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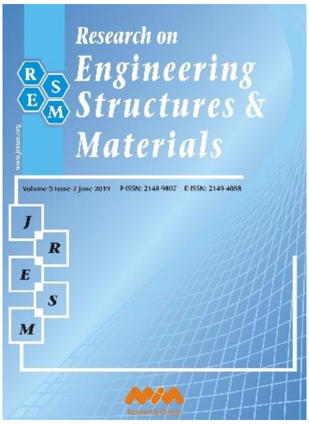

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Research Article & Data Set

An acceleration record set for different frequency content, amplitude and site classes

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Abstract

Dynamic analyses are important tools for seismic evaluation of structures in which the features of the used ground motion records have a key role. For proper estimation, the record set should have the desired extent and variability. However, when present literature is examined, it may be seen that difficulties still exist to have a record set with preferred properties. To ease these difficulties, a study conducted in scope of a project supported by The Scientific and Technological Research Council of Turkey (TUBITAK) under the title of "Change of Earthquake Ground Motions Depending on Soil Properties" and grant number 215M357. A set of acceleration records having different frequency content and soil classes based on average top 30 m shear velocity are given. Set includes 8400 records generated from 84 base rock acceleration passing through 100 different soil cases. The set is assumed to provide a wide range of frequency content, amplitude and soil classification option to researchers. Also, properties of devastating earthquakes in Turkey are investigated. Depth-average shear wave velocity relations are given for sand and clay materials. It is observed that; scaling real earthquake records in 0.7-1.3 range does not alter the frequency-amplitude relationship, records with a PGA of more than 0.4g have higher amplification ratios for waves larger than roughly 1.0 s periods when compared to records with smaller PGA.

1. Introduction

Dynamic analyses are important tools for seismic evaluation of structures. In dynamic analyses, the features of the used ground motion records have a key role. One of the main effects that causes alteration in earthquake ground motion properties is the local site features. The earthquake waves at the base rock alters when passing through the different layers of soil during their course to the surface. It is known that the local site conditions can significantly affect the amplitude and frequency content, which are important features of a ground motion [1, 2].

The instrumental measurements in past earthquakes indicate that soil layers affect seismic ground motion both in time and frequency domain. Several examples can be given to these situations. In 1967 Caracas earthquake, resonance, which can be defined as the site and the structure having similar period, is observed. Since the soil stiffness in Caracas region is relatively uniform, it has been claimed that most of the structural damage is caused by the change in the base rock depth [3]. In the Mexican Earthquake of 1985, the soft soil layers 400 km away from the focus, increased the wave amplitudes 5 times more when compared to the stiff soils, and severely damaged the high rise (10-20 floors) buildings [4]. Spectral

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accelerations in the 2 s period were found to be 15-20 times greater in these soft clay layers than in the rock [5]. In the 1989 Loma Prieta Earthquake, low-frequency earthquake wave amplifications in some regions with soft clay soil layers are observed to be between 3 and 6 times [6]. When the highest acceleration values observed in Istanbul at approximately equal distance to the fault compared during the 1999 Kocaeli Earthquake, intensity differences reaching 5 times are reported, which is mainly due to local site conditions [7].

Tezcan et al. [8] examined the soil amplification phenomenon in Avcılar (Istanbul) region 120 km west of the Kocaeli Earthquake of 1999 by using Shake program with 8 representative soil profile combinations. In the analyzes, the Izmit record of 1999 Kocaeli Earthquake was used with different modifications. The results of the analysis indicated three peak periods at 0.70, 1.00 and 1.60 sec, with magnification factors ranging from 2.5 to 5. It can be thought that this situation is compatible with the damage observed in the 5-8-storey buildings, whose periods vary between 0.70 and 1.00 s. The damage in Avcılar is suggested to be a consequence of the site amplification in soft soil layers despite the low acceleration in the base rock and distance to the epicenter [8].

Even though the given examples underline the importance of accounting for the local site conditions, there are limited number of acceleration records with desired features and site classes for the use of researchers using dynamic analyses. Problem of finding acceleration records with chosen characteristics is also mentioned in literature [9, 10]. Therefore, this study is conducted to broaden the ground motion records with different frequency content, amplitude and site classes.

In scope of the study, an input acceleration record set is established using real records, records by deconvolution, scaled versions of real records and generating synthetic records with desired properties. Then the input records set is used to determine the output set which is the form of the input records after passing through the defined soil profiles.

2. The soil profiles

Used soil profiles is given in the supplementary spread sheet files attached to the article under "Site Definitions" page. Establishment of soil properties is performed according to the Uniform Building Code [11] and Turkish Building Seismic Code [12]. These codes classify local site conditions according to the average shear wave velocity of top 30 m soil layers (Table 1).

Table 1 Site classification [11, 12]

Site Class	Soil Type	V_{s30} (m/s)
ZA	Hard Rock	V_{s30}>1500
ZB	Rock	760-1500
ZC	Very dense soil/Soft rock	360-760
ZD	Stiff Soil	180-360
ZE	Soft Soil	V_{s30}<180
ZF	Soils requiring site specific evaluation	N/A

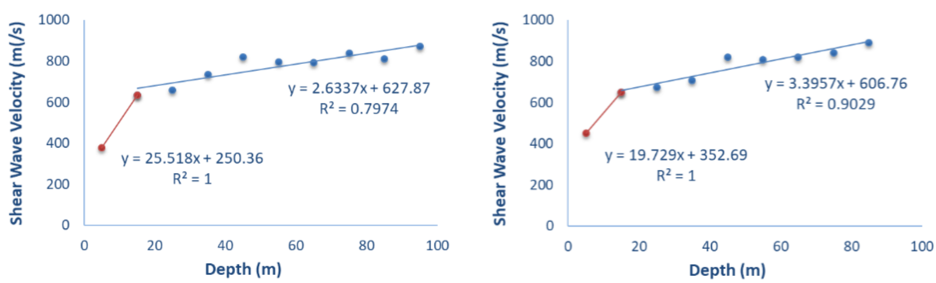
When the attached "Site Definitions" page is examined, it may be seen that first 2 sites are the sites that reflects the conditions of the input motion. Therefore, for these sites, the input and output motions are the same. The successive 31 site definitions include soil profiles with 30 or less than 30 m depth as it is the only value accounted by the codes. The properties of soil layers in these sites are established in a parametric manner to examine code defined values. The rest of the considered sites are deeper than 30 m to examine if the top 30 m is enough to define soil behavior adequately. In determination of the properties of soil layers, the study by Beyaz [13] is referred. In the mentioned study, Beyaz, has investigated the soil profiles of the 64 ground motion recording stations in Turkey using borehole geophysics.

In order to have representative soil layer properties under the 30m depth, the borehole results by Beyaz [13] is examined. Average values of the respective soil shear wave velocities are determined as listed in Table 2.

Table 2 Average and standard deviation values of shear wave velocities of soil layers

	Sand V_s (m/s)		Clay V_s (m/s)	
Depth (m)	Average	Standard Dev.	Average	Standard Dev.
5	377.95	105.41	451.33	188.43
15	633.13	137.43	648.63	216.08
25	659.75	120.32	673.80	170.93
35	733.80	186.15	708.33	207.46
45	820.94	171.56	821.00	117.44
55	796.44	176.96	808.56	174.66
65	792.24	166.27	821.07	168.52
75	837.07	136.30	840.43	147.34
85	810.50	177.62	890.56	138.65
95	870.67	129.77	699.00	44.64

After obtaining average value data, it was aimed to establish a relationship between V_s and depth values in order to get the value at a chosen depth. When the graphs for sand and clay material in Fig. 1 is examined, it seems that for depths smaller than 15 m, there is a steep increase. However, after 15 m the increase in shear wave velocity has a much flat nature. Therefore, it was found appropriate to establish separate relations for the region with low depth (5 -15m) and for the region with higher depth (15 - 95 m). Among the attempted relations, best correlation is obtained by linear relations whose equations are given in the figure. High correlation coefficients obtained from the equations indicates strong relation with good accuracy (Fig. 1). Additionally, Table 2 shows that the coefficient of variation is getting smaller with increasing depth.



a) sand b) clay

Fig. 1 Average shear wave depth velocity relation for sand and clay

3. Destructive earthquake properties

Before selection of earthquake records the destructive ground motion properties are examined. For a case example, Turkey is selected as an earthquake prone country.

Devastating earthquakes in Turkey between 1903-2011 are investigated. The data is collected from Wikipedia [14], Kandilli Observatory [15] and AFAD [16]. Since the information of these earthquakes was taken from different sources they are checked with the AFAD's [17] database and the parameters of magnitude type, magnitude value and focal depth are obtained in a compatible manner. Fault mechanism information, is taken from "National Strong Motion Data Base of Turkey" which is composed by collaboration of TUBITAK, METU and AFAD. Since some earthquakes have no mechanism data, rake angle values are used to determine the fault mechanism [18]. In spite of all these efforts, fault mechanism information could not be reached for some earthquakes in year 1935 and before. All gathered information is summarized in Table 3.

By the assembled data, certain features of the devastating earthquakes that occurred in Turkey is revealed. The mean depth of focus is 18.61 km. In other words, shallow earthquakes are general destructive earthquake characteristic in Turkey. Earthquakes with a depth of 0-60 km are considered shallow earthquakes. Earthquakes at a depth of 60-300 km are earthquakes with moderate depth. Deep earthquakes are earthquakes with depths of more than 300 km. Most earthquakes occurred in Turkey is in shallow earthquake category. Deep earthquakes are felt in much larger areas, but their damage is inversely proportional to this. However, shallow earthquakes do more damage in a smaller region when compared to deep earthquakes with similar magnitude [15].

When examined in terms of fault mechanisms, there are 22 strike-slip, 7 normal and 3 reverse faults in 32 devastating earthquakes with known fault mechanism information. Strike-slip faults are found to be the dominant mechanism with a 68.75% ratio. It is seen that, with a ratio of 21.88%, normal faults have also an important share in Turkey. However, earthquakes with a reverse fault have a lower ratio of 9.37%.

Table 3 Characteristics of devastating earthquakes in Turkey

Date	Time	Location	Lat.	Long.	Casualty	Mag.	Focal Depth (km)	Fault Mechanism
1903	01:46	Malazgirt, Muş	39.14	42.65	600	6.3 (Ms)	30	
1912	03:29	Mürefte Tekirdağ	40.75	27.20	216	7.4 (Ms)	10	Strike-slip
1914	00:07	Burdur	37.82	30.27	300	7.0 (Ms)	10	
1924	16:34	Horasan, Erzurum	40.00	42.10	60	6.8 (Ms)	10	
1928	02:29	İzmir	38.50	28.00	50	6.2 (Ms)	35	
1929	08:37	Suşehri, Sivas	40.20	37.90	64	6.1 (Ms)	10	
1935	16:41	Erdek, Balıkesir	40.40	27.50	5	6.2 (Ms)	35	
1938	12:59	Kırşehir	39.10	34.00	160	6.6 (Ms)	10	Strike-slip
1939	02:36	Dikili, İzmir	39.10	26.80	60	6.6 (Ms)	10	
1939	23:57	Erzincan	39.77	39.53	32700	7.9 (Ms)	20	Strike-slip
1942	19:01	Bigadiç, Balıkesir	39.20	28.20	16	6.1 (Ms)	10	
1942	14:03	Erbaa, Tokat	40.87	36.47	3000	7.0 (Ms)	10	
1943	17:32	Hendek, Adapazarı	40.60	30.50	336	6.6 (Ms)	10	Strike-slip
1943	22:24	Ladik, Samsun	41.05	33.72	4000	7.2 (Ms)	10	
1944	03:25	Gerede, Bolu	40.80	32.20	3959	7.3 (Ms)	10	Strike-slip
1944	04:34	Ayvalık, Balıkesir	39.37	26.53	30	6.8 (Ms)	40	Normal
1949	20:43	Karlıova, Bingöl	39.54	40.57	450	6.7 (Ms)	40	Strike-slip
1951	18:36	Kurşunlu, Çankırı	40,88	32,87	50	6.9 (Ms)	10	Strike-slip
1953	21:06	Yenice, Çanakkale	40,02	27,53	265	7.2 (Ms)	10	Strike-slip
1955	09:07	Söke, Aydın	37,55	27,05	23	6.8 (Ms)	40	Normal
1957	04:25	Fethiye, Muğla	36,50	28,60	67	7.1 (Ms)	80	Strike-slip

Date	Time	Location	Lat.	Long.	Casualty	Mag.	Focal Depth (km)	Fault Mechanism
1957	06:36	Abant, Bolu	40,67	31,00	52	7.1 (Ms)	10	Strike-slip
1964	16:31	Manyas, Balıkesir	40,10	27,93	23	7.0 (Ms)	34	Normal
1966	12:23	Varto, Muş	39,17	41,56	2396	6.9 (Ms)	26	Reverse
1967	16:56	Mudurnu, Adapazarı	40,67	30,69	89	6.8 (Ms)	33	Strike-slip
1968	10:19	Bartın	41,79	32,31	29	6.5 (Ms)	5	Strike-slip
1969	03:48	Alaşehir, Manisa	38,50	28,40	53	6.5 (Ms)	4	Normal
1970	23:02	Gediz, Kütahya	39,20	29,50	1086	7.2 (Ms)	18	Normal
1971	16:44	Bingöl	38,83	40,52	1000+	6.8 (Ms)	3	Strike-slip
1975	12:20	Lice, Diyarbakır	38,50	40,70	2385	6.6 (Ms)	32	Reverse
1976	14:22	Muradiye, Van	39,12	44,03	3840	7.2 (Mw)	9	Strike-slip
1983	07:12	Erzurum	40,33	42,19	1155	6.6 (Mw)	15	Strike-slip
1992	17,18	Erzincan	39,70	39,69	498	6.6 (Mw)	22	Strike-slip
1995	17:57	Dinar, Afyon	38,06	30,13	90	6.4 (Mw)	31	Normal
1998	16:55	Ceyhan, Adana	36,88	35,31	146	6.3 (Ms)	10	Strike-slip
1999	03:02	İzmit	40,77	30,00	17118	7.5 (Mw)	15	Strike-slip
1999	18:57	Düzce	40,75	31,16	894	7.1 (Mw)	11	Strike-slip
2002	07:11	Sultandağı, Afyon	38,57	31,27	44	6.5 (Mw)	5	Normal
2003	05:26	Pülümür, Tunceli	39,46	39,79	1	6.0 (Mw)	15	Strike-slip
2003	00:27	Bingöl	39,01	40,46	177	6.3 (Mw)	10	Strike-slip
2010	04:32	Karakoçan, Elâzığ	38,87	39,99	41	6,1 (Mw)	5	Strike-slip
2011	01:41	Tabanlı, Van	38,76	43,36	601	7.1 (Mw)	19	Reverse

4. The input ground motion set

In order to have an acceleration record set in consistency with the nature, to have real earthquake records as many as possible is preferred. The acceleration recordings are intended to be selected from the actual earthquakes, recorded on the hard rock in accordance with the bed rock definition. Selecting records with different amplitude and frequency content is aimed to enable comprehensive evaluations.

As many seismic codes use Peak Ground Acceleration (PGA) as the amplitude indicator, it is also used in selection of input ground motions in scope of this study. The acceleration recordings having PGA values between 0 and 0.6 g are selected with 0.05 g increment in each group. In the first 4 groups (0-0.2 g) 8, in the next 4 groups (0.2-0.4 g) 7, in the last (0.4-0.6 g) 4 groups 6 earthquake records are present. The absence of any records with desired features with a PGA of more than 0.6g made it the limiting value.

The intensities of the records are anticipated to be generally amplified by the soil layers during their excursion from base rock to the surface. This situation leads the use of higher number of records with low intensity for the input to have a more uniformly distributed output intensity values.

In order to have records with different frequency content in each 0.05g step, the records are aimed to have different predominant period and Peak Ground Velocity (PGV)/Peak Ground Acceleration (PGA) ratio values. As known, the predominant period is defined as the period of the wave with the largest amplitude in the frequency content. The PGV/PGA ratio has wave period/2π value for a simple harmonic wave [1]. PGV/PGA ratio is known to be an important marker of frequency content and the shape of the acceleration spectrum [19–25].

The establishment of the input acceleration record is done with great care. There are significant limitations and absences in the present natural earthquake records for establishing an acceleration record set with the desired properties which is also the reason of the current study.

For some intervals, if there is not enough number of real earthquake acceleration record with the desired characteristics, alternatives like deconvolution of surface records to base rock form for known soil profiles, scaling some records with scale factors close to unity or generating synthetic records are employed. However, attention has been paid to the characteristics of the synthetic or scaled records to be in accordance with the real earthquake records. In this way, a set of 84 acceleration records with different amplitude and frequency content is established.

4.1. Real earthquake records

Since the selections made for the real acceleration record will constitute the main skeleton of the record set, each selected record should have different characteristics to represent whole behavior range to have appropriate results. However, there are obstacles in finding suitable earthquake records as the input motions that assumed to take place in bedrock should have a V_{s30} (shear wave velocity calculated for the upper 30 m) value around 1500 m/s.

Firstly, PEER (Pacific Earthquake Engineering Center) strong ground motion database [26] is searched to form a set of earthquakes with a V_{s30} value greater than or equal to 1500 m/s. At the same time, shallow earthquakes with smaller EpiD (Epicentral distance to the station) values are tried to be selected. These values are important in terms of being appropriate to the characteristics of devastating earthquakes that are inconsistent with case study. However, only 17 records are founded in the database.

This shows that there are significant difficulties in finding the appropriate acceleration records, because PEER is the center of the richest database. In the present literature, it is seen that Beyaz [13] has given soil profiles of 56 acceleration recording station with base rock information. In these profiles, it is observed that there may be base rocks with shear wave velocity values like 1000-1200 m/s without reaching 1500 m/s velocities. On the basis of this, the search filters are replaced with speeds higher than 1300 m/s to stay in a safe zone. Although, the number of records obtained becomes higher, many records could not be used due to the very low PGA and magnitude values. This situation was an important problem because records with PGA up to 0.6g is needed.

Since the PEER database is not sufficient in the ongoing process, databases of other regions and countries are investigated. They are designated as Japan [27], USA [28], New Zealand [29], Italy [30] and Europe database [31, 32]. As a result of all these efforts, highest possible portion of the acceleration record set that established is obtained from the real earthquake records.

4.2. Records obtained by deconvolution

The insufficiency of the number of seismic acceleration records compatible with bed rock characteristics, necessitates some alternative solutions. One of these is the deconvolution (inverse convolution) technique. In order to perform this process, it is necessary to know the soil properties of the station where the surface earthquake record is taken. Motion at is recorded by the devices on the ground surface. In this case, if the effect of the soil layers up to the surface is accepted as the transfer function, and the surface earthquake record as the output function, the initial form of the record can be determined by the inverse convolution calculations [13]. This process is called deconvolution. In scope of the study, these calculations are made using the ProShake program [33].

4.3. Records obtained by scaling

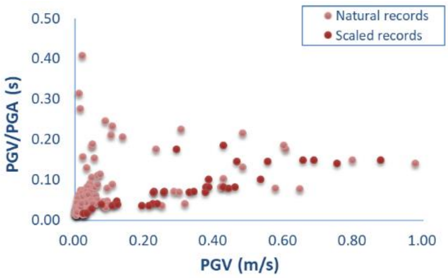
Although the deconvolution technique has enriched the acceleration record set, it is thought that some earthquakes may be used as scaled since the number of predicted records is not reached. The most important factor to be taken into account when performing this process is that the scale value to be used should be at a level that does not disrupt the characteristic of the current recording. Intensity and frequency content of ground motions are important characteristics which have impact on their effects on structures [34]. Scaling only alters the intensity of the acceleration record, but not the frequency content. However, in literature it is observed that higher intensity ground motions tend to have frequency content with higher period waves [35]. Therefore, with scale factors too different then unity, it is possible to move away from natural results.

It is recommended that the scaling process on actual earthquake records does not exceed certain limits. In literature some suggestions are given: When the acceleration record is scaled outside the range of 0.25-4.00, it is noticed that the spectral behavior of the records becomes uncertain [36]. It is recommended that the maximum value of scale factor is 4.0 for linear analyses and the factor should be in the range of 0.5-2.0 in the nonlinear analyses. Also, this coefficient should not be more than 2.0 for liquefaction studies [37–39].

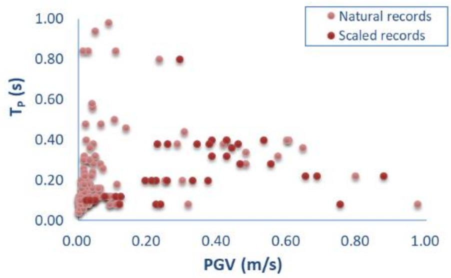
Considering all these, an appropriate scale range should be determined. The scaling of existing records without disturbing the frequency content-amplitude relationship of the earthquake such as PGV/PGA, mean period and predominant period is seen important in terms of achieving accurate results.

In order to avoid any alteration in the frequency-amplitude relationships, it is found appropriate to select maximum and minimum scale values. This selection is done by visual inspection and trial-error approach in scope of the study. The records are scaled by different values and their frequency content-amplitude relation is examined by using (PGV) and different frequency content parameters (PGV/PGA ratio, predominant period (T_P), mean period (T_M) [40]) graphs. The frequency content-amplitude relation of the scaled records with factors in the range of 0.7-1.30 are observed to be in consistent with unscaled natural earthquakes.

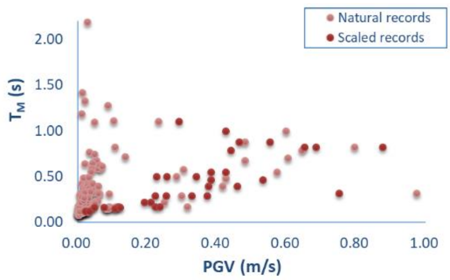
Fig. 2, shows the relationships between amplitude (PGV) and frequency content parameters for the scaled and natural earthquakes used in the study. When these relations are examined, it is seen that there are not any cases such as the separation of the scaled earthquakes from the natural earthquakes, scaled earthquakes in the extremities of the graphs. This shows that the frequency-amplitude relationship of acceleration records is not impaired by scaling. The reason for using PGV as amplitude parameter is that this parameter is shown as the one with highest correlation with other acceleration record parameters in the literature [41, 42] and PGV has a relatively high level of correlation with the seismic damage of various types of structures [43, 44].



a) PGV/PGA and PGV relation



b) T_P and PGV relation



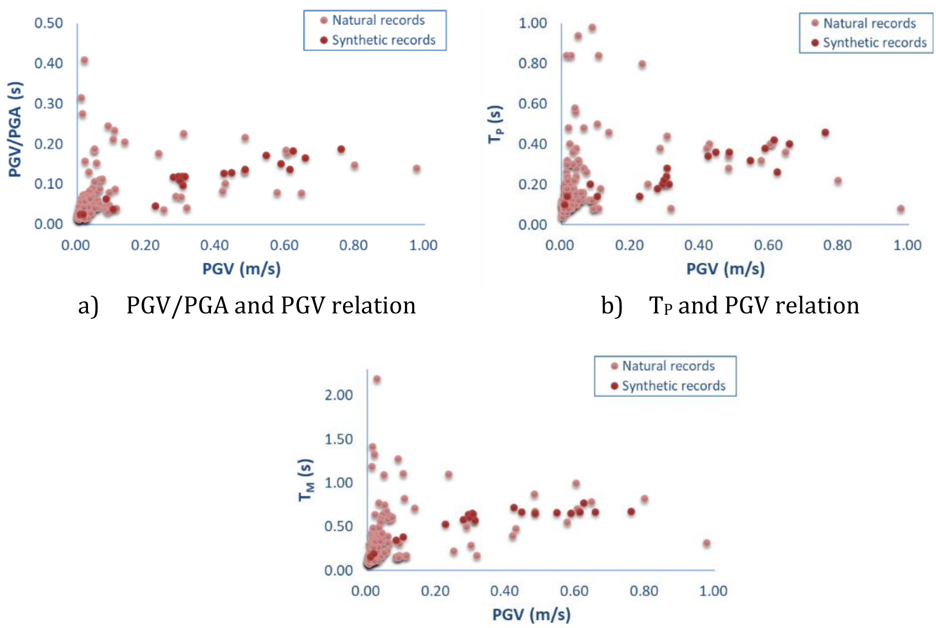
c) T_M and PGV relation

Fig. 2 The relationships between intensity and frequency content parameters for the scaled and natural earthquakes

4.4. Synthetic records

Although the acceleration record set reached a certain abundance by natural, scaled and records obtained using deconvolution method, it was not possible to reach desired quantities. This is due to the fact that the number of actual earthquake records and the recordings produced by the deconvolution technique are relatively low. Since the use of the scaling method many times may result in the dominance of the same records in the set, the addition of synthetic recordings seems to be a necessity.

Compatibility of the produced synthetic recordings with the natural earthquake characteristics is given importance. Produce earthquake records in the base rock feature is one of the first considerations. For this purpose, the use of the SeismoArtif program is deemed suitable since the base rock feature is provided in the software [45]. The acceleration record can be produced by entering hard rock value in the program, and a specific magnitude value can also be defined. The harmony of the produced synthetic records with the natural records is investigated graphically on the basis of PGV and PGV/PGA, T_P (predominant period) and T_M (mean period) relations (Fig. 3). A number of different acceleration records are generated and the ones that are far away from natural records in any of the 3 relations (indication of incompatibility in frequency content) are eliminated.



a) PGV/PGA and PGV relation

b) T_P and PGV relation

c) T_M and PGV relation

Fig. 3 The relationships between intensity and frequency content parameters for the synthetic and natural earthquakes

4.5. Established acceleration record set

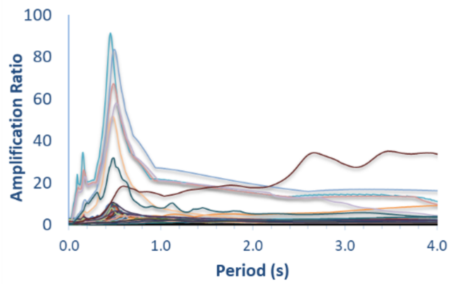
As a result of the explained studies, a set with 84 earthquake acceleration records is obtained by four different methods. In this context, it is thought that the acceleration records are both according to basement rock definition and having different amplitude and frequency content. Precedence is given to the real earthquake records. After these, deconvolution, scaling and synthetic records are used with mentioned priority order. The properties of the used input ground motions are given in the supplementary spread sheet files attached to the article under "Used Ground Motion Info" page.

In each PGA group, attention is paid to find an acceleration record with different properties in terms of fault type, earthquake characteristics, frequency content, and generation method (natural-deconvolution, scaled, synthetic). Due to the low number of natural acceleration records with desired base rock properties, the establishment of the acceleration record set is a very time consuming and demanding process.

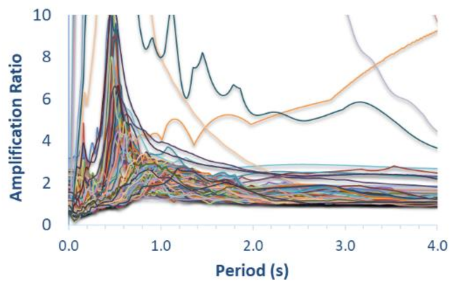
These 84 records which are compatible with base rock definition, are used to determine output acceleration records on the surface of the given 100 soil profiles using ProShake software. This way 8400 acceleration records with different frequency content, amplitude and site classes are obtained. These output records are given in the 7 supplementary spread sheet files attached to the article. The files are divided due to the high sizes exceeding 150 MBs.

5. Soil amplification

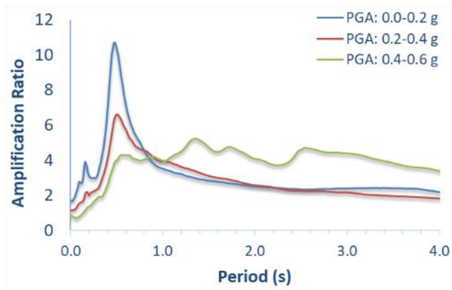
One of the goals in establishment of this acceleration record set is the investigation of soil amplification for different soil profiles. Exemplary results of soil amplification for a soil profile are given in Fig. 4 for all 84 acceleration records. Amplification ratios for each of the 84 acceleration records for example profile (output/input spectral acceleration ratios for the corresponding period) are given in Fig. 4a. Although the values between 0 and 10 s were obtained in the analysis, the graphical values are given up to 4 s which includes significant amplification zone and the effective range of most of the engineering structures.



a) Soil amplification for all records



b) Soil amplification (up to 10 folds)



c) Average soil amplification for different PGA ranges

Fig. 4 Soil amplification values for all 84 records and averages for different PGA ranges

In figures, extreme cases of amplification are seen up to 90 times, which is for small amplitude waves. However, the most of the values are up to 10 times amplification which is illustrated in Fig. 4b. The period of the examined soil profile is 0.44 s, which is roughly the value where maximum amplification occurs for most of the records. The average values of the different acceleration records may be more useful to understand the behavior. Therefore, in Fig. 4c, the average values for different PGA ranges are given.

It is seen that the magnification ratios are lower as expected with the increase of the ground motion amplitude. Maximum average amplification is around 10.5 times for 0.0-0.2g PGA group. 0.2-0.4g PGA group follows with 6.5 average amplification. The 0.4-0.6g group has a smaller average amplification of approximately 5.2 at a different period and has significantly higher amplification values than the other groups for periods larger than roughly 1.0 seconds. It is attributable to the richness of higher magnitude records in terms of waves with larger period. Although, it is not given here, same behavior is observed for other soil profiles, as well.

6. Summary & conclusions

As there is a problem in finding acceleration records with chosen characteristics in literature, this study is conducted to broaden the ground motion records for the researchers. Firstly, a set of 84 input records are established in consistent with base rock properties. These records are used to determine output acceleration records on the surface of the given 100 soil profiles. This way an acceleration record set with 8400 records with different frequency content, amplitude and site classes are obtained and given as attachment to this article (for files http://dx.doi.org/10.17515/resm2019.116ea0209.ds). The main conclusions of the study are as follows:

- The present acceleration data recorded from real earthquakes are not sufficient to conduct some scientific studies like the current one. Additionally, it is hard or not possible to find ground motion records for extensive dynamic analyses of some structures, which is also previously stated in literature.
- Depth-average shear wave velocity relations are examined and given for sand and clay materials. It is seen that the coefficient of variation is getting smaller with increasing depth.
- Properties of devastating earthquakes in Turkey are investigated as a case study of an earthquake prone country. The mean depth of focus is found to be 18.61 km. It is observed that shallow earthquakes with strike-slip mechanism is the main characteristics of destructive Turkish earthquakes.
- Scaling real earthquake records in 0.7-1.3 range does not observed to alter the frequency-amplitude relationship.
- It is seen that soil amplification ratios are lower with the increase of the ground motion amplitude. Records with PGAs of more than or equal to 0.4 g are observed to have higher amplification ratios for waves larger than roughly 1.0 s periods when compared to records with smaller PGA. It is attributable to the richness of higher magnitude records in terms of waves with larger period.

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References

[1] Kramer SL. Geotechnical Earthquake Engineering. Prentice-Hall, Inc. 1996. 653 p.
[2] Demirtas B, Bayraktar A, Dumanoglu A. Model updating effects on the seismic behavior of tall buildings under far and near-fault ground motions. Res Eng Struct Mater. 2017; 3(2):99–112.
[3] Rodriguez-Marek A, Bray JD, Abrahamson NA. An Empirical Geotechnical Seismic Site Response Procedure. Earthq Spectra. 2001; 17(1):65–87. https://doi.org/10.1193/1.1586167
[4] Hays W. Site Amplification of Earthquake Ground Motion. In: Third US National Conference on Earthquake Engineering. Charleston, South Carolina; 1986. p. 357–68.
[5] Seed HB, Romo MP, Sun JI, Jaime A, Lysmer J. The Mexico Earthquake of September 19, 1985—Relationships Between Soil Conditions and Earthquake Ground Motions. Earthq Spectra. 1988; 4(4):687–729. https://doi.org/10.1193/1.1585498
[6] Seed R, Dickenson SE, Riemer MF, Bray JD, Sitar N, Mitchell JK, et al. Preliminary Report on the Principal Geotechnical Aspects of the October 17, 1989, Loma Prieta Earthquake. 1990.
[7] Ansal A, Biro Y, Erken A, Gülerce Ü, Özçimen N. Seismic zonation in Istanbul: A case study. In: Geotechnical Earthquake Engineering and Microzonation Seminar. 2001.
[8] Tezcan SS, Kaya E, Engin Bal İ, Özdemir Z. Seismic amplification at Avcılar, Istanbul. Eng Struct. 2002; 24(5):661–7. https://doi.org/10.1016/S0141-0296(02)00002-0
[9] Bommer JJ, Douglas J, Strasser FO. Style-of-faulting in ground-motion prediction equations. Bull Earthq Eng. 2003; 1:171–203. https://doi.org/10.1023/A:1026323123154

[10] Ozmen HB, Inel M. Strength reduction factors for existing mid-rise RC buildings for different performance levels. Res Eng Struct Mater. 2018; 4(4):241–55. https://doi.org/10.17515/resm2018.60ea3107
[11] UBC-1997. Uniform building code. American Association of Building Officials, Whittier, CA. 1997.
[12] TBSC-2018. Turkish Building Seismic Code. Ministry of Environment and Urban Planning, Ankara; 2018.
[13] Beyaz T. Zemin Etkisinden Arındırılmış Deprem Kayıtlarına Göre Türkiye için Yeni Bir Deprem Enerjisi Azalım Bağıntısının Geliştirilmesi. Dissertation. Ankara University, Graduate School of Scence; 2004.
[14] Wikipedia-2016. Wikipedia web site [Internet]. 2016. Available from: https://tr.wikipedia.org/wiki/türkiye'deki_depremler_listesi
[15] Kandilli-2016. Kandilli Observatory web site [Internet]. 2016. Available from: http://www.koeri.boun.edu.tr/new/tr
[16] AFAD-2016. AFAD web sitesi [Internet]. 2016. Available from: http://www.deprem.gov.tr/tr/depremkatalogu
[17] AFAD. Disaster and Emergency Management Authority. Ankara, Turkey;
[18] Reynolds GH, Davis SJ. The structural geology of rocks and regions. USA: John Wiley & Sons Inc.; 1996.
[19] McGuire RK. Seismic ground motion parameter relations. ASCE J Geotech Eng Div. 1978; 104:481–90.
[20] Tso WK, Zhu TJ, Heidebrecht AC. Engineering implication of ground motion A/V ratio. Soil Dyn Earthq Eng. 1992; 11(3):133–44. https://doi.org/10.1016/0267-7261(92)90027-B
[21] XU L, HU J, XIE L. On Characteristics of Ground Motion Parameters for Special Long-Period Ground Motions. J Earthq Eng Eng Vib. 2008; 28(6):20–7.
[22] XU L, XIE L. Variations of Seismic Design Acceleration Amplitude with Depth for Underground Structures. World Inf Earthq Eng. 2009; 25(2).
[23] Tselentis GA, Danciu L. Probabilistic seismic hazard assessment in Greece - Part 1: Engineering ground motion parameters. Nat Hazards Earth Syst Sci. 2010. https://doi.org/10.5194/nhess-10-25-2010
[24] Kianoush MR, Ghaemmaghami AR. The effect of earthquake frequency content on the seismic behavior of concrete rectangular liquid tanks using the finite element method incorporating soil-structure interaction. Eng Struct. 2011. https://doi.org/10.1016/j.engstruct.2011.03.009
[25] Ozmen HB. Developing hybrid parameters for measuring damage potential of earthquake records: case for RC building stock. Bull Earthq Eng. 2017; 15(7).
[26] PEER. Pacific Earthquake Engineering Research Center [Internet]. 2016. Available from: http://peer.berkeley.edu/smcat/index.html
[27] Cosmos-2016. Global Component of the Center for Engineering Strong Motion Data [Internet]. 2016. Available from: https://strongmotioncenter.org
[28] USGS-2016. United States Geological Survey [Internet]. 2016. Available from: https://earthquake.usgs.gov/data/
[29] GeoNet-2016. New Zealand Strong Motion Database [Internet]. 2016. Available from: http://quakesearch.geonet.org.nz/
[30] Itaca-2016. Italian Accelometric Archive [Internet]. 2016. Available from: http://itaca.mi.ingv.it/
[31] ORFEUS-2016. Observatories & Research Facilities for European Seismology [Internet]. 2016. Available from: https://www.orfeus-eu.org
[32] ESD-2016. The European strong motion database [Internet]. 2016. Available from: http://www.isesd.hi.is/esd_local/frameset.htm
[33] EduPro Civil Systems. ProShake [Internet]. 2016.

[34] Ozmen HB, Inel M, Senel SM, Kayhan AH. Load carrying system characteristics of existing turkish rc building stock. Int J Civ Eng. 2015; 13(1).
[35] Rathje EM, Faraj F, Russell S, Bray JD. Empirical Relationships for Frequency Content Parameters of Earthquake Ground Motions. Earthq Spectra. 2004; 20(1):119–44. https://doi.org/10.1193/1.1643356
[36] Yağcı B. Microzonation methodologies and a study for Balikesir. Dissertation. Balıkesir University, Institute of Science, Department of Civil Engineering; 2005.
[37] Vatansever S. Gerçek Deprem Kayıtlarının Ölçekleme Yöntemlerinin Karşılaştırılması. Dissertation. Gebze Yüksek Teknoloji Enstitüsü; 2011.
[38] Vanmarcke EH. State-of-the-Art for Assessing Earthquake Hazards in the United States: Representation of Earthquake Ground Motions – Scaled Accelerograms and Equivalent Response Spectra. Vicksburg, Mississippi, USA; 1979.
[39] Krinitzsky EL, Chang F. K. State-of-the-Art for Assessing Earthquake Hazards in the United States: Specifying Peak Motions for Design Earthquakes. Mississippi, USA; 1977.
[40] Rathje EM, Abrahamson NA, Bray JD. Simplified Frequency Content Estimates of Earthquake Ground Motions. J Geotech Geoenvironmental Eng. 1998; 124(2):150–9. https://doi.org/10.1061/(ASCE)1090-0241(1998)124:2(150)
[41] Amiri GG, Dana FM. Introduction of the most suitable parameter for selection of critical earthquake. Comput Struct. 2005;
[42] Ozmen HB, Inel M. Damage potential of earthquake records for RC building stock. Earthq Struct. 2016; 10(6). https://doi.org/10.12989/eas.2016.10.6.1315
[43] Avşar Ö, Özdemir G. Response of Seismic-Isolated Bridges in Relation to Intensity Measures of Ordinary and Pulselike Ground Motions. J Bridg Eng. 2011;
[44] Avşar Ö, Yakut A, Caner A. Analytical fragility curves for ordinary highway bridges in Turkey. Earthq Spectra. 2011. https://doi.org/10.1193/1.3651349
[45]SeismoArtif-2016. SeismoArtif [Internet]. 2016. Available from: http://www.seismosoft.com/seismoartif