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Seismic performance of reinforce concrete buildings designed according to codes in Bangladesh, India and U.S.

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ABSTRACT

This paper focuses on the comparison of seismic design provisions in Bangladesh (BNBC-1993), India (IS-1893), and the U.S. (ASCE 7-10) in relation to analysis, design, and seismic performance of reinforced concrete buildings on the basis of the type of allowable analysis procedures, zoning system, site classification, fundamental vibration period of the structure, response reduction factor, importance factor, minimum design lateral force, allowable story drifts, and design response spectra.

Three geometrically similar commercial reinforced concrete buildings in high seismic regions of Bangladesh, India, and U.S. were designed and detailed per the respective codes. Three-dimensional nonlinear dynamic analyses of the designed structures were conducted. Each structure was subjected to a pair of orthogonally applied artificial ground motions compatible with the design response spectrum for each building code. The structural performance of each building was compared in terms of roof displacements, inter-story drifts, load-carrying capacity of beams and columns, and overall energy dissipation characteristics. The comparisons allowed an in-depth evaluation of the differences in the seismic performance of buildings designed according to ASCE 7-10, BNBC-1993, and IS-1893 codes. The Indian code performed better when subjected to the ground motion that is intended to represent the Indian design response spectrum.

1. Introduction

Major earthquakes have been recorded in Bangladesh, India, and the U.S. Bangladesh has experienced seven major earthquakes of magnitude over 7.0 during the last two hundred and fifty years, e.g., Bengal Earthquake of 1885 and Srimongol Earthquake of 1918. The Bhuj earthquake (M 7.7) of 2001 in India resulted in the loss of nearly 20,000 lives and severe damage to 339,000 houses. The 1989 Loma Prieta and 1994 Northridge earthquakes led to a loss of 120 lives and major damage to buildings and infrastructure. The situation is direr due to poorly constructed buildings and over population in Bangladesh and India. To minimize damage and loss of life, seismic design codes have been developed.

Design codes in the U.S. are refined and updated approximately every 3–5 years in order to keep up with advances in earthquake engineering and to incorporate research findings, and are reflected in American Society of Civil Engineers, ASCE 7-10 [2]. The Indian seismic code (IS-1893), first published in 1962, has been revised only five times in the last 50 years; the most recent revision being in 2002 after the devastating Bhuj earthquake. Bangladesh National Building Code (BNBC), developed in 1993, was officially enacted in 2006 without changing the code ([3]). According to Bari and Das [4], the value of design base shear is the least in BNBC-1993 in comparison to ASCE 7-10 and IS-1893. Some studies have pointed out a number of limitations of the code in terms of seismic hazard protection. Reinforced concrete frame buildings were heavily damaged in Bhuj earthquake, and the majority of them collapsed completely according to a reconnaissance report prepared by World Seismic Safety Initiative ([13]). Based on the observations and lessons learned from Bhuj earthquake, most of the weaknesses in the 1984 edition of IS-1893 were removed in the 2002 version of the code. Buildings designed according to the U.S. seismic provisions are generally expected to perform well.

Although the three design codes share some commonalities, it is unclear whether a building designed according to ASCE 7-10, BNBC-1993, and IS-1893 codes would perform as intended when the building is subjected to a design level ground motion that has a response spectrum comparable to the one used in design. For example, are the drift limits met? is week girder-strong column design methodology achieved? The focus of the reported research was to answer these and other questions by comparing the seismic performances of reinforced

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Table 1

Comparison of seismic provisions of ASCE 7 [2], IS 1893 [9] and BNBC 1993.

ASCE 7 [7]	IS 1893 [9]	BNBC 1993
(a) Zoning system i. Each region is assigned a location specific mapped spectral acceleration parameter (*SS*, short period and *S*1, 1 sec). ii. *SS* & *S*1 are modified for Site Class effects to get Maximum Considered Earthquake (MCE) spectral response acceleration parameters (*SMS* and *SM*1). iii. The design spectral acceleration *SDS* and *SD*1 parameters can be obtained by dividing *SMS* and *SM*1 parameters by 1.5.	i. The country is divided into 4 zones (II, III, IV and V). ii. Each zone is assigned a factor (*Z*), which is used to obtain the response spectrum depending on the perceived seismic hazard in that zone corresponding to MCE.	i. The country is divided into 3 zones (1, 2, 3) ii. Each zone is assigned a coefficient (*Z*).
(b) Site classification i. Average shear wave velocity ($\bar{v}_s$), average field standard penetration resistance ($\overline{N}$), and average undrained shear strength ($\bar{s}_u$) for the top 30.5 m are used to classify different sites.	i. Site classification depends only on the standard penetration value (*N*).	i. Site classification depends on shear-wave velocity and soil profile depth. Site soils are classified into four types: S_1, S_2, S_3, and S_4.
(c) Approximate fundamental period i. Approximate fundamental period for "Reinforced Concrete (RC) Moment Resisting Frame" is $T_a = 0.0466{h_n}^{0.9}$, h_n in m.	i. Approximate fundamental period for "Reinforced Concrete Moment Resisting Frame", $T_a = 0.075{h_n}^{0.75}$, h_n in meter.	i. Approximate fundamental period for "Reinforced Concrete Moment Resisting Frame", $T_a = 0.073\ {h_n}^{0.75}$, h_n in meter.
(d) Response reduction factor (R) Classification of RC moment resisting frames: i. Ordinary Moment Resisting Frame (OMRF), $R = 3$. ii. Intermediate Moment Resisting Frames (IMRF), $R = 5$. iii. Special Moment Resisting Frame (SMRF), $R = 8$.	Classification of RC moment resisting frames: i. Ordinary Moment Resisting Frame (OMRF), $R = 3$. ii. Special Moment Resisting Frame (SMRF), $R = 5$.	Classification of RC moment resisting frames: i. Ordinary Moment Resisting Frame (OMRF), $R = 5$. ii. Intermediate Moment Resisting Frames (IMRF), $R = 8$. iii. Special Moment Resisting Frame (SMRF), $R = 12$.
(e) Importance factor i. Based on the four risk categories (I, II, III, & IV), ASCE 7 has four seismic importance factors (I_e): 1.0, 1.0, 1.25, and 1.5, respectively	i. Based on the functional use and the occupancy of the buildings, IS 1893 has two importance factors (*I*): 1.0 and 1.5	i. Based on the five risk categories (I, II, III, IV, & V), BNBC has five seismic importance factors: 1.25, 1.25, 1.0, 1.0, 1.0, respectively.
(f) Drift criterion i. Allowable "inelastic" story drifts are limited to $0.020H_{storey}$ for commercial buildings having Risk category I or II. ii. The allowable limits decrease as the risk category increases. Refer to Table 12.12.1, ASCE7-10.	i. Allowable "elastic" story drifts are $0.004H_{storey}$ for all the structures irrespective of any structural or risk category. Refer to clause 7.11.1, IS 1893(Part 1): 2002.	Story Drift, Δ, shall be limited as follows: i. $\Delta \le 0.04h/R \le 0.005h$ for $T \le 0.7$ sec. ii. $\Delta \le 0.03h/R \le 0.004h$ for $T \ge 0.7$ sec. iii. $\Delta \le 0.0025h$ for unreinforced masonry structures where h = height of the building Refer to Section 1.5.6.1 BNBC.
(g) Minimum design lateral force i. Design lateral force calculated from static analysis is $V = C_s \times W$ where C_s = the seismic response coefficient $C_s = \frac{S_{DS}}{\left(\frac{R}{Ie}\right)}$ and W = the seismic weight of the building	i. Design lateral force calculated from static analysis is $V = \frac{1}{2} \times \frac{S}{g} \times \frac{I}{R} \times W$ where (S/g) = spectral response acceleration parameter for MCE response spectrum corresponding to T_a, and W = the seismic weight of the building	i. Design lateral force calculated from static analysis is $V = \frac{Z \times I \times C}{R} \times W$ where Z = Seismic zone coefficient, $C = 1.25S/T^{2/3}$, and W = the seismic weight of the building
(h) Response spectrum i. Spectral Acceleration, For $T < T_0$, $S_a = S_{DS}(0.4 + 0.6\frac{T}{T_0})$ $T_0 = 0.2.S_{D1}/S_{DS}$ ii. $T_0 > T > T_S$, $S_a = S_{DS}$, $T_S = S_{D1}/S_{DS}$ iii. $T_S > T > T_L$, $S_a = \frac{S_{D1}}{T}$ where T_L = long period transition period iv. $T > T_L$, $S_a = \frac{S_{D1}T_L}{T^2}$	i. For rocky or hard soil sites, $S_a/g = \begin{cases} 1 + 15T, & (0.0 < T < 0.10) \\ 2.5, & (0.1 < T < 0.40) \\ 1/T, & (0.4 < T < 4.0) \end{cases}$ ii. For medium soil sites, $S_a/g = \begin{cases} 1 + 15T, & (0.0 < T < 0.10) \\ 2.5, & (0.1 < T < 0.55) \\ 1.36/T, & (0.55 < T < 4.0 \end{cases}$ iii. For soft soil sites, $S_a/g = \begin{cases} 1 + 15T, & (0.0 < T < 0.10) \\ 2.5, & (0.1 < T < 0.67) \\ 1.67/T, & (0.67 < T < 4.0) \end{cases}$ iv. To get a site-specific design response spectrum, a factor $(Z/2)$ is to be multiplied.	i. According to Section 2.5.7.1 in BNBC 93, "a site-specific response spectra shall be developed based on the geologic, tectonic, seismologic, and soil characteristics associated with specific site. The spectra shall be developed for a damping ratio of 0.05 unless a different value is found." ii. "In absence of a site-specific response spectrum, the normalized response spectra given in Fig. 6.2.11 BNBC 93 shall be used with the procedure described in Section 2.5.7.2 BNBC 93".

concrete buildings designed according to the codes from Bangladesh, India, and the U.S. For this purpose, geometrically similar reinforced concrete moment-resisting frames, used as commercial buildings, were selected and designed. The three codes were compared on the basis of the type of allowable analysis procedures, zoning system, site classification, fundamental vibration period of the structure, response reduction factor, importance factor, minimum design lateral force, allowable story drifts, and design response spectra. Nonlinear response history analysis of each structure was conducted, and a number of key metrics were used to compare the performances of the three structures.

2. Comparison of seismic provisions

ASCE 7-10 utilizes seismic design category (SDC) concept to