Computational Engineering and Physical Modeling 2-4 (2019) 78-94

Contents lists available at CEPM

Computational Engineering and Physical Modeling

Journal homepage: www.jcepm.com

Blast Mitigations of Mid Rise Structures by Cladding Material

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

1. Research Scholar, Civil Engineering Department, Government Engineering College Haveri Karnataka India
2. Professor and HOD Civil Engineering Department, Government Engineering College Haveri Karnataka India

Corresponding author: *kirankk0202@gmail.com*

https://doi.org/10.22115/CEPM.2020.196935.1066

ARTICLE INFO

Article history:
Received: 04 August 2019
Revised: 22 November 2019
Accepted: 09 March 2020

Keywords:
Blast load;
Pressure impulse curve;
Cladding material;
Storey drift;
Storey drift ratio.

ABSTRACT

Structure exposed to blast load is unpredictable, causes severe damage to the structure and also takes the life of people.Cladding material is a light weight material, mobile, versatile, economical material used for energy abortion of the structure exposed to blast load. Here a study is made on ten story structure exposed to blast load. Each floor as a three degree of freedom that is one along translation between floor and the structure and two translation between structure and cladding material, totally thirty degree of freedom is considered. The cladding material is used for the connection of every floor. Rubber material is also used for the connection between the cladding and structure. The responses in terms of pressure impulse curve, story drift , story drift ratio is also considered.The maximum energy is observed by using cladding material of the structure and considerable amount of responses is reduced.

1. Introduction

For the public benefits and services civil infra structures, which include buildings, energy, communications and transportations systems. Civil infrastructures are subjected to unpredictable load such as earthquakes, hurricanes, tornadoes, storm surges, accidental and intentional blasts

How to cite this article: Kiran KK, Kori J. Blast Mitigations of Mid Rise Structures by Cladding Material. Comput Eng Phys Model 2019;2(4):78–94. https://doi.org/10.22115/cepm.2020.196935.1066

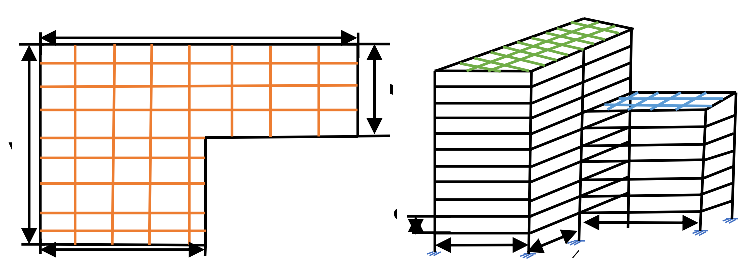
[1]. From the previous incident (World trade Centre, Taj Hotel attack Mumbai) that have taken place around the world is due to terrorist attack, that leads not only threat to life of people but also cause damages to structure [2].

In the design of hand book for metal foam aluminum foam is widely used for the protection of structure against blast load [3]. Aluminum foam is used for cladding because of the advantages properties such as light weight material, with excellent plastic energy absorbing capacity, soft material, blast energy absorbing, low density, it is a mobile[4].The applications of aluminum foam are aerospace, biomedical, automotive and biomedical industries [5].To protect the structure against impulse load by conventional method is uneconomical, expensive labour, time consuming in construction and retrofit [6].The metallic foam under goes large deformations exposed to blast load, thus metallic foam attached to the structure absorb maximum energy and protect to the structure [7]. Many research works were carried out both in analytical and experimental method of a structure exposed to blast load, the structure can be protected by using aluminum foam as a sacrificial cladding material [4,8–17]. The reinforced concrete member subjected to blast load a modal is prepared by using LS-DYNA and its protected by using cladding material [18]. Some research works are carried out against pounding effect of multi-storey structure subjected to seismic load which can be prevented by using rubber [19–21].

The combinations of pressure and impulse (pressure and time) curve is known as Pi curve. Pi curve are used to determine the damage criteria for houses, small office building, light framed industrial building, also used to specific organs (eardrums, lungs etc) of the human body in the response of blast loading [22,23]. For pressure impulse (Pi) diagrams of structural elements subjected to transient load (Blast load), detailed numerical and theoretical methods are shown [24]. An analytical formula is derived to determine the pressure impulse curve for a column subjected to a blast load [25]. A Pi diagram of SDOF system for elastic plastic hardening and elastic plastic softening under the blast load is derived [26]. There are various methods to plot the pressure impulse curve like analytical method, theoretical method, and energy-based method and so on. Among them energy-based method is accurate and easy method. The fundamental improvement of protection of a structure is obtained by plotting pressure impulse curve [27].

In this paper mid-rise of unsymmetrical ten storey structure exposed to blast load is considered. The structure is dynamically protected by using cladding system. Response are calculated displacement, velocity, acceleration, pressure impulse curve, normalised pressure impulse curve, inter storey displacement, storey drift, storey drift ratio.

2. Ten storey structure model subjected to blast load



(a) **(b)**

Fig. 1. (a) Plan & (b) Elevation of the 10 storey unsymmetrical structures.

Fig. 1. shows the 10 storey unsymmetrical plan and elevations of structure. First five storey structure is unsymmetrical and remaining is unsymmetrical both in plan and elevations. The blast load exposed to the front elevation of the structure. Table 1 shows the input parameter of the structure exposed to blast load.

Table 1
Input parameter of a structure.

Sl No	Parameter of the Structure	Symbol	Magnitude
1	Weight of the blast	W	1000 TNT
2	Height of each floor	H	3m
3	Mass of each floor	M	11213 kg
4	Stiffness	K	1000*21860 N/m
5	Area of each floor	A	60 m^2
6	Natural Frequency	w_n	12.567 Hertz
7	Damping ratio	ζ	5%
8	Material	-	Steel
9	Property	-	Elastic

The following equations are used to determine the peak load of the structure subjected to blast load

$$R_h = \left(R_G{}^2 + h^2\right)^{1/2} \tag{1}$$

Where R_h - Standoff distance, R_G- Scaled standoff distance, h-height of each floor

$$Z_h = R_h / W^{1/3} \tag{2}$$

$$P_{so} = \frac{1772}{Z_h{}^3} - \frac{114}{Z_h{}^2} + \frac{108}{Z_h} \tag{3}$$

$$t_{blast} = W^{1/3} 10^{[-2.75+0.27\log(Z_h)]} \tag{4}$$

$$U = a_o \cdot \sqrt{\frac{6P_{so}+7P_o}{7P_o}} \tag{5}$$

$$t_A = \frac{R_h}{U} \tag{6}$$

$$P_r = C_r\, P_{so} \tag{7}$$

$$C_r = 3\left(\sqrt[4]{\frac{P_S}{101}}\right) \tag{8}$$

Where Z_h – Scaled standoff distance

$$P(t) = P_o + P_r\left(1 - \frac{t}{t_o}\right)\exp\left(-\gamma\frac{t}{t_o}\right) \tag{9}$$

$$\gamma = Z_h^{2}\text{-}3.7Z_h+4.2 \tag{10}$$

Where, P(t) is the pressure in time; γ is parameter controlling the rate wave amplitude, Pr is peak reflected over pressure, P_{so} is peak incident over pressure, t_A is time of arrival, t_{blast} is blast load duration, U- wave velocity, P_o is ambient air pressure and a_o is speed of sound in air 335 m/sec.

3. Cladding material connected to structure

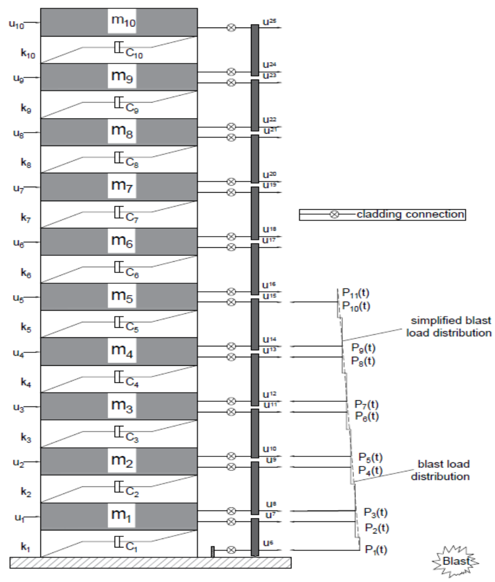


Fig. 2. Simulated structures with cladding panels.

Fig. 2. shows the connections details of the structure with cladding material. Fig 3 shows the blast load acting on ten storey structures. The maximum peak reflected over pressure occurs at 11 node of 2500 kPa on 0.01 sec.

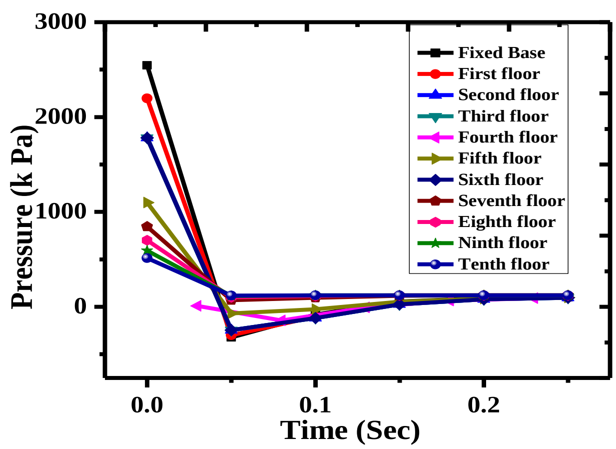


Fig. 3. Blast load acting on 10 storey structure.

The following equation represents the equation of motion of a 10 storey structure subjected to blast load.

$$m_c\ddot{u}_c + c_c\dot{u}_c + k_c u_c + F_c = F_m\left(1 - \frac{t}{t_{blast}}\right) \qquad \text{for } 0<t<t_{blast} \qquad (11)$$

$$m_c\ddot{u}_c + c_c\dot{u}_c + k_c u_c + F_c = 0 \qquad \text{for } t>t_{blast} \qquad (12)$$

Where u_c, $\dot{u}_c$ and $\ddot{u}_c$ are the displacement, velocity and acceleration of the cladding material. F_c are the friction force, F_m is the peak blast force. Table 2 shows the blast load parameter of the 10 storey structures. The maximum force occurs at 11 node of 42.5660 kN on 26.3585 sec.

Table 2
Blast load for 20 DOF systems.

node	**R(m)**	**Z(m/kg$^{1/3}$)**	**P_r(kPa)**	**F_m (kN)**	**t_{blast} (sec)**
u_{11}	50.0899	13.6061	12.7826	42.5660	26.3585
u_{12}	50.3587	13.6061	12.7826	42.5660	26.3585
u_{13}	50.8035	13.6548	12.7201	42.3580	26.4171
u_{14}	51.4198	13.6548	12.7201	42.3580	26.4171
u_{15}	52.2015	13.7351	12.6182	42.0187	26.5136
u_{16}	53.1413	13.7351	12.6182	42.0187	26.5136
u_{17}	54.2310	13.8460	12.4801	41.5586	26.6465
u_{18}	55.4617	13.8460	12.4801	41.5586	26.6465
u_{19}	56.8243	13.9860	12.3097	40.9912	26.8138
u_{20}	58.3095	13.9860	12.3097	40.9912	26.8138
u_{21}	50.0899	14.1535	12.1117	40.3319	27.0129
u_{22}	50.3587	14.1535	12.1117	40.3319	27.0129
u_{23}	50.8035	14.3464	11.8909	39.5968	27.2412
u_{24}	51.4198	14.3464	11.8909	39.5968	27.2412
u_{25}	52.2015	14.5628	11.6523	38.8021	27.4959
u_{26}	53.1413	14.5628	11.6523	38.8021	27.4959
u_{27}	54.2310	14.8004	11.4004	37.9633	27.7740
u_{28}	55.4617	14.8004	11.4004	37.9633	27.7740
u_{29}	56.8243	15.0573	11.1394	37.0944	28.0728
u_{30}	58.3095	15.0573	11.1394	37.0944	28.0728

The static displacement of the constant peak force of blast is F_m. The static displacement and maximum cladding displacement is given by the expressions

$$U_{st} = \frac{F_m}{k_c} \qquad (13)$$

$$U_{c,max} = e^{-\zeta\omega_n(t_1 - t_{blast})}\,\frac{\sqrt{\left(u_c\,(t_{blast}) - \frac{f_c}{k_c}\right)^2 \omega_d{}^2 + \left(\left(\dot{u}_c(t_{blast}) + \left(u_c\,(t_{blast}) - \frac{f_c}{k_c}\right)\zeta\omega_n\right)^2\right)}}{\omega_d} + \frac{f_c}{k_c} \qquad (14)$$

Where ζ is the damping ratio, ω_n is the natural frequency, t_1 is the initial time, ω_d is the damping frequency. Table 3 shows the cladding connections design parameters of various nodes of connection details in which mass of the cladding, natural time period, stiffness, damping ratio and force of the cladding material.

Fig. 4. shows the storey drift of 10 storey structure, the maximum drift occurs at eight floor and minimum occurs at second floor. Fig 5 shows the storey drift ratio of 10 storey structure at higher storey. Table 4, Table 5 and Table 6 shows the response reduction of a structure by using cladding material. It is observed that 33.309% of reduction of displacement, 38.963% of reduction of velocity and 22.172 % of reduction of acceleration.

Table 3
Cladding connections design parameters.

node	m_c (kg)	T_n(sec)	k_c (kN /m)	C_c (kN-s/m)	f_c (kN)	u_{st} (m)	$U_{c,max}$ (m)
u_{11}	225	0.76	15.11	7.38 $X10^{-2}$	4	2.3935	0.2282
u_{12}	225	0.76	15.11	7.38 $X10^{-2}$	4	2.3935	0.2282
u_{13}	225	0.76	15.11	7.38 $X10^{-2}$	4	2.3871	0.2271
u_{14}	225	0.76	15.11	7.38 $X10^{-2}$	4	2.3871	0.2271
u_{15}	225	0.76	15.11	7.38 $X10^{-2}$	4	2.3767	0.2252
u_{16}	225	0.76	15.11	7.38 $X10^{-2}$	4	2.3767	0.2252
u_{17}	225	0.76	15.11	7.38 $X10^{-2}$	4	2.3624	0.2228
u_{18}	225	0.76	15.11	7.38 $X10^{-2}$	4	2.3624	0.2228
u_{19}	225	0.76	15.11	7.38 $X10^{-2}$	4	2.3448	0.2197
u_{20}	225	0.76	15.11	7.38 $X10^{-2}$	4	2.3448	0.2197
u_{21}	225	0.76	15.11	7.38 $X10^{-2}$	4	2.3242	0.2162
u_{22}	225	0.76	13.88	7.07 $X10^{-2}$	4	2.3242	0.2162
u_{23}	225	0.76	13.88	7.07 $X10^{-2}$	4	2.3012	0.2123
u_{24}	225	0.76	13.88	7.07 $X10^{-2}$	3.3	2.3012	0.2123
u_{25}	225	0.76	13.88	7.07 $X10^{-2}$	3.3	2.2761	0.2080
u_{26}	225	0.76	13.88	7.07 $X10^{-2}$	3.3	2.2761	0.2080
u_{27}	225	0.76	13.88	7.07 $X10^{-2}$	3.3	2.2494	0.2035
u_{28}	225	0.76	13.88	7.07 $X10^{-2}$	3.3	2.2494	0.2035
u_{29}	225	0.76	13.88	7.07 $X10^{-2}$	3.3	2.2215	0.1989
u_{30}	225	0.76	13.88	7.07 $X10^{-2}$	3.3	2.2215	0.1989

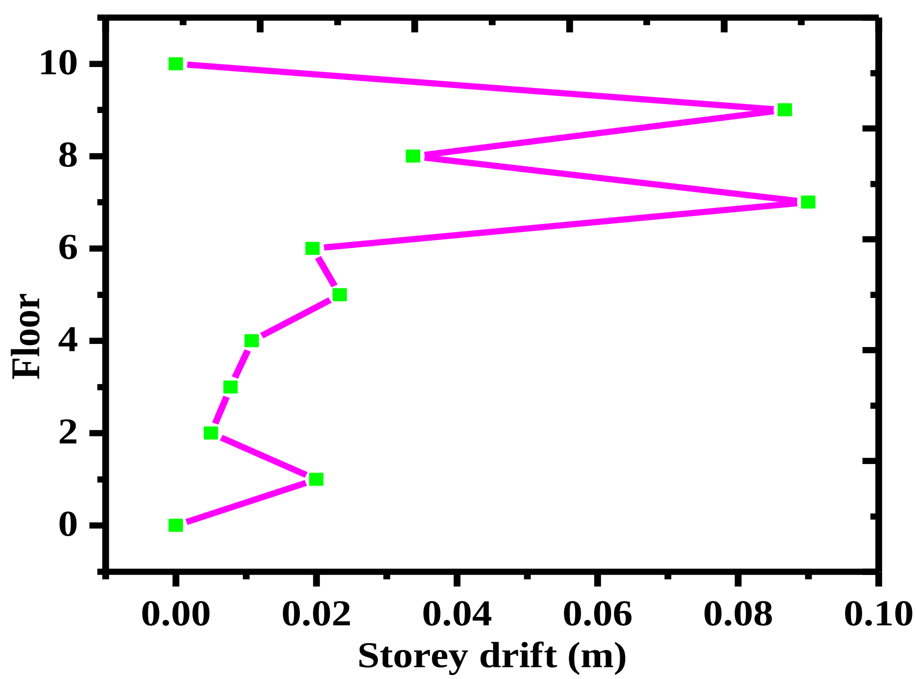


Fig. 4. Storey drift of 10 storey structure.

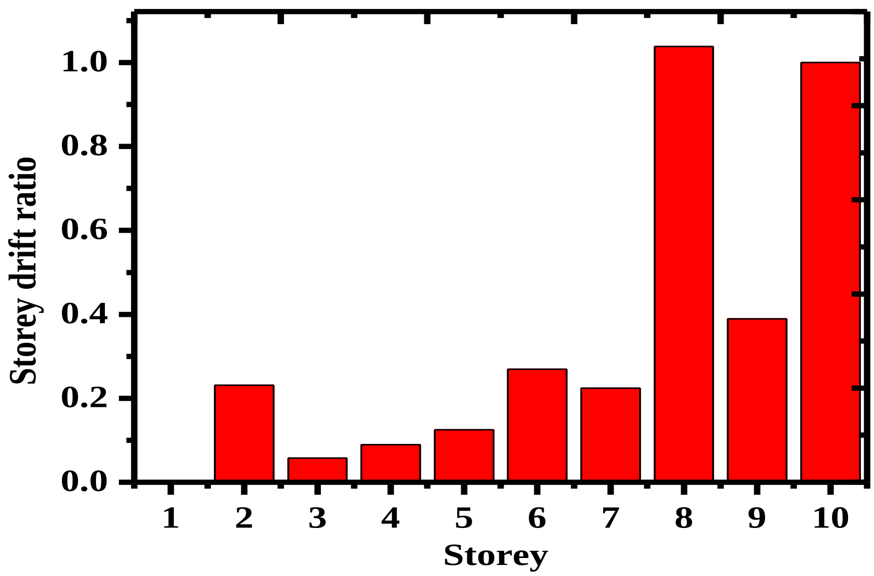


Fig. 5. Storey drift ratio of 10 storey structure.

Table 4
Percentage of reduction of displacement of 10 storey structure by using cladding material.

Floor	Displacement of bare frame (m)	Displacement of cladding frame (m)	Percentage of reductions
1	0.36	0.28	22.22
2	0.34	0.28	17.65
3	0.45	0.32	28.89
4	0.52	0.36	30.77
5	0.65	0.42	35.38
6	1	0.59	41.00
7	1.35	0.7	48.15
8	3.24	2.84	12.35
9	4.05	1.06	73.83
10	6.39	4.93	22.85

Table 5
Percentage of reduction of velocity of 10 storey structure by using cladding material.

Floor	Velocity of bare frame (m/msec)	Velocity of cladding frame (m/msec)	Percentage of reductions
1	0.13	0.1	23.08
2	0.16	0.12	25.00
3	0.18	0.13	27.78
4	0.21	0.14	33.33
5	0.26	0.17	34.62
6	0.4	0.23	42.50
7	0.54	0.28	48.15
8	0.81	0.34	58.02
9	1.62	0.42	74.07
10	0.13	0.1	23.08

Table 6
Percentage of reduction of acceleration of 10 storey structure by using cladding material.

Floor	Acceleration of bare frame ($m/msec^2$)	Acceleration of cladding frame ($m/msec^2$)	Percentage of reductions
1	13.61	9.96	26.82
2	13.6	10.62	21.91
3	11.91	8.81	26.03
4	12.5	8.58	31.36
5	11.76	8.51	27.64
6	14	12.38	11.57
7	15.09	11.91	21.07
8	18.73	16.74	10.62
9	31.72	24.72	22.07
10	28.85	22.32	22.63

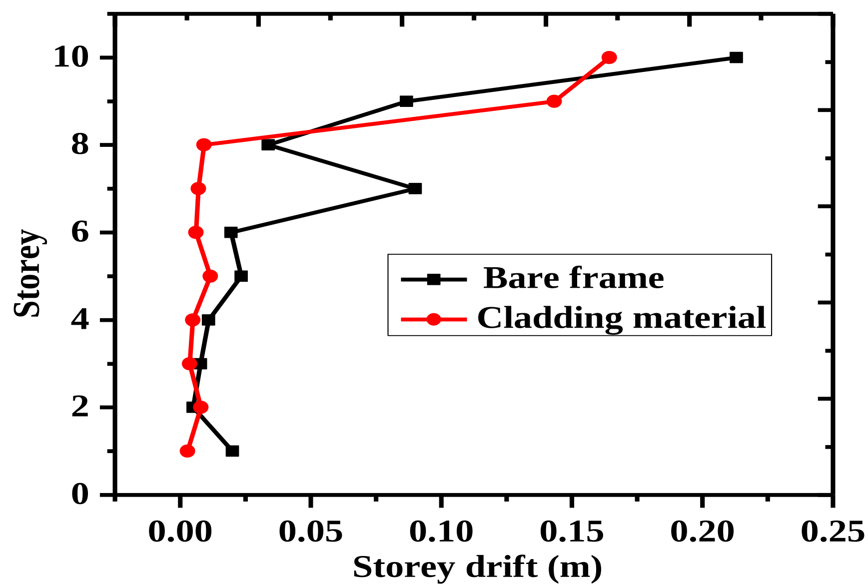


Fig. 6. Reduction of storey drift of 10 storey structure by cladding material.

From Fig.6. shows the reduction of storey drift along the various floors by using cladding material. Fig.7 shows the deformations of the rubber and cladding material at various nodes

Fig. 8. shows the reductions of accelerations of a structural system in floor wise by using cladding material in 2 and 3dimensional view.

Fig. 9. shows the reductions of velocity of a structural system in floor wise by using cladding material in 2 and 3dimensional view.

Fig. 10 shows the reductions of displacement of a structural system in floor wise by using cladding material in 2 and 3dimensional view.

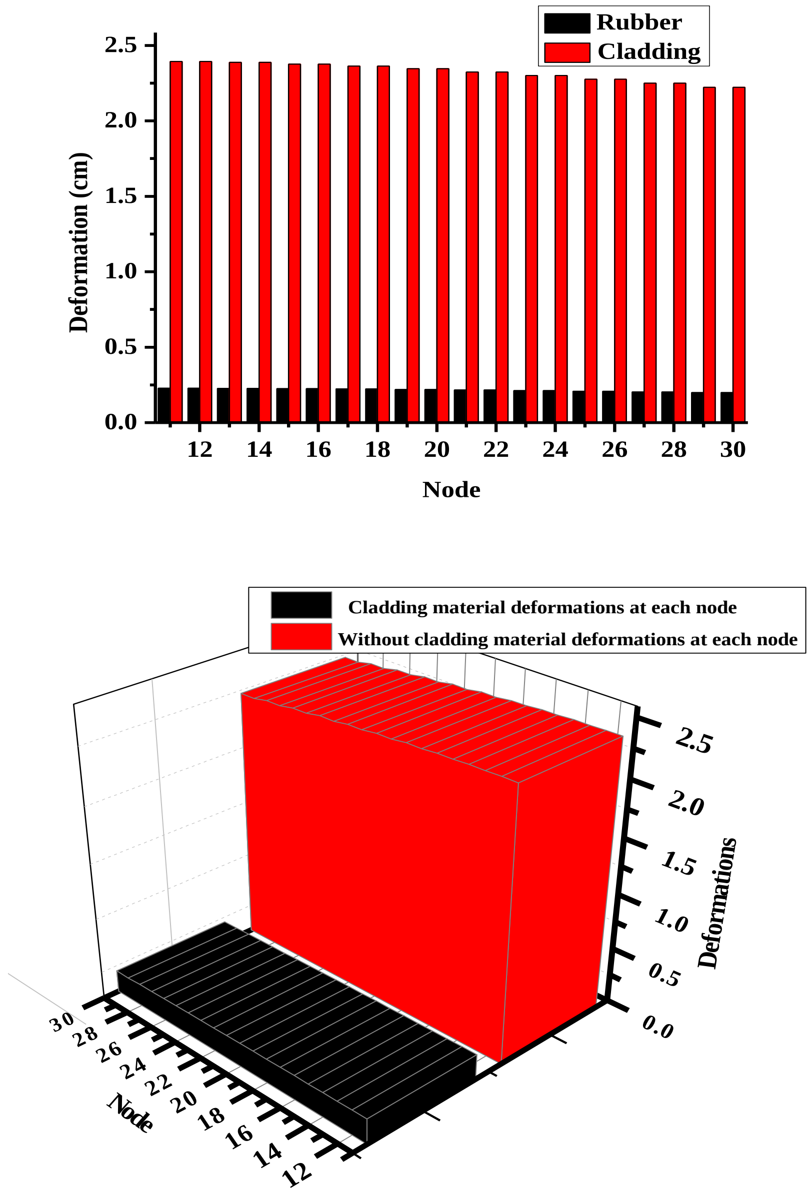
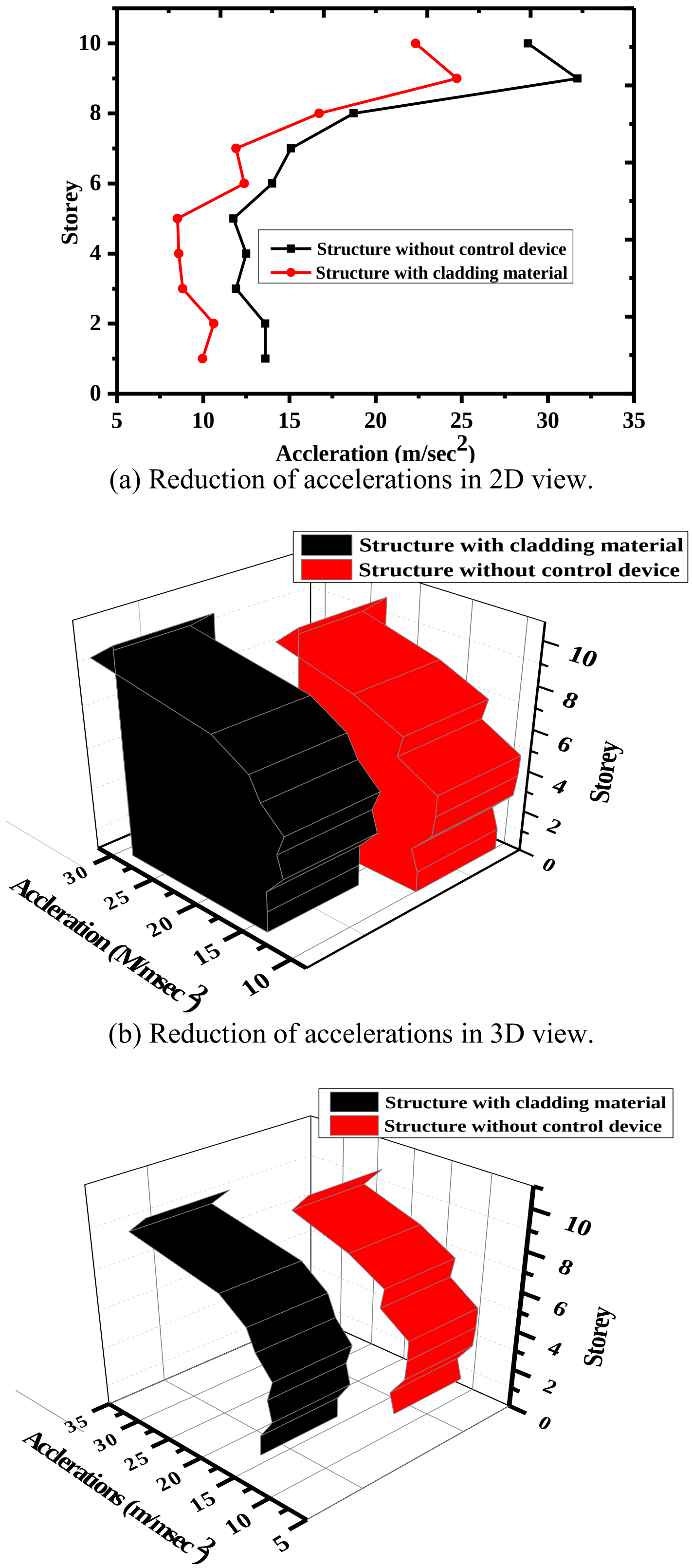


Fig. 7. Maximum deformation of cladding and rubber.

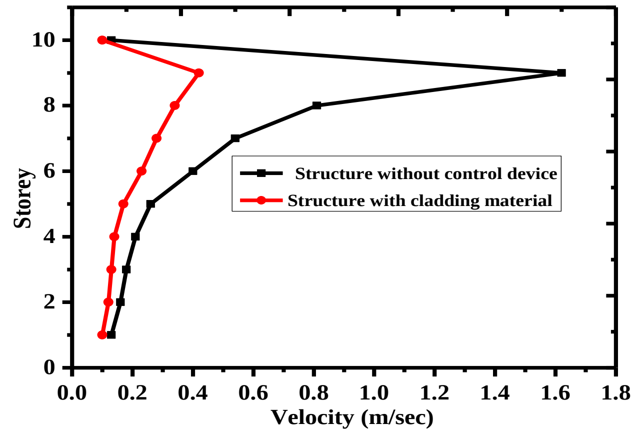


(a) Reduction of accelerations in 2D view.

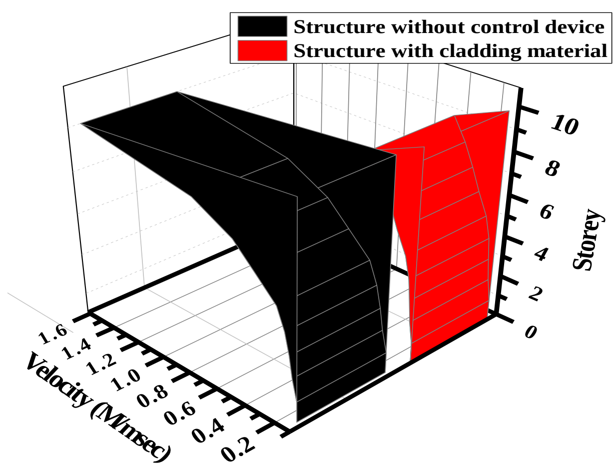
(b) Reduction of accelerations in 3D view.

(c) Reduction of accelerations in 3D view.

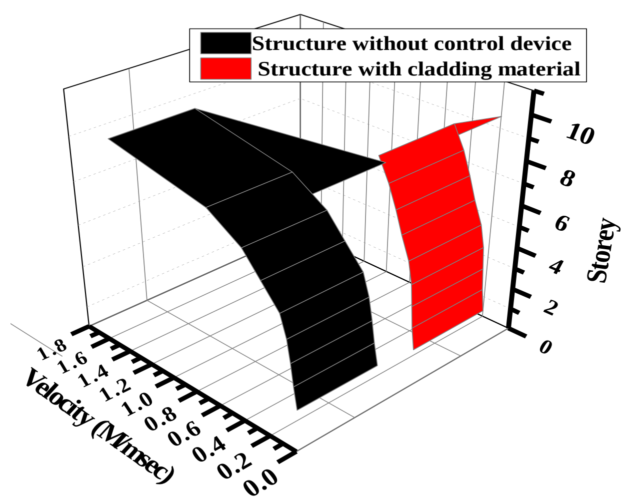
Fig. 8. Reduction of accelerations of a structural system by cladding material.



(a) Reduction of velocity in 2D view

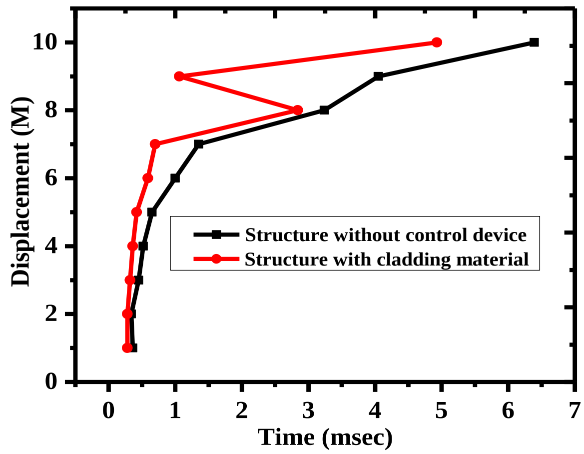


(b) Reduction of velocity in 3D view

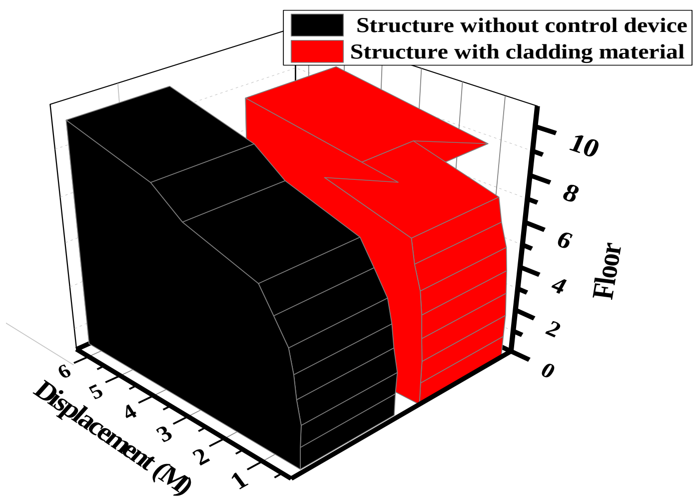


(c) Reduction of velocity in 3D view

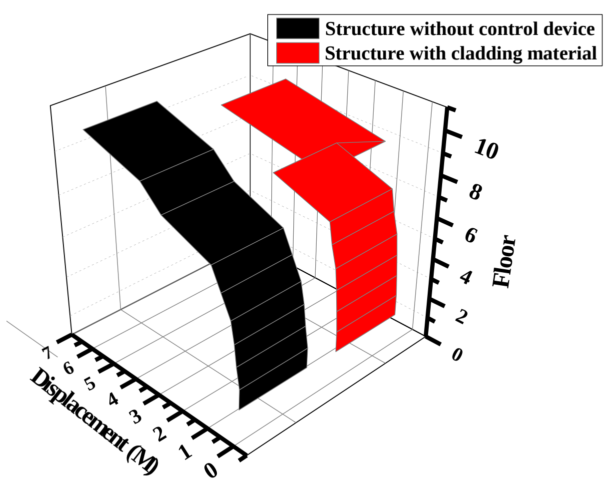
Fig. 9. Reduction of velocity of a structural system by cladding material



(a) Reduction of displacement in 2D view



(b) Reduction of displacement in 3D view



(c) Reduction of displacement in 3D view

Fig. 10. Reduction of displacement of a structural system by cladding material.

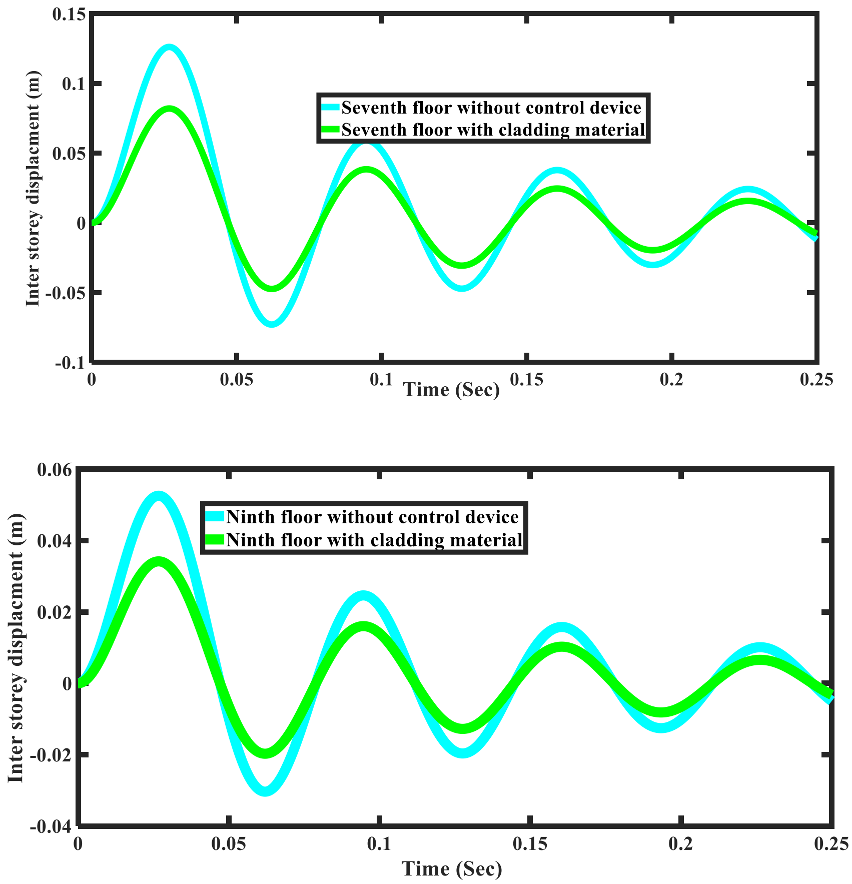
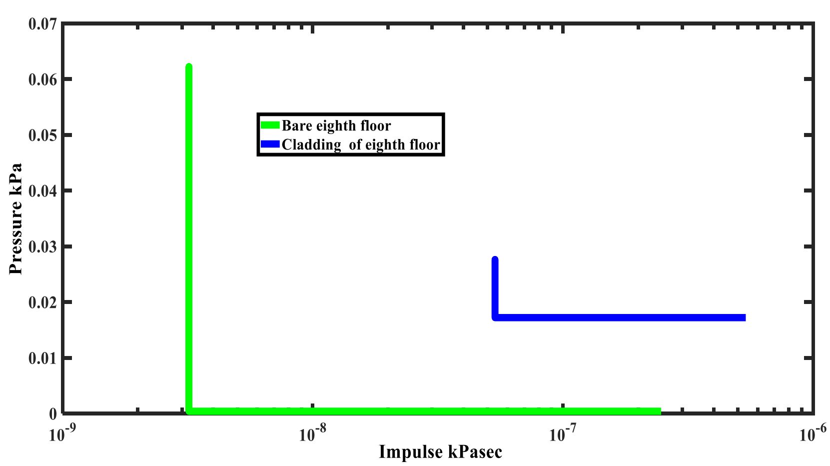


Fig. 11. Reduction of inter storey displacement of seventh and ninth floor by cladding material

Fig. 11 shows the reduction of inter storey displacement at seventh and ninth floor by using cladding material. Fig. 12 shows the pressure impulse curve of first and sixth floor. By using cladding material for 0.1 to 0.2 kpa of pressure at first floor and 0.002 to 0.006 kPa of pressure at sixth floor cannot cause damage to the structure. From the pressure impulse curve, the structure is safe from the curve falls below right.



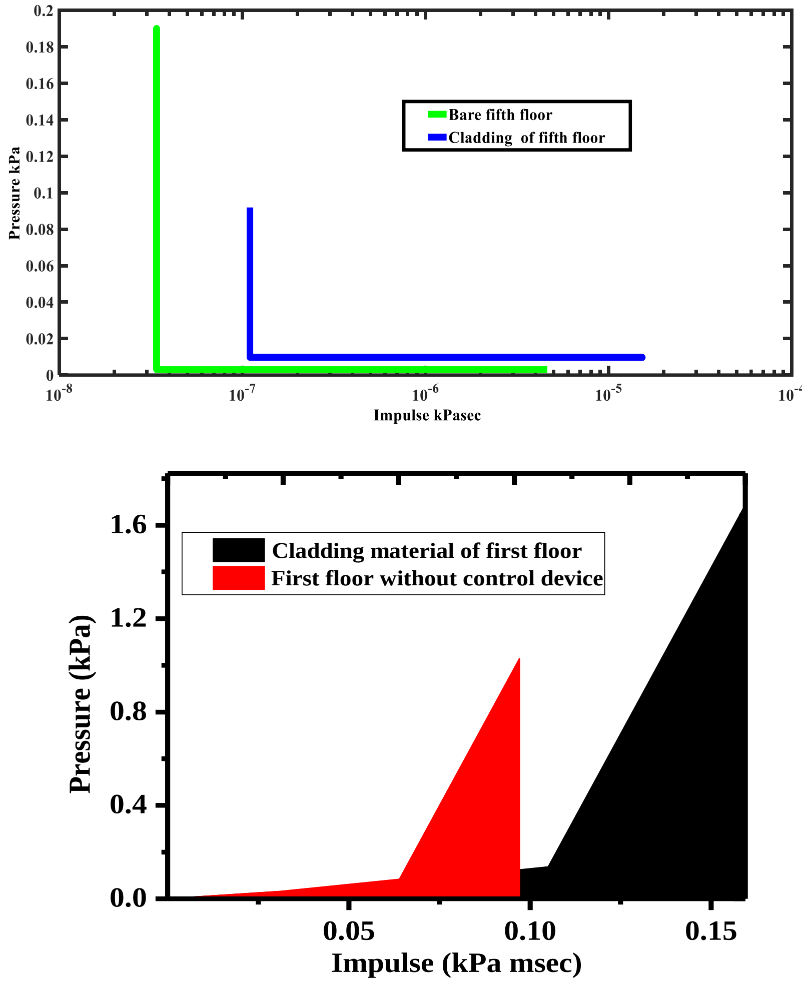
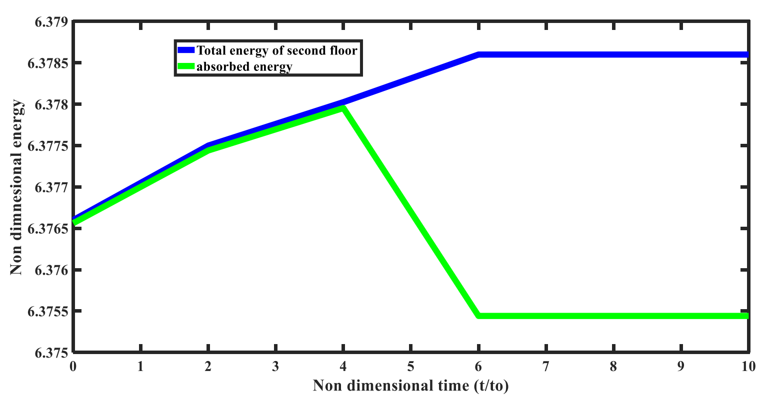


Fig. 12. Pressure impulse curve of 10 storey structure by cladding material.

4. Non dimensional energy of a structure

The maximum energy absorbed by the cladding to the energy value is known as non-dimensional energy. Non dimensional time is the ratio of time to initial time. Fig 13 shows the non-dimensional energy of 6.4275 and 6.375 is the total energy of fifth and second floor. By using cladding material, the 6.3925 and 6.378 is absorbed of the fifth and second floor.



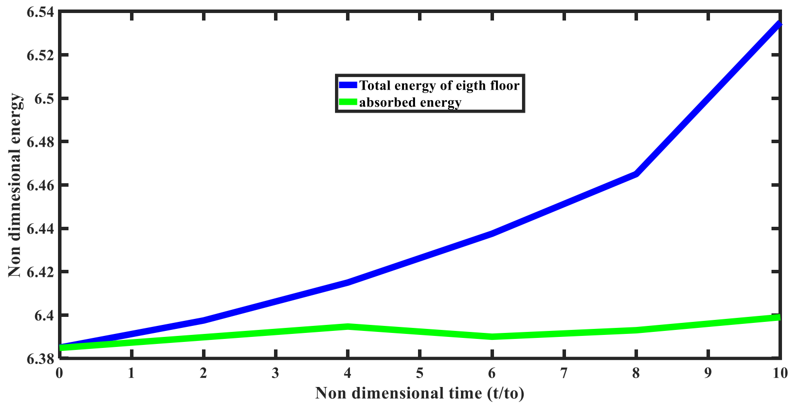


Fig. 13. Absorption of non-dimensional energies and non-dimensional time by cladding material

5. Conclusions

From the study observed the following conclusions are drawn

a. Cladding is not a material used for the design resistance of a structure against blast load but it is used for the maximum energy absorbed from the blast, then transfer remaining energy is transferred to the structure.

b. The response of a structural system exposed to blast load is 40% is reduced by using cladding material and also clear view of 3D is represented.

c. About 40% of reduction of storey drift occurs of a structure by using cladding material.

d. About 28% of pressure is not affected to the structure by using a cladding material.

e. About 58% of energy absorbed by the cladding material of the structure exposed to blast load.

f. By using cladding material substantial amount of response is reduced for the mid-rise structure exposed to blast load.

References

[1] Cao L, Lu S, Laflamme S, Quiel S, Ricles J, Taylor D. Performance-based design procedure of a novel friction-based cladding connection for blast mitigation. Int J Impact Eng 2018;117:48–62. doi:10.1016/j.ijimpeng.2018.03.003.

[2] Goel MD, Matsagar VA. Blast-Resistant Design of Structures. Pract Period Struct Des Constr 2014;19:04014007. doi:10.1061/(ASCE)SC.1943-5576.0000188.

[3] Ashby MF, Evans T, Fleck NA, Hutchinson JW, Wadley HNG, Gibson LJ. Metal foams: a design guide. Elsevier; 2000.

[4] Hanssen AG, Enstock L, Langseth M. Close-range blast loading of aluminium foam panels. Int J Impact Eng 2002;27:593–618. doi:10.1016/S0734-743X(01)00155-5.

[5] Nammi SK, Edwards G, Shirvani H. Effect of cell-size on the energy absorption features of closed-cell aluminium foams. Acta Astronaut 2016;128:243–50. doi:10.1016/j.actaastro.2016.06.047.

[6] Zhou H, Ma G, Li J, Zhao Z. Design of Metal Foam Cladding Subjected to Close-Range Blast. J Perform Constr Facil 2015;29:04014110. doi:10.1061/(ASCE)CF.1943-5509.0000606.

[7] Ma GW, Ye ZQ. Energy absorption of double-layer foam cladding for blast alleviation. Int J Impact Eng 2007;34:329–47. doi:10.1016/j.ijimpeng.2005.07.012.

[8] Reid SR, Peng C. Dynamic uniaxial crushing of wood. Int J Impact Eng 1997;19:531–70. doi:10.1016/S0734-743X(97)00016-X.

[9] Hanssen AG, Olovsson L, Børvik T, Langseth M. Close-Range Blast Loading of Aluminium Foam Panels: A Numerical Study. IUTAM Symp. Mech. Prop. Cell. Mater., Dordrecht: Springer Netherlands; n.d., p. 169–80. doi:10.1007/978-1-4020-9404-0_18.

[10] Ma GW, Ye ZQ. Analysis of foam claddings for blast alleviation. Int J Impact Eng 2007;34:60–70. doi:10.1016/j.ijimpeng.2005.10.005.

[11] Li JD, Ma GW, Zhou HY, Du XL. Blast mitigation of civil structures by using density gradient aluminium foam cladding. Int J Prot Struct 2011;2:333–49.

[12] Zhu F, Zhao L, Lu G, Wang Z. Structural Response and Energy Absorption of Sandwich Panels with an Aluminium Foam Core under Blast Loading. Adv Struct Eng 2008;11:525–36. doi:10.1260/136943308786412005.

[13] Nurick GN, Langdon GS, Chi Y, Jacob N. Behaviour of sandwich panels subjected to intense air blast – Part 1: Experiments. Compos Struct 2009;91:433–41. doi:10.1016/j.compstruct.2009.04.009.

[14] Wu C, Huang L, Oehlers DJ. Blast Testing of Aluminum Foam–Protected Reinforced Concrete Slabs. J Perform Constr Facil 2011;25:464–74. doi:10.1061/(ASCE)CF.1943-5509.0000163.

[15] Qi C, Yang S, Yang L-J, Wei Z-Y, Lu Z-H. Blast resistance and multi-objective optimization of aluminum foam-cored sandwich panels. Compos Struct 2013;105:45–57. doi:10.1016/j.compstruct.2013.04.043.

[16] Shen J, Lu G, Zhao L, Qu Z. Response of Curved Sandwich Panels Subjected to Blast Loading. J Perform Constr Facil 2011;25:382–93. doi:10.1061/(ASCE)CF.1943-5509.0000234.

[17] Mullin MJ, O'Toole BJ. Simulation of energy absorbing materials in blast loaded structures. 8th Int. LS-DYNA Users Conf., 2004, p. 2–7.

[18] 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.

[19] Anagnostopoulos SA. Pounding of buildings in series during earthquakes. Earthq Eng Struct Dyn 1988;16:443–56. doi:10.1002/eqe.4290160311.

[20] Davis RO. Pounding of buildings modelled by an impact oscillator. Earthq Eng Struct Dyn 1992;21:253–74. doi:10.1002/eqe.4290210305.

[21] Polycarpou PC, Komodromos P, Polycarpou AC. A nonlinear impact model for simulating the use of rubber shock absorbers for mitigating the effects of structural pounding during earthquakes. Earthq Eng Struct Dyn 2013;42:81–100. doi:10.1002/eqe.2194.

[22] E BW, A CP, S WP, J KJ, A SR. Explosion hazards and evaluation. Amsterdum, New York : Elsevier Scientific Publications. 1983.

[23] Jarrett DE. Derivation of the British explosives safety distances. Ann N Y Acad Sci 1968;152:18–35.

[24] Krauthammer T. Modern Protective Structures. CRC Press, New York 2005.

[25] Shi Y, Hao H, Li Z-X. Numerical derivation of pressure–impulse diagrams for prediction of RC column damage to blast loads. Int J Impact Eng 2008;35:1213–27. doi:10.1016/j.ijimpeng.2007.09.001.

[26] Fallah AS, Louca LA. Pressure–impulse diagrams for elastic-plastic-hardening and softening single-degree-of-freedom models subjected to blast loading. Int J Impact Eng 2007;34:823–42. doi:10.1016/j.ijimpeng.2006.01.007.

[27] Dyke SJ, Spencer Jr BF, Sain MK, Carlson JD. Modeling and control of magnetorheological dampers for seismic response reduction. Smart Mater Struct 1996;5:565.