Blast resistance of steel plate shear walls designed for seismic loading

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Abstract. Since a blast loading or explosion can create nonlinear wave action and impact pressure on a structure, it necessary to construct a structure to resist blast loading as like other loads. In this study the nonlinear behaviour of a blast loading is simulated by calculating the pressure diagram with respect to time under the guidance of IS 4991 – 1968, code for “Criteria for Blast Resistant Design of Structures for Explosions above Ground”. The study carried out for different charge weight (100kg TNT, 200kg TNT and 400kg TNT) and standoff distances of 20metre. Nonlinear behaviour of a Blast loading to steel structures with shear plates of thickness 6 mm, 8 mm and 10 mm are modelled in ETABS and the analysis is carried out to obtain base shear, story displacement, story deformation pattern, column forces, etc.

1. Introduction
The effect of blast load to the structure on different faces (front, rear and side faces) are different. Since the pressure created due to blast load will gradually decreases with time, this can be applied to model by defining time history function in ETABS. Resistance of a structure to these effects will depend on the properties of the structure. It is achieved by providing more stability for any structure and which can be done in different ways.

2. Methodology
Analysis of steel structure modelled in ETABS is done by considering different charge weights and standoff distance of 20m. Performance is measured in terms of lateral displacements and stresses in the members of the structure. Further, with different blast intensities, the analysis is repeated on the same structure and its performance with different blast intensities is studied and compared.

3. Modelling and Inputs
A typical industrial steel structure of three levels (3 storied) is considered for the study, having three bays in X direction with equal bay spacing of 5m and three bays in Y direction with equal bay spacing of 5m. The Geometrical and material specification of the structure is tabulated. The structural steel is of grade FE350. The steel profiles or sections adopted are of Indian standard.
The 3D structural system is analysed for all other conventional loads such as dead, live wind and earthquake before analysing for blast load to ensure the stability of the structure. Effect of blast loading or explosion on the response of the steel structural system is studied by considering different blast intensities.

### Table 1. Dimensions and Properties of structure

| Sl No | Item                  | Specification               |
|-------|-----------------------|-----------------------------|
| 1     | Material              | Structural Steel            |
| 2     | No. of stories        | 3                           |
| 3     | No. of bays in        | 3                           |
| 4     | No. of bays in        | 3                           |
| 5     | Bay spacing in        | 5m                          |
| 6     | Bay spacing in        | 5m                          |
| 7     | Modulus of            | $2 \times 10^5$ N/mm²       |
| 8     | Density               | 7850 kg/m³                  |
| 9     | Poisson's ratio       | 0.3                         |

4. **Blast Load Design**

Design blast load for any structure is the probable intensity of pressure that is going to act on any face. Since the effect is different for different faces, the pressure diagram is developed by using IS 4991 – 1968. The pressure will maximum for front face which is oriented with the face normal to the direction of propagation of the shock front. The pressure determined on different faces of the building depending upon the clearance time, drag coefficient, geometrical dimensions of the building, Duration of the equivalent triangular pulse, etc.
Table 2. Blast Parameters from Ground Burst of 1 T Explosive

| Distance, m (x) | Peak side on over pressure ratio $p_{so}/p_a$ | Match no, M | Positive phase duration, in milliseconds | Peak elected over pressure ratio $p_{te}/p_a$ | Duration of equivalent triangular pulse, $t_d$ in milliseconds |
|----------------|---------------------------------------------|-------------|-----------------------------------------|---------------------------------------------|--------------------------------------------------|
| 27             | 1.8                                         | 1.6         | 20.92                                   | 5.81                                        | Structural                                        |
|                |                                              |             |                                        |                                             | Steel                                             |

Table 3. Drag Coefficient, Cd

| Shape Of Element                      | Drag Coefficient, Cd |
|---------------------------------------|----------------------|
| Front face sloping                    | 0.4                  |
| Roof, rear and side faces for         | -0.4                 |

Figure 2. Pressure Diagram for 100kg charge Weight

Figure 3. Pressure Diagram for 200kg charge Weight
5. Blast Analysis
The analysis of structure is carried even for the dead load, live load, super dead load and earthquake load. The live load and super dead load are taken as 1.5 KN/m$^2$. Every members of the structure are modelled by using ISMB500 section from IS code for steel and shear plates of 6 mm, 8 mm and 10 mm thick are used at each middle span sides. A 3D steel structure is modelled using one dimensional frame elements for columns and beams and two-dimensional shell elements for slabs. One dimensional frame element having six degrees of freedom at either end or two-dimensional shell elements having six degrees of freedom at each node.

Figure 4. Pressure Diagram for 400kg charge weight

Figure 5. Floor plan of model.

Figure 6. Elevation of Structure

Figure 7. Load Cases Considered for analysis
6. Results and Comparisons

After analysis of modelled steel structure, the results obtained from ETABS are as follows.

6.1 Base shear

Table 4. Max Base Shear in X and Y-Direction

| Model                     | X Direction | Y Direction |
|---------------------------|-------------|-------------|
|                           | 6 mm | 8 mm | 10 mm | 6 mm | 8 mm | 10 mm |
| 0.1 MTonne Charge weight  | 9085 | 10886 | 12502 | 2713 | 3428 | 4053 |
| 0.2 MTonne Charge weight  | 14470 | 17293 | 20121 | 3695 | 4625 | 5452 |
| 0.4 MTonne Charge weight  | 22102 | 26320 | 30036 | 4610 | 5749 | 6754 |

In the above table no 4 it is observed that the base shear is gradually increased in both the directions when the charge weight is changed from .1 tonnes to .2 tonnes and then .4 tonnes. In each of the charge weight conditions for any charge weight the base shear is maximum in the direction normal to propagation of blast loads, i.e. in X direction.

6.2 Max Displacements

In the below table no 5 it is observed that the displacement is gradually increased in both the directions when the charge weight is increased from 0.1 tonnes to 0.2 tonnes and then 0.4 tonnes. In each of the charge weight conditions for any charge weight the displacement is maximum in the direction normal to propagation of blast loads, i.e. in X direction.
Table 5. Max Displacements in X and Y Direction.

| Model                      | Maximum Displacements (mm) | X Direction | Y Direction |
|----------------------------|-----------------------------|-------------|-------------|
|                            | 6 mm | 8 mm | 10mm | 6 mm | 8 mm | 10mm |
| 0.1 MTonne Charge weight   | 5.2  | 5.78 | 6.22 | 2.43 | 2.8  | 2.96 |
| 0.2 MTonne Charge weight   | 9.2  | 9.52 | 10.1 | 3.3  | 3.57 | 3.86 |
| 0.4 MTonne Charge weight   | 14.15| 14.38| 14.77| 4.08 | 3.76 | 3.91 |

Figure 9. Max Displacements Vs. charge weight

6.3 Max Column Forces

Table 6. Max Column Forces

| Forces | 0.1MTonne Charge weight | 0.2MTonne Charge weight | 0.4MTonne Charge weight |
|--------|-------------------------|-------------------------|-------------------------|
|        | 6 mm | 8 mm | 10mm | 6 mm | 8 mm | 10mm | 6 mm | 8 mm | 10mm |
| P (kN) | 52.31| 60.2 | 66.5 | 84.5 | 97.37| 110.2| 131.4| 151.5| 167.2|
| M2 (kN-m)| 1.8 | 1.2  | 1.4  | 2.4  | 2.3  | 2.3  | 3    | 2.9  | 2.8  |
| M3(kN-m) | 99  | 92   | 86   | 157. | 145.6| 131.5| 239  | 221  | 204.3|
| P(kN)   | 45.9 | 48.7 | 51.1 | 74   | 79.1 | 88.6 | 116.4| 124  | 130.4|
| M2(kN-m) | 1.5 | 1.5  | 1.4  | 2.1  | 2    | 1.9  | 2.6  | 2.4  | 2.3  |
| M3(kN-m) | 83.7| 79   | 71   | 131  | 125.6| 102.3| 201  | 189  | 178  |
| P(kN)   | 45.9 | 48.7 | 51.1 | 74   | 79.1 | 88.6 | 116.4| 124  | 130.4|
| M2(kN-m) | 1.5 | 1.5  | 1.4  | 2.1  | 2    | 1.9  | 2.6  | 2.4  | 2.3  |
| M3(kN-m) | 83.7| 79   | 71   | 131  | 125.6| 102.3| 201  | 189  | 130.4|
The column forces are sorted and tabulated above are, maximum axial (P), minor axis moment and (M2) in ground Story columns. Major axis moment (M3). The following graphs, Figure 10, 11 and Figure 12 show the variation of design forces in the columns of ground story, as the blast load intensity increased, the axial and major axis bending moment increased significantly whereas the minor axis bending moment showed a drop after the initial increase with the blast load intensity.
7. Conclusions

- Detailed literature survey has been done to know what are the studies are conducted on the blast loading in different conditions. Pressure time history has been plotted in accordance with the IS 4991 – 1968. A steel structure has been modelled in ETABS to analyse and get the results.
- From the analysis it was observed that the maximum story displacement is exerted in X direction, it was in the fourth story for the case of 0.4 Mtonnes charge weight.
- The story displacement has increased for every increase in thickness of shear plate from 6 mm to 8 mm and then to 10 mm.
- Story displacement is also increased for of charge weight from 0.1 Mtonnes to 0.2 Mtonnes and then to 0.4 Mtonnes.
- Max Base shear is observed in case of 0.4 Mtonnes charge weight with 10 mm plate thickness.
- Column forces are more in case of 0.4 Mtonnes charge weight with 10 mm plate thickness, it was in the column number 12.
- Combined story response plots for step 1 and 2 are also shown.

References

[1] Hassan Ostadhossein, Saeid Lotfi 2018 Journal of Solids and Structures 15 2
[2] T. Ngo, P. Mendis, A. Gupta, J. Ramsay 2007EJSE Special Issue: Loading on structures Hindawi Publishing Corporation Advances in Civil Engineering, Volume 2016, Article ID 2604232, 14 pages, http://dx.doi.org/10.1155/2016/2604232
[3] M. Larcher, M. Arrigoni, C. Bedon, et al. 2016 Advances in Civil Engineering Article ID 2604232 doi:10.1155/2016/2604232
[4] L. Figuli, D. Papán, 2014 Applied Mechanics and Materials 617 92-95
[5] D. Papán, Z. Papánová 2015 Journal of Engineering and Technology 2 1407
[6] J. M. Biggs, Introduction to Structural Dynamics, McGraw-Hill book company, 1964, ISBN 07-005255-7
[7] Prashant Sunagar, 2013 International Journal of Innovative Research in Science Engineering and Technology 4 7156-7165.