Structural Response of Two-Storey Reinforced Concrete Building Under Blasting Effects

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Abstract

Terrorist attacks are caused collapsing of many building in the world. A terrorist attack usually shows itself with an explosion of blasting agent or bomb which can cause catastrophic effects on buildings, roads, environments and people. An explosion can damage a building badly, it can collapse walls, spall columns, beams and blows windows out. So it can be say that the detonation of blasting causes many economical and life losing. Briefly, structural response of buildings has to be investigated against to explosives inflicted to a bomb or other blast agents to avoid this losing. So, this study investigates the structural response of buildings under blasting effects through a numerical evaluation. For the purpose, two-storey reinforced concrete (RC) building is analytically modeled in ANSYS Workbench software considering RC columns, beams, floors as structural elements and walls and windows as non-structural elements. Then two tons of TNT as blasting is defined in the building and it is exploded for 3 micro-second. This explicit analysis is performed using ANSYS AUTODYN software which is often used to simulate the response of materials to short duration severe loadings from impact, high pressure or explosions. The deformed shapes, pressure values and damage ratios are presented with contour diagrams as results of explicit analysis. The results shows that the blasting is so affected to structural response of the building

Keywords — Analytical modeling, Blasting effects, Explicit Analysis, Reinforced concrete building, Structural response

1 Introduction

Terrorist attacks are one of the biggest problems in the world. A terrorist attack usually shows itself with an explosion of a bomb which can cause catastrophic effect on buildings, roads, environments and people. An explosion can damage a building badly, it can collapse walls, spall columns, beams and blows windows out. If the charge weight of the bomb is big enough, it can demolish the building. Explosion can cause injuries (temporary and/or permanent) and loss of life can result collapsing of structures, impact, fire, smoke and effect of blast (See Figure 1).

Figure 1. Some pictures from terrorist attacks or blasting

Blast load does not always show itself as a result of terrorist attack, it also shows itself with other ways such as explosion of; natural gas, boiler room, coal gas in wastewater pipe systems (See Figure 2). Nowadays, the design loads of the structures (dead, live and dynamic) are calculated at project phase but blast loads are not calculated and they can be greater than the design load of the building. Important and critical buildings such as hospitals, public buildings, schools, military buildings, bridges and etc. should be designed at project phase in order to resist blast loads.

Figure 2. Some pictures from several blasting such as natural gas, boiler room

Researchers have been made on blast effect to explain detailed information, parameters, standards to design strong structures against explosives, protect environment and people from effect of blast loading. The manuals TM 5-1300 [1], FEMA 426 [2], FEMA 427 [3], and the hand books written by Mays and Smith [4], Shepherd [5], and Dusenberry [6] tell about the design criteria of safe buildings against blast effects. On the other hand, Brode [7], Newmark and Hansen [8], Henrych [9], Mills [10] have proposed empirical formulas to calculate; peak overpressure, scaled distance and wave impulse. According to these formulas, the parameters of the simple structures can be calculated. Ngo et al. [11] investigated about the blast loading and blast effects on structures. The study contains; empirical methods, formulas, graphics about explosion, analysis, computer programs on blast effect and numerical example solved with computer program. Vijayaraghavan et al. [12] described the blast effects of a great explosion in front of the city affecting people, environment and buildings. Draganić and Sigmund [13] compared to charge mass of TNT for different vehicles, conversion factors of explosives, graphics about explosion and analysis, empirical methods, formulas and numerical example. Rigby et al. [14] examined the different types of explosives had used on experiment and computer simulation to compare the peak overpressures on constant stand-off distances. Results had plotted on graphics for comparison between experiment and computer simulation. Yusof et al. [15] studied about the different charge weight of explosives subjected to a concrete wall had simulated on AUTODYN. The response of the concrete wall was analyzed against different weight of explosive.

This study aims to research that blasting effects on the structural response of building. For the purpose two-storey reinforced concrete (RC) building is analytically modeled in explicit analysis is performed using ANSYS AUTODYN software under blasting loads. In the content of the study, literature review related to blast effects and theory, description of explosives, criteria for buildings against blast loading are presented. Theory of blast effect is explained, with graphs (pressure-time), tables (reflected pressure-charge; risk criteria, conversion factors for explosives, estimated quantities of explosives in various vehicles) and figures. Numerical example includes the description of two-storey building, 3D finite element modeling and explicit analysis. The deformed shapes, pressure values and damage ratios are presented with contour diagrams as results of this study.

2 Theory of Blast

An explosion is rapid increased in volume and released of energy in an extreme manner, usually with the generation of high temperature. The explosion is a phenomenon and the energy is released rapidly and abruptly. Explosion causes shock wave which expands spherically. It can subject big pressure on the nearest structures abruptly. Surfaces of the structures reflects blast wave but after reflection the pressure of the blast wave (see Figure 3) decreases.

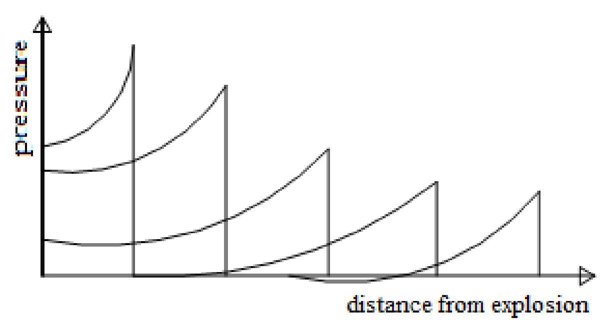

Figure 3. Pressure wave-distance interaction related to blasting [4]

The act of explosion can be modeled as a pressure-time graph which can be drawn in Figure 4. According to the graph in Fig. 4, "0" is the start time of explosion before the shock wave reaches to the structure (t0) in the millisecond range and subjects (pressure reaches to Pso immediately) pressure to surface; this phase is called positive phase. Then the pressure decreases and slope reaches to negative phase (-Pso); this causes negative pressure. At positive phase; big amount of energy released and shock wave impacts to structure that spalling, bending, cracking situations are to be expected. Negative phase means vacuum which pulls debris fragments to explosion source. At the negative phase; absolute peak negative pressure (-Pso) is smaller than the absolute peak positive pressure (Pso); on the other hand negative phase (t1-t0) duration is longer than the positive phase (t2-t1) duration. P0 and duration are related to some important parameters such as charge weight (W), distance (R) from the surface, and type of the material. Generally duration of the explosion is approximately 2,5 ~ 3 milliseconds and value of Pso can reach to big overpressures [1].

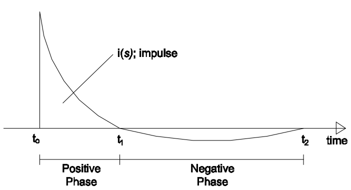

Figure 4. Pressure- Time graph of the explosion [10]

2.1 Importance of Surface and Place of Structure Against Explosion

The effect of the explosion depends on the place of the explosion and geometry of the structure. Structures with big surfaces and concave surfaces; buildings with multi-level, close to other buildings and close to road, are vulnerable to explosion. On the other hand, structures with short surfaces and convex surfaces, far to road and other buildings are safer. Schematic view of safe and unsafe building against blasting effects are plotted in Figure. 5.

When an explosion occurs, the shock wave penetrates through window and/or door and affects walls, floors, contents and people being subjected to a high pressure. Dr. Baker [16] developed P-I curve (pressure-impulse curves) to analyze blast damage. According to graph that he proposed risk criteria and situation of the buildings against overpressure can be seen in Tables 1-3. According to the Tables 1-3 that he proposed there are three situations about risk criteria; general buildings, industrial buildings and window panels.

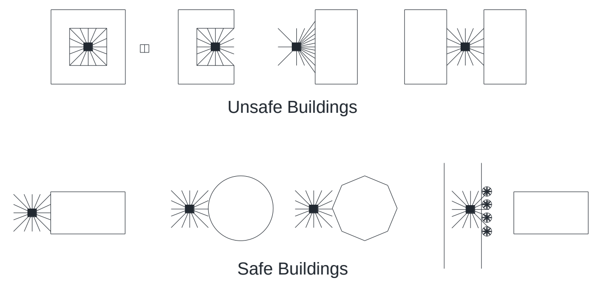

Figure 5. Safe and unsafe buildings against to blasting effects [16]

Risk criteria for steel and reinforced concrete structure is given in Table 2. Steel and reinforced concrete acts less response to blast pressure rather than breakable materials like glass. These structures have big plastic deformation capacity; when elastic limit is exceeded, the structures resist these stresses (at considerable higher pressures) but plastic deformation occurs. These structures will fail when they face against overpressures (min. 2 times the elastic limit).

When an explosion occurs pane windows are usually destroyed. The explosion causes shock wave which expands spherically and produces shock wave which impulses windows panes and blows them out. Baker proposed damage criteria for windows panes are given in Table 3.

2.2 Basic Parameters of Explosion

TNT (Trinitrotoluene) is used as a reference to analyze the scaled distance (Z) and stress. But when we meet other explosive to analyze, we must change mass into an equivalent mass of the TNT. Mays [4] has proposed conversion factors for explosives (see Table 4). Explosives is commonly used by terrorists as a weapon, they usually carry explosives with vehicles to attack. Mays [4] has proposed estimated quantities of explosives in various vehicles in Table 5.

Table 1. Risk criteria for general buildings [16]

Overpressure (kPa)	Effect
4.5	Threshold for minor structural damage. Wrenched joints and partitions.
17.0	Threshold for major structural damage. Some load bearing members fail.
40.0	Threshold for partial demolition. %50 to %75 of walls destroyed or unsafe

Table 2. Risk criteria for modern and industrial buildings [16]

Overpressure (kPa)	Effect
1.5	Threshold for minor damage to steel structures. Some permanent deformations are to be expected.
3.0	Threshold for major damage to steel structures. Some elements may fail.
1.7	Threshold for minor damage to reinforced concrete structures. Some permanent deformations are to be expected.
3.4	Threshold for major damage to reinforced concrete structures. Some elements may fail.

Table 3. Risk criteria for windows pane [16]

Overpressure (kPa)	Effect
1.0	Threshold of minor window pane failure. About %5 of window panes will fail.
3.0	Threshold of major window pane failure. Many window panes will fail. The glass fragments may reach high velocities and people behind these windows.

Table 4. Conversion factors for explosives [4]

Explosive	Spesific Energy Qx / kj/kg	TNT Equivalent Qx / QTNT
Compound B (60 % RDX, 40 % TNT)	5190	1.148
RDX	5360	1.185
HMX	5680	1.256
Nitroglycerin (liquid)	6700	1.481
TNT	4520	1.000
Explosive Gelatin	4520	1.000
60 % Nitroglycerin Dynamite	2710	0.600
Semteks	5660	1.250
C4	6057	1.340

Table 5. Estimated quantities of explosives in various vehicles [4]

Veichle Type	Charge Mass (kg)
Compact Car Trunk	115
Trunk of a Large Car	230
Closed Van	680
Closed Truck	2.270
Truck with a Trailer	13.610
Truck with Two Trailers	27.220

3 Numerical Example

3.1 Description of the Building and Its Finite Element Modeling

In this study, a two-storey building is preferred to simulate an existing building which was bomb in August 2015 in Istanbul, Turkey (See Figure 6). So 3D drawing model of a two-storey reinforced concrete building selected for numerical example is given in Figure 7. As seen in Figure 7 that, main structural elements of the building are RC columns, beams and floors; the non-structural elements are brick walls and window panels. Also the model contains air and void and TNT. The geometrical dimensions of the building are presented in Figure 8. As seen in Figure 8 that, the building has 3.75 m storey height and has 12x8 m foundation with 0.5 m height. It has two and one bays along to orthogonal directions. The dimensions are in m types in Figure 8.

Figure 6. Some pictures from bombing of a building in August 2015 in Istanbul

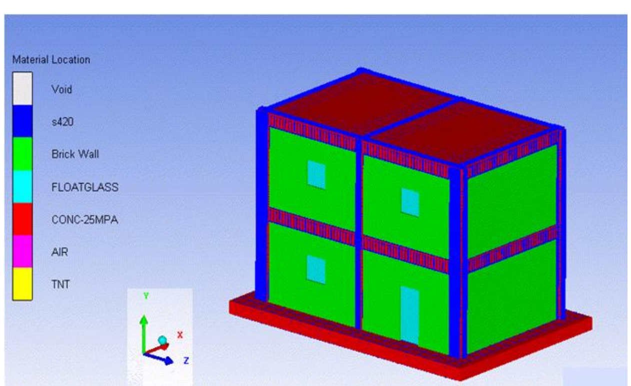

Figure 7. 3D drawing model of a two-storey reinforced concrete building

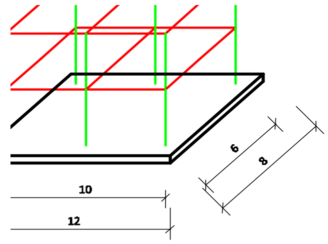

Figure 8. Geometrical dimensions of two-storey building

The named elements of the building which are used to present analyze results are given in Figure 9. The names can be explained in Figure 9 such as; 1c1-column 1 on the first storey, 2b3- beam 3 on the second storey, 1s2- slab 2 on the first floor, 2w1-wall 1 on the second storey. The other naming is done similar thought.

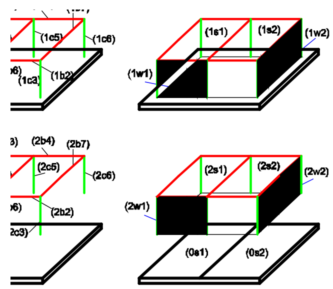

Figure 9. The named elements of the building

The two-storey building subjected to the study have six columns in a stores that four of them sized with 60x30 cm and two of them sized with 30x30 cm dimensions (see Figure. 10a), the section dimensions of the beams are same selected as 30x50 cm (See Fig. 10b). The height of the reinforced concrete slab is assumed as 15 cm. The dimensions and properties given here for RC column, beam, and slabs are suitably selected for a two-storey building against to dead, live and earthquake loads according to Turkish Standard 500 [17], and Turkish Seismic Code [18].

According to geometrical properties, 3D finite element model of two-storey building constituted using ANSYS Workbench [19] software as given in Figure 11. In finite element model of the building, walls are designed with brick wall with the thickness of 20 cm. The thickness of the window panels is 1 cm. In addition, the second floor slab contains an opening of 3.7 x 2 m for stairwell which is also preferred to open way to blasting waves. Explosion material is selected as 2 ton TNT and it is placed at the middle of the first storey of the building (see Figure 12). Blast modeling is constituted using ANSYS AUTODYN [20] software, also the explicit analysis of the building is performed in this software for a duration of 3 micro seconds. The material properties of components used in the modeling and analysis such concrete, reinforcement, wall, window, air, and TNT are given in Table 6.

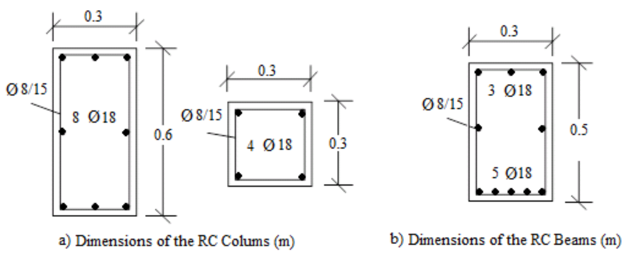

Figure 10. The gauge points placed to the elements to evaluate the analysis results

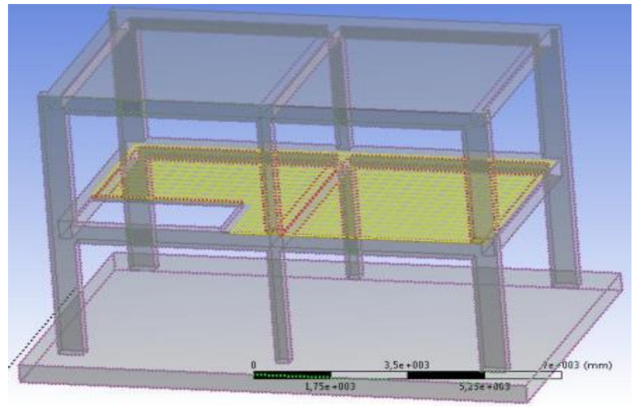

Figure 11. 3D finite element model of a two-storey reinforced concrete building

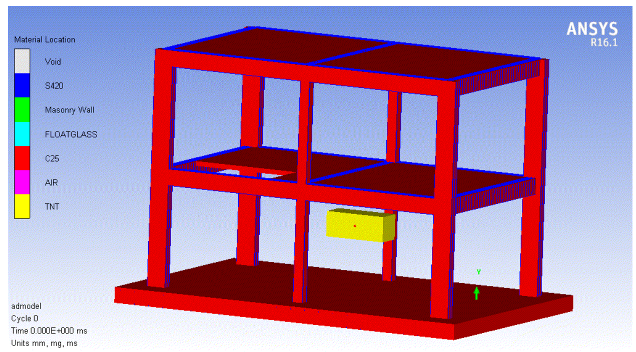

Figure 12. The place of blasting material (TNT) in the building

Table 6. The material properties of components used in the modeling and analysis

Material Component	Material Type	Elasticity Modulus (MPa)	Density (g/cm3)	Compressive Strength (MPa)	Tensile Strength (MPa)
Concrete	C25	3.527 x 104	2.75	25	2.5
Reinforced	S420	2 x 105	7.83	420	420
Wall	Brick Wall	7.8 x 103	2.4	5	0.5
Window	Float Glass	4.54 x 104	2.2		
Air	Air	-	1.225 x 10-3	-	-
Blasting	TNT	-	1.63	-	-

3.2 Analysis Results

After performing explicit analysis considering explosion, the deformed shape of the two-storey building is illustrated in Figure 13. As seen in Figure 13, the all walls are damaged or collapsed except second storey wall (wall number 2w2). The concrete of 30 x 30 columns at the first storey (column name; 1c2 and 1c5) is completely destroyed and reinforcement bars highly deformed. Also other two columns (1c3 and 1c4) on the first storey are highly damaged and reinforcement bars deformed lowly. However, the concrete of the columns 1c1 and 1c6 are partly deformed. As seen in Figure 13 that the most of the beams are completely damaged and the others are highly damaged at the first storey. The slab concrete is exactly cracked and the reinforcement bars are highly yielded and fractured.. At the second storey of the building, the columns and beams are partly damaged compared to those of first storey. Also the slab of the storey is lowly damaged. On the other hand, the concrete of foundation is partly damaged as seen in Figure 13.

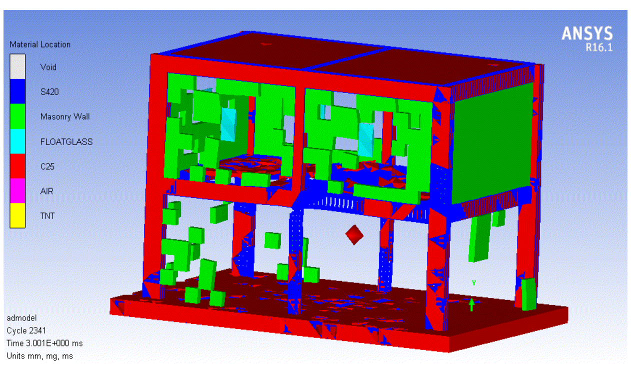

Figure13. Deformed shape of the two-storey building after explosion

The pressure values on the elements of the building obtained from blasting analysis are demonstrated in Figure 14. It can be seen from Figure 14 that, biggest values are occurred on the columns 2c2 and 2c5 at the second storey with pressure value of +23.5 MPa approximately. The columns 1c2 and 1c5 on the first storey have approximately -2.1 MPa pressure value which is the minimum values of the pressure occurred on the building. It also shows that the explosion is so big that it makes impulse the slab and beam (number 1b6) upwards very strongly. In addition, the pressure values on the other columns on the building change between 10 MPa and 4.3 MPa. The pressure value of 15 MPa (averagely) can be read from Figure 14 for beams 1b1, 1b2, 1b3, 1b4, 1b5, 1b6, and 1b7. Related to slab of first storey the pressure is about the 10 MPa.

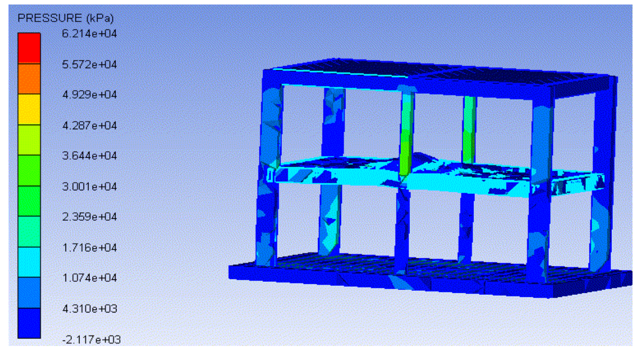

Figure 14. The pressure values on the elements of the building obtained from blasting analyses

The damage ratios occurred due to blasting are shown in Figure 15. As it seen from Figure 15 that the slab of first storey is taken the biggest damage of nearly %100; however the damage is sharply decreased on some local parts near stairwell opening. On the foundation, the big ratio of damage can be seen on two points but damage value suddenly decreases to outward. Also, the big percentage of damage values can be read on the first floor members, however, the damage values are negligible on the second floor slab.

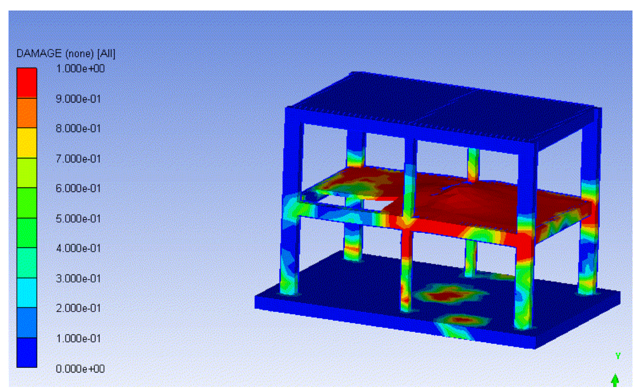

Figure 15. The damage ratios occurred due to blasting

4 Conclusions

A numerical study is conducted to examine the structural response of two-storey reinforced concrete building under blasting effects. A two-storey RC building is selected for the numerical example. The 3D finite element modeling of the building is constituted in ANSYS Workbench software. The blasting load is assumed for two tons TNT in the building and explicit analysis for 3 micro seconds are performed using ANSYS AUTODYN software. The blasting effects on the structural and nonstructural elements of the building according to analysis results are presented. The main conclusions drawn are as fallows from the study:

- ✓ Almost all son structural elements such as window panels and brick walls completely collapsed. Only some of the in second storey of the building are partly damaged.
- ✓ The RC columns, beams and slabs of first storey where the explosion is taken place are wholly cracked. Also the reinforcement bars are yielded and fractured.
- ✓ Nearly 25 MPa pressure is occurred on the some points s of the building due to blasting, and this causes the highly damage ratio on the structural element of the building. Also the biggest damage are obtained on the slab of first storey however the damage is sharply decreased on some local parts near stairwell opening. On the other hand the damage ratios are negligible on the slab of second floor.
- ✓ Big charge mass of explosives can demolish buildings completely. So it is recommended that the building (especially vital buildings) have to be designed at project phase against explosive loads. Step by step, designs have to be made through handbooks, standards and instructions to blast loads.

5 Acknowledgements

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