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Supplementary Information with "Risk-Targeted Importance Factors for Prescriptive Seismic Design of Critical Buildings"

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Summary

The present technical report provides supplementary details and data for the article titled, *Risk-Targeted Importance Factors for Prescriptive Seismic Design of Critical Buildings* by Badal & Sinha [1] (hereinafter referred to as *the article*). The article proposes a framework to determine risk-targeted importance factors suitable for use with prescriptive design standards. As an illustration, six special reinforced concrete (RC) moment frame buildings conforming to Indian standards [2–4] are considered in the article. The example buildings are selected from a larger ensemble of special RC moment frame buildings [5]. Further, the article ascertains fragility of the example buildings using rigorous incremental dynamic analyses (IDA) [6]. In the proposed framework [1], ensemble of ground motion records for carrying out nonlinear time history analyses is recommended to be based on ensuring a multi-site hazard-consistency [7] or, at the simplest, matching condition spectra (CS). The CS represents conditional mean spectrum (CMS) along with the covariance matrix of spectral ordinates [8].

In Chapter 1 of the present report, ground motion selection along with the inputs from PSHA is presented in tabular format. Results for seismic hazard are taken from an ongoing national PSHA study [9]. A suite of 22×2 ground motion time history records are selected for each example building. The ground motion records are selected from the extensive database of NGA West2 [10]. Algorithms for selecting ground motion records are based on Jayaram *et al.* [11]. The chapter also shows the characteristics of selected ground motion suites and compares the distribution of their response spectra against the targeted CS.

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1. Selection of Ground Motion Suite

The proposed framework in the article is illustrated using six special RC frame buildings located in high seismic regions (Zone-IV) with PGA_{2475} = 0.24g (e.g., Delhi) and very high seismic regions (Zone-V) with PGA_{2475} = 0.36g (e.g., Guwahati) [2]. The seismic hazard results have been taken from an ongoing national PSHA study [9]. Coordinates of Delhi are considered as (28.62°N, 77.22°E) and that of Guwahati as (26.17°N, 91.77°E). **Fig. 1** is reproduced from the article. **Fig. 1a** shows the hazard curve for PGA, whereas **Fig. 1b** compares the design standard response spectra with site-specific spectra for a 475-year return period. **Fig. 1c–d** depict a range of hazard curves for different spectral acceleration. Hazard curves correspond to a reference rock site (shear wave velocity in upper 30 m, V_{s30} = 760 m/s).

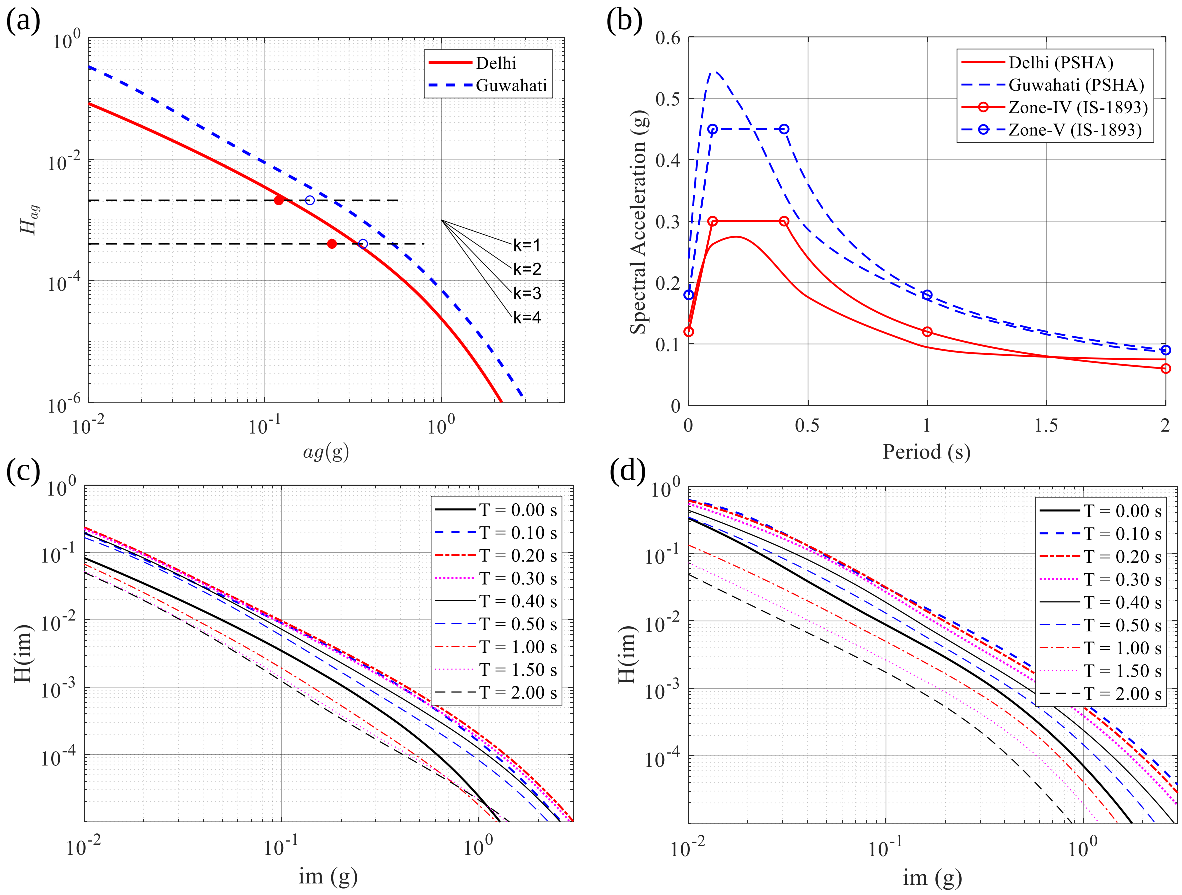

Fig. 1. (a) Hazard curves for peak ground acceleration, ag, of locations under this study [9]. DBE (Tr = 475 year) and MCE (Tr = 2475 year) are marked with dashed horizontal lines. Solid and hollow markers denote design standard-specified seismic hazard for Delhi and Guwahati, respectively [2]. Different slopes in log-log space are also marked. (b) PSHA-based and design-standard uniform hazard spectrum for the return period of 475 years. Hazard curves for (c) Delhi and (d) Guwahati for spectral accelerations at various periods.

Table 1 shows the hazard values for all example buildings. Hazard deaggregation results corresponding to return periods, $Tr = 475$ y and 2475 y are also shown in the table. The article uses hazard deaggregation corresponding to 2475y return period target. Ground motion prediction model (GMPM) used for the determination of spectral shape factor ($\bar{\varepsilon}$) are taken as the predominant model considered in the PSHA study. For Zone-IV site, CB14 [12] and for Zone-V site, BCH16 [13] GMPMs have been used. The scaling factor to match spectral ordinate on conditioning period has been limited to 2. The error in selected ground motion record compared to the targeted record and its dispersion in minimized over the range of the 0.2 to 2.0 times of conditioning period, T^*.

Table 1
Typical seismic risk categories and importance factors in design standards.

Building ID	Zone	N_{st}	$T^* = T_1$ (s)	$Sa(T_1)$ (g)		Tr = 475y			Tr = 2475y		
				Tr = 475y	Tr = 2475y	$\bar{M}$	$\bar{R}$ (km)	$\bar{\varepsilon}$	$\bar{M}$	$\bar{R}$ (km)	$\bar{\varepsilon}$
2211	IV	2	1.06	0.091	0.223	5.84	16.9	0.93	6.19	13.0	1.32
2213	IV	4	1.72	0.076	0.186	5.91	16.3	1.65	6.32	13.8	1.91
2215	IV	7	2.55	0.071	0.169	6.01	16.4	2.27	6.46	14.5	2.30
2219	V	2	0.96	0.179	0.442	5.85	0.1	0.92	7.47	14.7	0.78
2221	V	4	1.55	0.111	0.303	6.59	8.7	1.08	7.57	15.7	1.02
2223	V	7	2.39	0.074	0.194	7.26	16.6	0.61	7.60	15.8	1.21

N_{st}: Number of stories
T_1: Analytical vibration period corresponding to the first mode
T^*: Conditioning period for spectral matching. Taken as equal to T_1
Tr: Return period of interst
$(\bar{M}, \bar{R}, \bar{\varepsilon})$: Modal magnitude, distance (Joyner-Boore), and spectral shape factor from PSHA

Fig. 2 shows the response spectra for selected ground motion suite for all example buildings. Conditional spectra with 2.5 and 97.5%ile are also shown. The selected ground motion records are found to accurately match the mean and target dispersion in the range of the period of vibration. **Table 2** through **Table 7** enlist the selected ground motion IDs given by their RSN [10], magnitude, distance (R_{JB}), closest distance ($ClosestD$), and event code.

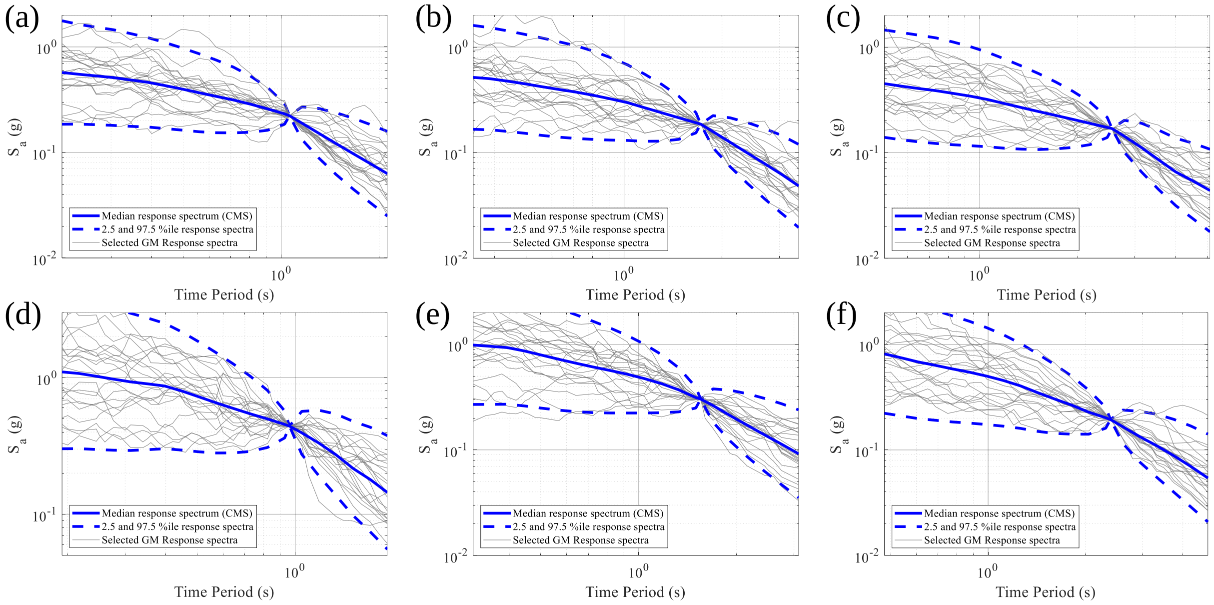

Fig. 2. Response spectra of selected ground motion suites along with conditional mean spectrum and 2.5–97.5%ile spectral ordinates for 2-, 4-, and 7-story buildings in (a, b, c) Zone-IV and in (d, e, f) Zone-V.

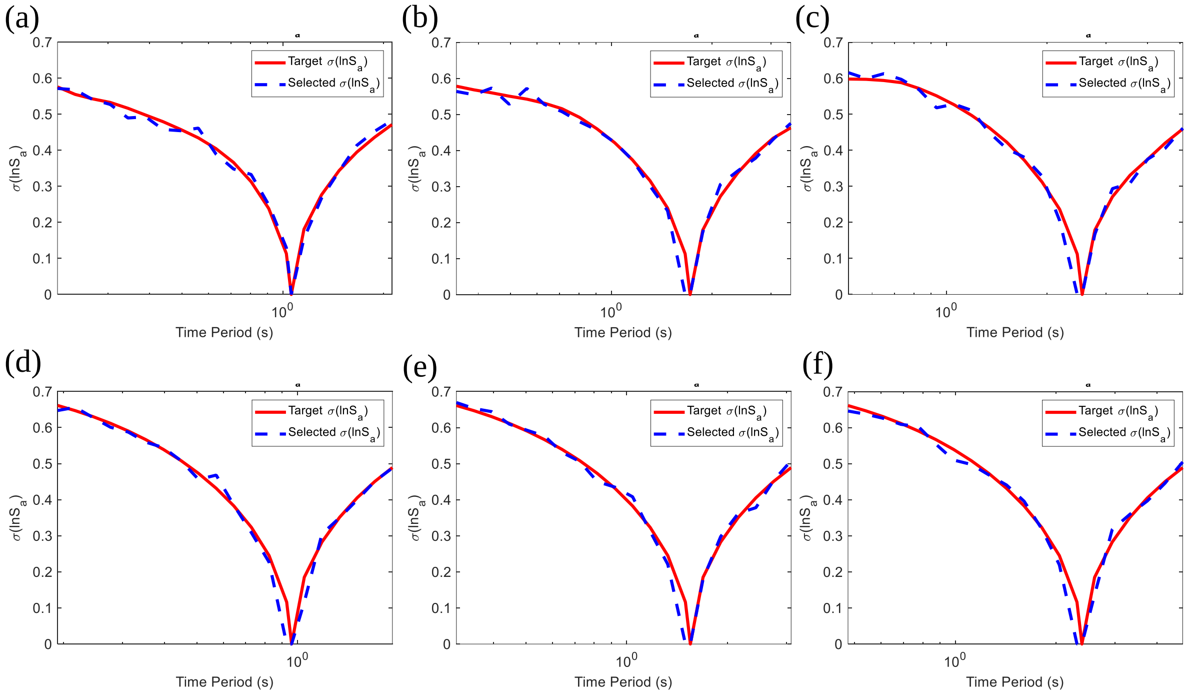

Fig. 3. Comparison of target and selected standard deviation in logarithm of spectral ordinates for 2-, 4-, and 7-story buildings in (a, b, c) Zone-IV and in (d, e, f) Zone-V.

Table 2
Selected ground motion records for Building ID 2211

S. No.	RSN	Event Code	*M*	R_{JB} (km)	*ClosestD*† (km)
1	31	PARKF	6.19	12.9	12.9
2	160	IMPVALL	6.53	0.4	2.7
3	183	IMPVALL	6.53	3.9	3.9
4	212	LIVERMOR	5.8	23.9	25.0
5	285	ITALY	6.9	8.1	8.2
6	341	COALINGA	6.36	37.9	39.0
7	352	COALINGA	6.36	38.1	39.1
8	408	COALINGA	5.77	6.3	11.1
9	409	COALINGA	5.77	6.3	11.1
10	457	MORGAN	6.19	13.0	13.0
11	458	MORGAN	6.19	11.5	11.5
12	461	MORGAN	6.19	3.5	3.5
13	633	WHITTIER	5.99	10.5	17.9
14	692	WHITTIER	5.99	11.5	18.5
15	786	LOMAP	6.93	30.6	30.8
16	952	NORTHR	6.69	12.4	18.4
17	968	NORTHR	6.69	43.2	46.7
18	987	NORTHR	6.69	20.4	28.3
19	1135	KOZANI	5.1	9.4	10.3
20	1436	CHICHI	7.62	98.5	99.2
21	2395	CHICHI02	5.9	5.6	8.6
22	2627	CHICHI03	6.2	13.0	14.7

†Closest distance to the ruptured area

Table 3
Selected ground motion records for Building ID 2213

S. No.	RSN	Event Code	*M*	R_{JB} (km)	*ClosestD*† (km)
1	230	MAMMOTH	6.06	1.1	6.6
2	250	MAMMOTH	5.94	9.7	16.0
3	339	COALINGA	6.36	28.0	29.4
4	548	CHALFANT	6.19	21.6	21.9
5	720	SUPERST	6.54	27.0	27.0
6	753	LOMAP	6.93	0.2	3.9
7	832	LANDERS	7.28	69.2	69.2
8	836	LANDERS	7.28	87.9	87.9
9	850	LANDERS	7.28	21.8	21.8
10	873	LANDERS	7.28	164.0	164.0
11	931	BIGBEAR	6.46	35.0	35.2
12	970	NORTHR	6.69	44.5	44.8
13	989	NORTHR	6.69	9.9	20.5
14	1078	NORTHR	6.69	1.7	16.7
15	1158	KOCAELI	7.51	13.6	15.4
16	1292	CHICHI	7.62	60.2	63.4
17	1316	CHICHI	7.62	85.9	88.2
18	1361	CHICHI	7.62	72.2	74.5
19	1532	CHICHI	7.62	17.2	17.2
20	2618	CHICHI03	6.2	25.2	26.1
21	2661	CHICHI03	6.2	21.1	22.1
22	3270	CHICHI06	6.3	44.2	45.3

Table 4
Selected ground motion records for Building ID 2215

S. No.	RSN	Event Code	*M*	R_{JB} (km)	*ClosestD*† (km)
1	158	IMPVALL	6.53	0.0	0.3
2	300	ITALY	6.2	8.8	8.8
3	571	SMART1	7.3	53.3	53.3
4	728	SUPERST	6.54	13.0	13.0
5	737	LOMAP	6.93	24.3	24.6
6	757	LOMAP	6.93	35.3	35.5
7	884	LANDERS	7.28	36.2	36.2
8	949	NORTHR	6.69	3.3	8.7
9	988	NORTHR	6.69	15.5	23.4
10	1111	KOBE	6.9	7.1	7.1
11	1120	KOBE	6.9	1.5	1.5
12	1182	CHICHI	7.62	9.8	9.8
13	1193	CHICHI	7.62	9.6	9.6
14	1309	CHICHI	7.62	90.6	92.8
15	1344	CHICHI	7.62	84.0	86.3
16	1418	CHICHI	7.62	101.6	103.5
17	1475	CHICHI	7.62	56.0	56.1
18	1538	CHICHI	7.62	27.5	27.5
19	1628	STELIAS	7.54	26.5	26.5
20	2457	CHICHI03	6.2	18.5	19.7
21	2509	CHICHI03	6.2	34.4	35.1
22	2734	CHICHI04	6.2	6.0	6.2

Table 5
Selected ground motion records for Building ID 2219

S. No.	RSN	Event Code	*M*	R_{JB} (km)	*ClosestD*[†] (km)
1	96	MANAGUA	5.2	4.3	5.0
2	407	COALINGA	5.77	2.0	8.5
3	639	WHITTIER	5.99	4.5	15.2
4	727	SUPERST	6.54	5.6	5.6
5	728	SUPERST	6.54	13.0	13.0
6	744	LOMAP	6.93	50.7	51.0
7	773	LOMAP	6.93	54.0	54.2
8	825	CAPEMEND	7.01	0.0	7.0
9	879	LANDERS	7.28	2.2	2.2
10	902	BIGBEAR	6.46	39.5	40.5
11	952	NORTHR	6.69	12.4	18.4
12	959	NORTHR	6.69	0.0	14.7
13	987	NORTHR	6.69	20.4	28.3
14	1004	NORTHR	6.69	0.0	8.4
15	1050	NORTHR	6.69	4.9	7.0
16	1077	NORTHR	6.69	17.3	26.5
17	1087	NORTHR	6.69	0.4	15.6
18	1238	CHICHI	7.62	22.7	22.7
19	1546	CHICHI	7.62	9.3	9.3
20	1762	HECTOR	7.13	41.8	43.1
21	2739	CHICHI04	6.2	12.4	12.5
22	3474	CHICHI06	6.3	1.0	10.1

Table 6
Selected ground motion records for Building ID 2221

S. No.	RSN	Event Code	M	R_{JB} (km)	$ClosestD^{\dagger}$ (km)
1	6	IMPVALL	6.95	6.1	6.1
2	95	MANAGUA	6.24	3.5	4.1
3	96	MANAGUA	5.2	4.3	5.0
4	143	TABAS	7.35	1.8	2.1
5	150	COYOTELK	5.74	0.4	3.1
6	265	VICT	6.33	13.8	14.4
7	359	COALINGA	6.36	24.8	26.4
8	495	NAHANNI	6.76	2.5	9.6
9	529	PALMSPR	6.06	0.0	4.0
10	564	GREECE	6.2	6.5	6.5
11	727	SUPERST	6.54	5.6	5.6
12	752	LOMAP	6.93	8.7	15.2
13	766	LOMAP	6.93	10.4	11.1
14	808	LOMAP	6.93	77.3	77.4
15	1004	NORTHR	6.69	0.0	8.4
16	1050	NORTHR	6.69	4.9	7.0
17	1120	KOBE	6.9	1.5	1.5
18	1166	KOCAELI	7.51	30.7	30.7
19	1292	CHICHI	7.62	60.2	63.4
20	1489	CHICHI	7.62	3.8	3.8
21	1492	CHICHI	7.62	0.0	0.7
22	2752	CHICHI04	6.2	21.6	21.7

Table 7
Selected ground motion records for Building ID 2223

S. No.	RSN	Event Code	M	R_{JB} (km)	*ClosestD*† (km)
1	77	SFERN	6.61	0.0	1.8
2	160	IMPVALL	6.53	0.4	2.7
3	180	IMPVALL	6.53	1.8	4.0
4	495	NAHANNI	6.76	2.5	9.6
5	529	PALMSPR	6.06	0.0	4.0
6	753	LOMAP	6.93	0.2	3.9
7	806	LOMAP	6.93	23.9	24.2
8	1042	NORTHR	6.69	7.9	12.5
9	1044	NORTHR	6.69	3.2	5.9
10	1054	NORTHR	6.69	5.5	7.5
11	1063	NORTHR	6.69	0.0	6.5
12	1086	NORTHR	6.69	1.7	5.3
13	1087	NORTHR	6.69	0.4	15.6
14	1101	KOBE	6.9	11.3	11.3
15	1262	CHICHI	7.62	49.3	53.2
16	1477	CHICHI	7.62	30.2	30.2
17	1511	CHICHI	7.62	2.7	2.7
18	1521	CHICHI	7.62	0.0	9.0
19	1787	HECTOR	7.13	10.4	11.7
20	1792	HECTOR	7.13	74.0	74.0
21	3275	CHICHI06	6.3	45.1	46.2
22	3317	CHICHI06	6.3	34.6	36.0

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