Response of RC Structure Exposed to Explosion

Ankur Yadav[1]

[1]P.G. Student, Mewar University,
Chittorgarh, Rajasthan, India

Abstract - The purpose of buildings extends beyond merely providing habitat to people. Buildings should be designed in a manner which ensures security of their occupants. Hence, it is important to study the effects that last loads can have on buildings. Blast loads are dynamic in nature just like wind and earthquake loads. This study focuses mainly on analyzing the effects of blast loads on four different cases of structural systems and finding ways to reduce these effects using methods like shear wall and steel bracing with the help of ETAB 2015. It was concluded that the provision of a shear wall around the structure contributes highly in resisting blast loads, as compared to the other alternatives under discussion.

1. INTRODUCTION

The purpose of buildings extends beyond merely providing habitat to people. Buildings should be designed in a manner which ensures security of their occupants. With structurally more secure buildings, people will feel more protected against unfortunate events such as acts of terrorism, etc. Hence, it is important to study the effects that blast loads can have on buildings. Blast loads are dynamic in nature, and can be calculated precisely, just like wind and earthquake loads.

The foremost aim of this work is to discuss and analyze the performance of different structural systems under the impact of blast loads in events of explosions. The method for mitigating effects of detonation has been discusses, thus preventing harm to life, property and equipment. Relevant literature has been studied thoroughly, with emphasis on topics like possibility of vulnerability evaluation, risk easing, developing ductility and structural response characteristics, etc.

1.1 Characteristics of Blast and its Effect on Structures

Energy discharge from an explosion is characterized as a combination of air pressure and an audible blast. The energy so released is divided into two phenomena. The first is thermal radiation. The second is a pair of air and ground reactions, known as air blast accompanied by ground shock. The principal cause of damage to a building exposed to blast load is air blast. Ground shock, on the other hand, propagates by compressing the air molecules in its path producing the ambient overpressure or the incident pressure (Bangash and Bangash, 2006).

The sequence of events that take place when a high explosive material is initiated was explained by Smith and Hetherington (1994). A typical conventional pressure wave from setting off is illustrated in Figure 1.1
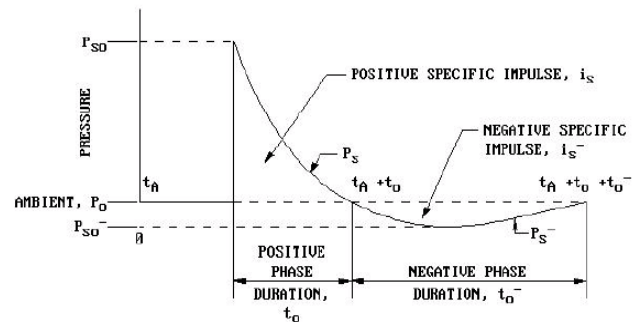

Figure 1.1 Incident and reflected pressures on building

1.1.1 The Source

Chemical charge is traditionally considered to be sphere in shape. Shock front on the surface of the ground from the contact burst can be said to be vertical. The effect of a contact burst is almost twice the magnitude of an air blast. This situation is considered to have the most significant impact.

1.1.2 Shock Wave

As a result of a blast, a shock wave is generated in the air. The high-speed time-dependent pressure and suction effect of this shock wave burst outward in all directions from the point origin. The positive pressure phase is followed by a negative phase as depicted in Fig. 1.2.
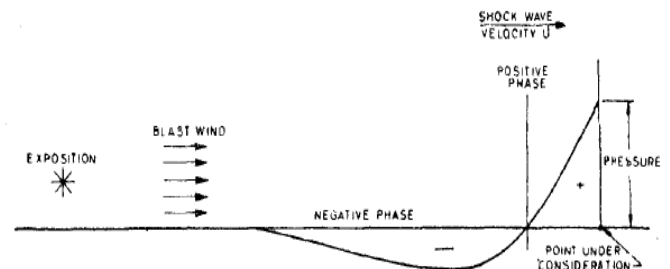

Figure 1.2 Shock wave produced by blast

1.1.3 Pressures and Duration

Characteristics of incident blast wave are expressed by the peak initial overpressure P_{so}, the overpressure P_s versus time curve, the maximum dynamic pressure q_o, the dynamic pressure q verses time t curve and the duration of positive phase t_0. The peak positive intensity drops down to zero instantaneously. Hence, the total length of the positive phase is only a few milliseconds. The maximum negative overpressure is much smaller than the peak positive overpressure, with limiting value equalling one atmosphere. However, the negative phase lasts 2 to 5 times long as positive phase.

1.1.4 General Principles

The natural time period of the member and the effective load to be considered for design are inversely proportional. As compared to the natural period of the structural elements, the

duration of positive phase of blast is generally small. Hence, this may be treated as an impulse dilemma. As it is impossible to predict the direction of a future explosion, every face of the structure will be considered as a front face. Also, when the blast field surrounds the structure, the difference of pressures on front and rear faces tends to tilt and turn over the structure as a whole.

1.1.5   Scaling laws

The distance of the explosion point from the structure under consideration is one of the most significant parameters for blast loading computations. The peak pressure value and velocity of the blast wave reduce sharply on increase of distance between the blast source and the target surface, as illustrated in the Fig.3. The figure shows how the positive phases of the blast waves are longer in duration whenever the distance from the explosion point increases.
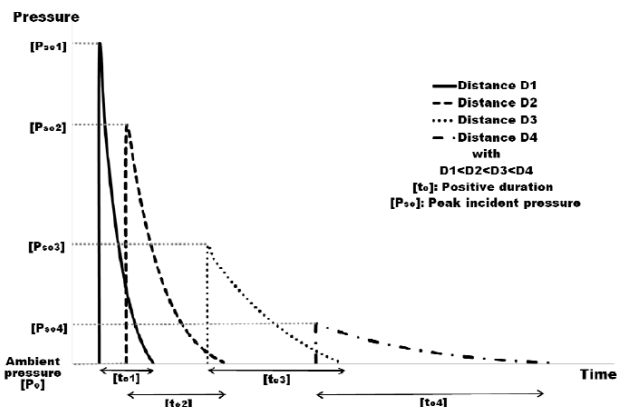
Figure 1.3 Influence of distance on the blast positive pressure phase.

According to Hopkinson-Cranz law, a dimensional scaled distance is introduced as described by the following equation:

$$Z = \frac{R}{\sqrt[3]{W}}$$

Where, R is the distance from the explosion source to the point of interest [m] and W is the weight (more precisely: the mass) of the explosive [kg].

2. LITERATURE REVIEW

Mohammed Ettouney (1996) (ref. 4), conducted a study on blast resistant design of commercial buildings. This paper describes design modifications that might limit the occupant's exposure to extreme blast pressures and provides details that improve ductility and structural response characteristics. And he suggested that use of well-distributed lateral-load resisting method in the horizontal floor plan and adding more shear walls is not architecturally practical, a joint lateral-load resisting mechanism can also be used.

Theodor Krauthammer (1999) (ref. 7) conducted series of numerical studies on the behaviour of structural concrete and structural steel connection subjected to blast loads. These studies slowly improved the understanding of the role that structural details play in affecting the behaviour. The result from these investigations showed that structural details are important for insuring the safety of blast resisting structures and the issues of material models and strain-rate effects were addressed.

B.M. Luccioni, R.D. Ambrosini, and R.F. Danesi (2003) (ref. 11) conducted study on the analysis of the structural failure of a reinforced concrete building caused by a blast load. All the process from the explosion of the explosive charge to the complete destruction, including the proliferation of the blast wave and its interaction with the structure is reproduced. The problem analyzed corresponds to an actual building that has suffered a terrorist attack. The paper includes comparisons with photographs of the real damage created by the explosive charge that validates all the simulation procedure.

Larry C. Muszynski and Michael R. Purcell (2003) (ref. 9) and conducted an investigative study on composite reinforcement to strengthen existing concrete structures against air blast. The results of these tests were considered successful, considering the fact that the externally reinforced walls suffered high displacements, yet did not fail. The pressure and impulse data show that both structures would have failed disastrously without the externally applied composite reinforcing materials. The test of external reinforcement of concrete as a retrofit was successful. The failure of the carbon-fiber laminate and E-glass reinforced columns was perhaps caused by the wall acting as a pusher plate against the columns. The carbon-fiber laminate reinforcement might have performed better if it was used in a continuous sheet rather than strips.

Marjanishvili, S. M. (2004) (ref. 12) present four successively more complicated analysis procedures for evaluating the progressive collapse hazard: linear-elastic static; nonlinear static; linear-elastic dynamic and nonlinear dynamic. And conclude that the most effective analysis method for progressive collapse evaluation utilizes the useful parts of all four procedures by systematically applying increasingly comprehensive analysis procedures to confirm that the possibility of progressive collapse is high. And he suggested that, in order to establish the likelihood of progressive collapse, a progressive analysis process be used. In progressive analysis, a structure's response is evaluated by starting with simpler static methodology and then by moving on to increasingly complex analysis methods as required, until it is determined that the chance of progressive collapse is low or until all available engineering methodologies are carried out.

T. Ngo, P. Mendis, A. Gupta & J. Ramsay (2007) (ref. 13) described an overview of Blast Loading and Blast Effects on Structures, This paper presents a complete overview of the effects of explosion on structures. A justification of the nature of explosions and the mechanism of blast waves in free air is given. This paper also introduces different methodologies to estimate blast loads and structural response. It is recommended that guidelines on abnormal load cases and provisions on progressive collapse prevention should be incorporated in the current Building Regulations and Design Standards. Requirements on ductility levels also help improve the building performance under severe load conditions.

Zeynep Koccaz, Fatih Sutcuand and Necdet Torunbalci (2008) (ref. 14) conducted study on essential techniques for increasing the capacity of a building to provide defense against explosive effects is discussed both with an architectural and structural approach. And they concluded that with correct choice of the structural system, well designed beam-column connections, and structural elements designed adequately, moment frames that transfer sufficient load and high quality material; it is possible to build a blast resistant building.

Hrvoje Draganić, and Vladimir Sigmund (2012) (ref. 15) conducted a study on the process of determining the blast load on structures, explored the available literature on blast loads and

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provides a numerical example of a fictive structure exposed to this load. The blast load was analytically determined as a pressure-time history and numerical model of the structure was developed in SAP2000. The results confirm the initial hypothesis that it is possible with conventional software to simulate an explosion effects and give a preliminary evaluation of the structure.

Vasilis Karlos and George Solomos (2013) (ref. 16) from the European Laboratory for Structural Assessment carried out a study on Calculation of the external explosion loads to be considered in the blast protection design of a structure. Empirical methods for the prediction of blast loads have been selected as this is closer to the traditional engineering design approach. Technical information has been collected, adapted and presented in this study for the calculation of the external explosion loads to be considered in the blast protection design of a structure.

Priyanka A and Rajeeva S.V (2013) (ref. 17) present the dynamic response of a High Rise Structure subjected to blast load. The fundamentals of blast hazards and the interaction of blast waves with structures are examined in this study it is about the lateral stability of a high rise building modelled using SAP2000. It is found that the most optimal model is regular infill frame which shows the lowest value of storey drift and the structure is very good in lateral stability against blast load. Therefore the column size can reduce for economical design consideration.

Quazi Kashif1, Dr. M. B. Varma (2014) (ref. 18) conducted a study on Effect of Blast on G+4 RCC Frame Structure, in this study a five storey R.C.C symmetric building was analyzed for blast load for 100 kg and 500 kg of TNT placed at 30 m distance from point of detonation. Blast load in each case is calculated from IS 4991-1968 and non-linear direct integration time historey analysis is carried out on Finite element software SAP-2000. It concluded that Variation of displacement is Non-Uniform along the height of building and different from Earthquake and Wind (Building is not behaving as cantilever structure under blast load) and the performance of the building is critical when the blast exceeds 500 kg

Sarita Singla, Pankaj Singla, Anmol Singla (2015) (ref. 19) conducted a study on computation of blast loading for a multi-storey framed building In this study, blast pressures for different weights of surface blast or TNT and varying stand-off distances are computed for a multi-storey framed building adopting wave scaling laws given by U.S Army technical manual (UFC3-340-02). Blast pressures for different cases are computed using correlation between blast pressure and blast scaled distance based on charts given in U.S manual. Time historey loading is also obtained with parameters of reflected total over pressure and duration of positive phase of blast.

3. METHODOLOGY

In this we do detailed study of literature available on the blast resistant analysis and design of structures for explosion.

3.1 Problem Properties

Analysis of 2 storey structure is to be analyzed in ETAAB
The dimensional properties of frames chosen as follows:
The length of Frame = 3 bays of 3.5m each = 14m
The Width of Frame = 4 bays of 3.5 m each = 14m

3.2 Model Generation

Model 1: Normal framed structure of column size 400mmx400mm, beam size of 300mmx400mm
Model 2: Increased cross section of column size 600mmx600mm, and beam size of400 mmx600mm
Model 3: Addition of shear walls of thickness 150 mm around the structure on model 1
Model 4: Addition of X shaped Steel bracing on model 1

Bracing used: Channel section of ISLC 200
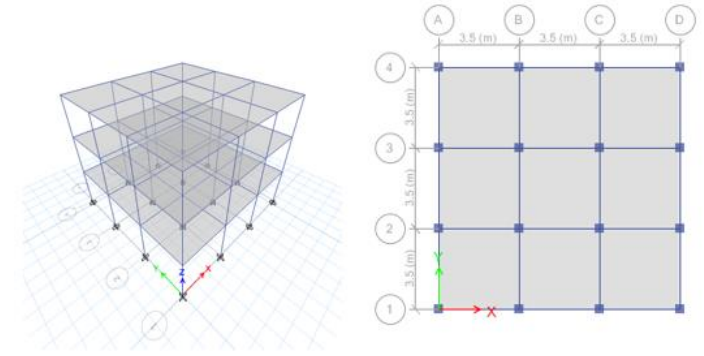
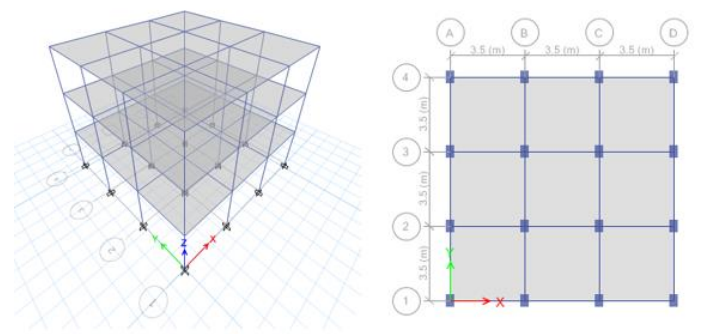Figure 3.1 3D Elevation and plan view of model 1

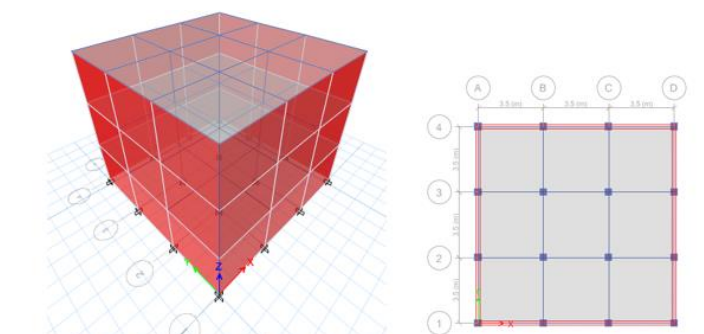

Figure 3.2 3D Elevation and plan view of model 2

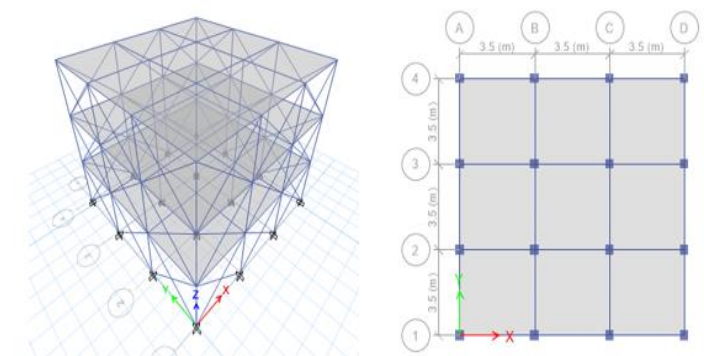Figure 3.3 3D Elevation and plan view of model 3

Figure 3.4 3D Elevation and plan view of model 4

3.3 Different cases used

Case 1: Blast of 100 kg explosive with standoff distance of 30m
Case 2: Blast of 100 kg explosive with standoff distance of 20m

3.4 Load Calculation and Application

Live load taken as 3 KN/m2 for all the floors.
Blast Load acting on structure due to explosion calculated using IS: 4991 - 1968 (Reaffirmed 2003) are as follows for different blast load and standoff distance are as follows,
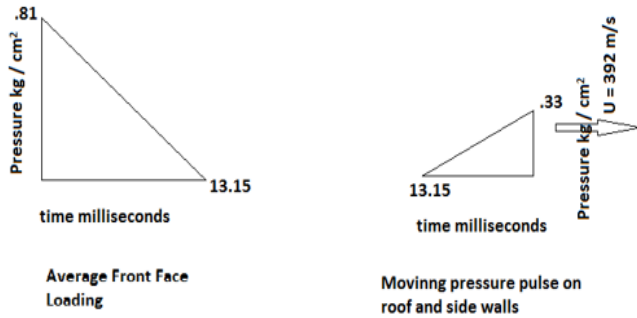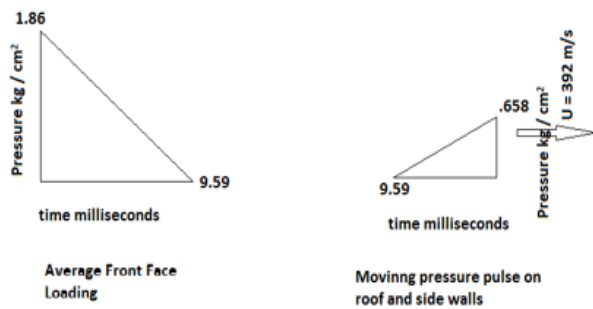

Figure 3.5 Case 1 blast pressure on structure

Figure 3.6 Case 2 blast pressure on structure
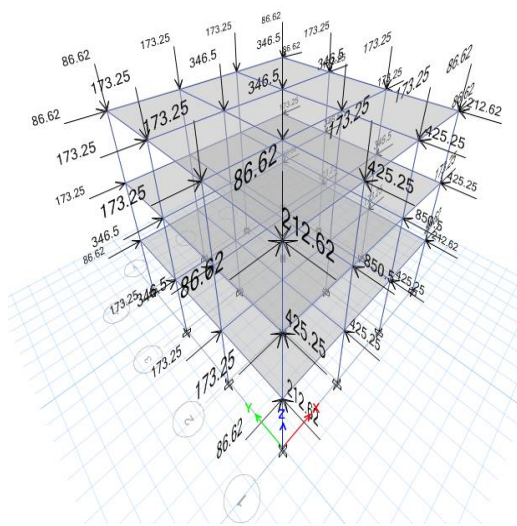
Figure 3.9 Load application in case 1
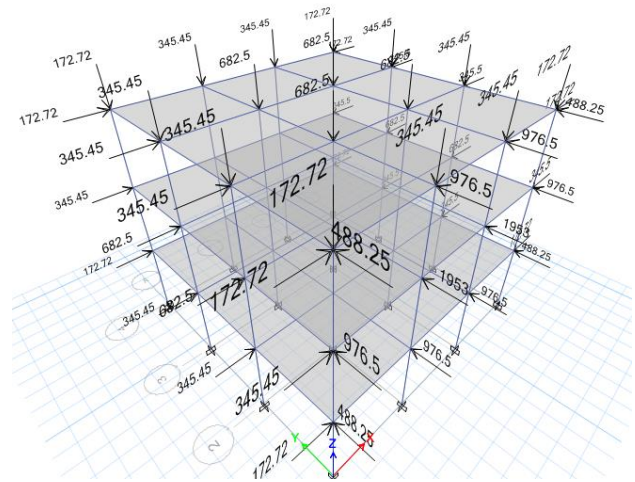
Figure 3.10 Load application in case 2

4. ANALYSIS RESULT

The analysis is done by ETAB 2015, Models are generated and loads are applied based on case (blast weight and standoff distance).Here live load on all floors taken as 3 KN/m2.And the structure analyzed by non-linear static analysis since the loads are converted to static joint loads. Total 16 models analyzed based on 4 load cases.

4.1 CASE 1: Blast load of 100 kg from 30 m Standoff distance

4.1.1 MODEL 1 (normal c/s Structure)
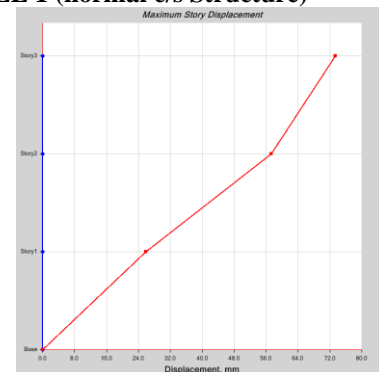
Figure 4.1 Maximum storey displacement in model 1
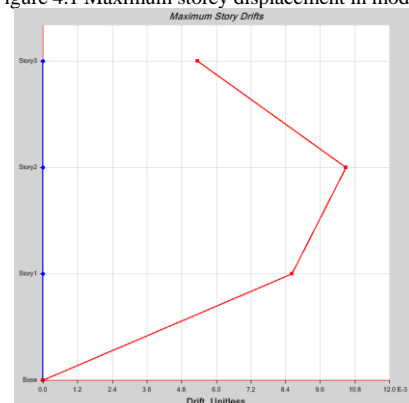
Figure 4.2 Maximum storey drift in model 1
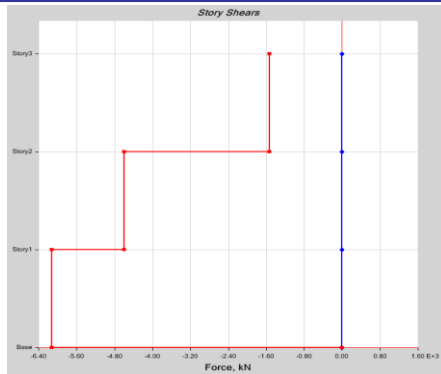
Figure 4.3 Storey shear in model 1

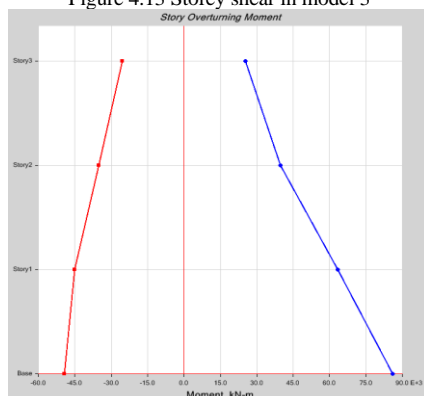Figure 4.4 Overturning moment in model 1

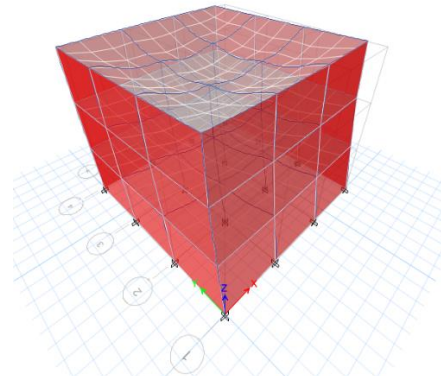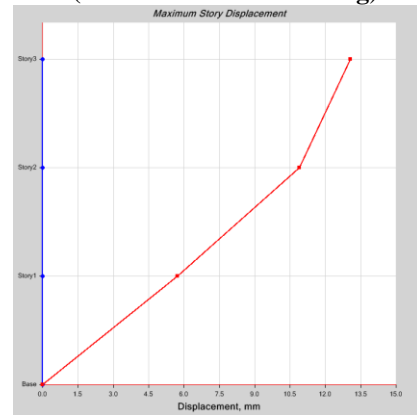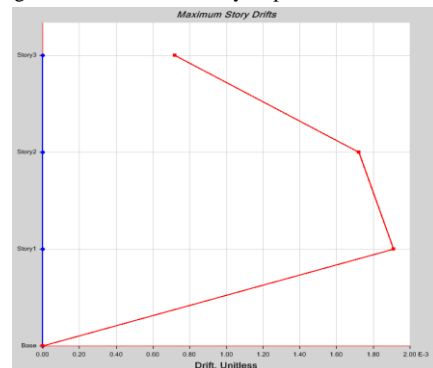

Figure 4.5 Deformed shape of model 1

4.1.2 MODEL 2 (increased c/s Structure)
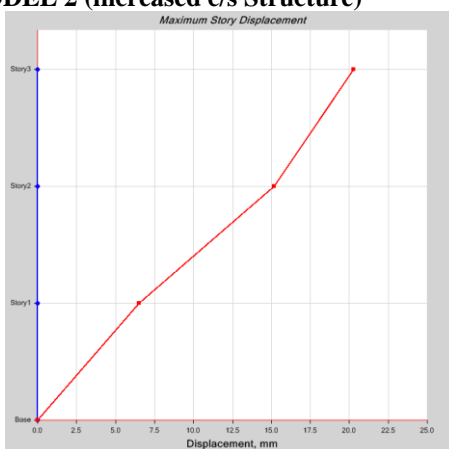
Figure 4.6 Maximum storey displacement in model 2

Figure 4.7 Maximum storey drift in model 2
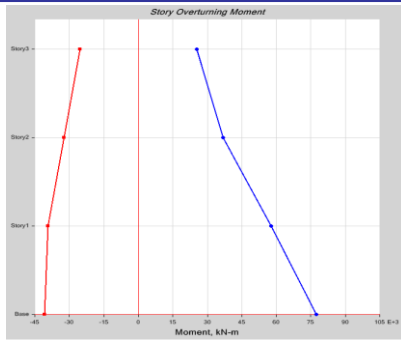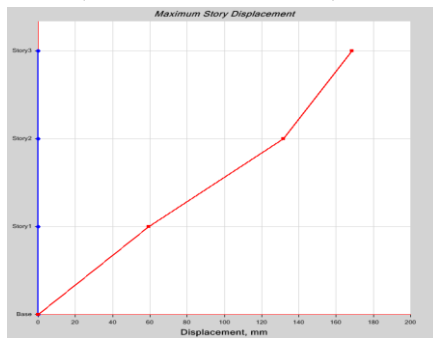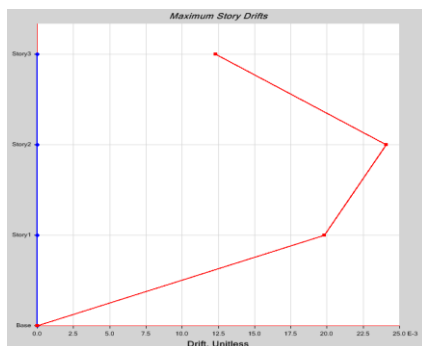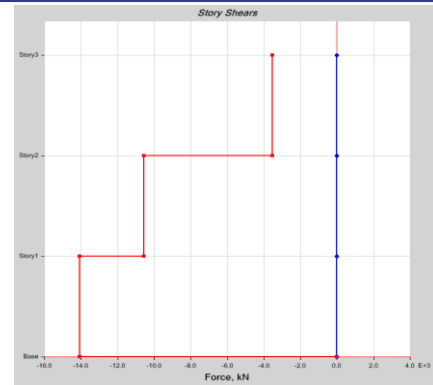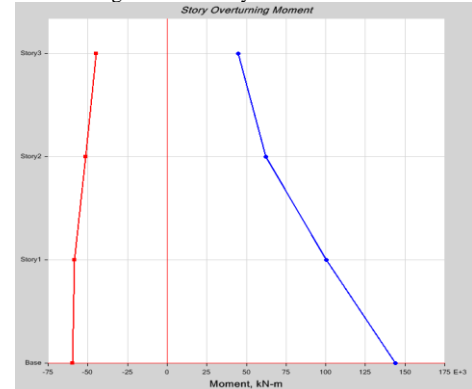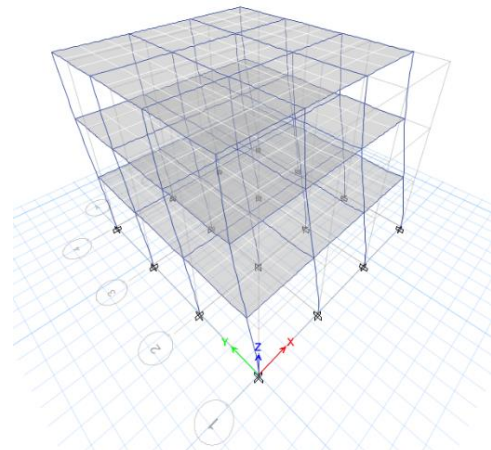

Figure 4.8 Storey shear in model 2

Figure 4.9 Overturning moment in model 2
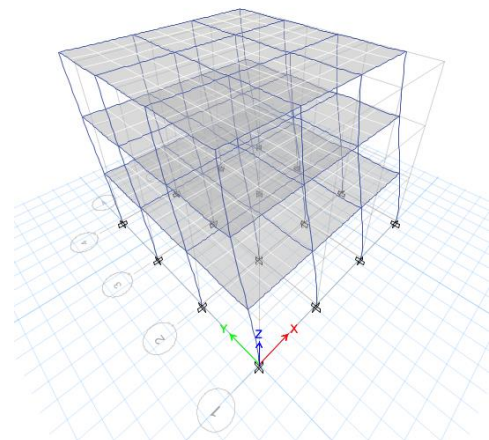
Figure 4.10 Deformed shape of model 2

4.1.3 MODEL 3 (Addition of shear wall)
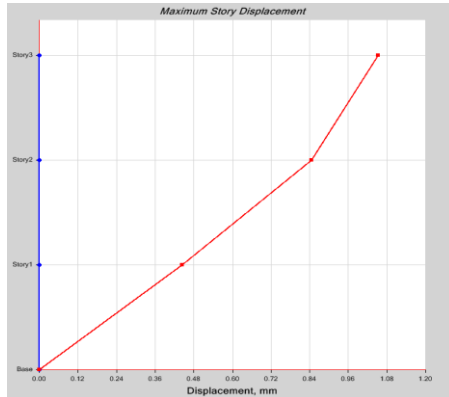
Figure 4.11 Maximum storey displacement in model 3
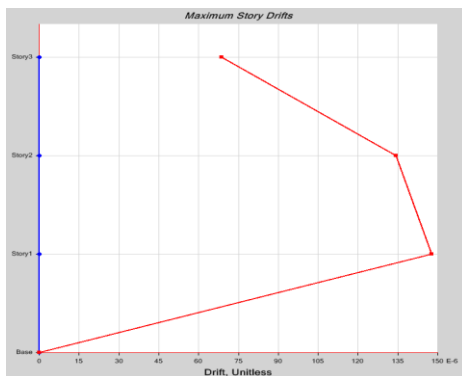
Figure 4.12 Maximum storey drift in model 3
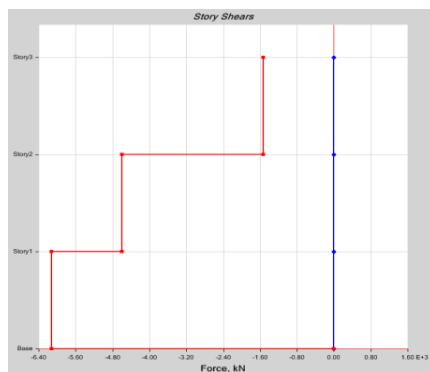
Figure 4.13 Storey shear in model 3

Figure 4.14 Storey shear in model 3

Figure 4.15 Deformed shape of model 3
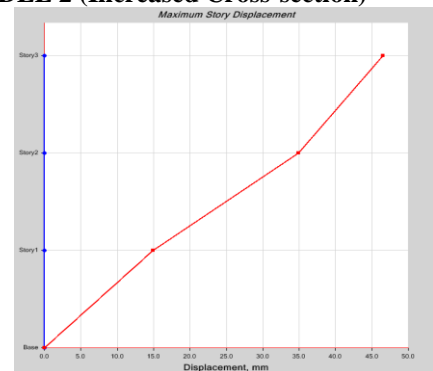
4.1.4 MODEL 4 (Addition of Steel Bracing)

Figure 4.16 Maximum storey displacement in model 4

Figure 4.17 Maximum storey drift in model 4
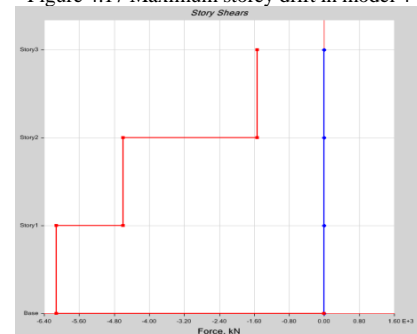
Figure 4.18 Storey shear in model 4

Figure 4.19 Overturning moment in model 4

Figure 4.23 Storey shear in model 1

Figure 4.20 Deformed shape of model 4

Figure 4.24 Overturning moment in model 1

4.2 CASE 2: Blast load of 100 kg from 20 m Standoff distance
4.2.1 MODEL 1 (Normal Cross-section)

Figure 4.21 Maximum storey displacement in model 1

Figure 4.25 Deformed shape of model 1

4.2.2 MODEL 2 (Increased Cross-section)

Figure 4.22 Maximum storey drift in model 1

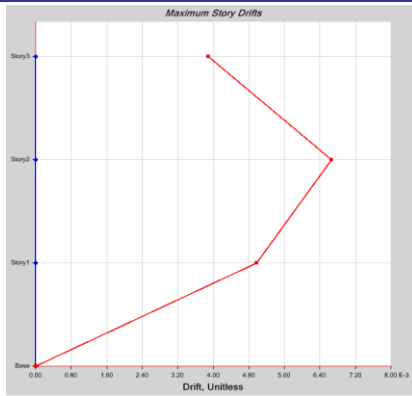Figure 4.26 Maximum storey displacement in model 2

Figure 4.27 Maximum storey drift in model 2

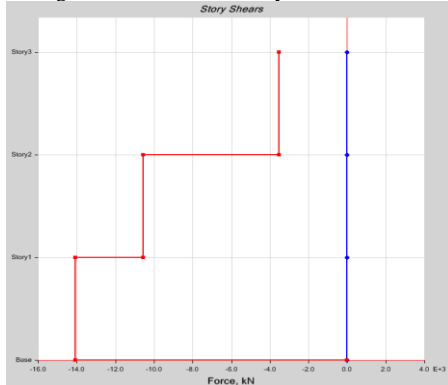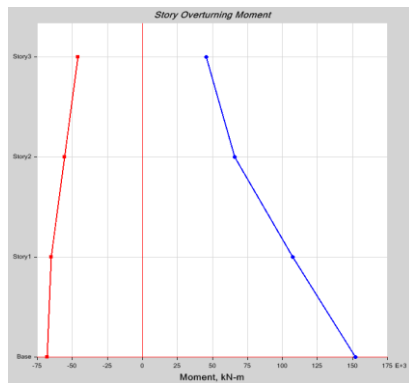
Figure 4.28 Storey shear in model 2
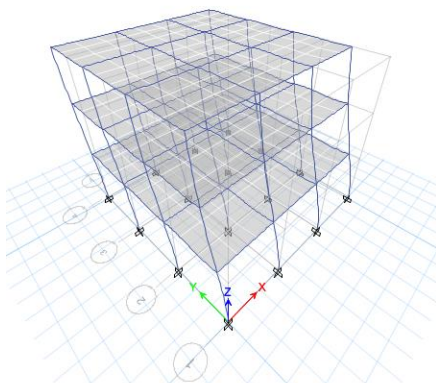

Figure 4.29 Overturning moment in model 2

Figure 4.30 Deformed shape of model 2

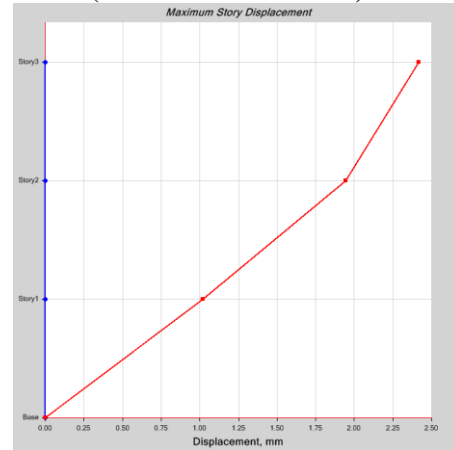**4.2.3 MODEL 3 (Addition of Shear wall)**

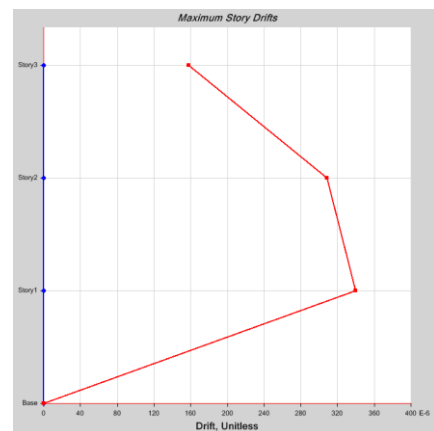Figure 4.31 Maximum storey displacement in model 3

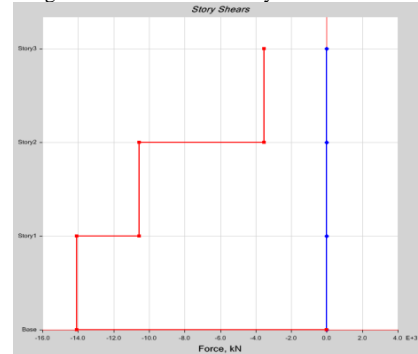Figure 4.32 Maximum storey drift in model 3

Figure 4.33 Storey shear in model 3

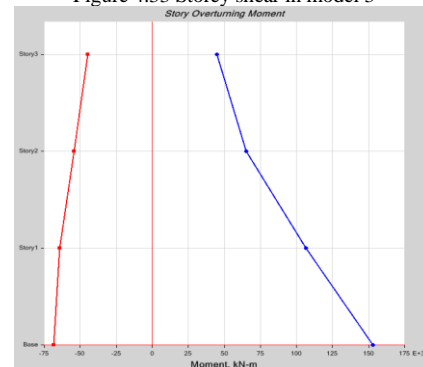Figure 4.34 Overturning moment in model 3

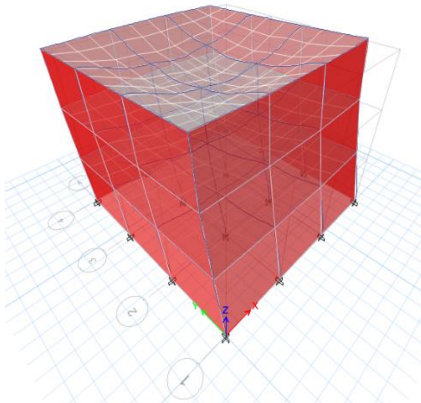Figure 4.35 Deformed shape of model 3

4.2.4 MODEL 4(Steel Bracing)

Figure 4.36 Maximum storey displacement in model 4

Figure 4.37 Maximum storey drift in model 4

Figure 4.38 Storey shear in model 4

Figure 4.39 Overturning moment in model 4

Figure 4.40 Deformed shape of model 4

5. COMPARISON OF RESULTS
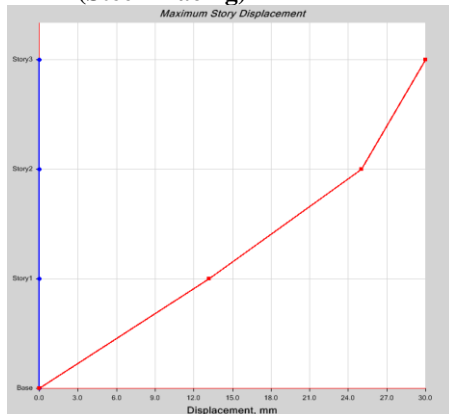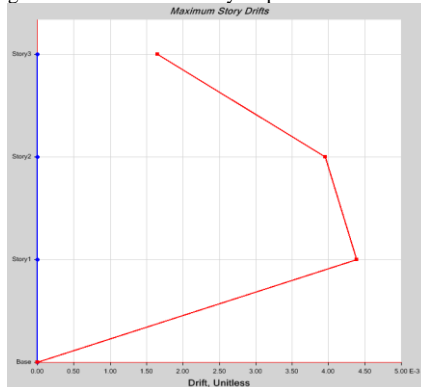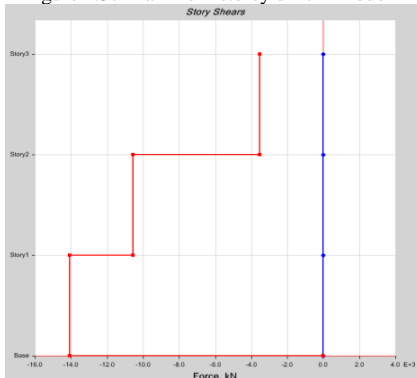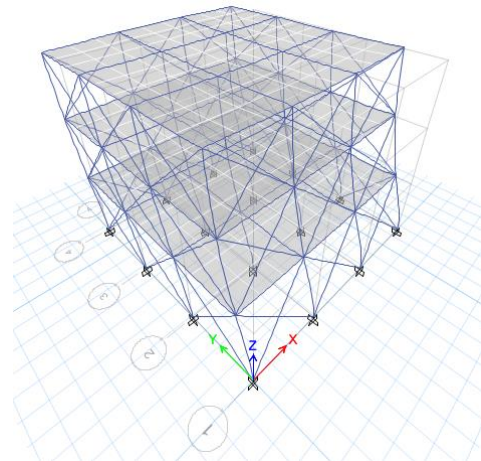
5.1 CASE 1 (100 Kg Blast load from 30 m Standoff distance)
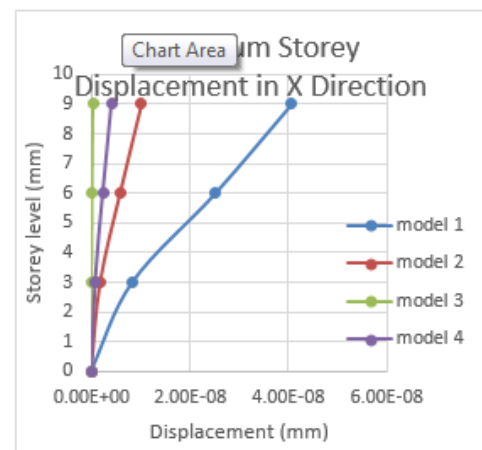
5.1.1 MAXIMUM STOREY DISPLACEMENT

Figure 5.1 Maximum storey displacements in X direction in Case 1

Figure 5.2 Maximum storey displacements in Y direction in Case 1

5.1.2 MAXIMUM STOREY DRIFT

Figure 5.3 Maximum storey drifts in Case 1 in Y Direction

5.2 CASE 2 (100 Kg Blast load from 20 m Standoff distance)

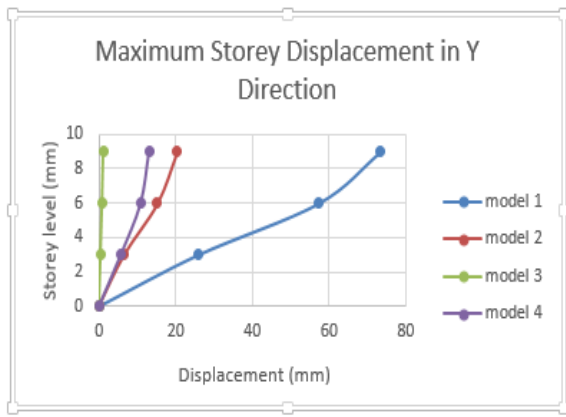### 5.2.1 MAXIMUM STOREY DISPLACEMENT
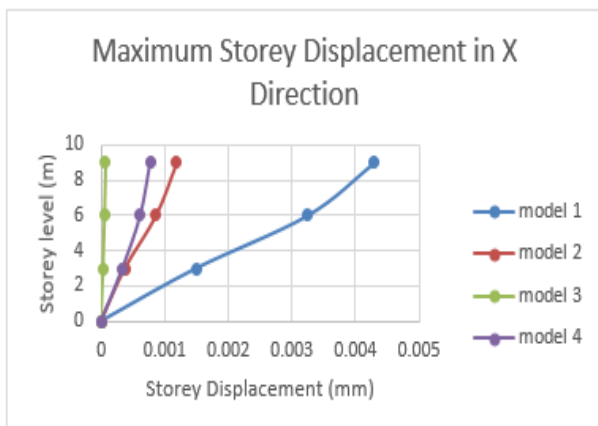
Figure 5.4 Maximum storey displacements in X direction in Case 2

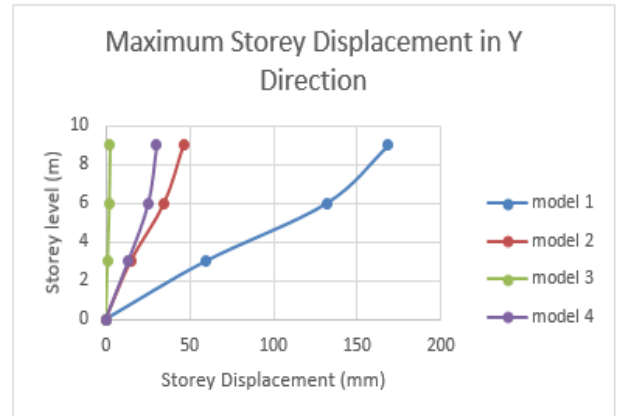Figure 5.5 Maximum storey displacements in Y direction in Case 2

5.2.2 MAXIMUM STOREY DRIFT
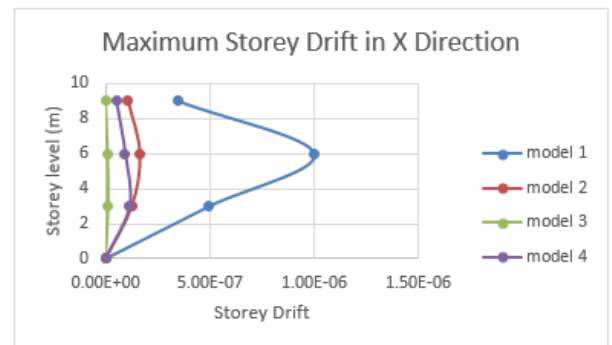
Figure 5.6 Maximum storey drifts in Case 2 in X Direction
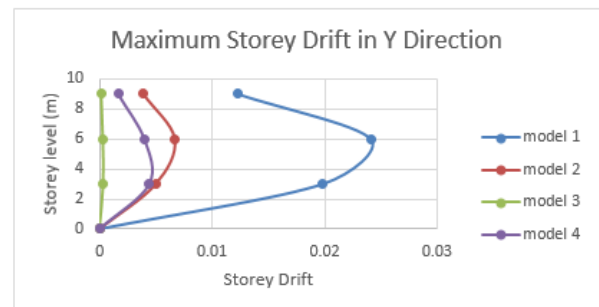
Figure 5.7 Maximum storey drifts in Case 2 in Y Direction

6. CONCLUSIONS

As per the results Problem Properties obtained from the analysis, the following conclusions can be drawn:

- The displacement and storey drifts increase drastically with the increase of blast load and decrease of standoff distance in the structure. Blast parameters are dependant on blast load and standoff distance. Therefore, the response of the structure depends majorly on blast load and standoff distance values.
- The maximum lateral displacement are 380 mm, 150 mm for 300 kg blast load from 30m and 20 m standoff distance, and 73.4mm, 168.5mm are the lateral displacement for 100 kg blast load from 30 m and 20 m standoff distance for model no 1 (Normal cross-section structure which is not designed for blast resistance).18 mm is the allowable maximum lateral displacement as per IS 1893 (H/500). Thus, the maximum lateral displacement is not satisfying the limit given by IS Code in model 1.

- The maximum Inter storey drifts are 54.3, 21.4 for 300 Kg blast load from 30 m and 20 m standoff distance, and 10.5,24 are the max storey drift for 100kg blast load from 30 m and 20 m standoff distance for the model 1. According to IS 1893 maximum allowable storey drift is 12 (.004* Storey height). Hence, maximum storey drift are not satisfying IS code recommendation in model 1.
- For all the cases in model 2 when we increase beam and column cross-section of structure compared to model one the maximum storey displacement are reduced by around 70 %., and maximum storey drift reduced by around 65%.
- In model 3, the addition of shear wall around the structure in model 1 results in the reduction of maximum storey displacement by around 95 %, and max storey drift by around 95% compared to the maximum storey displacement and drift from model 1.In this model shear wall helps to decrease storey displacement effectively so that the maximum displacement and maximum storey drift in this model are within the allowable max storey displacement and max storey drift given by IS 1893.
- In model 4, the addition of steel bracing around the structure helps to reduce the maximum storey displacement by around 80% and maximum storey shear by around 80% compared to maximum storey displacement and maximum storey shear from model 1.
- Large values of storey shear and overturning moments are developed due to blast loads. In order to resist these moments and storey shear, large cross sections are required. Here outer shear wall structure and steel braced structure demonstrate more resistance against these.

7. FUTURE SCOPE

- A thorough study could be carried out on structures taking into account heavier blast loads. The effects of blast loads in high rise structures could also be studied in detail.
- The variation between reactions of symmetrical structures as compared to non-symmetrical structures could be studies.
- Improvement in resistance of the structure to blast loads could be conducted as a study by using different types of steel bracings and adding internal shear walls. The location of shear wall addition can also be studied.

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