

T.C.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**DEVELOPMENT OF GROUND MOTION SELECTION AND
SCALING FRAMEWORK COMPATIBLE WITH TBEC-2018**



DOĞUKAN KARATAŞ
A THESIS SUBMITTED FOR THE DEGREE OF
MASTER OF SCIENCE
DEPERTMANT OF CIVIL ENGINEERING
EARTHQUAKE AND STRUCTURAL ENGINEERING DEPARTMENT

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THESIS SUPERVISOR
ASSIST. PROF. DR. AHMET ANIL DİNDAR

GEBZE
2023

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DR. ÖĞR.ÜYESİ AHMET ANIL DİNDAR

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JÜRİ

ÜYE

(TEZ DANIŞMANI)

: Dr. Öğr. Üyesi Ahmet Anıl DİNDAR

ÜYE

: Doç. Dr. Gülüm TANIRCAN

ÜYE

: Dr. Öğr. Üyesi Ahu Mutlu KOMEÇ

ONAY

Gebze Teknik Üniversitesi Fen Bilimleri Enstitüsü Yönetim Kurulu'nun

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SUMMARY

In the seismic provisions of current building codes and standards, dynamic nonlinear time-history analysis is the ultimate assessment tool for failure mechanisms. Owing to the rapid development of computational methods in structural analysis, there is a growing tendency to perform nonlinear dynamic analysis. However, there is currently no consensus in the earthquake engineering community on how to appropriately select and scale the ground acceleration time series for seismic design and performance assessment of buildings. This study proposes a framework named as “Scalepy” for ground motion selection and scaling, with a focus on selecting the earthquake records that are most compatible with the response spectrum. The challenge of selecting set of accelerograms for time-domain analysis is of practical and academic interest. The algorithm is based on an iterative method to find the record set that causes the least scatter from a given design spectrum. As scaling procedure, the conventional amplitude scaling method is used, to avoid of manipulation the frequency content. Since the largest source of uncertainty comes from ground motion selection, this method aims to obtain optimal time series for engineering demand parameters in amplitude scaling. Scalepy is developed in Python programming language as an open-source project which is shared in GitHub repository to enable any user or developer to contribute the algorithm and methodology without any restriction.

Key Words: Ground Motion, Selection, Scaling, Earthquake, Python, Open-Source.

ÖZET

Zaman-tanım alanında yapılan doğrusal olmayan dinamik analizler, günümüz deprem şartnameleri için, bina performansını belirlemek için birincil araçlardır. Son yıllarda bilgisayarlı hesap araçlarının gelişen gücü göz önüne alındığında, doğrusal olmayan dinamik analizler ile bina performansı belirlemek, gittikçe daha verimli hale gelmektedir. Buna rağmen, zaman-tanım alanında yapılan analizlerin temel girdisi olan ölçeklenmiş deprem kayıtlarının nasıl seçileceği ve kullanılacağı hakkında, deprem mühendisliği alanında bir fikir birliği bulunmamaktadır. Bu çalışma, tepki spektrumuyla en uyumlu kayıtların bulunmasını sağlayan ve bu kayıtları seçilen bir tasarım spektrumuna uyarınca ölçekleyen bir “Scalepy” isimli bir algoritma geliştirmeyi öngörüyor. Bu algoritma, veri tabanında bulunan deprem kayıtlarından, tepki spektrumuna göre en az saçılım gösteren belirli sayıdaki kaydı, iteratif bir metot yardımıyla bulunması prensibine dayanıyor. Yapısal analizlerdeki en büyük bilinmezlik, binlerce kayıt arasından en uygun olanları belirlemek olduğundan, bu algoritma tepki parametrelerini optimize etmeyi amaçlıyor. Bu çalışma Python programlama dilinde, açık kaynak olarak geliştirilmiş olup Github deposunda paylaşılmış olup kullanıcı ve geliştiricileri herhangi bir engel olmadan algoritma ve yöntemi geliştirmeleri mümkün kılacaktır.

Anahtar Kelimeler: Yer Hareketi, Deprem, Seçme Ölçeklenmesi, Python, Açık Kaynak.

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LIST OF ABBREVIATIONS AND ACRONYMS

<u>Abbreviations</u>	<u>Explanations</u>
<u>and Acronyms</u>	
V_{s30}	: Shear-wave velocity of 30m depth
Sae	: Spectral Acceleration
w_i	: Weighting factor for the squared error at period T_i
y_i	: Ordinate of geometric mean spectrum at period T_i
y_{ti}	: Ordinate of target spectrum at period T_i

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1. INTRODUCTION

1.1. Motivation

In the seismic provisions of current building codes and standards, time-history analysis is the ultimate and an accurate assessment tool for seismic response of structures in Performance-Based Earthquake Engineering (PBEE). This assessment can be necessary for both to design a new structure or to determine the seismic performance of an existing structure (i.e., high-rise buildings, nuclear power plants). The selection of ground motions for use in nonlinear response history analysis is the most critical step for code-based design checks. Owing to the rapid development of computational methods in structural analysis, there is a growing tendency to perform nonlinear dynamic analysis. One of the objectives of ground motion selection and scaling methodologies is to enable engineers to estimate the median response, or to predict the distribution of structural response, with relatively small number of ground motions. However, there is currently no consensus in the earthquake engineering community on how to appropriately select and scale the ground acceleration time series for time domain analysis.

When nonlinear time history analysis is of concern, an ensemble of accelerograms representing the pre-defined seismic demand is required. This requirement brings forward the significance of obtaining a suitable set of accelerograms since nonlinear structural response can be very sensitive to the employed ground motion time series. Various code-based ground motion selection and scaling methods have been proposed to achieve a reasonably accurate fit between the spectral ordinates of selected accelerograms and target spectrum [1]. However, these documents are mostly lack of appropriate guidance for selection and scaling of ground motions used in the analyses [2]. Thus, in practice, it is the engineers call to decide on the procedure for selection and scaling of ground motion records [3].

Previous versions of ASCE 7 (e.g., ASCE 7-10, American Society of Civil Engineers, 2010 and ASCE 7-16, American Society of Civil Engineers, 2016) presented almost no guidelines on the use of spectrum-compatible records. For the Turkish Seismic Code, in TSC-2007 [4], a nonlinear time-history analysis was first performed to evaluate the performance of existing structures. With the publication of

TBEC-2018 (Turkish Building Seismic Code, 2018) [5], a few methodologies have added for the selection and scaling of time series. However, there is no detailed guideline of the procedure referred in Turkish Seismic Code, th it is still the researcher's or designer's responsibility to find a reasonable way for selecting an appropriate set of time series. To overcome this difficulty, Pacific Earthquake Engineering Research Center (PEER) has provided a web service where the users can conduct a scaling procedure for the given code based and user defined response spectra. Such a tool has been missing for Turkish researchers and practicing engineers.

Therefore, the purpose of this study is to propose a method for record selection to find the optimal set of seismic records that establish the minimum dispersion in the design response spectrum and create a framework for whole selection and scaling procedure. This framework named as "ScalePy" has been developed in Python programming language as an open-source project, which means it is possible to contribute to development of the framework in the future.

1.2. Scope

A valid seismic performance evaluation of structures requires the right selection of input motions for use in nonlinear response history analysis. The current research effort is focused on the creation of strategies for choosing and scaling earthquake records. The primary goal of this dissertation is to propose a novel methodology for determining the optimal ground motion set for a given target spectrum without interfering the frequency content of the motion. Therefore, spectral matching approaches based on signal processing are not in the scope of this study. The critics to the spectral matching have arisen in the academic studies where the magnitude of the natural motions should be arranged rather than the frequency content.

1.3. Organization

This dissertation is composed of five chapters. The subsequent chapters are organized as follows:

- Chapter 1 provides a background about what is the current research situation about selection and scaling of ground motion records and a literature survey about the subject.
- Chapter 2 provides a brief information about the widely used selection and scaling methodologies and seismic code provisions about the subject.
- Chapter 3 presents the fundamentals of new proposed methodology, workflow, and iteration steps.
- Chapter 4 demonstrates numerical examples with selected scenarios. Four different data set has been prepared for 38 locations in Turkey. These big data set has used to perform sensitivity analysis and assessment of the efficiency of the proposed method.
- Finally, Chapter 5 presents the summary and key conclusions of this dissertation and recommendations for future work.

2. GROUND MOTION SELECTION AND SCALING

2.1. Literature Survey

Studies about selection and scaling of ground motion records date back to mid-80s. In the literature it is well documented that the selected ground motions should possess similar characteristics in terms of both magnitude and distance from the fault.

Nau and Hall (1984) [6] concluded that scaling the records with respect to spectral ordinates reduce the dispersion on the structural response. Kappos and Kyriakakis (2000) [7] emphasized proper scaling of records with respect to the spectrum intensity. Shome et al. (1988) highlighted the correlation between the dispersion in the structural response and number of ground motions to be used in time domain analysis. Stewart et al. (2001) [8] and Bommer and Acevedo (2004) [9] pointed the importance of magnitude and duration match between the selected recordings and the target earthquake scenario. Naeim et al. (2004) [10] emphasized that not only the magnitude but also a proper distance interval that matches the target earthquake scenario. Cimellaro et al. (2011) [11] observed that the magnitude and distance properties of the selected ground motions affect the dispersion on the engineering demand parameters.

Another important concern about scaling is the value of scaling factors. Watson-Lamprey and Abrahamson (2006) [12] highlighted the shortcomings of excessive scaling that may invoke the bias in the structural response. Hancock et al. (2008) [13] quantified the upper limit upper limit of scaling factor as 10.

According to Al Atik and Abrahamson (2010) [14], regarding the selection process, it is stated that earthquake records in an ideal situation should be selected based on the source, path and site conditions including the magnitude, distance from the fault, the fault type, and directivity.

The time domain scaling approach scale the time histories up or down consistently by a scaling factor that can be either positive or negative to match the target spectrum. While it is hard to match the records to the target spectrum along the whole period, engineers tend to concentrate more on the period of interest of the building that is (0.2T_n to 1.5T_n) according to the Turkish Building Earthquake Code (TBEC 2018). This approach does not change the frequency content of the time history

records. Additionally, the records could be scaled separately, or the average of spectra could be scaled to match the target spectrum [15].

2.2. Definition of Target Spectrum

A traditional approach for developing design spectra is based on the mean hazard curve of the probabilistic seismic hazard analysis (PSHA). The PSHA produces a suite of hazard curves for spectral ordinates for different response periods. A set of spectral ordinates can be obtained and plotted as a function of response period to form the elastic response spectrum for the selected design return period. This spectrum is known as Uniform Hazard Spectrum (UHS). There is an alternative to UHS, Conditional Mean Spectrum (CMS), provides the expected response spectrum, conditioned on occurrence of a target spectral acceleration value at the period of interest [16].

The principal regions (acceleration, velocity and displacement) of the design spectrum are identified in which the response is approximately a constant, amplified value. Amplification factors are then applied to the maximum ground motion in these regions to obtain the desired design spectrum.

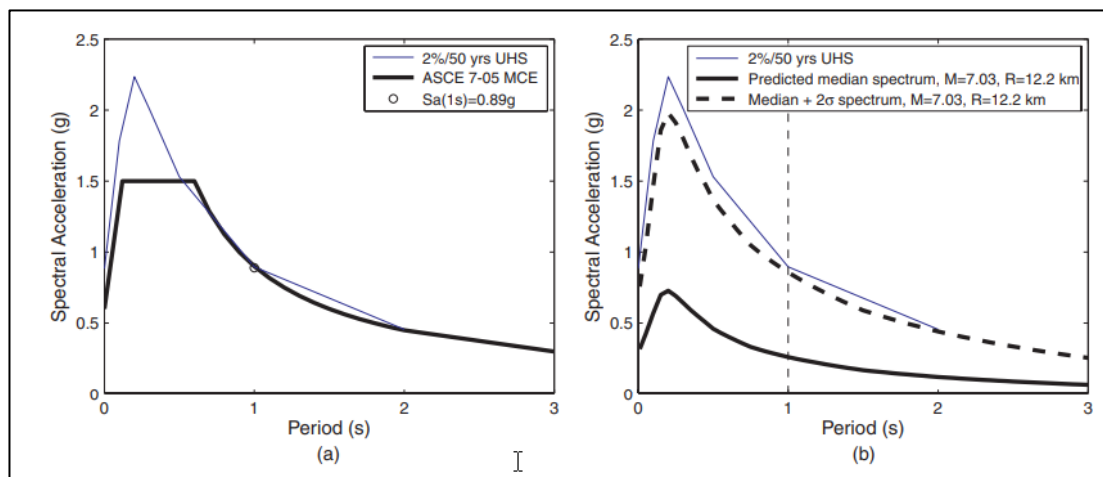


Figure 2.1: CHS and UHS design spectra.

A target spectrum function is created in the framework which inputs are:

- Spectral acceleration parameter at short periods
- Spectral acceleration parameter at a period of 1 second
- Soil type.

This function returns the target spectrum according to TBEC-2018.

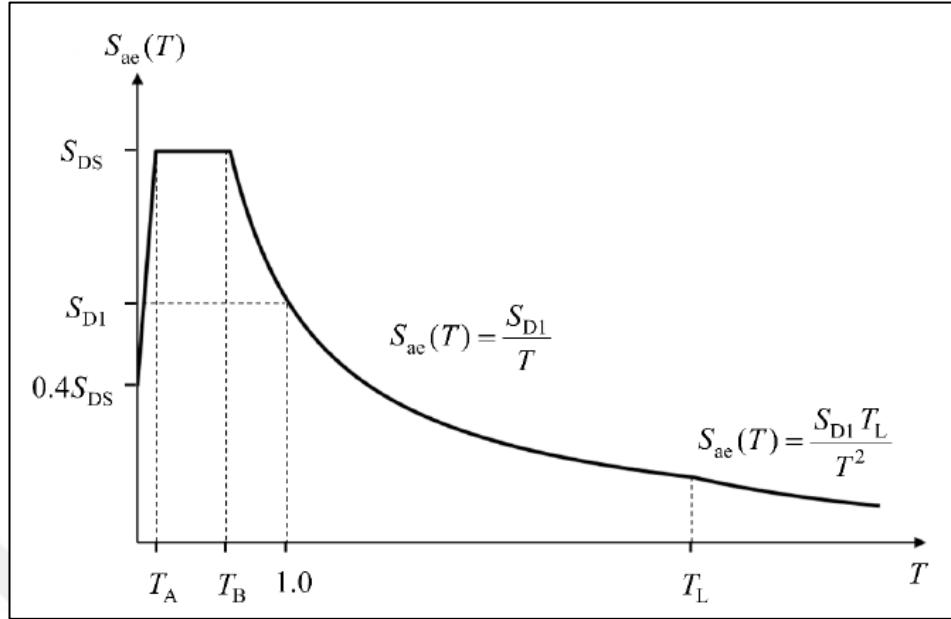


Figure 2.2: Target spectrum definition acc. to TBEC-2108

2.3. Selection Criteria

The current practice for ground motion selection is to assemble earthquake records according to the seismological parameters. Selected earthquakes are expected to have similar parameters with the real earthquake scenario (e.g., magnitude, source-to-site distance, site class, fault mechanism).

The magnitude of the earthquake (M) is the most important parameter for the initial selection of the records because this parameter directly influences the frequency content and the duration of the ground motions. Since the earthquake magnitude (M) and distance (R) of the rupture zone from the site of interest are the most common parameters related to a seismic event, it is evident that every selection procedure must involve these two criteria.

Nevertheless, several studies questioned the effectiveness of these two criteria [17]. Therefore, it is common to use several additional criteria, which can be found in this study, among earthquake engineers.

2.3.1. Additional Selection Criteria

Additional selection criterion complementing both magnitude and distance is the actual soil profile. The geotechnical profile is known to influence seismic motions by modifying the amplitude and the computed response spectra. In this study, shear-wave velocity at the uppermost 30 m (V_{s30}) used as a suitable metric for site classification. Alternatively, site classification can be done according to seismic code provisions and soil categorization schemes can be utilized for the record selection procedure.

Another important issue in the literature is consideration of rupture mechanism or type of faulting. Information generated from the predictive equations developed in the NGA Project demonstrated that earthquakes with reverse-oblique mechanism have similar characteristics to those from reverse faulting events, but there are significant differences with other types of faulting mechanisms. The impact that various studies has showed that, faulting mechanism has an impact of earthquake characteristics led many researchers to use these parameters in the earthquake selection process.

2.4. Scaling Methods

There are certain methods of scaling time histories. These included spectral matching methods where the frequency content of the ground motions is manipulated to establish spectral convergence. The other method, known as amplitude scaling method, is limited to varying only the amplitude of the ground motions. Regardless of the scaling method, there are still no detailed workflow for selecting records. There are some proposed methods, namely spectral matching based selection, and ground motion intensity-based selection.

2.4.1. Amplitude Scaling

In this approach, recorded motion is scaled up or down uniformly to best match the target spectrum within a period range of interest, without changing the frequency content. When dealing with more than one input time history, one can either use the same procedure to fit each record separately or try to best fit the average of the

produced to the target spectrum. The proposed algorithm which is used in this study, matches the average and individuals to the target spectrum.

2.4.2. Frequency Matching

This method is based on the concept of using actual records to generate time histories that fit a given target response spectrum. The physical characteristics of the earthquake motion are retained throughout the procedure, which makes the technique powerful in comparison with the classical artificial record generation. In this method, an actual motion is filtered in the frequency domain by its spectral ratio with the design target spectrum.

The Fourier phases of the motions remain unchanged during the entire procedure. The technique is repeated iteratively until the desired matching is achieved for a certain range of periods. A frequency domain scaling methodology uses an actual record to produce a similar motion that matches almost perfectly a target (design) spectrum. The resulting time histories should be investigated in terms of suitability as input for linear and nonlinear time history analyses of engineering structures.

2.5. Seismic Code Provisions

Seismic codes describe general guidelines but do not provide specifics for selecting earthquake records for nonlinear dynamic analysis purposes. There are three main reasons for that:

- Time-history analysis are rather recent.
- Research on this topic is still under development.
- Full agreement has not yet been reached.

Most contemporary seismic codes, such as Eurocode 8 [18], ASCE Standards and TBEC-2018 describe relatively similar procedures for earthquake simulation. However, TBEC – 2018 include no guideline for selection criteria.

This framework is adapted to requirements according to the TBEC-2018 (Turkish Building Seismic Code, 2018). The selection and scaling requirements were first mentioned in TSC-2007 (Turkish Seismic Code – 2007). According to the TSC-2007, requirements concerning real earthquake records are:

- At least 3 ground motions should be considered.
- The duration of the strong ground motion shall not be less than 5 times the first natural vibration period of the building and 15 seconds.
- The mean of the spectral acceleration values of the generated earthquake ground motion corresponding to the zero period will not be less than A_0 (effective ground acceleration coefficient $\times$ gravitational acceleration).
- The mean of re-calculated spectral acceleration values shall not be less than 90% of the elastic spectral accelerations ($S_{ae}(T)$) for periods between $0.2 \times T_1$ and $2 \times T_1$ (T_1 as first natural vibration period) in the earthquake direction considered. In the case of linear elastic analysis, the spectral acceleration values ($S_{aR}(T_n)$) to be taken as basis of determining the reduced earthquake ground motion, will be calculated with the reduced acceleration spectrum coordinate formula.

According to the TBEC-2018, requirements for selection and scaling are:

- Seismic acceleration records to be used in the time domain analyses must be compatible with the Design Acceleration Spectrum. Appropriate acceleration records must be selected accordingly, scaled, and modified for this operation.
- In the selection of acceleration records the following properties must be taken into consideration: Fault distances, source mechanisms and local ground conditions, past earthquake records, number of acceleration sets must be at least eleven. Maximum 3 record can be selected from same event.
- Amplitudes of the average of the selected acceleration records between $0.2 \times T$ and $1.5 \times T$ periods are scaled so that they are not smaller than the design acceleration spectrum, where T is the fundamental period of the building.

3. PROPOSED METHODOLOGY

3.1. Principles of the Recommended Algorithm

To find the earthquake record set which has minimum diversity with the target response spectrum, an iterative algorithm is used. This algorithm is searching PEER Ground Motion Database. There are several stages of selection procedures:

- i) Filtering earthquake according to given magnitude range, soil type, fault distance, fault mechanism, 5-75% significant duration, 5-95% significant duration, and arias intensity.
- ii) Eliminate the selected earthquake records in the first stage if there are more than 3 records from the same event.
- iii) Use the curve similarity algorithm to find most similar records to the design spectrum.

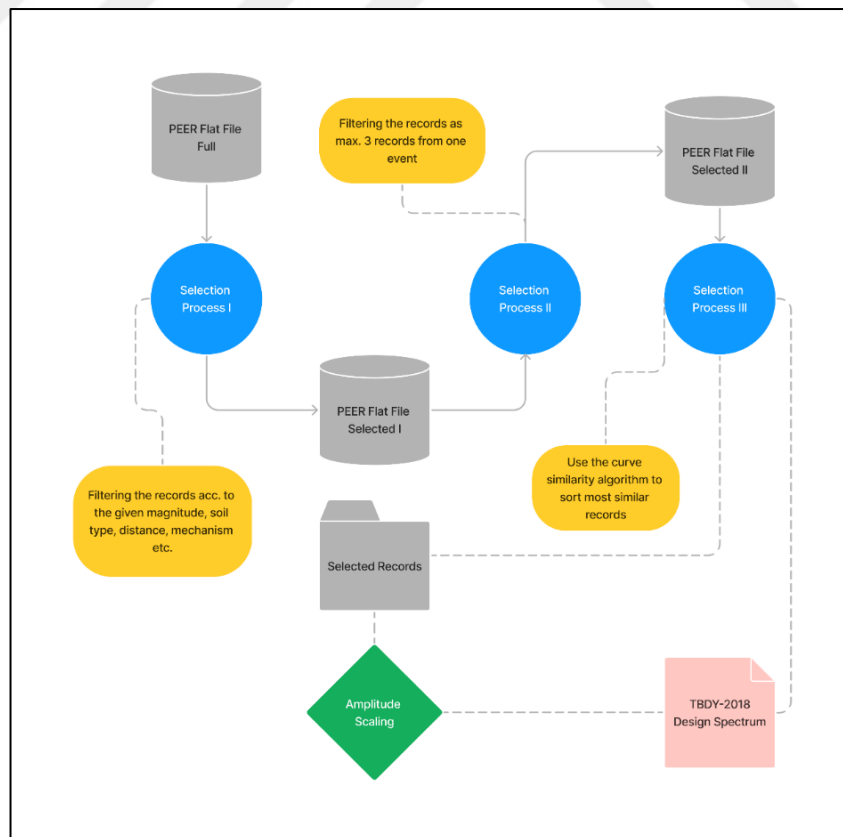


Figure 3.1: Selection algorithm flowchart.

Selection algorithm can be used to find most similar 11 ground motion records to the design spectrum. This method is reducing the uncertainties in the scaling procedure because the dispersion of the acceleration content is minimum.

After the selection procedure, this framework enables us to compare two new concepts for selection and scaling of ground motions. First one is, the possibility to calculate orientation-independent spectrums (RotDnn) and the second one is a different amplitude scaling method in P695 [19].

3.2. Orientation-Independent Spectrum

Chapter 16 of ASCE7-16 proposed two methodologies to select and scale real ground motions to perform nonlinear time history analysis:

- First method proposes to produce a maximum-direction (RotD100) MCER spectrum according to provisions in Chapter 11 along with mapped acceleration parameters.
- Second method proposes to produce two or more site-specific response spectrum which is not less than 75% of the spectral values in the MCER (Method 1) over the period of range of interest.

This methodology allows engineers to use two new methods to produce response spectrum. RotD100 is maximum spectral acceleration observed in any orientation of horizontal ground motion shaking and RotD50 is median spectral accelerations over all orientations.

Current approaches to the matching methods are mostly matching a single component to a target spectrum. This produces no issues when the load resisting system is split into two dimensional multiple models. This analysis models requires only one horizontal accelerogram input. On the other hand, when it comes to calculate the lateral response a three-dimensional complex model with time-history analysis, uncertainties of the ground motion input have increased. The approach of RotDnn concept is the solution to decrease these uncertainties with the orientation-independent spectrums.

These approaches still not recognized by the Turkish Seismic Code and its applications, but when we consider that Turkish Earthquake Code mostly follows the provisions of ASCE, most probably these approaches will take place in the next Turkish Seismic Code.

In this framework, a function to calculate RotD100 spectrums has added to compare the results with the SRSS approach [20].

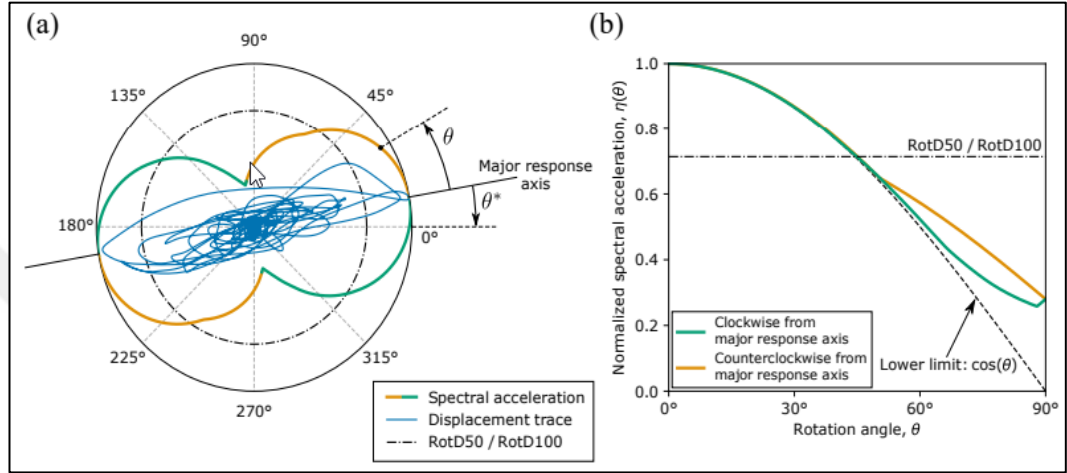


Figure 3.2: RotD50 and RotD100 spectral acceleration.

3.3. FEMA P695 Scaling Procedure

A different scaling procedure has added to the framework to compare the results of the existing scaling procedure. Amplitude scaling method mentioned in FEMA P695 is developed as a function in the framework. This function includes two steps:

- Individual records of a given set are normalized by their respective peak ground velocities. In essence, some records are factored upwards (and some factored downwards), while maintaining the same overall ground motion strength of the record set. The following formulas define the normalization factor NM and calculation of normalized horizontal components.

$$NM_i = \text{Median}(PGV_{PEER,i})/PGV_{PEER,i} \quad (3.1)$$

$$NTH_{1,i} = NM_i \times TH_{1,i} \quad (3.2)$$

$$NTH_{2,i} = NM_i \times TH_{2,i} \quad (3.3)$$

Where:

- NM_i = Normalization factor of both horizontal components of the i^{th} record (of the set of interest),
- $PGV_{peer,i}$ = Peak ground velocity of the i^{th} record (PEER NGA Database),
- $Median(PGV_{PEER,i})$ = Median of $PGV_{PEER,i}$ values of records in the set,
- $NTH_{1,i}$ = Normalized i^{th} record, horizontal component 1,
- $NTH_{2,i}$ = Normalized i^{th} record, horizontal component 2,
- $TH_{1,i}$ = Record i , horizontal component 1 (PEER NGA Database)
- $TH_{2,i}$ = Record i , horizontal component 2 (PEER NGA Database)

- Second step in this procedure is the scaling of the normalized set. For collapse evaluation, the Methodology requires the set of normalized ground motion records to be collectively scaled upward (or downward) to the point that causes 50 percent of the ground motions to collapse the archetype analysis model being evaluated. This approach is used to determine the median collapse capacity S_{ct} , of the model. Once this has been established, the Methodology requires that the collapse margin ratio, CMR, be computed between median collapse capacity, S_{ct} , and MCE demand, S_{mt} .

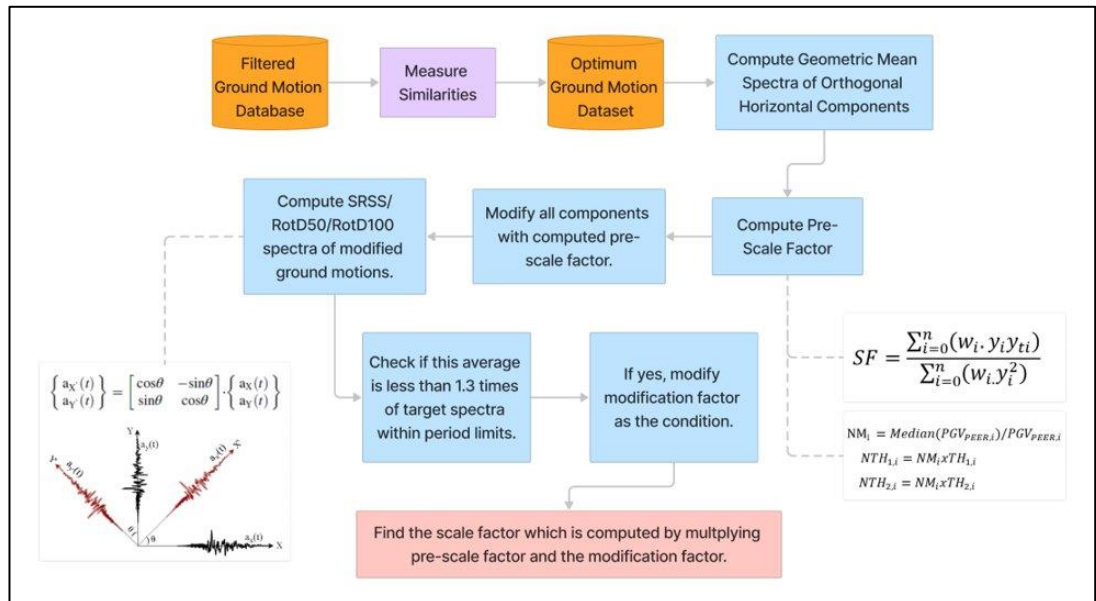


Figure 3.3: Scaling algorithm flowchart.

3.4. Ground Motion Database

The ground-motion record library used in this study is gathered from the PEER (Pacific Earthquake Engineering Research)-NGA (<http://peer.berkeley.edu>) database. This web-based database includes a very large set of ground motions recorded in worldwide in active tectonic regimes. The database has a comprehensive meta-data, which includes various characteristics of the earthquake source data. This source data is used in this study as selection database. Due to copyright issues, all databases cannot be linked to source-code. After iteration and scaling, our algorithm returns selected earthquakes record sequence number and scaling factors.

This web-based database has also a tool for scaling selected ground motions. This tool is not using an iteration or optimization of records. Therefore, in this study, this scaling tool is used for the comparison of results.

3.5. Iteration and Correlation

Dealing with multiple time histories requires to fit each record separately, besides fitting the average of the ground motions to the target spectrum. In this study, the scaling method applied to the ground motion records is an amplitude scaling method. In this approach, records adjusting by multiplying with a scalar called as scale factor, over the period range of interest, without changing the frequency content. Following procedure is used to find this scalar:

- i) Filter ground motion database acc. to selected magnitude range, soil type, mechanism etc.

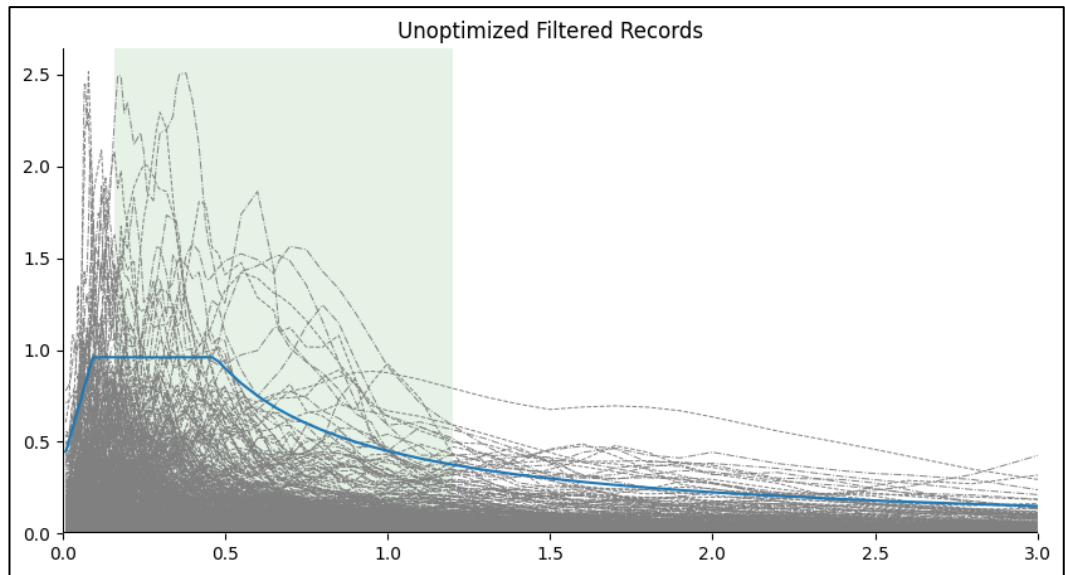


Figure 3.4: Orthogonal horizontal components of unoptimized ground motions.

ii) Find most similar 11 ground motion record.

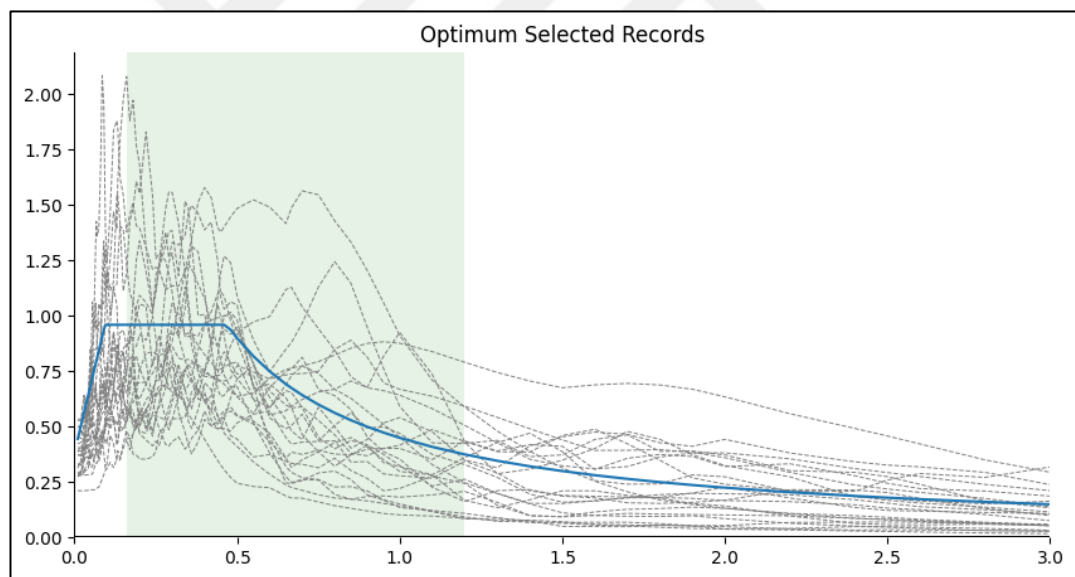


Figure 3.5: Orthogonal horizontal components of optimized ground motions.

iii) Compute geometric mean spectra of orthogonal horizontal components of ground motion records.

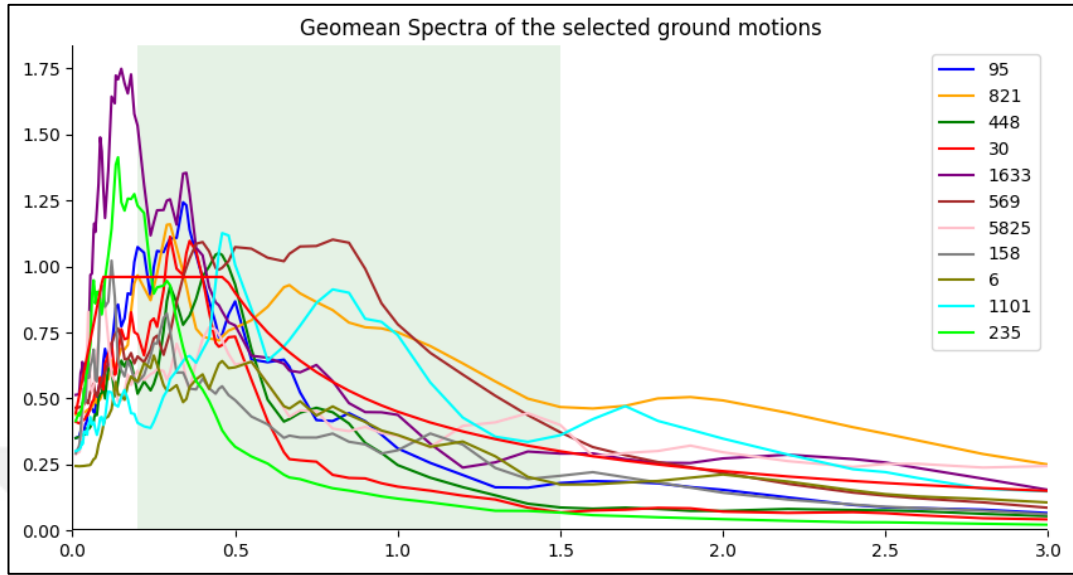


Figure 3.6: Geometric mean spectra of components.

iv) Compute pre-scale factor with the following equation.

$$SF = \frac{\sum_{i=0}^n (w_i \cdot y_i \cdot y_{ti})}{\sum_{i=0}^n (w_i \cdot y_i^2)} \quad (3.4)$$

- SF = Scale factor
- w_i = Weighting factor for the squared error at period T_i
- y_i = Ordinate of geometric mean spectrum at period T_i
- y_{ti} = Ordinate of target spectrum at period T_i

v) Modify each orthogonal horizontal components of the ground motion records by pre-scaled factor computed in step 3.

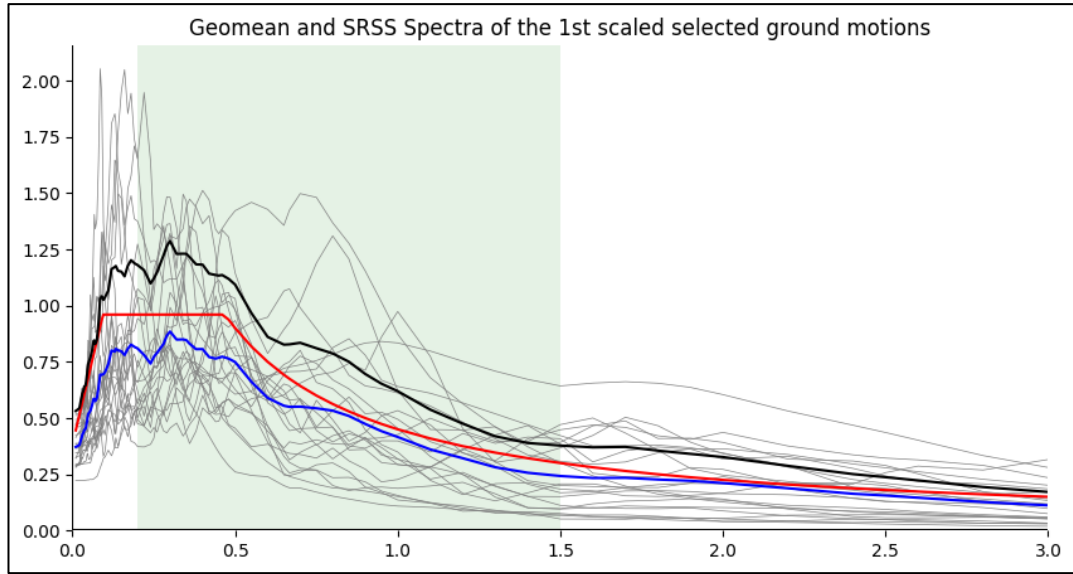


Figure 3.7: Geometric mean scaled average.

vi) Compute the SRSS spectra of modified ground motion records and take their average. This SRSS average shall not be less than 1.3 times of the target spectra within period limits. Hence, obtain a further scalar for every ground motion records to meet this requirement if necessary.

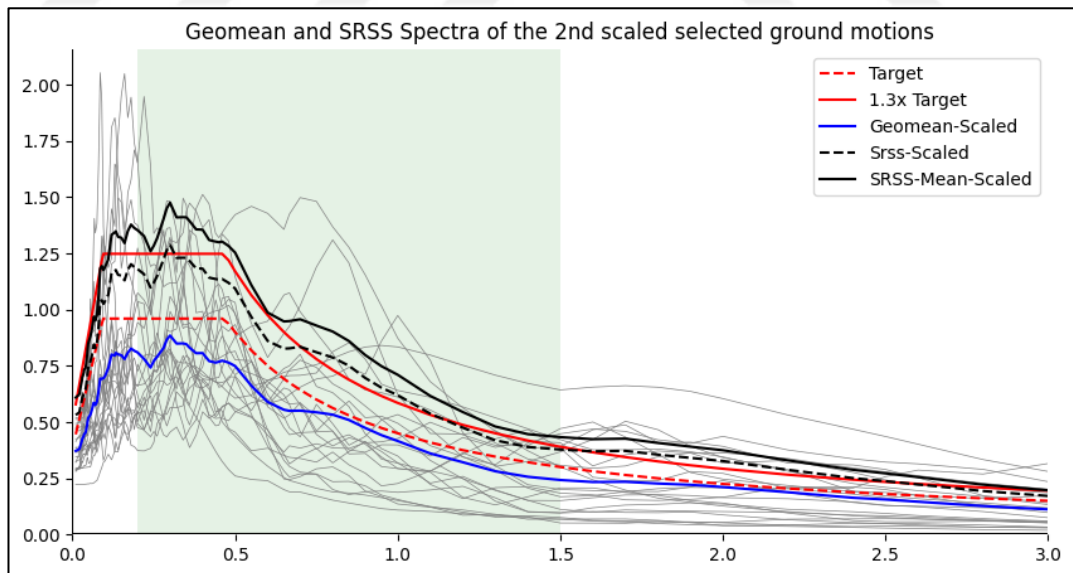


Figure 3.8: SRSS scaled spectra.

vii) Find the scale factor which is computed by multiplying the pre-scale factor and the scalar found in step 5 [21].

4. NUMERICAL EXAMPLE

For the numerical comparison, 19 locations have used with different soil types and predicted mechanisms and distances which have selected for the project 121M713 [22]. Test locations is shown in the map below.



Figure 4.1: Test location map.

These locations have analyzed two different earthquake intensity levels.

For all the cases 4 data sets has been prepared to perform a sensitivity analysis of the scale factors.

- Data Set 1: Results obtained by conventional PEER NGA selection and scaling procedure.
- Data Set 2: Results obtained by developed framework selection and scaling procedure with SRSS spectrum.
- Data Set 3: Results obtained by developed framework selection and scaling procedure with RotD100 spectrum.
- Data Set 4: Results obtained by developed framework selection and scaling procedure with using FEMA P695 scaling method.

After all the iterative procedure, 152 sets of scale factors have obtained to test the efficiency of the developed framework. 3 data cases with different earthquake

intensity levels, soil types and mechanisms has selected to document on this study, all the results can be found on Appendix A.

Table 3.1: Test case locations.

	Location	Lat	Lon	Level	Soil	Mechanism	Distance
0	Küçükçekmece	40.996	28.775	DD-1	ZA	Oblique	60
1	Erzurum	39.909	41.276	DD-1	ZB	Oblique	60
2	Soma	39.183	27.606	DD-1	ZC	Strike Slip	40
3	Dikili	39.071	26.890	DD-1	ZD	Oblique	60
4	Besni	37.692	37.861	DD-1	ZE	Strike Slip	60
5	İntepe	40.013	26.333	DD-1	ZA	Oblique	40
6	Toprakkale	37.063	36.147	DD-1	ZB	Oblique	40
7	Aksu	36.953	30.848	DD-1	ZC	Strike Slip	60
8	Bağlıca	37.869	41.751	DD-1	ZD	Strike Slip	100
9	Bozyazı	36.104	32.972	DD-1	ZE	Oblique	160
10	Bartın	41.634	32.338	DD-1	ZA	Strike Slip	120
11	Karakasım	41.517	26.644	DD-1	ZB	Oblique	140
12	Dargeçit	37.546	41.717	DD-1	ZC	Strike Slip	100
13	Kuzucubelen	36.840	34.438	DD-1	ZD	Strike Slip	140
14	Akıncı	37.166	40.847	DD-1	ZE	Strike Slip	180
15	Yenimehmetli	39.420	32.169	DD-1	ZA	Oblique	160
16	Çamlıdere	37.154	39.067	DD-1	ZB	Strike Slip	80
17	Akarsu	37.234	41.060	DD-1	ZC	Strike Slip	160
18	Kızıltepe	37.193	40.586	DD-1	ZD	Strike Slip	180
19	Küçükçekmece	40.996	28.775	DD-2	ZA	Oblique	60
20	Erzurum	39.909	41.276	DD-2	ZB	Oblique	60
21	Soma	39.183	27.606	DD-2	ZC	Strike Slip	40
22	Dikili	39.071	26.890	DD-2	ZD	Oblique	60
23	Besni	37.692	37.861	DD-2	ZE	Strike Slip	60
24	İntepe	40.013	26.333	DD-2	ZA	Oblique	40
25	Toprakkale	37.063	36.147	DD-2	ZB	Oblique	40
26	Aksu	36.953	30.848	DD-2	ZC	Strike Slip	60
27	Bağlıca	37.869	41.751	DD-2	ZD	Strike Slip	100
28	Bozyazı	36.104	32.972	DD-2	ZE	Oblique	160
29	Bartın	41.634	32.338	DD-2	ZA	Oblique	120
30	Karakasım	41.517	26.644	DD-2	ZB	Oblique	140
31	Dargeçit	37.546	41.717	DD-2	ZC	Strike Slip	100
32	Kuzucubelen	36.840	34.438	DD-2	ZD	Strike Slip	140
33	Akıncı	37.166	40.847	DD-2	ZE	Strike Slip	180
34	Yenimehmetli	39.420	32.169	DD-2	ZA	Oblique	160
35	Çamlıdere	37.154	39.067	DD-2	ZB	Strike Slip	80
36	Akarsu	37.234	41.060	DD-2	ZC	Strike Slip	160
37	Kızıltepe	37.193	40.586	DD-2	ZD	Strike Slip	180

4.1. Numerical Example Case 1

For first numerical example case, test case 29 has selected. This numerical analysis has conducted for DD-2 earthquake intensity level at Bartın location which has a ZA type soil and oblique type fault mechanism.

Table 4.1: Test case 29 data set 1 scale factors.

RSN	Scale Factor
98	10.449
146	1.190
455	3.326
879	0.214
6336	29.678
6428	5.216
6429	9.499
6434	7.224
8521	36.669
8569	22.088
9828	16.224

Table 4.2: Test case 29 data set 2 scale factors.

RSN	Scale Factor
146	6.3058
455	6.8979
98	7.2535
3920	7.8063
3799	8.2653
6051	8.7178
5967	8.9405
8168	9.1692
14430	9.2484
9828	9.3243
18072	9.3842

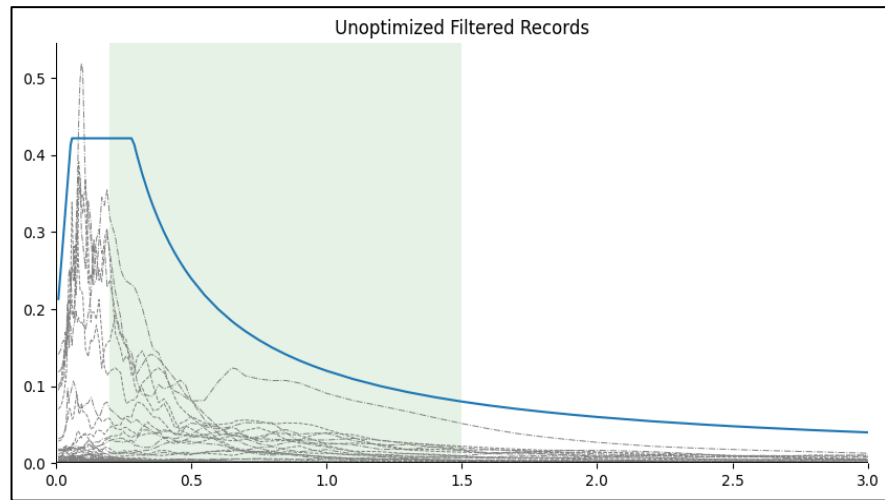


Figure 4.2: Test case 29 data set 2 unoptimized filtered records.

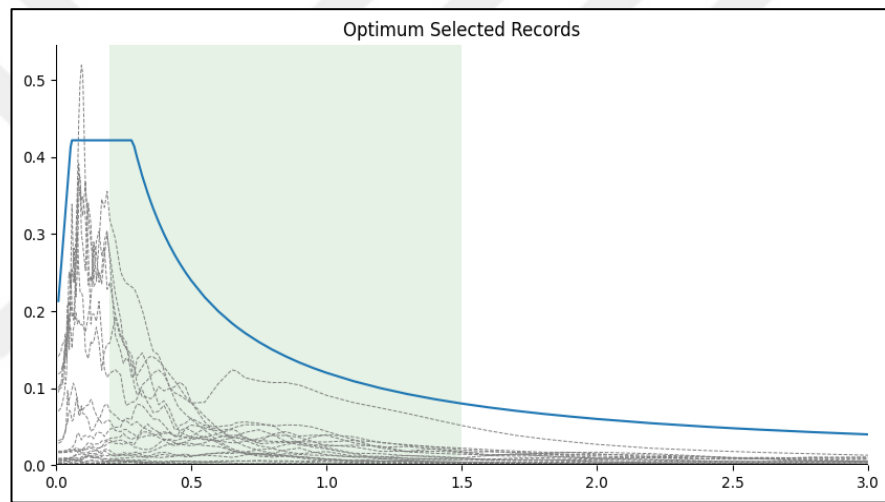


Figure 4.3: Test case 29 data set 2 optimum selected records.

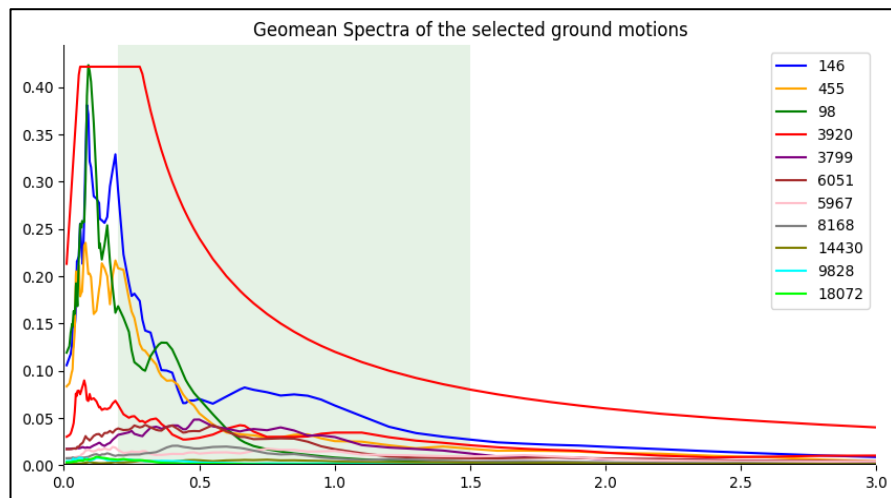


Figure 4.4: Test case 29 data set 2 geometric mean of selected ground motions.

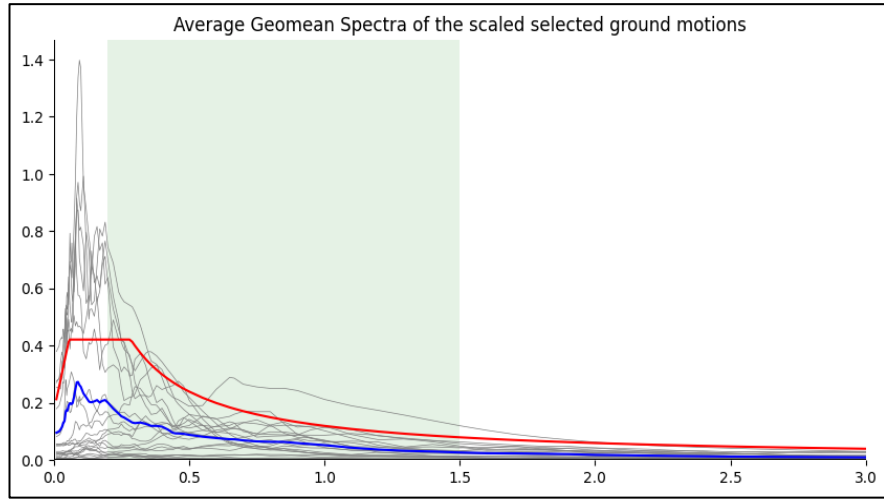


Figure 4.5: Test case 29 data set 2 average geometric mean of selected ground motions.

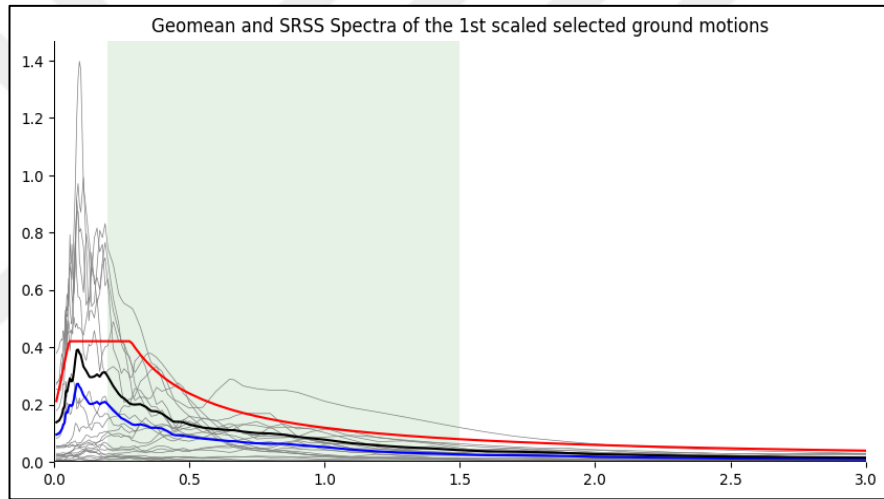


Figure 4.6: Test case 29 data set 2 SRSS spectra of selected ground motions.

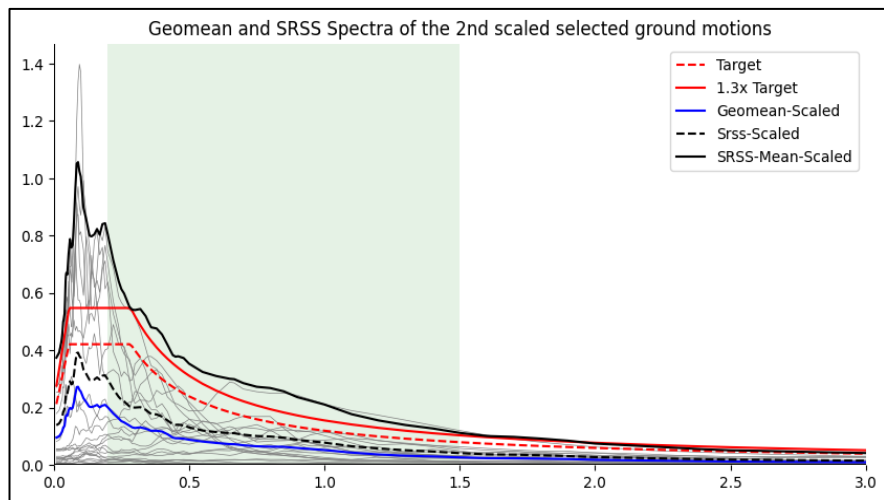


Figure 4.7: Test case 29 data set 2 scaled ground motions.

Table 4.3: Test case 29 data set 3 scale factors.

RSN	Scale Factor
146	7.593
455	8.306
98	8.734
3920	9.400
3799	9.952
6051	10.497
5967	10.765
8168	11.041
14430	11.136
9828	11.228
18072	11.300

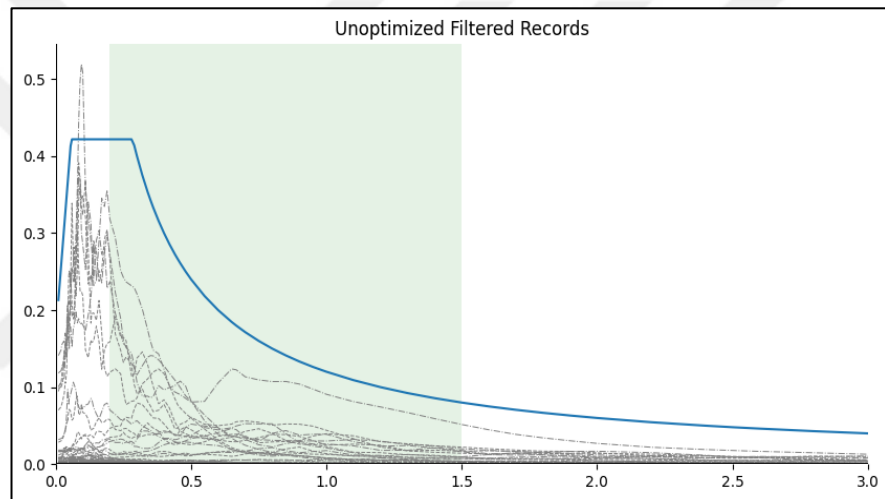


Figure 4.8: Test case 29 data set 3 unoptimized filtered records.

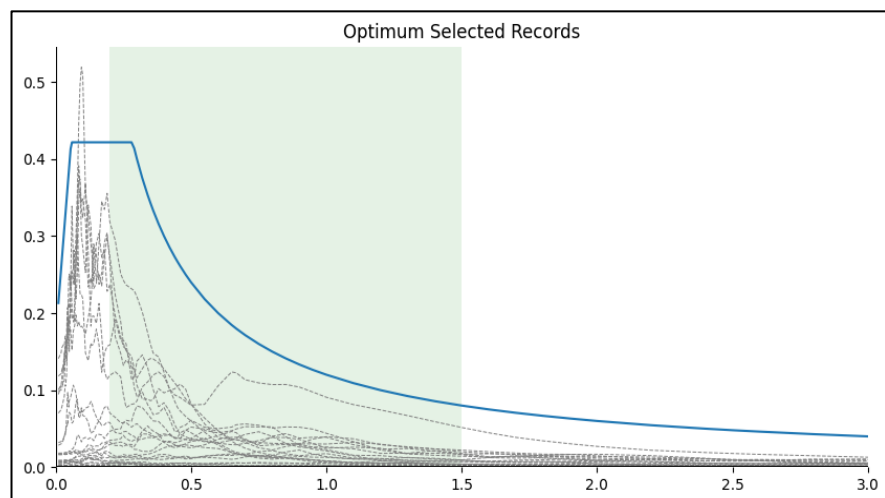


Figure 4.9: Test case 29 data set 3 optimum selected records.

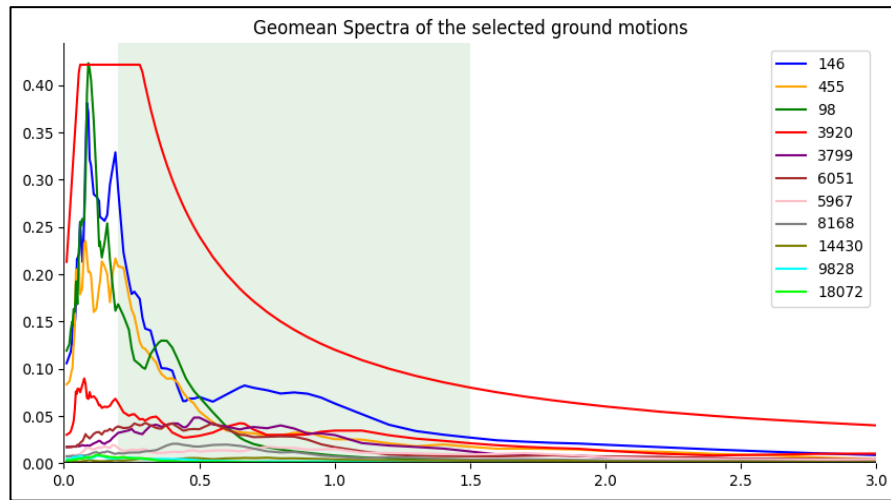


Figure 4.10: Test case 29 data set 3 geometric mean of selected ground motions.

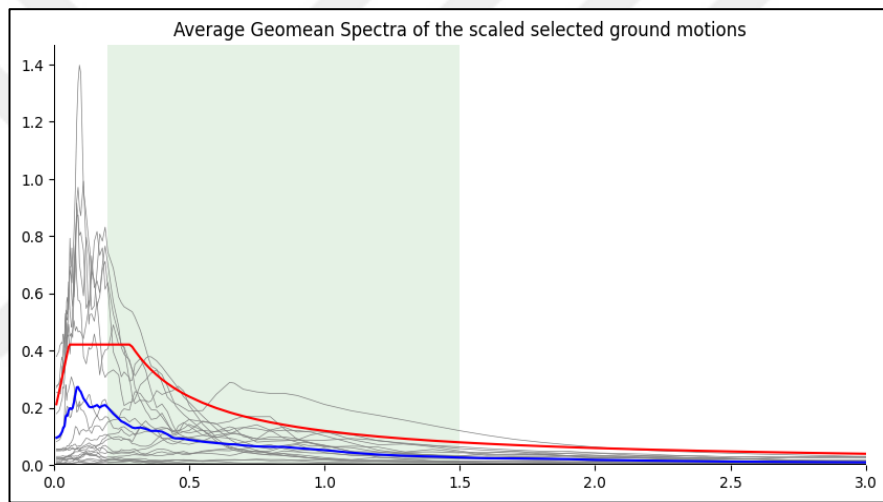


Figure 4.11: Test case 29 data set 3 average geometric mean of selected ground motions.

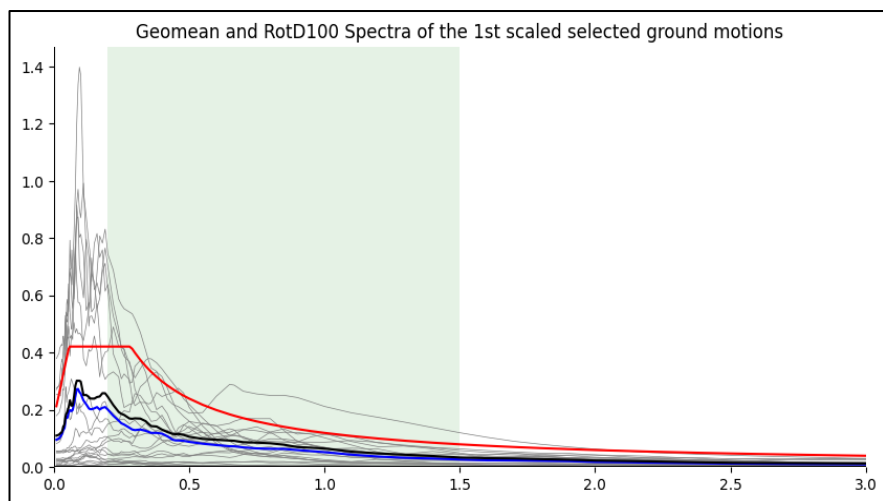


Figure 4.12: Test case 29 data set 3 RotD100 of selected ground motions.

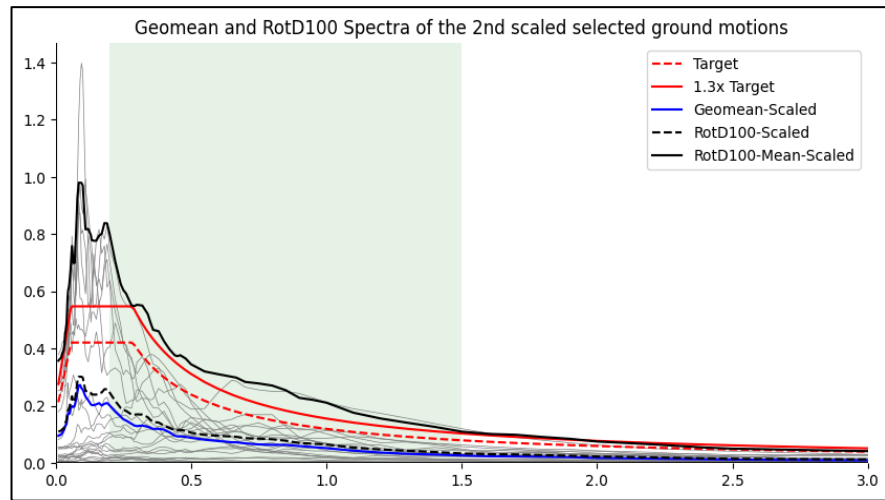


Figure 4.13: Test case 29 data set 3 scaled ground motions.

Table 4.4: Test case 29 data set 4 scale factors.

RSN	Scale Factor
146	4.858
455	4.858
98	4.858
3920	4.858
3799	4.858
6051	4.858
5967	4.858
8168	4.858
14430	4.858
9828	4.858
18072	4.858

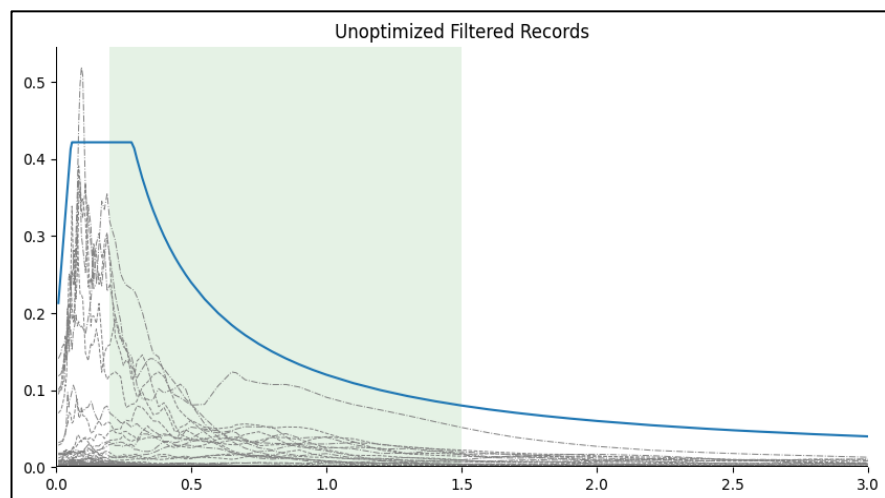


Figure 4.14: Test case 29 data set 4 unoptimized filtered records.

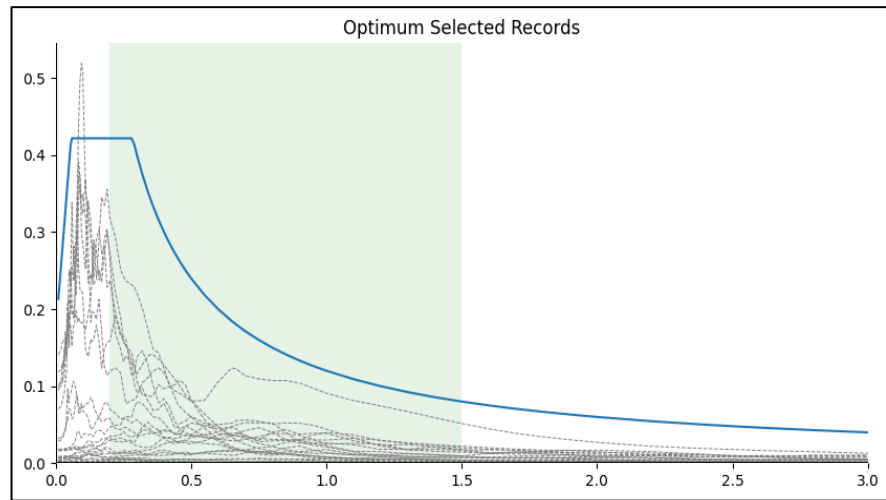


Figure 4.15: Test case 29 data set 4 optimum selected records.

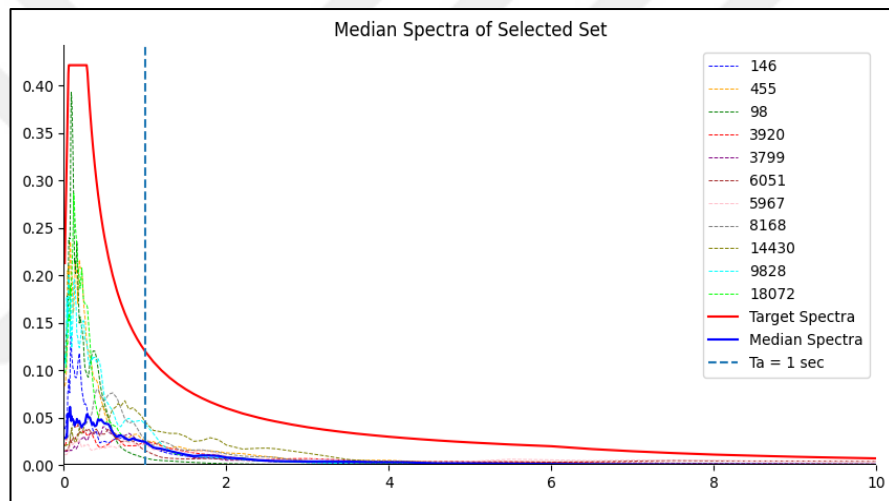


Figure 4.16: Test case 29 data set 4 median spectra of selected set.

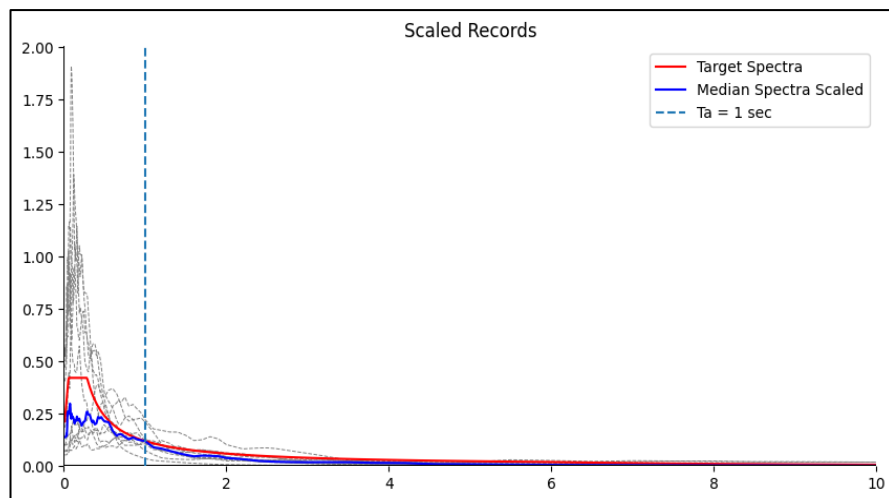


Figure 4.17: Test case 29 data set 4 scaled records.

Table 4.5: Numerical example 1 comparison table.

	PEER	Scalepy SRSS	Scalepy RotD100	P695
	10.449	6.3058	7.593	4.858
	1.190	6.8979	8.306	4.858
	3.326	7.2535	8.734	4.858
	0.214	7.8063	9.400	4.858
	29.678	8.2653	9.952	4.858
	5.216	8.7178	10.497	4.858
	9.499	8.9405	10.765	4.858
	7.224	9.1692	11.041	4.858
	36.669	9.2484	11.136	4.858
	22.088	9.3243	11.228	4.858
	16.224	9.3842	11.300	4.858
Average	12.889	8.3010	9.9960	4.858
Standard Deviation	11.443	1.0330	1.2440	-

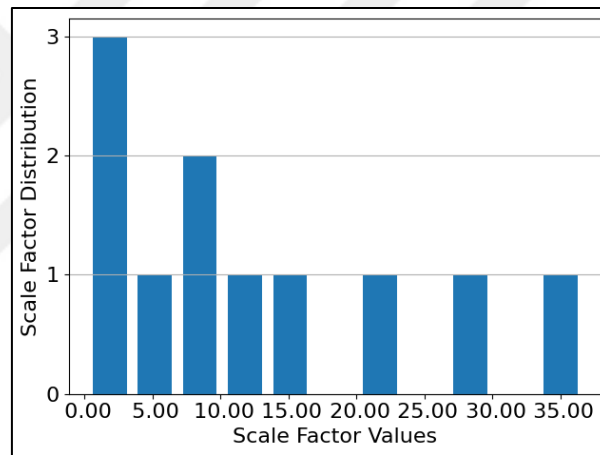


Figure 4.18: Numerical example 1 scale factor distribution PEER.

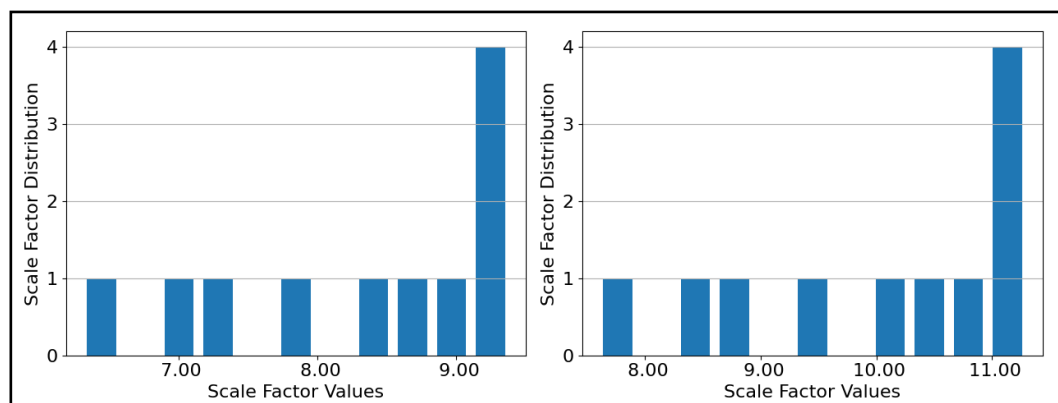


Figure 4.19: Numerical example 1 scale factor distribution ScalePy SRSS and RotD100.

4.2. Numerical Example Case 2

For second numerical example case, test case 7 has selected. This numerical analysis has conducted for DD-1 earthquake intensity level at Antalya location which has a ZC type soil and strike-slip type fault mechanism.

Table 4.6: Test case 7 data set 1 scale factors.

RSN	Scale Factor
103	4.655
212	2.218
246	3.275
450	1.935
548	1.198
838	1.424
1160	3.056
1166	1.243
1762	1.331
1794	0.981
1813	2.038

Table 4.7: Test case 7 data set 2 scale factors.

RSN	Scale Factor
1633	1.290
727	1.163
495	1.151
407	1.138
150	1.198
230	1.248
825	1.187
1111	1.160
125	1.193
568	1.161
901	1.158

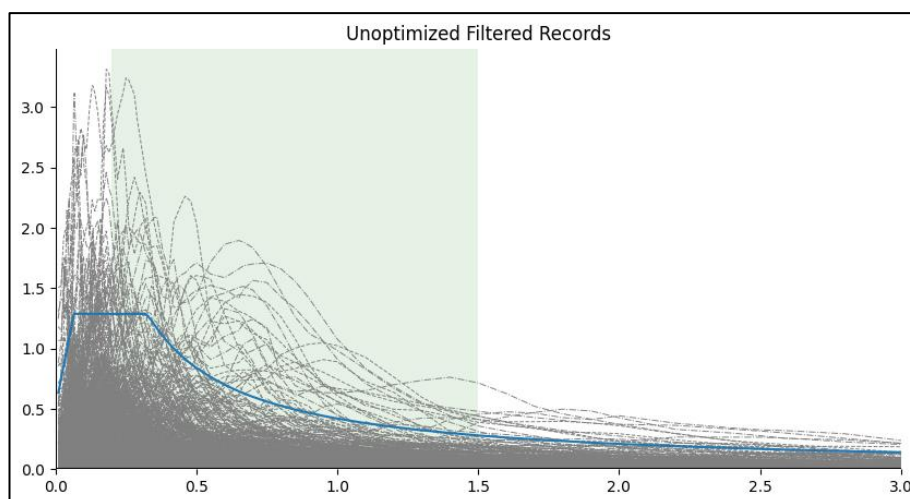


Figure 4.20: Test case 7 data set 2 unoptimized filtered records.

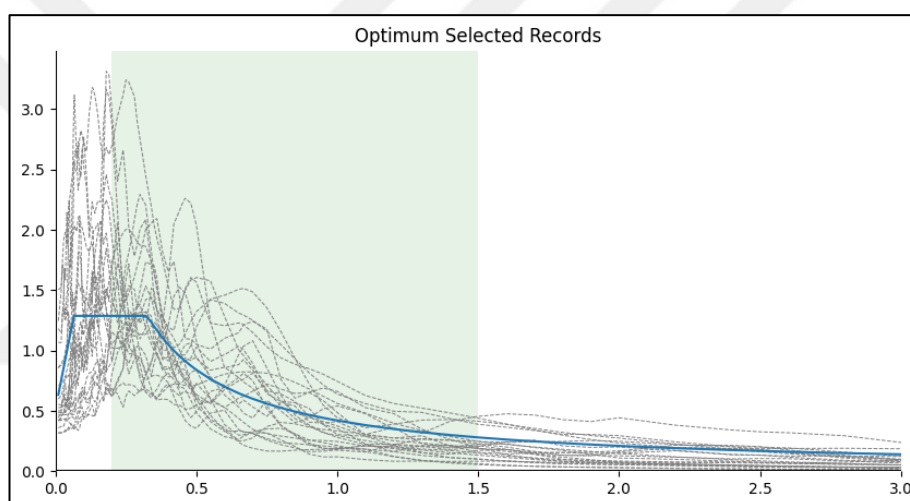


Figure 4.21: Test case 7 data set 2 optimum selected records.

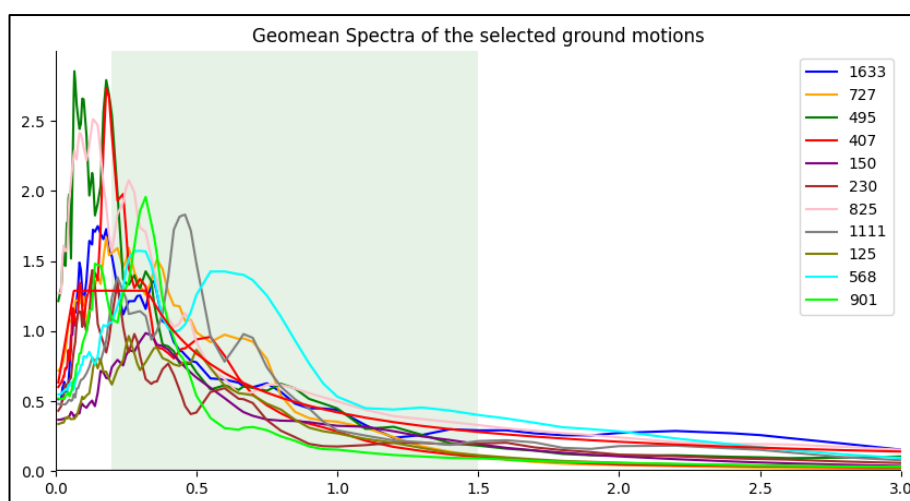


Figure 4.22: Test case 7 data set 2 geometric mean of the records.

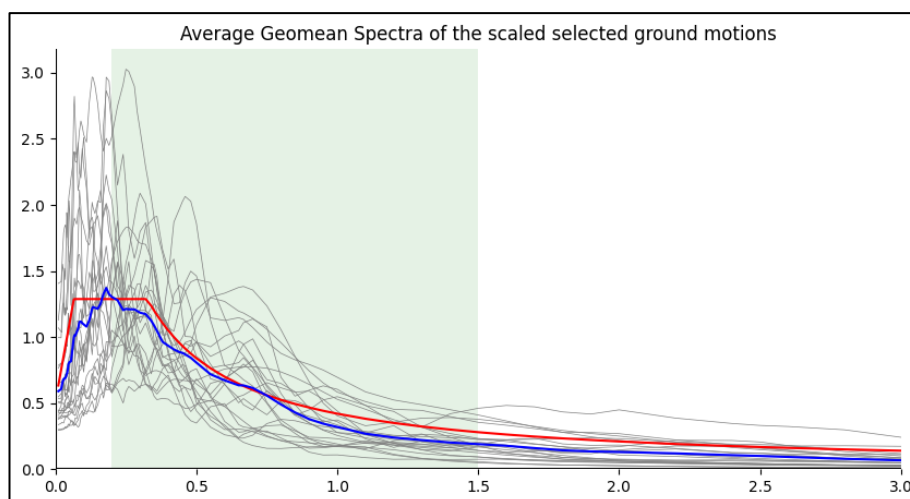


Figure 4.23: Test case 7 data set 2 average geometric mean of the records.

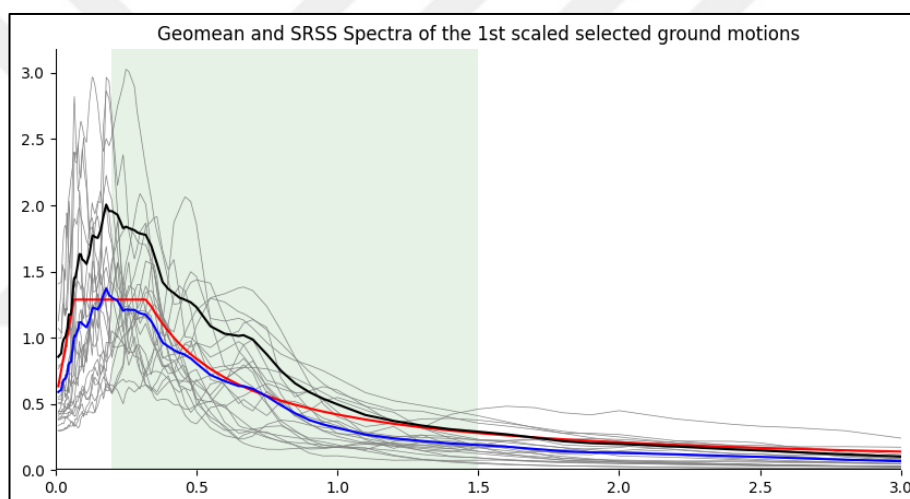


Figure 4.24: Test case 7 data set 2 SRSS mean of the records.

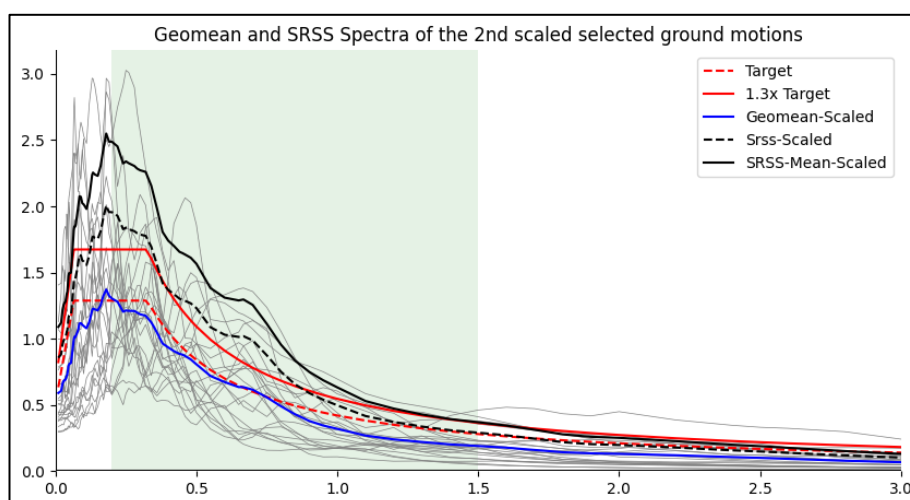


Figure 4.25: Test case 7 data set 2 scaled records.

Table 4.8: Test case 7 data set 3 scale factors.

RSN	Scale Factor
1633	1.541
727	1.390
495	1.376
407	1.360
150	1.431
230	1.491
825	1.418
1111	1.387
125	1.425
568	1.387
901	1.383

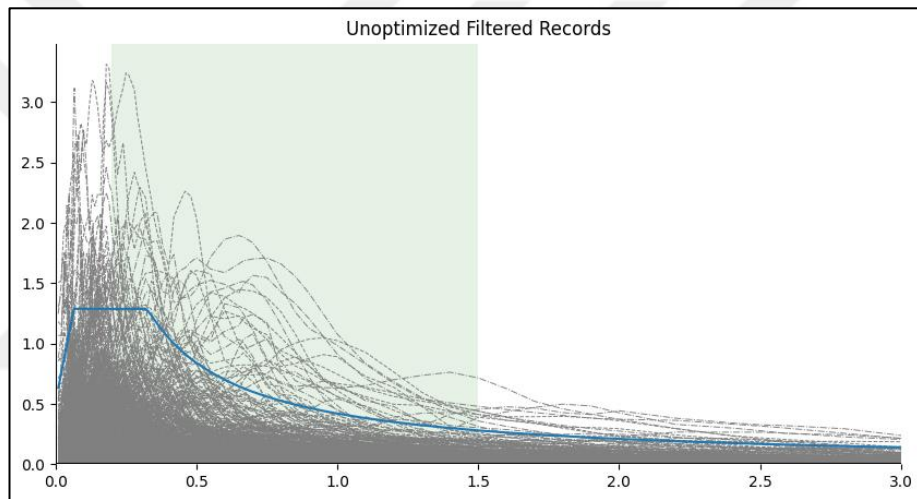


Figure 4.26: Test case 7 data set 3 unoptimized filtered records.

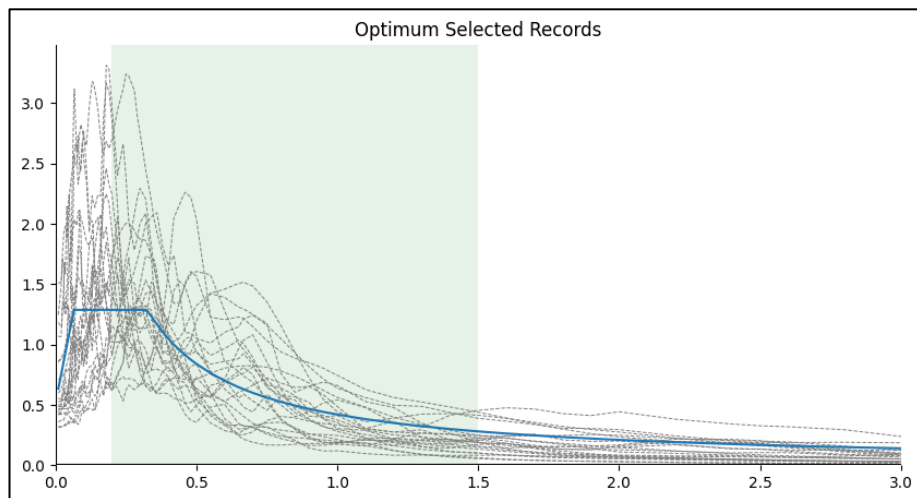


Figure 4.27: Test case 7 data set 3 optimum selected records.

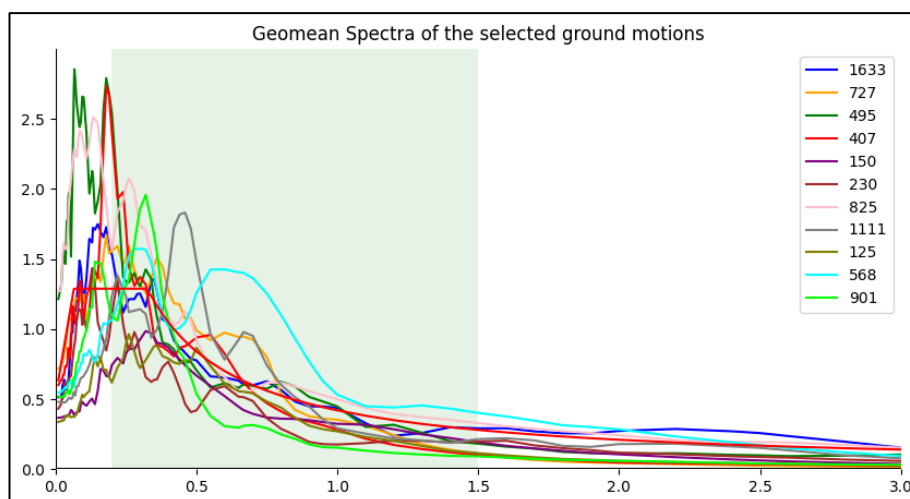


Figure 4.28: Test case 7 data set 3 geometric mean spectra of the records.

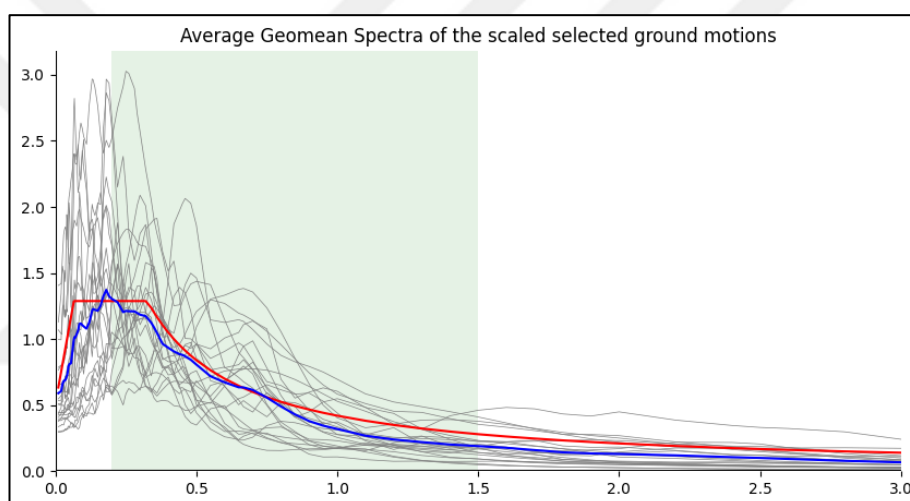


Figure 4.29: Test case 7 data set 3 average geometric mean spectra of the records.

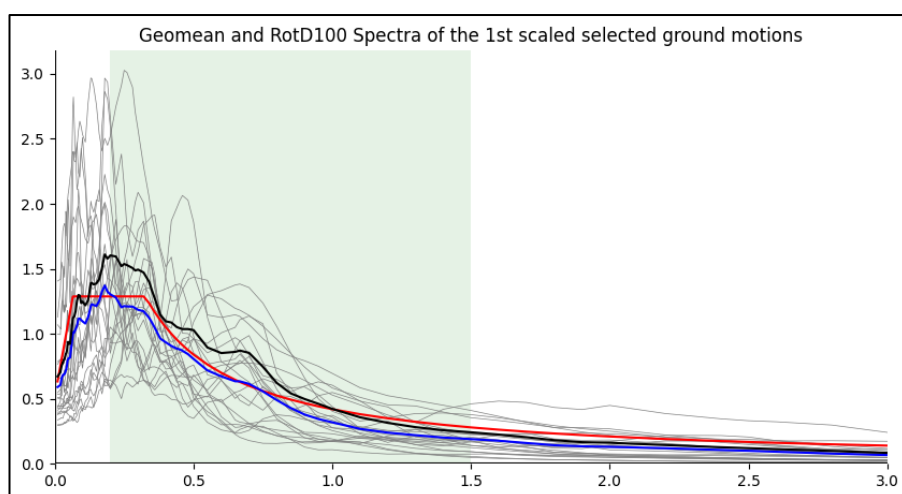


Figure 4.30: Test case 7 data set 3 RotD100 mean spectra of the records.

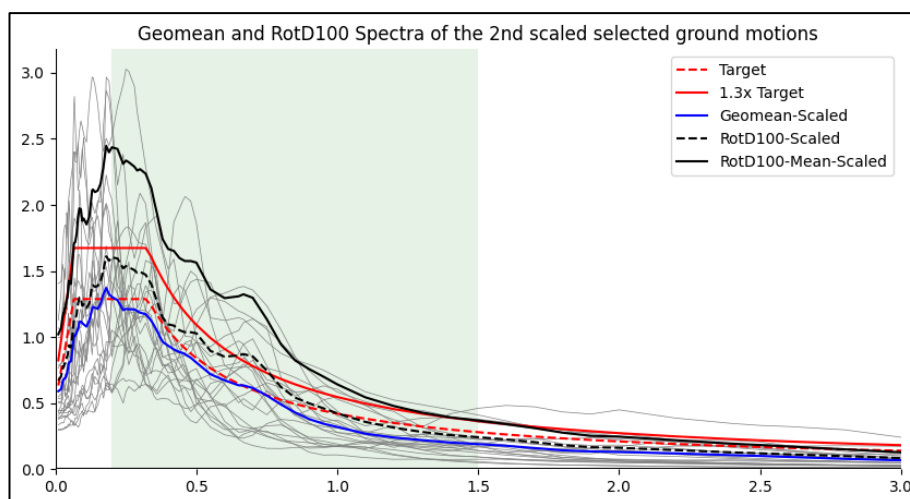


Figure 4.31: Test case 7 data set 3 scaled records.

Table 4.9: Test case 7 data set 4 scale factors.

RSN	Scale Factor
1633	1.327
727	1.327
495	1.327
407	1.327
150	1.327
230	1.327
825	1.327
1111	1.327
125	1.327
568	1.327
901	1.327

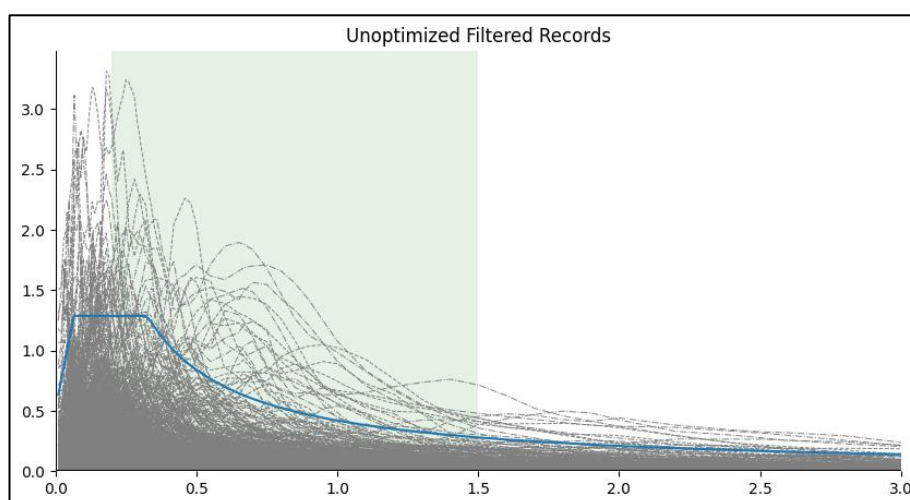


Figure 4.32: Test case 7 data set 4 unoptimized records.

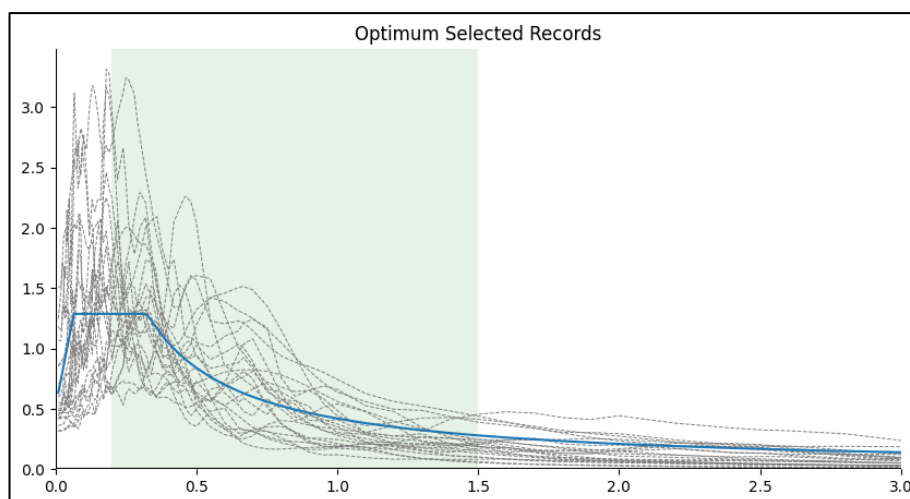


Figure 4.33: Test case 7 data set 4 optimum selected records.

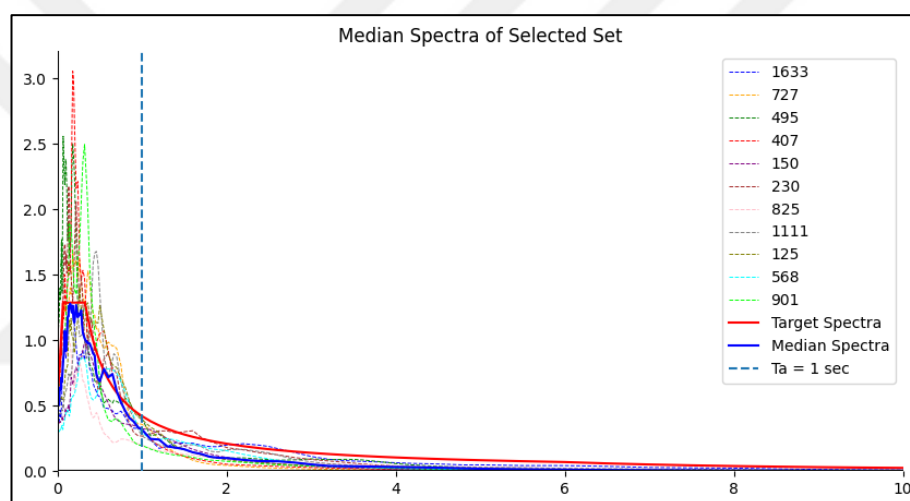


Figure 4.34: Test case 7 data set 4 median spectra of selected set.

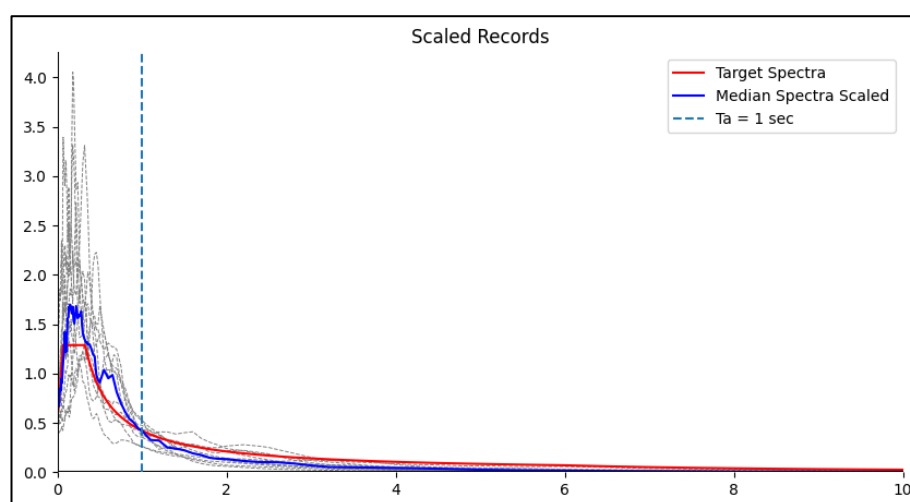


Figure 4.35: Test case 7 data set 4 scaled records.

Table 4.10: Numerical example 2 comparison table.

	PEER	Scalepy SRSS	Scalepy RotD100	P695
	4.655	1.290	1.541	1.327
	2.218	1.163	1.390	1.327
	3.275	1.151	1.376	1.327
	1.935	1.138	1.360	1.327
	1.198	1.198	1.431	1.327
	1.424	1.248	1.491	1.327
	3.056	1.187	1.418	1.327
	1.243	1.160	1.387	1.327
	1.331	1.193	1.425	1.327
	0.981	1.161	1.387	1.327
	2.038	1.158	1.383	1.327
Average	2.123	1.186	1.417	1.327
Standard Deviation	1.075	0.044	0.052	-

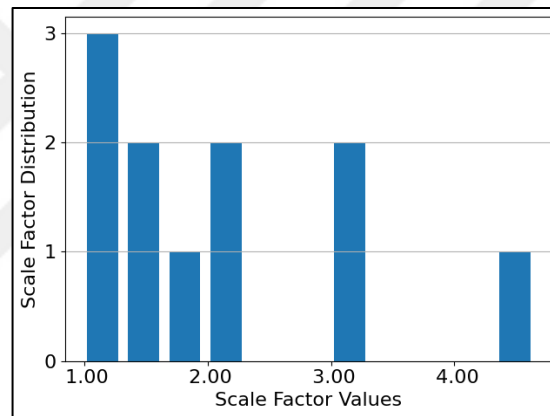


Figure 4.36: Numerical example 2 scale factor distribution PEER.

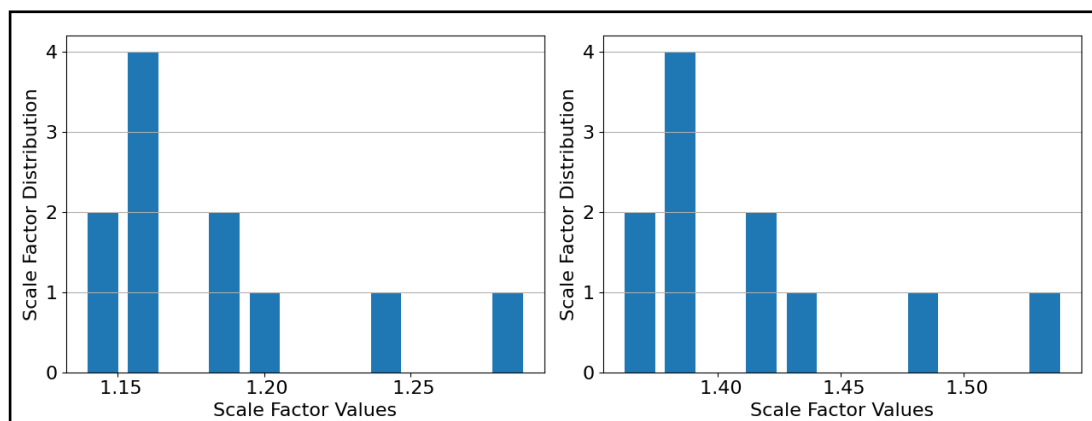


Figure 4.37: Numerical example 2 scale factor distribution Scalepy SRSS and RotD100.

4.3. Numerical Example Case 3

For third numerical example case, test case 32 has selected. This numerical analysis has conducted for DD-2 earthquake intensity level at Mersin location which has a ZD type soil and strike-slip type fault mechanism.

Table 4.11: Test case 32 data set 1 scale factors.

RSN	Scale Factor
916	1.086
918	2.567
1788	1.497
1825	1.254
1826	1.485
1827	1.617
1828	2.324
1829	3.455
6014	1.816
6420	1.891
6242	2.484

Table 4.12: Test case 32 data set 2 scale factors.

RSN	Scale Factor
1100	1.197
148	1.029
6887	1.021
549	0.976
1634	0.948
6886	0.954
902	0.935
6874	0.944
96	0.928
316	0.918
147	0.912

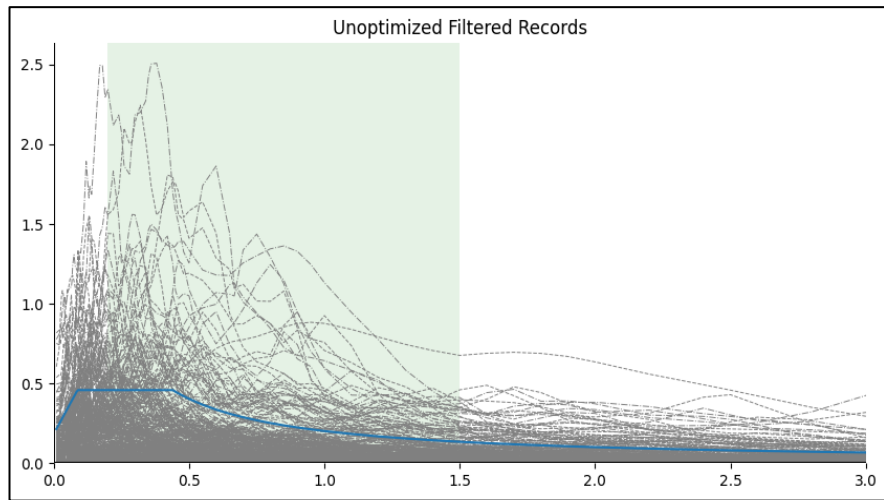


Figure 4.38: Test case 32 data set 2 unoptimized filtered records.

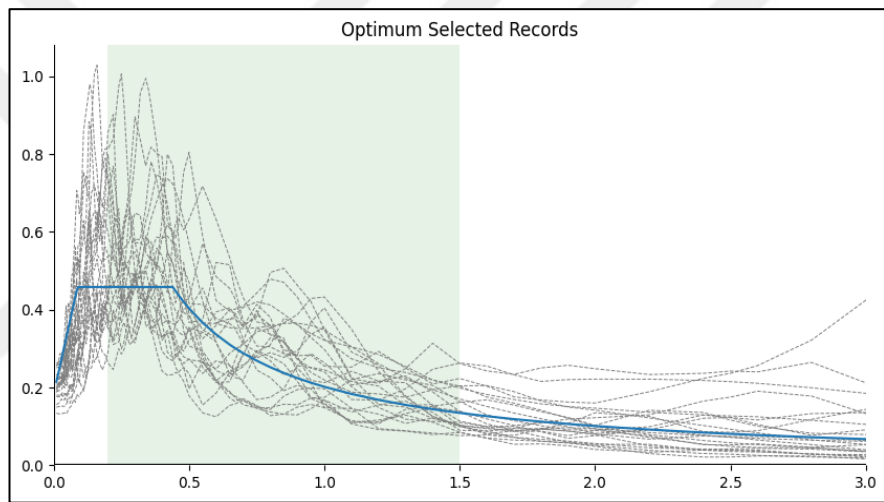


Figure 4.39: Test case 32 data set 2 optimum selected records.

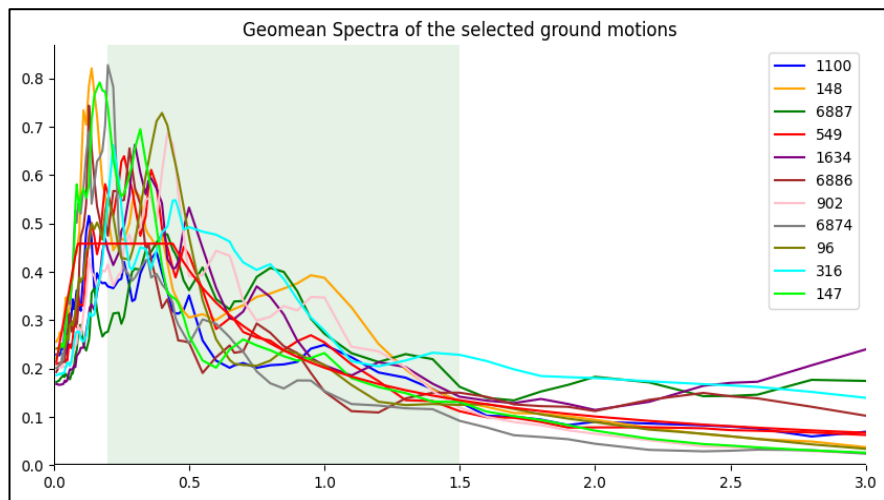


Figure 4.40: Test case 32 data set 2 geometric mean of records.

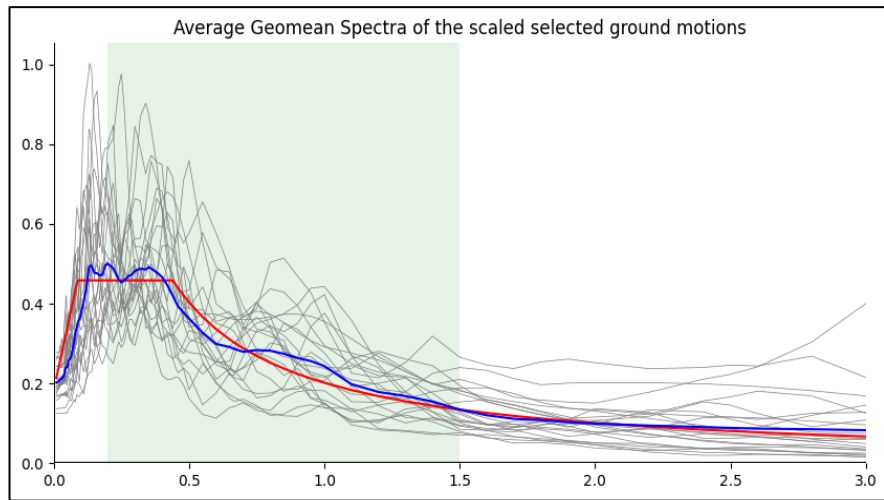


Figure 4.41: Test case 32 data set 2 average geometric mean of records.

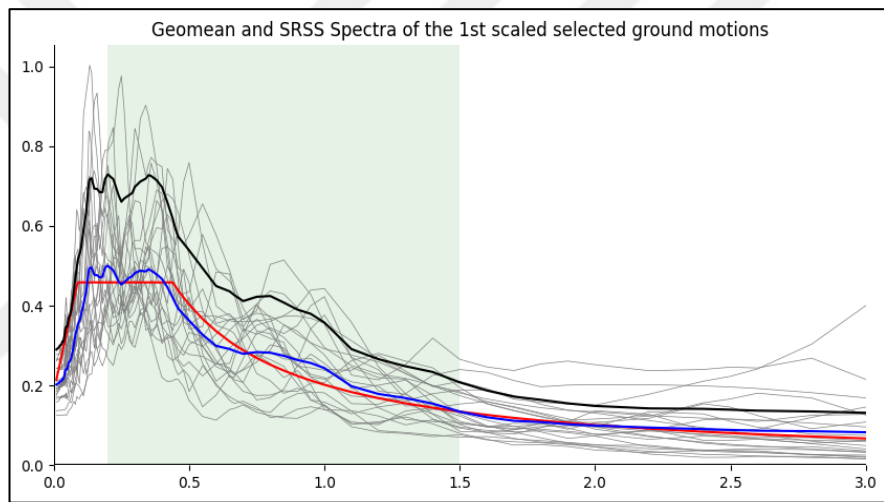


Figure 4.42: Test case 32 data set 2 SRSS mean of records.

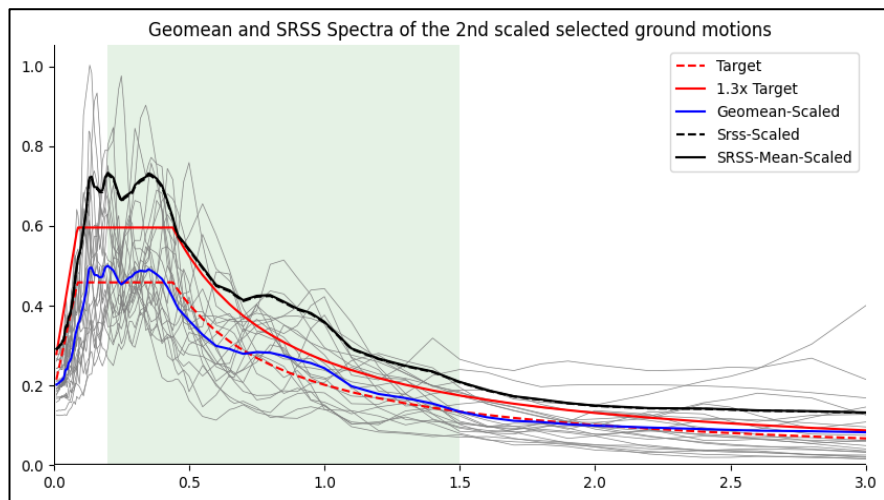


Figure 4.43: Test case 32 data set 2 scaled records.

Table 4.13: Test case 32 data set 3 scale factors.

RSN	Scale Factor
1100	1.499
148	1.290
6887	1.280
549	1.223
1634	1.188
6886	1.195
902	1.172
6874	1.183
96	1.163
316	1.150
147	1.143

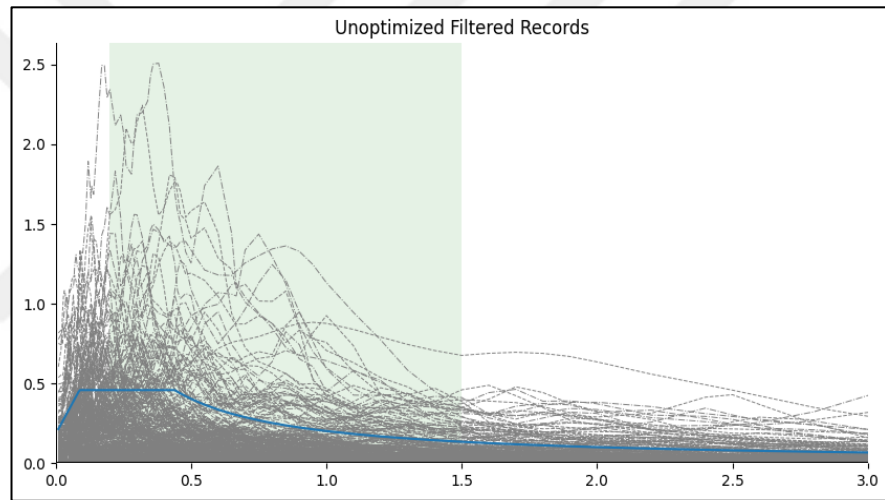


Figure 4.44: Test case 32 data set 3 unoptimized filtered records.

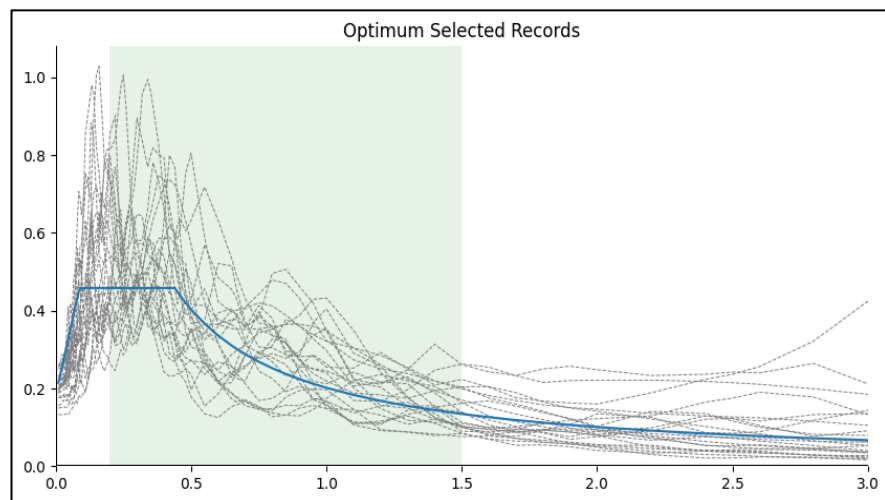


Figure 4.45: Test case 32 data set 3 optimum selected records.

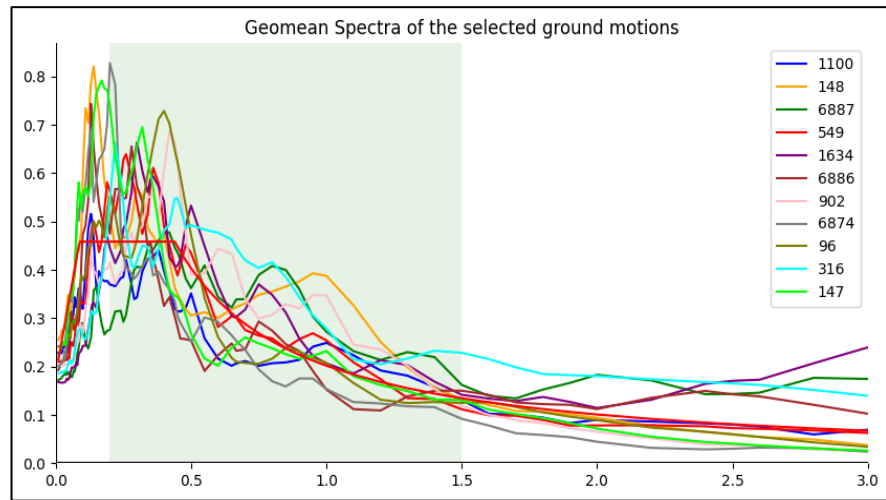


Figure 4.46: Test case 32 data set 3 geometric mean of records.

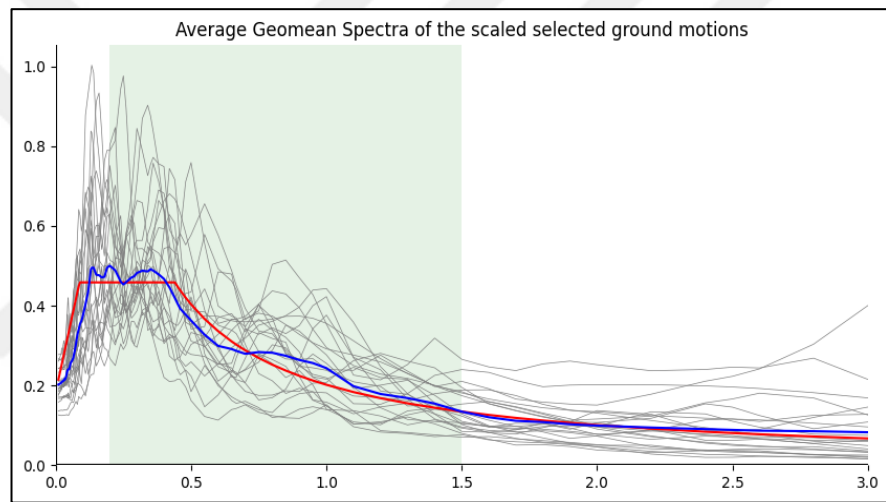


Figure 4.47: Test case 32 data set 3 average geometric mean of records.

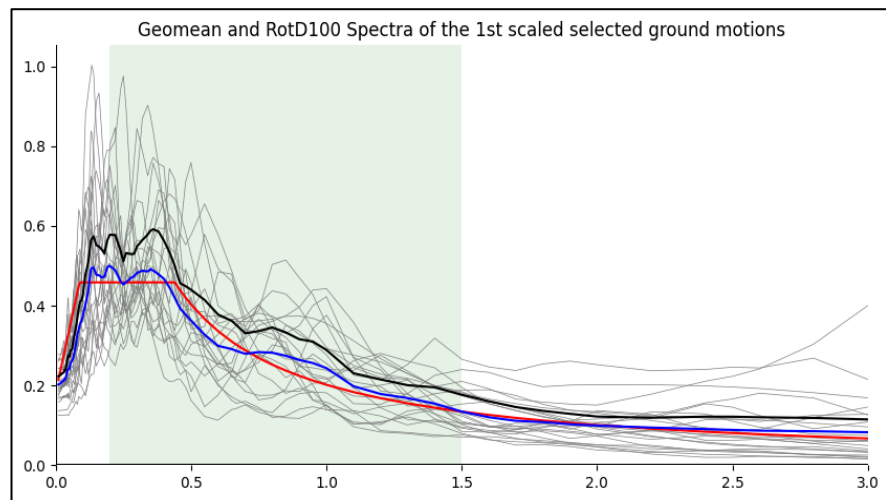


Figure 4.48: Test case 32 data set 3 RotD100 mean of records.

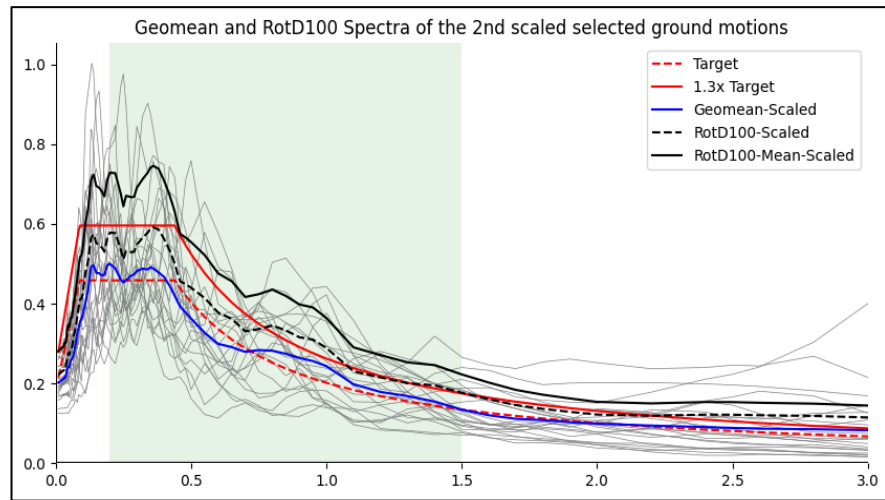


Figure 4.49: Test case 32 data set 3 scaled records

Table 4.14: Test case 32 data set 4 scale factors.

RSN	Scale Factor
1100	0.885
148	0.885
6887	0.885
549	0.885
1634	0.885
6886	0.885
902	0.885
6874	0.885
96	0.885
316	0.885
147	0.885

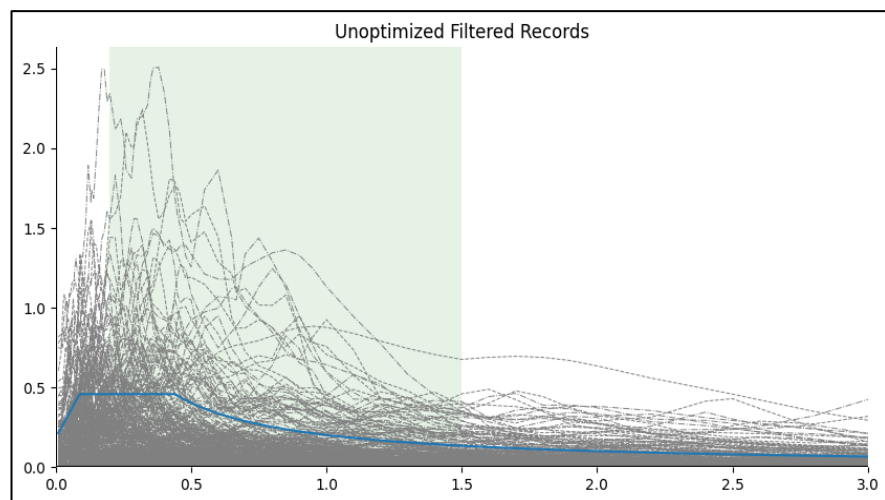


Figure 4.50: Test case 32 data set 4 unoptimized filtered records.

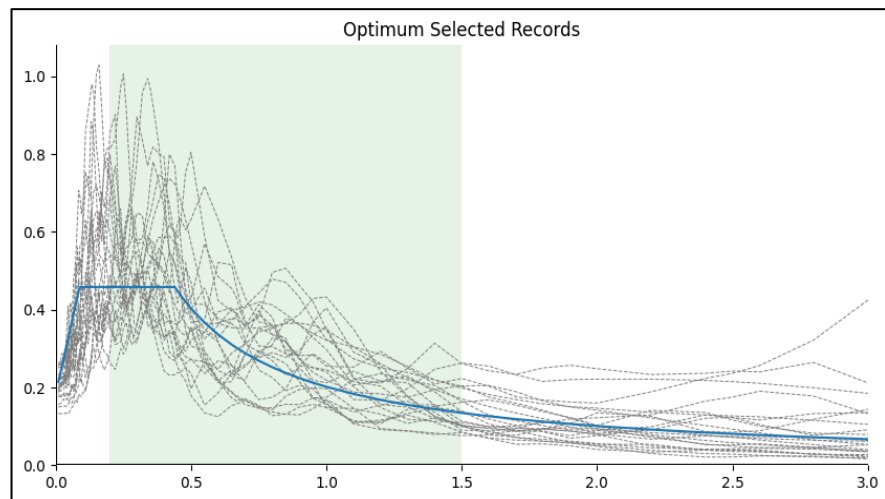


Figure 4.51: Test case 32 data set 4 optimum selected records.

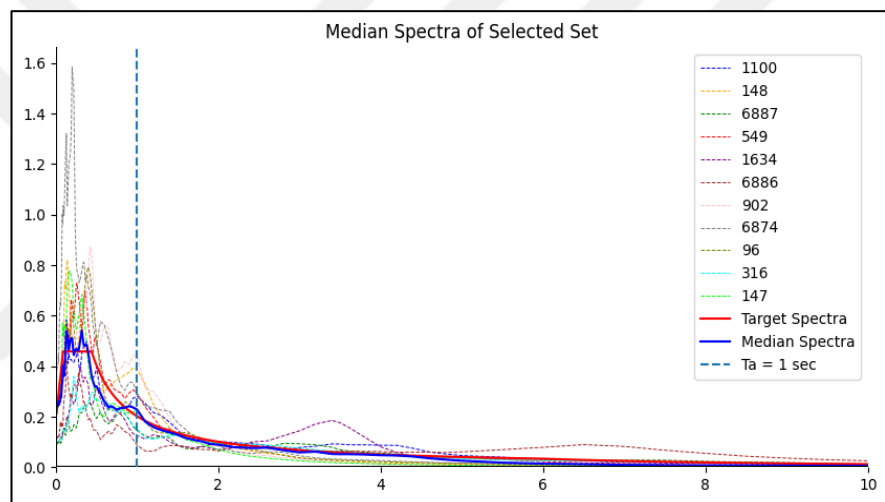


Figure 4.52: Test case 32 data set 4 median spectra of selected set.

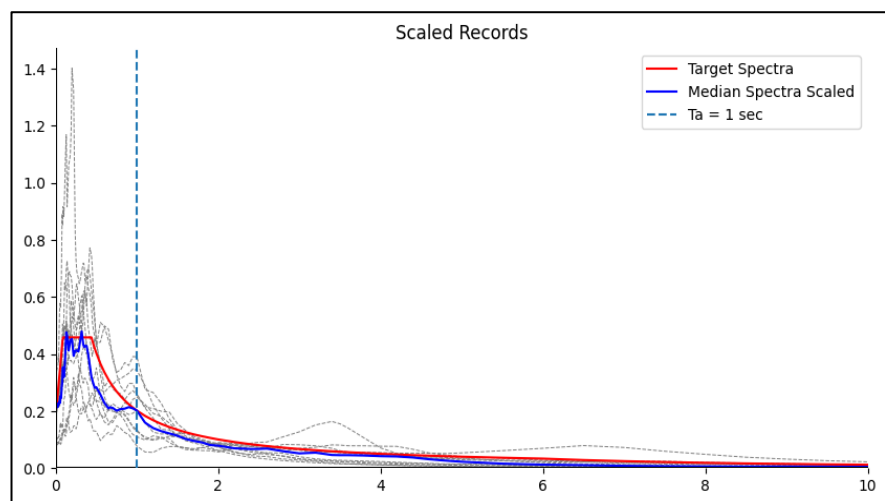


Figure 4.53: Test case 32 data set 4 scaled records.

Table 4.15: Numerical example 3 comparison table.

	PEER	Scalepy SRSS	Scalepy RotD100	P695
	1.086	1.197	1.499	0.885
	2.567	1.029	1.290	0.885
	1.497	1.021	1.280	0.885
	1.254	0.976	1.223	0.885
	1.485	0.948	1.188	0.885
	1.617	0.954	1.195	0.885
	2.324	0.935	1.172	0.885
	3.455	0.944	1.183	0.885
	1.816	0.928	1.163	0.885
	1.891	0.918	1.150	0.885
	2.484	0.912	1.143	0.885
Average	1.952	0.978	1.226	0.885
Standard Deviation	0.664	0.078	0.098	-

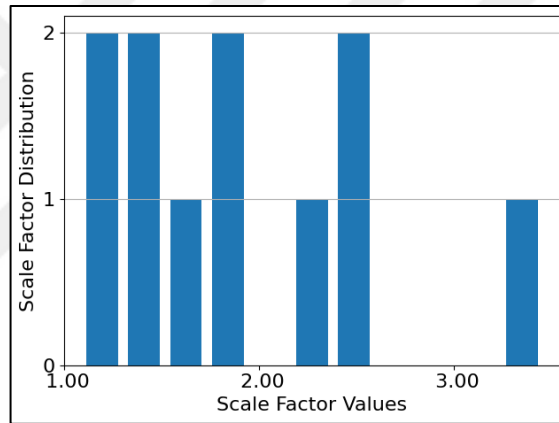


Figure 4.54: Numerical example 3 scale factor distribution PEER.

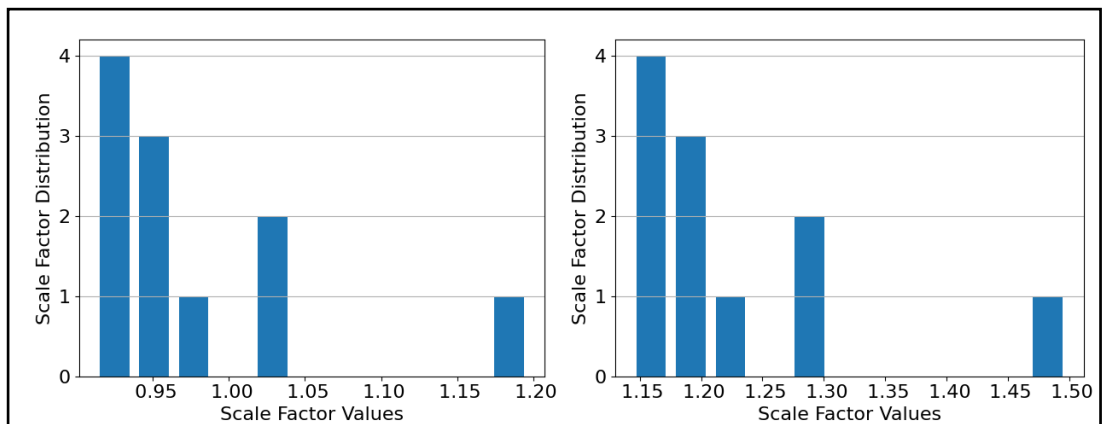


Figure 4.55: Numerical example 3 scale factor distribution Scalepy SRSS and RotD100.

5. SUMMARY AND CONCLUSION

5.1. Summary

This dissertation proposed a record selection and scaling methodology with the aim of finding the optimum set of real earthquake records to be used in the performance verification or design of structural systems. The academic and practical studies showed that, spectrally matched records are more compatible with the response spectrum than the records matched with amplitude scaling method. However, there is concerns about frequency matching method because the frequency content of real earthquake records is manipulated, among earthquake engineering community [20].

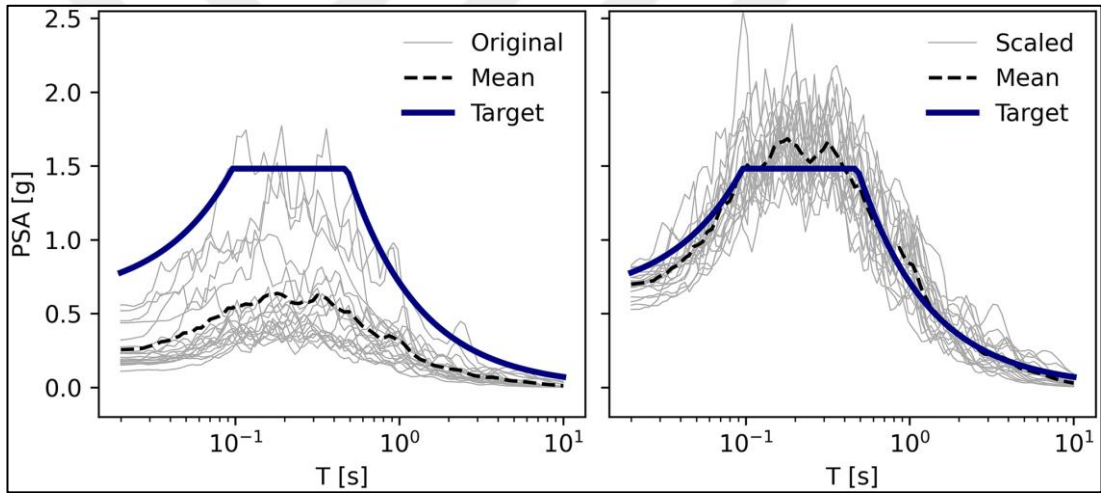


Figure 5.1: Scaled earthquake records using frequency scaling method.

Because of these concerns, tendency to use amplitude scaling method is increased among the researchers and analysts. However, there is no consensus on record selection process and how to reduce the dispersion of the acceleration content from the design spectrum. In this approach, a framework is programmed to reduce spectral variation within the ground motion suite with an iteration algorithm. The framework has four basic functions. First function is generating a target spectrum according to TSC – 2018.

Second function is selecting the set of records which correlates best with the target spectrum generated from the first function.

There are 19554 earthquake records in database which is cloned from PEER NGA database. This function has multiple selection filtering stages:

- First stage is filtering the database according to the user input (magnitude range, soil type, RJB range, fault mechanism, duration, arias intensity).
- Second stage is filtering the selected records with an iterative algorithm which is measuring the similarities of the acceleration curves to find the record set with minimum dispersion from the target spectrum.
- Third stage is checking the set if there are 3 or more records from the same event which is not recommended.
- Last stage is sorting all selected records in terms of scaling factors and select 11 records with minimum scale factors.

The third function is performing amplitude scaling for 11 selected records according to the generated target spectrum with the spectrum creation possibilities with SRSS, RotD50 and RotD100.

The selection and scaling applications of the proposed methodology to select ground motions for matching target spectrum are presented in Chapter 4. To assess the efficiency of the developed framework for this study, selection and scaling procedure has applied to 19 different locations with two different earthquake intensity levels. 3 of the 38 numerical example cases has shown with the results in the dissertation.

To compare the effectiveness of the proposed framework, widely used PEER selection and scaling tool is used as comparison tool. The comparative studies are performed to examine the sensitivity of the scale factors to different ground motion selection and scaling approaches.

The main comparison parameters in the study are the dispersion of the scale factors of selected ground motions. Histograms are showing the distribution of the calculated scale factors for different selection and scaling procedures. The developed tool named “ScalePy”, and the PEER NGA selection and scaling tool is named as “PEER”. Also, SRSS and RotD100 spectrum creation functions in the ScalePy tool has an internal quality check.

5.2. Conclusion

The main conclusions derived from this dissertation are given below.

- i) In general, obtaining a sufficient number of ground motion records that fully satisfy with the target earthquake scenario's related target hazard level (e.g., magnitude, distance, fault mechanism, soil class) is challenging. This study makes use of the computational capability of searching through a large database, which takes about 9 seconds to discover the best matched record set. The probability of discovering an adequate set of accelerograms may increase as the database grows. This attribute also allows the analyst to simply alter inputs to loosen limits for candidate records.
- ii) The case studies in this dissertation show that the proposed procedure prevents large dispersion of scale factors. The scale factors have a significantly low standard deviation in every case which is important to avoid uncertainties in engineering demand parameters. These results indicate that the proposed method avoids potential bias resulting from scaling the ground motions.
- iii) The numerical test cases show that, soil type is the main determinant factor in the scale factor distribution. In the real ground motion database, there is limited number of locations which has ZA and ZE type of soil. This lack of records is causing a significant incensement for scale factors. Nevertheless, proposed methodology is still calculating a set of scale factors which is low and has less dispersion, when it is compared with the PEER NGA selection and scaling tool. The real ground motion records which have recorded a location with a ZB, ZC and ZD has better results, because there is a sufficient number of real ground motion records.
- iv) In this study, orientation-independent spectrum concept has shown, which is probably will be a mandatory concept in the future seismic code in Turkey. RotD100 spectrum is resulting slightly higher scale factors in comparison with the SRSS spectrum as expected.
- v) In general, the average scale factor is significantly lower, and the scale factor have a lower, nearly 0, standard deviation with developed framework, in comparison with conventional PEER NGA selection and scaling tool. In addition,

PEER NGA tool is not consistent in every application. It is returning different results with the same inputs time to time. Developed framework is consistent and open source, to make the theory behind transparent. For example, a comparison table for numerical example 2 has shown below.

Table 5.1: Result comparison for case 2.

	Average Scale Factor	Standard Deviation of Scale Factor Set
PEER NGA	2,123	1,075
Scalepy SRSS	1,186	0,044
Scalepy RotD100	1,417	0,052

A comparison table for numerical example 3 has shown below.

Table 5.2: Result comparison for case 3.

	Average Scale Factor	Standard Deviation of Scale Factor Set
PEER NGA	1,952	0,664
Scalepy SRSS	0,978	0,078
Scalepy RotD100	1,226	0,098

vi. A different scaling procedure, FEMA P695, has implemented in the developed framework to verify the results of the studies. P695 scaling procedure is resulting higher scaling factors in most of the numerical examples, in comparison with the proposed methodology. Nevertheless, since the P695 method is scaling all the records with a single scalar, the acceleration content maybe resulting more engineering demand parameters. As a result, the most efficient way of selection and scaling of real ground motions is to use the proposed methodology in this study.

5.3. Future Work

The main objective of this dissertation is to propose a new methodology for selection and scaling of ground motion records. In terms of that, an open-source framework is developed in python programming language. This means, the source-code of this study is stored in Github site.

Since this study is based on an iterative method, the expansion of the ground motion record database may increase the success of this framework. Currently, there is 19554 ground motion records is stored in the public repository.

Due to complexity of the earthquake engineering problems, obtaining sufficient results is only possible with the power of computer programming. Source code can be also found in the Appendix A. Also, the repository can be found in the link [23].

REFERENCES

- [1] Naeim, F., Alimoradi, A., Pezeshk, S., (2004), “Selection and scaling of ground motion time histories for structural design using genetic algorithms”, *Earthquake Spectra*, 20 (2), 413–426.
- [2] Iervolino, I., Galasso, C., Cosenza, E., (2010), “REXEL: computer aided record selection for code-based seismic structural analysis”, *Bulletin of Earthquake Engineering*, 8, 339–362.
- [3] Reyes, J.C., Kalkan, E., (2011), “How many records should be used in ASCE/SEI-7 ground motion scaling procedure”, *Earthquake Spectra*, 28 (3), 1223–1242.
- [4] TSC, (2007), “TSC-07 Specification for buildings to be built in seismic zones”, Ministry of Public Works and Settlement, Government of Republic of Turkey, Ankara, Turkey.
- [5] TSC, (2018), “TSC-18 Turkish Building Seismic Code”, 2018
- [6] Nau, J.M., Hall, W.J., (1984), “Scaling methods for earthquake response spectra”, *Journal of Structural Engineering (ASCE)*, 110 (7), 1533–1548.
- [7] Kappos, A.J., Kyriakakis, P., (2000), “A re-evaluation of scaling techniques for natural records”, *Soil Dynamics and Earthquake Engineering*, 20, 111–123.
- [8] Stewart, J.P., Chiou, S.J., Bray, J.D., Graves, R.W., Somerville, P.G., Abrahamson, N.A., (2001), “Ground motion evaluation procedures for performance-based design”, PEER Report 2001/09, Pacific Earthquake Engineering Research Center, University of California, Berkeley, 229 pp.
- [9] Bommer, J.J., Acevedo, A.B., (2004), “The use of real earthquake accelerograms as input to dynamic analysis”, *Journal of Earthquake Engineering*, 8 (Special Issue 1), 43–91.
- [10] Alimoradi A., Beck JL., (2006), “Machine-learning methods for earthquake for earthquake ground motion analysis and simulation”, *Journal of Structural Engineering* 133 (6), 757-766
- [11] Cimellaro, G.P., Reinhorn, A.M., D'Ambrisi, A. and De Stefano, M., “Fragility analysis and seismic record selection”, *Journal of Structural Engineering* (2011), (ASCE), 137 (3), 379–390.
- [12] Watson-Lamprey, J., Abrahamson, N., (2006), “Selection of ground motion time series and limits on scaling”, *Soil Dynamics and Earthquake Engineering*, 26, 477–482.

- [13] Hancock, J., Bommer, J.J., Stafford, P.J., (2008), “Numbers of scaled and matched accelerograms required for inelastic dynamic analyses”, *Earthquake Engineering and Structural Dynamics*, 37 (14), 1585–1607.
- [14] Abrahamson, N.A., Silva, W.J., (2008), “Summary of the Abrahamson and Silva NGA Ground-Motion Relations”, *Earthquake Spectra*, 24 (1), 67–97.
- [15] Yasin M. Fahjan, “Selection and Scaling of Real Earthquake Accelerograms to Fit the Turkish Design Spectra”, 2008, *Teknik Dergi*, 1231-1250
- [16] Jack W. Baker, 2011, “Conditional Mean Spectrum: Tool for ground motion selection”, *Journal of Structural Engineering*, 137(3), 322-331
- [17] Esra Zengin, “A Proposed Ground Motion Selection and Scaling Procedure for Nonlinear Response History Analysis”, 2016
- [18] European Committee for Standardization (CEN), (2004), “Eurocode 8: Design of structures for earthquake resistance-Part 1: General rules, seismic actions and rules for buildings”, EN1998-1, Brussels.
- [19] FEMA P695, “Quantification of Building Seismic Performance Factors”, June 2009, FEMA
- [20] Alan Poulos, Eduardo Miranda, Jack W. Baker, 2022, “Evaluation of earthquake response spectra directionality using stochastic simulations”, *Bulletin of the Seismological Society of America*, 112(1), 307-315.
- [21] Cavdar E., Ozdemir G., Bayhan B., (2019), “Significance of Ground Motion Scaling Parameters on Amplitude of Scale Factors and Seismic Response of Short and Long Period Structures”, *Earthquake Spectra*, 35, 1663
- [22] Web 1, (2022), <https://energybaseddesign.gtu.edu.tr/>,
(Erişim Tarihi: 14/03/2023)
- [23] Web 2, (2023), <https://github.com/dogukankaratas/scalepy>,
(Erişim Tarihi: 14/03/2023)

APPENDICES

Appendix A: Comparison Tables

Table A.1: Comparison table for case 0.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	2,759	6,3974	8,3706	34,626
	7,687	7,234	9,4653	34,626
	1,380	8,0303	10,5071	34,626
	2,299	8,8877	11,629	34,626
	1,639	9,5959	12,5556	34,626
	7,650	10,0469	13,1457	34,626
	3,307	10,423	13,6378	34,626
	21,265	10,7034	14,0047	34,626
	27,328	10,9957	14,3872	34,626
	0,275	11,1326	14,5663	34,626
	5,288	11,2621	14,7358	34,626
Average	7,35	9,52	12,46	34,63
Standard Deviation	8,41	1,59	2,08	0,00

Table A.2: Comparison table for case 1.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	2,628	2,484	3,1518	1,804
	0,438	2,157	2,7364	1,804
	7,321	2,366	3,0016	1,804
	1,314	2,552	3,2374	1,804
	1,769	2,586	3,2812	1,804
	3,542	2,731	3,4647	1,804
	2,190	2,852	3,6179	1,804
	1,560	2,975	3,7743	1,804
	3,243	3,084	3,9123	1,804
	5,262	3,161	4,0103	1,804
	1,165	3,250	4,1233	1,804
Average	2,77	2,75	3,48	1,80
Standard Deviation	1,92	0,33	0,42	0,00

Table A.3: Comparison table for case 2.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	7,930	1,645	2,085	2,209
	3,779	1,845	2,337	2,209
	5,579	1,885	2,389	2,209
	3,269	1,999	2,532	2,209
	2,041	2,012	2,549	2,209
	2,426	2,049	2,596	2,209
	5,206	2,083	2,639	2,209
	2,117	2,157	2,733	2,209
	2,267	2,216	2,808	2,209
	1,672	2,279	2,888	2,209
	2,808	2,336	2,960	2,209
Average	3,55	2,05	2,59	2,21
Standard Deviation	1,85	0,19	0,25	0,00

Table A.4: Comparison table for case 3.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	5,912	3,395	3,928	4,604
	4,807	3,797	4,393	4,604
	1,233	3,814	4,413	4,604
	5,463	3,980	4,605	4,604
	1,691	4,133	4,782	4,604
	5,280	4,336	5,018	4,604
	7,193	4,454	5,154	4,604
	3,320	4,612	5,337	4,604
	5,615	4,736	5,480	4,604
	2,522	4,835	5,595	4,604
	4,533	4,973	5,755	4,604
Average	4,32	4,28	4,95	4,60
Standard Deviation	1,80	0,48	0,55	0,00

Table A.5: Comparison table for case 4.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	3,226	1,398	1,712	1,587
	10,316	1,506	1,844	1,587
	7,214	1,582	1,938	1,587
	2,003	1,620	1,984	1,587
	1,314	1,649	2,019	1,587
	3,074	1,696	2,078	1,587
	1,480	1,691	2,071	1,587
	21,291	1,736	2,126	1,587
	2,717	1,785	2,186	1,587
	4,753	1,814	2,222	1,587
	1,791	1,859	2,277	1,587
Average	5,38	1,67	2,04	1,59
Standard Deviation	5,68	0,13	0,16	0,00

Table A.6: Comparison table for case 5.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	N/A	6,335	8,4495	3,736
	N/A	7,163	9,5536	3,736
	N/A	7,951	10,6047	3,736
	N/A	8,487	11,3193	3,736
	N/A	8,801	11,7373	3,736
	N/A	8,938	11,9204	3,736
	N/A	9,056	12,0777	3,736
	N/A	9,168	12,2276	3,736
	N/A	9,261	12,3516	3,736
	N/A	9,327	12,4395	3,736
	N/A	9,392	12,5263	3,736
Average	-	8,53	11,38	3,74
Standard Deviation	-	0,95	1,26	0,00

Table A.7: Comparison table for case 6.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,883	3,141	4,006	7,183
	5,247	3,506	4,472	7,183
	0,942	3,896	4,969	7,183
	2,735	4,293	5,476	7,183
	1,268	4,581	5,842	7,183
	2,538	4,804	6,127	7,183
	1,569	5,046	6,436	7,183
	1,118	5,275	6,728	7,183
	2,324	5,493	7,006	7,183
	0,188	5,703	7,273	7,183
	0,835	5,905	7,531	7,183
Average	1,88	4,69	5,99	7,18
Standard Deviation	1,30	0,87	1,10	0,00

Table A.8: Comparison table for case 7.

	PEER	Scalepy SRSS	Scalepy RotD100	P695
	4,655	1,290	1,541	1,327
	2,218	1,163	1,390	1,327
	3,275	1,151	1,376	1,327
	1,935	1,138	1,360	1,327
	1,198	1,198	1,431	1,327
	1,424	1,248	1,491	1,327
	3,056	1,187	1,418	1,327
	1,243	1,160	1,387	1,327
	1,331	1,193	1,425	1,327
	0,981	1,161	1,387	1,327
	2,038	1,158	1,383	1,327
Average	2,12	1,19	1,42	1,33
Standard Deviation	1,07	0,04	0,05	0,00

Table A.9: Comparison table for case 8.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	3,448	1,316	1,631	1,268
	2,468	1,347	1,669	1,268
	1,473	1,330	1,649	1,268
	2,072	1,378	1,707	1,268
	2,509	1,394	1,727	1,268
	3,230	1,449	1,796	1,268
	2,388	1,264	1,567	1,268
	0,995	1,307	1,619	1,268
	1,757	1,348	1,670	1,268
	2,593	1,386	1,717	1,268
	1,935	1,420	1,759	1,268
Average	2,26	1,36	1,68	1,27
Standard Deviation	0,69	0,05	0,06	0,00

Table A.10: Comparison table for case 9.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,259	2,451	3,177	1,436
	1,504	2,423	3,141	1,436
	4,051	2,361	3,061	1,436
	1,568	2,514	3,260	1,436
	5,688	2,657	3,444	1,436
	1,652	2,743	3,556	1,436
	3,323	2,846	3,690	1,436
	1,661	2,941	3,813	1,436
	1,794	3,012	3,905	1,436
	3,765	3,079	3,991	1,436
	4,316	3,130	4,058	1,436
Average	2,78	2,74	3,55	1,44
Standard Deviation	1,43	0,27	0,34	0,00

Table A.11: Comparison table for case 10.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	19,018	11,683	14,085	8,842
	2,165	12,792	15,422	8,842
	6,053	13,424	16,184	8,842
	0,389	14,431	17,398	8,842
	54,015	15,255	18,391	8,842
	9,494	16,074	19,378	8,842
	17,288	16,478	19,866	8,842
	13,147	16,890	20,363	8,842
	66,738	17,033	20,535	8,842
	40,199	17,173	20,703	8,842
	88,358	17,284	20,838	8,842
Average	28,81	15,32	18,47	8,84
Standard Deviation	28,01	1,87	2,26	0,00

Table A.12: Comparison table for case 11.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,319	2,114	2,697	5,03
	3,674	2,3629	3,014	5,03
	0,660	2,6798	3,418	5,03
	1,915	2,8936	3,691	5,03
	0,888	3,0875	3,938	5,03
	1,777	3,2384	4,131	5,03
	1,099	3,4017	4,339	5,03
	0,783	3,5556	4,535	5,03
	6,125	3,7016	4,722	5,03
	0,950	3,8423	4,901	5,03
	0,585	3,9777	5,074	5,03
Average	1,80	3,17	4,04	5,03
Standard Deviation	1,60	0,58	0,74	0,00

Table A.13: Comparison table for case 12.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,614	1,218	1,487	1,317
	1,506	1,289	1,574	1,317
	0,656	1,255	1,532	1,317
	1,481	1,255	1,532	1,317
	1,083	1,261	1,540	1,317
	1,058	1,298	1,585	1,317
	0,658	1,328	1,621	1,317
	2,611	1,353	1,651	1,317
	0,996	1,344	1,641	1,317
	0,159	1,304	1,592	1,317
	3,163	1,324	1,616	1,317
Average	1,36	1,29	1,58	1,32
Standard Deviation	0,83	0,04	0,05	0,00

Table A.14: Comparison table for case 13.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	2,695	1,153	1,469	1,264
	2,948	1,208	1,539	1,264
	1,713	1,224	1,560	1,264
	1,022	1,233	1,570	1,264
	1,438	1,077	1,372	1,264
	1,741	1,047	1,334	1,264
	1,960	1,074	1,368	1,264
	1,657	1,098	1,399	1,264
	1,435	1,113	1,417	1,264
	1,982	1,045	1,332	1,264
	1,343	1,067	1,359	1,264
Average	1,81	1,12	1,43	1,26
Standard Deviation	0,55	0,07	0,09	0,00

Table A.15: Comparison table for case 14.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,761	2,659	3,456	1,121
	3,938	2,089	2,714	1,121
	1,094	1,962	2,550	1,121
	0,717	1,873	2,433	1,121
	1,678	1,979	2,571	1,121
	0,808	2,044	2,655	1,121
	0,218	2,120	2,755	1,121
	0,598	2,191	2,847	1,121
	0,409	2,244	2,916	1,121
	1,483	2,294	2,980	1,121
	0,977	2,332	3,030	1,121
Average	1,24	2,16	2,81	1,12
Standard Deviation	0,98	0,21	0,27	0,00

Table A.16: Comparison table for case 15.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	0,113	5,5064	7,031	1,672
	0,499	5,5322	7,064	1,672
	0,671	5,3994	6,894	1,672
	0,371	5,8152	7,425	1,672
	0,131	5,997	7,657	1,672
	0,545	1,6472	2,103	1,672
	4,876	1,7106	2,184	1,672
	1,327	1,7598	2,247	1,672
	10,741	1,8057	2,306	1,672
	18,199	1,8273	2,333	1,672
	5,175	1,842	2,352	1,672
Average	3,88	3,53	4,51	1,67
Standard Deviation	5,52	1,94	2,48	0,00

Table A.17: Comparison table for case 16.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,356	1,2737	1,539	0,988
	3,792	1,3066	1,579	0,988
	0,244	1,2574	1,519	0,988
	0,193	1,3297	1,607	0,988
	0,460	1,3867	1,675	0,988
	0,343	1,3508	1,632	0,988
	2,735	1,396	1,687	0,988
	3,282	1,3929	1,683	0,988
	1,793	1,4369	1,736	0,988
	1,175	1,4805	1,789	0,988
	1,230	1,5195	1,836	0,988
Average	1,51	1,38	1,66	0,99
Standard Deviation	1,20	0,08	0,10	0,00

Table A.18: Comparison table for case 17.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	2,377	1,294	1,592	1,412
	1,133	1,369	1,685	1,412
	1,673	1,333	1,640	1,412
	0,988	1,333	1,640	1,412
	0,612	1,340	1,649	1,412
	0,727	1,379	1,697	1,412
	1,561	1,332	1,639	1,412
	0,635	1,336	1,644	1,412
	2,699	1,362	1,676	1,412
	0,501	1,385	1,705	1,412
	1,049	1,384	1,703	1,412
Average	1,27	1,35	1,66	1,41
Standard Deviation	0,70	0,03	0,03	0,00

Table A.19: Comparison table for case 18.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	2,191	1,1024	1,368	1,077
	1,568	1,1486	1,425	1,077
	0,936	1,1883	1,475	1,077
	1,317	1,1764	1,460	1,077
	1,594	1,157	1,436	1,077
	2,052	1,1465	1,423	1,077
	1,517	1,1213	1,391	1,077
	0,632	1,1371	1,411	1,077
	1,117	1,1513	1,429	1,077
	1,674	1,1688	1,450	1,077
	1,229	1,1791	1,463	1,077
Average	1,44	1,15	1,43	1,08
Standard Deviation	0,44	0,02	0,03	0,00

Table A.20: Comparison table for case 19.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	0,174	3,599	4,780	2,593
	0,774	4,069	5,404	2,593
	1,042	4,516	5,998	2,593
	0,575	4,999	6,639	2,593
	0,204	5,323	7,069	2,593
	0,845	5,601	7,439	2,593
	7,564	5,815	7,723	2,593
	2,059	5,973	7,933	2,593
	16,662	6,138	8,152	2,593
	28,231	6,212	8,250	2,593
	8,027	6,262	8,316	2,593
Average	6,01	5,32	7,06	2,59
Standard Deviation	8,56	0,87	1,16	0,00

Table A.21: Comparison table for case 20.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,382	2,041	2,570	5,996
	3,851	2,461	3,099	5,996
	0,691	1,772	2,231	5,996
	2,008	1,883	2,370	5,996
	0,903	2,013	2,534	5,996
	1,863	2,110	2,657	5,996
	1,152	2,194	2,762	5,996
	0,821	2,282	2,873	5,996
	1,706	2,360	2,972	5,996
	3,996	2,442	3,074	5,996
	6,138	2,516	3,167	5,996
Average	2,23	2,19	2,76	6,00
Standard Deviation	1,64	0,24	0,30	0,00

Table A.22: Comparison table for case 21.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,508	1,114	1,372	1,123
	0,601	1,249	1,539	1,123
	1,144	1,095	1,349	1,123
	1,352	1,145	1,411	1,123
	1,715	1,102	1,358	1,123
	2,517	1,048	1,292	1,123
	1,657	1,089	1,343	1,123
	0,589	1,129	1,391	1,123
	0,544	1,164	1,435	1,123
	0,752	1,102	1,359	1,123
	0,146	1,093	1,347	1,123
Average	1,14	1,12	1,38	1,12
Standard Deviation	0,66	0,05	0,06	0,00

Table A.23: Comparison table for case 22.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	5,411	2,170	2,525	2,849
	2,774	2,411	2,805	2,849
	0,711	2,569	2,989	2,849
	3,153	2,697	3,138	2,849
	0,976	2,812	3,272	2,849
	3,049	2,933	3,413	2,849
	4,035	3,032	3,528	2,849
	1,916	3,126	3,637	2,849
	0,932	3,205	3,729	2,849
	4,455	3,267	3,802	2,849
	2,616	3,352	3,901	2,849
Average	2,73	2,87	3,34	2,85
Standard Deviation	1,45	0,36	0,42	0,00

Table A.24: Comparison table for case 23.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	2,285	1,365	1,749	1,402
	5,110	1,452	1,860	1,402
	1,419	1,265	1,621	1,402
	0,931	1,267	1,623	1,402
	2,178	1,342	1,719	1,402
	1,042	1,386	1,775	1,402
	0,717	1,444	1,850	1,402
	0,776	1,498	1,919	1,402
	5,315	1,546	1,981	1,402
	1,924	1,590	2,038	1,402
	1,269	1,631	2,090	1,402
Average	2,09	1,43	1,84	1,40
Standard Deviation	1,56	0,12	0,15	0,00

Table A.25: Comparison table for case 24.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	0,114	7,613	9,899	2,034
	0,506	7,901	10,273	2,034
	0,376	8,474	11,018	2,034
	0,133	2,080	2,704	2,034
	0,553	2,156	2,803	2,034
	4,947	2,190	2,847	2,034
	1,346	2,219	2,885	2,034
	10,898	2,247	2,921	2,034
	18,465	2,269	2,950	2,034
	5,251	2,285	2,971	2,034
	69,755	2,301	2,992	2,034
Average	10,21	3,79	4,93	2,03
Standard Deviation	19,62	2,58	3,36	0,00

Table A.26: Comparison table for case 25.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	0,919	1,917	2,554	3,558
	0,546	2,269	3,023	3,558
	1,453	2,549	3,396	3,558
	1,135	2,792	3,720	3,558
	2,550	2,964	3,949	3,558
	1,102	3,127	4,167	3,558
	5,311	1,956	2,606	3,558
	2,151	2,005	2,671	3,558
	4,734	2,048	2,729	3,558
	4,724	2,089	2,783	3,558
	1,763	2,133	2,842	3,558
Average	2,40	2,35	3,13	3,56
Standard Deviation	1,64	0,41	0,55	0,00

Table A.27: Comparison table for case 26.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,527	1,615	1,971	1,706
	1,561	1,602	1,955	1,706
	4,572	1,531	1,869	1,706
	1,534	1,575	1,922	1,706
	2,321	1,505	1,837	1,706
	1,049	1,532	1,870	1,706
	2,808	1,565	1,910	1,706
	2,468	1,471	1,796	1,706
	3,501	1,487	1,815	1,706
	1,810	1,504	1,835	1,706
	2,755	1,527	1,864	1,706
Average	2,36	1,54	1,88	1,71
Standard Deviation	0,98	0,04	0,05	0,00

Table A.28: Comparison table for case 27.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,612	1,168	1,480	1,048
	1,714	1,167	1,478	1,048
	1,288	1,130	1,432	1,048
	1,157	1,142	1,446	1,048
	2,033	1,155	1,463	1,048
	1,032	1,172	1,484	1,048
	1,836	1,160	1,470	1,048
	2,508	1,179	1,494	1,048
	2,051	1,196	1,514	1,048
	2,221	1,192	1,510	1,048
	2,371	1,206	1,528	1,048
Average	1,80	1,17	1,48	1,05
Standard Deviation	0,47	0,02	0,03	0,00

Table A.29: Comparison table for case 28.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,997	2,208	2,856	0,856
	0,692	2,399	3,103	0,856
	5,119	1,912	2,473	0,856
	3,979	1,759	2,276	0,856
	2,510	1,813	2,346	0,856
	7,337	1,702	2,202	0,856
	2,887	1,767	2,286	0,856
	3,373	1,826	2,362	0,856
	2,767	1,870	2,419	0,856
	3,952	1,911	2,472	0,856
	4,273	1,943	2,514	0,856
Average	3,54	1,92	2,48	0,86
Standard Deviation	1,66	0,20	0,26	0,00

Table A30: Comparison Table for Case 29

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	10,449	6,3058	7,593	4,858
	1,190	6,8979	8,306	4,858
	3,326	7,2535	8,734	4,858
	0,214	7,8063	9,400	4,858
	29,678	8,2653	9,952	4,858
	5,216	8,7178	10,497	4,858
	9,499	8,9405	10,765	4,858
	7,224	9,1692	11,041	4,858
	36,669	9,2484	11,136	4,858
	22,088	9,3243	11,228	4,858
	16,224	9,3842	11,300	4,858
Average	12,89	8,30	10,00	4,86
Standard Deviation	11,44	1,03	1,24	0,00

Table A.31: Comparison table for case 30.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	0,841	3,002	3,799	7,671
	1,888	3,212	4,065	7,671
	0,816	3,307	4,185	7,671
	5,245	3,241	4,102	7,671
	1,605	3,432	4,343	7,671
	11,004	3,607	4,564	7,671
	7,488	3,748	4,743	7,671
	3,499	3,896	4,930	7,671
	14,467	4,002	5,065	7,671
	18,893	4,085	5,169	7,671
	21,214	4,164	5,269	7,671
Average	7,91	3,61	4,57	7,67
Standard Deviation	7,09	0,38	0,48	0,00

Table A.32: Comparison table for case 31.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	2,236	1,560	1,850	1,582
	1,335	1,409	1,670	1,582
	0,726	1,432	1,697	1,582
	2,837	1,448	1,717	1,582
	0,767	1,487	1,763	1,582
	0,723	1,403	1,663	1,582
	0,832	1,426	1,690	1,582
	2,043	1,458	1,729	1,582
	0,389	1,477	1,751	1,582
	0,859	1,499	1,777	1,582
	3,790	1,423	1,687	1,582
Average	1,50	1,46	1,73	1,58
Standard Deviation	1,03	0,04	0,05	0,00

Table A.33: Comparison table for case 32.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,086	1,197	1,499	0,885
	2,567	1,029	1,290	0,885
	1,497	1,021	1,280	0,885
	1,254	0,976	1,223	0,885
	1,485	0,948	1,188	0,885
	1,617	0,954	1,195	0,885
	2,324	0,935	1,172	0,885
	3,455	0,944	1,183	0,885
	1,816	0,928	1,163	0,885
	1,891	0,918	1,150	0,885
	2,484	0,912	1,143	0,885
Average	1,95	0,98	1,23	0,89
Standard Deviation	0,66	0,08	0,10	0,00

Table A.34: Comparison table for case 33.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,129	1,236	1,533	0,985
	3,592	1,129	1,400	0,985
	3,202	1,113	1,380	0,985
	0,697	1,106	1,371	0,985
	10,368	1,095	1,357	0,985
	1,069	1,127	1,398	0,985
	6,523	1,109	1,375	0,985
	7,410	1,081	1,340	0,985
	0,945	1,104	1,369	0,985
	10,424	1,120	1,388	0,985
	7,365	1,136	1,409	0,985
Average	4,79	1,12	1,39	0,99
Standard Deviation	3,59	0,04	0,05	0,00

Table A.35: Comparison table for case 34.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	0,059	4,659	5,821	6,794
	0,260	4,482	5,600	6,794
	3,351	4,807	6,006	6,794
	0,193	5,218	6,519	6,794
	0,068	5,430	6,784	6,794
	0,284	5,607	7,005	6,794
	2,545	5,776	7,216	6,794
	0,693	5,921	7,398	6,794
	5,606	6,028	7,531	6,794
	9,499	6,131	7,660	6,794
	2,791	6,187	7,730	6,794
Average	2,30	5,48	6,84	6,79
Standard Deviation	2,85	0,58	0,73	0,00

Table A.36: Comparison table for case 35.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	0,746	2,390	2,547	4,398
	2,084	2,609	2,781	4,398
	1,508	2,759	2,940	4,398
	1,804	2,950	3,144	4,398
	3,287	1,444	1,538	4,398
	1,669	1,529	1,630	4,398
	1,514	1,207	1,286	4,398
	0,985	1,242	1,324	4,398
	3,676	1,278	1,362	4,398
	2,391	1,315	1,401	4,398
	2,537	1,345	1,434	4,398
Average	2,02	1,82	1,94	4,40
Standard Deviation	0,86	0,66	0,71	0,00

Table A.37: Comparison table for case 36.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	0,845	1,265	1,512	1,838
	0,935	1,368	1,634	1,838
	1,073	1,390	1,661	1,838
	0,858	1,406	1,680	1,838
	2,981	1,444	1,725	1,838
	0,754	1,363	1,628	1,838
	2,571	1,285	1,535	1,838
	0,612	1,233	1,472	1,838
	1,684	1,257	1,501	1,838
	1,016	1,241	1,482	1,838
	1,921	1,243	1,485	1,838
Average	1,39	1,32	1,57	1,84
Standard Deviation	0,76	0,07	0,09	0,00

Table A38: Comparison table for case 37.

	PEER	ScalePy SRSS	ScalePy RotD100	P695
	1,249	1,223	1,563	1,277
	1,317	1,270	1,623	1,277
	1,645	1,337	1,709	1,277
	1,182	1,316	1,682	1,277
	1,845	1,325	1,694	1,277
	2,122	1,315	1,681	1,277
	2,197	1,344	1,718	1,277
	2,725	1,282	1,639	1,277
	2,439	1,262	1,614	1,277
	1,164	1,285	1,643	1,277
	2,946	1,306	1,670	1,277
Average	1,89	1,30	1,66	1,28
Standard Deviation	0,61	0,03	0,04	0,00

