Effectiveness of Seismically Resistant Braced Frames to Blast Loading

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Abstract. The increment in the tally of terrorist radicalisation from the past time has exhibited that the consequence of blast loads on structures is a crucial matter that should be taken into cogitation. This paper considers the effect of blast load on seismically designed framing systems namely Moment Resisting Frame (MRF), Concentric Braced Frame (CBF), Eccentric Braced Frame (EBF) and Buckling Restraint Braced Frame (BRBF). The bracings are one of the efficient lateral load resisting systems and their behaviour is observed under the blast loading. The burst load is estimated to be an unconfined surface burst explosion on front face of the structure. Comparative analysis of storey displacement among different framing systems is performed. Failure of members is studied through the analysis of plastic hinge formation. The results indicate that braced frames perform better when exposed to such kind of impact load. Buckling Restraint brace (BRB) exhibited higher level of resistance to blast loading due to its ability to yield in both compression and tension.

1. Introduction

Over the last few decades, accidental explosions and violent attacks due to radicals have brought urgency in inquest in the field of response of structures that are exposed to blare produced from burst of explosives. Deterioration of structures amplified with the deprivation of mortal lives occur when a bomb explosion takes place within or surrounding a building. Major attacks happened in the past were the Oklahoma bombing (1995), car bomb explosion outside the main terminal of Glasgow international airport, Britain (2007), Zaveri Bazaar bombing case in Mumbai (2007), bomb explosion in front of Aleppo Hotel in Syria (2014) and many more.

This paper deals with investigating the behaviour of seismically designed frames having the same configuration subjected to blast loading. The seismically designed frames include Moment Resisting Frame (MRF), Concentric Braced Frame (CBF), Eccentric Braced Frame (EBF) and Buckling Restraint Braced Frame (BRBF). The behaviour is investigated using generalised Finite Element Method (FEM) based software tool i.e., ETABS v16.2.1. The blast load is assumed to be an unconfined surface burst detonated from 15 m from the front face of the building. Adeli et al. [1] used the applied element method to analyse the different steel framing systems and concluded that EBF had fewer number of failed members when subjected to shock loading.

1.1. Buckling Restraint Braced Frame (BRBF)

BRBFs are one of the advanced systems of lateral load resisting systems used in the modern structures [2]. The geometric configuration of BRBF is similar to that of the Concentric Braced Frame (CBF). The difference lies in the composition of BRB itself. A schematic diagram describing the different components of BRB is shown in figure 1.
2. Blast Load Phenomena

A sudden release in energy creates pressure disturbance which is known as a blast. This pressure disturbance is created due to rapid expansion of an energetic material. The phenomena signifying that the blast wave is radiated from the origin of fulmination is expressed in figure 2. The pressure amplitude of blast load rises to higher degree and the eternity of the load from burst also inflates with the propagation of blast wave from the origin [3]. The creation of vacuity at the origin takes place and also the flip-flop of advancement of gas occurs due to overexpansion at the centre of the blast. Due to outward expansion of negative pressure region, a negative pressure is created that is below the ambient pressure. The positive phase is trailed by this negative phase. The pressure generated during negative phase has lower magnitude than pressure generated during positive phase but it has prolonged duration than the latter. Generally, out of the two phases of burst, the negative phase is less important so it can be omitted.

2.1. Blast Wave Characteristics

The propagation of the reaction front is supersonically more rapid than the speed of sound in a detonation process. This wave propagated from the blast is called as a shock wave. Blast wave has a catastrophic jump in pressure. The pressure disturbance at any end from the blast point, has the shape shown in figure 3. At time $t_a$, the arrival of shock front at a given location gives rise to the incident pressure with its peak value, $P_m$, followed by its perish to the clime value in duration called as the positive phase duration. After that there is a negative lapse with a time lapse $t_o$ which is more than the positive lapse and it is designated by the negative pressure which has a greatest value of $P_m$ with the flip-flop of flow of particles. The magnitude of the negative pressure is well below the magnitude of ambient pressure. In design, generally this negative lapse is of less significance than the positive lapse, and its magnitude $P_o$ is, in all cases, less than the clime atmospheric pressure $p_o$. For blast wave, the area resultant of the integration under the pressure v/s time curve is defined as the incident impulse density which is described as $i_i$ for negative lapse and $i_o$ for positive lapse.
3. Modelling

Four 7-storey Reinforced Cement Concrete (RCC) frames including MRF, CBF, EBF and Buckling Restraint Braced Frame (BRBF) are modelled using ETABS v16.2.1 software. The geometry of the bracings is kept as inverted – V shape. The 3-D view of the considered frame is shown in the figure 4.

3.1. Blast Wave Characteristics

The frame consists of five bays both in x and y direction. Length of three bays is 4m each and that of two bays is 3m each. Hence the plan dimension of building is 18m x 18m. Depth of foundation is kept 2m. Height of each storey is 3m with total height of 21m above plinth level. Dimensions of different structural components of frame are shown in table 1.

| Structural Elements | Dimensions       |
|---------------------|------------------|
| Column              | 350mm x 450mm    |
3.2. Structural Details
The design considerations of Buckling Restrained Braces (BRB) are taken in accordance with the provisions from National Institute of Standards and technology (NIST) brief no. 11, which is a guide for practicing engineers issued by U.S. Department of Commerce under National Earthquake Hazards Reduction Program (NEHRP) [4]. The strength parameters of different components of the considered frame are shown in table 2.

| Grade of Concrete | M35 |
|-------------------|-----|
| Grade of Rebar    | Fe 500 |
| Grade of Steel    | Fe 250 |
| Grade of BRB components | Steel tube 290 MPa, Core plate 345 MPa |

Length of yielding core of BRB is considered as three-fifth brace length. Area of flat steel plate to be used as core plate is taken as 6.4 cm².

4. Blast Load Calculation
The blast parameters due to the detonation of charge weight of 100 kg (Trinitrotoluene) at a standoff expanse of 15 m from the front face of the building are calculated with reference to IS 4991: 1968 (reaffirmed 2013).

4.1. Front Face Loading
At any time t, the net pressure that occurs on the fore front of building is:

\[
\text{The reflected pressure } p_r \text{ or } (p_r + C_d q), \text{ whichever is greater}
\]

\[C_d = \text{drag coefficient}
\]

\[p_r = \text{The value of overpressure (reflected) falling from the max. value } p_{ro} \text{ to overpressure in duration } t_c \text{ is described as:}
\]

\[t_c = 3S/U \text{ or } t_d \text{ whichever is less}
\]

Where,

\[S = H \text{ (height of building) or B/2 (width/two), lesser of the two}
\]

\[U = \text{Velocity of shock wave (M . a)}
\]

\[a = \text{velocity of echo (344 m/s) at MSL at } 20^\circ C
\]

\[M = \text{Mach number of wave given by } \sqrt{1 + 6p_{so}/7p_a}
\]

4.2. Side Face Loading
For side walls, the blast wave is described as a moving triangular wave with the maximum value of overpressure \((p_r + C_d q)\) over time \(t_d\) [5]. The calculated blast parameters are mentioned in table 3.

| S.No. | Parameters | Value |
|-------|------------|-------|
| 1     |            |       |
1. Scaled distance (x) 32.32 m
2. Ambient air pressure \( (P_a) \) 1 kg/cm²
3. Peak side on overpressure \( (P_{so}) \) 1.25 kg/cm²
4. Peak reflected overpressure \( (P_{ro}) \) 3.62 kg/cm²
5. Dynamic pressure \( (q_o) \) 0.47 kg/cm²
6. Scaled time \( (t_o) \) 11.35 ms
7. Duration of equivalent triangular pulse \( (t_d) \) 7.7 ms
8. Front wall loading 3.7 kg/cm²
9. Side wall loading 1.1 kg/cm²

5. Analysis

Blast load function is defined as the time history function in ETABS. Hinges are allocated to columns and beams at a relative distance of 0.1 and 0.9 from either joint. Direct integration analysis based on the non-linear time history is carried out using ETABS software tool.

Blast load is applied as the impact load in the time duration of 7.7 milliseconds on the considered frame as shown in the figure 7. The values of \( P_{ro} \) and \( P_{so} \) are multiplied with the transverse dimension of beam and column and applied in the units of kN/m. The time history impulse of \( P_{ro} \) and \( P_{so} \) is shown in figure 5 and figure 6.

![Figure 5: Blast wave on front wall](image)

![Figure 6: Blast wave on side wall](image)
6. Results

The considered frames suffer deterioration with detriment of beams and columns. The structural elements in the closer vicinity experienced more damage due to high blast pressures. The storey displacement is found to be maximum in Moment Resisting Frame (MRF) and minimum in case of Buckling Restrained Braced Frame (BRBF) as shown in figure 8. The maximum storey displacement in MRF, CBF, EBF and BRBF is 2.2cm, 1.45cm, 1.31cm and 1.1cm respectively. The plastic hinge analysis is also performed and the number of members failed is found to be maximum in MRF and least in BRBF as shown in figure 9(i), figure 9(ii), figure 9(iii) and figure 9(iv).

Figure 7: Application of blast load

Figure 8: Storey displacement v/s Storey height
The plastic hinges are shown in green dots in figure 9(i), 9(ii), 9(iii) and 9(iv). The number of members failed in MRF, CBF, EBF and BRBF is 14, 10, 10 and 7 respectively.

7. Conclusion

Based upon the results obtained from the analysis of four seismically designed frames, it is concluded that:

- The maximum storey displacement in CBF is around 34% less than that in MRF and in case of EBF it is around 40.4% less as compared to MRF.
- The maximum storey displacement in BRBF is around 50% less than that in MRF.
- The maximum storey displacement in BRBF is around 24.1% and 16.03% less than that in CBF and EBF respectively.
- The number of structural members failed in CBF and EBF is approximately 28.6% lesser than that in MRF.
- The number of structural members failed in BRBF is approximately 50% lesser than that in MRF.
- The number of structural members failed in BRBF is approximately 30% lesser than that in CBF and EBF.
Hence the braced frames perform better as compared to MRF under blast loading. The special type of braced frames that is BRBF resisted perform to blast loading to a greater extent to other type of braced systems.

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