Blast Mitigations of Mid Rise Structures by Cladding Material

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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 [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

![Plan & Elevation of the 10 storey structure](image)

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>
<thead>
<tr>
<th>Sl No</th>
<th>Parameter of the Structure</th>
<th>Symbol</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weight of the blast</td>
<td>W</td>
<td>1000 TNT</td>
</tr>
<tr>
<td>2</td>
<td>Height of each floor</td>
<td>H</td>
<td>3m</td>
</tr>
<tr>
<td>3</td>
<td>Mass of each floor</td>
<td>M</td>
<td>11213 kg</td>
</tr>
<tr>
<td>4</td>
<td>Stiffness</td>
<td>K</td>
<td>1000*21860 N/m</td>
</tr>
<tr>
<td>5</td>
<td>Area of each floor</td>
<td>A</td>
<td>60 m²</td>
</tr>
<tr>
<td>6</td>
<td>Natural Frequency</td>
<td>(w_n)</td>
<td>12.567 Hertz</td>
</tr>
<tr>
<td>7</td>
<td>Damping ratio</td>
<td>(\xi)</td>
<td>5%</td>
</tr>
<tr>
<td>8</td>
<td>Material</td>
<td>-</td>
<td>Steel</td>
</tr>
<tr>
<td>9</td>
<td>Property</td>
<td>-</td>
<td>Elastic</td>
</tr>
</tbody>
</table>

Table 1.
Input parameter of a structure.

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

\[ Z_h = \frac{R_h}{W^{1/3}} \tag{2} \]
\[ P_{so} = \frac{1772}{Z_h^2} - \frac{114}{Z_h^2} + \frac{108}{Z_h} \]  

(3)

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

(4)

\[ U = a_o \cdot \sqrt{\frac{6P_{so}+7P_o}{7P_o}} \]  

(5)

\[ t_A = \frac{R_h}{U} \]  

(6)

\[ P_r = C_r P_{so} \]  

(7)

\[ C_r = 3 \left( \frac{P_S}{101} \right) \]  

(8)

Where \( Z_h \) – Scaled standoff distance

\[ P(t) = P_o + P_r \left( 1 - \frac{t}{t_0} \right) \exp(-\gamma \frac{t}{t_0}) \]  

(9)

\[ \gamma = Z_{h^2} - 3.7Z_h + 4.2 \]  

(10)

Where, \( P(t) \) is the pressure in time; \( \gamma \) is parameter controlling the rate wave amplitude, \( P_r \) is peak reflected over pressure, \( P_{so} \) is peak incident over pressure, \( t_A \) is time of arrival, \( t_{\text{blast}} \) 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.](image-url)
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.](image)

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

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

(11)

\[ m_c \ddot{u}_c + c_c \dot{u}_c + k_c u_c + F_c = 0 \quad \text{for } t > t_{\text{blast}} \]  

(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.**

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

\[ U_{st} = \frac{F_m}{k_c} \]  

\[ U_{c,\text{max}} = e^{-\zeta \omega_n (t_1 - t_{\text{blast}})} \frac{\sqrt{\left(\frac{k_c}{f_c} \right)^2 \omega_d^2 + \left( \frac{u_c(t_{\text{blast}})}{k_c} + \frac{u_c(t_{\text{blast}})}{k_c} \frac{\omega_n}{f_c} \right)^2} + \frac{f_c}{k_c}}{\omega_d} \]  

Where $\zeta$ is the damping ratio, $\omega_n$ is the natural frequency, $t_1$ is the initial time, $\omega_d$ 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.

**Table 3.**

Cladding connections design parameters.

<table>
<thead>
<tr>
<th>node</th>
<th>$m_c$ (kg)</th>
<th>$T_n$(sec)</th>
<th>$k_c$ (kN/m)</th>
<th>$C_c$ (kN/s/m)</th>
<th>$f_c$ (kN)</th>
<th>$u_{st}$ (m)</th>
<th>$U_{c,\text{max}}$ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u_{11}$</td>
<td>225</td>
<td>0.76</td>
<td>15.11</td>
<td>7.38 X10^{-2}</td>
<td>4</td>
<td>2.3935</td>
<td>0.2282</td>
</tr>
<tr>
<td>$u_{12}$</td>
<td>225</td>
<td>0.76</td>
<td>15.11</td>
<td>7.38 X10^{-2}</td>
<td>4</td>
<td>2.3935</td>
<td>0.2282</td>
</tr>
<tr>
<td>$u_{13}$</td>
<td>225</td>
<td>0.76</td>
<td>15.11</td>
<td>7.38 X10^{-2}</td>
<td>4</td>
<td>2.3871</td>
<td>0.2271</td>
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<tr>
<td>$u_{14}$</td>
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<td>0.76</td>
<td>15.11</td>
<td>7.38 X10^{-2}</td>
<td>4</td>
<td>2.3871</td>
<td>0.2271</td>
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<td>$u_{15}$</td>
<td>225</td>
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<td>15.11</td>
<td>7.38 X10^{-2}</td>
<td>4</td>
<td>2.3767</td>
<td>0.2252</td>
</tr>
<tr>
<td>$u_{16}$</td>
<td>225</td>
<td>0.76</td>
<td>15.11</td>
<td>7.38 X10^{-2}</td>
<td>4</td>
<td>2.3767</td>
<td>0.2252</td>
</tr>
<tr>
<td>$u_{17}$</td>
<td>225</td>
<td>0.76</td>
<td>15.11</td>
<td>7.38 X10^{-2}</td>
<td>4</td>
<td>2.3624</td>
<td>0.2228</td>
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<tr>
<td>$u_{18}$</td>
<td>225</td>
<td>0.76</td>
<td>15.11</td>
<td>7.38 X10^{-2}</td>
<td>4</td>
<td>2.3624</td>
<td>0.2228</td>
</tr>
<tr>
<td>$u_{19}$</td>
<td>225</td>
<td>0.76</td>
<td>15.11</td>
<td>7.38 X10^{-2}</td>
<td>4</td>
<td>2.3448</td>
<td>0.2197</td>
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<td>$u_{20}$</td>
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<td>0.76</td>
<td>15.11</td>
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<td>4</td>
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</tr>
<tr>
<td>$u_{21}$</td>
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<td>0.76</td>
<td>15.11</td>
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<td>4</td>
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<td>0.76</td>
<td>13.88</td>
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<tr>
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<td>3.3</td>
<td>2.2215</td>
<td>0.1989</td>
</tr>
</tbody>
</table>

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.
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.

<table>
<thead>
<tr>
<th>Floor</th>
<th>Displacement of bare frame (m)</th>
<th>Displacement of cladding frame (m)</th>
<th>Percentage of reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.36</td>
<td>0.28</td>
<td>22.22</td>
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<tr>
<td>2</td>
<td>0.34</td>
<td>0.28</td>
<td>17.65</td>
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<tr>
<td>3</td>
<td>0.45</td>
<td>0.32</td>
<td>28.89</td>
</tr>
<tr>
<td>4</td>
<td>0.52</td>
<td>0.36</td>
<td>30.77</td>
</tr>
<tr>
<td>5</td>
<td>0.65</td>
<td>0.42</td>
<td>35.38</td>
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<td>6</td>
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<td>10</td>
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<td>4.93</td>
<td>22.85</td>
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Table 5.
Percentage of reduction of velocity of 10 storey structure by using cladding material.

<table>
<thead>
<tr>
<th>Floor</th>
<th>Velocity of bare frame (m/msec)</th>
<th>Velocity of cladding frame (m/msec)</th>
<th>Percentage of reductions</th>
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</thead>
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<td>0.1</td>
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<td>10</td>
<td>0.13</td>
<td>0.1</td>
<td>23.08</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Floor</th>
<th>Acceleration of bare frame (m/msec²)</th>
<th>Acceleration of cladding frame (m/msec²)</th>
<th>Percentage of reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.61</td>
<td>9.96</td>
<td>26.82</td>
</tr>
<tr>
<td>2</td>
<td>13.6</td>
<td>10.62</td>
<td>21.91</td>
</tr>
<tr>
<td>3</td>
<td>11.91</td>
<td>8.81</td>
<td>26.03</td>
</tr>
<tr>
<td>4</td>
<td>12.5</td>
<td>8.58</td>
<td>31.36</td>
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<tr>
<td>5</td>
<td>11.76</td>
<td>8.51</td>
<td>27.64</td>
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<tr>
<td>6</td>
<td>14</td>
<td>12.38</td>
<td>11.57</td>
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<td>7</td>
<td>15.09</td>
<td>11.91</td>
<td>21.07</td>
</tr>
<tr>
<td>8</td>
<td>18.73</td>
<td>16.74</td>
<td>10.62</td>
</tr>
<tr>
<td>9</td>
<td>31.72</td>
<td>24.72</td>
<td>22.07</td>
</tr>
<tr>
<td>10</td>
<td>28.85</td>
<td>22.32</td>
<td>22.63</td>
</tr>
</tbody>
</table>

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 3-dimensional view.

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

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

![Graph showing non-dimensional energy absorption](image1)

**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


