ANALYSIS OF RCC AND SIMCON BUILDINGS SUBJECTED TO BLAST EFFECTS

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ABSTRACT

A bomb explosion within or immediately nearby a building can cause catastrophic damage on the building’s external and internal structural frames, collapsing of walls, blowing out of large expanses of windows, and shutting down of critical life-safety systems. Loss of life and injuries to occupants can result from many causes, including direct blast-effects, structural collapse, debris impact, fire, and smoke. The indirect effects can combine to inhibit or prevent timely evacuation, thereby contributing to additional casualties. In addition, major catastrophes resulting from gas-chemical explosions result in large dynamic loads, greater than the original design loads, of many structures. Due to the threat from such extreme loading conditions, efforts have been made during the past three decades to develop methods of structural analysis and design to resist blast loads. Designing the structures to be fully blast resistant is not a realistic and economical option, however current engineering and architectural knowledge can enhance the new and existing buildings to mitigate the effects of an explosion. Generally conventional structures are not designed for blast load due to the reason that the magnitude of load caused by blast is huge and, the cost of design and construction is very high. As a result, the structure is susceptible to damage from blast load. Recent past blast incidents in the country trigger the minds of developers, architects and engineers to find solutions to protect the occupants and structures from blast disasters. In this work, blast analysis of multi-storeyed structures was done. Both RCC and SIMCON high rise buildings were subjected to blast effects and their fundamental frequencies were determined. Time history analysis was carried out in ETABS software to find the effect of buildings subjected to blasts.

Key words: Blast loads, Fundamental Frequency, Modal Analysis, SIMCON and Time History Analysis.
1. INTRODUCTION

The increase in the number of terrorist attacks especially in the last few years has shown that the effect of blast loads on buildings is a serious matter that should be taken into consideration in the design process. Although these kinds of attacks are exceptional cases, man-made disasters; blast loads are in fact dynamic loads that need to be carefully calculated just like earthquake and wind loads. Damage to the assets, loss of life and social panic are factors that have to be minimized if the threat of terrorist action cannot be stopped [5]. Designing the structures to be fully blast resistant is not a realistic and economical option, however current engineering and architectural knowledge can enhance the new and existing buildings to mitigate the effects of an explosion.

A bomb explosion within or immediately nearby a building can cause catastrophic damage on the building's external and internal structural frames, collapsing of walls, blowing out of large expanses of windows, and shutting down of critical life-safety systems. Loss of life and injuries to occupants can result from many causes, including direct blast-effects, structural collapse, debris impact, fire, and smoke [8]. The indirect effects can combine to inhibit or prevent timely evacuation, thereby contributing to additional casualties. In addition, major catastrophes resulting from gas-chemical explosions result in large dynamic loads, greater than the original design loads, of many structures. Due to the threat from such extreme loading conditions, efforts have been made during the past three decades to develop methods of structural analysis and design to resist blast loads.

1.1. Ideal Blast Wave

An explosion can be defined as a very fast chemical reaction involving a solid, dust or gas, during which a rapid release of hot gases and energy takes place. The phenomenon lasts only some milliseconds and it results in the production of very high temperatures and pressures. During detonation the hot gases that are produced expand in order to occupy the available space, leading to wave type propagation through space that is transmitted spherically through an unbounded surrounding medium. Along with the produced gases, the air around the blast (for air blasts) also expands and its molecules pile-up, resulting in what is known as a blast wave and shock front [22].

Fig1 shows the idealised profile of the pressure in relation to time for the case of a free air blast wave, which reaches a point at a certain distance from the detonation [22]. The pressure surrounding the element is initially equal to the ambient pressure $P_0$, and it undergoes an instantaneous increase to a peak pressure $P_{so}$ at the arrival time $t_A$, when the shock front reaches that point. The time needed for the pressure to reach its peak value is very small and for design purposes it is assumed to be equal to zero. The peak pressure $P_{so}$ is also known as side-on overpressure or peak overpressure. The value of the peak overpressure and the velocity of propagation of the shock wave decreases with increase in distance from the detonation centre. After its peak value, the pressure decreases with an exponential rate until it reaches the ambient pressure at $t_A+t_0$, to being called the positive phase duration. After the
positive phase of the pressure-time diagram, the pressure becomes smaller (referred to as negative) than the ambient value, and finally returns to it.

Figure 1 Ideal Blast Wave’s Pressure Time History

The negative phase is longer than the positive one, its minimum pressure value is denoted as $P_{so}$ - and its duration as $t_o$. During this phase the structures are subjected to suction forces, which is the reason why sometimes during blast loading glass fragments from failures of facades are found outside a building instead in its interior. During detonation the hot gases that are produced expand in order to occupy the available space, leading to wave type propagation through space that is transmitted spherically through an unbounded surrounding medium. Along with the produced gases, the air around the blast (for air blasts) also expands and its molecules pile-up, resulting in what is known as a blast wave and shock front.

The negative phase of the explosive wave is usually not taken into account for design purposes as it has been verified that the main structural damage is connected to the positive phase. Additionally, the pressures that are produced from the negative has of the blast wave are relatively small compared to those of the positive phase and since these are in the opposite direction, it is usually on the safe side to assume that they do not have a big impact on the structural integrity of buildings under blast loads. However, the pressures that are below the ambient pressure value should be taken into account if the overall structural performance of a building during a blast is assessed and not only its structural integrity. The damage in a building depends on the energy imparted to it through the reflected shock front of explosion, which is contributed by both the positive and negative phases of the pressure-time history. The pressure and hence forces on the building vary in time and space over the exposed surface of the building, depending on the location of the detonation in relation to the building. Therefore, when studying the response of a structure under a specific blast, the location of detonation which produces the most severe effects on the structure should be identified.

1.2. Weapons of Blast

An explosion is a sudden release of energy, which can be caused by many sources, namely mechanical, chemical and nuclear in the increasing order of potential to cause damage. Explosives are classified as low and high depending on the amount of energy released by them and the consequent damage caused by them. The low explosives only burn, but do not detonate. They are set-off to deflagrate, rather than to detonate. They are primarily used as propellants, and have a cut-off detonation speed of about
1000m/s. An example of the low explosive is the black powder [13]. On the other hand, the high explosive is designed to shatter, rather than to push. Different explosive materials release different amounts of energy per unit mass (energy density) upon detonation. The nature of the shockwave produced and the magnitude of the pressure generated from an explosion is thus dependent on the type of explosive involved. This creates a potential difficulty in blast load analysis as various explosive materials generate unique blast wave parameters in an explosion and would require knowledge of explosion behaviour and characteristics of a large number of explosives (Cooper 1994; Held 1983). Trinitrotoluene (TNT) is, therefore, used as the standard explosive to which all other explosives are compared and their equivalence to TNT established (PEC and Baker Risk 2008). TNT equivalence is used to represent the mass of TNT that will produce the same amount of energy or explosion effects as a unit mass of a particular explosive in an explosion (Sochet 2010). TNT conversion factors have been determined for different explosive materials and tabulated in a number of blast design guides (PEC and Baker Risk 2008). For the purpose of this thesis, all explosive charge materials other than TNT are converted to TNT equivalent masses. Depending on the type of explosion, the detonation speed can be in the range 1000-9000 m/s. Examples of the high explosives are dynamite and TNT. Two significant by-products of an explosion are large amount of heat and extremely high overpressure in the air adjoining the explosive. For instance, a small amount of explosive of 1 gram of TNT alone produces 1120 calories of heat. Clearly, very high temperatures are feasible in the vicinity of the explosion. Hence, flammable material must be kept away from potentially hazardous areas where explosions can be expected.

1.3. SIMCON
The investigations conducted in North Carolina University have demonstrated that a special type of continuous fiber-mat HPFRCC, called SIMCON which stands for Slurry Infiltrated Mat Concrete, is well suited for the development of novel repair, retrofit and new-construction solutions that lead to economical and improved structural performance. SIMCON uses a manufactured continuous mat of interlocking discontinuous steel fibers, placed in a form, and then infiltrated with flowable cement-based slurry. The use of continuous mats, typically made with stainless steel to control corrosion in very thin members, permits development of high flexural strengths and very high ductility with a reduced volume of fibers. SIMCON uses a manufactured continuous mat of interlocking discontinuous steel fibers, placed in a form, and then infiltrated with flowable cement-based slurry.

The use of continuous mats, typically made with stainless steel to control corrosion in very thin members, permits development of high flexural strengths and very high ductility with a reduced volume of fibers. In a retrofit situation continuous SIMCON fiber-mats, delivered in large rolls, can be easily installed by wrapping around members to be rehabilitated. In new construction of high-performance composite frames SIMCON is well suited for manufacturing high strength, high ductility, and thin stay-in-place formwork elements that eliminate the need for secondary and most of the primary reinforcement. A two-dimensional layout of SIMCON and its unique manufacturing properties related to its fiber-mat configuration, open up novel possibilities for a cost-effective and improved structural performance that were not previously possible using other HPFRCCs, FRCs or any other conventional construction materials. Construction with SIMCON was also found to be simpler than if other HPFRCs, reinforced concrete, steel plates or different non-cement based composites were used.
2. MODELLING

For the present thesis work, modelling and analysis are carried out for rectangular shaped building. The rectangular building plan is shown in fig.2. All storeys are similar to ground floor plan. In this thesis, RCC and SIMCON are the two materials used for the building design. Total 12 models i.e. 6 models using RCC and 6 models using SIMCON are considered for the study. A rectangular shaped building is modeled in both RCC and SIMCON. Three, five, seven, nine, twelve and fifteen storey buildings both in RCC and SIMCON are modeled. The height of each floor in all cases is taken as 3m. The material properties for SIMCON are obtained from experimental results [8].

![Figure 2 Rectangular Building Plan](image)

The space frame building is modelled in Etabs. The beams and columns are modelled as frame elements and the slab is modelled as a shell element. The wall is considered to be made of brick having thickness 230mm. The wall load is assigned on the beams. The bottom of the frame is fixed. The thickness of slab is 200mm for all the cases. The beam and column details are shown in table.1.

<table>
<thead>
<tr>
<th>No. of Storeys</th>
<th>Beam Size (mm x mm)</th>
<th>Column Size (mm x mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Storey</td>
<td>250 x 350</td>
<td>250 x 450</td>
</tr>
<tr>
<td>5 Storey</td>
<td>350 x 450</td>
<td>350 x 350</td>
</tr>
<tr>
<td>7 Storey</td>
<td>350 x 450</td>
<td>350 x 450</td>
</tr>
<tr>
<td>9 Storey</td>
<td>350 x 450</td>
<td>350 x 350</td>
</tr>
<tr>
<td>12 Storey</td>
<td>400 x 450</td>
<td>400 x 550</td>
</tr>
<tr>
<td>15 Storey</td>
<td>450 x 450</td>
<td>450 x 600</td>
</tr>
</tbody>
</table>

The concrete used for RCC building is M60 and Fe415 steel. The 3 D models of 15 storey RCC building and SIMCON building are shown in fig.3 and fig.4.
3. ANALYSIS

Modal analysis is used to determine a structure’s vibration characteristics like natural frequencies and mode shapes. It is the most fundamental of all dynamic analysis types and is generally the starting point for other, more detailed dynamic analyses. Define various loads (Dead load, live load, Earthquake load) in Etabs software. In dead Load, self weight multiplier is used 1 to calculate dead load as default. Live load or any other define load, the multiplier is zero. After defining loads and various load combinations the modal analysis is carried out. The frequencies of mode number upto 12 are considered for the thesis work. Brick wall load is assigned on beams. The brick wall of 230mm thickness is considered. Time history analysis is used to determine the dynamic response of a structure to arbitrary loading. ETABS can complete any number of time history cases in a single execution of the program. Each case can differ in the load applied and in the type of analysis to be performed. The pressure and time for time history analysis is calculated as per IS 4991:1968 Criteria for Blast Resistant Design OF Structures for Explosions above Ground. The time history analysis is carried out using Etabs software. The pressure versus time plot is like a triangular time history function.

4. RESULTS AND DISCUSSIONS

The fundamental frequencies for all SIMCON buildings are greater than RCC buildings. The increase in the frequency of the SIMCON buildings is mainly due to its high strength, high energy absorption capacity when blast wave reaches the building and high ductility. The SIMCON buildings with lesser number of storeys have higher fundamental frequencies than RCC buildings. The increase in the frequencies for SIMCON buildings shows the ability of SIMCON to resist blast effects to a great extend. But higher storied buildings have comparatively low frequencies because as the height of building increases or number of storeys increases the fundamental frequency decreases. But SIMCON buildings have greater fundamental frequency than the RCC buildings even if there is variation in height of the buildings. The fundamental frequencies for RCC and SIMCON buildings are given in table.2.
Table 2 Fundamental Frequencies of RCC and SIMCON Buildings

<table>
<thead>
<tr>
<th>Storey</th>
<th>Fundamental Frequency for RCC Building (Hz)</th>
<th>Fundamental Frequency for RCC Building (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>2.45478</td>
<td>3.15365</td>
</tr>
<tr>
<td>5</td>
<td>2.17971</td>
<td>2.79309</td>
</tr>
<tr>
<td>7</td>
<td>1.59135</td>
<td>2.03673</td>
</tr>
<tr>
<td>9</td>
<td>1.24592</td>
<td>1.59333</td>
</tr>
<tr>
<td>12</td>
<td>1.01506</td>
<td>1.30160</td>
</tr>
<tr>
<td>15</td>
<td>0.85361</td>
<td>1.02370</td>
</tr>
</tbody>
</table>

Overall dynamic behavior of SIMCON buildings is better than RCC buildings. As the height of SIMCON buildings increases, its frequency decreases but then also it is greater than RCC buildings. Table.3 shows the frequencies of SIMCON buildings for all 6 cases which is studied in this thesis. A graph which shows the variation of fundamental frequency with height is shown in fig.6.

Table 3 Frequencies of 3, 5, 7, 9, 12 and 15 storey SIMCON Buildings

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>3 storey</th>
<th>5 storey</th>
<th>7 storey</th>
<th>9 storey</th>
<th>12 storey</th>
<th>15 storey</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.15</td>
<td>2.79</td>
<td>2.03</td>
<td>1.59</td>
<td>1.30</td>
<td>1.02</td>
</tr>
<tr>
<td>2</td>
<td>4.05</td>
<td>3.42</td>
<td>2.50</td>
<td>1.96</td>
<td>1.49</td>
<td>1.16</td>
</tr>
<tr>
<td>3</td>
<td>4.29</td>
<td>3.49</td>
<td>2.52</td>
<td>1.97</td>
<td>1.58</td>
<td>1.27</td>
</tr>
<tr>
<td>4</td>
<td>9.64</td>
<td>8.53</td>
<td>6.20</td>
<td>4.85</td>
<td>3.99</td>
<td>3.15</td>
</tr>
<tr>
<td>5</td>
<td>12.8</td>
<td>10.5</td>
<td>7.66</td>
<td>6.01</td>
<td>4.61</td>
<td>3.62</td>
</tr>
<tr>
<td>6</td>
<td>13.9</td>
<td>10.9</td>
<td>7.83</td>
<td>6.06</td>
<td>4.81</td>
<td>3.86</td>
</tr>
<tr>
<td>7</td>
<td>15.8</td>
<td>14.5</td>
<td>10.6</td>
<td>8.35</td>
<td>6.97</td>
<td>5.56</td>
</tr>
<tr>
<td>8</td>
<td>22.4</td>
<td>18.3</td>
<td>13.1</td>
<td>10.2</td>
<td>8.15</td>
<td>6.47</td>
</tr>
<tr>
<td>9</td>
<td>25.7</td>
<td>19.5</td>
<td>13.8</td>
<td>10.6</td>
<td>8.18</td>
<td>6.54</td>
</tr>
<tr>
<td>10</td>
<td>27.1</td>
<td>20.4</td>
<td>15.0</td>
<td>11.8</td>
<td>9.94</td>
<td>6.93</td>
</tr>
<tr>
<td>11</td>
<td>27.9</td>
<td>25.1</td>
<td>19.0</td>
<td>14.7</td>
<td>11.6</td>
<td>9.30</td>
</tr>
<tr>
<td>12</td>
<td>29.0</td>
<td>26.3</td>
<td>19.4</td>
<td>15.3</td>
<td>11.7</td>
<td>9.31</td>
</tr>
</tbody>
</table>

Figure 6 Graph of SIMCON buildings showing variation of Frequency with different stories
The comparison graphs of top storey displacements for both RCC and SIMCON three, five and seven storey buildings are shown in fig.7, fig.8, fig.9, fig.10, fig.11 and fig.12. All other storeys had lesser storey displacements when compared to top storeys. From the obtained values for top storey displacements, it could be concluded that RCC buildings have larger storey displacements when compared to SIMCON buildings. The increase in the frequency of the SIMCON buildings is mainly due to its high strength, high energy absorption capacity when blast wave reaches the building and high ductility. RCC buildings have greater storey displacements when compared to SIMCON buildings. The decrease in the storey displacements of the SIMCON buildings is mainly due to its high strength, high energy absorption capacity when blast wave reaches the building and high ductility. Also as the height of the buildings increases the storey displacements also increases but here also the displacements are less in SIMCON buildings. The top storeys have large displacements when compared to bottom storeys because flexural strength of buildings decreases as its height increases.

**Figure 7** Top storey displacement for 3 storey

**Figure 8** Top storey displacement for 5 storey
Analysis of RCC and Simcon Buildings Subjected To Blast Effects

Figure 9: Top storey displacement for 7 storey

Figure 10: Top storey displacement for 9 storey

Figure 11: Top storey displacement for 12 storey

Figure 12: Top storey displacement for 15 storey
5. CONCLUSIONS

After completing the present work on analysis of RCC and SIMCON buildings subjected to blast effects the following conclusions have been made.

1. SIMCON buildings have more fundamental frequency than RCC buildings. Overall dynamic behavior of SIMCON buildings is better than RCC buildings.
2. As the height of SIMCON buildings increases, its frequency decreases but then also it is greater than RCC buildings.
3. RCC buildings have greater storey displacements when compared to SIMCON buildings.
4. The top storeys have large displacements when compared to bottom storeys.
5. As the height of the buildings increases the storey displacements also increases but here also the displacements are less in SIMCON buildings.
6. When standoff distance decreases then the blast effect on the building increases. But the blast effects on SIMCON buildings are comparatively less when compared to RCC buildings. The reduced displacements in SIMCON buildings subjected to blast effects shows that these structures can resist blast effects greatly than RCC buildings.

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Analysis of RCC and Simcon Buildings Subjected To Blast Effects


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