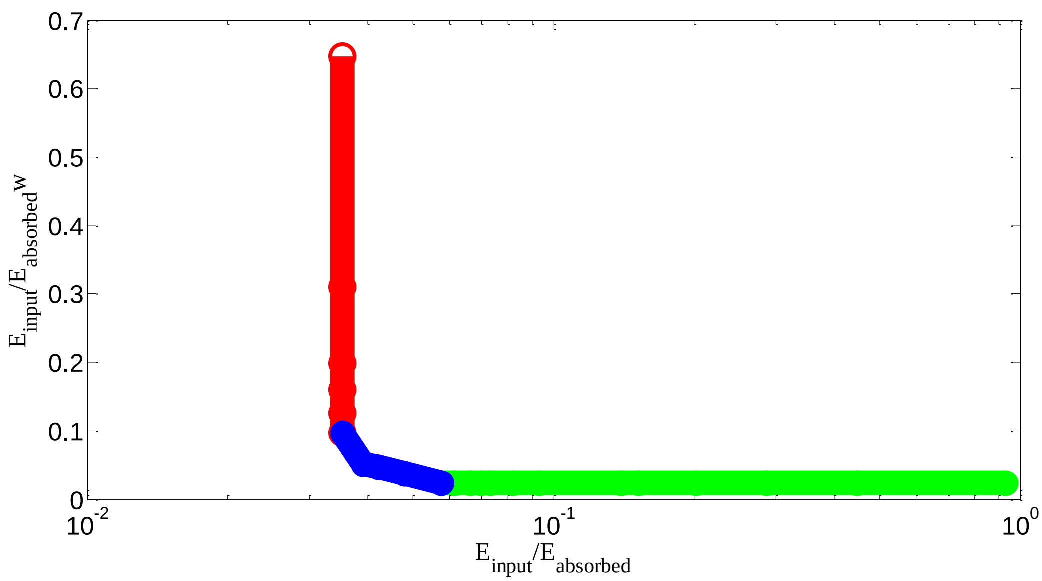


Fig. 10. Pressure impulse curve for SDOF system subjected to blast load on rear wall.

The pressure impulse diagram for SDOF system for blast load acting on rear wall is plotted in figure 10 of the bare system. With the steady impulse 0.035 kPams, most extreme weight of 0.65 kPa is taken and a consistent pressure of 0.05Pa outcomes in a drive with the greatest pressure of 1kPams.

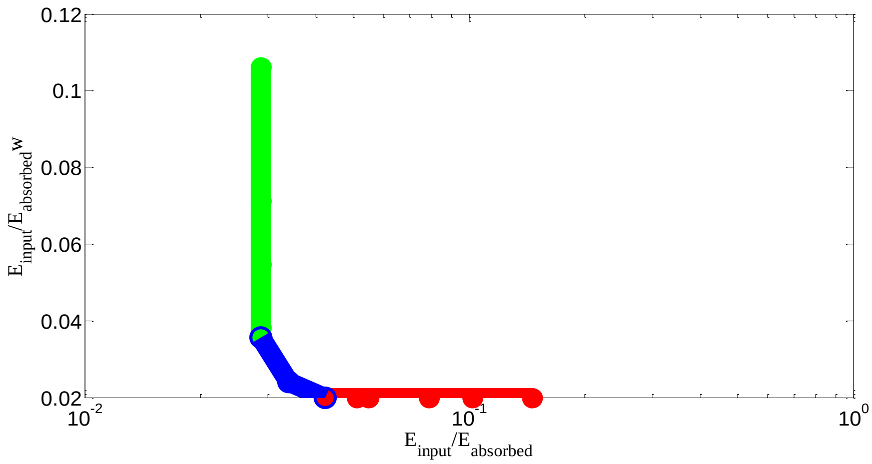


Fig. 11. Pressure impulse curve for SDOF system subjected to blast load on roof wall.

The pressure impulse diagram for SDOF system for blast load acting on roof wall is plotted in figure 11 of the bare system.The consistent impulse of 0.045 kPams brings about the most extreme pressure of 0.15 kPa and with a steady pressure of 0.02kPa, the drive with the greatest pressure of 0.15kPams is acquired.

4. Load-cladding structural model[10]

In the current model LCS is employed. Its consists that is blast load of linear decaying P(t), foam cladding by a cover plate and a reinforced concrete .

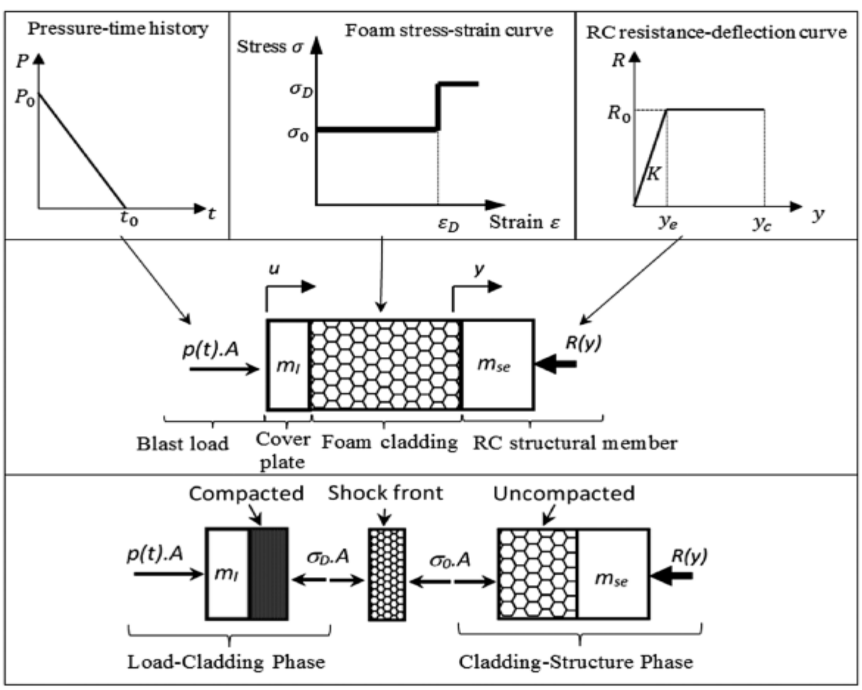


Fig. 12. LCS model For RC Structures.

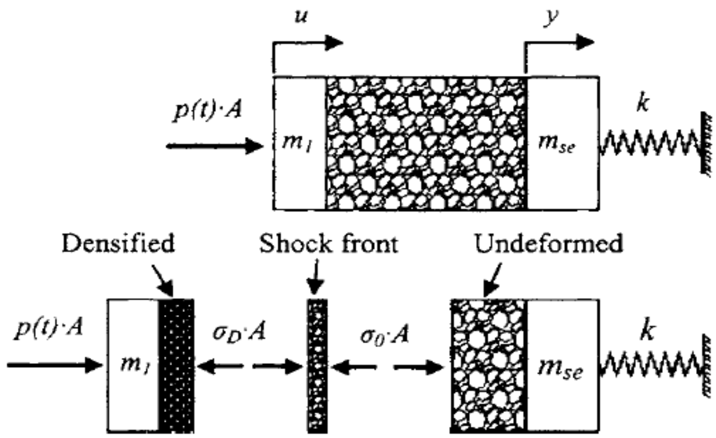


Fig. 13. Load Cladding Structural Model of Free Body Diagram.

The Figure 12 andFigure 13 indicates the foam cladding material exposed to blast load, fully compacted and uncompacted section of cladding.The equation of motion of the front load cladding phase can

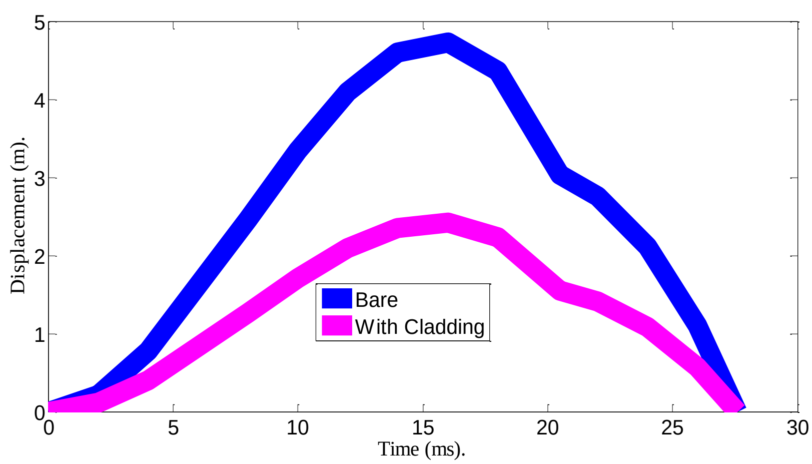
$$P(t) = \begin{cases} P_o(1 - t/t_o) \; for t \leq t_o \\ \hline 0 \; for t \geq t_o \end{cases} \tag{11}$$

$$\left[m_l + \frac{\rho A}{\varepsilon_D}(\dot{U} - \dot{y}) \right] \ddot{U} + \frac{\rho A}{\varepsilon_D}(\dot{U} - \dot{y})^2 + [\sigma_o - P(t)]A = 0 \tag{12}$$

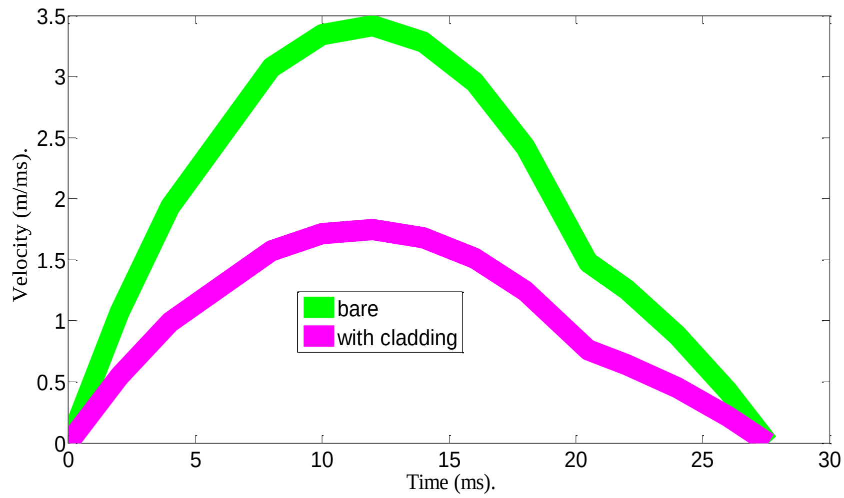
Where m_l -mass of the structure, P_o -peak load, σ_o -plateau stress, σ_D - Densification stress, ρ - Density of the foam material, A- area of the foam material.

5. Response of SDOF system with cladding material

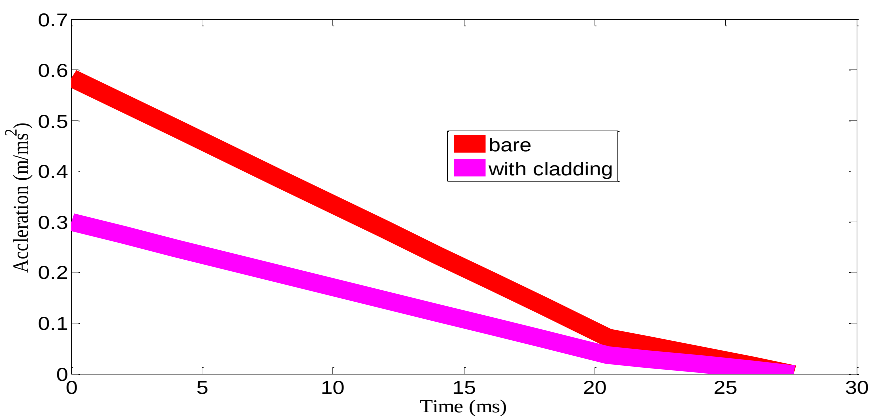
The following figure represents the response of SDOF system with cladding material subjected to blast load.



(a): Response of blast load on front wall along displacement with and without cladding material.



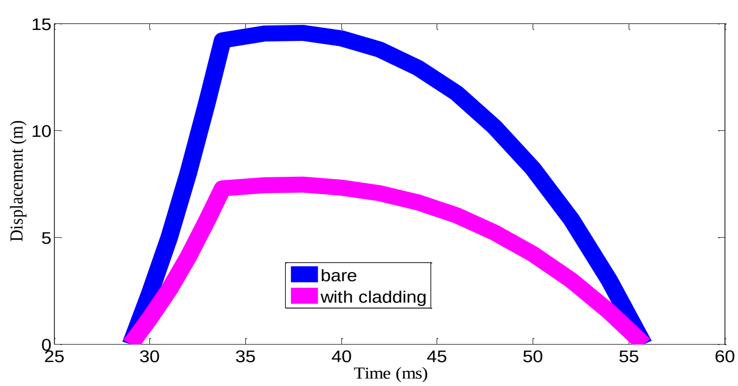
(b): Response of blast load on front wall alongvelocity with and without cladding material.



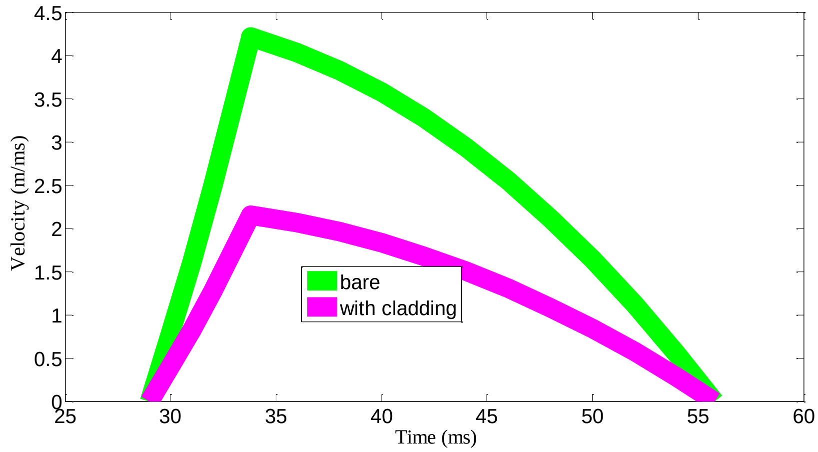
(c): Response of blast load on front wall alongacceleration with and without cladding material.

Fig.14. Response of the SDOF with cladding material subjected to blast load on front wall.

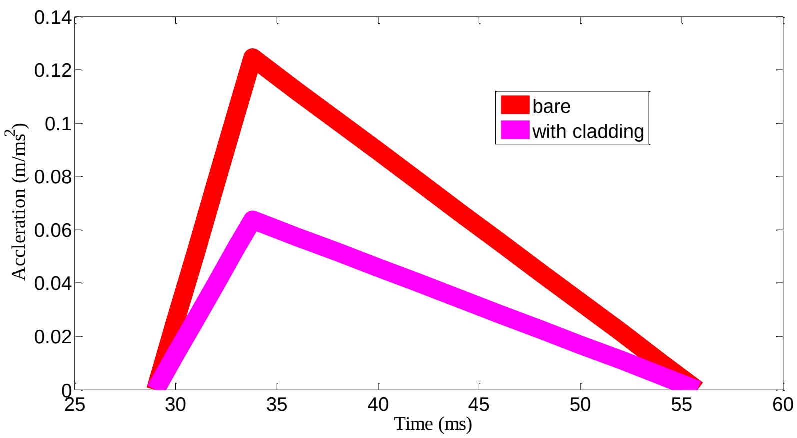
In the figure 14 discussed that by using cladding material , the front wall response of the displacement is reduced by 4.8m to 2.8m, velocity is reduced b y 3.48 m/ms to 1.8 m/ms and accleration is reduced to 0.58 m/ms^2 to 0.3 m/ms^2



(a): Response of blast load on rear wall alongdisplacment with and without cladding material.



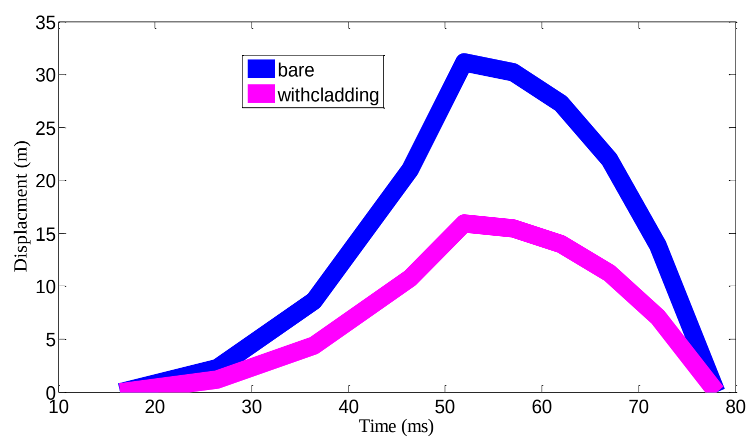
(b): Response of blast load on rear wall along velocity with and without cladding material.



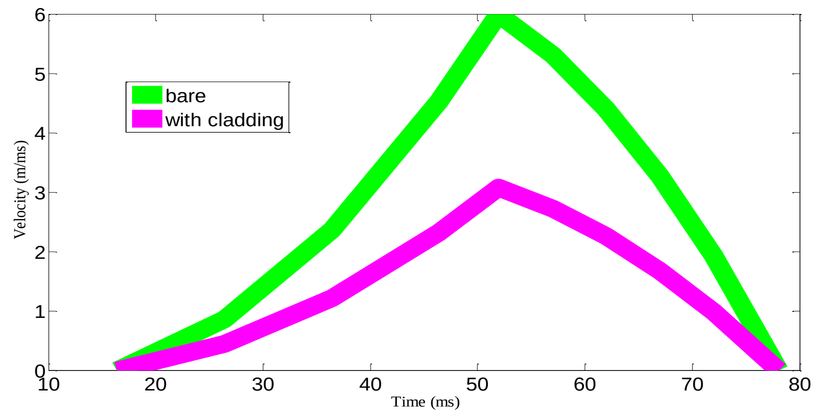
(c): Response of blast load on rear wall along acceleration with and without Cladding material.

Fig. 15. Response of the SDOF with cladding material subjected to blast load on rear Wall.

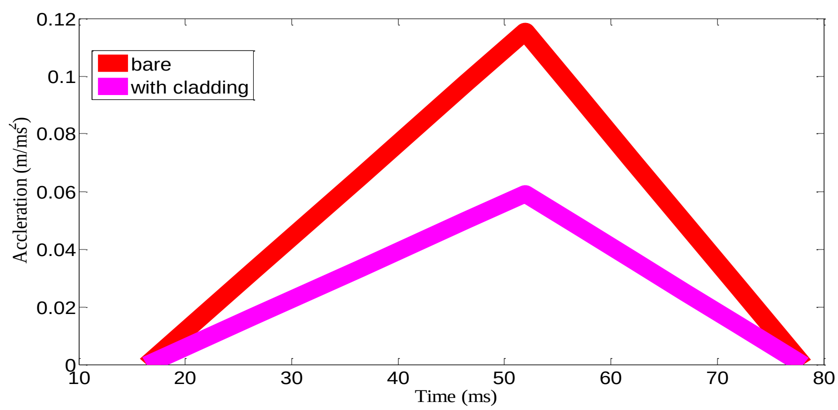
In the figure 15 discussed that by using cladding material , the rear wall response of the displacement is reduced by 15m to 7m, velocity is reduced by 4.3 m/ms to 2.2 m/ms and accleration is reduced to 0.13 m/ms^2 to 0.07 m/ms^2



(a): Response of blast load on roof along displacement with and without cladding material.



(b): Response of blast load on roof of velocity with and without cladding material.



(c): Response of blast load on roof alongacceleration with and without cladding material.

Fig. 16. Response of the SDOF with cladding material subjected to blast load on roof.

In the figure 16 discussed that by using cladding material , the roof response of the displacement is reduced by 32m to 16m, velocity is reduced by 6 m/ms to 3 m/ms and accleration is reduced to 0.19 m/ms^2 to 0.16 m/ms^2.The table 2, table3 and table4 represents SDOF system subjected to blast load on front wall, rear wall and roof along with the reduction of reponse by using cladding material.

Table 2
Displacment reduction of SDOF system exposed to Blast load by using Cladding material.

Sl.No	Type of Member acting on Load	Peak Displacement of the SDOF System Without Cladding (m)	Peak Displacement of the SDOF System With Cladding (m)
1	Front wall	4.8	2.8
2	Rear wall	15	7
3	Roof	32	16

Table 3
Reduction of velocity of SDOF system subjected to Blast load by using Cladding material.

Sl.No	Type of Member acting on Load	Maximum Velocity of the SDOF System Without Cladding (m/ms)	Maximum Velocity of the SDOF System Without Cladding (m/ms)
1	Front wall	3.48	1.8
2	Rear wall	4.3	2.2
3	Roof	6	3

Table 4
Reduction of acceleration of SDOF system subjected to Blast load by using Cladding material.

Sl.No	Type of Member acting on Load	Peak acceleration of the SDOF System Without Cladding (m/ms^2)	Peak acceleration of the SDOF System Without Cladding (m/ms^2)
1	Front wall	0.58	0.3
2	Rear wall	0.13	0.07
3	Roof	0.19	0.06

6. Nondimensional parameters κ and τ [20]

The structure is attached to the foam material, a curve is obtained by the concept of LCS model, which is called non-dimensional p-i diagram of the protected cladding structure.The foam material plays a vital role in the resistance capacity the structure subjected to blast load. The relation of the non-dimensional parameters κ and τ can be obtained by the equation:

$$P = \frac{P_o A}{K \, y_C / 2} \tag{13}$$

$$i = \frac{I_o}{y_c \sqrt{K m_{se}}} \tag{14}$$

Where P_o -Peak load,

M_{se} is the structural mass, Non dimensional parameter κ, σ_o − plateau stress =5.4MPa =5.4*10^6 N/m^2 , K- Structural Stiffness of the structure=122.46*10^6 N/m, Y_c- Maximum displacement=4.24 m, A-area of foam =30 m^2, The value of κ =0.624.

$$\kappa = \frac{\sigma_o A}{\kappa y_c / 2} \tag{15}$$

Second non dimensional parameter is

$$\tau = \frac{\sqrt{(m_f + 2m_l)\frac{l\varepsilon_D}{\sigma_o A}}}{T/2} \tag{16}$$

Where

m_f - Mass of the foam material-9270.45 N

m_l - Mass of the load structure-11.213*10^3 N

l - Thickness of the foam layer-75 mm

ε_D - Densification strain of the foam material-0.54

T - Natural period of the structure-1160msec

The properties of the foam material are referred in the paper [21]

The value of τis 0.053.

The non dimensional parameters of the p and i for κ = 0.624and τ = 0.053are shown in Figure 17, Figure 18 and figure 19.

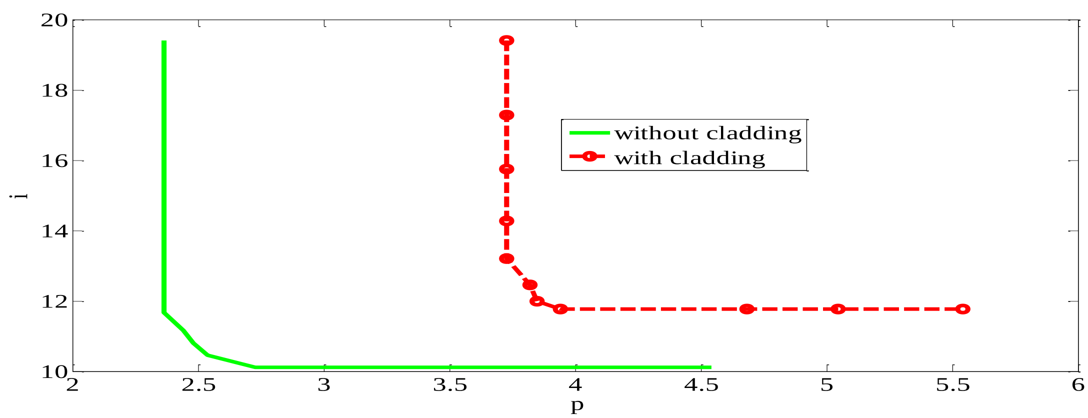


Fig. 17. Non dimensional parameter pi diagrams of the structures withoutandwith cladding material for Blast load acting on front wall [19].

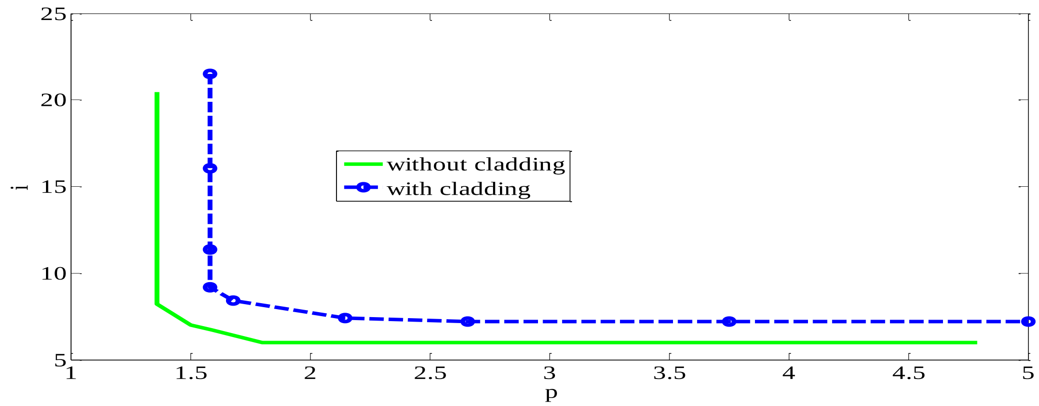


Fig. 18. Non-dimensional parameter pi diagrams of the structures without and with cladding material for Blast load acting on rear wall (19).

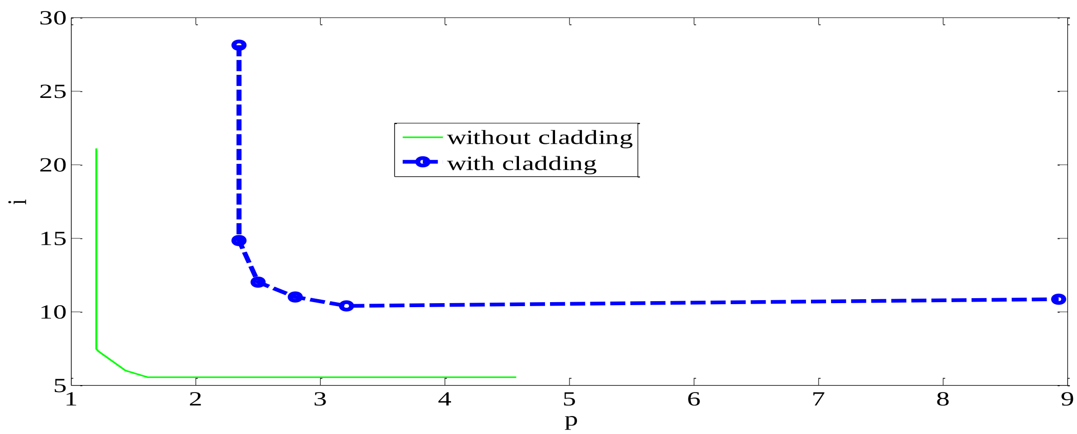


Fig. 19. Non dimensional parameter pi diagrams of the structures without and with cladding material for Blast load acting on roof (19).

7. Conclusion

From this Proposed model, following conclusions can be made:

1. An analytical technique for the SDOF structural system subjected to blast load studied,SDOF system is cost effective, less time consumption.
2. The response of blast load acting on SDOF structural system on front wall , rear wall and roof is studied.
3. The LCS analytical model is used to control the response of blast load acting on SDOF system is studied , the response of displacment is 50% is reduced in all the thress cases of loading, where as velocity 45% is reduced and accleration is 48% is reduced.

4. The pressure impulse curve plays a vital role in the study of response of structural system subjected to blast load is considered , the results shows that 40% pressure impulse curve will take the load of the structural system by using cladding material.
5. The nondimensional parameter are κ and τ studied and also describe the relation between the foam cladding and the main structure, the results shows that foam cladding material is properly designed may increase the structural system blast load carrying capacity.

References

[1] Theodor. Krauthammer. Modern Protective Structures CRC. 2015.

[2] Risk Reinsurance, Human Resources, Terrorism & Political Violence Risk Map 2016.

[3] Xia Y, Wu C, Zhang F, Li Z-X, Bennett T. Numerical Analysis of Foam-Protected RC Members under Blast Loads. Int J Prot Struct 2014;5:367–90. doi:10.1260/2041-4196.5.4.367.

[4] Biggs JM. Introduction to Structural Dynamics. New York: McGraw-Hill. 1964.

[5] Mays G, Smith PD, Smith PD. Blast effects on buildings: Design of buildings to optimize resistance to blast loading. Thomas Telford; 1995.

[6] Krauthammer T, Astarlioglu S, Blasko J, Soh TB, Ng PH. Pressure–impulse diagrams for the behavior assessment of structural components. Int J Impact Eng 2008;35:771–83. doi:10.1016/j.ijimpeng.2007.12.004.

[7] Ye ZQ, Ma GW. Effects of Foam Claddings for Structure Protection against Blast Loads. J Eng Mech 2007;133:41–7. doi:10.1061/(ASCE)0733-9399(2007)133:1(41).

[8] Xu J, Wu C, Li J, Cui J. Simplified finite element method analysis of ultra-high-performance fibre-reinforced concrete columns under blast loads. Adv Struct Eng 2017;20:139–51. doi:10.1177/1369433216646012.

[9] Remennikov AM. Blast Resistant Consulting: A New Challenge for Structural Engineers. Aust J Struct Eng 2002;4:121–34. doi:10.1080/13287982.2002.11464913.

[10] Xia Y, Wu C, Li Z-X. Optimized Design of Foam Cladding for Protection of Reinforced Concrete Members under Blast Loading. J Struct Eng 2015;141:06014010. doi:10.1061/(ASCE)ST.1943-541X.0001190.