Determination of Design Acceleration Spectra for Different Site Conditions, Magnitudes, Safety Levels and Damping Ratios in Iran

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Abstract: *By application of design spectra in seismic analyses, determination of design spectra for different site conditions, magnitudes, safety levels and damping ratios will improve the accuracy of seismic analysis results. The result of this research provides different design acceleration spectra based on Iran earthquakes database for different conditions. For this purpose first a set of 146 records was selected according to causative earthquake specifications, device error modification and site conditions. Then the design acceleration spectra are determined for 4 different site conditions presented in Iranian code of practice for seismic resistant design of buildings (Standard No. 2800), different magnitudes ($M_S \leqq 5.5$ & $M_S > 5.5$), different damping ratios (0, 2, 5, 10, 20 percent) and also various safety levels (50% & 84%). Also this research compares the determined design spectra with those in Standard No. 2800.*

Keywords: *Design Acceleration Spectrum; Site Conditions; Magnitude; Safety Level; Damping.*

1. Introduction

Design spectra are used in seismic analysis methods such as equivalent static lateral force analysis, dynamic spectral analysis and time history dynamic analysis. Design spectra are directly used in the first and second methods and indirectly in the last method.

Design spectra are determined by various techniques categorized in two main methods:

1. Methods based on hazard analysis: These methods are suitable for regions that there are not enough earthquake records for them. These types of methods are using hazard analysis by considering region's earthquakes history, active faults and also fault distance to the region. In these methods statistical-probabilistic techniques are utilized for determination of design spectra.

2. Methods using actual earthquake records: These methods are useful for regions with enough reliable records gathered for different site conditions. The design spectrum could be derived from response spectrum of records by the mean of mathematical methods. Response spectrum is the maximum response of a single degree of freedom system to a specific excitement as a function of natural frequency and damping of the system.

Due to existence of more than 3000 records for different types of grounds in Iran, by using an accurate method, appropriate design spectra could be resulted.

In Iranian code of practice for seismic resistant design of buildings - Standard No. 2800 [1] dynamic spectral analysis is one of the accepted methods, but application of spectra in Standard No. 2800 may cause some kinds of inaccuracy since:

- It is not clarified that the presented spectra is related to which safety level.
- The effect of earthquake magnitude is not considered in design spectra.
- The presented spectra are applicable just for 5 percent damping ratio.

Regard to the mentioned parameters, this research tries to generate a complete set of design acceleration spectra needed for structural design by considering the ground type, earthquake

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magnitude, different damping ratios and also various safety levels. Finally the achieved spectra are compared with the design spectra of Standard No. 2800.

2. History and Theoretical Aspects

2.1 Effect of Soil Characteristics on Response and Design Spectra

Before the San Fernando earthquake (1971) there were not enough recorded accelograms for previous earthquakes and the existing accelograms were recorded on alluvial soils and the effect of soil characteristics was not concluded in them. Further studies by Hayashi et al. [2] in 1971 and also Kuribayashi et al. [3] in 1972 clarified that the soil characteristics have important effects on spectral shapes. Complementary researches by Mohraz et al. [4] in 1972 and addition studies of Hall et al. [5] in 1975 have also stated this effect.

Significant data achieved after San Fernando earthquake have provided the opportunity to investigate the effects of soil characteristics on ground motions and response spectra. By the same target another research is done by Seed et al. [6] and also Mohraz [7].

2.2 Effect of Earthquake Magnitude and Duration on Response and Design Spectra

Determination of peak ground acceleration at a certain zone depends on the earthquake magnitude and epicenteral distance, thus earthquake magnitude certainly affects the spectral amplification. Mohraz [8] in 1978 on the effect of earthquake magnitude on response amplification shows that acceleration amplification for earthquakes having $6<M<7$ is more than the amplification for earthquakes having magnitude within $5<M<6$.

The effect of strong motion duration on spectral shapes is studied by Peng et al. [9] in 1989. They used random vibration method for evaluation of probabilistic field depended response spectra. Strong motion accelograms have more probability for containing large-period waves. These types of waves cause superior responses in large-period (low-frequency) zone of spectrum.

3. Database Selection

The first step of this research was the selection of a complete set of earthquake records by considering the following items:

1. Availability of causative earthquake record specifications including magnitude, focal depth, focal distance, date of earthquake event and etc. Among the 3000 existing records in Iran earthquakes database, only those are selected for correction, which their causative earthquake specifications are known exactly.
2. Possibility of suitable record correction and insignificant error residence after correction. The recorded earthquakes of Iran are registered by SMA1 and SSA2 accelographs, which based on each apparatus characteristics and recording accuracy the correction methods are different.

Based on previous records correction study in Iran by Mahdavian [10] in 2000 and regard to apparatus type, recording and numerating accuracy, the same method is used for periods between 0.1 to 0.35 seconds in small-period range and 20 to 23 seconds for large-period range. Remaining records having some errors after the correction were omitted from the selected list. SWS software [11] utilized for device and base line corrections.

3. Determination of earthquake recording station soil type. By considering the distinct effect of soil type on earthquake record characteristics, there was a significant attempt for recognizing the soil type of the earthquake recording stations. For this mean different previous studies were used. These studies are based on geo-electric investigations, seismographic tests, micro-tremor tests, Fourier spectral shapes of earthquake records and also geotechnical observations [12, 13, 14 & 15].

After studying and comparing the previous researches the soil type of each recording station was categorized in one of 4 soil types indicated in Iranian code of practice for seismic resistant design of buildings [1]. Soil categorization in this code is based on geotechnical properties and the velocity of shear wave passing through the soil layer. The specification of each soil class is

Table 1 Soil Types Categorization [1]

Ground Type	Explanation of materials	Shear wave velocity (m/s)
I	Un-weathered igneous rocks, hard sedimentary rocks and metamorphic rocks (as gneisses and crystalline silicate rocks)	Vs>750
	Very hard conglomerates very compact and very hard sediment	375<Vs<750
II	Soft igneous rocks e.g. tuffs, clay stones, shale and semi-weathered or altered rocks Crushed (but not hardly) hard rocks , foliated metamorphic rocks, conglomerate and compact sand and gravel	375<Vs<750
III	Weathered rocks, semi-compact sands and gravels, other compact sediments Compact sandy clay soils, with low ground water level	175<Vs<375
IV	Soft sediments, clay soils, weak cemented and un-cemented sands, incompact soils with high ground water level Any kind of soft soils	Vs<175

defined in Table 1.

By taking all above items into account, a set of 146 records was selected among 3000 existing earthquake records. The parameters of these records are presented in Table 2 and the peak ground acceleration (PGA) of them is gathered in Table 3 through Table 6.

4. Research Methodology

After the selection of suitable records based on the above-mentioned concerns, the response spectrum of these records was determined and they have been normalized with respect to PGA values. Classification of records regard to soil type and magnitude of causative earthquake for different safety levels and damping ratios was the next step. By this procedure design acceleration spectra for both horizontal and vertical components have been achieved. The obtained design spectra could be utilized for different site conditions, magnitudes, safety levels, etc. in structural design.

4.1 Spectra Classification Based on Soil Type

Due to particular effect of soil type on response spectra, the selected records were classified according to Standard No. 2800 soil classification table and then for each class the design spectrum is determined.

This procedure clarified some inconsistency in calculated response spectrum shapes and for this reason the soil specifications of record registration station was revised by paying attention to other stations response spectrum. These items cause the recording stations soil-based classification being revised.

In some cases derived design spectrum shapes were so close to each other and because of this vicinity some of the spectra were assumed to be classified in two main groups: rock or soil, this type of classification derived more obvious results. The spectra closed shapes are due to uncertainty in defining the recording station soil type and also the effect of earthquake magnitude in different soil types.

4.2 Spectra Classification Based on Earthquake Magnitude

Previous studies of many researchers approved the effect of earthquake magnitude on response spectra. In this study by assuming M_s=5.5 as the limit of destructive earthquakes in Iran, the selected records were categorized in 3 subdivisions for each soil type:

- All records related to one soil class
- Records of causative earthquakes having $M_s \leqq 5.5$

- Records of causative earthquakes having M_s>5.5

Based on this type of classification, design spectra are acquired for each subdivision.

4.3 Spectra Classification Based on Different Safety Levels

When the design spectrum is calculated based on average of response spectra it means that the achieved design spectrum is conservative for one half of the responses and also it is non-conservative for the remaining half. In this case the probability of real structure response exceeding the evaluated value based on design spectrum is 50 percent. Also when the spectrum is calculated based on average plus one standard deviation it means the probability of the not exceeding over the estimated values are 84 percent. It is wise to use different safety levels for different structures with various importance factors. For this mean in all mentioned subdivisions design spectra were derived for average and average plus one standard deviation values.

By following this procedure, the safety level of presented spectra in Standard No. 2800 could be estimated.

4.4 Design Spectra for Different Damping Ratios

However in ordinary engineering 5% damping design spectrum is applicable, but for special cases and for finding the effect of damping on spectral shapes, the design spectra are created for 0, 2, 5, 10 and 20% damping ratios. The results in this paper are presented just for 5% damping for comparing the achieved spectra with ones presented in Standard No. 2800.

4.5 Design Spectra for Horizontal and Vertical Earthquake Components

Even though because of the weight of structure the effect of vertical earthquake component is only important in some particular elements, but the obtained design spectra for vertical component show the considerable structure response to this component. For this reason design spectra are presented separately for each earthquake components.

5. Results and Discussions

5.1 Comparison of Achieved Spectra for a Certain Soil Type

5.1.1 Spectra of Soil Type I

a. Comparison of obtained design acceleration spectra from total set of records with different safety levels, regard to Standard No. 2800 spectrum

In Fig. 1 horizontal component acceleration spectra acquired based on soil Type I records for 3 different safety levels (average, average plus 0.5 standard deviation, average plus standard deviation) are compared with Standard No. 2800 spectrum presented for soil Type I.

Figure 1 shows that the Standard No. 2800 spectrum is conservative for periods greater than 0.4 seconds (natural period T0 of Soil Type I) even though for average plus one standard deviation. This safety factor increases for higher periods. The peaks of gained response spectra are near to a period equal to 0.2 seconds and related values of average plus one standard deviation, average plus 0.5 standard deviation and average are 3.25, 2.8 and 2.5, relatively.

b. Comparison of obtained design spectra based on different magnitudes and safety levels, regard to Standard No. 2800 spectrum

In this step soil Type I acceleration spectra were divided in 3 categories for $M_s \leqq 5.5$, M_s>5.5 and total records. The achieved spectra are compared with Standard No. 2800 spectrum for two different safety levels: average and average plus

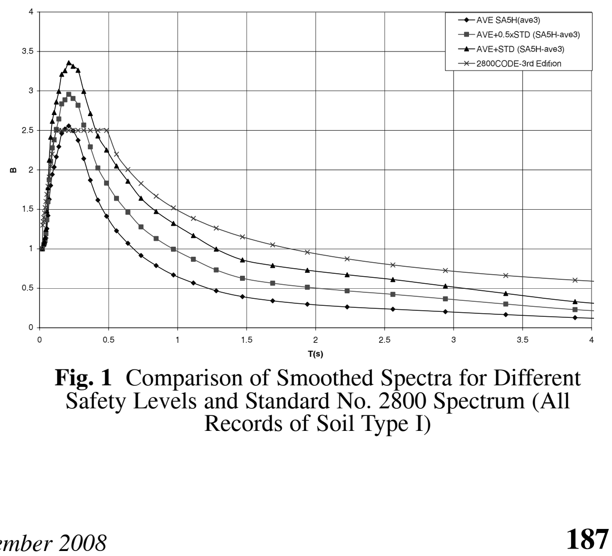

Fig. 1 Comparison of Smoothed Spectra for Different Safety Levels and Standard No. 2800 Spectrum (All Records of Soil Type I)

Table 2 Selected Earthquakes Record Specification

RECORD No.	STATION	DUR (s)	YEAR (19--)	m_b	M_s	F.D. (km)	E.D. (km)	Class
1006-1	BANDAR-ABBAS	45.34	75	5.9	6.1	37	36	2
1007	MINAB	28.47	75	5.9	6.1	72	73	4
1013	TONEKABON	14.34	75	4.4	3.5	19	34	4
1014-4	HAJIABAD	10.94	75	5.3	5	25	15	3
1022-2	PARSABAD	21.96	76	5.2	5	15	53	2
1040-3	NAGHAN	12.9	76	5.1	4.7	14	18	1
1042	SEDEH	18.4	76	5.8	6.4	57	56	3
1043	GHAEN	19.54	76	5.8	6.4	10	10	1
1044	KHEZRI	21.05	76	5.6	6.2	10	46	2
1046-1	MAKU	28.09	76	6.1	7.3	49	53	2
1047-6	VANDIK	9.75	76	4.8	4.3	5	11	2
1048-1	KALAT	19.9	76	5.1	4.8	14	9	3
1049-2	SEYEHCHESHMEH	11.6	76	4.3			4	1
1050-1	BANDARABASS	45.2	77	6.2	6.9	48	48	2
1050-2	BANDARABASS	21.34	77	5.8	5.84	53	53	2
1050-3	BANDARABASS	17.5	77	5.8	5.4	57	58	2
1051-4	BANDARABASS	30.8	77	6.2	6	37	43	2
1052	GHESHM	8.97	77	6.2	6	37	71	
1054-1	NAGHAN	20.96	77	6.1	6	3	5	1
1070	KONARTAKHTEH	15.7	77	4.9			7	3
1080-10	NAGHAN	10.39	78		5	4	65	1
1080-11	NAGHAN	5	78	5	4.5	14	28	1
1080-8	NAGHAN	15.7	77	5	4.5	22	22	1
1081-1	DASTGERD	18	77	5	4.5	37	37	2
1082-1	DEYHUK	58.4	78	6.7	7.3	17	37	1
1084-1	TABAS	49	78	6.7	7.3	10	27	1
1084-18	TABAS	15.1	78	4.6	3.9	10	27	1
1084-19	TABAS	19.46	78	4.8	4.3	10	26	1
1084-21	TABAS	12.39	78	4.9	4.5	10	21	1
1084-34	TABAS	19.02	78	4.6	3.9	6	22	1
1084-46	TABAS	16.16	78	5	4.7	22	17	1
1084-47	TABAS	15.26	78	4.7	4.2	12	64	1
1084-48	TABAS	15.24	78	4.9	4.8	10	64	1
1094-1	KAZERUN	15.87	78		4.5	10	9	2
1102	BAJESTAN	15.6	79	6	6.8		145	3
1107	KHEZRI	26.58	79	5.9	6.7	69	72	1
1109	GONABAD	27.18	79		6.8	70	97	2
1113	KHAF	32.42	79	6	6.8		103	2
1117	SEDEH	37.08	79	6	6.7	97	85	3
1131	TORBATHYDAREYH	44.82	79	6.1	7.1		143	3
1137	BIRJAND	41.4	79	6.1	7.1		135	1
1138-1	SEDEH	49.48	79	6.2	7.3	98	87	3
1150	LAHIJAN	13.66	80	5.3	5.1	25	33	4
1168	KERMAN	19.9	81	6.1	6.6		75	4
1172-6	GOLBAF	14.54	81	4.9	4	16	13	3
1173	RAFSANJAN	37.58	81	5.9	7		178	3
1174	KERMAN	38.04	81	5.9	7	30	75	4
1175	RAYEN	43.02	81	5.9	7	75	55	1
1176-15	GOLBAF	13.32	81	4.2	3.1	32	30	3
1176-18	GOLBAF	14.22	81	4.7	4.1	29	18	3
1176-20	GOLBAF	11.98	81	4.6	3.9	12	2	3
1176-22	GOLBAF		81	4.5	3.7	26		3
1176-5	GOLBAF	59.32	81	5.9	7	35	13	3
1177	ZARAND	43.9	81	5.9	7		7148	3
1178-2	RAVAR	14.4	81	5.9	7		169	3
1183-1	GOLBAF	13.8	81	4.8	4	12	17	3
1183-10	GOLBAF	17	81	5.1	4.6	10	6	3
1185	RUDSAR	19	80	5.1	4.7	19	16	4
1191-5	GOLBAF	11.48	82	4.6	3.9	10	31	3
1193-9	BOHNABAD	10	79	4.8	3.7	12	7	
1224-2	ARDEL	15.6	84	5	4.2		15	3
1258-2	FIRUZABAD	20.3	85	4.4	3.9		48	3
1289-4	NURABADMAMASANI	25.68	86	5.5	5	19	19	3
1289-5	NURABADMAMASANI	17.1	86	5.4	4.9	20	21	3
1299	ESFARAYEN	18.12	87	4.9	4.5	15	24	
1322-1	KAZERUN	17.18	88	5.6	5.5	4	39	2
1322-2	KAZERUN	17.96	88	5.7	6.1	40	37	2
1329	NURABADMAMASANI	17.28	88	5.5	5.7	23	24	3
1341-1	ARDEL	19.96	89	4.6	4.2	10	14	3
1347-4	SIRCH	18.6	89	5.6	5.7	32	38	1
1354	ABHAR	29.48	90	6.4	7.7		95	4
1355	RUDSAR	53.1	90	6.2	7.4	87	90	4
1357-1	LAHIJAN	60.54	90	6.4	7.7		76	4
1359	TONEKABON	35.94	90	6.4	7.7		131	4
1360	MANJIL	11	90	5.1	4.7	4	16	2
1361	GACHSAR	49.48	90	6.4	7.7		185	3
1362-1	ABBAR	58.16	90	6.2	7.4	23	43	1
1364	ZANJAN	59.78	90	6.2	7.4	77	75	1

RECORD No.	STATION	DUR (s)	YEAR (19--)	m_b	M_s	F.D. (km)	E.D. (km)	Class
1368-1	RUDBAR1	11.74	90	4.5	3.7	5	48	3
1369	ROODSHOR	18.1	90	6.4	7.7		198	4
1372	ESHTEHARD	45.78	90	6.4	7.7		144	3
1377-1	MANJIL	9.56	90	5.3	4.4	15	21	2
1377-2	MANJIL	9.84	90	4.8			42	2
1382-6	RUDBAR1	14.12	90	4.7	4.1	8	43	3
1382-7	RUDBAR1	13.36	90	4.8	4.3	10	36	3
1395-1	RUDBAR1	11.44	90	4.7	4.1	12	52	3
1397-3	MANJIL	14.5	90	4.9	4.1		37	2
1400	FORK	13.64	90	4.6			11	
1402	KONARTAKHTEH	10.9	91	5.1	4.6	22	45	3
1406	TAFRESH	18.58	90	6.4	6.7		236	
1419-1	SEFIDRUD DAM	25.16	91				15	1
1420-4	RUDBAR1	19.94	91	5.6	5	14	12	3
1420-6	RUDBAR1	12.54	91	4.3	3.3	8	35	3
1425	SIRCH	7.66	92	4.6	3.9	15	8	1
1437	KONARTAKHTEH	12.08	92	5.1	5	52	76	3
1486-1	FIRUZABAD		94	5.8	6	30	29	3
1489-1	FIRUZABAD	12.98	94	5.5	5.3	27	25	3
1490-2	MEMAND	27.14	94	5.8	5.8	26	17	2
1490-6	MEMAND	9.94	94	4.7	3.97	25	23	2
1492-15	ZARRAT	25.56	94	5.1	4.7	17	21	1
1492-16	ZARRAT	43.5	94	5.8	5.8	18	26	1
1492-2	ZARRAT	17.88	94	4.8	4.1	15	34	1
1492-6	ZARRAT	33.24	94	5.5	5.3	16	15	1
1492-8	ZARRAT	26.84	94	5	4.9	22	32	1
1493-2	FIRUZABAD	38.36	94	5.8	5.8	23	15	3
1494-2	KAVAR	17.88	94	4.8	4.1	15	32	1
1495	MOHARLO	24.28	94	5.8	5.8	32	46	1
1496	SARVASTAN	20.44	94		5.7	75	69	
1497	FARSHABAD	26.84	94	5.8	5.8	60	54	2
1498	BABANAR	24.28	94	5.8	5.8	50	51	2
1500-4	ZANJIRAN	15.34	94	4.8	4.1	15	17	2
1502-4	ZANJIRAN	21.7	94	4.5	4.1	8	66	2
1502-8	ZANJIRAN	24.28	94	5.1	4.7	8	12	2
1502-9	ZANJIRAN	63.98	94	5.8	5.8	1	12	2
1506-1	HOSSEINEHOLYA	30.68	94	5.3	5.2	19	21	4
1506-4	HOSSEINEHOLYA	20.44	94	5.3	4.9	14	25	4
1506-5	HOSSEINEHOLYA	15.34	94	4.9	4.3	15	31	4
1506-8	HOSSEINEHOLYA	15.36	94					4
1507	DEZ DAM	17.88	94	5	4.4		31	2
1508-2	ANDIMESHK	20.44	94	4.9	4.7	41	40	2
1512-1	SEDEH	8.08	93	4.8	4.7	22	46	3
1518-2	FIRUZABAD	15.36	94	4.5	4.1	15		3
1519-4	ZARRAT	20.44	94	5	4.5	16	29	1
1520-4	KAVAR	17.88	94	5	4.5	30	28	1
1522	GAEMIEH	15.34	94	5			59	
1523-28	JOVAKAN	20.44	94	5	4.5	13	8	1
1528-16	FIN	15.34	95				48	3
1528-3	FIN	31.96	95	4.9	4.3	6	26	3
1529-3	LALY	21.72	95	4.3			41	3
1530-1	NIR	21.76	94	5	4.7	16		3
1532	DEHBALA	19.16	95	4.7	4	32	32	2
1533-2	SEIFABAD	15.34	95	5	4	18	15	
1535-2	RUDBAR1	17.88	95	4.8	4.3	8	30	3
1537	SEFIDRUD DAM	17.88	95	4.9			33	1
1539	MASHHAD	16.6	95	4.9	3.8		74	2
1541	RASHT5	15.34	95	4.9	4.5	32	32	3
1547-2	SEFIDRUD DAM	20.44	95	4.8			35	1
1550-1	MASAL	15.34	94	4.8	4.3	15	34	3
1551-2	SHABESTAR	17.88	95	4.2	3.1	17	12	1
1560-4	LALY	21.72	95	5	4.5	14	17	3
1562-2	ZARRAT	15.34	95	4.5	4.1	15	32	1
1571-10	SHABANKAREH	43.5	96	4.4	4.5		13	4
1575-1	BABAKALAN	15.34	95	4.8	4.1	12	38	2
1583-3	SAADABAD	34.52	96	4.5	4.1	12	12	1
1585-1	SHABANKAREH	26.84	96	4.2			17	4
1589-1	SAADABAD	29.4	96	4.6	4.3		12	1
1589-3	SAADABAD	25.56	96	4.3			12	1
1600-2	TANGAB DAM	19.16	96	4.5	4.1	12	14	
1600-3	TANGAB DAM	17.88	96	4.3			20	
1636-2	RUDBAR1	15.36	96	4.3	3.3	15		3
1695	ASTARA		97		6.1	30		4
1701-1	ARDEBIL		97		6.1	28		4
1874-5	GOLBAF		98	4.9	4.5	10		3
1874-7	GOLBAF		98	4.4	3.5	8		3

Table 3 Earthquakes Parameters for Registered Records in Soil Type I

RECORD No.	PGA			RECORD No.	PGA		
	L	V	T		L	V	T
1040-3	38.9	44.5	46.8	1364	-127	-50	58.3
1043	135	-191	166	1419-1	-323	125	316
1049-2	17.1	10.4	22	1425	-50	20.4	-87
1054-1	730	-468	-544	1492-15	112	35.1	84.1
1080-10	73.1	-99	98.1	1492-16	-311	106	252
1080-11	42.1	-45	-35	1492-2	24.3	-11	-21
1080-8	101	-78	-146	1492-6	220	-62	243
1082-1	-318	159	-374	1492-8	-58	21.4	-48
1084-1	-806	-632	-810	1494-2	24.4	-14	-14
1084-18	59.8	51.2	97.8	1495	22.2	-12	-20
1084-19	-61	50.4	-47	1519-4	-66	23.2	-54
1084-21	-123	52.3	-106	1520-4	-18	-13	37.4
1084-34	130	104	213	1523-28	-130	-32	-101
1084-46	-97	-90	64.9	1537	20.9	-13	10.6
1084-47	-142	93.7	130	1547-2	-65	-25	-16
1084-48	-140	90.6	-137	1551-2	-39	87.8	-40
1107	37	-19	42.5	1562-2	-28	18.3	15.9
1137	-32	-20	-29	1583-3	72.7	21.6	-45
1175	-34	31.6	35.6	1589-1	-44	15.3	-48
1347-4	67.2	25.9	71.5	1589-3	-52	19.4	-95
1362-1	424	252	-437				

Table 4 Earthquakes Parameters for Registered Records in Soil Type II

RECORD No.	PGA			RECORD No.	PGA		
	L	V	T		L	V	T
1006-1	-84.4	41.46	124.18	1377-2	-101	-33	61.6
1022-2	-89.2	-70.9	151.44	1397-3	-47.8	27.99	-104.19
1044	-25.8	12.67	-18.91	1490-2	-416	164.9	451.89
1046-1	91.38	46.45	67.74	1490-6	-169	-105	-173.69
1047-6	-227	143.8	308.82	1497	15.23	9.64	-22.81
1050-1	97.42	-41.7	155.55	1498	-28.7	-15.1	-39.03
1050-2	34.19	-18.5	-39.96	1500-4	63.88	37.73	75.57
1050-3	33.18	-17.1	-40.46	1502-4	-201	-57	-194.2
1051-4	-43.4	-17.9	-37.79	1502-8	91.18	-50.9	-92.32
1094-1	-38.2	-15.7	-79.64	1502-9	1007	-805	*******
1109	-30	22.71	-35.23	1507	-23.1	18.76	25.88
1113	74.29	32.93	-67.57	1508-2	-18.2	20.11	-35.99
1322-2	37.5	-15	-32.51	1532	-31.3	15.74	31.08
1360	431.9	-173	-364.45	1539	-19.2	16.28	-14.1
1377-1	166.8	75.05	201.85				

Table 5 Earthquakes Parameters for Registered Records in Soil Type III

RECORD No.	PGA			RECORD No.	PGA		
	L	V	T		L	V	T
1575-1	-23.8	14.3	-20.3	1368-1	79.94	-63.2	106.8
1042	19.6	-11.7	-25.8	1372	-68.9	-40.8	72.88
1048-1	36.66	23.79	-32.7	1382-6	-305	131.5	289.3
1070	40.06	-14.4	29.87	1382-7	-183	-74.7	96.56
1102	40.13	-21.6	32.58	1395-1	-47.5	55.85	98.08
1117	-27.8	14.54	-23.5	1402	67.13	27.15	47.17
1131	46.24	-29.1	42.14	1420-4	295.1	-117	295.1
1138-1	-85.9	-38.3	-76.2	1420-6	130.3	48.82	-86.9
1172-6	-36.7	-31.9	-54.6	1437	50.44	-26.4	48.21
1173	-47	-17.7	48.47	1486-1	-129	38.49	79.23
1176-15	-42.7	20.53	26.55	1489-1	-61.7	-23.6	-59.9
1176-18	27.41	-25.4	-34.8	1493-2	257	104.4	279.5
1176-20	-29.7	25.38	-26.4	1512-1	43.48	-64.9	-42.5
1176-22	-23.3	15.05	-53.7	1518-2	12.66	-7.37	-7.95
1176-5	213.9	-263	-275	1528-16	-19.4	12.99	21.76
1177	-41	25.69	43.32	1528-3	495.4	394.7	448.6
1178-2	-65.5	37.79	57.23	1529-3	-25.9	14.76	-24
1183-1	-94.7	51.55	65.96	1530-1	-81.8	-44.8	56.84
1183-10	-94.6	79.15	-162	1535-2	-97.8	-83.4	-92.9
1191-5	-39.6	28.33	-59.6	1541	-17	6.31	-23.5
1224-2	-162	112.2	226.8	1550-1	7.73	2.96	8.87
1258-2	124.7	-54.5	-60.7	1560-4	-80.4	-69.9	106
1289-4	91.92	-46.8	74.96	1636-2	23.22	16.73	19.11
1289-5	-33.7	15.45	25.84	1874-5	108.9	-41.4	121.1
1329	85.04	-28.5	-70.2	1874-7	-97.8	66.53	94.41
1341-1	-154	81.43	-92.3				

Table 6 Earthquakes Parameters for Registered Records in Soil Type IV

RECORD No.	PGA			RECORD No.	PGA		
	L	V	T		L	V	T
1007	-28.3	-15.8	22.75	1369	-38.1	-31	-43.2
1013	42.03	-9.6	19.99	1506-1	-186	96.21	-125
1150	-56.6	49.31	101.4	1506-4	180.6	-46.7	124.4
1168	-41.1	18.79	35.15	1506-5	27.33	14.88	-18.6
1174	-99.1	-49.6	-84.5	1506-8	25.5	-14.7	-34.7
1185	-112	37.7	-67	1571-10	53.71	39.62	-85.6
1354	-125	73.41	-209	1585-1	-47.3	47.89	-103
1355	90.26	65.88	-78.6	1695	43.68	-18.5	38.22
1357-1	-105	75.26	171	1701-1	-164	-58.4	121
1359	126.2	-34.1	80.76				

one standard deviation.

Figure 2 shows that for average safety level (50% probability for exceeding) Standard No. 2800 spectrum is conservative for all 3 subdivisions in periods higher than 0.4 seconds. Again the peaks of obtained response spectra happen about a period equal to 0.2 with a value of 2.5 for minor earthquakes and total records and 2.7 for strong earthquakes. The safety factor of the code spectrum for higher periods increases by magnitude decrement.

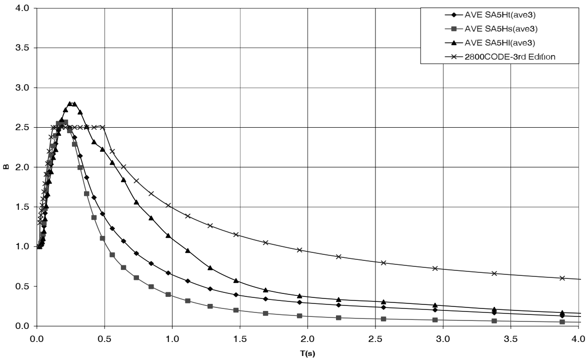

Fig. 2 Comparison of Smoothed Spectra Average for Minor Earthquakes, Strong Earthquakes, All Records and Standard No. 2800 Spectrum (Soil Type I)

c. Comparison of horizontal and vertical components

Finally the spectra for horizontal and vertical components gained from all records data are compared for two different safety levels (average and average plus one standard deviation). Related results in Fig. 3 indicate that for all periods except for very minor periods (less than 0.2 seconds) and large periods (more than 2.5 seconds) the responses of horizontal component are more than vertical component responses and the difference between horizontal and vertical components is negligible. The vertical component response is about 15 percent more than vertical components response in a period range between 0.1 to 2.5 seconds.

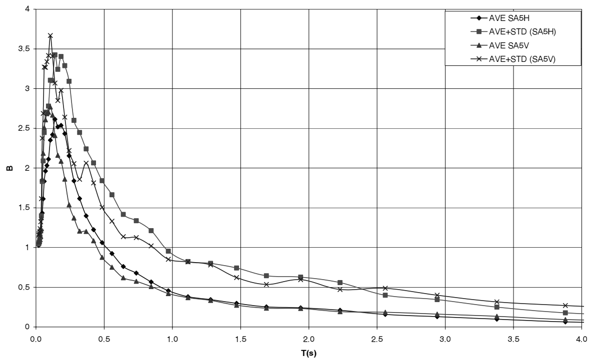

Fig. 3 Comparison of Horizontal and Vertical Response Spectra for Different Safety Levels (5% Damping, Soil Type I, All Records)

5.1.2 Spectra of Soil Type II

a. Comparison of obtained design acceleration spectra from total set of records with different safety levels, regard to Standard No. 2800 spectrum

In Fig. 4 horizontal component acceleration spectra acquired based on soil Type II records for 3 different safety levels (average, average plus 0.5 standard deviation, average plus standard deviation) are compared with Standard No. 2800 spectrum presented for soil Type II.

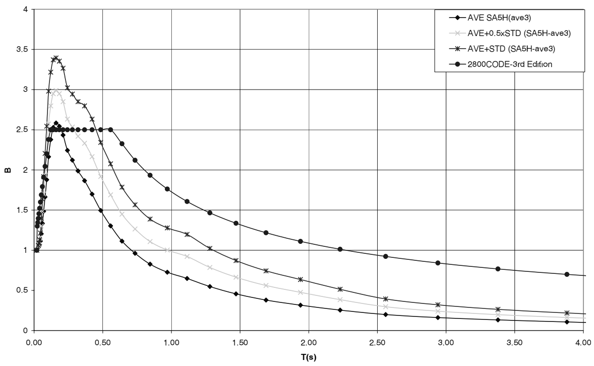

Fig. 4 Comparison of Smoothed Spectra for Different Safety Levels and Standard No. 2800 Spectrum (All Records of Soil Type II)

Figure 4 shows that the Standard No. 2800 spectrum is conservative for periods greater than 0.5 seconds (T0 of Soil Type II) even though for average plus one standard deviation. This safety factor increases for higher periods. The peaks of gained response spectra happen near to a period equal to 0.2 seconds and related values of average plus one standard deviation, average plus 0.5 standard deviation and average are 3.3, 2.9 and 2.5, relatively.

b. Comparison of obtained design spectra based on different magnitudes and safety levels, regard to Standard No. 2800 spectrum

In this step soil Type II acceleration spectra were divided in 3 categories for $M_s \leqq 5.5$, $M_s > 5.5$ and total records. The achieved spectra are compared with Standard No. 2800 spectrum for two different safety levels: average and average plus one standard deviation.

Figure 5 shows that for average safety level (50% probability for exceeding) Standard No. 2800 spectrum is conservative for all 3 subdivisions in periods higher than 0.5 seconds. Again the peaks of obtained response spectra occur about a period equal to 0.2 with a value of 2.5 for minor earthquakes and total records and 2.6 for strong earthquakes. The safety factor of code spectrum for higher periods increases by magnitude decrement in the selected records.

c. Comparison of horizontal and vertical components

This time the spectra for horizontal and vertical components gained from all records data are compared for two different safety levels (average and average plus one standard deviation). Related results in Fig. 6 indicate that vertical component response is approximately 15 percent more than horizontal component response. In a period range between 0.1 and 2.5 seconds average values of both components are approximately the same.

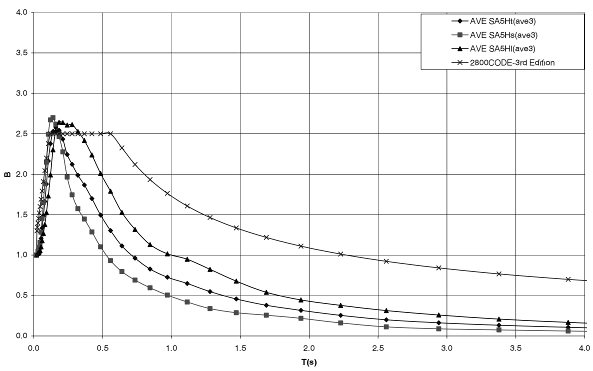

Fig. 5 Comparison of Smoothed Spectra Average for Minor Earthquakes, Strong Earthquakes, All Records and Standard No. 2800 Spectrum (Soil Type II)

5.1.3 Spectra of Soil Type III

a. Comparison of obtained design acceleration spectra from total set of records with different safety levels, regard to Standard No. 2800 spectrum

In Fig. 7 horizontal component acceleration spectra acquired based on soil Type III records for 3 different safety levels (average, average plus 0.5 standard deviation, average plus standard deviation) are compared with Standard No. 2800 spectrum presented for soil Type III.

Figure 7 shows that the Standard No. 2800 spectrum is conservative for periods greater than 0.7 seconds (T0 of Soil Type III) even though for average plus one standard deviation. This safety factor increases for higher periods. The peaks of

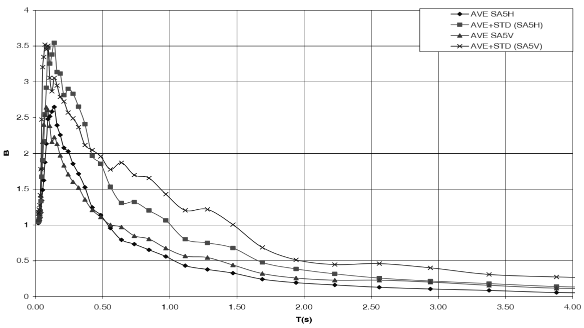

Fig. 6 Comparison of Horizontal and Vertical Response Spectra for Different Safety Levels (5% Damping, Soil Type II, All Records)

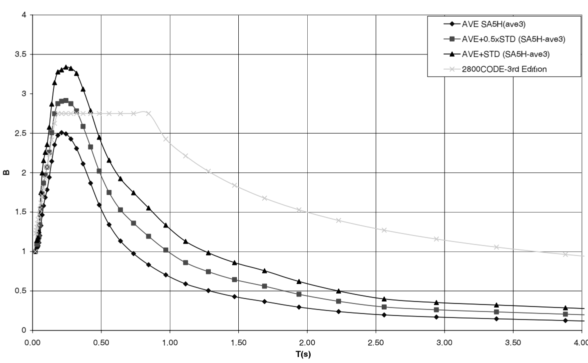

Fig. 7 Comparison of Smoothed Spectra for Different Safety Levels and Standard No. 2800 Spectrum (All Records of Soil Type III)

gained response spectra occur around a period equal to 0.25 seconds and related values of average plus one standard deviation, average plus 0.5 standard deviation and average are 3.3, 2.9 and 2.45, relatively.

b. Comparison of obtained design spectra based on different magnitudes and safety levels, regard to Standard No. 2800 spectrum

In this step soil Type III acceleration spectra were divided in 3 categories for $M_s \leqq 5.5$, $M_s > 5.5$ and total records. The achieved spectra are compared with Standard No. 2800 spectrum for two different safety levels: average and average plus one standard deviation.

Figure 8 shows that for average safety level (50% probability for exceeding) Standard No. 2800 spectrum is conservative for all 3 subdivisions in periods higher than 0.7 seconds. Again the peaks of obtained response spectra happen around a period equal to 0.25 with a value of 2.45 for minor earthquakes and total records and 2.7 for strong earthquakes. The safety factor of code spectrum for higher periods increases by magnitude decrement in the selected records.

c. Comparison of horizontal and vertical components

At last the spectra for horizontal and vertical components gained from all records data are compared for two different safety levels (average and average plus one standard deviation). Related results in Fig. 9 indicate that vertical component response is just approximately 5 percent more than horizontal component response. Another result observed from this figure declares for periods greater than 1 second the response of vertical components are larger than horizontal component response, but in another range (periods between 0.2 to 1 seconds) the response of horizontal component is larger than vertical one. For period range between 0.1 to 2.5 seconds the vertical component response is just 6 percents larger than horizontal one. A remarkable result deriving from this comparison is the point related to vertical component getting larger than horizontal component, this point increased from 0.5 seconds in soil Type II to 1.0 second for soil Type III.

5.1.4 Spectra of Soil Type IV

a. Comparison of obtained design acceleration spectra from total set of records with different safety levels, regard to Standard No. 2800 spectrum

In Fig. 10 horizontal component acceleration spectra acquired based on soil Type IV records for 3 different safety levels (average, average plus 0.5 standard deviation, average plus standard deviation) are compared with Standard No. 2800 spectrum presented for soil Type IV. It should be noted that standard No. 2800 spectrum has been resulted from two present spectra for soil type IV.

Figure 10 shows that the Standard No. 2800 spectrum is conservative for periods greater than 1.0 second (T0 of Soil Type IV) even though for average plus one standard deviation. This safety factor increases for higher periods. The peaks of gained response spectra happen around a period

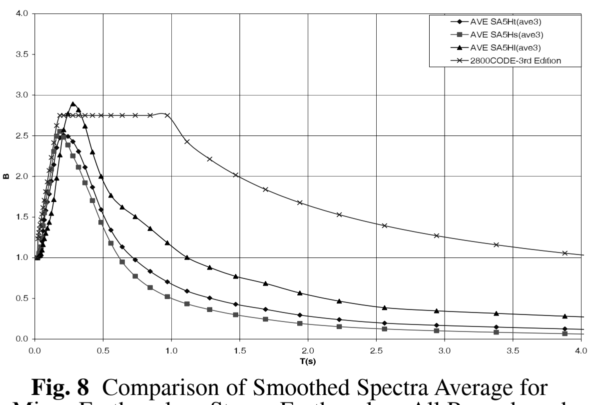

Fig. 8 Comparison of Smoothed Spectra Average for Minor Earthquakes, Strong Earthquakes, All Records and Standard No. 2800 Spectrum (Soil Type III)

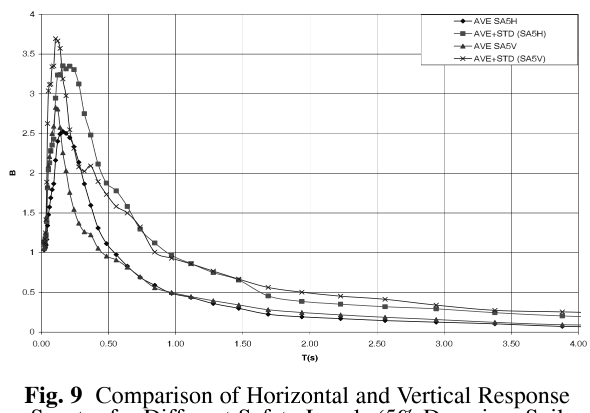

Fig. 9 Comparison of Horizontal and Vertical Response Spectra for Different Safety Levels (5% Damping, Soil Type III, All Records)

equal to 0.25 seconds and related values of average plus one standard deviation, average plus 0.5 standard deviation and average are 3.0, 2.7 and 2.35, relatively.

b. Comparison of obtained design spectra based on different magnitudes and safety levels, regard to Standard No. 2800 spectrum

In this step soil Type IV acceleration spectra were divided in 3 categories for $M_s \leqq 5.5$, $M_s > 5.5$ and total records. The achieved spectra are compared with Standard No. 2800 spectrum for two different safety levels: average and average plus one standard deviation.

Figure 11 shows that for average safety level (50% probability for exceeding) Standard No. 2800 spectrum is conservative for all 3 subdivisions in periods higher than 1.0 second but the suggested response in the code is not conservative for periods smaller than 1.0 second. Again the peaks of obtained response spectra occur about a period equal to 0.25 with a value of 2.35 for minor earthquakes, 2.5 for total records and 2.55 for strong earthquakes. The safety factor of the code spectrum for higher periods increases by magnitude decrement in the selected records.

c. Comparison of horizontal and vertical components

This time the spectra for horizontal and vertical components gained from all records data are compared for two different safety levels (average and average plus one standard deviation). Related results in Fig. 12 indicate that vertical component response is approximately 15 percent more than horizontal component response for periods larger than 1.3 seconds. In a range between 0.2 to 1.3 seconds the horizontal component is about 13 percent larger than vertical one. Another similar result deriving from this comparison is the point related to vertical component getting larger than horizontal component, this point increased from 1.0 seconds in soil Type III to 1.7 second for soil Type IV.

5.2 Comparison of Achieved Spectra for Different Soil Types

Because of important effect of soil type on the shapes of design and response spectra the selected records were classified in according to 4

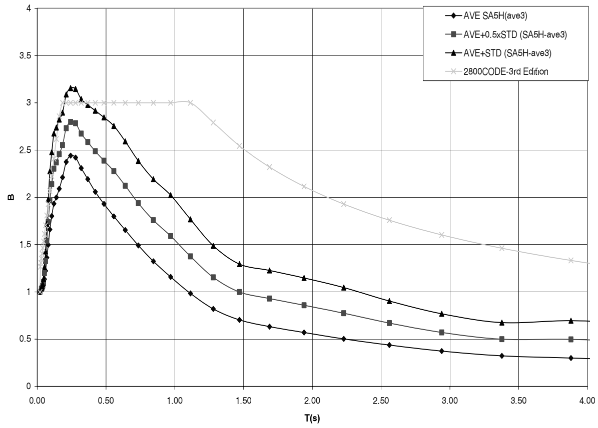

Fig. 10 Comparison of Smoothed Spectra for Different Safety Levels and Standard No. 2800 Spectrum (All Records of Soil Type IV)

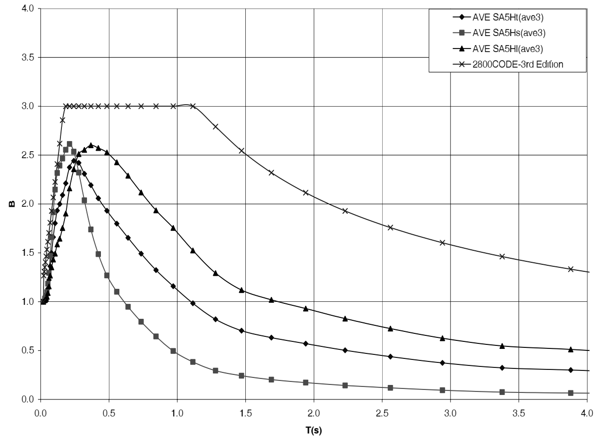

Fig. 11 Comparison of Smoothed Spectra Average for Minor Earthquakes, Strong Earthquakes, All Records and Standard No. 2800 Spectrum (Soil Type IV)

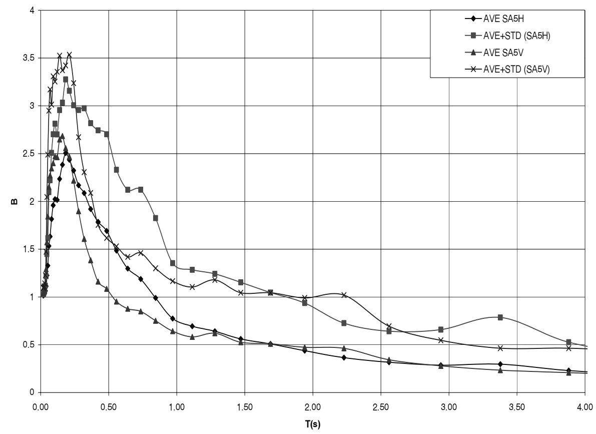

Fig. 12 Comparison of Horizontal and Vertical Response Spectra for Different Safety Levels (5% Damping, Soil Type IV, All Records)

different soil types defined in Standard No. 2800. The achieved spectra for different soil types were drawn in a unique graph for a comprehensive comparison of them. This method is performed for different safety levels and also by considering the causative earthquake magnitudes.

The most important result is obtained during comparison of average and average plus one standard deviation for all selected records. Fig. 13 compares the average spectrum for 4 different soil types, except for soil Type 4 other soil type spectra are not distinctive and are so closed to each other. Despite the keeping Standard 2800 spectrum sequence, the anticipated difference between different soil types was not achieved. This phenomenon might happen because of inexact soil type definition of types I and II or types III and IV. Another reason could be causative earthquake distinction, which due to effect of magnitude on response spectra caused the spectral values vicinity.

Because of this problem, records of soil type I combined with soil type II records (rock type layers having V_s>375 m/s) and relatively records of soil type III are combined with soil type IV records (soil type layer having V_s<375 m/s). After this combination new achieved spectra were compared for determining the effects of soil type on design spectra.

Figure 14 evidently shows the effect of soil type on design spectra for average safety level.

5.3 Comparison of Suggested Spectra and Standard No. 2800 Spectra

According to previous discussion, suggested spectra of all records were divided in to 2 main categories: rock and soil. These spectra were compared by combined Standard No. 2800 spectra. The combination of Standard No. 2800 spectra was done by combining soil types I and II and also soil types III and IV, relatively. Selected safety levels are average and average plus standard deviation.

Figure 15 describes this comparison which states presented spectrum in Standard No. 2800 is conservative for all periods above 0.5 seconds regard to all suggested spectra of this research. Also for minor periods range based on soil type and safety level the Standard No. 2800 suggested

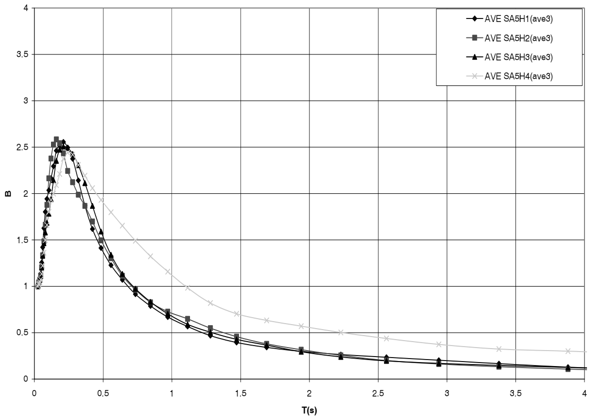

Fig. 13 Comparison of Design Spectra of All Soil Types (Average, All Records)

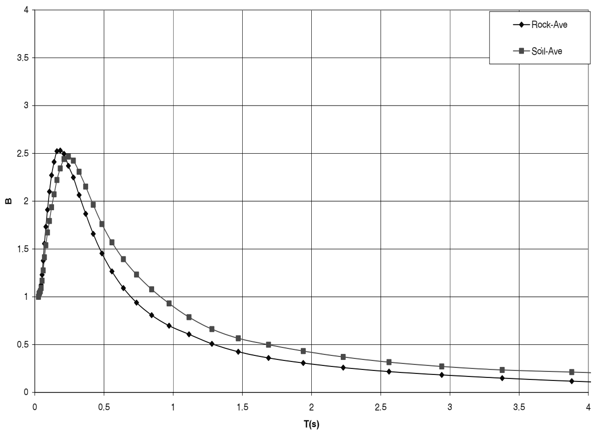

Fig. 14 Comparison of Design Spectra Based on Classification of Layers in Rock and Soil Classes (Average, All Records)

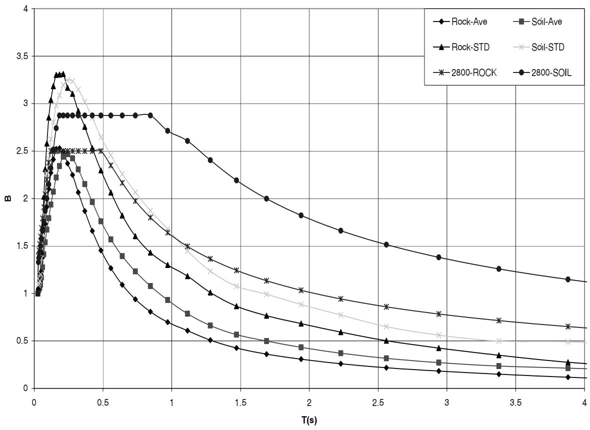

Fig. 15 Comparison of Suggested Spectra and Standard No. 2800 Spectra (All Records)

spectra are not conservative.

6. Conclusions

- All maximum responses for presented spectra (except for soil type IV) of this study are greater than Standard No. 2800 spectra for the average plus standard deviation safety level. Maximum responses of Standard No. 2800 spectra rest at the average plus 0.5×STD safety level.

- For soil types I and II the related period which maximum response occurs is about 0.2 second. This value is about 0.25 seconds for soil types III and IV that all cases are less than Ts parameter quantity defined in Standard No. 2800.

- Due to lack of information for defining the definite type of soil layer, categorization of them into two major classes (rock type layers having V_s>375 m/s or soil type layer having V_s<375 m/s) is a rational classification until complementary investigation being done for defining the record registration stations soil type.

- The difference in spectral responses of horizontal and vertical components for a certain earthquake is not significant so with an appropriate approximation, horizontal spectral responses could be used instead of vertical spectral values.

- Earthquake magnitude affects the maximum spectral response and the related periods where the peak value occurs.

7. Acknowledgements

The cooperation of Building & Housing Research Center, Tehran, Iran, is acknowledged for providing the database of the earthquake records.

8. Notation

AVE : Average
ave3 : Average of 3 Consequent Data for Curve Smoothing
B : Dynamic Amplification Factor
Dur : Duration
E.D. : Epicenteral Distance
F.D. : Focal Depth
g : Gravity Acceleration
H : Horizontal
L : Longitudinal Component of Ground Motion
M : Magnitude
m_b : Body Wave Magnitude
M_s : Surface Wave Magnitude
PGA : Peak Ground Acceleration
SA : Spectral Acceleration
SA5Hl : Spectral Acceleration-5% Damping-Horizontal-Large Data (M_s>5.5)
SA5H : Spectral Acceleration-5% Damping-Horizontal-Small Data ($M_s \leqq 5.5$)
SA5Ht : Spectral Acceleration-5% Damping-Horizontal-Total Data (all M_s)
SA5V : Spectral Acceleration-5% Damping-Vertical
s : Second
STD : Standard Deviation
T : Transverse Component of Ground Motion
T_0 : Soil Natural Period
V : Vertical Component of Ground Motion
V_s : Shear Wave Velocity

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