

Analytical Study of Concrete-encased Steel Column Building against Blast Load

Sumedh Kishor Limaye^{1,*}, Umesh L. Deshpande²

Abstract

Study of behavior of composite building with Concrete-Encased Steel (CES) columns for blast loading is done. This is compared with the behavior of conventional building having reinforced concrete (RC) columns. In the following study, both composite and RC buildings are subjected to 0.1 ton, 0.3 ton and 0.5 ton TNT equivalent charge weight of blast load with a standoff distance of 20 m, 30 m and 40 m. To study the static properties due to variation in standoff distance and blast intensity, (G+4) buildings with composite and RC columns are analyzed using parameters like storey displacement, storey drift, bending moment are compared. The Linear Static Analysis is carried out by using ETABS 2018 software. From the results obtained, it is observed that the vulnerability of a multi-storey structure is least for a low intensity blast generated at a comfortably longer standoff distance.

Keywords: Blast, TNT, loading, CES-column, composite, standoff distance, ETABS

INTRODUCTION

Blast force is applied on structures due to explosions by various reasons such as bombing by terrorists, dynamite explosion, blast due to gas leakage, nuclear blast, accidents in thermal power plants, chemical factories, etc. The various terrorists activities worldwide, the largest being the destruction of World Trade Centre building located in New York in 1993 shows the inevitability of detailed analysis of performance of structures subjected to blast loading and also to find the safety for the life of the people and structures from the explosions. Blast Force is a dynamic loading that need to be treated as equivalent to earthquake and wind loads. Thus, there is necessity to design structures for resistance against blast loading. The analysis of structures subjected to blast loads requires an acute study of blast phenomena and its effects on various structural elements. Use of Concrete-Encased Steel (CES) column sections as a composite member is being used as an optimization of materials. Thus, a study of effect of blast loading on composite buildings having CES columns is necessary. This project consists of studying the effect of blast loading on various models of buildings with and without CES columns.

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Received Date: 15 February 2021

Accepted Date: 20 April 2021

Published Date: 16 August 2021

Citation: Sumedh Kishor Limaye, Umesh L. Deshpande. Analytical Study of Concrete-encased Steel Column Building against Blast Load. Journal of Structural Engineering and Management. 2021; 8(2): 1–12p. DOI: <https://doi.org/10.37591/josem.v8i2.5489>

LITERATURE REVIEW

Dan Nourzadeh et al. [1–3] studied responses of a multi-story building to moderate blast loading and earthquake ground motions at different locations. Goel et al. [4] reviewed various strategies for blast mitigation. Functioning of the commonly adopted blast-resistant measures was described. Denny et al. [5–7] studied the effects of long-duration blast loading on steel I-section column elements. Guzas et al. [6, 8] adopted computer simulation to study blast effects on steel beam-column members. Binglin Lai et al. [9] studied the buckling behavior of high strength Concrete Encased Steel (CES) columns through

experimental work and analytical analysis. *Figulia et al.* [10] has done a study on effects of blast loading on steel structures. Experimental work was conducted by blast tests on two different steel rolled beams using ANFO (ammonium nitrate and fuel oil) explosives. *Khan et al.* [8] investigated the effects of blast loading on the three steel frame buildings with different geometric configurations. Fragility curves were developed for the blast-analysis done on different orientations of the I-section steel columns. Out of the three configurations considered, the pyramidal geometric configuration was found to be the most effective in reducing the blast load effect.

Mohammad M. Abdullah et al. [2] studied and analyzed the behavior of steel structure subjected to blast loads with different charge weights. To obtain the response of a G+3 building model for different charge weights at the same standoff distance, SAP2000 software was used to analysis the model based on design parameter and load time history of each member. It was concluded that maximum storey drift was 15.9 mm at the 4th floor for 100 kg TNT. *Ke-Chiang Wu et al.* [5] conducted a field test using contact explosive on one composite column specimen. Two empirical equations were derived after a parametric study of the relationship between residual axial capacity and structural and loading parameters. *Barış Sevim et al.* [3] studied the blasting response of a two-storey reinforced concrete (RC) building under different charge weight of TNT explosives [11]. The results showed that the different charge weight of TNT explosives considerably affected blasting response of the two-storey RC building. *UFC Manual* [12] provides guidance to the design of the structures subjected to accidental explosions and aids in the assessment of the explosion-resistant capabilities of existing buildings.

BLAST LOADING

The magnitude and distribution of the blast loads on the structure depends upon the following factors: (1) type of explosive material and weight of explosive (2) the location of the detonation relative to the protective structures, i.e. the standoff distance; and (3) the magnitude of the pressure after its interaction with the ground barrier. The quantity we need for calculating blast force on the structure is the peak over-pressure. It is the rise in pressure above atmospheric pressure due to the shock wave from a blast. For design purposes, the negative phase of the over-pressure is not important and can be ignored. For analysis purpose, the standoff distance is converted into 'scaled distance'. It is the factor which relates/gives similar blast effects from various size charges of the same explosive at various distances. It is computed by dividing the distance of concern by an exponential root of the explosive quantity detonated per delay.

OBJECTIVES OF INVESTIGATION

The main purpose of analysis is to compare the response of the composite building with conventional RC building for blast loading. The behavior of composite and conventional RC buildings after application of blast loading is studied by performing Linear Static Analysis using ETABS 2018 software. In total, three criteria for standoff distances (20 m, 30 m, 40 m) + 3 criteria for TNT equivalent charge weights (0.1 ton, 0.3 ton, 0.5 ton) + blast load applied in X and Y directions separately + 2 types of buildings (RCC and composite) = $3 \times 3 \times 2 \times 2 = 36$ different building models are analyzed and comparative study is done using parameters like storey displacement, storey drift and storey shear.

Following are the objectives of the present study:

1. To carry out Linear Static Analysis on composite and RC building models
2. To study the behavior of composite and RC building models due to blast loading
3. To perform comparative assessment of effect of blast loading on RC and composite buildings

ANALYSIS DATA FOR ALL BUILDING MODELS

The 36 building models, designated from M1 to M9 as 'RCC frame buildings' and from M10 to M18 as 'composite column buildings' are modeled using Extended Three-dimensional Analysis of Building System (ETABS) computer program/software, 2018 version. The framing plan of the

building model (Figure 1) and its three-dimensional view (Figure 2) are shown below. The various properties of the building models are given below:

1. Materials
 - a. RCC Framed Structure: Reinforced concrete columns and beams = both with M30 Concrete and Fe500 bars
 - b. Composite Framed Structure: R.C.C. beams = (M30 Concrete and Fe500 bars) and Concrete-Encased Steel columns = (M30 Concrete + Fe500 bars along with ISMB250 embedded Steel section of grade Fe250)
2. Slab Thickness: 120 mm
3. Size of RCC Beams: $(230 \times 450) \text{ mm}^2$
4. Size of RCC Columns: $(300 \times 450) \text{ mm}^2$
5. Size of CES Columns: $(300 \times 450) \text{ mm}^2$
6. Density of Concrete: 25 kN/m^3
7. Density of brick masonry: 18.83 kN/m^3
8. Number of storey: Five (Ground + 4)
9. Plan Size: $18 \text{ m} \times 22 \text{ m}$
10. No. of Bays in X-direction = 3; Span Length = 6.5, 5, 6.5 m resp.
11. No. of Bays in Y-direction = 4; Span Length = 6, 5, 5, 6 m resp.
12. Floor to floor height: 3.0 m
13. Total Height = 15 m

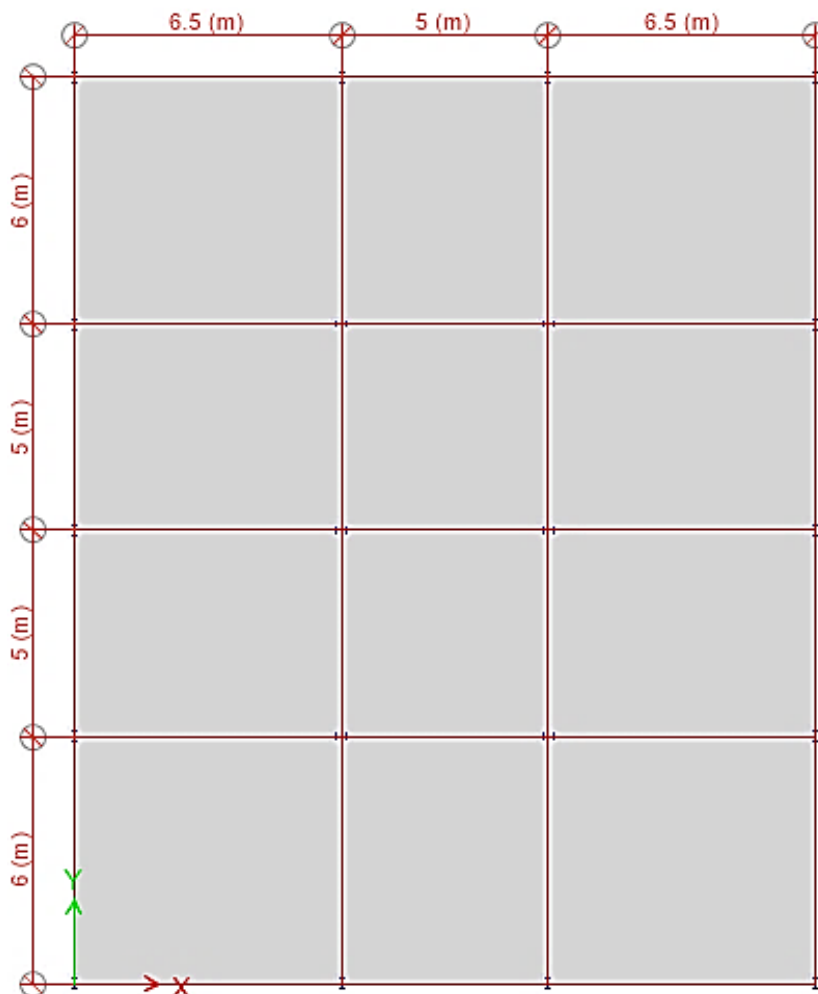


Figure 1. Plan of the building at plinth level.

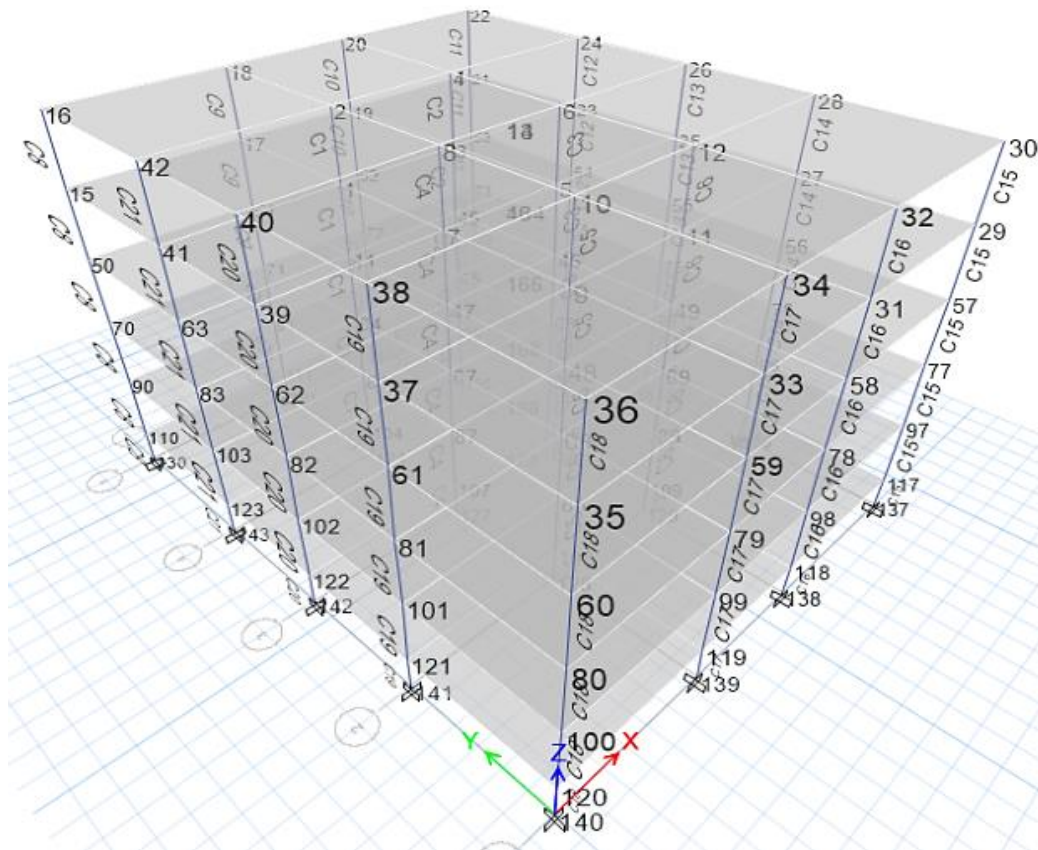


Figure 2. 3D view of building model.

LOADS CONSIDERED IN ANALYSIS

Gravity Loads

The intensity of dead load and live load considered in the study are given below:

Dead Loads

Dead load comprising of self-weight of members, i.e., beam, column and slab.

- Slab = $25 \cdot D$ kN/m² {D = depth of slab (m)}
- Floor finish = 1 kN/m²
- Wall load = $18.83 \cdot b \cdot H$ kN/m {b-width of wall (m), H-floor to floor height of wall (m)}

Live Load

= 2 kN/m² on floor area.

Blast Loads

IS 4991–1968 is used for blast load calculations [11]. The maximum values of the reflected over-pressure (p_{ro}) as caused by the explosion of different explosive values at various standoff distances (X) from the point of explosion are given in Table 1. {S = scaled distance}. For calculation of peak reflected over-pressure for different charge weights and different actual standoff distances we have used the scaling law:

$$(S) = (X)/W^{(1/3)} \text{ \{Clause 5.3 of IS 4991–1968\}}$$

ANALYSIS

After converting various blast intensity values into blast point loads (as in above calculation Tables), these point loads are applied on the respective building models of composite and RCC using

ETABS 2018 software. An illustration of applying blast load along X-direction (Figure 3) and joints to be considered on which load acting in X-direction/axis is to be applied (Figure 4) are shown below; similar is the case for when blast is along Y-direction.

RESULTS

After performing analysis, the following criteria were adopted for the study:

1. Standoff distances (20 m, 30 m, 40 m)
2. Blast weights (0.1 ton, 0.3 ton, 0.5 ton)
3. Direction in which blast load is applied
4. Type of structure

The comparative study was done using the following parameters:

- a. Storey displacement
- b. Storey drift
- c. Bending moment on columns on which blast load is incident.

Table 1. Values of peak reflected over-pressure (p_{ro}).

W [ton]	X (m)	S (m)	p_{ro} [kg/cm ²]
0.1	20	43.09	1.858
0.1	30	64.63	0.806
0.1	40	86.18	0.508
0.3	20	29.88	4.267
0.3	30	44.81	1.679
0.3	40	59.75	0.937
0.5	20	25.20	7.413
0.5	30	37.80	2.468
0.5	40	50.40	1.316

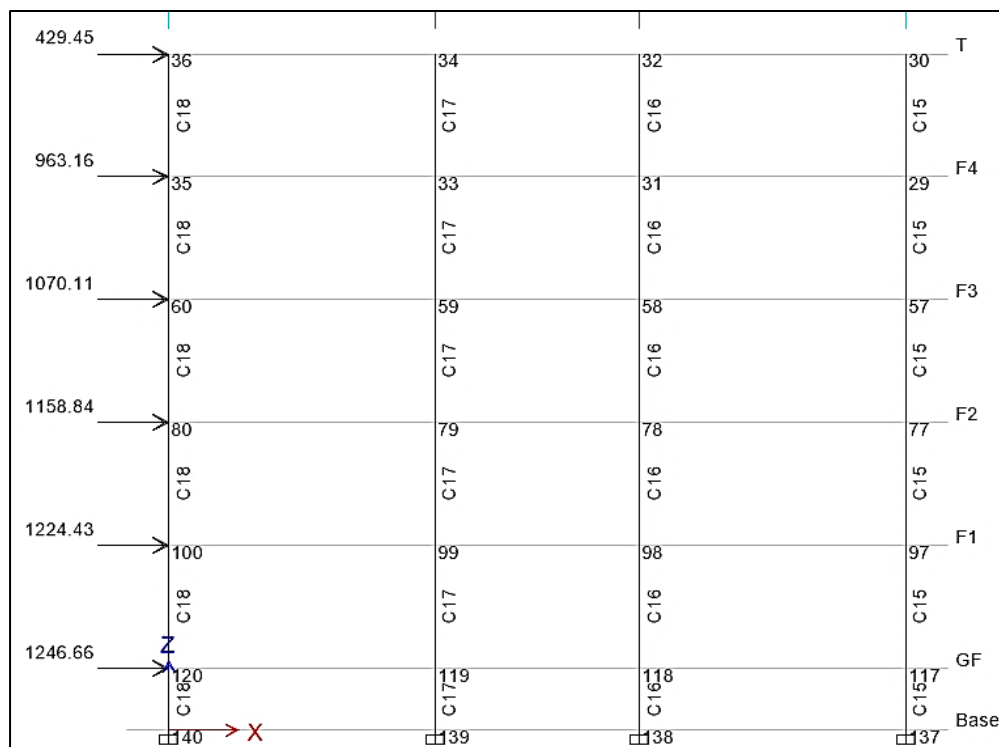


Figure 3. Applying loading along X-direction.

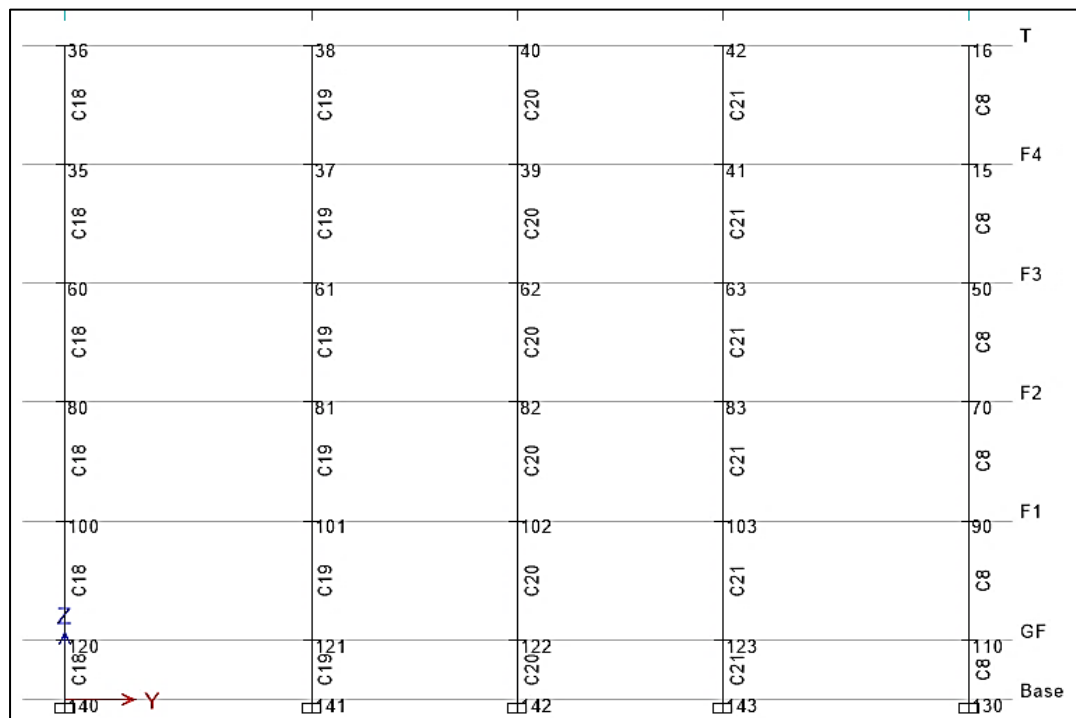


Figure 4. Joints on which load acting in X-direction/axis is to be applied.

For illustration, M7 building model is taken to show graphs obtained post-analysis in ETABS and are shown in Figures 5 and 6. The plots for the storey displacement (Figure 5) and storey drift (Figure 6) are shown below.

Further bar chart diagrams were drawn to show comparison between maximum values of storey displacement, storey drifts and values of Bending Moment for each column facing the blast loading. The maximum displacement values (Figure 7 and Figure 8) for both X and Y-direction of blasting are represented graphically; while the maximum storey drift values (Figure 9 and Figure 10) are shown as bar diagram.

Here, for the blast load direction as X, the columns considered for the analysis were C8, C18, C19, C20, and C21 (on the building face which is along Y-direction). From the illustrative graphs (Figure 11 and Figure 12), it can be observed that the maximum Bending Moment values for columns C19 and C21 are almost the same, only marginal less than the corresponding values for that of C20. Columns C19 and C21 are adjacent to the central column C20, with 5 m apart from both sides. The maximum Bending Moment is for column C20, which is at the center of the building face whose axis is along Y-direction and on which blast loading is incident normal. For the blast load direction as Y, the columns considered for the analysis were C15, C16, C17, and C18 (on the building face which is along X-direction). The Bending Moment values for columns C16 and C17 (which are at the center of the building face) are the same, greater than the corresponding values for C15 and C18 (Figure 13 and Figure 14).

OBSERVATIONS

The values of storey displacement and storey drift are greater for every RCC building model than the composite building model, irrespective of direction of blast load applied and other blast parameters. For blast loading in both X- and Y-direction, the maximum value of storey displacement roughly vary from 41–56% when compared between RCC and composite building models. Whereas variation between maximum drift values of RCC and composite building models is 43–51%.

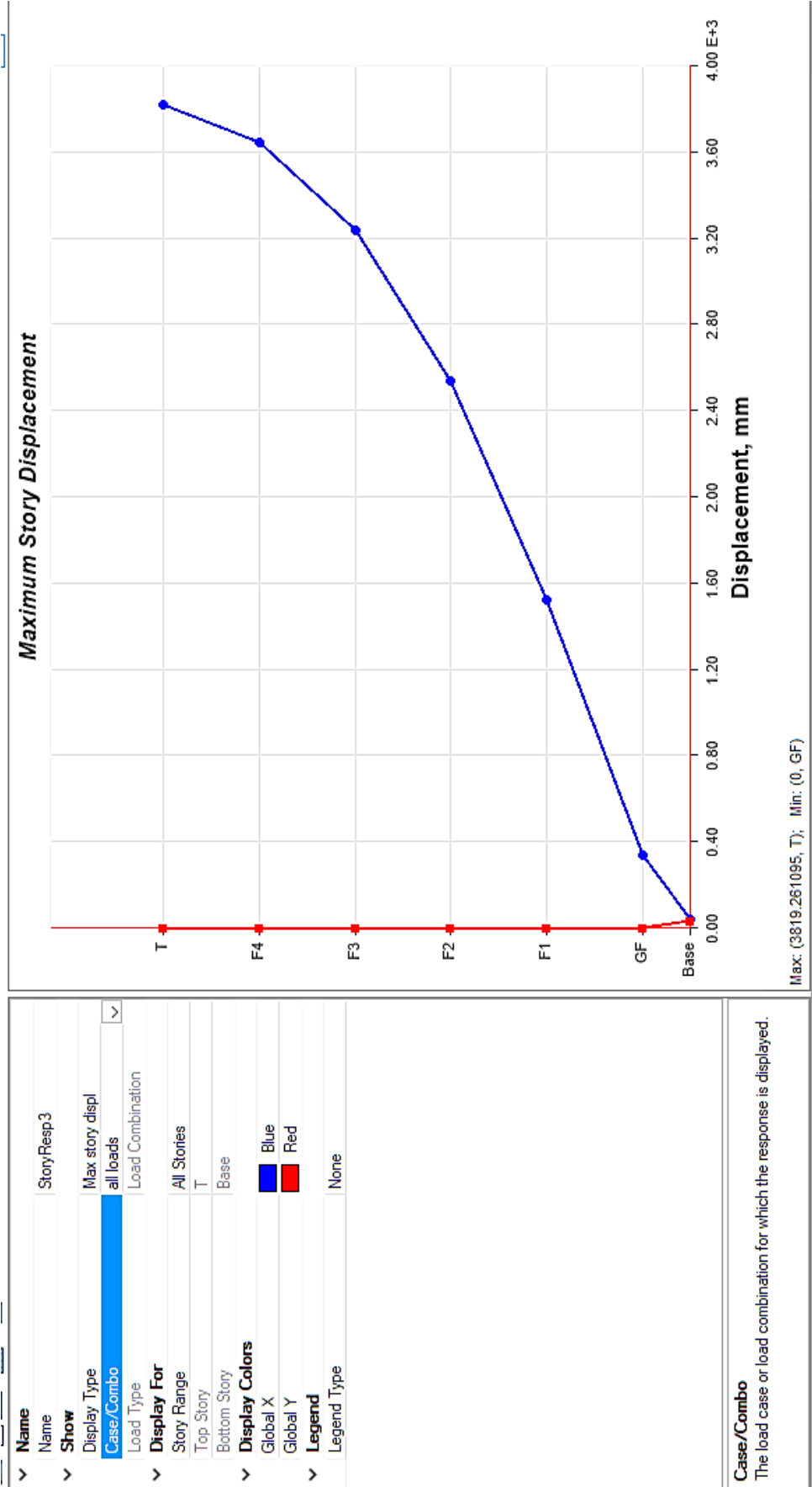


Figure 5. Storey displacement [mm] plot for M7 model when blast along X-axis.

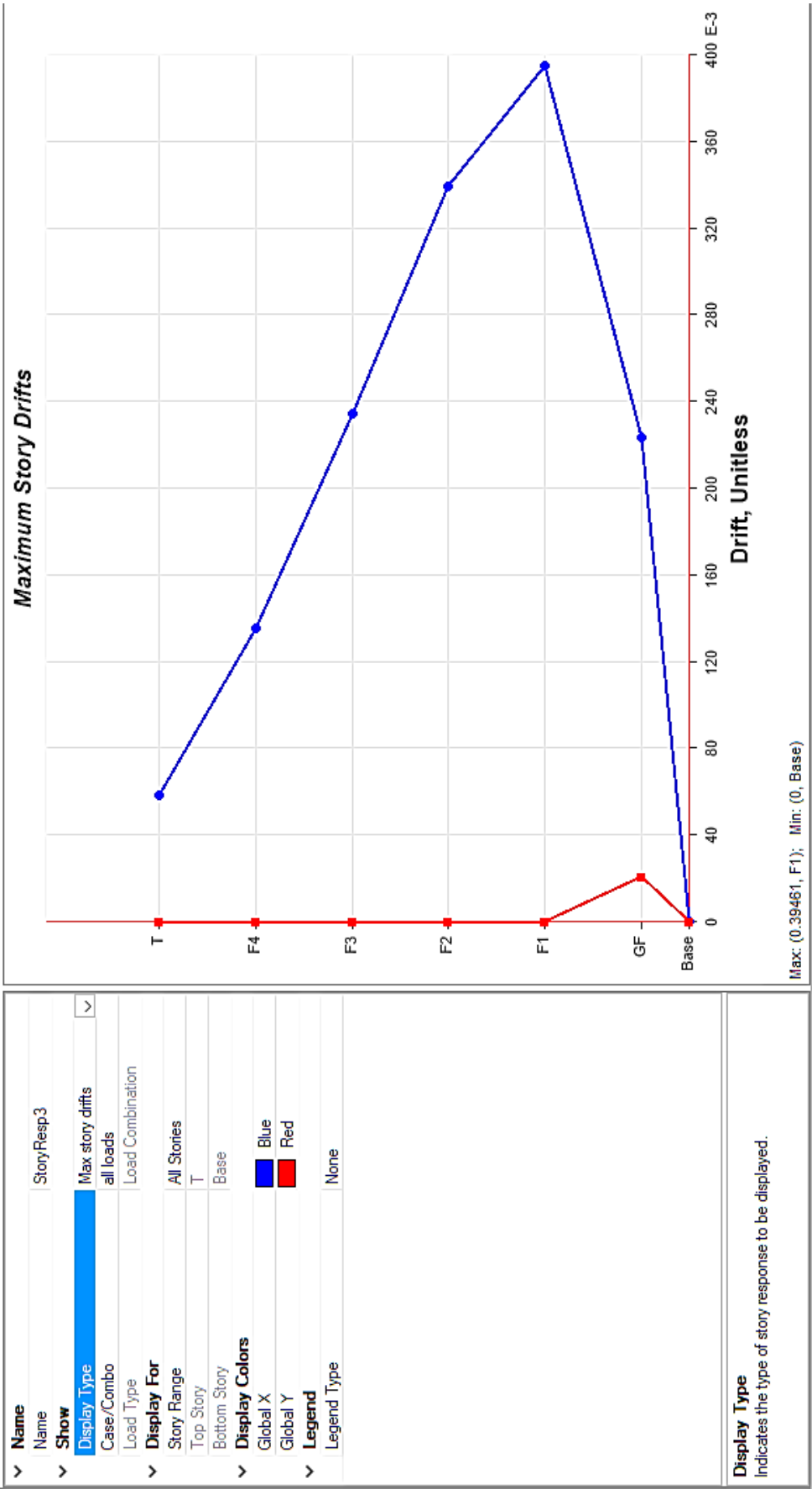


Figure 6. Storey drift plot for M7 model when blast along X-axis.

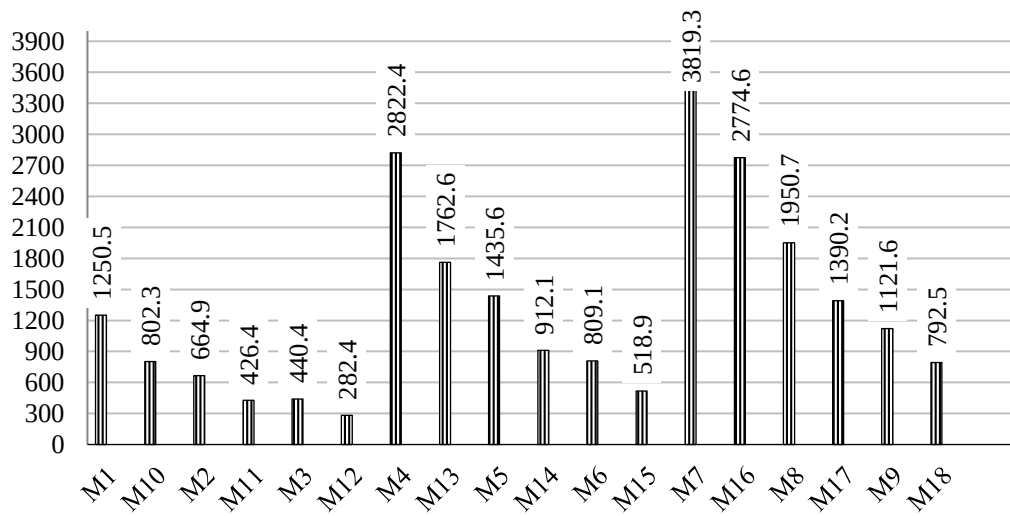


Figure 7. Maximum storey displacement values for blast load applied in X-direction.

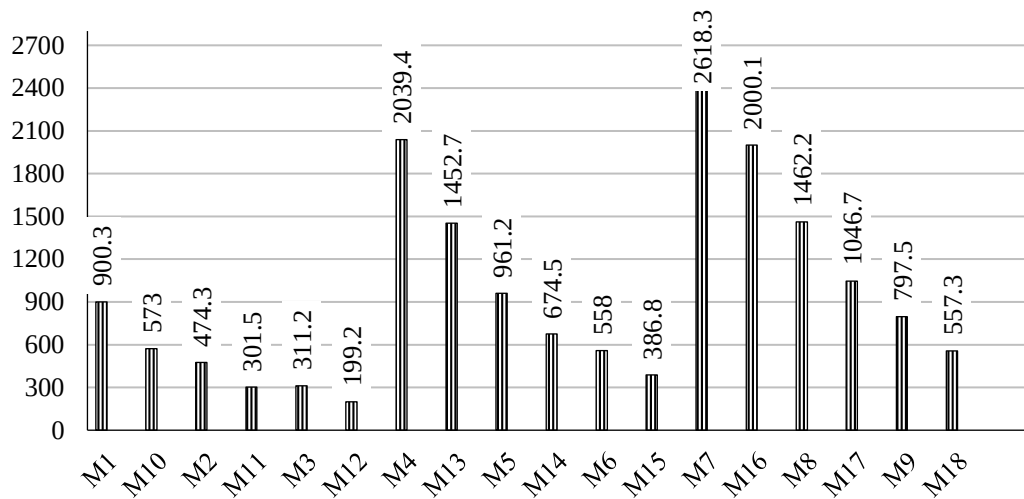


Figure 8. Maximum storey displacement values for blast load applied in Y-direction.

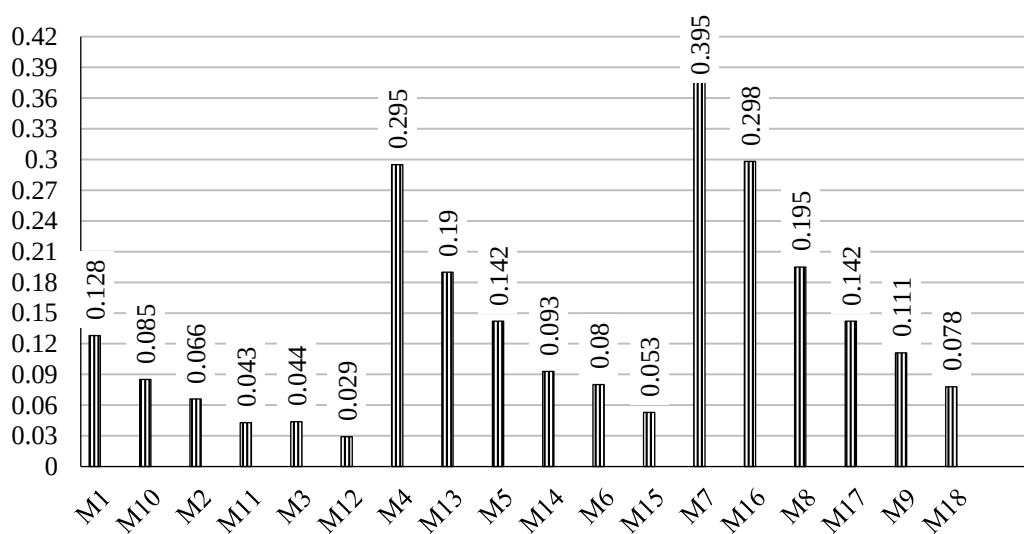


Figure 9. Maximum storey drift values for blast load applied in X-direction.

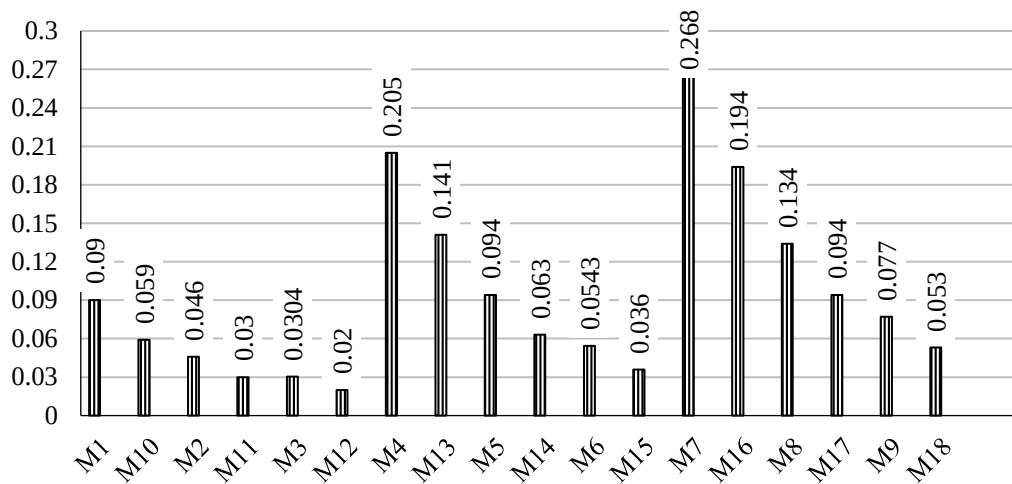


Figure 10. Maximum storey drift values for blast load applied in Y-direction.

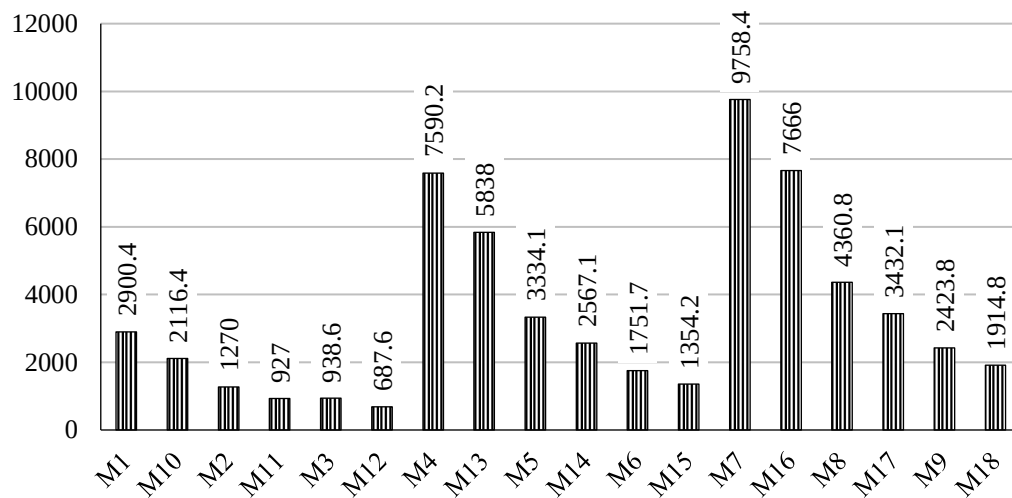


Figure 11. Maximum bending moment on C19 and C21 columns when blast along X-axis [kN-m].

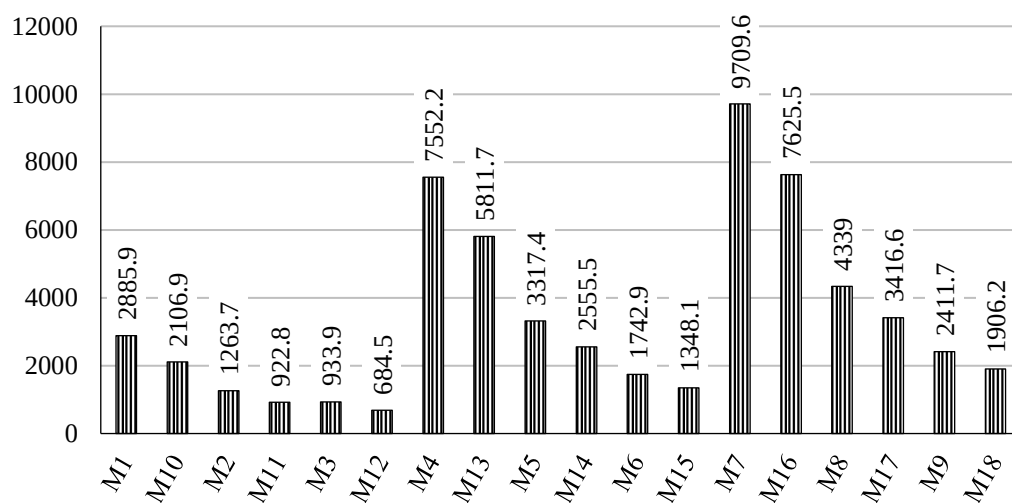


Figure 12. Maximum Bending Moment on C20 column when blast along X-axis [kN-m].

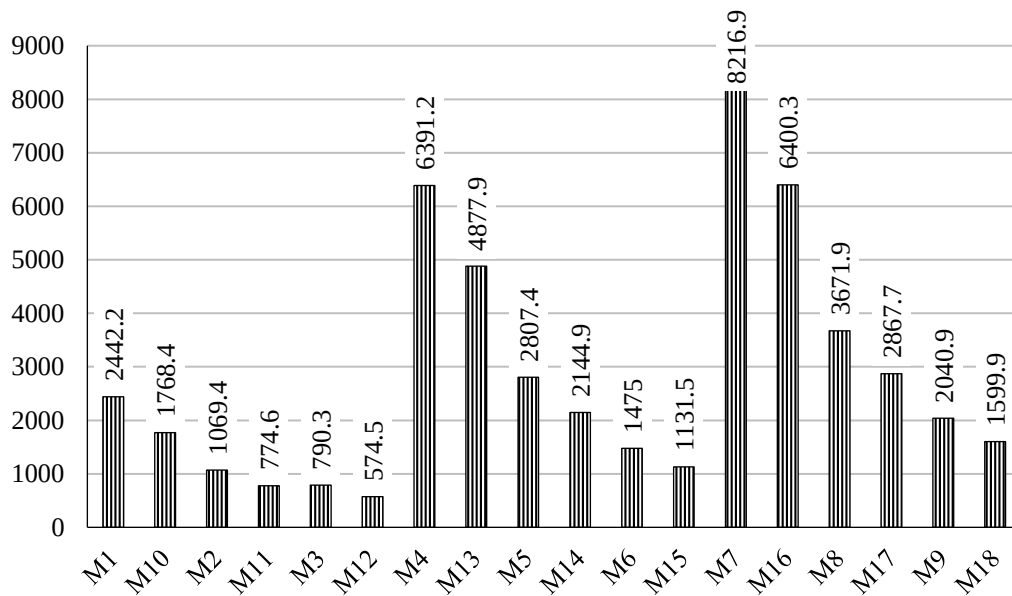


Figure 13. Maximum Bending Moment on C15 and C18 columns when blast along Y-axis [kN-m].

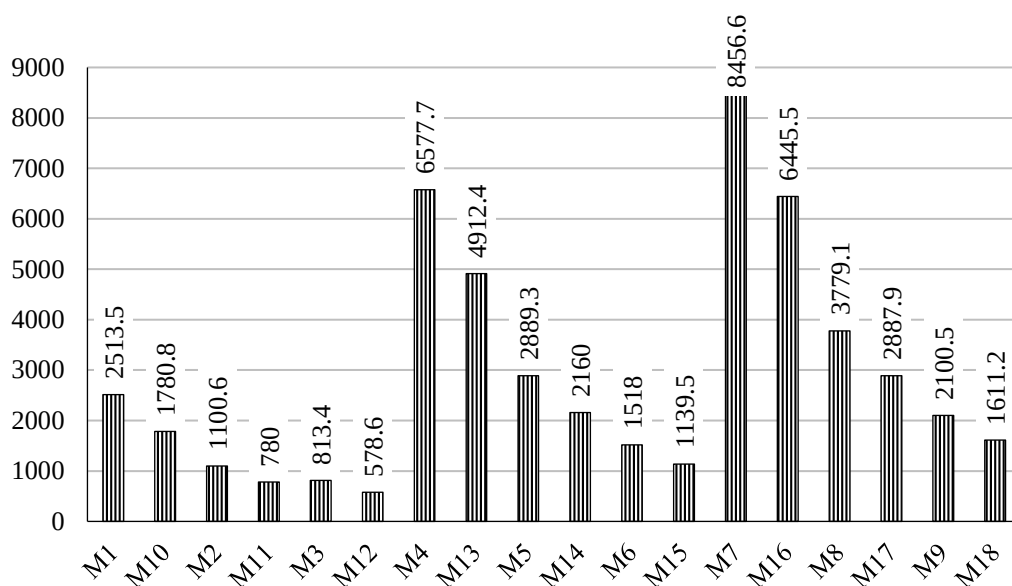


Figure 14. Maximum Bending Moment on C16 and C17 columns when blast along Y-axis [kN-m].

The maximum values of Bending Moment between RCC and composite building models when blast applied in X-direction vary from 27–38% for columns C8 and C18; whereas for columns C19 and C21, the maximum values of Bending Moment roughly vary from 26–37%. For column C20, the maximum values of Bending Moment between RCC and composite building models vary from 26–37%, also the values are almost same [but slightly greater] with the B.M. values of columns C19 and C21. When blast applied in Y-direction the maximum values of Bending Moment between RCC and composite building models vary from 27–38% for columns C15 and C18; whereas for columns C16 and C17, the maximum values of Bending Moment roughly vary from 30–41%. Overall, both RCC and composite buildings have greater impact of blast loading applied in X-direction than loading applied in Y-direction.

CONCLUSION

A multi-storey structure is most likely to get damaged for a high intensity blast generated at a comfortably shorter standoff distance. Thus, it can be concluded that the RCC building is more vulnerable to blasts compared to the composite building having CES columns, irrespective of direction of blast loading applied. Thus, irrespective of type of building (RCC or composite), buildings rectangular in plan have greater impact of blasts incident on the face of the longer side (i.e. greater width) of the building than blasts incident on the face of shorter side.

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