Performance-Based Design Response Spectrum Evaluation for a Peninsular Indian Site

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Abstract

The performance-based design response spectrum (PB-DRS) is perceived as the requisite of performance-based design of structures, systems, and components of nuclear facilities. In view of such requirement, this study evaluates PB-DRS carriers for a Peninsular Indian site. A probablistic seismic hazard analysis with multi-expert participation is deloyed to obtain seismic hazard results. Furthermore, PB-DRS from the uniform hazard response spectrum, regulatory guide 1.208, and ASCE 43-05 are respectively used to further evaluate and compare. The results reveal that PB-DRS from the uniform hazard response spectrum and regulatory guide 1.208 can be used for the performance-based seismic design, e.g., reactor buildings. Meanwhile, PB-DRS from ASCE 43-05 can be used for floor-molding components such as steam generators.

Keywords: Probabilistic seismic hazard analysis (PSHA), Design Response Spectrum (DRS), Uniform Hazard Response Spectrum (UHRS), Ground Motion Response Spectrum (PB-GMRS)

1. Introduction

The objective of the performance-based design for structures, systems, and components (SSC) in a nuclear facility (NF) or nuclear power plant (NPP) is to ensure a target performance level of SSC under a probable seismic load. The probable seismic load is characterized by a site-specific performance-based design response spectrum (PB-DRS). The traditional approaches for evaluating ground motion parameters for an NF/NPP site are deterministic seismic hazard analysis (DSHA) and/ or probabilistic seismic hazard analysis (PSHA). However, the limitation of DSHA is that it does not provide any details of the likelihood of controlling earthquakes relative to other earthquake events like smaller and short-distance events or bigger and long-distance events. On the contrary, PSHA considers the effect of all earthquake events and faults in the region of interest along with their probability of occurrence. Also, PSHA utilizes data on earthquake magnitudes, distance from the site, probability of magnitude, distance, and the conditional probability of ground motion parameters for the given intensity, etc. However, the outcome of PSHA cannot be directly used for the performance-based design of SSC.

In the recent past, several researchers have carried out seismic hazard analysis for Peninsular India (PI). Raghu Kanth et al. [1] have obtained an empirical relation to estimating a 5% damped response spectrum for PI. All India hazard maps were provided by the National Disaster Management Authority (NDMA) [2]. PSHA results were discussed by Anbazhagan et al. [3] for Bangalore City. Sitharam et al. [4] have conducted surface-level hazard assessments for India. Scaria et al. [5] have presented seismic hazard analysis for different PI sites. Empirical amplification factors were also provided to obtain uniform hazard spectra. Sreejaya et al. [6] have presented seismic hazard maps for India. Meenakshi et al. [7] have provided a tripartite design spectrum for the PI region. Sreejaya et al. [8] have carried out physics-based simulations using a three-dimensional model of PI. The information available in the present literature is suitable only for the conventional seismic design of SSC.

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For the performance-based design of the SSC of NF/NPP, PB-DRS is an essential requirement. Even though extensive literature is available for seismic hazard analysis of PI, no information is available for the performance-based design response spectrum (PB-DRS) for PI. Hence, the primary objective of the present study is to demonstrate the methodology of the revaluation of PB-DRS for a typical hard-rock PI site.

Three methods are used for the evaluation of PB-DRS of the PI site. In the first method, the uniform hazard response spectrum (UHRS) corresponds to the 84th percentile (Mean plus sigma) for a 10,000-year return period and is considered as DRS of Safe Shutdown Earthquake (SSE). In the second approach, the performance-based ground motion response spectrum (PB-GMRS) has been evaluated from UHRS for 10,000 and 1,00,000-year return periods by procedure given in regulatory guide (RG)1.208 [9]. In the third approach, the component-specific PB-DRS has been evaluated using the procedure given in ASCE 43-05 [10]. This study uses the probabilistic seismic hazard analysis with the Multi Expert Participation (PSHA-MEP) procedure [13] to obtain PB-DRS. In the literature, a comparison of various methodologies for the evaluation of PB-DRS is also not available. The second objective of the present study is to compare the PB-DRS obtained from the three methods. The details are provided in the paper.

2. Seismo-Tectonic Models and Data Base for PSHA of Peninsular Indian Site

A seismo-tectonic map of a representative Peninsular Indian (PI) site is presented in Fig. 1. The earthquake dataset comparison events with magnitudes greater than 3, are included in Annexure-A. This data includes the date of occurrence, epicentral coordinates, and magnitude. This data is obtained from published literature, the NDMA earthquake catalog [2], and the India Meteorological Department (IMD) catalog [11]. Earthquakes with a magnitude of more than 3 are considered for the present study. As the aftershocks and foreshocks are admittedly dependent on the main shock, such events get clustered in a general catalog. Declustering of the data is done by removing such events from the main catalog. The data completeness has been checked by using the procedure given by Stepp [12].

The earthquake activity around the PI site is superimposed on fault lines to obtain various source models. In the present study, the PSHA-MEP procedure [13] is used. In this procedure, prominent experts in the area of PSHA [13] have finalized the seismic source characterization, Ground Motion Models, logic tree parameter selection, and corresponding weightage assignment. As the earthquake epicenters are scattered around the faults, areal sources were chosen for hazard assessment. Moreover, two different source models are considered based on guidelines of seismic source characterization and expert elicitation [13].

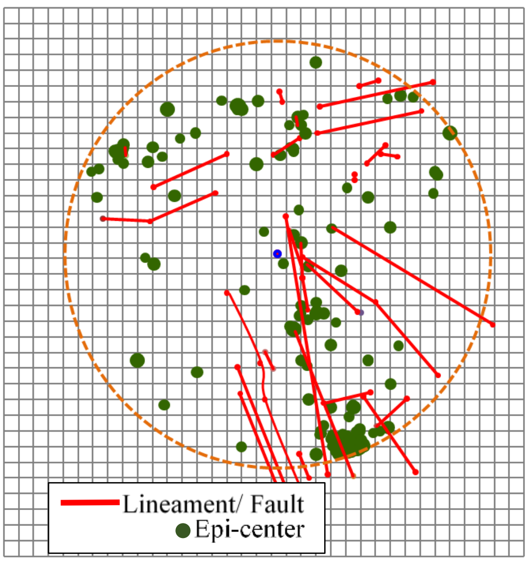

Fig. 1 Seismo-tectonic map of a typical Peninsular Indian site

The first source model is shown in Fig. 2. This model comprises six areal sources and is designated as Model-1. The second model comprises seven areal sources, as shown in Fig. 3. This model comprises seven areal sources and is designated as Model-2. A typical hard-rock site that has a shear wave velocity (Vs_{30}) of 2.9 km/s (as per soil profile type classification of the National Earthquake Hazards Reduction Program (NEHRP) is considered for the present study.

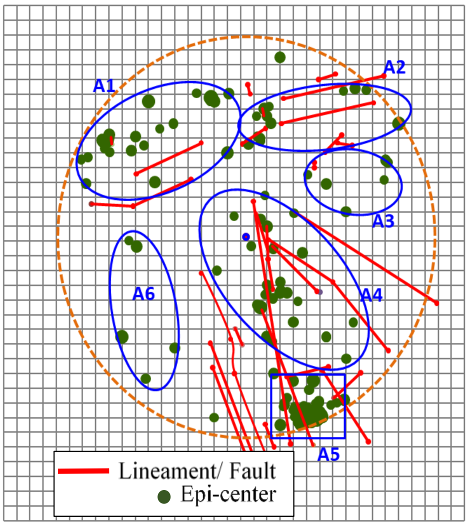

Fig. 2 First source model for a typical Peninsular Indian site (model-1)

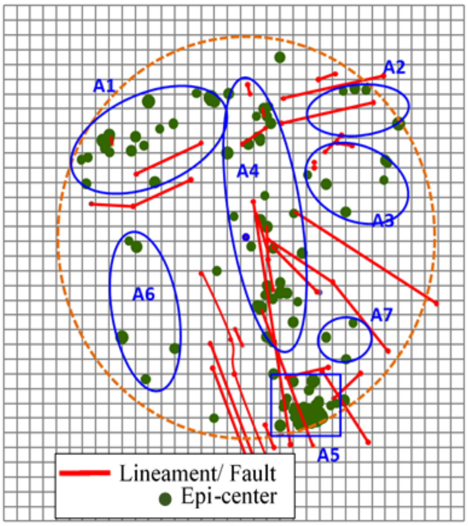

Fig. 3 Second source model for a typical Peninsular Indian site (model-2)

3. Seismic Activity Model of Sources

3.1. Minimum magnitude (m_{min})

Minimum magnitude represents the smallest seismic event that could potentially damage structures. For the present work, earthquakes with a magnitude greater than three are considered.

3.2. Maximum magnitude (m_{max})

The maximum regional magnitude (m_{max}) is defined as the maximum magnitude of a seismic event resulting in a selected region. An estimation of m_{max} for every earthquake source is required for a realistic PSHA assessment. This ensures that unrealistic big seismic events are not included in each source. Three methods used to estimate m_{max} are described below.

3.2.1. Mmax equals largest mobs plus an increment

In the first method, an increment of 0.67 magnitude unit is used for the observed maximum magnitude for each source.

3.2.2. Mmax from fault length

In the second method, the maximum magnitude is estimated from sub-surface rupture length (RLD) using the following empirical correlation [14], as shown in Eq. (1).

$$M = a + b * \log(RLD) \quad (1)$$

where *a* and *b* are 4.38 and 1.49 for all types of slip, and RLD is taken as one-third of fault length in km.

3.2.3. Mmax from magnitude-frequency extrapolation of historical record

In this method, m_{max} is calculated from the magnitude-frequency extrapolation of the historical record for 1000 years [15]. m_{max} for all sources in these source models 1 and 2 are given in Table 1 and Table 2 respectively.

Table 1 Mmax for model-1 using three methods

Model-1	Method 1: $M_{max.obs}$ +0.7	Method 2: From Rupture length	Method 3: From extrapolation of historical activity
A1	7.7	6.7	6.3
A2	7.2	7.0	6.0
A3	5.0	5.5 (*)	5.5
A4	6.4	7.5	5.9
A5	7.2	7.1	6.2
A6	6.7	5.5 (*)	5.5

Table 2 Mmax for model-2 using three methods

Model-2	Method 1: $M_{max.obs}$ +0.7	Method 2: From Rupture length	Method 3: From extrapolation of historical activity
A1	7.7	6.7	6.2
A2	7.2	7.0	5.1
A3	5.0	5.4 (*)	5.4
A4	7.2	7.5	6.4
A5	7.2	7.1	6.2
A6	6.7	5.3 (*)	5.3

(*) for the area in which no fault is present, extrapolation method has been used.

3.3. Magnitude recurrence relationship

Gutenberg & Richter had given a recurrence relationship which gives the mean annual frequency of magnitude m (number of earthquakes of magnitude greater than or equal to “*m*” per year) and is given by Eq. (2).

$$\log_{10} N_m = a - bm \quad N_m = 10^{a-bm} \tag{2}$$

where ‘*a*’ and ‘*b*’ for a given region are obtained from the seismic event records available in that region. Two procedures are used for the derivation of regional *‘a’* and ‘*b*’ values and they are *a* Kijko-Sellovell method [16] and *b* Regression analysis. The regional seismicity parameters are estimated using complete data in the regression method. In the `Kijko-Sellovell method, total data termed as a mixed data set comprising historical and instrumented data is used for the estimation of seismicity parameters.

Based on the regression method, ‘*a*’ and ‘*b*’ parameters have been estimated as 4.03 and 0.958 for the region including dam-induced seismic region (Area A5), 3.09 and 0.88 for the region excluding dam-induced seismic region (Area A5). Based on the Kijko-Sellovell maximum likelihood estimation method [16] ‘*a*’ and ‘*b*’ parameters have been estimated as 4.375 and 1.15 for the region including dam-induced seismic region, 2.23 and 0.75 for the region excluding dam-induced seismic region.

3.4. Apportionment of ‘a’ and ‘b’ values for various sources

Three methods based on activity, geometry, and energy, respectively, are used for apportionment of a and b to various sources. Apportionment of ‘*a*’ and ‘*b*’ for all sources of two models by the Kijko-Sellovelle method and the Regression method are given in Table 3 and Table 4, respectively.

Table 3 Apportionment of ‘a’ and ‘b’ for all Sources of two models by the kijko-sellovelle method

Model-1	Activity		Geometry		Energy	
	a	b	a	b	a	b
A1	1.7576	0.75	1.5494	0.75	1.8319	0.75
A2	1.4703	0.75	1.6794	0.75	1.5311	0.75
A3	1.1113	0.75	1.1023	0.75	1.5311	0.75
A4	1.7714	0.75	1.7246	0.75	1.5450	0.75
A5	4.3750	1.15	4.3750	1.15	4.3750	1.15
A6	1.0444	0.75	1.3201	0.75	1.5155	0.75
Model-2	Activity		Geometry		Energy	
	a	b	a	b	a	b
A1	1.7286	0.75	1.6281	0.75	1.8249	0.75
A2	0.8683	0.75	1.1411	0.75	1.5155	0.75
A3	1.1113	0.75	1.3545	0.75	1.5155	0.75
A4	1.8895	0.75	1.7468	0.75	1.5724	0.75
A5	4.3750	1.15	4.3750	1.15	4.3750	1.15
A6	1.0444	0.75	1.4541	0.75	1.5155	0.75
A7	0.8683	0.75	0.8207	0.75	1.5155	0.75

Table 4 Apportionment of a and b for all sources of two models by regression method

Model-1	Activity		Geometry		Energy	
	a	b	a	b	a	b
A1	2.6176	0.880	2.4094	0.880	2.6919	0.880
A2	2.3303	0.880	2.5394	0.880	2.3911	0.880
A3	1.9713	0.880	1.9623	0.880	2.3911	0.880
A4	2.6314	0.880	2.5846	0.880	2.4050	0.880
A5	4.0300	0.958	4.0300	0.958	4.0300	0.958
A6	1.9044	0.880	2.1801	0.880	2.3755	0.880
Model-2	Activity		Geometry		Energy	
	a	b	a	b	a	b
A1	2.5886	0.880	2.4881	0.880	2.6849	0.880
A2	1.7283	0.880	2.0011	0.880	2.3755	0.880
A3	1.9713	0.880	2.2145	0.880	2.3755	0.880
A4	2.7495	0.880	2.6068	0.880	2.4324	0.880
A5	4.0300	0.958	4.0300	0.958	4.0300	0.958
A6	1.9044	0.880	2.3141	0.880	2.3755	0.880
A7	1.7283	0.880	1.6807	0.880	2.3755	0.880

4. Hazard Calculation for Peninsular India Site

It is common practice to consider different ground motion input parameters [17-18] for hazard assessment. PSHA has been carried out using the logic tree shown in Fig. 4. Logic tree parameter selection and corresponding weightage assignment are based on expert elicitation [13]. Expert weights are shown in parentheses. Based on the type of region, ground-motion predict equations (GMPEs) are also selected by the group of experts as part of PSHA-MEP [13]. As PI is an intra-plate stable continental region, four intra-plate GMPEs are used. GMPEs used in the present analysis are Atkinson & Boore [19], Pezeshk [20], Toro [21], and RSD [22].

4.1. Hazard curves

The resulting peak ground acceleration (PGA) hazard curves for all GMPEs are shown in Fig. 5. PGA for 10,000 and 1,00,000-year return periods with this logic tree (weighted average) is 0.198g and 0.417g, respectively. PGA for the 84th percentile (mean plus sigma) for 10,000 and 1,00,000-year return periods are 0.215g and 0.453g, respectively.

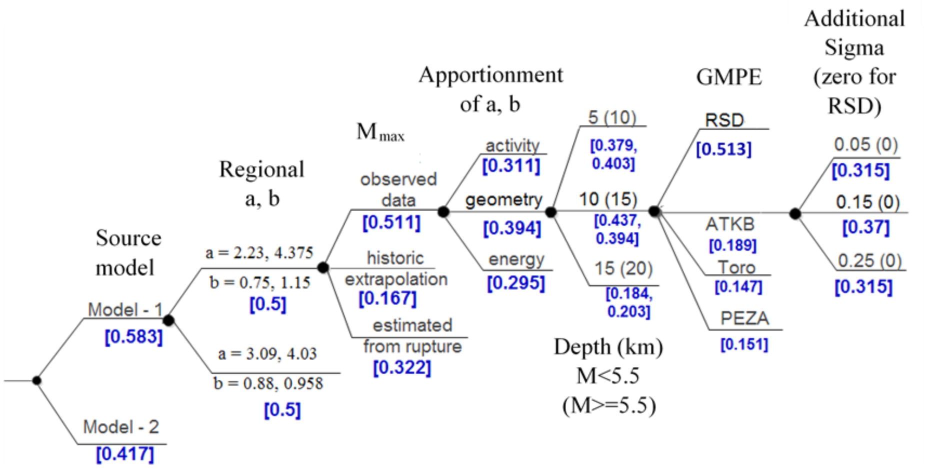

Fig. 4 Logic tree for hazard assessment

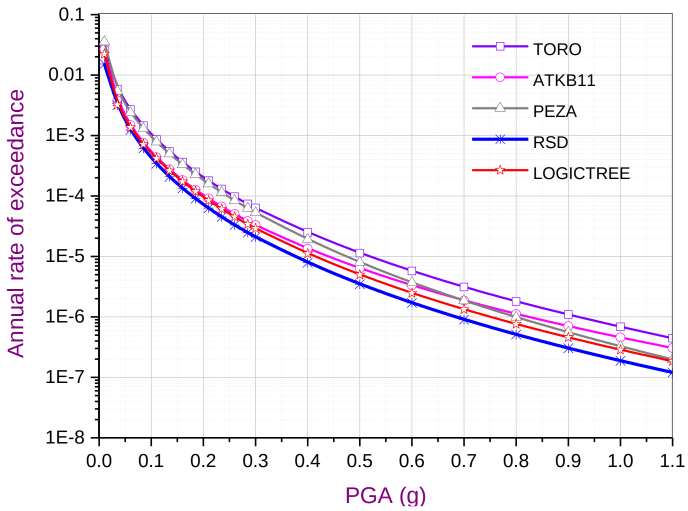

Fig. 5 PGA hazard curves for all GMPE

4.2. Method-1: UHRS for various return periods

UHRS has been generated using hazard curves for different frequencies. UHRS for a 10,000-year return period for all GMPE for the 84th percentile (mean plus sigma) is shown in Fig. 6. In the first method, it is proposed to consider UHRS corresponds to the 84th percentile for a 10,000-year return period as DRS of SSE corresponding to the bedrock of the site. UHRS for a 100,000-year return period for all GMPE for the 84th percentile is shown in Fig. 7.

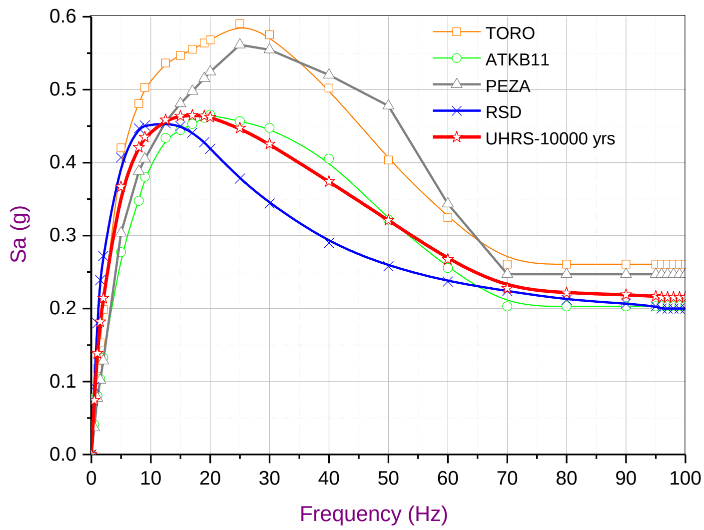

Fig. 6 UHRS for 10,000 years return period for all GMPE using a logic tree with the 84th percentile

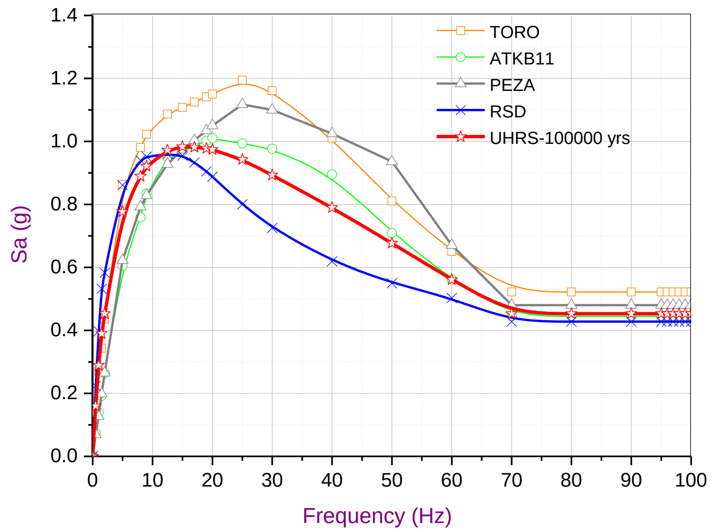

Fig. 7 UHRS for 1,00,000 years return period for all GMPE using a logic tree with 84th percentile

5. Evaluation of Performance-Based Ground Motion Spectrum for Peninsular Indian Site

SSC, which are designed by using Performance-Based approaches, and PB-GMRS can be used as design response spectrum (DRS) of SSE for hard rock.

Table 5 GMRS for peninsular India site as per RG 1.208

f (Hz)	UHRS-1E4	UHRS-1E5	A_R	DF	GMRS (g)
0	0.000	0.000	0.000	1.000	0.000
0.5	0.068	0.147	2.161	1.112	0.076
1	0.127	0.266	2.091	1.082	0.138
1.5	0.167	0.359	2.145	1.105	0.185
2	0.197	0.417	2.118	1.094	0.215
5	0.337	0.715	2.121	1.095	0.369
8	0.387	0.819	2.116	1.093	0.423
9	0.400	0.849	2.121	1.095	0.438
12.5	0.422	0.895	2.121	1.095	0.462
15	0.427	0.905	2.122	1.095	0.467
17	0.427	0.904	2.115	1.092	0.467
19	0.427	0.900	2.110	1.090	0.465
20	0.425	0.897	2.110	1.090	0.463
25	0.411	0.868	2.109	1.090	0.448
30	0.391	0.822	2.102	1.087	0.425
40	0.344	0.727	2.114	1.092	0.376
50	0.295	0.623	2.110	1.090	0.322
60	0.246	0.517	2.102	1.087	0.267
70	0.198	0.417	2.106	1.089	0.216
80	0.198	0.417	2.106	1.089	0.216
90	0.198	0.417	2.106	1.089	0.216
95	0.198	0.417	2.106	1.089	0.216
96	0.198	0.417	2.106	1.089	0.216
97	0.198	0.417	2.106	1.089	0.216
98	0.198	0.417	2.106	1.089	0.216
99	0.198	0.417	2.106	1.089	0.216
100	0.198	0.417	2.106	1.089	0.216

5.1. Method-2: evaluation of PB-GMRS for PI site as per RG 1.208

In the second approach, the PB-GMRS has been evaluated from UHRS for 10,000 and 100,000-year return periods, using the procedure given in RG 1.208. As per RG 1.208 [9], the horizontal PB-GMRS is obtained by multiplying the mean Uniform Hazard Response Spectrum for a 10,000-year return period, by a factor (F) as follows:

$$PB-GMRS = RSP_{1000} xF \tag{3}$$

where RSP_{10000} is the mean UHRS for 10,000 year return period and

$$F = \max\left[0.6R^{0.8}, 1.0\right] \tag{4}$$

where R (shown in Eq. (4)) is the ratio of the mean Uniform Hazard Response Spectrum for a 1,00,000-year return period and the mean Uniform Hazard Response Spectrum for a 10,000-year return period.

$$R = RSP_{1E5} / RSP_{1E4} \tag{5}$$

PB-GMRS for the PI site has been evaluated as per RG-1.208 for the logic tree and the resulting PB-GMRS is shown in Fig. 8. All calculations of PB-GMRS are given in Table 5. PGA for PB-GMRS is 0.216g.

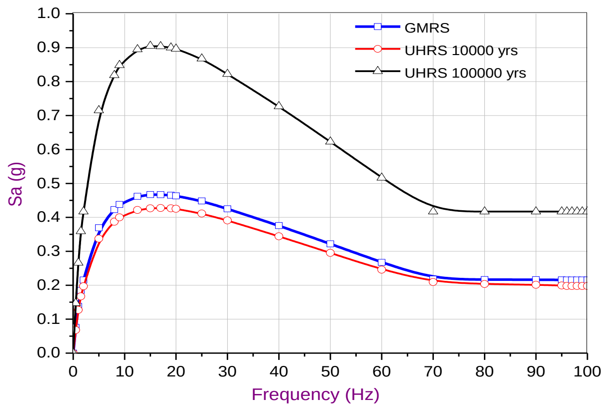

Fig. 8 Ground motion response spectrum (GMRS) for the site as per RG 1.208

5.2. Method-3: component specific evaluation of DRS for PI site as per ASCE 43-05

In the third approach, component-specific PB-DRS has been evaluated using the procedure given in ASCE 43-05. The procedure for evaluation of PB-DRS is given in ASCE 43-05 [10]. If the fragility parameters of SSC are known, PB-DRS can be evaluated from basic theory. The approach for achieving risk consistent horizontal site-specific, PB-DRS is given below. This procedure comprises scaling up the mean UHRS for 10,000 year return period with a design factor (F), to get the PB-DRS:

$$PB-DRS = RSP_{1E4} xF \tag{6}$$

The design factor (F) depends on:

(1) Probability ratio R is given as:

$$R = \frac{AF_{UHRS}}{AF_{Target}} \tag{7}$$

where AF_{UHRS} is the Annual frequency of RSP_{10000}, and AF_{Target} is the Target annual frequency of unacceptable earthquake performance.

(2) Hazard slope ratio A, which defines the change in ground motion corresponding to a tenfold change in exceedance frequency. It is defined as,

$$A = \frac{SA_{0.1AF_{UHRS}}}{SA_{AF_{UHRS}}} \tag{8}$$

where $SA_{AF_{UHRS}}$ is the spectral acceleration at the exceedance frequency, AF_{UHRS} and $SA_{0.1AF_{UHRS}}$ is the spectral acceleration at the exceedance frequency, which is denoted as $0.1AF_{UHRS}$.

5.2.1. Details of design factor (F)

Seismic hazard curves can be represented as,

$$SH(a) = K_I a^{-K_H} \tag{9}$$

where $SH(a)$ is the annual frequency of exceedance of ground motion level, and a K_I is suitable constant. K_H is the slope parameter given as:

$$K_H = \frac{1}{\log(A)} \tag{10}$$

where, A is the spectral acceleration ratio, frequency by frequency, from a seismic hazard curve corresponds to a ten-fold reduction in hazard exceedance frequency;

For computing the probability ratio, R which corresponds to any particular earthquake design criteria, the mean seismic fragility curve of the components is required. The conditional probability of unacceptable performance concerning ground motion level is given by the mean seismic fragility curve. It is usually lognormally distributed and is characterized using two parameters: (a) median capacity level and (b) a composite logarithmic standard deviation, β. The typical range of β for SSC at ground level is 0.3 to 0.5. The range of β for higher floor-mounted SSC is typically 0.4 to 0.6.

For any SSC, the mean probability, P, of unacceptable performances is evaluated by convolution of the seismic hazard and fragility curves and is provided as.

$$P = -\int_0^\infty \frac{dSH_a}{da} P_{F/a}\, da \tag{11}$$

where $P_{F/a}$ is the conditional failure probability at the chosen ground motion level, which is defined by the mean fragility curve.

The hazard curve between Annual frequencies, AF_{UHRS}, and AF_{Target} is approximated as:

$$R = \frac{AF_{UHRS}}{AF_{Target}} = (F_S)^{K_H e^f} \tag{12}$$

$$f = X_P K_H \beta - 1/2 (K_H \beta)^2 \tag{13}$$

Where, F_S is the Safety factor between the input ground motion and the SSC seismic capacity, which is linked with the conditional failure probability($P_{F/a}$). X_P is the standard normal variant corresponding to the failure probability ($P_{F/a}$). The safety factor, F_S, is provided to get the desired probability ratio, R

$$F_S = \left[\mathrm{R}e^{-f} \right]^{1/K_H} \tag{14}$$

The assumptions about nominal safety factors, F_{SN} are:

$$F_{SN1\%} \geq 1.0 \text{ (1\% conditional probability of failure)} \quad (15)$$

$$F_{SN10\%} \geq 1.5 \text{ (10\% conditional probability of failure)} \quad (16)$$

Based on Eq. (16), the UHRS multiplied by a design factor, DF_a,

$$DF_a = F_{P1\%} \quad (17)$$

where $F_{P1\%}$ is computed using the 1% standardized normal variant, $X_{P1\%}$=2.326, in Eq. (13)

Alternatively, the UHRS would be multiplied by a Design Factor, DF_b given by,

$$DF_b = F_{P10\%}/1.5 \quad (18)$$

where $F_{P10\%}$ is computed using the 10% standardized normal variant, $X_{P10\%}$=1.282, in Eq. (13). For logarithmic standard deviations, β ranging from 0.3 to 0.6, the ratio of (DF_b/DF_a) is given in Table 6.

Table 6 Ratio of Design Factors

β	DF_b/DF_a
0.3	0.91
0.4	1.01
0.5	1.12
0.6	1.25

5.2.2. Evaluation of DRS for components with known fragility parameters using UHRS

Similarly, DRS for components with β of 0.4, 0.5, and 0.6 are evaluated. The comparison of DRS for different β values with GMRS is shown in Fig. 9. It is observed that the spectral values of component-specific DRS for β of 0.3 and 0.4 are almost the same as GMRS, while DRS for β of 0.5 and 0.6 are slightly the more than GMRS.

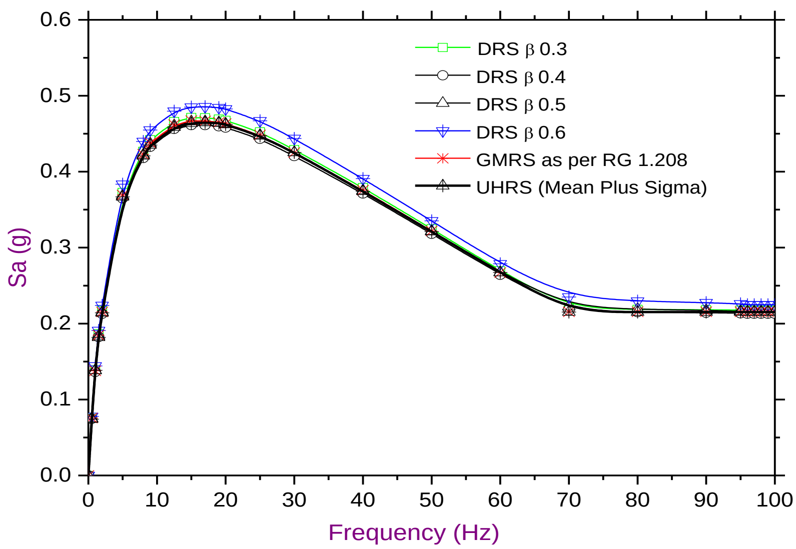

Fig. 9 Comparison of GMRS (RG 1.208) with component-specific (β = 0.3 to 0.6) design response spectra (DRS) and UHRS (mean plus sigma)

The procedure given in the preceding section has been applied to evaluate DRS for components with known composite logarithmic standard deviation, β. A range of β (0.3, 0.4, 0.5, and 0.6) is chosen for comparative study using UHRS. The computation of DRS for components with β of 0.3 using UHRS is given in Table 7.

Table 7 Computation of component-specific (β 0.3) design response spectrum (DRS)

f (Hz)	UHRS-1E4	UHRS-1E5	A_R	K_H	f	$F_{P10\%}$	DF	DRS (g) (β - 0.3)
0	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
0.5	0.068	0.147	2.161	2.987	0.747	1.683	1.122	0.076
1	0.127	0.266	2.091	3.122	0.762	1.638	1.092	0.139
1.5	0.167	0.359	2.145	3.017	0.751	1.673	1.115	0.187
2	0.197	0.417	2.118	3.068	0.756	1.655	1.104	0.217
5	0.337	0.715	2.121	3.063	0.756	1.657	1.105	0.373
8	0.387	0.819	2.116	3.072	0.757	1.654	1.103	0.427
9	0.400	0.849	2.121	3.063	0.756	1.657	1.105	0.442
12.5	0.422	0.895	2.121	3.062	0.756	1.657	1.105	0.466
15	0.427	0.905	2.122	3.061	0.756	1.658	1.105	0.471
17	0.427	0.904	2.115	3.075	0.757	1.653	1.102	0.471
19	0.427	0.900	2.110	3.084	0.758	1.650	1.100	0.469
20	0.425	0.897	2.110	3.084	0.758	1.650	1.100	0.468
25	0.411	0.868	2.109	3.085	0.758	1.650	1.100	0.452
30	0.391	0.822	2.102	3.099	0.760	1.645	1.097	0.429
40	0.344	0.727	2.114	3.077	0.757	1.652	1.102	0.379
50	0.295	0.623	2.110	3.083	0.758	1.650	1.100	0.325
60	0.246	0.517	2.102	3.100	0.760	1.645	1.097	0.270
70	0.209	0.417	1.992	3.341	0.783	1.576	1.051	0.220
80	0.204	0.417	2.047	3.213	0.771	1.611	1.074	0.219
90	0.201	0.417	2.071	3.162	0.766	1.626	1.084	0.218
95	0.199	0.417	2.091	3.121	0.762	1.638	1.092	0.218
96	0.198	0.417	2.106	3.091	0.759	1.648	1.098	0.217
97	0.198	0.417	2.106	3.091	0.759	1.648	1.098	0.217
98	0.198	0.417	2.106	3.091	0.759	1.648	1.098	0.217
99	0.198	0.417	2.106	3.091	0.759	1.648	1.098	0.217
100	0.198	0.417	2.106	3.091	0.759	1.648	1.098	0.217

A comparison of GMRS (RG 1.208) with UHRS (Mean Plus Sigma) is shown in Fig. 10 and it can be seen that both are almost the same. A summary of PGA values for various cases is given in Table 8. Previously, NDMA [2] has provided details of seismic hazard contours for PI. The PGA value for the 10,000-year return period for a similar PI site is 0.32g. The PGA values from the present study using various methods range between 0.198g to 0.225g. These values are slightly lower than NDMA values due to the difference in the source models, GMPE, etc. Design Response Spectrum (DRS) has been derived based on three approaches. The first one is the "mean+sigma" approach, the second one is the "Performance-Based approach" given in RG 1.208 and the third one is the "Performance-Based approach" using ASCE 43-05, for different fragility parameters. The DRS obtained using three approaches are found to be closely matching to each other at a 10,000-year return period. Hence, it can be observed that all three approaches are appropriate for the evaluation of the DRS of a site. However, component-specific DRS has to be evaluated using the ASCE 43-05 approach for higher floor-mounted components (with β lying between 0.4 to 0.6). Hence, it is concluded that performance-based Design Ground Motion for an NF/NPP site (PB-DRS) can be obtained using either Method-1 (UHRS-Mean Plus Sigma) or Method-2 (GMRS as per RG 1.208). This PB-DRS can be used for performance-based seismic design of typical NF/NPP contain structures like Reactor Building and Containment etc. PB-DRS evaluated using component-specific DRS as per ASCE 43-05 approach can be suitable for performance-based seismic design of higher floor-mounted components. If all SSC of NF/NPP are designed using PB-DRS, stipulated performance goals can be achieved. This results in an acceptable protection level for NF/NPP under low probability of severe earthquakes.

Table 8 Summary of PGA values for various cases

S. No.	Description	PGA (g)
1.	PGA (g) –mean 10,000 years RP	0.198
2.	PGA (g) – (mean +sigma) 10,000 years RP	0.215
3.	PGA (g) – GMRS as per RG 1.208	0.216
4.	PGA (g) – DRS (β 0.3) 10,000 years RP	0.217
5.	PGA (g) – DRS (β 0.4) 10,000 years RP	0.213
6.	PGA (g) – DRS (β 0.5) 10,000 years RP	0.216
7.	PGA (g) – DRS (β 0.6) 10,000 years RP	0.225

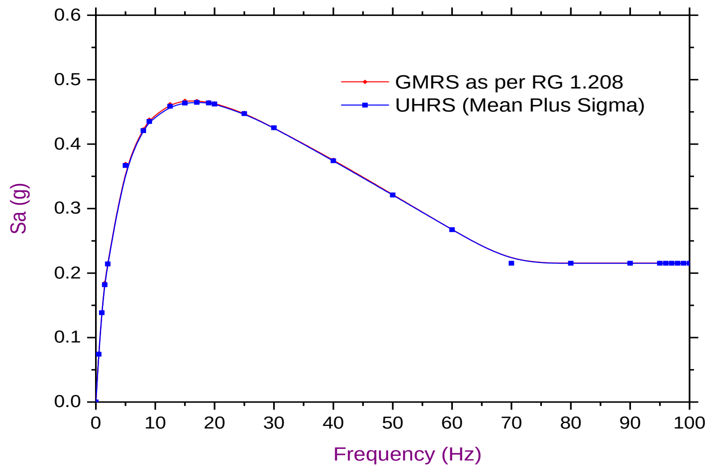

Fig. 10 Comparison of GMRS (RG 1.208) with UHRS (mean plus sigma)

6. Conclusions

PSHA-MEP has been performed to obtain ground motion parameters for a typical Peninsular Indian (PI) site. Three methods are used for the evaluation of the performance-based design response spectrum (PB-DRS) corresponding to the bedrock of the PI site. The following observations are made from the study:

(1) UHRS corresponds to the 84th percentile (Mean plus sigma) for a 10,000-year RP and can be used as the DRS of SSE corresponding to the bedrock of the site.

(2) PGA obtained for a PI Site for a 10,000-year return period with this logic tree (weighted average) is 0.198g and for the 84th percentile (mean plus sigma) for a 10,000-year return period is 0.215g.

(3) PB-GMRS has been generated with the Performance-Based approach provided in RG 1.208. The SSC was designed by using Performance-Based approaches, this PB-GMRS can be used as a DRS of SSE.

(4) Component-specific PB-DRS has been evaluated using the procedure given in ASCE 43-05 and it is observed that the spectral values of PB-DRS are almost the same as GMRS for β of 0.3 and 0.4. It is also observed that DRS for β of 0.5 and 0.6 are slightly more than GMRS.

(5) The DRS obtained using the “mean+sigma approach” and “Performance-Based approach” closely match each other for a 10,000-year return period. Hence, it can be concluded that both approaches are appropriate for the evaluation of the DRS of a site.

(6) For performance-based seismic design of structures like Reactor Building and Containment, etc., PB-DRS obtained from the “mean+sigma approach” or “Performance-Based approach as per RG 1.208” can be used. PB-DRS evaluated using component-specific DRS as per ASCE 43-05 approach can be suitable for performance-based seismic design of higher floor-mounted components.

(7) Performance-based seismic design of entire NF/NPP using PB-DRS results in enhanced protection under low probable but severe seismic events.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] S. T. G. Raghu Kanth and R. N. Iyengar, “Estimation of Seismic Spectral Acceleration in Peninsular India,” Journal of Earth System Science vol. 116, pp. 199-214, 2007.

[2] Technical Report of the Working Committee of Experts of NDMA, “Development of Probabilistic Seismic Hazard Map of India,” Centre for Disaster Mitigation, National Disaster Management Authority (NDMA), Technical Report NDMA/BB /S&T-1 /2007, 2010.

[3] P. Anbazhagan, J. S. Vinod, and T. G. Sitharam, “Probabilistic seismic hazard analysis for Bangalore,” Natural Hazards, vol. 48, pp. 145-166, 2009.

[4] T. G. Sitharam, S. Kolathayar, and N. James, “Probabilistic Assessment of Surface Level Seismic Hazard in India Using Topographic Gradient as a Proxy for Site Condition,” Geoscience Frontiers, vol. 6, no. 6, pp. 847-859, 2015.

[5] A. Scaria, I. D. Gupta, and V. K. Gupta, “An Improved Probabilistic Seismic Hazard Mapping of Peninsular Shield Region of India,” Soil Dynamics and Earthquake Engineering, vol. 141, article no. 106417, 2021.

[6] K. P. Sreejaya, S. T. G. Raghukanth, I. D. Gupta, C. V. R. Murty, and D. Srinagesh, “Seismic Hazard Map of India and Neighbouring Regions,” Soil Dynamics and Earthquake Engineering, vol. 163, article no. 107505, 2022.

[7] Y. Meenakshi, B. Podili, and S. T. G. Raghukanth, “Design Energy Spectra for Peninsular India: A Preliminary Step towards Energy-Based Design in India,” Soil Dynamics and Earthquake Engineering, vol. 177, article no. 108358, 2024.

[8] K. P. Sreejaya and S. T. G. Raghukanth, “A 3D Computational Model for Ground Motion Simulation in Peninsular India,” Physics of the Earth and Planetary Interiors, vol. 353, article no. 107208, 2024.

[9] Regulatory Guide: A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion, Vers. 1.208, Office of Nuclear Regulatory Research, 2007.

[10] Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, ASCE/SEI 43-05, 2005.

[11] Indian Meteorological Department, “Earthquake Catalogue,” https://dsp.imdpune.gov.in/, 2003.

[12] J. C. Stepp, “Analysis of Completeness of the Earthquake Sample in the Puget Sound Area and Its Effect on Statistical Estimates of Earthquake Hazard,” Proceedings of the International Conference on Microzonation, Seattle, U. S. A., Vol. 2, pp. 897-910, 1972.

[13] A. R. Kiran, S. Bandopadhyaya, Santosh, R. Rastogi, G. Vinod, and M. K. Agrawal, et al., “Report on Theme Meeting-Probabilistic seismic hazard analysis with Multi Expert Participation,” Technical Report RSD/RKS/MKA/2014/132557, 2014.

[14] D. L. Wells and K. J. Coppersmith, “New Empirical Relationships among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement,” Bulletin of the Seismological Society of America, vol. 84, no. 4, pp. 974-1002, 1994.

[15] R. L. Wheeler, “Methods of Mmax Estimation East of the Rocky Mountains,” U. S. Geological Survey, Open File Report 2009-1018, 2009.

[16] A. Kijko and M. A. Sellevoll, “Estimation of Earthquake Hazard Parameters from Incomplete Data Files Part II. Incorporation of Magnitude Heterogeneity,” Bulletin of the Seismological Society of America, vol. 82, no. 1, pp. 120-134, 1992.

[17] A. Gogoi, S. Baruah, and S. Sharma, “Regression Analysis of Ground Motion Parameters for the Earthquakes (Mw≥4.0) in NE India with Special Emphasis on 3 Jan 2016 M6.7, Tamenglong Earthquake,” Physics and Chemistry of the Earth, Parts A/B/C, vol. 129, article no. 103316, 2023.

[18] P. Anbazhagan, A. Kumar, and T. G. Sitharam, “Ground Motion Prediction Equation Considering Combined Dataset of Recorded and Simulated Ground Motions,” Soil Dynamics and Earthquake Engineering, vol. 53, pp. 92-108, 2013.

[19] G. M. Atkinson and D. M. Boore, “Modifications to Existing Ground-Motion Prediction Equations in Light of New Data,” Bulletin of the Seismological Society of America, vol. 101, no. 3, pp. 1121-1135, 2011.

[20] S. Pezeshk, A. Zandieh, and B. Tavakoli, “Hybrid Empirical Ground-Motion Prediction Equations for Eastern North America Using NGA Models and Updated Seismological Parameters,” Bulletin of the Seismological Society of America, vol. 101, no. 4, pp. 1859-1870, 2011.
[21] G. R. Toro, N. A. Abrahamson, and J. F. Schneider, “Model of Strong Ground Motions from Earthquakes in Central and Eastern North America: Best Estimates and Uncertainties,” Seismological Research Letters, vol. 68, no. 1, pp. 41-57, 1997.
[22] A. Ravi Kiran, M. K. Agrawal, and J. Chattopadhyay, “Development of a New Ground Motion Model for a Peninsular Indian Rock Site,” Proceedings of Engineering and Technology Innovation, vol. 23, pp. 36-47, 2023.

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Annexure-A Earthquake Data (Magnitude >3)

S. No.	Day	Mo.	Year	Epi-center		M
				Lat.	Long.	
1	-	-	1594	19.10	73.20	3.7
2	26	5	1618	18.90	72.90	6.5
3	0	0	1678	19.10	73.20	5.0
4	-	-	1684	21.20	72.90	3.7
5	-	-	1702	19.70	73.10	3.7
6	4	2	1705	21.75	72.15	7.0
7	9	12	1751	19.10	73.20	4.3
8	5	1	1752	19.10	73.30	4.3
9	5	2	1752	18.70	73.40	4.3
10	31	10	1757	18.20	74.20	3.7
11	-	-	1760	18.50	73.90	3.7
12	17	8	1764	17.90	73.70	6.0
13	29	5	1792	18.50	73.00	4.3
14	23	2	1812	18.50	73.90	3.7
15	9	10	1842	22.30	73.20	4.3
16	27	5	1847	21.40	75.00	6.5
17	26	12	1849	18.90	72.90	3.0
18	-	11	1854	18.90	72.90	3.0
19	8	12	1854	18.90	72.90	3.7
20	25	12	1856	20.00	73.00	5.0
21	27	4	1860	21.17	72.90	3.7
22	18	11	1862	20.87	74.83	3.7
23	4	7	1869	20.20	74.20	4.3
24	12	7	1869	20.90	74.80	4.3
25	3	1	1871	21.20	72.90	3.7
26	27	7	1871	21.17	72.90	3.0
27	14	4	1872	21.70	72.20	4.7
28	12	7	1872	20.87	74.83	3.0
29	22	10	1872	21.63	73.03	3.0
30	-	12	1877	18.93	72.85	3.7
31	6	5	1891	19.07	72.97	3.0
32	27	7	1891	21.33	71.37	3.0
33	30	4	1896	18.98	73.47	3.0
34	16	1	1900	20.42	72.97	3.0
35	21	4	1919	21.70	71.20	6.0
36	20	7	1935	21.00	72.40	5.7
37	16	9	1935	19.10	73.00	3.0
38	28	5	1941	18.00	73.10	4.3
39	8	4	1951	18.50	70.80	6.0
40	-	-	1951	17.30	73.20	4.7
41	28	10	1964	17.63	73.79	3.5
42	3	11	1964	17.40	73.74	3.4
43	9	8	1965	17.40	73.74	3.1
44	6	11	1965	17.39	73.77	3.8
45	8	11	1965	17.41	73.80	3.6

S. No.	Day	Mo.	Year	Epi-center		M
				Lat.	Long.	
184	2	4	1971	17.47	73.8	3.3
185	14	4	1971	17.38	73.78	3.3
186	14	5	1971	17.42	73.77	3.3
187	6	6	1971	17.42	73.75	3.1
188	10	6	1971	17.40	73.7	3.2
189	15	6	1971	17.45	73.62	3.5
190	7	8	1971	17.40	73.75	3.0
191	11	8	1971	17.34	73.62	3.2
192	25	8	1971	17.44	73.78	3.0
193	18	9	1971	17.40	73.79	3.0
194	22	9	1971	17.38	73.75	3.0
195	27	9	1971	17.41	73.78	3.0
196	26	10	1971	17.45	73.76	3.0
197	22	11	1971	17.39	73.75	4.2
198	21	1	1972	17.39	73.77	3.3
199	27	2	1972	17.37	73.73	3.4
200	2	3	1972	17.56	73.56	3.2
201	8	3	1972	17.54	73.62	3.0
202	3	4	1972	17.39	73.71	3.0
203	6	4	1972	17.48	73.53	3.0
204	30	4	1972	17.38	73.72	3.5
205	1	5	1972	17.43	73.83	3.6
206	4	5	1972	17.38	73.79	3.0
207	21	5	1972	17.48	73.51	3.3
208	30	5	1972	17.43	73.77	3.6
209	4	6	1972	17.38	73.73	3.7
210	6	6	1972	17.52	73.56	3.1
211	13	6	1972	17.40	73.80	3.2
212	13	6	1972	17.42	73.79	3.0
213	16	8	1972	17.37	73.77	3.2
214	25	8	1972	17.41	73.78	3.3
215	16	9	1972	17.41	73.77	3.3
216	19	9	1972	17.49	73.58	3.3
217	23	9	1972	17.36	73.73	3.5
218	13	10	1972	17.43	73.76	3.0
219	13	2	1973	17.59	73.74	3.0
220	6	3	1973	17.34	73.67	3.5
221	1	4	1973	17.51	73.53	3.1
222	2	4	1973	17.36	73.75	3.7
223	2	4	1973	17.38	73.75	3.3
224	4	4	1973	17.51	73.67	3.0
225	19	4	1973	17.37	73.72	3.8
226	19	4	1973	17.42	73.65	3.1
227	5	6	1973	17.41	73.75	3.6
228	2	7	1973	17.39	73.76	3.0

S. No.	Day	Mo.	Year	Epi-center		M
				Lat.	Long.	
46	9	11	1965	17.46	73.78	3.8
47	13	12	1965	19.20	73.00	3.7.
48	17	2	1966	17.44	73.75	3.0
49	29	5	1966	17.40	73.75	3.0
50	24	9	1966	17.35	73.73	3.1
51	30	9	1966	17.38	73.76	3.3
52	5	10	1966	17.37	73.75	3.1
53	14	1	1967	17.41	73.77	3.2
54	18	1	1967	17.41	73.72	3.2
55	23	3	1967	17.37	73.77	3.2
56	30	6	1967	17.43	73.72	3.3
57	2	7	1967	17.43	73.72	3.1
58	12	9	1967	17.43	73.72	3.9
59	13	9	1967	17.40	73.70	5.5
60	20	9	1967	17.41	73.72	3.2
61	22	9	1967	17.39	73.77	3.5
62	24	9	1967	17.39	73.77	3.0
63	29	10	1967	17.35	73.65	3.1
64	8	11	1967	17.39	73.78	3.5
65	9	11	1967	17.43	73.73	3.2
66	13	11	1967	17.44	73.74	3.1
67	16	11	1967	17.44	73.85	3.5
68	21	11	1967	17.41	73.75	3.2
69	1	12	1967	17.41	73.75	3.2
70	1	12	1967	17.38	73.78	3.5
71	2	12	1967	17.42	73.76	3.2
72	9	12	1967	17.38	73.71	3.2
73	10	12	1967	17.37	73.75	6.5
74	3	1	1968	17.36	73.70	4.0
75	4	1	1968	17.41	73.73	3.5
76	7	1	1968	17.43	73.79	3.8
77	8	1	1968	17.39	73.73	3.0
78	12	1	1968	17.38	73.75	4.1
79	13	1	1968	17.55	73.42	3.1
80	15	1	1968	17.36	73.70	3.3
81	16	1	1968	17.41	73.75	4.0
82	17	1	1968	17.38	73.69	3.5
83	18	1	1968	17.42	73.76	3.1
84	20	1	1968	17.45	73.77	3.2
85	21	1	1968	17.40	73.64	3.1
86	27	1	1968	17.36	73.71	3.5
87	27	1	1968	17.35	73.71	3.5
88	7	2	1968	17.41	73.70	4.3
89	8	2	1968	17.41	73.65	3.6
90	9	2	1968	17.46	73.79	3.0
91	9	2	1968	17.46	73.68	3.0
92	11	2	1968	17.36	73.73	3.3

S. No.	Day	Mo.	Year	Epi-center		M
				Lat.	Long	
229	10	7	1973	17.38	73.79	3.4
230	14	9	1973	17.33	73.58	3.6
231	18	9	1973	17.48	73.81	3.7
232	6	10	1973	17.41	73.79	3.0
233	17	10	1973	17.54	73.75	3.2
234	17	10	1973	17.41	73.72	5.2
235	17	4	1974	17.46	73.51	3.9
236	19	4	1974	17.35	73.66	3.6
237	20	4	1974	17.38	73.70	3.6
238	23	4	1974	17.50	73.54	3.1
239	24	4	1974	17.45	73.55	3.3
240	25	4	1974	17.50	73.52	3.9
241	27	4	1974	17.38	73.67	3.1
242	28	4	1974	17.35	73.69	3.8
243	29	4	1974	17.52	73.58	3.2
244	1	5	1974	17.41	73.42	3.3
245	29	5	1974	17.49	73.47	3.5
246	28	7	1974	17.39	73.74	3.5
247	30	7	1974	17.35	73.66	3.9
248	8	8	1974	17.42	73.73	3.0
249	10	8	1974	17.52	73.51	3.1
250	12	8	1974	17.51	73.55	3.0
251	15	8	1974	19.73	71.02	4.8
252	18	9	1974	17.38	73.66	3.5
253	20	12	1974	17.41	73.74	3.8
254	27	2	1975	17.36	73.74	3.4
255	16	4	1975	17.37	73.76	3.0
256	2	9	1975	17.36	73.69	4.0
257	2	12	1975	17.34	73.61	3.8
258	29	12	1975	17.35	73.72	3.3
259	21	3	1976	17.41	73.75	3.1
260	22	4	1976	17.34	73.67	3.7
261	25	7	1976	17.39	73.75	3.0
262	9	8	1976	17.39	73.73	3.1
263	8	9	1976	17.37	73.75	3.1
264	5	11	1976	17.52	73.57	3.5
265	9	11	1976	17.50	73.53	3.1
266	12	11	1976	17.52	73.53	3.3
267	12	12	1976	17.37	73.73	3.9
268	13	7	1977	17.41	73.75	3.1
269	26	8	1977	17.35	73.72	3.3
270	13	3	1978	17.60	73.26	3.2
271	2	4	1978	17.33	73.66	3.4
272	24	6	1978	17.38	73.76	3.3
273	1	7	1978	17.39	73.73	3.3
274	14	11	1978	17.37	73.77	3.6
275	22	11	1978	17.47	73.54	3.5

S. No.	Day	Mo.	Year	Epi-center		M
				Lat	Long.	
93	11	2	1968	17.34	73.67	3.1
94	12	2	1968	17.34	73.68	4.5
95	20	2	1968	17.36	73.71	3.1
96	20	2	1968	17.46	73.73	3.7
97	22	2	1968	17.38	73.76	3.0
98	3	3	1968	17.46	73.75	3.2
99	7	3	1968	17.36	73.70	3.0
100	9	3	1968	17.36	73.64	3.2
101	19	3	1968	17.40	73.75	3.0
102	23	3	1968	17.40	73.76	3.1
103	28	3	1968	17.34	73.59	3.5
104	30	3	1968	17.37	73.68	3.2
105	9	4	1968	17.41	73.77	3.0
106	1	5	1968	17.43	73.79	3.3
107	22	5	1968	17.40	73.75	3.2
108	9	6	1968	17.50	73.40	3.1
109	9	6	1968	17.45	73.73	3.0
110	10	6	1968	17.57	73.27	3.5
111	10	6	1968	17.53	73.45	3.3
112	14	6	1968	17.55	73.25	3.0
113	5	7	1968	17.40	73.78	3.2
114	26	7	1968	17.41	73.79	3.5
115	28	7	1968	17.37	73.77	3.5
116	30	7	1968	17.44	73.78	3.2
117	30	7	1968	17.41	73.79	3.3
118	10	8	1968	17.40	73.80	3.1
119	24	8	1968	17.37	73.66	3.5
120	31	8	1968	17.35	73.71	4.1
121	7	9	1968	17.42	73.69	3.2
122	19	9	1968	17.44	73.70	3.0
123	20	9	1968	17.35	73.56	4.2
124	22	9	1968	17.41	73.73	3.1
125	23	9	1968	17.39	73.72	3.2
126	8	10	1968	17.33	73.57	3.1
127	29	10	1968	17.41	73.84	4.7
128	29	10	1968	17.41	73.84	4.6
129	30	10	1968	17.38	73.76	3.3
130	10	11	1968	17.44	73.80	3.5
131	23	11	1968	17.39	73.66	3.5
132	25	11	1968	17.39	73.63	3.2
133	3	12	1968	17.37	73.63	3.0
134	5	12	1968	17.51	73.60	4.3
135	10	12	1968	17.41	73.78	3.0
136	11	12	1968	17.36	73.75	3.1
137	19	1	1969	17.41	73.73	3.2
138	21	1	1969	17.40	73.75	3.6
139	27	1	1969	17.35	73.71	3.5

S. No.	Day	Mo.	Year	Epi-center		M
				Lat	Long.	
276	8	1	1979	17.34	73.47	3.6
277	28	2	1979	17.37	73.72	3.2
278	11	7	1979	17.37	73.76	3.0
279	10	10	1979	17.35	73.65	3.1
280	13	8	1980	17.46	73.70	3.1
281	19	4	1981	17.36	73.74	3.2
282	28	4	1981	17.91	73.72	3.0
283	2	5	1981	17.46	73.79	3.6
284	10	1	1982	17.49	73.64	3.1
285	8	5	1983	17.34	73.68	3.2
286	20	6	1983	17.42	73.80	3.4
287	14	9	1983	19.64	73.54	4.2
288	15	11	1984	17.35	73.63	3.2
289	11	12	1985	17.33	73.64	3.1
290	26	2	1986	20.58	73.90	4.2
291	21	4	1987	17.60	73.80	3.1
292	17	5	1988	17.38	73.69	3.4
293	31	7	1988	17.38	73.78	3.0
294	21	6	1989	20.10	72.90	4.0
295	10	11	1989	17.36	73.73	3.2
296	12	8	1991	18.35	71.60	3.9
297	10	7	1993	17.30	73.50	3.8
298	24	8	1993	20.60	71.30	4.9
299	4	9	1993	17.40	73.60	3.1
300	22	10	1993	17.36	73.61	4.3
301	31	12	1993	21.20	70.60	4.2
302	31	12	1993	21.12	72.72	4.2
303	12	3	1995	17.90	73.40	4.6
304	21	1	1996	17.40	72.20	3.2
305	4	2	1996	17.40	73.60	3.7
306	17	11	1996	21.50	73.00	4.1
307	17	11	1996	21.40	73.06	4.4
308	25	4	1997	17.40	73.70	3.7
309	1	3	1998	17.30	73.50	3.4
310	31	5	1998	19.02	73.09	3.6
311	8	6	1998	17.37	73.70	3.0
312	3	7	1998	17.41	73.77	3.2
313	17	7	1999	21.84	74.16	3.0
314	21	9	1999	21.81	71.93	3.0
315	25	2	2000	17.93	71.16	3.5
316	14	4	2000	21.86	74.51	3.4
317	13	8	2000	21.03	70.94	4.4
318	12	9	2000	21.81	72.42	4.3
319	13	9	2000	21.70	72.15	3.2
320	13	9	2000	21.70	72.14	3.1
321	14	9	2000	21.73	72.14	3.1
322	27	2	2001	21.40	71.58	3.7

S. No.	Day	Mo.	Year	Epi-center		M
				Lat	Long.	
140	10	2	1969	17.33	73.61	3.0
141	13	2	1969	17.41	73.63	4.3
142	13	2	1969	17.35	73.71	3.5
143	28	2	1969	17.41	73.44	3.1
144	3	3	1969	17.33	73.63	3.8
145	9	3	1969	17.39	73.77	3.0
146	18	3	1969	17.40	73.77	3.4
147	26	3	1969	17.38	73.77	3.4
148	15	4	1969	17.43	73.74	3.0
149	29	5	1969	17.40	73.74	3.1
150	15	6	1969	17.41	73.72	3.0
151	16	6	1969	17.67	73.30	3.3
152	27	6	1969	17.40	73.73	4.7
153	11	7	1969	17.35	73.72	3.0
154	22	7	1969	17.36	73.73	3.7
155	17	8	1969	17.39	73.76	3.3
156	11	9	1969	17.35	73.73	3.0
157	14	9	1969	17.39	73.77	3.0
158	16	9	1969	17.42	73.77	3.3
159	23	9	1969	17.41	73.75	3.2
160	1	10	1969	17.41	73.74	3.1
161	4	10	1969	17.38	73.77	3.1
162	6	10	1969	17.40	73.75	3.0
163	20	10	1969	17.42	73.77	3.2
164	4	11	1969	17.41	73.79	3.7
165	5	11	1969	17.45	73.80	3.0
166	24	2	1970	17.43	73.79	3.0
167	5	3	1970	17.40	73.81	3.4
168	23	3	1970	21.60	72.96	5.2
169	16	4	1970	17.40	73.76	3.6
170	2	5	1970	17.41	73.79	3.2
171	4	5	1970	17.41	73.75	3.3
172	8	5	1970	17.36	73.72	3.5
173	23	5	1970	17.35	73.69	3.1
174	20	6	1970	17.39	73.77	3.2
175	30	6	1970	17.45	73.76	3.3
176	6	8	1970	17.93	73.70	3.5
177	9	9	1970	17.37	73.77	3.3
178	21	9	1970	17.41	73.76	3.7
179	25	9	1970	17.42	73.66	3.0
180	25	9	1970	17.38	73.79	4.2
181	26	9	1970	17.36	73.65	4.4
182	25	11	1970	17.38	73.71	3.1
183	6	2	1971	17.40	73.79	3.2

S. No.	Day	Mo.	Year	Epi-center		M
				Lat	Long.	
323	11	11	2001	21.18	70.52	3.0
324	22	12	2001	19.73	72.76	3.3
325	6	2	2002	20.63	74.78	3.0
326	1	12	2002	20.70	73.62	3.0
327	20	12	2002	19.81	70.90	3.0
328	12	2	2003	20.14	72.50	3.1
329	14	3	2003	17.78	73.64	3.4
330	22	3	2003	17.42	73.79	3.7
331	27	3	2003	17.38	73.80	4.0
332	8	5	2003	17.42	73.80	3.2
333	12	5	2003	18.43	73.08	3.2
334	27	7	2003	21.88	74.34	4.2
335	14	8	2004	21.10	71.13	3.2
336	30	11	2004	21.14	70.58	3.0
337	11	12	2004	21.01	70.61	3.2
338	16	12	2004	17.38	73.80	3.5
339	1	3	2005	21.19	70.54	3.3
340	1	3	2005	21.18	70.53	3.5
341	14	6	2005	19.24	73.20	3.7
342	18	6	2005	19.14	73.21	3.1
343	4	11	2005	20.18	73.41	3.1
344	26	2	2006	21.14	70.50	3.2
345	31	3	2006	17.46	73.81	3.6
346	29	6	2006	17.60	74.06	3.0
347	16	8	2006	17.49	73.80	3.2
348	27	6	2007	17.57	73.97	3.0
349	6	11	2007	21.17	70.55	4.7
350	6	11	2007	21.25	70.61	4.9
351	14	12	2007	17.32	73.64	3.2
352	1	1	2008	21.16	70.60	3.5
353	1	1	2008	20.58	70.25	3.7
354	24	1	2008	20.91	70.18	3.0
355	31	3	2008	20.94	70.28	3.4
356	2	5	2008	21.22	72.85	3.1
357	20	5	2008	21.50	72.84	3.1
358	29	7	2008	17.64	74.17	4.9
359	8	8	2008	19.40	72.24	3.0
360	16	9	2008	17.40	73.76	4.9
361	5	10	2008	21.22	71.00	4.3
362	14	10	2008	21.06	70.54	3.3
363	9	11	2008	17.36	73.75	3.0
364	15	4	2010	18.69	74.31	3.3
365	20	10	2011	21.17	70.50	5.2
366	12	11	2011	21.15	70.51	4.3