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Response Spectrum Development for Seismic Demand Comparison of a Building in Indian Context

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Abstract

Earthquake is a natural hazard that causes damage or sometimes complete collapse of man-made structures. It is measured as ground excitation with acceleration and time data points measured at various locations through digital instruments. All ground excitations measured do have potential to cause damage to the structures but strong ground motion do. Strong Ground Motion is characterized by various parameters like Peak Ground Acceleration (PGA), Frequency Content, Root Mean Square (RMS) Acceleration, Arias Intensity and Duration of strong ground motion. Strong ground excitations poses varied seismic demand on structures.

In the present study, out of 184 ground motions recorded at 23 recording stations of Indian subcontinent, about 67 ground motions are quantified as strong ground motion based on PGA and Duration of the motion. Response Spectrum for each strong ground excitation is developed. A mean, mean plus one standard deviation and maximum response spectrum are developed for each strong ground motion using statistical analysis. Seismic demand posed by each response spectrum and IS specified design spectrum on four storey Reinforced Concrete (RC) shear frame building are evaluated. Comparison among seismic demand represented by peak acceleration and base shear are carried out. It is found that seismic demand posed by IS specified design spectrum for building is quite high as compared to mean response spectrum. Similar results are obtained for mean plus one standard deviation and maximum response spectrum except few strong ground motions that posed high seismic demand on building as compared to IS specified design spectrum.

Keywords: Strong Ground Motion, Response Spectrum, Statastical Analysis, Design Spectrum

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Nomenclature

$u^t(t)$,	total displacement of the mass
$u(t)$	relative displacement of the mass w.r.t ground displacement
$u_g(t)$	ground displacement
f_I	inertia force
f_D	damping force
f_S	elastic restoring force
m	mass of the system
c	damping co-efficient of the system
k	stiffness of the system
$\ddot{u}(t)$	relative acceleration of the mass w.r.t to ground acceleration

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$\dot{u}(t)$	relative velocity of the mass w.r.t to ground velocity
PGA	peak ground acceleration
$a(t)$	acceleration
RMS	root mean square
T_d	time duration
ω	natural frequency
ϕ	mode shape co-efficient

1. Introduction

Earthquake is disastrous natural force that causes damages to almost all manmade structures. Now-a-days hundreds of small earthquakes occur around the world. It is not only important to record them but equally important to understand them fundamentally so damages to various structures can be protected. Earthquakes are recorded digitally on measuring instruments in the form of acceleration-time data which known as Seismic Ground Motion or Seismic Excitation data [1]. Potential of such seismic excitations to cause damage to the structures depends on it’s characteristics. Seismic excitation is more commonly characterized by parameters like Peak Amplitude, Frequency Content, Duration, Root Mean Square (RMS) and Arias Intensity [2]. Threshold value of such parameters defines Strong Ground Motion or Strong Seismic Excitation among various ground motion records available. Structural response to such strong seismic excitation is of most significance from structural engineer’s point of view as this pose seismic demand on the structure which is an important design parameter.

Present design practice heavily depends on Design Spectrum specified in Indian Code IS:1893-2002 (Part-I) for seismic demand of a building. Paper covers two major aspects of the work as follows, (i) Response Spectrums are generated for strong seismic excitations recorded in Indian subcontinent [3] (ii) Seismic Demand posed by Response Spectrum generated and code based Design Spectrum are compared for a typical shear frame building to understand the conservativeness of the later one.

2. Literature Review

Basics of strong ground motion characterization, importance of response spectrum and role of smoothened design spectrum are studied through various literatures.

Vanmarcke and Lai [4] proposed a simple procedure for estimating the strong motion duration and the RMS strong motion acceleration of earthquake ground motion records. Two simple measures of duration had been mentioned. The first defines duration as the time interval between first and last peak equal to or greater than a given level. The second definition was based on the concept of cumulative energy obtained by integrating squared acceleration.

Bolt [5] defined the “bracketed duration” of a record, as the time elapsed between the first and last acceleration excursions greater than a given level. This definition required that the absolute value of the acceleration of a record exceed some level. Paper dealt with the use of 0.05 or 0.1g acceleration value as a threshold level.

Shoji et al. [6] dealt with the duration, RMS amplitude and PGA. It was observed that these parameters were affected by the hypocentral distance and local site conditions. The correlation between the duration, PGA and the range of shear wave velocity in the upper layer were conducted. In addition, duration and maximum amplitude were examined with emphasis on site amplification due to the local site conditions. Following conclusions were derived. (i) the duration had a general trend to become larger as near surface layers (upper 30 m) get softer, also PGA had the same tendency (ii) with increasing hypocentral distance, the scatter of data for the duration would be larger and larger. The variation of duration at ‘soft’ sites was larger than those at hard sites (iii) PGA and the duration had reciprocal tendency against hypocentral distance, namely PGA inversely proportional to the duration (iv) the duration was not less important than the maximum amplitude and frequency content in earthquake engineering.

Jenschke et al. [7] used three methods namely probabilistic, fourier spectra and response spectra to investigate characteristics of strong ground motions. A description was given of the results obtained with response spectrum method. The relations and properties of five different response spectrum, Absolute Acceleration (AA), Pseudo-absolute Acceleration (PSAA), relative velocity, pseudo-relative velocity, relative displacement response spectrum were studied. Few important observation derived includes (i) plotting pseudo-acceleration with frequency as abscissa avoids accumulation of oscillations near the origin that occurs when spectra plotted versus period and thus gives smoother curves (ii) AA and PSAA spectra were identical for zero damping and differ in a small amount for rest of damping curves (iii) the range of variability of acceleration was greatest, so it is more rational to use acceleration value for classifying ground motion events.

Newmark [8] developed vertical and horizontal (two components) response spectra for a series of 14 strong motion earthquake records for 0.5, 2, 5 and 10% of critical damping. It was decided that the ground motion data were generally valid only in the frequency range of 0.5 Hz to 30 Hz and accordingly the response spectra were plotted only for this range. The mean and mean plus one standard deviation response spectrum for both horizontal and vertical components were computed.

Mohraz [9] presented a study of 54 earthquake records (three components from each record) from 46 stations in 16 seismic events. Response spectrum was generated for each of these records. Three regions of amplifications were determined in a typical response spectrum; the low-frequency or displacement region, the intermediate-frequency or velocity region, and high-frequency or acceleration region.

3. Response Spectrum Development

The most important applications of the theory of structural dynamics is in analyzing the response of structures to ground shaking caused by an earthquake. Structural engineers are mostly concern with the displacement of the mass relative to ground motion. Once, the displacement response history is evaluated by dynamic analysis of the structure, the internal forces are determined by static analysis of the structure at each time instant.

Response spectrum is an important tool in the seismic analysis and design of structures. It provides a convenient means to summarize the peak response of all possible linear Single Degree of Freedom (SDOF) to a particular component of ground motion. The response spectrum is a plot of the peak values of a response quantity as function of the natural vibration period of the system. Each such plot is for a SDOF systems having fixed value of damping ratio ξ, and several such plots for different values of ξ are included to cover the range of damping values encountered in actual structures. A variety of response spectrums are defined depending on the response quantity that is plotted.

3.1. Equation of Motion [1]

Consider a single storey structural model that has only one degree of freedom i.e. lateral displacement of the girder as shown in Figure 1(a) and Figure 1(b). Under the action of the earthquake ground motion, $\ddot{u}_g$, the structure deforms. From Figure 1(b), f_I denotes the inertia force, f_S the spring force and f_D denotes the damping force.

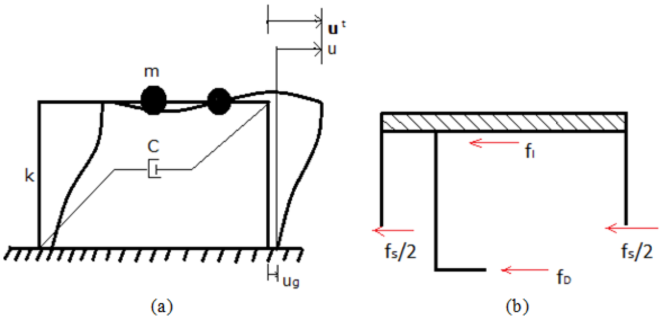


Fig. 1 (a) SDOF System subjected to Ground Motion (b) Free Body Diagram

According to Newton’s Second law of motion, a dynamic system is in equilibrium at each time instant. The displacement of ground is denoted by u_g, the total or absolute displacement of mass by u^t and the relative displacement between the mass and ground by u at each instant of time. These displacements are related by,

$$u^t(t) = u(t) + u_g(t) \tag{1}$$

The equation of motion for the SDOF system subjected to earthquake excitation can be derived by concept of dynamic equilibrium from the free body diagram. The equation of dynamic equilibrium is,

$$f_I + f_D + f_S = 0 \tag{2}$$

As the structure is linearly elastic, therefore elastic resisting force is,

$$f_S = ku \tag{3}$$

The viscous damping force f_D is assumed to vary linearly with relative velocity $c\dot{u}$, therefore for a linear system the damping force is,

$$f_D = c\dot{u} \tag{4}$$

The inertia force is equal to the product of mass times it's acceleration and acts opposite to the direction of acceleration. It is related to the total acceleration $\ddot{u}^t$ at the mass by,

$$f_I = m\ddot{u}^t \tag{5}$$

Substituting Equation (3) – (5) in Equation (2) and using Equation (1),

$$m\ddot{u}(t) + c\dot{u}(t) + ku(t) = -m\ddot{u}_g\,(t) \tag{6}$$

where m, k, and c are mass, stiffness and damping constant, respectively and $\ddot{u}$, $\dot{u}$ and u are relative acceleration, velocity and displacement of mass with respect to ground.

Analytical solution of equation of motion for SDOF system given by Equation (6) is not possible if the excitation varies arbitrarily with time and is not a continuous function of time. This can be solved by numerical time-stepping methods for integration of differential equations. There are two basic approaches to numerically evaluate the dynamic response. The first approach is numerical interpolation of the excitation and the second is numerical integration of the equation of motion. The well-known Newmark direct integration method is mostly used to compute dynamic response of the structure. In this method the acceleration is assumed to vary linearly between two instants of time. As Newmark direct integration methods are classical in nature, they are not described herein.

3.2. Ground Motion Excitation Compilation

Earthquake ground motion excitation recorded at various earthquake recording stations of the Indian sub-continent has been collected. Two major sources considered for data are (i) Atlas of Indian Strong Motion records prepared under Indian Strong Motion Programme by Department of Earthquake Engineering, Indian Institute of Technology, Roorkee and (ii) Web Portals – NICEE – IITK, NISEE – Berkeley, USA. A set of 184 time histories (23 events) has been collected and are grouped as East, North, South-East and West regions as shown in Table 1.

Table 1 Classification of Earthquake Ground Motion Records

Region	Events	Recording Stations	Region	Events	Recording Stations
East	North-East India	12	North	Dharmsala	9
	India-Burma border 1987	14		Uttarkashi 1991	13
	India-Bangladesh border 1987	18		Chamba	2
	India-Burma border 1988	33		Xizang-India border	1
	India-Burma border 1990	14		Chamoli 1999	11
	India-Burma border 1995	9		Chamoli 2005	8
	India-Bangladesh border 1997	11		Uttarkashi	7
	Nagaland	1		Uttarakhand	7
	India-Myanmar border (Manipur)	7	South-East	Andaman Island 2008	1
	Assam	3		Andaman Island 2010	1
	Phek	3	West	Kachchh	1
	Kohima	3			

3.3. Ground Motion Excitation Characterization

A number of parameters have been proposed in literature to characterize strong ground motion. This includes (i) Amplitude parameters like Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), Peak Ground Displacement (PGD) (ii) Frequency Content parameter like Fourier spectra, Response spectra (iii) Duration of the ground motion (iv) Other parameters like Root Mean Square (RMS) Acceleration, Arias Intensity [2]. In the present study, three parameters – PGA, Duration and RMS acceleration of ground motion excitation are considered to categorize ground motion excitation and strong ground motion. This are briefly defined as follows.

3.3.1 Peak Ground Acceleration (PGA) : PGA is the most commonly used measure of the intensity of shaking at a site and is taken to be the largest absolute value of the acceleration recorded at a site. It is defined mathematically as,

$$PGA = max|a(t)| \tag{7}$$

where $|a(t)|$ is the acceleration time history. PGA value for each ground motion is extracted using MATLAB.

3.3.2 RMS Acceleration : Unlike PGA parameter which deals with amplitude only, this parameter includes the effects of frequency content of ground motion. This parameter is quite useful to provide basis for evaluation of strong ground motion duration. It is defined mathematically as,

$$a_{RMS} = \sqrt{\frac{1}{T_d}\int_0^{T_d}[a(t)]^2\,dt} \tag{8}$$

where a_{RMS} is root mean square acceleration, T_d is duration of the motion, $a(t)$ is the acceleration time history. RMS acceleration value for each time history is calculated through Simpson 1/3rd Rule implemented by writing code in MATLAB.

3.3.3 Duration : It is defined as the time between the first and last exceedances of a threshold acceleration. In the present study, RMS acceleration value is used as a basis for evaluation of strong ground duration.

Apart from above definitions, ground motion is considered as strong ground motion if duration of particular ground motion is close to total time data records. Table 2 shows PGA & RMS acceleration and duration of the strong ground motion extracted from total 187 ground motions.

Table 2 Strong Ground Motion Earthquake Records

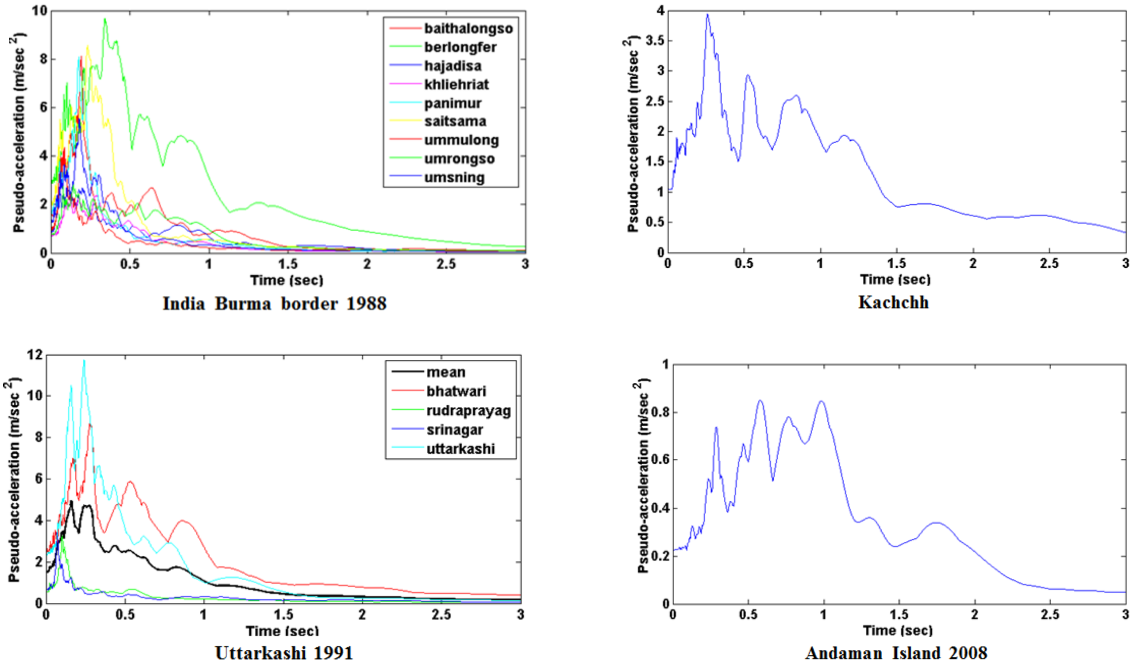
Region	Recording Station	PGA (m/sec^2)	Recorded Time (sec)	RMS Value (m/sec^2)	Strong Motion Duration
Dharmsala	Bhawarna	0.365	11.98	0.0604	11.26
	Jawali	0.149	17.96	0.0346	17.90
	Shahpur	2.000	20.10	0.1908	4.22
North-East India	Nongkhlaw	0.539	29.64	0.0878	20.98
	Penursla	0.91	18.58	0.1136	12.96
	Saitsama	1.11	20.66	0.1215	9.84
	Ummulong	1.11	16.94	0.1241	10.54
India-Burma Border 1987	Bamungao	0.194	29.48	0.0446	29.16
	Berlongfer	0.706	42.76	0.1267	35.70
	Diphu	0.843	39.10	0.1337	36.16
	Hatikhali	0.305	36.22	0.0645	35.56
	Saitsama	0.364	27.52	0.084	25.36
India-Bngladesh Border 1988	Mawphlang	0.796	28.16	0.166	24.76
	Nongkhlaw	1.05	45.28	0.1084	35.22
	Pynursla	0.487	34.60	0.0689	29.66
	Ummulong	0.553	24.52	0.0859	23.84
	Umsning	0.39	23.86	0.0735	23.82
India-Burma Border 1988	Baithalongso	1.51	78.08	0.2352	66.36
	Berlongfer	2.95	119.70	0.2949	44.86
	Hjadisa	0.902	64.20	0.1570	51.10
	Khliehriat	0.688	61.50	0.1155	57.06
	Panimur	1.65	72.06	0.2455	62.36
	Saitsama	2.07	81.10	0.2852	58.10
	Ummulong	0.886	66.14	0.1717	53.56
	Umrongso	0.748	67.74	0.1456	55.26
	Umsning	1.20	70.60	0.1858	56.72
India-Burma Border 1990	Baithalongso	0.603	22.00	0.1349	21.54
	Berlongfer	1.42	62.84	0.1597	21.82

	Diphu	0.898	32.24	0.1649	20.12
	Saitsama	0.61	26.52	0.12	22.96
Uttarkashi	Bhatwari	2.48	36.16	0.3531	11.04
	Rudraprayag	0.523	39.70	0.1316	32.22
	Srinagar	0.654	41.10	0.1127	37.24
	Uttarkashi	2.37	39.92	0.3446	10.72
Chamba	Chamba	1.43	18.24	0.1635	5.40
	Rakh	0.29	9.18	0.0541	5.90
India-Burma Border 1995	Berlongfer	0.707	81.72	0.0852	60.46
	Diphu	0.790	28.58	0.1614	21.60
	Hatikhali	0.437	18.84	0.0924	17.04
Xizang-India Border	Ukhimath	0.371	15.20	0.061	4.76
India-Bangladesh Border 1997	Katakhal	1.05	26.58	0.2093	19.22
	Nongpoh	0.476	47.38	0.0528	40.30
	Nongstoin	0.469	39.02	0.0739	31.12
	Pynursla	0.279	28.62	0.0583	25.20
Chamoli 1999	Ghamsiali	0.714	26.32	0.1619	26.22
	Gopeshwar	1.95	25.42	0.267	15.78
	Roorkee	0.554	43.53	0.0795	37.95
	Ukimath	0.891	24.78	0.1431	21.20
Kachchh	Ahmedabad	1.04	133.525	0.1134	54.77
Chamoli 2005	Chamoli	0.411	44.61	0.0503	17.17
	Roorkee	0.023	66.215	0.0035	54.67
Uttarkashi 2007	Nathpa	0.049	40.70	0.0091	34.96
	Roorkee	0.019	63.58	0.0036	56.10
Andaman Islands 2008	Port Blair	0.041	181.455	0.005	127.57
Nagaland	Tinsukia	0.023	66.10	0.0031	45.07
Uttarakhand	Champawat	0.017	70.10	0.0016	42.127
	Munsiari	0.095	70.09	0.0083	20.628
	Pithoragarh	0.034	76.56	0.00354	41.757
Andaman Islands 2010	Port Blair	0.041	181.435	0.0050	127.566
India-Myanmar (Manipur) Border	Guwahati	0.184	164.80	0.0142	85.557
	Jorhat	0.039	95.10	0.0083	94.285
	Naogoan	0.321	135.45	0.026	75.712
Assam	Golaghat	0.09	66.69	0.0179	42.262
	Khokharajhat	0.059	110.995	0.0072	77.90
Phek (Nagaland)	Golaghat	0.147	76.555	0.0146	58.08
Kohima	Golaghat	0.162	79.475	0.0139	66.826
	Jorhat	0.09	128.87	0.01	94.62

It is evident from Table 2 that strong motion classification is combination of parameters mentioned earlier. It is clear from above table that in few region of West and South region has very few ground motion data available.

3.4. Response Spectrum Generation

Pseudo-acceleration response spectrums, for each of the strong motion excitations as shown in Table 2, are determined. A SDOF system, 3000 in nos., with natural time period interval of 0.001 second are considered. Thus, response spectrums for each strong ground motions are obtained for 3 sec (3000*0.001) of time period through code written in MATLAB which solves Eqn. (6) using Newmark-Beta algorithm. A representative pseudo-acceleration response spectrum, region wise, is shown in Fig. 2.



India Burma border 1988

Kachchh

Uttarkashi 1991

Andaman Island 2008

Fig. 2 Representative Pseudo Acceleration Response Spectrum for East, West, North and South-East Region of the India

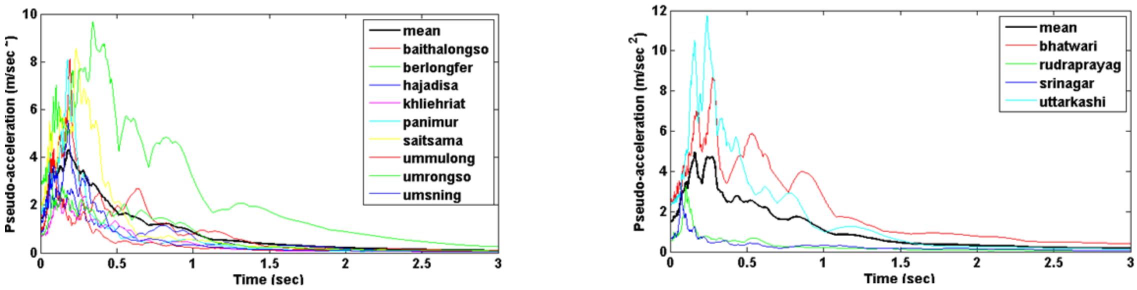
4. Statistical Analysis of Response Spectrum

Response of structure to different strong ground motions is different. Thus, pseudo acceleration response spectrum generated is unique and applicable to determine response of structure subjected to that particular strong motion. In order to utilize the response spectrum to design structures against seismic force, single response spectrum representing nos. of strong motions to be derived. This is done using statistical analysis of response spectrum.

An obvious and commonly adopted approach of 'Average Response Spectrum' is considered herein. This is briefly illustrated here. Assume 'I' is the number of strong ground motions for earthquake events and corresponding to each 'I' strong motion, response spectrum is generated. Thus, at each Time Period T_n there are as many spectral values as number 'I' of strong ground motion records. For example, as per Table 1, Dharmsala recording station has 9 ground motion records, i.e. I = 9. At each T_n there will be 9 spectral pseudo-acceleration value $a_1, a_2, \ldots\ldots, a_9$. Thus mean spectral pseudo acceleration can be computed as,

$$Mean = \frac{(a_1 + a_2 + \cdots + a_9)}{9} \qquad (9)$$

By connecting all mean values of pseudo acceleration for each Time Period T_n will be Mean Response Spectrum. Figure 3 shows Mean Pseudo-Acceleration Response Spectrum derived along with Pseudo Response Spectrum for four region of the Indian sub-continent.



India Burma border 1988

Uttarkashi 1991

Fig. 3 Representative Mean Pseudo Acceleration Response Spectrum for East and North Region of the India

Representative mean pseudo acceleration response spectrum for East and South-East regions remains same as the ones shown in Fig. 2 since they have been developed through single strong motion excitation record. It is clear from Fig. 3 that for both East and North regions, mean response spectrum estimates lesser seismic demand for few of the strong ground motion excitation records. It can be concluded from this observation that seismic demand estimated for any building from mean response spectrum, building may likely suffer damage onset of earthquake events that may pose higher seismic demand than the ones obtained from mean response spectrum. Apart, for West and South-west region mean response spectrum pose a very uncertain seismic demand due to lack of earthquake strong motion records.

5. Seismic Demand Comparison of a Building

Main focus of the present study is to compare seismic demand posed by response spectrum developed for various strong ground motion records of the country on a building. This is compared with seismic demand posed by design spectrum specified in IS:1893-2002 (Part- I), since this is most commonly used for seismic design of a building. Study aims towards assessing adequacy of design spectrum defined in Indian code of practice for earthquake loading.

A G + 3 storey Reinforced Concrete (RC) shear building as shown in Fig. 4 with following input data is considered.

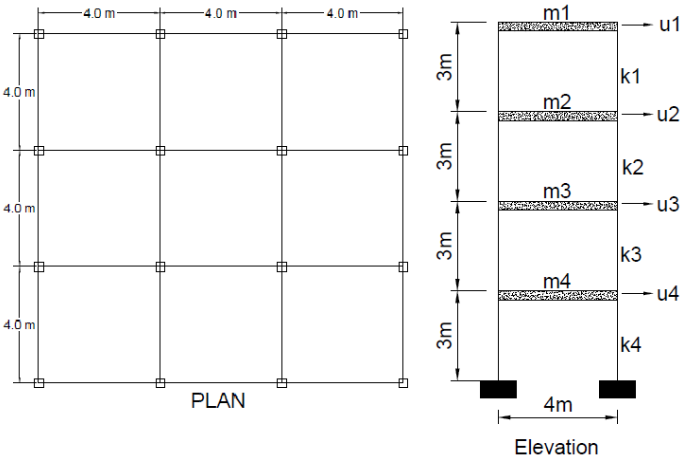


Fig. 4 Plan and Elevation of G + 3 Story Building

Nos. of Storey : 4, Storey Height : 3 m, Slab Thickness : 120 mm, Nos. of Bays in X- & Y - Direction : 3, Bay Width in X- & Y - Direction : 4 m, Column Size : 0.3 m × 0.3 m, Beam Size : 0.23 m × 0.23 m, f_{ck} = 25 N/mm^2, f_y = 415 N/mm^2, Live Load on Typical Storey = 3 kN/m^2. The building is located in seismic zone V having soil condition of rock deposit. The building is mathematically modeled as Multi Degree of Freedom (MDOF) system using lumped mass approach to carry out dynamic analysis. The diagonal lumped mass matrix is given as $m_i\ (i = 1,2,3) = 82935.78$ kg and $m_4 = 66422.02$ kg. Considering stiffness of column with both end fixed against rotation as $k = 12\,EI/h^3$ with usual notation, stiffness for each storey can be given by $k_{11} = k_{22} = k_{33} = 240000$ kN/m, $k_{12} = k_{21} = k_{23} = k_{32} = k_{34} = k_{43} = -120000$kN/m and $k_{44} = 120000$ kN/m. Natural frequencies of the buildings are determined through solving eigen value problem $[\boldsymbol{k} - \omega_n{}^2\boldsymbol{m}]\boldsymbol{\phi} = \boldsymbol{0}$ using MATLAB.

The natural frequencies of a building are $\omega_1 = 13.81$ rad/sec, $\omega_2 = 39.46$ rad/sec, $\omega_3 = 59.62$ rad/sec and $\omega_4 = 72.01$ rad/sec. Corresponding mode shapes of building are,

$\phi_1 = [0.359 \quad 0.671 \quad 0.894 \quad 1]^T$,$\phi_2 = [-0.944 \quad -0.872 \quad 0.1381 \quad 1]^T$,

$\phi_3 = [1.222 \quad -0.558 \quad -0.968 \quad 1]^T$ and $\phi_4 = [-1.239 \quad 1.962 \quad -1.87 \quad 1]^T$.

With dynamic properties obtained, seismic demand in the form of Pseudo Acceleration (Sa) and Base Shear (V_B) is derived using dynamic as well as equivalent static analysis as prescribed in IS:1893-2002 (Part-I). Pseudo acceleration is determined using time period of first fundamental mode 0.4547 sec and Base Shear is determined with combining four fundamental modes through Complete Quadratic Combination (CQC) for dynamic analysis. Static analysis considers time period estimated by empirical equation of building frame without infill to determine pseudo acceleration. These are compared with values determined using mean response spectrum. For appropriate comparison Uttarkashi and Xizang-India border strong ground motion is mapped with Zone IV while rest of all strong ground motion records are mapped with Zone V of IS:1893-2002 (Part-I). Table 3 shows Psedu-acceleration and base shear values for East, West, South-East and North region of the country.

Table 3 Pseudo-Acceleration and Base Shear Values for Various Region of the Indian Country

Region		T_n Program Calculated	Mean Response Spectrum	T_n Empirical Equation	Mean Response Spectrum	IS:1893-2002 (part – I)	
						Static Analysis	Dynamic Analysis
EAST REGION							
North-East India	A	0.455 sec	0.4698	0.483 sec	0.4212	3.656	3.88
	V_B		29.62		26.55	230.5	244.62
India-Burma Boarder 1987	A		0.4914		0.48	3.656	3.88
	V_B		30.98		30.26	230.5	244.62
India-Bangladesh Boarder 1987	A		0.3593		0.3171	3.656	3.88
	V_B		22.65		19.99	230.5	244.62
India-Burma Boarder 1988	A		2.02079		1.8105	3.656	3.88
	V_B		127.85		114.14	230.5	244.62
India-Burma Boarder 1990	A		1.694		1.3492	3.656	3.88
	V_B		106.8		85.06	230.5	244.62
India-Burma Boarder 1995	A		1.19		1.1297	3.656	3.88
	V_B		75.02		71.22	230.5	244.62
India-Bangladesh Boarder 1997	A		0.7358		0.7601	3.656	3.88
	V_B		46.39		47.92	230.5	244.62
Nagaland	A		0.0093		0.0085	3.656	3.88
	V_B		0.59		0.54	230.5	244.62
Manipur	A		0.0601		0.0582	3.656	3.88
	V_B		3.79		3.67	230.5	244.62
Assam	A		0.0514		0.047	3.656	3.88
	V_B		3.24		2.96	230.5	244.62
Phek	A		0.0156		0.0686	3.656	3.88
	V_B		0.98		4.32	230.5	244.62
Kohima	A		0.2396		0.047	3.656	3.88
	V_B		15.11		13.79	230.5	244.62
NORTH REGION							
Dharmsala	A	0.455 sec	0.7136	0.483 sec	0.7122	3.656	3.88
	V_B		44.99		44.9	230.5	244.62
Uttarkashi 1991	A		2.6195		2.4655	2.437	2.587
	V_B		165.15		155.44	153.64	163.1
Chamba	A		1.1325		1.0894	3.656	3.88
	V_B		71.4		68.68	230.5	244.62
Xizang-India Border	A		0.2723		0.272	2.437	2.587
	V_B		17.17		17.15	153.64	163.1
Chamoli 1999	A		1.9769		1.9	3.656	3.88
	V_B		124.64		119.79	230.5	244.62
Chamoli 2005	A		0.2491		0.1788	3.656	3.88
	V_B		15.7		11.27	230.5	244.62
Uttarkashi 2007	A		0.0186		0.0143	2.437	2.587
	V_B		1.17		0.9	153.64	163.1
Uttarakhand	A		0.0178		0.0164	3.656	3.88
	V_B		1.12		1.03	230.5	244.62
SOUTH-EAST REGION							
Andaman Island 2008	A	0.455 sec	0.6203	0.483 sec	0.6198	3.656	3.88
	V_B		39.11		39.08	230.5	244.62
Andaman Island 2008	A		0.0839		0.1055	3.656	3.88
	V_B		5.29		6.65	230.5	244.62
WEST REGION							
Kuchchh	A		1.5756		1.8466	3.656	3.88
	V_B		99.34		116.42	230.5	244.62

It is evident from Table 3 that barring few strong ground motion excitations (India-Burma Border 1988-1990-1995, Uttarkashi 1991, Chamba, Chamoli 1999, Kuchchh), all strong ground motion offer quite low seismic demand on a building as compared to seismic demand estimated from IS:1893-2002 (Part-I). From ones point of view building is safe when designed according to IS code, however second point of view this margin is huge. Strong ground excitation Uttarkashi 1991 only possess seismic demand on building higher than the ones estimated from IS code. Present study shows that for given building structure seismic demand estimated by IS code is predominant which fairly justify the use of code based design spectrum.

6. Conclusions

Pseudo acceleration response spectrum is generated for strong ground motion excitation of Indian sub-continent. About 187 acceleration ground motion data are collected and strong ground motion excitations (67 Nos.) are classified based on parameters like PGA, RMS and Duration. Statistical analysis is carried out to determine representative mean pseudo acceleration response spectrum. A G + 3 storey RC shear building is considered to estimate seismic demand by response spectrum and IS code based design spectrum. Seismic demand in the form of Pseudo Acceleration and Base Shear are calculated for a building and are mutually compared. It is found that largely seismic demand estimated for a building is quite low due to mean response spectrum as compared to IS code based design spectrum. Thus, use of IS code based design spectrum to estimate seismic demand is fairly justified for given building structure. However, this may not be generalized for building structures ranging from stiff to flexible. A study with consideration of more rigorous statistical analysis may be resorted to see the impact of response spectrum on seismic demand.

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