Response of Steel & CFT (Concrete Filled Tube) Frame Structures with Various Bracing under Blast Explosions

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Abstract - *In this paper an attempt is made to explore the performance of G+9 storied steel and CFT (Concrete Filled Tube) buildings against blast loading for 3000 kg TNT (Tri nitro toluene) placed at 50ft, 75ft and 100ft distance from point of explosion at center position of the building for different cases. Five different types of bracings such as diagonal, X, K, V and inverted V have been used for both buildings at the mid spans. Blast loads on the joints were calculated with the help of excel as per European Standards and the analysis was performed by ETABS v.16 software. The calculated blast pressures were multiplied with tributary areas and pressures were converted into point forces and assigned as static joint loads at frontal face of buildings. The result shows that the 'X' bracing performed well comparing to other bracing for both buildings. It is also found that CFT building with 'X' bracing has performed much better than steel building with 'X' bracing in terms of story displacement and number of failure structural members. From the cost analysis it was found that in CFT building with 'X' bracing costs increases 4.92% although displacement decreases around 27% and member failure decreases around 94% with compare to steel building with 'X' bracing.*

KEYWORD: CFT structure, Steel structure, Blast Explosion, TNT, Bracing, Storey Displacement and Member failure.

1.INTRODUCTION

Day by day the terrorist attacks on various structures are increasing in many cities due to political, geological reasons. The modern world has been in threat due to modern explosives. These explosives can cause massive destruction to human lives as well as structures. Conventional structures normally are not designed to resist blast loads because the magnitudes of design loads are significantly lower than those produced by most explosions that's why most of the structure fail to resist blast load. To avoid such effects on structure various methods are developed to analyse and design to resist such loads. Due to detonation of physical, nuclear and chemical explosives blast occurred near public building, crowded place etc. which causes severe damage and loss of life. Blast wave propagate through air with decreasing speed but with more than that of speed of sound. Terrorist attacks on buildings may not be eliminated completely but the effects of these attacks on buildings and structures can be mitigated to a large extent with precautions and preventive strategies.

1.1 Blast wave characteristics

Explosion is the result of release large amount of energy, which lasts for milliseconds initiates a pressure wave because of expansion of hot gases. As the pressure waves move with the velocity of sound, the temperature and the pressure of the air causing the velocity to increase. The front of the blast waves weakens as the wave moves away from source of explosion. After a short time, the pressure behind the front may drop below the ambient pressure, which is called negative pressure. Negative phase 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

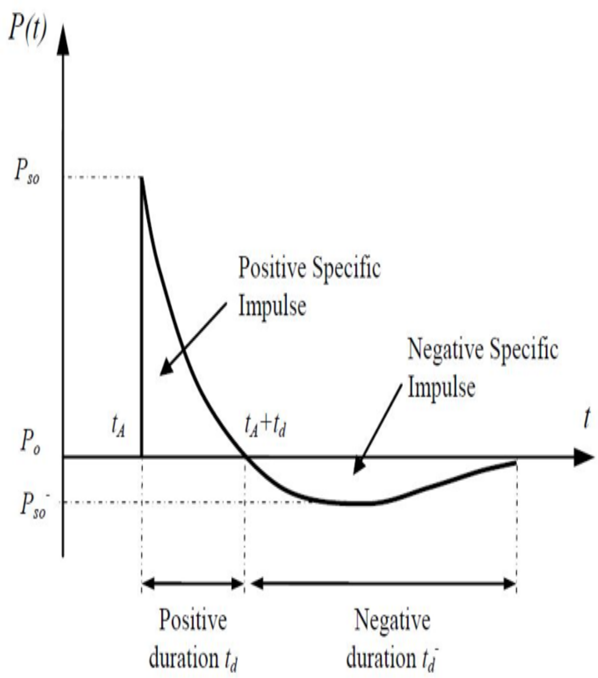


Figure-1: Blast wave pressure-Time history

1.2 Explosion and blast-loading types

There are three types of blast loading which are known as free air burst, air burst and surface burst.

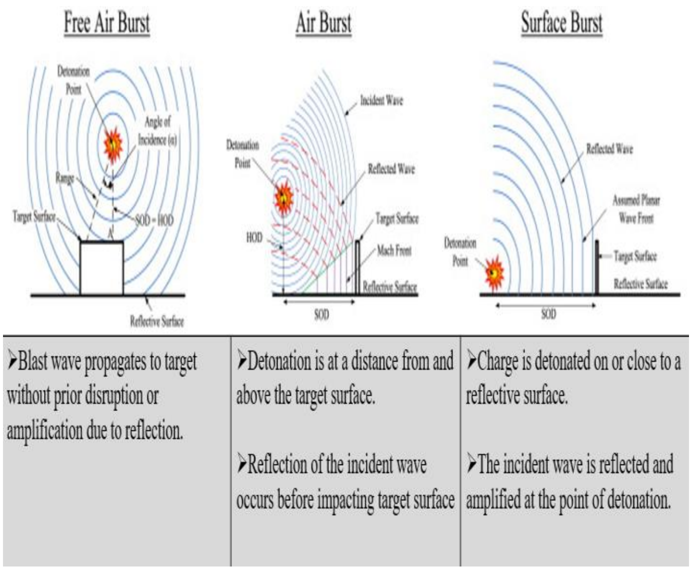


Figure-2: Blast wave types

1.3 Explosive type and weight

The weight of an explosive is usually estimated by taking into account a relevant attack scenario, which would involve a vehicle-borne or a personnel-borne improvised explosive device. Clearly, the larger the used vehicle that could be directed towards a structure, the larger the weight of the explosives it could carry leading to higher equivalent TNT weight values. In table 2 an estimate of the quantity of explosives that could be transported by various vehicle types is presented. Approximately one third of the total chemical energy of the explosive is released by detonation. The rest is released at a slower rate as heat of combustion through burning of the explosive products mix with the surrounding air. Table 1 provides estimates of the produced heat of detonation of some common explosives.

Table 1: Indicative values of heat of detonation of common explosives

Name of explosive	Heat of detonation (Mj/kg)
TNT	4.10-4.55
C4	5.86
RDX	5.13-6.19
PETN	6.69
PENTOLITE 50/50	5.86
NITROGLYCERIN	6.3
NITROMETHANE	6.4
NITROCELLULOSE	10.6
AMON.NIT. (AN)	1.59

Table 2: Upper limit of charge weight per means of transportation

Carrier	Explosive weight (kg)
Suitcase	10
Medium-Sized Car	200
Large-sized car	300
Pick-up truck	1400
Van	3000
Truck	5000
Truck with trailer	10000

2. Methodology

In the present study ten storey steel and CFT frame structures have been analyzed for explosive load of 3000 kg TNT (Tri nitro toluene) placed at 50ft, 75ft and 100ft distance from point of explosion.

- Model details:
  - Plan dimension of 72 ft X 72 ft was modeled in ETABS.
  - Number of spans 4 in each direction, Span length 18 ft.
  - Column size- 20-inch X 12 inch.
    - Steel area-19.15 Square inch.
    - Concrete area- 221 Square inch (For Filled Steel Tube)
  - Beam size- 10-inch X 18 inch (I Section), Steel area 9.83 Square inch.
  - Bracing size- 6-inch X 8 inch (Steel Tee), Steel area 3.44 Square inch.
- Assigned load:
  - Live load- 40 psf
  - Partition wall load- 45 psf
  - Floor finish- 20 psf
  - Line load- 400 lb/ft

For blast loading explosive weight kept unchanged and the explosive was kept at center position of the building for every cases.

Cases are as follows:

Case 1: Response of Steel building and CFT building under blast load with 'Diagonal' bracing in mid span with standoff distance R = 50 ft, 75 ft & 100 ft respectively.

Case 2: Response of Steel building and CFT building under blast load with 'V' bracing in mid span with standoff distance R = 50 ft, 75 ft & 100 ft respectively.

Case 3: Response of Steel building and CFT building under blast load with 'Inverted V' bracing in mid span with standoff distance R = 50 ft, 75 ft & 100 ft respectively.

Case 4: Response of Steel building and CFT building under blast load with 'K' bracing in mid span with standoff distance R = 50 ft, 75 ft & 100 ft respectively.

Case 5: Response of Steel building and CFT building under blast load with 'X' bracing in mid span with standoff distance R = 50 ft, 75 ft & 100 ft respectively.

For checking the capacity of a structure or structural element to withstand the effect of an extraordinary event, the following gravity load combination has been considered according to ASCE 7-10.

(0.9 or 1.2) DL + Aκ + 0.5LL

Here, Ak = the load or load effect resulting from extraordinary event A (like explosion or blasting)

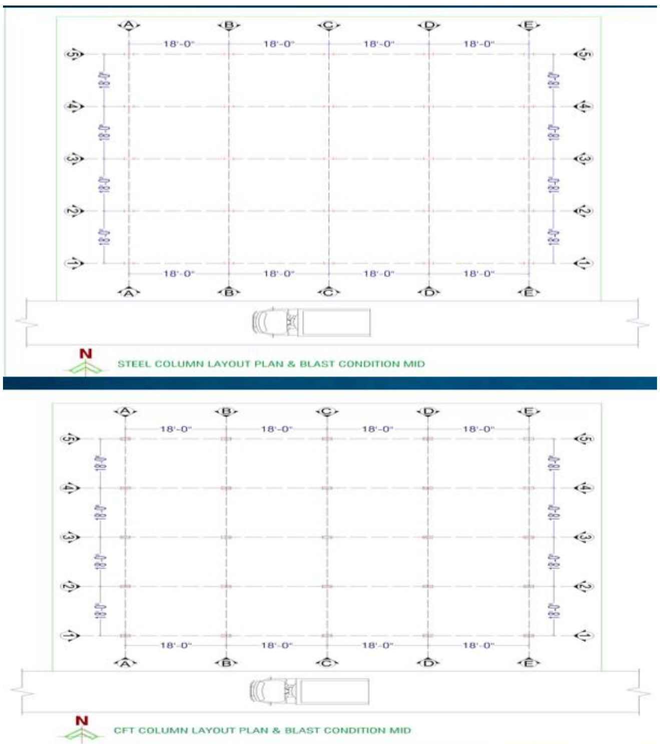
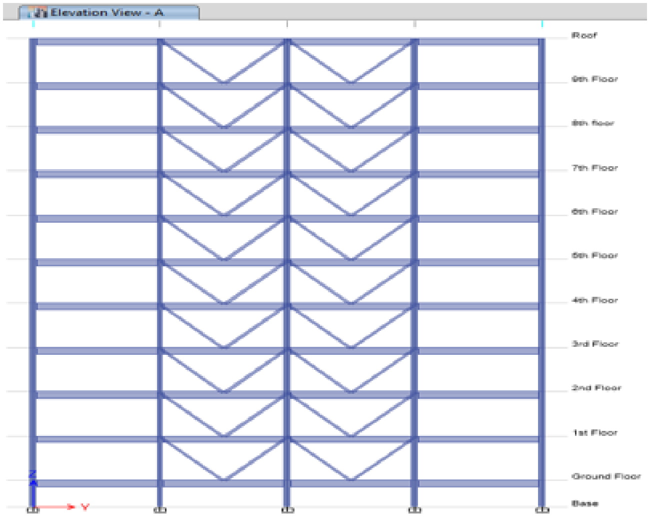
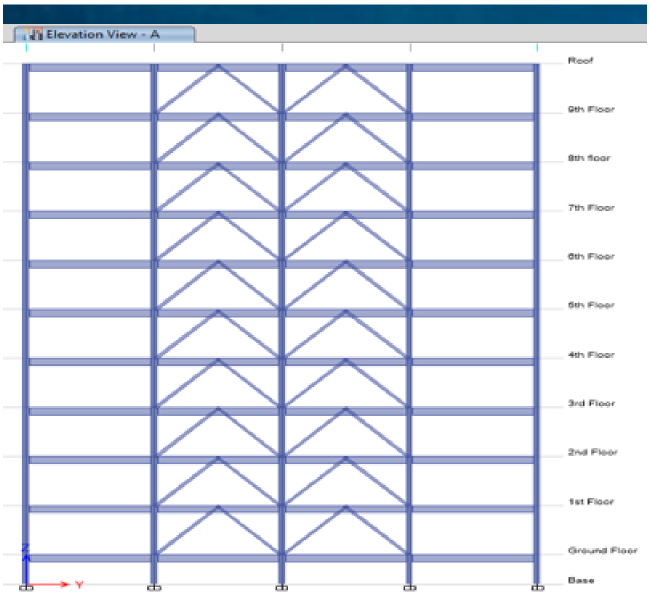
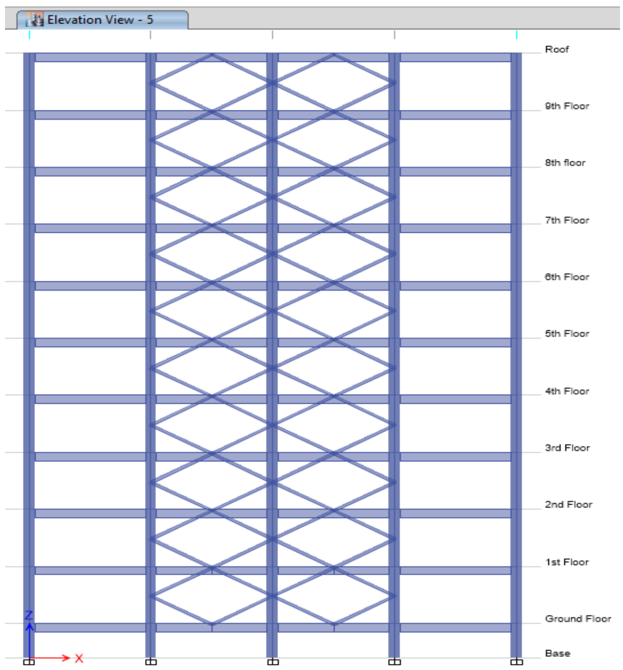


Figure-2: Plan of the building models







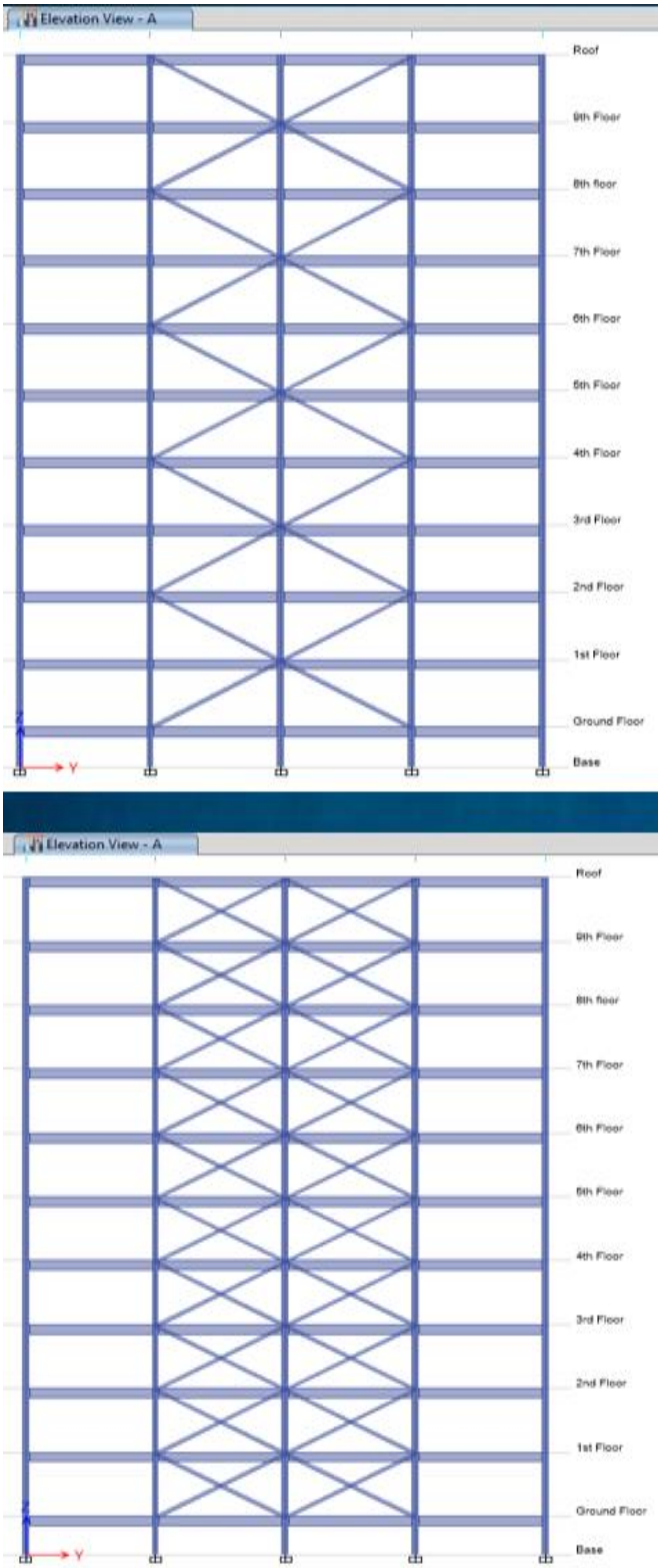


Figure-3: Elevation of the building with 'V' bracing, 'Inverted V' bracing, 'K' bracing, 'Diagonal' bracing and 'X' bracing

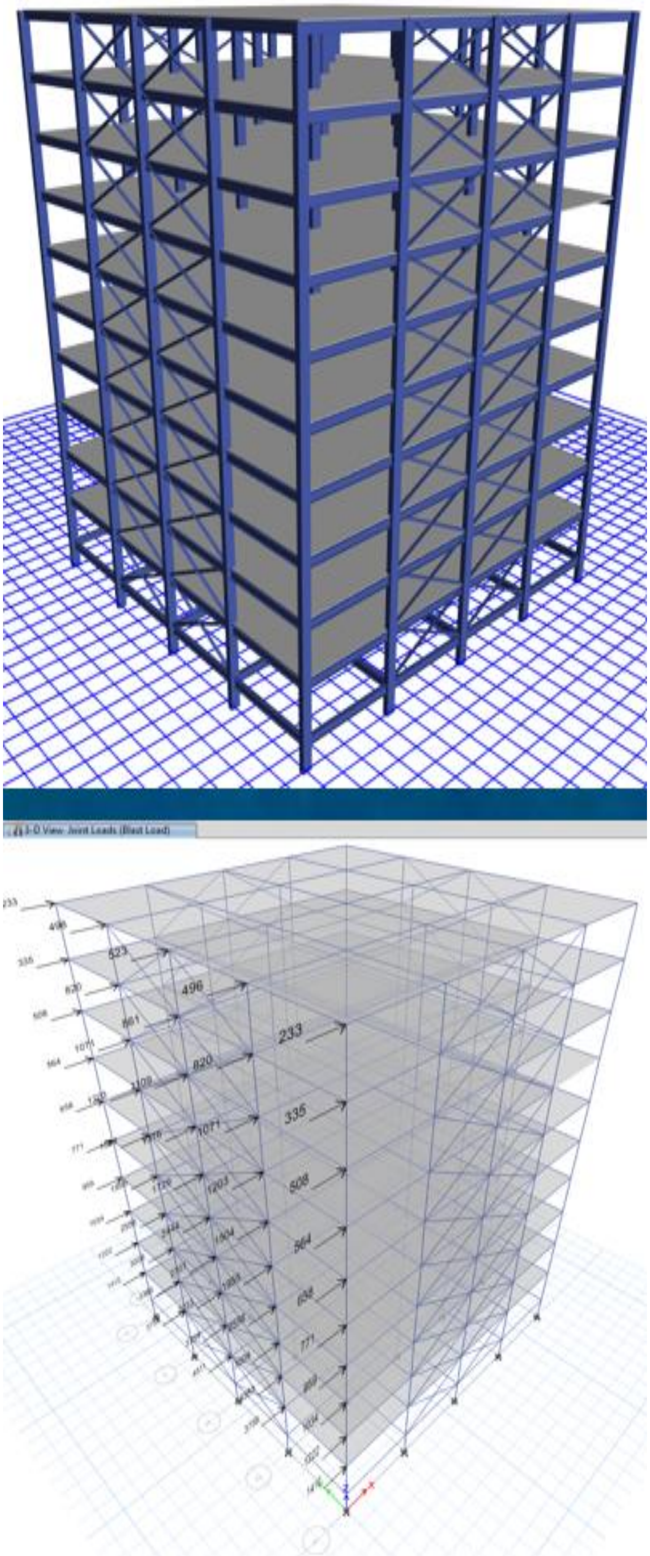


Figure-4: 3D view of the building model and blast load assign in the building

3. Analysis Result & Discussion

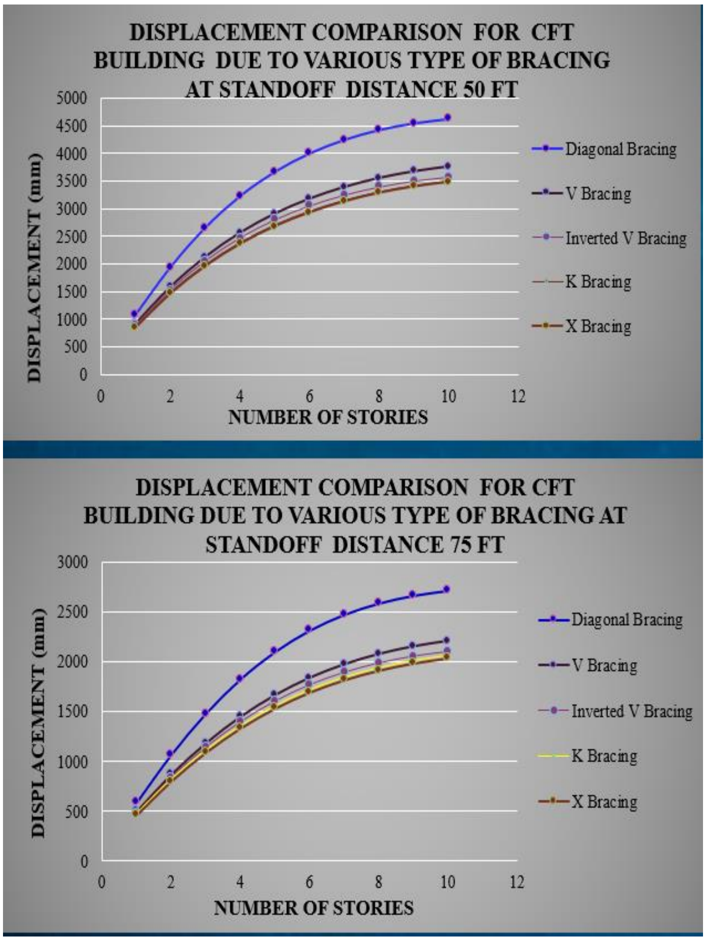


Figure-5: Displacement comparison for CFT buildings due to 50 & 75 ft stand-off distance.

From the Figure-5, it can be seen that at R=50 ft, maximum displacement occurs with 'Diagonal' bracing in CFT building and the 'X' bracing performs 37% better than 'Diagonal' bracing and for R=75 ft, maximum displacement occurs with 'Diagonal' bracing and the 'X' bracing performs 37% better than 'Diagonal' bracing.

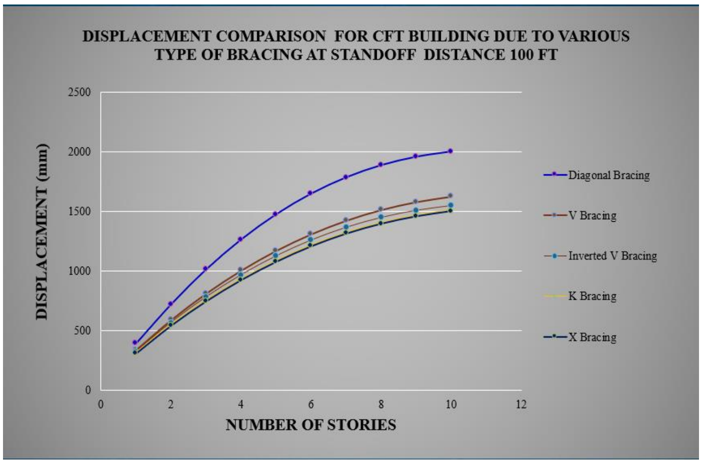


Figure-6: Displacement comparison for CFT buildings due to 100 ft stand-off distance.

Figure-6 shows that at R=100 ft, maximum displacement occurs with 'Diagonal' bracing and the 'X' bracing performs 37% better than 'Diagonal' bracing.

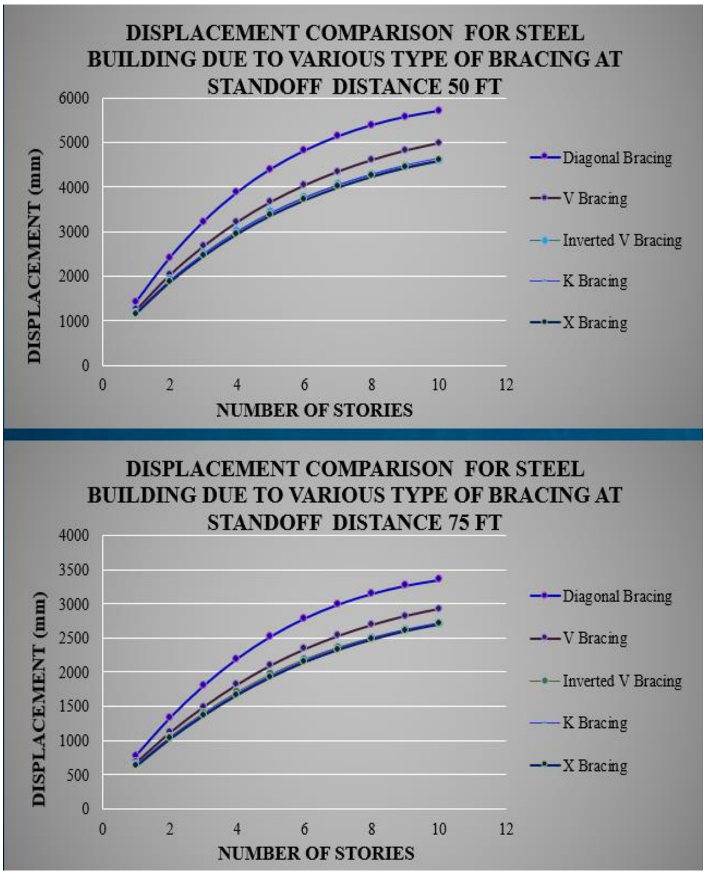


Figure-7: Displacement comparison for steel buildings due to 50 & 75 ft stand-off distance.

From Figure-7 it can be said that at R=50 ft, maximum displacement occurs with 'Diagonal' bracing in Steel building and the 'X' bracing performs 32% better than 'Diagonal' bracing and for R=75 ft, maximum displacement occurs with

'Diagonal' bracing and the 'X' bracing performs 31% better than 'Diagonal' bracing.

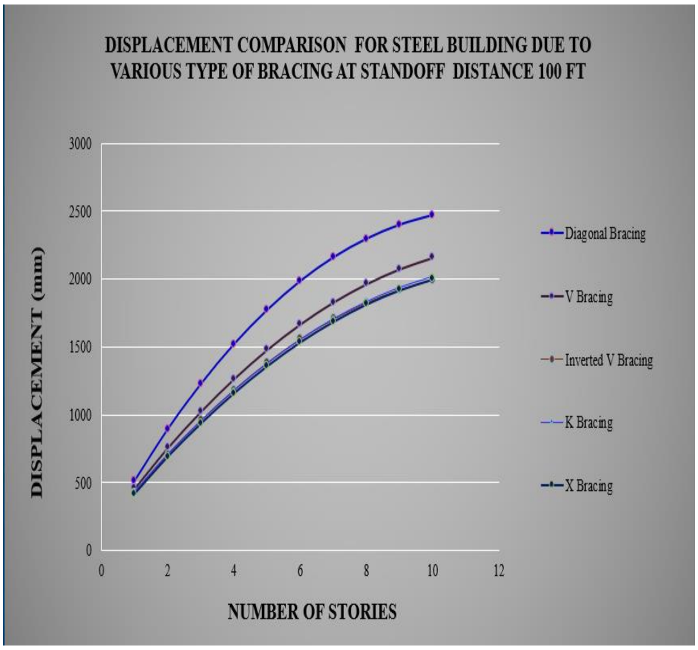


Figure-8: Displacement comparison for steel buildings due to 100 ft stand-off distance.

Figure-8 shows that for R=100 ft, maximum displacement occurs with 'Diagonal' bracing and the 'X' bracing performs 31% better than 'Diagonal' bracing.

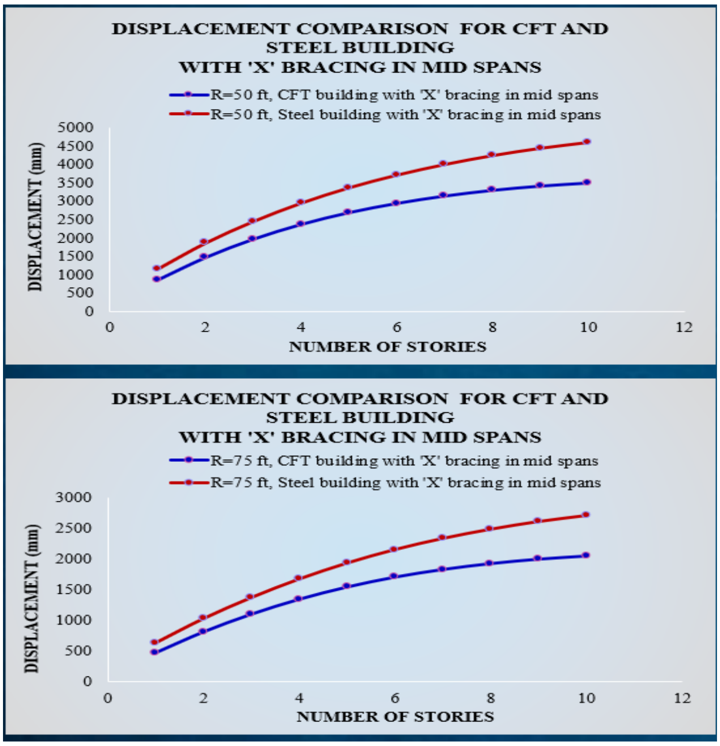


Figure-9: Displacement comparison between CFT and Steel frame building for X bracing at R= 50 ft and 75 ft

Figure-9 shows that steel building has shown maximum storey displacement comparing to CFT building. At R=50ft, the displacement has decreased 35% for 'X' bracing in CFT building comparing to Steel building. On the other hand, the displacement has decreased 35% for 'X' bracing in CFT building at R=75ft, comparing to steel building.

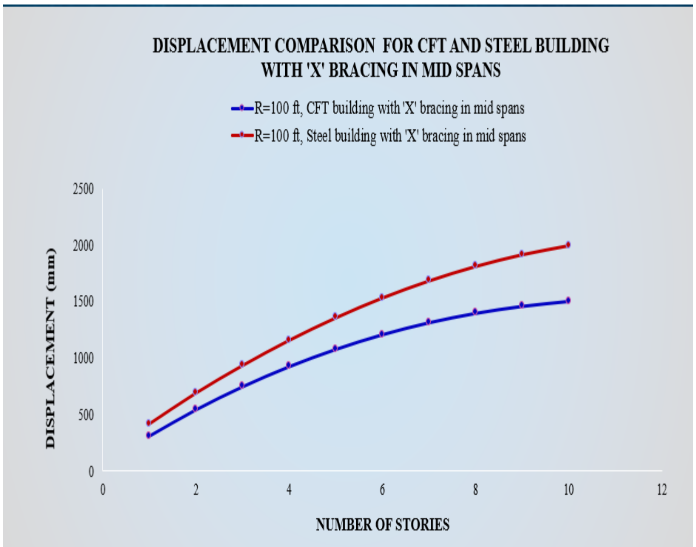


Figure-10: Displacement comparison between CFT and Steel frame building for X bracing at R= 100 ft

Figure-10 shows that at R=100 ft, the displacement has decreased 35% for 'X' bracing in CFT building comparing to Steel building.

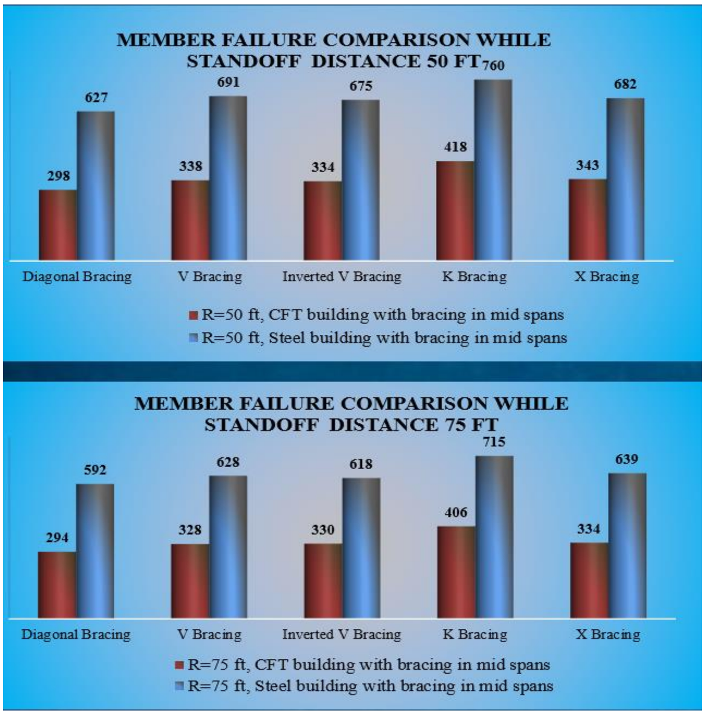


Figure-11: Structural members failure comparison between CFT and Steel building at R= 50 ft and 75 ft

From the above Figure-11 it can be seen that at 50 ft explosive distance, the structural members of steel buildings have failed more than the CFT buildings. CFT building perform 40% better than steel building in aspects of member failure. Also, at 75 ft explosive distance the buildings behave in the same manner. At 75 ft CFT building perform 35% better than steel building.

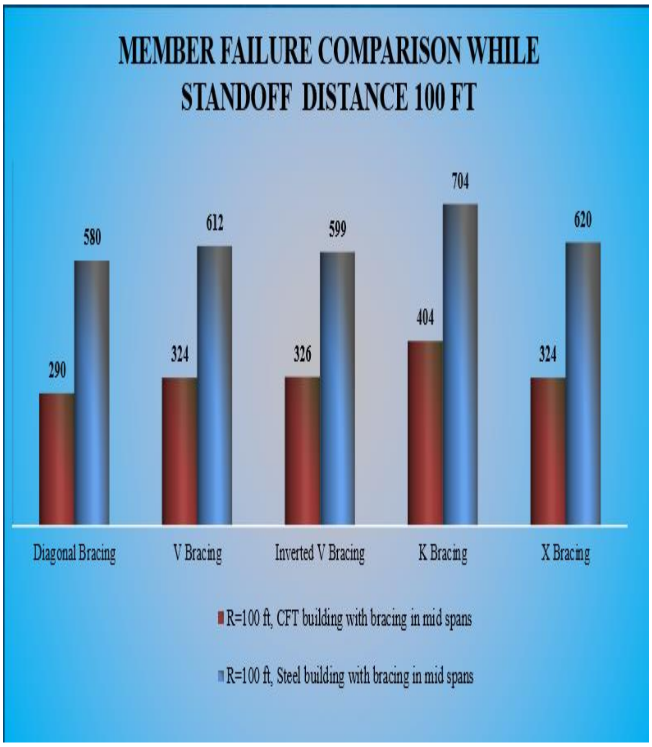


Figure-12: Structural members failure comparison between CFT and Steel building at R= 100 ft

Figure-12 shows that, the structural members of steel buildings have failed more than the CFT buildings while the explosive in middle position at 100 ft explosive distance. CFT building perform 34% better than steel building

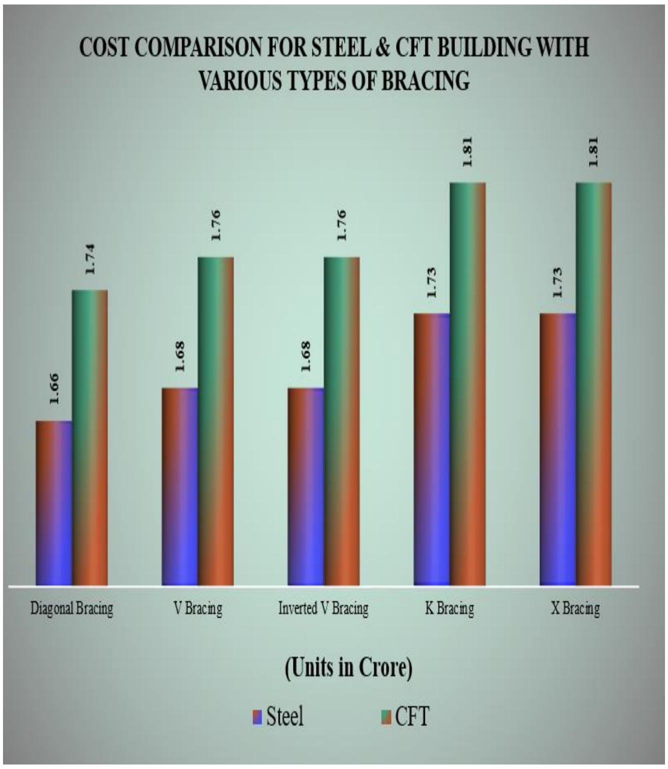


Figure-13: Cost comparison between CFT and steel building

Figure-13 shows that from cost analysis it can be concluded that in CFT building with 'X' bracing costs increases 4.92%. Where displacement decreases 28%, 28% &29% and member failure decreases 99%, 91% & 91% for standoff separation 50ft, 75ft & 100ft respectively with compare to steel building with 'X' bracing.

4. CONCLUSIONS

- ✓ From the above results we can conclude that CFT building with 'X' bracing at mid spans has performed much better than steel buildings in terms of storey displacement and number of failure members at least standoff separation.
- ✓ As the standoff distance decrease the blast load increases which results higher displacement and failure members have increased drastically in the both steel and composite structures.
- ✓ At 100 ft standoff distance and with 'X' bracing there were less member failed due to blast loading for CFT building.
- ✓ The response of the buildings depends on the standoff distance and the stability of the building increases as the standoff distance increase.
- ✓ Magnitude of blast load increases as source of explosion close to structure and decreases as source moves away.

5. Recommendation

- ✓ Considering the parameters such as storey displacement, failure members and cost analysis it can be recommended that CFT frame structures with X bracing may become a solution for making explosion resistant structures.
- ✓ Advanced composites as blast absorbing materials can be introduced such as ceramic/composite armor, fiber composites, foams, magneto-rheological (MR) fluids and porous materials are typical high energy absorbing materials.
- ✓ Retrofitting of existing structures can be a solution to withstand the effects of explosive loads.

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BIOGRAPHIES

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	Md. Alamgir Hossain has completed his Bachelor in Civil Engineering from World University of Bangladesh in 2018. He is currently working in Matarbari Ultra Super Critical Coal Fired Power Plant as a Site Engineer.
	Mr. Md. Mohiuddin Ahmed graduated in Civil Engineering in 2013. At the beginning of his career, he got experience in design and construction of earthquake resilient high-rise buildings in different parts of Bangladesh. He has more than 20 Research Publications including publication in Elsevier Conference Proceeding.

	Shariful Islam was born in 1996 in feni, Bnagladesh. He is skilled at construction management and structural design. He has completed his Diploma in Architecture & Interior Design Engineering in 2016 and Bachelor in Civil Engineering from University of Information Technology and Sciences in 2021. He was awarded from GPH Ispat & Prothom Alo Structural Engineering Competition.