Risk Estimation of Blast Damage to Buildings

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ABSTRACT

This paper has evaluated the blast capacity of a five-story reinforced concrete building with a nonlinear static procedure. The buildings based on seismic design codes are used to resist the various blast loads. The corresponding capacity curves of buildings in the longitudinal and transverse directions are achieved. The damage states of HAZUS are adopted in this study to relate with blast scaled distance. The fragility of buildings subjected to blast scaled distances is developed to serve as references for risk estimation of blast loading.

Keywords: Reinforced concrete building; blast; seismic design; fragility curves.

1. Introduction

Public buildings become explosive attack target because of increasing terrorist activities around the world [1]. However, the bomb attack is not considered in the most building design. Therefore, this research is to identify the most vulnerable components in the buildings to a near field blast event. Severe damage had been occurred in recent blast events in several public buildings to a near field blast event. The damage includes loss of facades and loss of structural integrity. This incidents are the Jewish Community Centre, Argentina 1994 [2], and the WTC twin tower attack, Sri Lanka, 1997 [3], the Murrah building bombing, USA 1995 [2], the Central Bank bombing, Sri Lanka 1996 [4] and, Khobar Towers bombing Saudi Arabia, 1996 [5], the Lahore city bomb blast 2009 [6] and, the Baghdad bomb blasts on foreign embassies 2010 [7].

The nonlinear behavior of the structures with seismic design is important in the seismic performance. The blast resistance with this seismic design will be conducted in this research. The previous study is to assess the effect of seismic design criteria on blast resistance of RC framed structures [8]. However, the previous researches mainly using isolated beams or columns to identify the damage, the damage components with neighboring structures are not adequate to relate their interactions or damage propagation. In this study, the damage beams or columns are identified with considering the entire building to specify the most critical ones.

The scope of this research is to develop the blast fragility curves of an existing RC building. The nonlinear static pushover analysis is performed to achieve this blast fragility curves in terms of scaled distances.

2. Analytical modeling

An existing RC framed four-story building was selected for this nonlinear analysis. Figure 1 illustrates the general geometric arrangement of the structure. This building has five and one bays in the longitudinal and transverse directions, respectively.

The selected RC framed four-story building has bay lengths of 9.3 m in longitudinal directions, except a 6 m of the end bay, and 12 m in transverse directions. The building has been designed to resist gravity, live, seismic, and wind loads. The floor to floor story height of each level is 4.15 m except the fourth floor which is 3.5 m, and a 5.8 m in height at the roof level. Column cross-sections are 70 cm × 70 cm with 3.3 % longitudinal reinforcement. The dimensions of the beams in the longitudinal and transverse directions are depth D = 80 cm and width W = 55 cm cross section. Both transverse and longitudinal beams have 1.38% longitudinal reinforcement. The slab thickness of the floor is 15 cm. Concrete compressive strength is 27.46 MPa and steel grade is 411.88 MPa. For design purposes using Force-Based Design (FBD) methodology and linear elastic analysis, cracked members properties are adopted; 35% of the gross inertia is used for columns while 70% of the gross inertia is used for beams. The complete three-dimensional (3D) lateral load resisting frame was developed in FEM code SAP2000 version 15 for a global analysis [9]. Beams and columns are frame type elements with nonlinear hinges at the both ends of elements. In addition, slabs are shell type. Columns at the base are assumed to be fixed on the ground level without soil-structure interaction.

The blast loads were applied as single load case to all parts of the structure to investigate global response. The aim of this is to identify the critical components of the beams or the columns suffered severe damages. The identified columns will be removed for the future research of the progressive collapse analysis.

3. Responses of explosive loadings

The effects of bomb explosion on a particular target are in terms of the charge weight W (kgf), and the standoff distance R (m) between the blast source and the target. The corresponding equations are given as follows;

$$Z = R/W^{1/3} \quad \text{(1)}$$

where Z is the scaled distance.

The peak overpressure P_{max} (in kgf/cm^2) is expressed as follows [10]:

$$P_{max} = \frac{14.0717}{Z} + \frac{5.5397}{Z^2} - \frac{0.3572}{Z^3} + \frac{0.00625}{Z^4} \quad \text{if } Z \in [0.05, 0.3] \quad \text{(2)}$$

$$P_{max} = \frac{6.1938}{Z} - \frac{0.3262}{Z^2} + \frac{2.1324}{Z^3} \quad \text{if } Z \in [0.3, 1] \quad \text{(3)}$$

$$P_{max} = \frac{0.662}{Z} + \frac{4.05}{Z^2} + \frac{3.288}{Z^3} \quad \text{if } Z \in [1, 10] \quad \text{(4)}$$

The overpressure imposed on the walls of buildings is equivalent to lateral loadings at the each floor level. Bomb detonations with different charge weight and distance produce equal peak pressures if their reduced distance is the same. The peak pressures with incremental intensity are applied to both directions independently to achieve various damage scenarios.

The distribution of plastic hinges reveals that the most plastic hinges of beams and columns are mainly at the first and second floors as depicted in Figures 2 and 3, for a pushover analysis in the longitudinal and transverse directions, respectively. The building is not perfect symmetric in plan. Therefore, this building experienced a torsion deformation is presented in Figures 4 and 5, in the longitudinal and transverse directions, respectively. In addition, a comparison of capacity curves in both directions depicted in Figure 6 reveals that the capacity in the longitudinal direction is larger than those in the transverse direction.

Figure 7 shows the displacement profiles of the structure due to the applied load. The displacement profiles of four corner columns of the building in the final step of a progressive pushover procedure are illustrated in Figure 7(a). The displacements of each floor are larger at the second floor, and the displacements decreased as the increase of the floor level. The torsion deformations are pronounced with the increase of applied lateral loading intensity. Figures 4 and 5 demonstrate the torsion effects in the longitudinal and transverse directions, respectively.

Interstory drift for different directions reported in Figure 8(a) demonstrates that the ultimate capacity of four corner columns experienced larger drift ratio in the transverse direction than those in the longitudinal direction. The interstory drift profiles of controlled corner columns with a step-by-step procedure are presented in Figure 8(b) with HAZUS damage states.

The interstory drifts at threshold of damage in HAZUS for the mid-rise reinforced concrete frames are 0.0033(Slight), 0.0058(Moderate), 0.0156(Extensive), and 0.04(Complete) [11]. An interesting comparison in terms of interstory drifts with incremental lateral applied forces shows that the maximum drift at the third floor in the first three steps shifts those to the second floor in the transverse direction. The increase of the torsion effects may lead to this maximum drift shifting from the third to the second floors. However, the simulated blast damage scenarios are smaller than those complete damage states.

4. Fragility Assessment

Fragility curves provide an effective approach to estimate the probability of exceedance with the scaled distance of the blast loadings. Fragility curves consider the probability that the blast demand (D) placed on the structure exceeds the capacity (C) conditioned on a chosen intensity measure (IM) representative of the blast loading. This evaluation is accomplished by the convolution of the capacity models, commonly referred to as limit state models and the demand models. Demand models are probability distributions of structural demand conditioned on the IM, known as Probabilistic Seismic Demand Models (PSDMs). To describe the uncertainty about the demand, the logarithmic standard deviation, commonly referred to as the dispersion, $\beta_{D/IM}$ based on moderate code seismic design level specified in HAZUS is equal to 0.7.

PSDM can be formulated as shown in Eq. (5):

$$P\left[D \geq \frac{d}{IM}\right] = 1 - \varphi\left(\frac{\ln(d) - \ln\left(\frac{1}{Z}\right)}{\beta_{D/IM}}\right) \quad \text{.......... (5)}$$

where $\varphi(\cdot)$ is the standard normal cumulative density function and 1/Z is shown in Eq. (1).

The capacity models are described by a two-parameter lognormal distribution with median, 1/Z and dispersion, $\beta_{1/Z}$. Having described the demand and capacity models, the component fragility, conditioned on the chosen IM, can be evaluated as in Eq. (6).

$$P[D \geq C/IM] = \varphi\left(\frac{\ln(S_D/S_C)}{\sqrt{\beta_{D/IM}^2 + \beta_C^2}}\right) \quad \ldots\ldots (6)$$

Figures 9(a) and 9(b) plot the fragilities for the four-story RC building at the four limit states, slight, moderate, extensive and complete damage, in the longitudinal and the transverse directions, respectively. The building in the transverse direction is the more vulnerable than those in the longitudinal direction. This expectation can be demonstrated in capacity curves as illustrated in Figure 6.

5. Concluding Remarks

This paper has evaluated the blast capacity of a five-story reinforced concrete building with a nonlinear static procedure. The buildings based on seismic design codes are used to resist the various blast loads. The corresponding capacity curves of buildings in the longitudinal and transverse directions are achieved. The damage states of HAZUS are adopted in this study to relate with blast scaled distance. The fragility of buildings subjected to blast scaled distances is developed to serve as references for risk estimation of blast loading.

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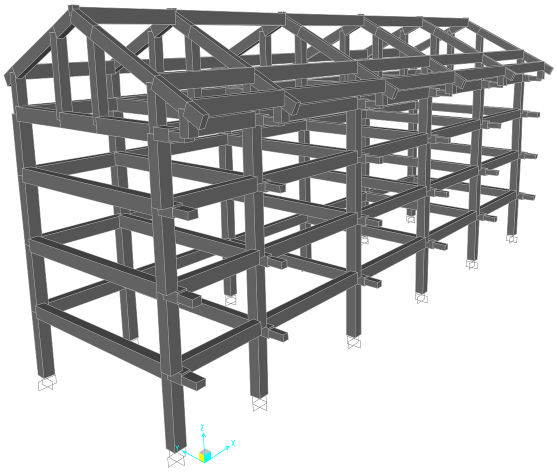


Figure 1. Schematic representation of a four-story RC building.

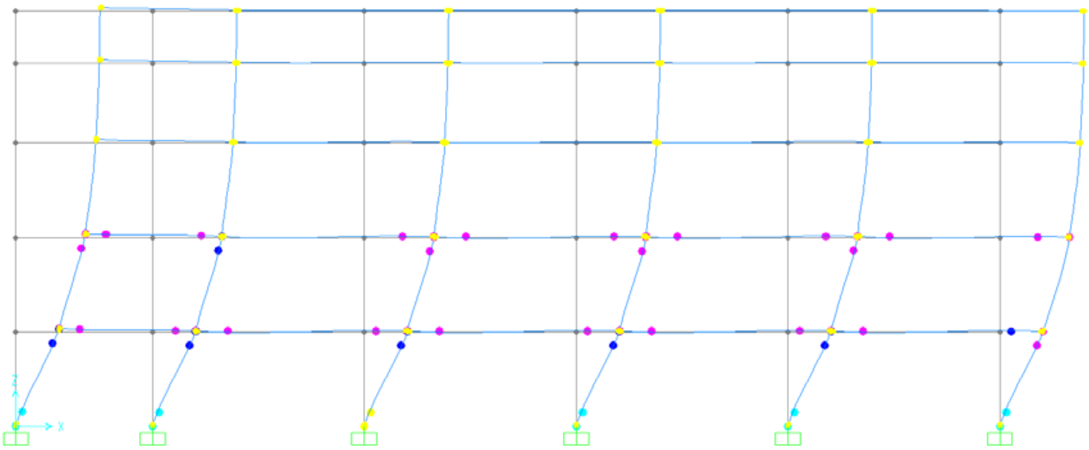


Figure 2. Pushover in the longitudinal direction.

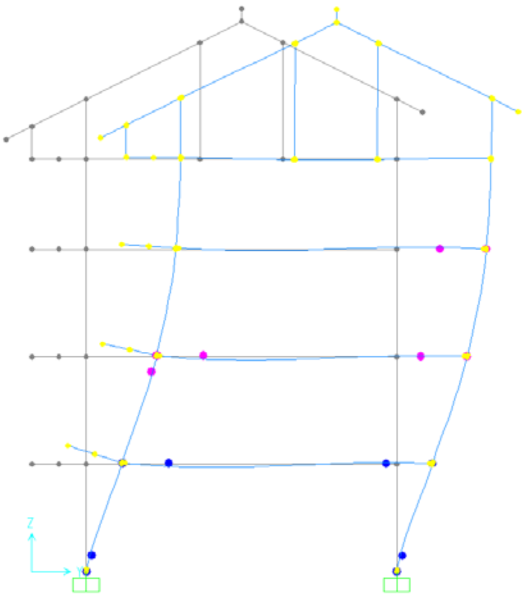


Figure 3. Pushover in the transverse direction.

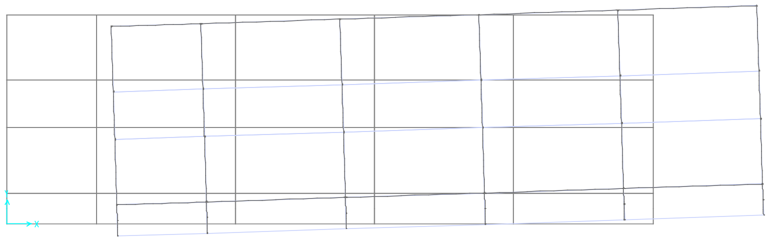


Figure 4. Plane torsion with a pushover in the longitudinal direction.

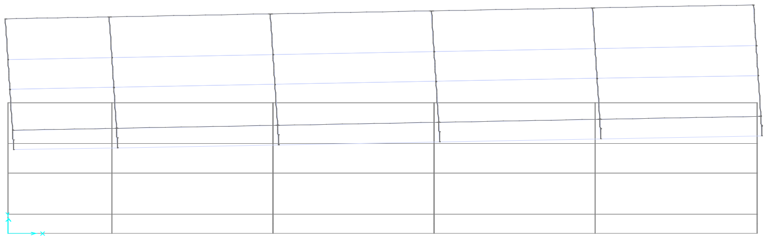


Figure 5. Plane torsion with a pushover in the transverse direction

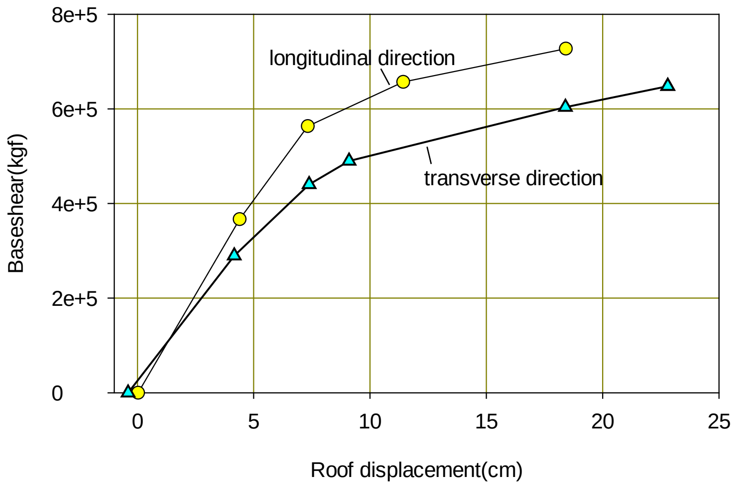
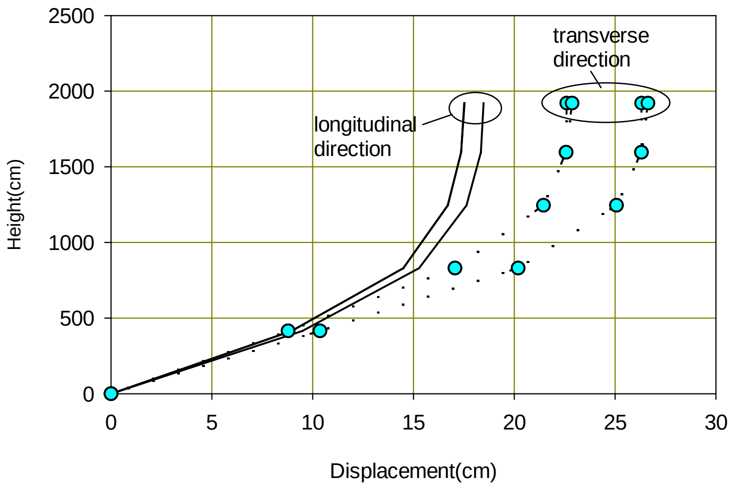
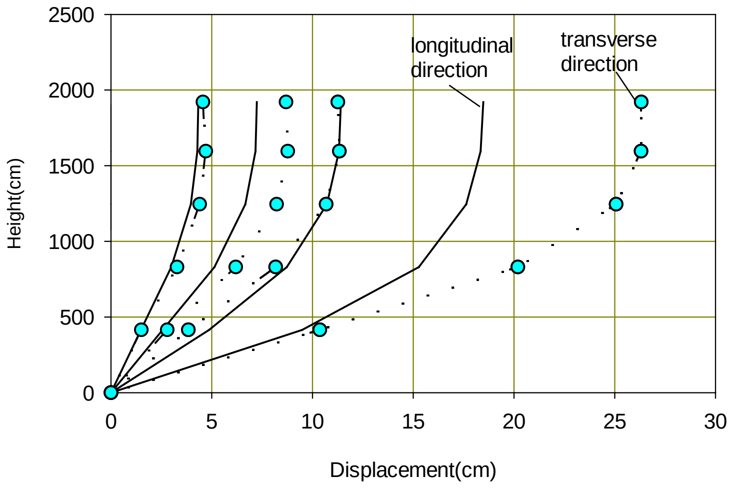


Figure 6. Capacity curves in the transverse and longitudinal directions



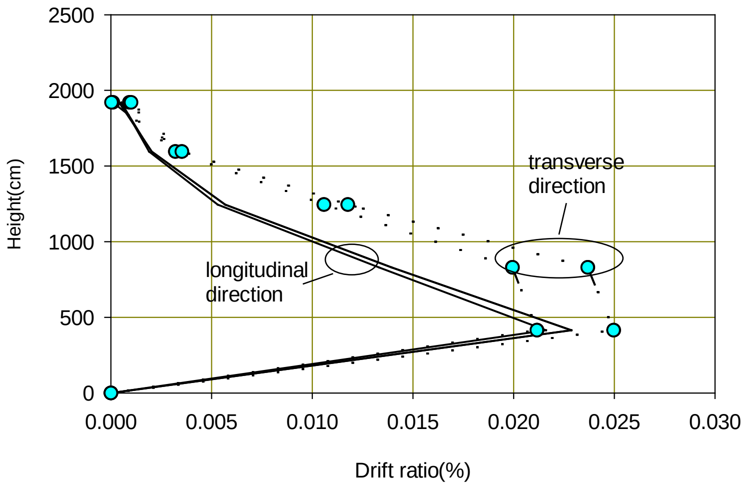
(a)



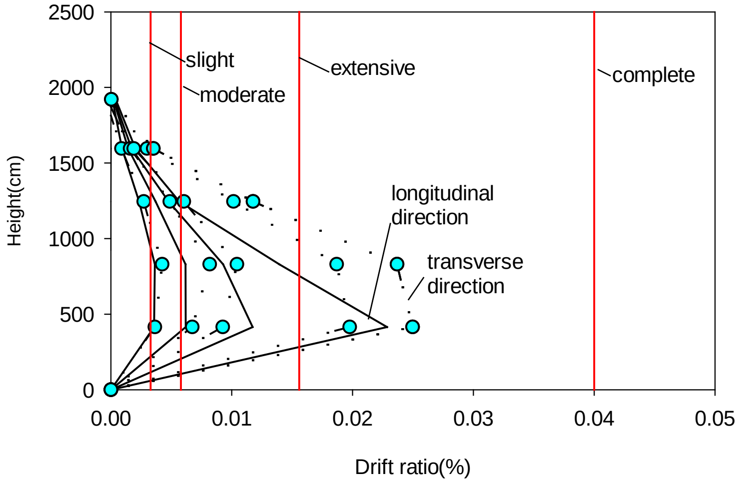
(b)

Figure 7. Displacements on the various floors with a pushover in the transverse and longitudinal directions

(a) Four corner monitored points at the last step of pushover analysis (b) maximum monitored points with a step-by-step procedure



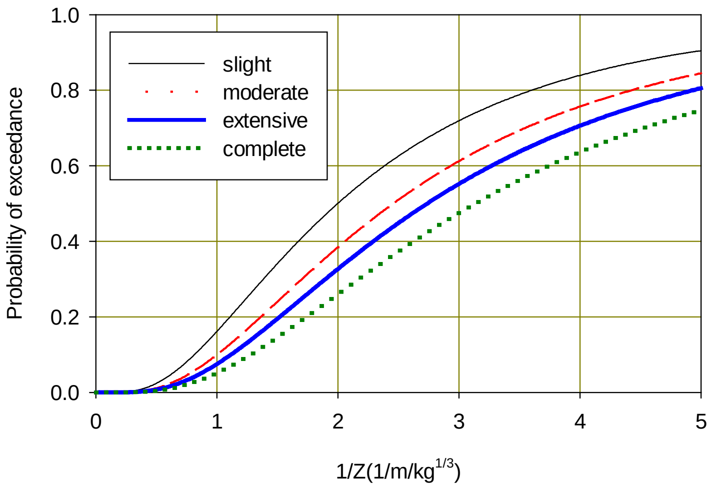
(a)



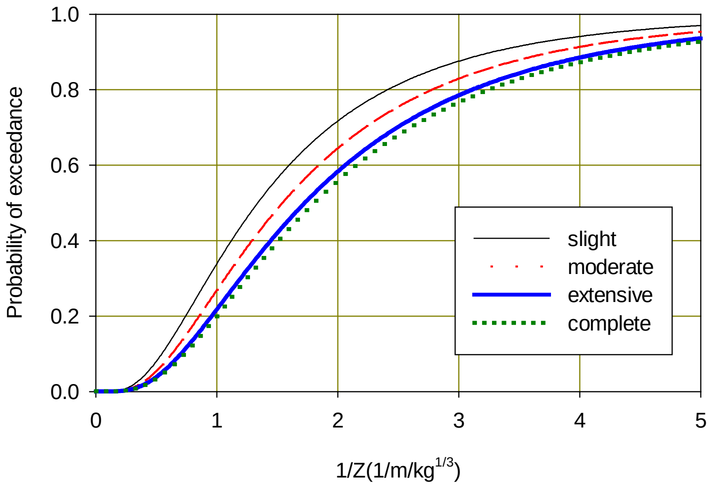
(b)

Figure 8. Drift ratios on the various floors with a pushover in the transverse and longitudinal directions

(a) Four corner monitored points at the last step of pushover analysis (b) maximum monitored points with a step-by-step procedure



(a)



(b)

Figure 9. Fragility curves of buildings subjected to blast loadings (a) longitudinal (b) transverse directions