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Comparative Analysis of PGA-MMI Relationships for January 26th, 2001 M7.6 Bhuj Earthquake

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Abstract—*For the developing country like India, infrastructure industry is booming. Many new technologies, construction practices and international standards have been adopted by India within last decade. After investing such big amount for providing better services to the society, it is must for India to protect the infrastructure from the natural disasters. Earthquake is one of the natural disaster and we have witnessed the devastating post-earthquake effects, too. Earthquake hazards must be address properly for the safety of lives, infrastructure and society at large, which is the urgent need of the hour.*

Generally we come to know about the earthquake hazards, after earthquake has occurred. Therefore, we are lacking for appropriate mitigation. But it would be better if we can predict the hazards from the past data and records. For that, intensity is a great parameter to deal with. MMI is modified mercalli intensity; intensity refers to the effects actually experienced at that place and MMI is one of the intensity scale denoted by roman numbers from I to X. PGA is peak ground acceleration; it is a measure of earthquake acceleration on the ground, how hard the earth shakes in a given geographic area. Many researchers and scientists had tried to develop the relationship between PGA and MMI for the different tectonic regions.

We compared available empirical relationships developed between PGA and MMI for the January 26th, 2001 M7.6 Bhuj, India earthquake. Almost about 80 locations of Gujarat region have been selected for the study. An effort is made here to derive PGA values from MMI values using different empirical relationships available, which can be used for Indian continent region. With this, we can nearly predict the hazards and plan accordingly to mitigate.

1. INTRODUCTION

The Bhuj earthquake occurred in Gujarat, India on 26th of January, 2001. The event struck within the Kutch peninsula near India's western coast and was felt over much of the Indian sub-continent. Some of the parts of Gujarat were severely damaged. Instrumental recordings of the Bhuj 2001 earthquake are insufficient to comment anything about it. In that case, intensity data can be really helpful. Seismic intensity has traditionally been used worldwide for quantifying the shaking pattern and to identify the area under damage of the earthquake. It describes the thing in a more simplified way.

Scientists have developed many relationships of intensity with peak ground motion parameters. One of the ground motion parameter is PGA i.e. peak ground acceleration. One of the intensity is MMI i.e. modified mercalli intensity. We have used PGA-MMI relationships over here to estimate the PGA from MMI data for the Bhuj 2001 earthquake.

2. METHODOLOGY

A dataset has been prepared for the 80 different locations of Gujarat state, for their latitude, longitude, intensity, epicentral distance and shear velocity, which has been shown in Table 1.

Table 1: Collected Data over 80 locations of Gujarat

Location	Latitude	Longitude	MMI	D	Vs
Adhoi	23.400	70.513	10.5	28.9	600
Adipur	23.082	70.066	9.5	41.0	600
Ahmedabad1	23.043	72.578	7	243.6	300
Ahmedabad2	23.030	72.577	7	243.6	280
Ahmedabad3	23.009	72.590	7.5	245.5	300
Ahmedabad4	23.009	72.568	7.5	243.3	280
Ahmedabad5	23.050	72.577	6	243.3	300
Ahmedabad6	23.058	72.564	7.5	241.9	280
Ahmedabad7	23.030	72.551	7.5	241.9	300
Amreli District	21.360	71.150	7	247	930
Anand District	22.320	73.000	6.5	309	442
Anjar	23.117	70.019	10	27	600
Bagathala	22.847	70.717	8.5	80.5	500
Bajana	23.118	71.768	8	161	290
Balamba	22.716	70.436	8	-	500
Beraja	22.986	69.600	5.5	80	500
Bhachau	23.287	70.352	10.5	20	600
Bhadreshwar	22.916	69.891	8.5	66	600
Bharuch	21.719	72.971	6	339	300
Bhavnagar District	21.460	72.110	7	290	380
Bhuj	23.245	69.662	10	61	600
Bhujpur	22.867	69.635	7.5	86.5	300
Bidada	22.900	69.463	6.5	97	300
Chasra	22.969	69.816	8.5	66	500
Chitrod	23.40	70.70	8	48	360

Disa	24.25	72.167	7.5	213	760
Deshalpur	23.735	70.681	6.5	58	530
Dholavira	23.438	66.766	9	53	600
Dhori	23.438	67.766	9.5	35	600
Dhrangadhra	22.991	71.467	8	135	760
Dhrol	22.574	70.407	8	95	800
Dudhai	23.318	70.134	10	50	600
Dwarka	22.247	68.965	7	184	600
Gandhidham	23.074	70.131	9	40	170
Gandhinagar	23.296	72.635	7	246	360
Gundala	22.901	69.752	9.5	76	425
Halwad	23.017	71.174	8	106	650
Jamnagar	22.467	70.067	9	107	800
Jawaharnagar	23.367	69.986	10	26	600
Jhinjhuwada	23.356	71.747	8	155	279
Junagadh	21.516	70.457	7	212	800
Kandla	23.051	70.215	8	41	170
Kandla Port Trust	22.982	70.218	8	48	170
Kera Badadia	23.083	69.598	7	75	600
Khangharpur	NL	NL	8	156	-
Kharaghodha Tank	23.231	71.747	8	70	278
Khavda	23.840	69.720	6.5	251	500
Kheda District	22.450	72.450	9	105	370
Kotdi-roha	23.136	69.255	8	123	600
Kuda	23.113	71.385	9	36	170
Lodhai	23.402	69.880	8.5	105	250
Luna	23.714	69.252	8	64	250
Malia	23.093	70.748	8	112	530
Mandvi	22.834	69.343	7	218	300
Mehsana District	23.420	72.370	6.5	195	300
Modhera	23.587	72.132	8	91	300
Morbi	22.811	70.827	10	95	500
Mota Asambia	22.968	69.447	8	100	425
Nakhatrana	23.352	69.258	7	281	600
Nandiad	22.687	72.854	8	55	300
Navlakhi	22.969	70.464	7.5	389	170
Navsari	20.954	72.919	8	160	500
Okha	22.462	69.061	7	239	600
Palanpur	24.171	72.430	7.5	198	1000
Patan	23.874	72.109	8	161	278
Patdi	23.197	71.792	7.5	267	280
Porbandar	21.644	69.603	8	147	550
Radhanpur	23.841	71.603	7.5	137	278
Rajkot	22.301	70.801	9	45	800
Rapar	23.576	70.641	9	47	800
Ratnal	23.194	69.870	9	38	600
Samakhiali	23.329	70.587	10	68	360
Sukhpur	23.232	69.600	8.5	54	600
Suraj Bari	23.207	70.703	7	363	170
Surat	21.193	72.822	7	168	500
Surendranagr	22.706	71.678	9.5	34	300
Suvi	23.618	70.483	7.5	68	600
Vadala	22.918	69.850	6	328	600
Vadodara	22.303	73.187	6	417	490
Valsad	20.611	72.924	10	21	500
Vondh	23.301	70.397	7	115	600

MMI values in the Table 1 are taken from Susane et al. 2003. Vs values in the table 1 are taken from annual report 2009-10 of Institute of Seismological Research, Gandhinagar, Gujarat.

A literature review has been done to collect available empirical relationships for PGA-MMI. Out of all the empirical relationships available, those which are suitable for Indian peninsula were sorted out.

2.1 Wald et al. 1999

Wald et al. has developed a PGA-MMI relationship for California in 1999. As California and India have similarity in terms of tectonic conditions, we can use this empirical relationship for the Indian condition.

$$I_{mm} = 3.66\log(PGA) - 1.66 \quad (1)$$

From the equation (1) we have derived PGA values for all the intensity values over 80 locations and plotted a graph of MMI v/s PGA shown in Fig. 1.

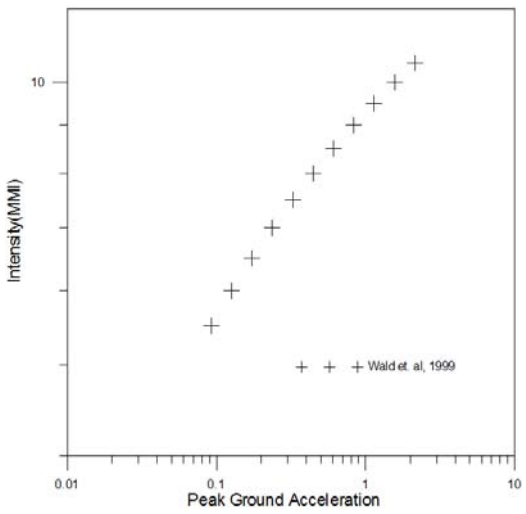

Fig. 1: MMI v/s PGA for the empirical relationship given by Wald et al. 1999

2.2 Murphy and O'Brien 1977

Murphy and O'Brien have studied 1500 strong motion accelerograms from 900 Western US, 500 Japanese and 60 Southern European earthquakes with $3.0 \leq M \leq 8.0$ and $1 \leq MMI \leq 10$ and they have given the following equation for the global level,

$$\text{Log}_{10}(PGA) = 0.25\, I_{MMI} + 0.25 \quad (2)$$

From the equation (2) we have derived PGA values for all the intensity values over 80 locations and plotted a graph of MMI v/s PGA shown in Fig. 2.

2.3 Iyengar and Raghukanth 2003

Iyengar and Raghukanth have developed the following empirical relationship for India,

$$Ln(PGA) = 0.6782MMI - 6.8163 \quad (3)$$

From the equation (3) we have derived PGA values for all the intensity values over 80 locations and plotted a graph of MMI v/s PGA shown in Fig. 3.

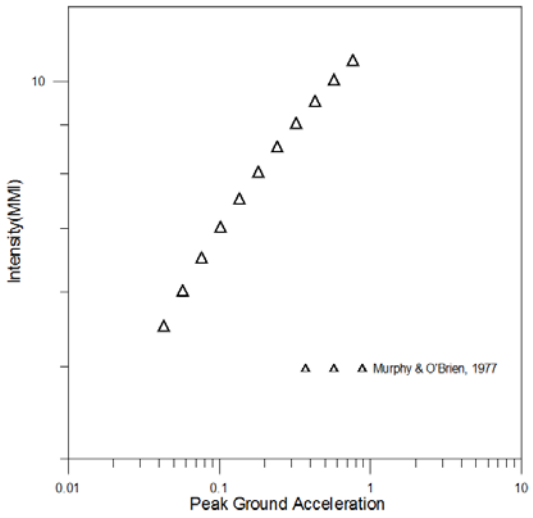

Fig. 2: MMI v/s PGA for the empirical relationship given by Murphy and O'Brien 1977

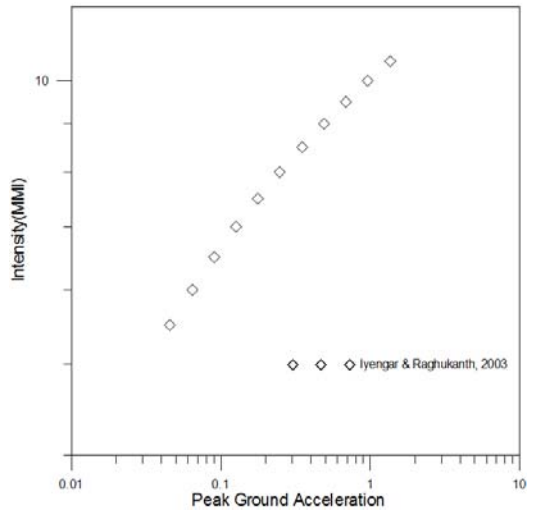

Fig. 3: MMI v/s PGA for the empirical relationship given by Iyengar and Raghukanth 2003

2.4 Atkinson and Sonley 2000

From 29 California earthquakes Atkinson and Sonley has developed an empirical relationship between PGA and MMI.

$$Log\ (PGA) = c_1 + c_2(MMI) + c_3 LogD + c_4 M \quad (4)$$

Where c_1, c_2, c_3 and c_4 are 1.60, 0.15, -0.46 and 0.03 respectively as per the calculations done by them.

From the equation (4) we have derived PGA values for all the intensity values over 80 locations and plotted a graph of MMI v/s PGA shown in Fig. 4.

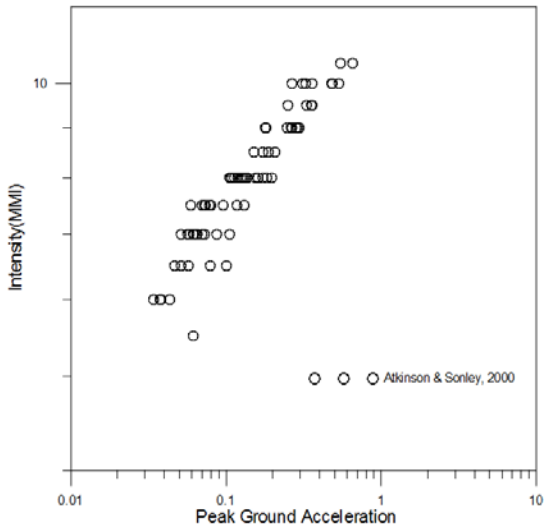

Fig. 4: MMI v/s PGA for the empirical relationship given by Atkinson and Sonley 2000

3. RESULT & DISCUSSION

After developing the graphs, we have combined all the four graphs in one for the better comparison, which is shown below in the Fig. 5

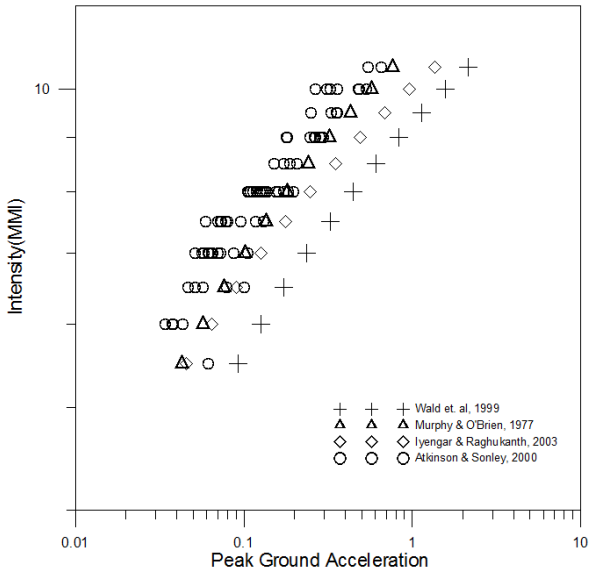

Fig. 5: MMI v/s PGA for the Bhuj 2001 earthquake

From the Fig. 5 few observations have been made. Relationship given by Solney and Atkinson, 2000 is distance based hence it gives the result in a range. As it includes the epicentral distance as one of the parameter, it is most accepted among others. Relationship of Murphy and O'Brien, 1977 gives higher value of the intensity for the lower value of PGA, which is generally not acceptable in real practice. Results derived from the relationship given by Iyengar and raghukanth, 2003 lies between the derived results of Murphy and O'Brien, 1977 and Wald et al.,1999.

4. CONCLUSION

As we can derive mean and standard deviation for all the PGA values, shown in Table 2, we can have certain idea about the PGA value for particular intensity value. Thus, we can identify the range of PGA values though we have no instrumental data recorded. PGA maps can be generated too.

Table 2: PGA values corresponding to MMI for Bhuj 2001 earthquake, Mean and standard deviation of PGA.

MMI	Wald	M&O	R&I	A&S	Mean	SD
10.5	0.01	0.77	1.36	0.55	0.67	0.56
9.5	0.01	0.43	0.69	0.33	0.36	0.28
7	0.01	0.10	0.13	0.06	0.07	0.05
7	0.01	0.10	0.13	0.06	0.07	0.05
7.5	0.01	0.14	0.18	0.07	0.10	0.07
7.5	0.01	0.14	0.18	0.07	0.10	0.07
6	0.01	0.06	0.06	0.04	0.04	0.03
7.5	0.01	0.14	0.18	0.07	0.10	0.07
7.5	0.01	0.14	0.18	0.07	0.10	0.07
7	0.01	0.10	0.13	0.06	0.07	0.05
6.5	0.01	0.08	0.09	0.05	0.05	0.04
10	0.01	0.57	0.97	0.48	0.51	0.39
8.5	0.01	0.24	0.35	0.17	0.19	0.14
8	0.01	0.18	0.25	0.11	0.14	0.10
5.5	0.01	0.04	0.05	0.06	0.04	0.02
10.5	0.01	0.77	1.36	0.65	0.70	0.55
8.5	0.01	0.24	0.35	0.19	0.20	0.14
6	0.01	0.06	0.06	0.04	0.04	0.03
7	0.01	0.10	0.13	0.06	0.07	0.05
10	0.01	0.57	0.97	0.33	0.47	0.40
7.5	0.01	0.14	0.18	0.12	0.11	0.07
6.5	0.01	0.08	0.09	0.08	0.06	0.04
8.5	0.01	0.24	0.35	0.19	0.20	0.14
8	0.01	0.18	0.25	0.18	0.16	0.10
7.5	0.01	0.14	0.18	0.08	0.10	0.07
6.5	0.01	0.08	0.09	0.10	0.07	0.04
9	0.01	0.32	0.49	0.25	0.27	0.20
9.5	0.01	0.43	0.69	0.36	0.37	0.28
8	0.01	0.18	0.25	0.11	0.14	0.10
8	0.01	0.18	0.25	0.13	0.14	0.10
10	0.01	0.57	0.97	0.36	0.48	0.40
7	0.01	0.10	0.13	0.07	0.08	0.05
9	0.01	0.32	0.49	0.28	0.28	0.20
7	0.01	0.10	0.13	0.06	0.07	0.05
9.5	0.01	0.43	0.69	0.25	0.34	0.29
8	0.01	0.18	0.25	0.13	0.14	0.10
9	0.01	0.32	0.49	0.18	0.25	0.21
10	0.01	0.57	0.97	0.49	0.51	0.39
8	0.01	0.18	0.25	0.11	0.14	0.10
7	0.01	0.10	0.13	0.07	0.08	0.05
8	0.01	0.18	0.25	0.20	0.16	0.10
8	0.01	0.18	0.25	0.18	0.16	0.10
7	0.01	0.10	0.13	0.11	0.09	0.05
8	0.01	0.18	0.25	0.11	0.14	0.10
8	0.01	0.18	0.25	0.15	0.15	0.10
6.5	0.01	0.08	0.09	0.05	0.06	0.04
9	0.01	0.32	0.49	0.18	0.25	0.20
8	0.01	0.18	0.25	0.12	0.14	0.10
9	0.01	0.32	0.49	0.30	0.28	0.20
8.5	0.01	0.24	0.35	0.15	0.19	0.14
8	0.01	0.18	0.25	0.16	0.15	0.10
8	0.01	0.18	0.25	0.12	0.14	0.10
7	0.01	0.10	0.13	0.06	0.08	0.05
6.5	0.01	0.08	0.09	0.06	0.06	0.04
8	0.01	0.18	0.25	0.14	0.14	0.10
10	0.01	0.57	0.97	0.27	0.45	0.41
8	0.01	0.18	0.25	0.13	0.14	0.10
7	0.01	0.10	0.13	0.06	0.07	0.05
8	0.01	0.18	0.25	0.17	0.15	0.10
7.5	0.01	0.14	0.18	0.06	0.09	0.08
8	0.01	0.18	0.25	0.11	0.14	0.10
7	0.01	0.10	0.13	0.06	0.07	0.05
7.5	0.01	0.14	0.18	0.08	0.10	0.07
8	0.01	0.18	0.25	0.11	0.14	0.10
7.5	0.01	0.14	0.18	0.07	0.10	0.07
8	0.01	0.18	0.25	0.11	0.14	0.10
7.5	0.01	0.14	0.18	0.10	0.10	0.07
9	0.01	0.32	0.49	0.27	0.27	0.20
9	0.01	0.32	0.49	0.26	0.27	0.20
9	0.01	0.32	0.49	0.29	0.28	0.20
10	0.01	0.57	0.97	0.31	0.47	0.41
8.5	0.01	0.24	0.35	0.21	0.20	0.14
7	0.01	0.10	0.13	0.05	0.07	0.05
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7.5	0.01	0.14	0.18	0.13	0.11	0.07
6	0.01	0.06	0.06	0.04	0.04	0.03
6	0.01	0.06	0.06	0.03	0.04	0.03
10	0.01	0.57	0.97	0.54	0.52	0.39
7	0.01	0.10	0.13	0.09	0.08	0.05

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