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Comparison of Response of Building Structures to Blast Loading and Seismic Excitations

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Abstract

Blast loading and earthquake excitations can be regarded as the most destructive events a building structure can experience during its life. Response of the structures to these two types of dynamic loading can be of comparable magnitude. Therefore, in this study, response of a benchmark 10-story building to moderate blast loading is compared to that produced by several different synthetic ground motions whose spectra are compatible with the uniform hazard spectra for selected sites in the eastern and western regions of Canada. The results show that the lateral story drifts produced by blast loading are significantly larger than the corresponding seismic drifts. The study concludes that consideration of the global response of a building to blast loads is important, and response parameters, such as the lateral drifts and floor responses, should be paid attention in the design and response assessment procedures for blast loading.

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Keywords: Blast loading; dynamic analysis; seismic response; structural analysis; protective design.

1. Introduction

Two of the most destructive events that a building structure could experience are earthquake and blast. In designing a building structure to resist the forces induced by an earthquake, both the local response at the element level and the

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global response are considered. However, despite the similarities between seismic excitation and blast loading, the global response of buildings to blast loading is usually not considered as being critical. The response of building structures to blast loading is traditionally assessed by individual analysis of its critical members [1-3]. While this type of assessment can be conservative [4,5], it does not provide an estimate of the global response of the building, particularly of the deformations in the lateral load resisting system, which can at times be critical. On the other hand, the global deformations, such as inter-story drifts, have been traditionally considered as being among the most important response parameters of the building structures subjected to earthquakes.

The importance of estimating the global deformations has been pointed out by the authors in another research [6]. To compare the magnitude of such deformations and in general, the global response of the buildings to seismic events and blast loads, a benchmark 10-story building, designed for the seismic hazard of eastern and western Canadian region [4-6], is analyzed for its response to different blast load scenarios, and such response is compared to that produced by seismic excitation.

The benchmark 10-story building structure is modeled in OpenSEES software, using nonlinear beam-column elements. The building is subjected to 10 different earthquake ground motions, representing two different hazard levels (eastern and western regions of Canada), as well as to two different moderate far-field blast load levels. The lateral deformations of the structure under earthquake forces are compared to those obtained under the selected blast loads.

2. Description of Structure

A benchmark 10-story reinforced concrete (RC) building is used for the current study. The moment frame building is designed for moderate ductility [5], based on the provisions of the National Building Code of Canada [7] and the Canadian Standard for the Design of Concrete Structures [8]. A schematic view of the building is shown in Fig. 1. The structural characteristics and design calculations of the building are presented elsewhere [5]. The structure is modeled in OpenSEES code [9] for the purpose of this study. The nodes on the base of the structure (columns) are considered as being fixed, and as shown in Fig. 1, the response of the structure in the *x*-direction (shorter direction) is studied.

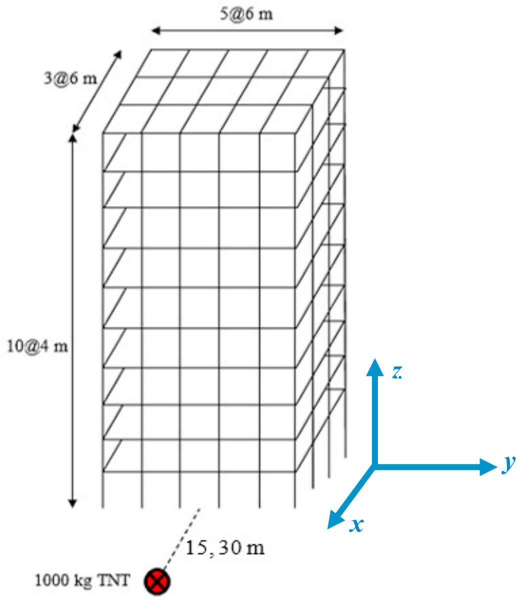

Fig. 1. Geometrical model of the building and the blast source

For modelling the RC beams and columns, some verified material models available in OpenSEES are used for both unconfined and confined concrete and for steel reinforcing bars. The unconfined concrete in the cover of the sections is modelled using Hognestad's unconfined concrete model [10]. The confinement effects on the strength of the concrete are considered using Chang and Mander's model [11]. The concrete material is modelled using concrete07 model in OpenSEES and the steel reinforcing bars are modelled by steel02 model. The material models present in the software are utilized to generate the nonlinear (displacement-based) fiber elements for representing the beams and columns. Each member is divided into four sub-elements, with three integration points per sub-element. The masses of the elements and the 150-mm thick slab are lumped at the end nodes of the sub-elements. The structure is then subjected to selected blast loads and to seismic excitations as discussed in the following sections.

3. Blast Load Analysis

As shown in Fig. 1, the structure is subjected to a hemispherical blast from a 1000-kg TNT charge, located at two different standoff distances of 15 m and 30 m. The two blast scenarios are considered moderate-magnitude far-field blasts. For analyzing the response of the structure to blast loading, the building is modeled using a 2D model. The use of such a model is justified because, as shown in Fig. 1, the building and the location of the blast charges are both symmetrical. Also, in previous research studies [5,6], the response results obtained from the analysis of 2D model were shown to closely match the results obtained from a 3D model.

Since the blast load is perpendicular to the face of the building along *y*-axis, the 2D model comprises the frames along the shorter *x*-direction and interconnected by rigid links. Also, only three of the six frames are modeled to take advantage of the symmetry. For analyzing the blast response of the structure, a strength increase factor of 1.1 is applied to all material strengths. At the same time, dynamic increase factors of 1.25 and 1.23 are applied to the compressive strength for concrete and yield strength steel reinforcing bars, respectively [2].

For an accurate analysis the blast loads may be applied to individual nodes of the structure based on the tributary area of the node the standoff distance of the node from the center of detonation, and incident angle of the blast wave arriving at the node. Considerable saving in the analysis time can be achieved by assuming that the blast load acts simultaneously at all nodes at a given story level based on the shortest standoff distance and the largest incident angles for the nodes on that story. In a previous study on the same benchmark structure [6], it was shown that such simplification still provides a response that is fairly close to the more exact estimate of the blast loading. Using this methodology, the blast pressure time-histories derived by using the ConWep program [12] and multiplied by the tributary area of each frame node are applied to the building frames. The pressure time-histories applied to each story of the building in the two selected blast scenarios are shown in Fig. 2.

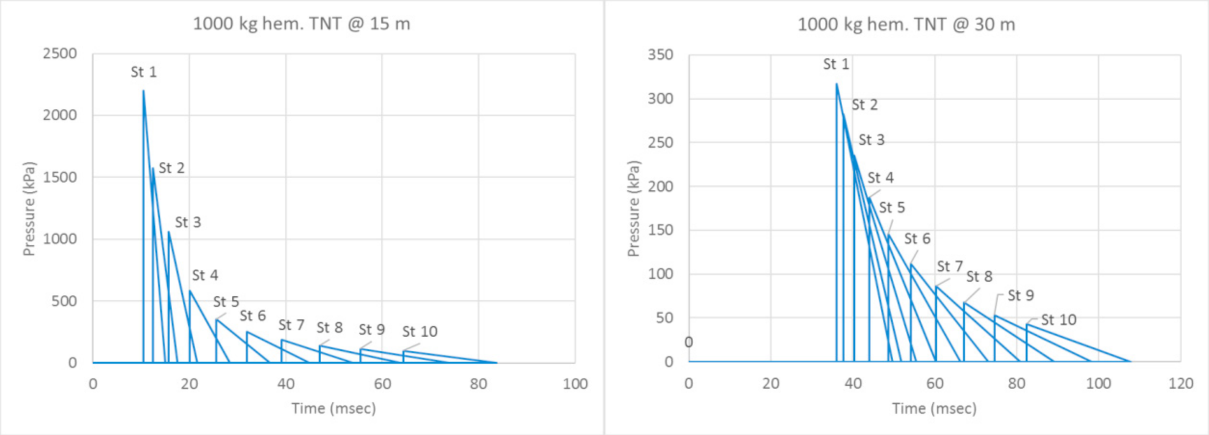

Fig. 2. Blast load time-histories applied to each story in the two selected scenarios

4. Seismic Response Analysis

Ten earthquake acceleration time-histories are selected to be applied to the 10-story building. Out of these records, five are scaled so that their response spectra are compatible with the uniform hazard spectrum (UHS) for Montreal in eastern Canada, while the other five are scaled so that their response spectra match the UHS for Vancouver in western Canada. The synthetic time-histories for the eastern region of Canada, namely E6C1, E6C13, E6C15, E6C18 and E6C42 to represent the hazard for Montreal and the time-histories for the western region, namely M6C1, M6C2, M6C26, M6C31 and M6C38 to represent the hazard for Vancouver, are extracted from the database of ground motions generated by Atkinson [13]. Scale factors of 0.55, 0.74, 0.56, 0.61, and 1.01, respectively are applied to the eastern ground motions, while scale factors of 0.78, 0.87, 1.19, 0.99, and 1.43, respectively are applied to the western ground motions. The response spectra of the scaled ground motions are compared with the UHS for Vancouver and Montreal in Figures 3(a) and 3(b), respectively.

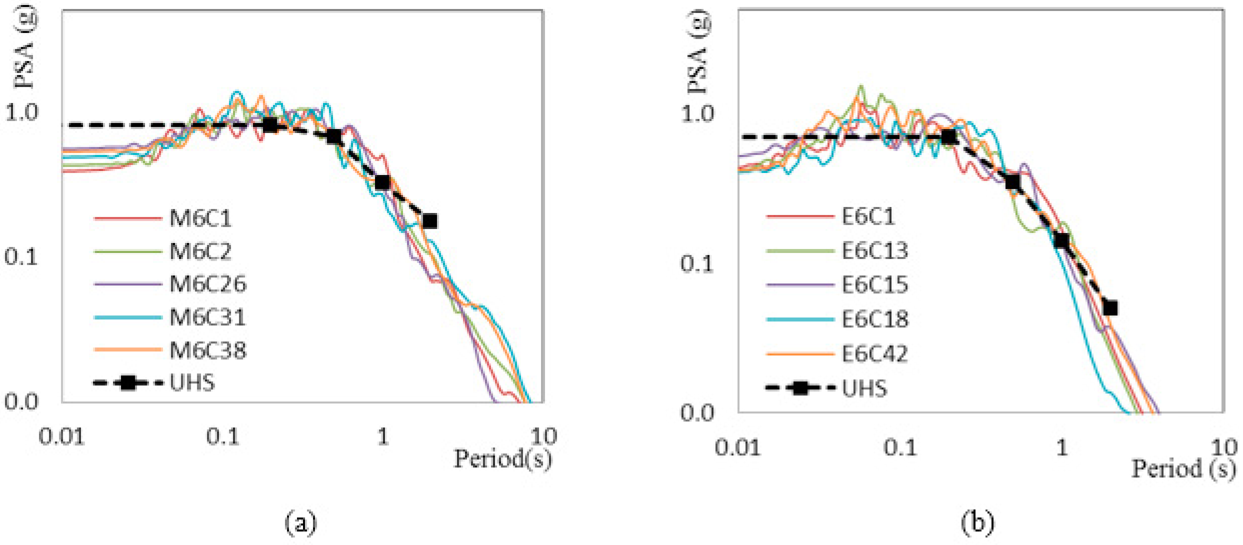

Figure 3. Comparison of the response spectra of the scaled spectrum compatible records with the target uniform hazard spectrum; (a) Vancouver, (b) Montreal [14]

For seismic analysis of the building, a 3D model of the building is used, where the ground motion time-histories are applied to the fixed nodes on the base of the structure in the same horizontal direction as the applied blast loads. In the seismic analysis, no strength or dynamic increase factors are used. However, the same material models for confined and unconfined concrete and steel reinforcement as used in the blast analysis are utilized.

5. Results and Discussion

The models described above are analyzed using dynamic solver in OpenSEES software. A 5% Rayleigh damping is used for both seismic and blast analyses. Also, the effect of large deformations is accounted for in the models, by considering P-delta effects. The dynamic analysis is performed by means of step-by-step integration using Newmark's average acceleration algorithm. The nonlinear iterative procedure is implemented using modified Newton-Raphson methodology. The analysis time step varies from 0.1 ms to 0.001 ms for the blast analysis, while a fixed value of 1 ms is used in the seismic analysis. Nonlinear dynamic analyses are carried on both the 2D and 3D models of the building. The maximum inter-story drift ratios obtained from the analyses are shown in Fig. 4.

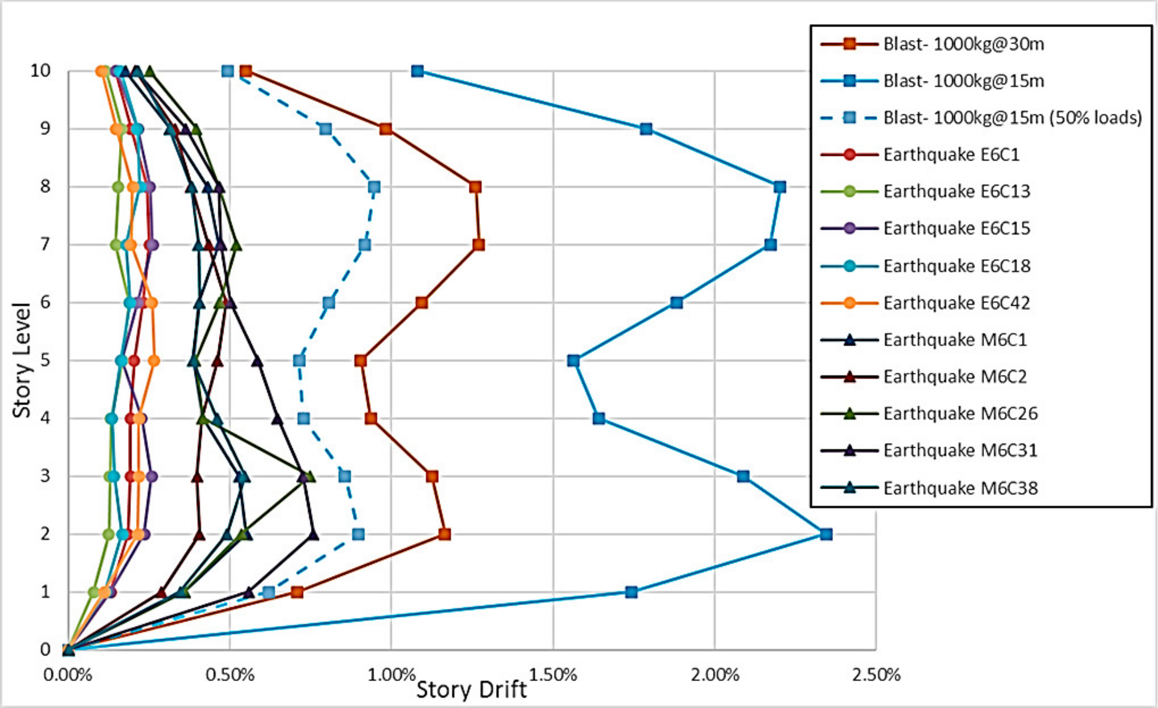

Fig. 4. Maximum story drift ratios obtained from earthquake and blast analyses

As observed from Fig. 4, the maximum story drift ratios produced by blast loads are much higher than those produced by both eastern and western Canada earthquake ground motions. Even the ground motions representing the seismic hazard for Vancouver, which are higher than the design seismic level of the building, do not cause any significant lateral displacement in the structure. On the other hand, even the smaller blast scenario (30-m standoff) pushes the structure into nonlinearity, and the larger blast scenario (15-m-standoff) pushes the structure above allowable lateral story drifts specified by the code of 2% [7]. It should be noted that the blast scenarios selected here are not extreme cases, as the 1000-kg TNT charge at standoff of 15 m or 30 m are specified as the design blast loads for performance of the building in heavy damage performance or collapse prevention category [15, 7].

6. Conclusion

In the case study presented here, a selected benchmark building is analyzed for its response under two moderate blast scenarios, and under a series of seismic ground motions compatible to design spectra for two different hazard levels. The major goal here is to compare the global response of the building to these two types of dynamic loading. The response results show that the inter-story drifts generated in the building due to the blast loading significantly exceeded those caused by the design- and higher than design-basis earthquakes. Thus, it may be reasoned that the blast loads could force the structure to deform laterally with magnitudes of deformations that are similar to or higher than those under seismic action. It would therefore be necessary for the designers to check the lateral deformations and the global response of the buildings under blast loads, in the same fashion as for earthquake forces.

References

[1] US Department of the Army (DoA), Fundamentals of Protective Design for Conventional Weapons, TM 5-855-1, USA ,1986.

[2] US Department of Defense (DoD), Structures to Resist the Effects of Accidental Explosions, UFC 3-340-02 (TM 5-1300, NAVFAC P-397, AFR 88-22), USA, 2008.

[3] American Society of Civil Engineers (ASCE), Design of Blast Resistant Buildings in Petrochemical Facilities, ASCE Task Committee on Blast Resistant Design, Reston, Virginia 2010.

[4] D. Nourzadeh, J.L. Humar, A. Braimah, Response of multi-sory frames and individual columns to blast loading, CSCE Annual Conference: 6th International Conference on Engineering Mechanics and Materials, Vancouver, 2017.

[5] D. Nourzadeh, Response of building structure and its components to blast loading, PhD Dissertation, Carleton University, Ottawa, 2017.

[6] D. Nourzadeh, J.L. Humar, A. Braimah, Global response of building structures to blast loading: case study of a 10-storey building, 11th International Conference on Shock & Impact Loads on Structures, Ottawa, 2015.

[7] National Research Council of Canada (NRC), National Building Code of Canada, Associate Committee on the National Building Code, Ottawa, 2010.

[8] Canadian Standards Association (CSA), Design of concrete structures, CSA A23.3-04, Rexdale, 2014.

[9] S. Mazzoni, F. McKenna, M. H. Scott, G. L. Fenves, Open System for Earthquake Engineering Simulation: User Command, Language Manual, PEER Center, UC Berkeley, 2009.

[10] E. Hognestad,. A Study on Combined Bending and Axial Load in Reinforced Concrete Members, Engineering Experiment Station, Univ. of Illinois at Urbana-Champaign, IL. pp. 43-46, 1951.

[11] G.A. Chang, and J.B. Mander, Seismic energy based fatigue damage analysis of bridge columns: Part 1 – evaluation of seismic capacity, NCEER Technical Report No. NCEER-94-0006, State University of New York, 1994.

[12] Hyde, David W., User's Guide for Microcomputer Programs ConWep and FunPro, Applications of TM 5-855-1, Fundamentals of Protective Design for Conventional Weapons, US Army Engineer Waterways Experiment Station, 1988.

[13] G.M. Atkinson, Earthquake time histories compatible with the 2005 NBCC uniform hazard spectrum, Canadian Journal of Civil Engineering, 2009.

[14] P. Mortazavi and J. Humar, Seismic design of single-story building with a nonlinear flexible roof diaphragm, 16th World Conference on Earthquake Engineering, Santiago, Chile, 2017.

[15] US Army Corps of Engineers (USACE), Conventional Construction Standoff Distances for the Low and Very Low Levels of Protection. PDC Technical Report 10-01. USA, 2010.