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COMPARISON OF RESPONSE SPECTRUM OF RECORDED EARTHQUAKES WITH INDIAN STANDARD CODE

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Abstract - Earthquake is natural calamity, results from ground movement which causes damage or sometimes complete collapse of structures. It is important to understand the response of structures subjected to strong ground motions. Maximum response of structure under strong ground motion is important for earthquake resistant design. Present paper attempt to develop Pseudo-Acceleration response spectrum for recorded earthquakes in India. The paper highlights on comparison of response spectrum of recorded earthquakes with Indian Standard Code for Maximum Pseudo-Acceleration. The analysis shows the highest and the lowest value of Pseudo-Acceleration for different earthquakes. The response spectrum is developed by solving equation of Single Degree of Freedom (SDOF) system.

Key words: Earthquake, Strong Ground Motion, Response Spectrum, Pseudo-Acceleration, Single Degree of Freedom (SDOF) system, Newmark's beta method, MATLAB-code, Indian Standard Code

I. INTRODUCTION

An earthquake is the shaking of surface of the Earth, resulting from the sudden release of energy in the Earth's lithosphere that creates seismic waves. Buildings collapse in an earthquake because of the vibration of the ground [1]. Strong ground motion has sufficient strength to affect people and damage structures. Strong ground motions produced by earthquakes are random in nature and contain energy of different magnitudes. They are prescribed by parameters such as Peak Ground Acceleration, Root Mean Square acceleration, Duration etc. Structures when subjected to strong ground motion i.e. seismic excitation respond differently depending upon its in-built dynamic properties.
The objective of the paper is to develop Pseudo-Acceleration response spectrum for recorded earthquakes in India and to compare it with Indian Standard Code for Maximum Pseudo-Acceleration. There are 28 Pseudo-Acceleration response spectrum developed for various earthquakes in the paper.
Structure modelled as Single Degree of Freedom (SDOF) system when subjected to seismic excitation, equation of motion is described as

$$m\ddot{u}(t) + c\dot{u}(t) + ku(t) = -m\ddot{u}_g(t) \qquad (1.1)$$

Where m, c and k are mass, damping and stiffness of the system respectively.
$u(t)$, $\dot{u}(t)$ and $\ddot{u}(t)$ are relative displacement, relative velocity and relative acceleration of the mass with respect to ground.
$\ddot{u}_g(t)$ is ground acceleration.
Numerical algorithm is required to solve Equation (1.1) and thus solution of Equation (1.1) is time intensive. In order to save computational effort to estimate seismic force, concept of Response spectrum was developed. It is widely accepted and is a central part of design code of various countries. Response spectrum provides maximum response of Single Degree of Freedom (SDOF) system under seismic excitation [2].

II. CONCEPT OF RESPONSE SPECTRUM

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 SDOF systems to a particular component of ground motion. It also provides a practical approach to apply the knowledge of structural dynamics to the design of structures and development of lateral force requirements in building codes. The response spectrum is a plot of the peak values of a response quantity as a function of the natural vibration period Tn of the system. Each such plot is for a SDOF systems having a fixed damping ratio ζ, and several such plots for different values of ζ are included to cover the range of damping values encountered in actual structures. A variety of response spectra are defined depending on the response quantity that is plotted as under.

A. Deformation Response Spectrum

Deformation Response Spectrum provides necessary information to compute the peak values of deformation and internal forces. It is denoted by D. It is shown in Fig. 1. Mathematical form is written as $D = \max|u(t)|$ (1.2)

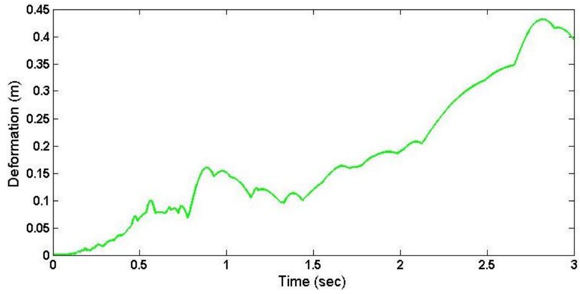

Fig. 1: Deformation Response Spectrum for El Centro Ground Motion (ζ = 0.02), [3]

B. Pseudo-Velocity Response Spectrum

Pseudo-Velocity is denoted by V. It is shown in Fig. 2.
It is written as $V = \omega_n D$ (1.3)

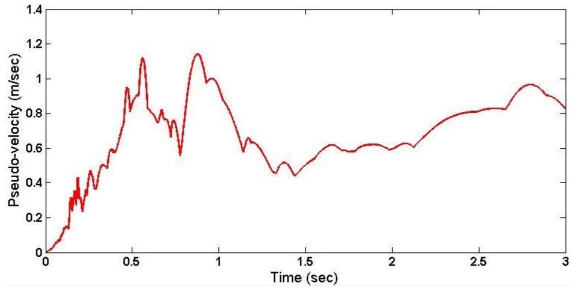

Fig. 2: Pseudo-Velocity Response Spectrum, [3]

C. Pseudo-Acceleration Response Spectrum

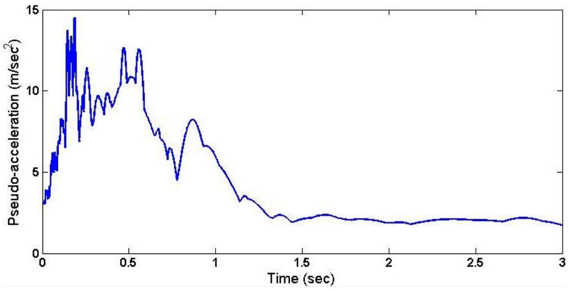

Fig. 3: Pseudo-Acceleration Response Spectrum, [3]

Pseudo-Acceleration is denoted by A. It is shown in Fig. 3.
It is written as $A = \omega_n^2 D$ (1.4)

III. LITERATURE REVIEW

The review of available literature on the subject primarily focuses on the issue related to Response of Structure. The nature of building is of fundamental importance in modern structural design in order to ensure safety and serviceability of the structure. Thus, it is important to measure the response of the structure subjected to ground motion. With this intention a research paper on, "A Multi-step approach to generate response-spectrum-compatible artificial earthquake accelerograms" had been studied. In the paper, authors had generated design response spectrum and time history records for two sites located within the city of Kabul, Afghanistan. The response spectrum is developed and iteratively compared to the ARMA (Auto Regressive Moving Average) model and the site-specific spectrum until a satisfactory match is achieved [4].

IV. CONSTRUCTION OF RESPONSE SPECTRUM

The response spectrum for a given ground motion component $\ddot{u}_g(t)$ can be developed by implementation of the following steps:

1. Numerically define the ground acceleration $\ddot{u}_g(t)$; typically, the ground motion ordinates are defined every 0.02 seconds.
2. Select the natural vibration period Tn and damping ratio ζ of an SDF system.
3. Compute the deformation response u(t) of this SDF system due to the ground motion $\ddot{u}_g(t)$ by any numerical method (e.g. Duhamel's Integral, or a frequency domain method).
4. Determine u_o, the peak value of u(t).
5. The spectral ordinates are defined as:

$D = u_o$

V= $(2\pi/Tn)$ D
A= $(2\pi/Tn)^2$ D
Where D= Displacement
V=Pseudo-Velocity
A= Pseudo-Acceleration
Tn = Time period

6. Repeat steps 2 to 5 for a range of Tn and ζ values covering all possible systems of engineering interest.
7. Present the results of steps 2 to 6 graphically to produce combined spectrum shown in Fig. 4.

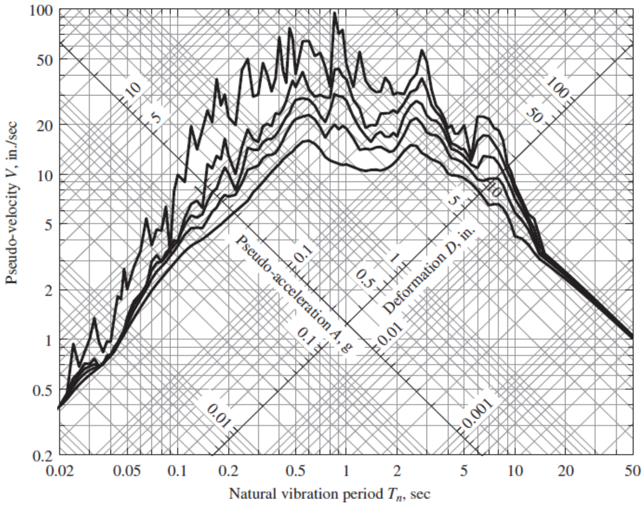

Fig. 4: Combined D-V-A response spectrum for El Centro ground motion; ζ = 0, 2, 5, 10 & 20 %, [2]

V. DEVELOPMENT OF RESPONSE SPECTRUM

Earthquake records have three - component (two horizontal components and a vertical component) time histories recorded by accelerometers in analogue or digital form. These records are used to conduct time history dynamic analyses and derive response spectra [3]. Response spectrum provides the maximum response of a structure to a particular earthquake ground motion at different frequencies or periods. Response spectrum for a specified earthquake records are used to obtain the response of a structure to an earthquake ground motion with similar characteristics. Response Spectrum is generated using the steps stated above. The study is limited to response spectrum determined for 5 percent damping although it can readily be extended to include other values of damping. All the plots are developed for 3000 SDOF systems having natural time period limited to 3 second with interval of 0.001 second is calculated using MATLAB code considering longitudinal component of an earthquake [5]. On the base of Maximum Pseudo-Acceleration, 28 Response Spectrum are developed for recorded Indian earthquakes in present paper.

A. Maximum Pseudo-Acceleration greater than 0.2 g

Response spectrum for Maximum Pseudo-Acceleration greater than 0.2 g is shown in Fig. 5. Coloured line gives the shape of maximum acceleration of Bhuj earthquake.

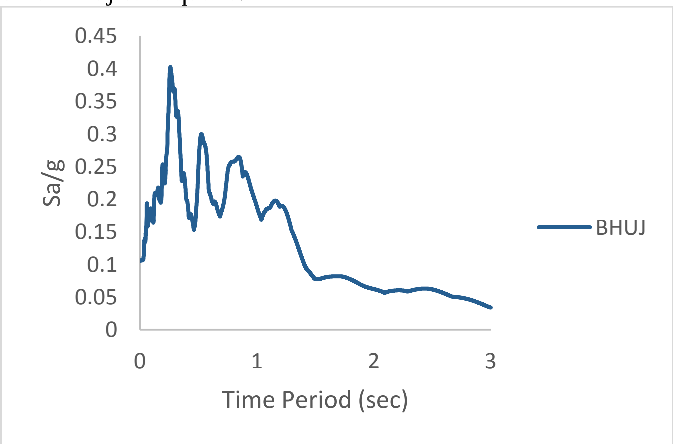

Fig. 5: Response Spectrum for Maximum Pseudo-Acceleration greater than 0.2 g

B. Maximum Pseudo-Acceleration between 0.1 g to 0.2 g

Response spectrum for Maximum Pseudo-Acceleration between 0.1 g to 0.2 g are shown in Fig. 6. All coloured lines give the shape of maximum acceleration of 02 different earthquakes CHM & RUD.

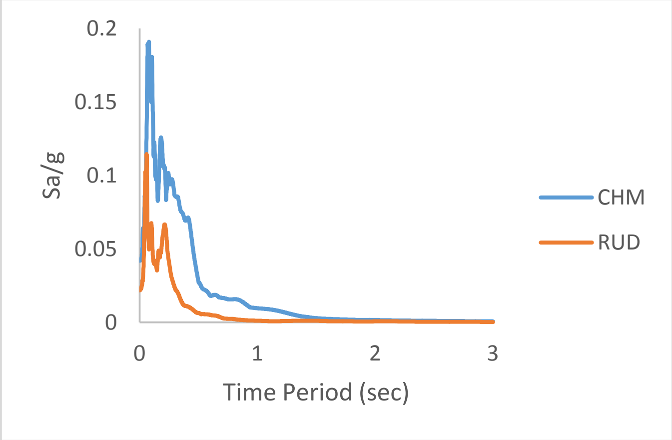

Fig. 6: Response Spectrum for Maximum Pseudo-Acceleration between 0.1 g to 0.2 g

C. Maximum Pseudo-Acceleration between 0.04 g to 0.1 g

Response spectrum for Maximum Pseudo-Acceleration between 0.04 g to 0.1 g are shown in Fig. 7. All coloured lines give the shape of maximum acceleration of 04 different earthquakes DIP, GUA, PAU & POR.

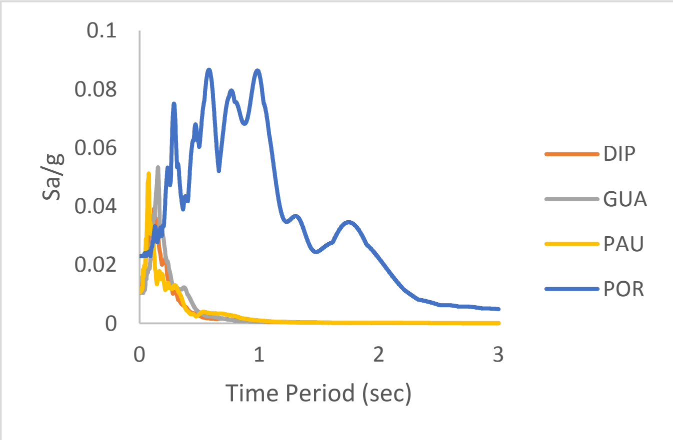

Fig. 7: Response Spectrum for Maximum Pseudo-Acceleration between 0.04 g to 0.1 g

D. Maximum Pseudo-Acceleration between 0.03 g to 0.04 g

Response spectrum for Maximum Pseudo-Acceleration between 0.03 g to 0.04 g are shown in Fig. 8. All coloured lines give the shape of maximum acceleration of 03 different earthquakes GOL, MUN & UTT.

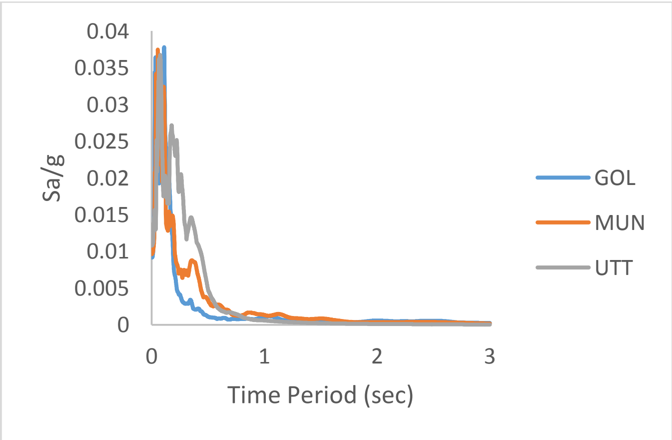

Fig. 8: Response Spectrum for Maximum Pseudo-Acceleration between 0.03 g to 0.04 g

E. Maximum Pseudo-Acceleration between 0.02 g to 0.03 g

Response spectrum for Maximum Pseudo-Acceleration between 0.02 g to 0.03 g are shown in Fig. 9. All coloured lines give the shape of maximum acceleration of 06 different earthquakes BAG, BHA, DHA, KAP, KOK & TEH.

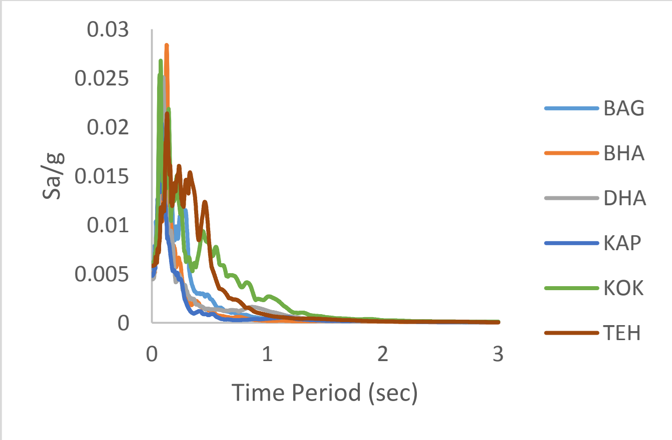

Fig. 9: Response Spectrum for Maximum Pseudo-Acceleration between 0.02 g to 0.03 g

F. Maximum Pseudo-Acceleration between 0.015 g to 0.02 g

Response spectrum for Maximum Pseudo-Acceleration between 0.015 g to 0.02 g are shown in Fig. 10. All coloured lines give the shape of maximum acceleration of 05 different earthquakes BOK, JHR, JSH, LKH & PIT.

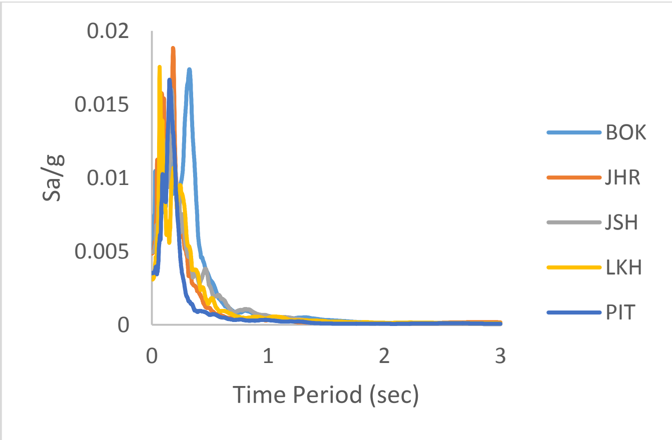

Fig. 10: Response Spectrum for Maximum Pseudo-Acceleration between 0.015 g to 0.02 g

G. Maximum Pseudo-Acceleration between 0.01 g to 0.015 g

Response spectrum for Maximum Pseudo-Acceleration between 0.01 g to 0.015 g are shown in Fig. 11. All coloured lines give the shape of maximum acceleration of 02 different earthquakes CHP1 & TUR.

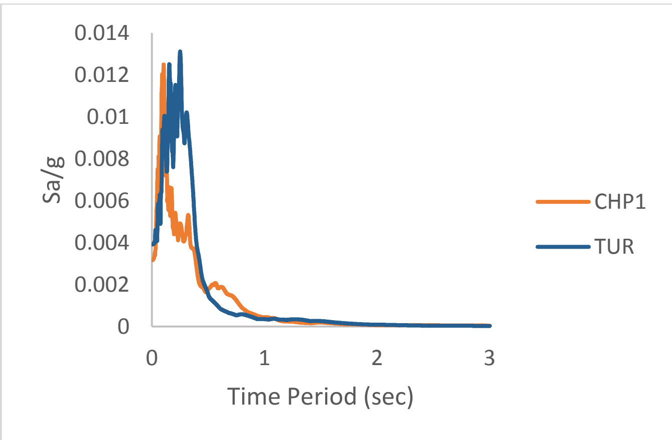

Fig. 11: Response Spectrum for Maximum Pseudo-Acceleration between 0.01 g to 0.015 g

H. Maximum Pseudo-Acceleration less than 0.01 g

Response spectrum for Maximum Pseudo-Acceleration lesser than 0.01 g are shown in Fig. 12. All coloured lines give the shape of maximum acceleration of 05 different earthquakes CHP2, GHA, ROO1, ROO2 & TIN.

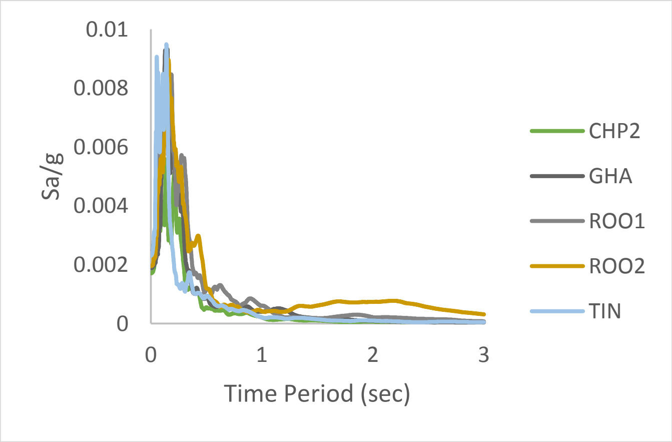

Fig. 12: Response Spectrum for Maximum Pseudo-Acceleration less than 0.01 g

VI. MAXIMUM PSEUDO-ACCELERATION OF RECORDED EARTHQUAKES

Details about Maximum Pseudo-Acceleration of Recorded Earthquakes are listed below.

Table - 1: Maximum Pseudo-Acceleration of Recorded Earthquakes

Sr. No.	Station Code	PGA	Max Sa/g	(Max Sa/g)/(PGA)	Tn (sec)
1	BAG	0.005530	0.020387	3.686587512	0.104
2	BHA	0.004997	0.028400	5.683476686	0.127
3	BHUJ	0.105830	0.402436	3.802661816	0.26
4	BOK	0.005046	0.017402	3.448684964	0.323
5	CHM	0.041926	0.191042	4.556649502	0.08
6	CHP1	0.003168	0.012498	3.944689098	0.104
7	CHP2	0.001711	0.005585	3.265044139	0.137
8	DHA	0.004439	0.025126	5.660194188	0.098
9	DIP	0.011107	0.049582	4.464019905	0.076
10	GHA	0.001885	0.009336	4.952902918	0.148
11	GOL	0.009170	0.037796	4.121652129	0.11
12	GUA	0.010419	0.053345	5.119963816	0.153
13	JHR	0.004855	0.018844	3.881300721	0.182
14	JSH	0.004945	0.016032	3.242015167	0.168
15	KAP	0.004813	0.020371	4.232517972	0.085
16	KOK	0.006039	0.026811	4.439698957	0.077
17	LKH	0.003091	0.017552	5.678537367	0.067
18	MUN	0.009650	0.037461	3.881977202	0.055
19	PAU	0.010703	0.051313	4.79430711	0.077
20	PIT	0.003510	0.016694	4.756070085	0.151
21	POR	0.022940	0.086688	3.778885833	0.58
22	ROO1	0.002386	0.008472	3.550641241	0.185
23	ROO2	0.001951	0.008971	4.598297796	0.159
24	RUD	0.021870	0.114627	5.241281664	0.06
25	THE	0.005818	0.021403	3.678781024	0.131
26	TIN	0.002306	0.009497	4.118230269	0.14
27	TUR	0.003918	0.013112	3.346732261	0.251
28	UTT	0.010793	0.036748	3.404810989	0.076

It can be shown from above Table: 1 that, the highest value for Maximum Pseudo-Acceleration is 5.6834 times more than Peak Ground Acceleration (PGA) value of BHA (Uttarkashi-Uttaranchal) earthquake at 0.127 sec. The lowest value for Maximum Pseudo-Acceleration is 3.2420 times more than Peak Ground Acceleration (PGA) value of JSH India

(Uttarakhand)-Tibet-Border-Region earthquake at 0.168 sec. According to, IS 1893 (Part 1): 2016 the highest value for Maximum Pseudo-Acceleration is 2.5 times more up to 1 sec than Peak Ground Acceleration (PGA) value [6].

Table - 2: Time History of Recorded Earthquakes in India

Sr. No.	Station Code	Region	Date	Origin Time	Record Time	Magnitude
1	BAG	Chamoli-Uttarakhand	14/12/2005	07:09:48	07:09:58.869	5.2
2	BHA	Uttarkashi-Uttaranchal	22/07/2007	23:02:12	23:02:23.679	5.0
3	BHUJ	BHUJ	26/01/2001	08:46:42.9	08:46:42.9	7.0
4	BOK	Myanmar-India-Manipuir-Border	30/08/2009	19:27:44	19:29:03.074	5.3
5	CHM	Chamoli-Uttarakhand	14/12/2005	07:09:48	07:09:26.424	5.2
6	CHP1	Chamoli-Uttarakhand	14/12/2005	07:09:48	07:10:39.234	5.2
7	CHP2	India (Uttarakhand)-Tibet-Border-Region	04/09/2008	12:53:21	12:53:33.864	5.1
8	DHA	India (Uttarakhand)-Tibet-Border-Region	04/09/2008	12:53:21	12:53:11.884	5.1
9	DIP	Myanmar-India-Manipuir-Border	30/08/2009	19:27:44	19:28:18.584	5.3
10	GHA	India (Uttarakhand)-Tibet-Border-Region	04/09/2008	12:53:21	12:53:49.849	5.1
11	GOL	Assam	11/05/2012	18:41:28	12:41:51.184	5.4
12	GUA	Myanmar-India-Manipuir-Border	30/08/2009	19:27:44	19:28:54.379	5.3
13	JHR	Assam	11/05/2012	18:41:28	12:41:44.039	5.4
14	JSH	India (Uttarakhand)-Tibet-Border-Region	04/09/2008	12:53:21	12:53:18.134	5.1
15	KAP	India (Uttarakhand)-Tibet-Border-Region	04/09/2008	12:53:21	12:53:12.009	5.1
16	KOK	Assam	11/05/2012	18:41:28	12:42:11.164	5.4
17	LKH	Myanmar-India-Manipuir-Border	30/08/2009	19:27:44	19:28:33.764	5.3
18	MUN	India (Uttarakhand)-Tibet-Border-Region	04/09/2008	12:53:21	12:53:00.379	5.1
19	PAU	Chamoli-Uttarakhand	14/12/2005	07:09:48	07:09:28.609	5.2
20	PIT	India (Uttarakhand)-Tibet-Border-Region	04/09/2008	12:53:21	12:53:19.299	5.1
21	POR	Andaman	27/06/2008	11:40:16	11:40:24.494	6.7
22	ROO1	Chamoli-Uttarakhand	14/12/2005	07:09:48	07:10:6.449	5.2
23	ROO2	Uttarkashi-Uttaranchal	22/07/2007	23:02:12	23:02:30.884	5.0
24	RUD	Chamoli-Uttarakhand	14/12/2005	07:09:48	07:09:35.069	5.2
25	TEH	Chamoli-Uttarakhand	14/12/2005	07:09:48	07:10:10.514	5.2
26	TIN	Nagaland-Myanmar	07/07/2008	02:50:36	02:51:13.869	5.1
27	TUR	Myanmar-India-Manipuir-Border	30/08/2009	19:27:44	00:22:37.714	5.3
28	UTT	Chamoli-Uttarakhand	14/12/2005	07:09:48	07:09:57.779	5.2

Source: India Meterological Department (IMD) [7]

Time history data of recorded earthquakes in India with its station code, region, date, origin time, record time and magnitude can be shown from above table 2.

VII. CONCLUSION

Maximum Pseudo-Acceleration is distributed between greater than 0.2 g to lesser than 0.01 g for above developed response spectrum of recorded 28 earthquakes. More values of the Pseudo-Acceleration suggesting more frequency of earthquake and it causes more damage to the structures and less value suggesting less frequency of earthquake. It can be seen from above developed 28 response spectrum that, Maximum Pseudo-Acceleration value of Bhuj earthquake is high and so it seems more severe compare to other mentioned earthquakes where as Maximum Pseudo-Acceleration value of CHP2 (India (Uttarakhand)-Tibet-Border-Region) earthquake is low and so it seems less severe compare to other mentioned earthquakes. The highest value for Maximum Pseudo-Acceleration is 5.6834 times more than Peak Ground Acceleration (PGA) value of BHA (Uttarkashi-Uttaranchal) earthquake at 0.127 sec and the lowest value for Maximum Pseudo-Acceleration is 3.2420 times more than Peak Ground Acceleration (PGA) value of JSH India (Uttarakhand)-Tibet-Border-Region earthquake at 0.168 sec. According to Indian Standard Code, IS 1893 (Part 1): 2016 the highest value for Maximum Pseudo-Acceleration is 2.5 times more up to 1 sec than Peak Ground Acceleration (PGA) value.

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