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2024

## Preliminary Spectral Matching Analysis of the Rod El-Farag Region in Cairo, Egypt

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## Preliminary Spectral Matching Analysis of the Rod El-Farag Region in Cairo, Egypt

### Cover Page Footnote

This research represents a collaboration between the Faculty of Engineering at Tanta University and the National Research Institute of Astronomy and Geophysics (NRIA). We sincerely appreciate this support and extend our gratitude to NRIA for providing the essential data and analysis.

# Preliminary Spectral Matching Analysis of The Rod El-Farag Region in Cairo, Egypt

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**Abstract:** Earthquake engineering assessments are essential for evaluating the seismic response of structures. Nonlinear dynamic analysis is a highly effective method for evaluating seismic response, considering the complex, three-dimensional, and dynamic behaviour of structures during earthquakes. The complexity of seismic damage assessment arises from ground motion and structural modelling parameters. Spectral matching is a key method in seismic codes and aids in selecting earthquake accelerograms for performance- and force-based designs. Spectrum-matched data is increasingly used to estimate nonlinear structural responses. Spectral matching utilizes the wavelet adjustments introduced by Abrahamson (1992) and refined by Hancock et al. (2006) to adjust earthquake accelerograms to match a specified response spectrum, enhancing the precision of seismic evaluations. This paper presents a preliminary spectral matching analysis of selected natural earthquake accelerograms using SeismoMatch. The results show that SeismoMatch effectively matches the time history response spectra with the target spectrum, nearly achieving perfect alignment. The Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), and Peak Ground Displacement (PGD) values obtained from spectral matching exhibited significant deviations from the original values, highlighting the impact of accelerograms amplitude scaling. Among the accelerograms analysed, the ground motion selected using SeismoMatch with the Al Atik & Abrahamson (2010) algorithm produced the closest match to the target spectra compared to the other selected accelerograms.

**Keywords:** Dynamic Analysis; Accelerograms; Spectral Matching, Wavelet; Response Spectra; SeismoMatch.

## I. INTRODUCTION

Earthquakes represent a significant natural hazard that impacts the environment and human populations, leading to severe destruction and loss of life. Assessing the frequency and characteristics of earthquakes in a specific region is essential for evaluating effective mitigation measures and ensuring safe planning for the future. Ground motion time histories are critical inputs for performing seismic response history analyses. Several methods are available for obtaining accelerograms for engineering analyses and assessments [1]. The techniques for generating these time histories include utilizing artificial ground motion or actual accelerograms to align with a specified target spectrum.

Artificial accelerograms are useful in seismic analysis, but significant limitations including variations in cycles, phase content, and duration compared to real ground motions render them inappropriate for nonlinear analyses. In contrast, real ground motion accelerograms can be adjusted to align with the target spectrum, especially around the natural vibration period of the structure. However, the variability inherent in real ground motions often necessitates conducting many dynamic analyses to achieve stable estimates of inelastic response. This requirement can be greatly reduced by matching real accelerograms to the target response spectrum, therefore, reducing discrepancies between the target and the spectral ordinates of each accelerogram. Iervolino [2] highlights that the signals employed for seismic structural analysis may include natural accelerograms, artificial waveforms and simulated accelerograms. Although the limited availability of ground motion data may lead researchers to create artificial time series, natural accelerograms are typically favored because they provide the most reliable input signals for developing site-specific response spectra.

Spectral matching adjusts the time history using both frequency and time domain methods. A widely used approach is to perform spectral matching in the frequency domain by modifying the Fourier amplitude spectra, which enables the generation of accelerograms that closely match the target spectrum derived from real ground motions [3]. However, this method can distort the velocity and displacement time series, potentially resulting in unrealistically high energy content [4]. An alternative approach employs wavelet adjustments in the time domain to alter the acceleration time series. This method preserves the advantages of Fourier techniques while offering a more targeted correction, minimizing additional energy input and maintaining the non-stationary characteristics of the original ground motion. The technique, initially developed by Lilhanand and Tseng [5,6], was later refined by Abrahamson in 1992 [7].

Numerous studies have concentrated on developing earthquake acceleration vibrations, or acceleration waves, as ground motion time histories. Bray and Travarasrou [8], Athanasopoulos [9], and Rathje et al. [10] emphasize that the selection of ground motion is crucial and can significantly affect the effectiveness of spectral matching. An inappropriate choice of input motion may lead to an inaccurate site-specific spectrum, which can compro-

mise the integrity of structural designs. Ergun and Ates [11] utilized recorded earthquake time histories to develop new time histories, specifically examining the effects of near-fault and far-fault conditions on structural performance. By analysing these variations, they provided insights that can inform engineering practices and design considerations, ultimately enhancing the resilience of structures in earthquake-prone areas. Artificial acceleration time histories were developed by Carlson et al. [12] using synthesized data from 28 recorded earthquake time histories. These artificial time histories were then employed as input for bilinear single-degree-of-freedom (SDOF) systems. The goal of their research was to create realistic acceleration profiles that could effectively simulate seismic loading conditions. This approach helps improve the reliability of structural analysis and design by providing more accurate representations of potential seismic impacts.

The methodology combined probabilistic seismic hazard analysis (PSHA) with spectral matching to produce seismic inputs that closely reflect local seismicity. Wood and Hutchinson [13] utilized PSHA to select earthquake ground motion time histories, ultimately creating new time histories that target specific response spectra. Their approach aimed to generate seismic input that accurately reflects the expected ground motion characteristics for a given site, enhancing the reliability of seismic assessments. Pavel and Vacareanu [14] collected actual earthquake time histories through the application of PSHA and subsequently developed new artificial time histories aimed at aligning with specific response spectra. Their research focused on ensuring that the artificial time histories accurately reflect the anticipated seismic behaviour for particular sites. Makrup [15] derived design ground motion by employing PSHA alongside established seismic codes. This methodology aimed to create ground motion scenarios that align with regulatory standards and accurately reflect the seismic risk for specific regions. The study contributes to the development of reliable design parameters for engineering applications, ultimately enhancing the safety and resilience of structures in earthquake-prone areas.

Dynamic nonlinear analysis of structures demands that the seismic input be defined as an acceleration time history. These inputs must align with the response spectra that represent the design seismic actions for the specific location. Makrup et al. [16] developed design accelerograms by utilizing both time and frequency domain matching techniques, tailored to the seismic hazards present in the Sorowako Field of Sulawesi Island, Indonesia. Their approach aimed to create realistic seismic input data that accurately reflects local seismic conditions. A review conducted by Pawirodikromo et al. [17] determined the bidirectional and directivity effects in artificial ground motions at different locations in Yogyakarta, Indonesia. Their study aimed to analyse how these factors influence the characteristics of ground motions, particularly in urban settings. By examining synthetic

ground motions, Saputra and Makrup [18] conducted hazard de-aggregation to analyse the seismic risk in Riau Province, Indonesia, and subsequently developed synthetic ground motion data tailored to the region. Their research aimed to better understand the contributing seismic sources and their impacts, facilitating the creation of realistic ground motion scenarios. Pratiwi et al. [19] conducted a structural dynamic evaluation of the Wadaslintang Dam, utilizing earthquake acceleration data in accordance with the Indonesian seismic code of 2019. Their study aimed to assess the dam's performance under seismic loading conditions, ensuring that the structure meets safety standards and can withstand potential earthquake impacts. A review of how soil response affects the frequency characteristics of ground motion was performed by Marzuko et al. [20]. Their study focused on how different soil conditions can alter the behaviour of seismic waves as they propagate through the ground, affecting the frequency content and amplitude of the resulting ground motion. By understanding these interactions, the authors aimed to improve predictive models for seismic analysis and enhance the response of structures to better withstand earthquake effects, particularly in areas with variable soil conditions.

Evaluating the seismic performance of structures is vital for ensuring safety against earthquake hazards. This involves incorporating earthquake risks into civil design by analysing site-specific response spectra, allowing to creation of resilient designs that better withstand seismic forces and protect lives. This paper presents a preliminary spectral matching analysis of selected natural earthquake accelerograms, comparing algorithms developed by Hancock et al. [21] and Al Atik and Abrahamson [22] and. The chosen natural earthquake accelerograms were selected based on their similarity in characteristics, such as magnitude and distance, influenced by site-specific conditions.

## II. DYNAMIC STRUCTURAL ANALYSIS

Earthquake engineering analyses are essential for determining how structures respond to earthquakes and for ensuring that a given structure can withstand a specified level of ground shaking while maintaining the required level of performance. Numerous studies have focused on the dynamic nonlinear analysis of structures [23-26]. Nonlinear dynamic analysis is the most accurate way to evaluate how structures will behave during an earthquake [27]. It is also the most popular and ideal method for assessing seismic damage to structures. The location, magnitude, and resulting shaking intensity of earthquakes are among the many factors that contribute to the structural modelling parameters, as well as the vagueness and uncertainties that complicate seismic damage assessment [28]. A review of the state-of-the-art record selection for probabilistic seismic risk analysis includes Magnitude ( $M$ ), Distance ( $R$ ), Ground motion intensity measurements, and Spectral matching [29-32].

Digitization of ground motion refers to the recording of acceleration data from earthquakes. There are two approaches to obtaining this data: using historical recordings from the study area or generating synthetic motion data. When selecting rock input motions, several factors must be considered, including magnitude, source mechanism, fault characteristics, and source distance. Additionally, site characteristics, represented by the site class categorization, are crucial in determining the appropriate input motion. In this study, we will utilize ground motion data from the nearest station to the research site for the seismic analysis. This data will be provided by the National Research Institute of Astronomy and Geophysics (NRIAG) [33]. Following this, we will apply the spectral matching analysis process to ensure consistency.

### III. RESEARCH REGION

This research focuses on the Rod El Farag region in Cairo, Egypt, to assess its structural dynamics and ground motion. It is an essential stage for evaluating the integrity and performance of the Rod El Farag Bridge. The bridge is recognized as the widest bridge in the world according to the Guinness World Records. It plays a crucial role in reducing traffic in the heart of Cairo and guaranteeing more effective transportation. The study location is illustrated in Fig. 1.

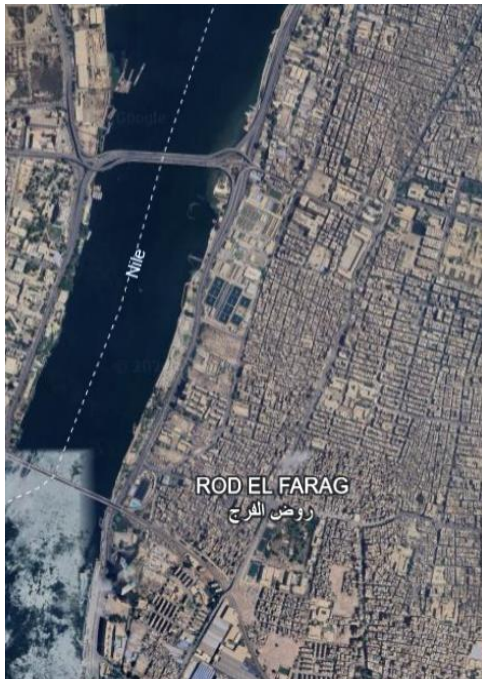


Figure 1. Research region [Google Map, 2024]

Evaluating the local rock and soil properties is essential for comprehending the site-specific response at the ground or foundation level. The way the ground responds to an earthquake is greatly

influenced by the properties of the soil. The geological and geotechnical data collected indicate that the shear wave velocity ( $V_s$ ) of the soils beneath the research site ranges from 180 to 360 m/s, suggesting the presence of deep deposits of compact or moderately compact sand and gravel. Based on the site class definitions in the Egyptian Code for Loads, this classification designates the site as site class E.

The spectral matching analysis is crucial for seismic design and analysis, as it ensures that the input ground motions reflect realistic seismic demands while adhering to specific engineering requirements. SeismoMatch [34] is a specialized software tool designed for spectral matching analysis of ground motion. It utilizes wavelet adjustments to perform the analysis in the time domain, ensuring that the selected ground motions align closely with a target response spectrum.

### IV. METHODOLOGY

The software incorporates two main algorithms for spectral matching: the Al Atik and Abrahamson and Hancock methods. Both approaches build on the foundational wavelet technique first introduced by Lilhanand and Tseng in the late 1980s [5,6]. Hancock et al. [21] developed their algorithms to mitigate the velocity and displacement drift observed in the earlier Abrahamson [7] algorithm. They utilized a modified tapered cosine wavelet is defined by

$$a_j(t) = \cos[\omega_j(t - t_j + \Delta t_j)] \exp[-|t - t_j + \Delta t_j| \psi_j + [c_1(t - t_j + \Delta t_j) + c_2] \exp[-|t - t_j + \Delta t_j| 5\psi_j]] \quad (1)$$

where  $a_j(t)$  is the amplitude of the  $j^{\text{th}}$  wavelet at time  $t$ ;  $t_j$  is the time of the peak response of the  $j^{\text{th}}$  oscillator under the action of the  $j^{\text{th}}$  wavelet;  $\omega_j$  is the circular frequency of the  $j^{\text{th}}$  wavelet;  $\beta_j$  is the damping level proportion of critic of the  $j^{\text{th}}$  oscillator;  $\bar{\omega}_j$  is the damped circular frequency  $\bar{\omega}_j = \omega_j \sqrt{1 - \beta_j^2}$ .

Al Atik and Abrahamson [22] introduced a new algorithm to improve the stability, efficiency, and speed of numerical solutions, while also addressing drift in the resulting velocity and displacement time series. They employed an enhanced tapered cosine wavelet specifically designed to better align with the target spectra is defined by

$$a_j(t) = \cos[\Omega_j(t - t_j + \Delta t_j)] e^{-\left(\frac{t - t_j + \Delta t_j}{\gamma_j}\right)^2} \quad (2)$$

$$\Delta t_j = \frac{1}{\Omega_j} \tan^{-1} \left( \frac{\sqrt{1 - \beta_j^2}}{\beta_j} \right), \quad \Omega_j = \omega_j \sqrt{1 - \beta_j^2}, \quad (3)$$

$$\gamma_j = \frac{6.508}{\Omega_j^{0.93}}$$

where  $t_j - \Delta t_j$  represents the peak occurrence time of wavelet and,  $\gamma_j$  represents a frequency-dependent coefficient used to adjust the duration of the wavelet. This adjustment helps generate a time history that aligns with the target spectrum while enhancing computational efficiency, stability, and effectiveness of the adjustment process.

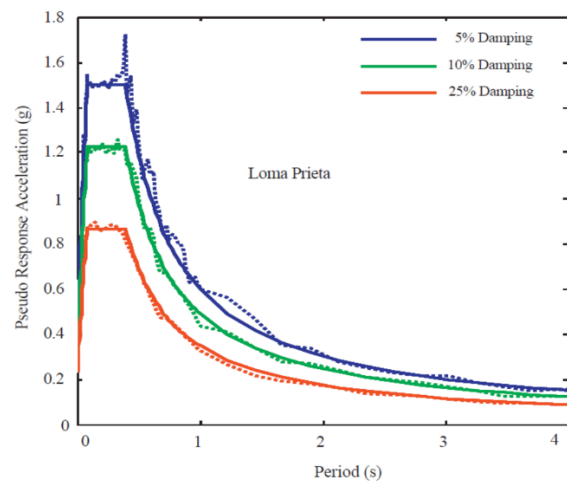
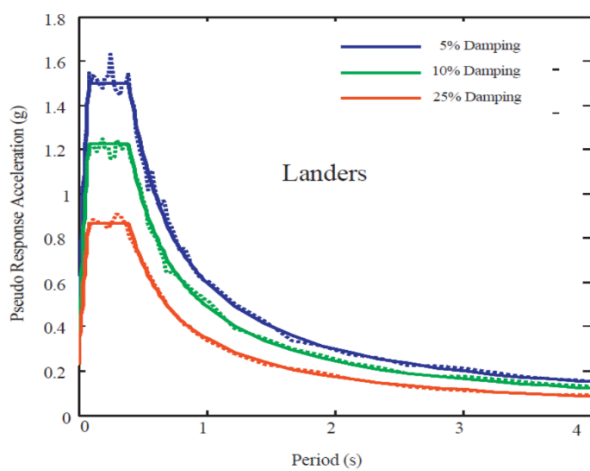
#### A. SeismoMatch verification

In order to highlight the novelty of the spectral matching methodology, it was compared with a previous study by Ozbulut and Stefan who used RspMatch to generate spectrum-compatible real ground motion records for dynamic time history analyses of an isolated bridge [35]. Table 1. shows the characteristics of two historical California earthquakes that have been chosen as seed accelerograms. Based on the International Building Code [36], a target response spectrum is chosen for a southern California location, presuming firm rock conditions [37].

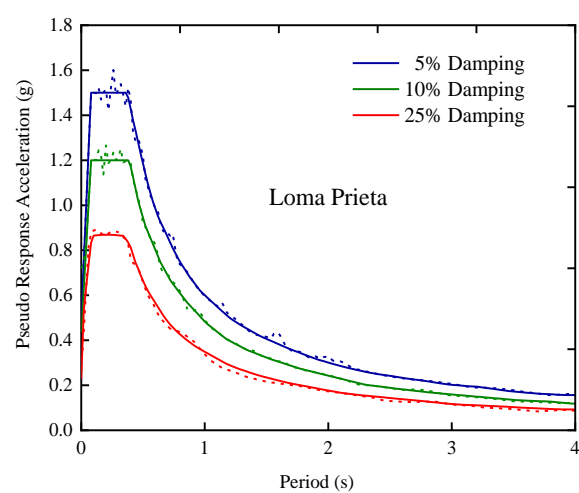
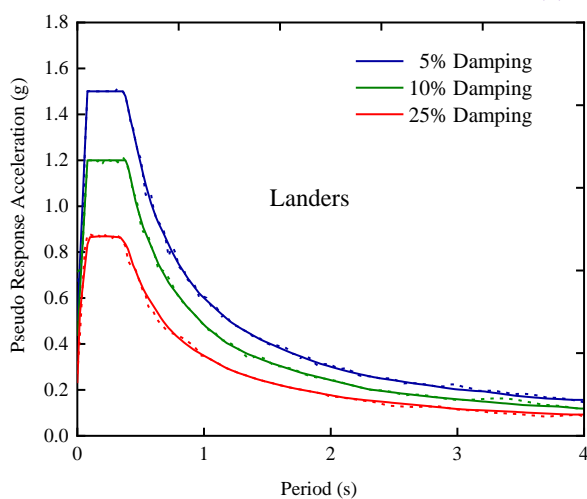
**Table 1. The characteristics of California earthquakes used in the analyses**

Earthquakes	$M_w$	Distance (km)	PGA (g)	Duration (s)
1992 Landers	7.3	1.1	0.72	13.1
1989 Loma Prieta	6.9	6.1	0.56	10.2

Figure 2. shows a comparison of spectrally matched response spectra of Landers and Loma Prieta earthquakes for 5%, 10%, and 25% damping levels using RspMatch and SeismoMatch software. The results were very close in both softwares and the high plus was at the same period, which shows the SeismoMatch ability to spectral matching analysis Matched response spectra using SeismoMatch are extremely compatible and identical to the target response spectrum compared with RspMatch. therefore, SeismoMatch is used in the current study



(a) RspMatch [22]

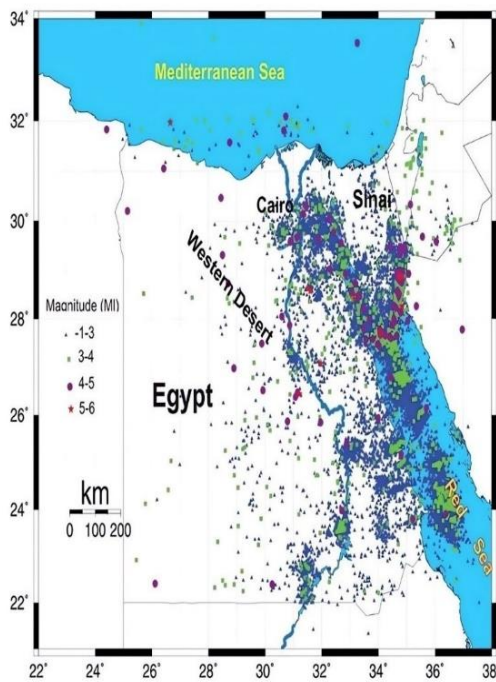


(b) SeismoMatch

**Figure 2. A comparison of spectrally matched response spectra of Landers and Loma Prieta earthquakes for different damping levels (a) RspMatch2005 (b) SeismoMatch**

### B. Selection of ground motion accelerograms

Microearthquakes play a significant role in monitoring and predicting ongoing tectonic processes and the future evolution of Earth. Consequently, the investigation of microearthquakes has emerged as a crucial field of study in seismology. Typically, the results obtained from this research are combined with findings from other interconnected disciplines and theoretical analyses to enhance our understanding of seismic activity. Fig. 3 displays the spatial distribution of local and regional earthquakes in Egypt with magnitudes greater than three ( $M > 3$ ). This perspective has undergone significant enhancements following the construction of the Earthquake Network System (ENSN). The majority of the activity consists of microearthquakes that are concentrated in the Suez Gulf, Aqaba Gulf, and northern Red Sea.



**Figure 3. Spatial distribution of local earthquakes of Egypt [1997-2024]**

The Egyptian National Seismic Network (ENSN) has collected waveform data from 60 seismic stations spanning the period from 1998 to 2024. Short-period seismic stations are equipped with seismometers such as STS1 and L4C (Natural Frequency = 1 Hz). Additionally, broadband seismic stations use seismometer models such as STS2 and Trillium. The ENSN's seismo-

logical acquisition system is a fully automated network designed specifically for the collection and processing of digital seismological data in real time. Each digital recorder is equipped with velocity sensors and an analog-to-digital converter. The Egyptian earthquake recordings were obtained from the National Research Institute of Astronomy and Geophysics (NRIA) to apply a greater magnitude to the structures and achieve a more accurate response of structures. The accelerograms were chosen based on the similarity of their characteristics, including distance, magnitude, and site-specific conditions. This process involves comparing the response spectrum of the recorded time history with a target spectrum. Following collection, the recordings are rescaled using SeismoMatch software to determine scale factors, as indicated in Table 2.

### C. Definition of Target Spectra

Seismic input in nonlinear dynamic structural assessments is commonly described using acceleration time histories and response spectra that align with a target response spectrum. The seismic ground motion, collected with specific features, was matched with the elastic response spectrum specified by the Egyptian Code for soil type E using the "SeismoMatch" software to ensure compatibility. The research region (Rod El Farag region) is situated in seismic region IV and has been analyzed to obtain the target response spectra. Response spectra for the target have been developed in accordance with the Egyptian Code for Loads. The following formulas define the elastic response spectrum  $S_e(T)$  for the horizontal components of seismic action:

when the period  $T$  is smaller than a certain value, the following equation can be used to calculate the elastic response spectrum:

$$S_e(T) = a_g \cdot \gamma_1 \cdot S \cdot \left[ 1 + \frac{T}{T_B} \cdot (2.5 \eta - 1) \right] \quad 0 \leq T \leq T_B \quad (4)$$

when the period  $T$  is between a certain range, the elastic response spectrum can be calculated by using the following equations:

$$S_e(T) = 2.5 \cdot a_g \cdot \gamma_1 \cdot S \cdot \eta \quad T_B \leq T \leq T_C \quad (5)$$

$$S_e(T) = 2.5 \cdot a_g \cdot \gamma_1 \cdot S \cdot \eta \left[ \frac{T_C}{T_B} \right] \quad T_C \leq T \leq T_D \quad (6)$$

When the period  $T$  is greater than a certain value, the elastic response spectrum can be calculated by using the following equation:

$$S_e(T) = 2.5 \cdot a_g \cdot \gamma_1 \cdot S \cdot \eta \left[ \frac{T_C \cdot T_D}{T^2} \right] \quad T_D \leq T \leq 4 \quad (7)$$

Table 2. List of selected ground motion accelerograms (NRIA, 2024)

Earthquakes	Date	Time UTC	Component		Depth (Km)	Magnitude	Record station	PGA (cm/s <sup>2</sup> )	
			Latitude	Longitude				E	N
EQ1	2013.01.17	21:17:21	31.98	30.60	10.00	4.90	HLW	1.17	1.95
EQ2	2015.06.27	15:34:02	28.95	34.69	21.50	5.50	THLW	1.19	1.69
EQ3	2015.09.03	1:44:39	30.51	28.44	10.00	4.50	THLW	0.33	0.26
EQ4	2018.03.30	7:44:28	29.97	31.62	7.47	3.30	THLW	0.17	0.17
EQ5	2019.11.27	7:23:41	35.66	23.16	67.00	6.00	KHLW	0.07	0.06
EQ6	2019.12.10	21:58:29	35.38	26.50	54.00	5.40	KHLW	0.09	0.07
EQ7	2020.10.06	0:59:58	29.76	30.77	4.30	3.00	KHLW	0.01	0.01
EQ8	2020.10.14	13:09:05	29.77	30.78	2.20	3.10	KHLW	0.01	0.01
EQ9	2020.11.22	9:52:26	30.93	31.25	21.00	3.50	KHLW	0.03	0.03
EQ10	2020.12.11	15:47:00	29.89	31.11	7.20	3.30	KHLW	0.02	0.02
EQ11	2020.12.15	2:30:00	29.56	29.56	20.20	3.83	KHLW	0.01	0.01
EQ12	2021.03.04	18:19:13	29.85	31.14	4.60	3.17	KHLW	0.02	0.02
EQ13	2021.03.14	2:40:10	30.16	31.86	21.60	2.84	KHLW	0.03	0.02
EQ14	2021.04.07	16:29:50	34.93	25.27	52.00	5.90	KHLW	0.05	0.05
EQ15	2021.06.15	23:08:52	30.10	35.18	15.00	4.20	KHLW	0.01	0.01

Continue Table 2. List of selected ground motion accelerograms (NRIA, 2024)

Earthquakes	Date	Time UTC	Component		Depth (Km)	Magnitude	Record station	PGA (cm/s <sup>2</sup> )	
			Latitude	Longitude				E	N
EQ16	2021.12.29	16:47:09	34.80	25.12	67.00	5.10	KHLW	0.02	0.03
EQ17	2022.01.22	19:23:47	29.60	32.01	5.95	3.50	KHLW	0.04	0.04
EQ18	2022.02.01	9:01:33	29.30	30.61	7.47	4.17	KHLW	0.10	0.70
EQ19	2022.02.02	21:03:50	35.07	31.95	88.37	5.12	KHLW	0.01	0.02
EQ20	2022.10.02	4:02:57	34.23	26.09	10.00	5.40	KHLW	0.01	0.01
EQ21	2022.10.14	1:07:49	35.24	31.93	25.00	6.60	KHLW	0.07	0.09
EQ22	2022.11.20	23:24:58	35.86	26.62	85.00	5.85	KHLW	0.06	0.10
EQ23	2022.11.26	23:55:52	30.14	31.50	18.27	2.92	KHLW	0.02	0.03
EQ24	2022.12.09	5:05:09	28.72	34.58	19.19	3.67	KHLW	0.01	0.01
EQ25	2022.12.22	2:58:30	28.01	33.43	20.41	3.93	KHLW	0.01	0.01
EQ26	2022.12.27	0:11:03	28.06	33.27	10.00	4.88	KHLW	0.03	0.04
EQ27	2023.01.25	12:37:00	35.71	28.64	42.00	5.95	KHLW	0.08	0.08
EQ28	2023.02.23	22:25:41	30.24	32.54	10.00	4.09	KHLW	0.07	0.05
EQ29	2023.05.13	20:12:17	28.01	33.40	20.24	3.85	KHLW	0.00	0.01
EQ30	2023.05.16	20:05:55	28.79	34.74	20.73	4.37	KHLW	0.01	0.01

where  $S_e(T)$  is the elastic response spectrum;  $T$  is the vibration period of a linear SDOF system;  $a_g$  is the design ground acceleration for type A ground;  $T_B, T_C$  are the limits of the periods of the constant spectral acceleration branch;  $T_D$  is the start of the constant displacement response range;  $\gamma_1$  is the structural importance factor;  $S$  is the soil factor; and  $\eta$  is the damping correction factor with a reference value of  $\eta = 1$  for 5% viscous damping.

Additionally, it is assumed that the shear wave velocity of the soils beneath the research site will fall within the 180-360 m/s range, indicating the presence of deep deposits of compact or moderately compact sand, gravel, or firm clay classified as ground type C. This classification is based on the Egyptian Code for Loads, which assigns soil factors ( $S=1.5, T_b=0.10, T_c=0.25, T_d=1.2$ ). The seismicity for the elastic (nonlinear) analysis is type 1, with a response modification factor ( $R$ ) of 1 and a structural importance factor ( $I$ ) of 1.3. The highest ground acceleration, denoted as  $a_g$ , has been established as the Peak Ground Acceleration (PGA) of 0.15 times the acceleration due to gravity ( $g$ ) for zone 3. The design response spectrum has a maximum spectral acceleration of 0.731g between the time period of 0.1 to 0.24 seconds. Fig.4. displays the design spectral spectrum,  $S_a$ , expressed in terms of  $g$ , as a function of the time period  $T$  in seconds.

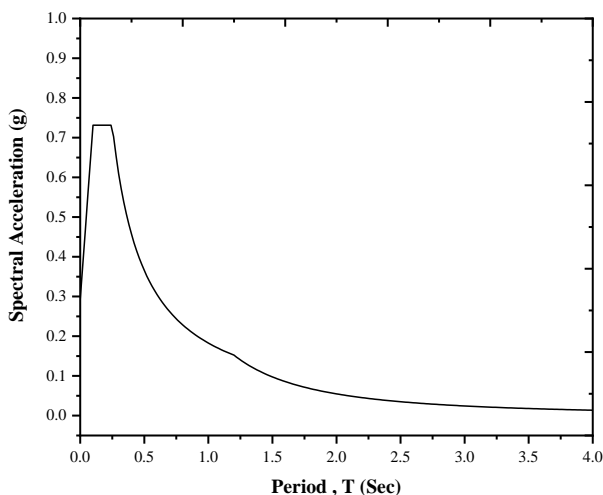


Figure 4. The targeted spectra [Rod El Farag region]

#### D. Spectral matching analysis

Several studies employed Al Atik and Abrahamson's algorithm techniques to generate an optimal match to the target spectrum. The matching parameters are presented in Table 3. Thirty selected accelerograms are utilized in the present investigation for spectrum matching analysis. A few of the accelerograms were matched twice. The initial matching process occurred within a time frame of 0.05 to 2 seconds. Subsequently, the initially matched accelerograms underwent a new matching procedure with a minimum duration of 0.05 seconds and a maximum duration of 4 seconds.

Table 3. SeismoMatch matching parameters

Matching parameters		Period Range		Integration parameters	
Param.	Value	Param.	Value	Param.	Value
Tolerance	0.1	Min Period	.05	Gamma	0.5
Max Iteration	30	Max Period	4	Beta	0.25
Scale Factor	1	Period Step	.02	Max dt/t	0.02
Eigen Value	0.001				
Group size	250				

The first procedure focuses on matching the short-period region of the response spectrum because long-period wavelet can affect the short-period spectral acceleration. The spectral misfit is considered as the difference between the ground motion spectrum and target spectrum for damping ratio and period. [38] After adjusting the original accelerograms and parameters, a new time histories that are modified to match the target spectrum as shown in Fig. 5.

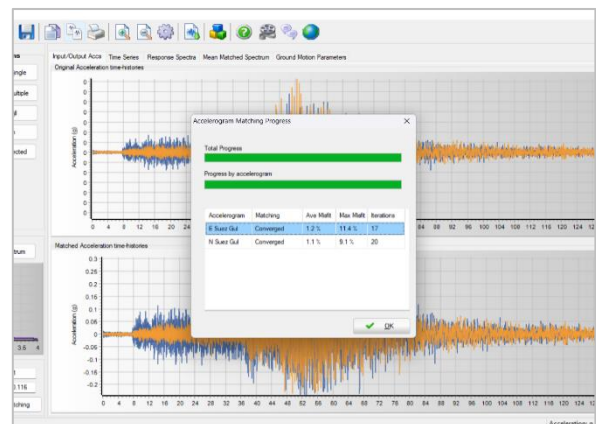


Figure 5. Accelerograms matching progress

## V. RESULT AND DISCUSSION

According to the initial parameters and the algorithm introduced by Al Atik and Abrahamson [22], the matched ground motions are summarized in Table 4., aligning with the elastic response spectrum specified in the Egyptian Code. The findings indicate that the algorithm developed by Al Atik and Abrahamson has a low average discrepancy for the majority of accelerograms and requires only a few iterations to attain consistent outcomes. The technique yields an average mismatch of 3.10% and a maximum misfit of around 17.07% across all accelerograms.

**Table 4. Summary of matched ground motions accelerograms**

Earthquakes	Component	Ave. Misfit	Max Misfit	Iterations	Max. Acc (g)
EQ1	E-W	1.7 %	10.2 %	17	0.73821 g
	N-S	2.2 %	12.6 %	21	0.73821 g
EQ2	E-W	4.7 %	29.1 %	27	0.73483 g
	N-S	2.3 %	28.1 %	27	0.73476 g
EQ3	E-W	6.7 %	29.9 %	30	0.73561 g
	N-S	3.6 %	18.5 %	30	0.75433 g
EQ4	E-W	3.2 %	13.8 %	30	0.73634 g
	N-S	1.9 %	15.1 %	30	0.74952 g
EQ5	E-W	5.4 %	27.7 %	30	0.89597 g
	N-S	6.0 %	34.3 %	30	1.13265 g
EQ6	E-W	2.3 %	8.4 %	26	0.74154 g
	N-S	2.2 %	9.3 %	22	0.76172 g
EQ7	E-W	3.2 %	13.7 %	23	0.75356 g
	N-S	1.5 %	8.7 %	28	0.73987 g
EQ8	E-W	2.2 %	14.2 %	26	0.74242 g
	N-S	1.8 %	9.1 %	26	0.75432 g
EQ9	E-W	6.7 %	29.9 %	30	0.73561 g
	N-S	3.6 %	18.5 %	30	0.75433 g
EQ10	E-W	1.8 %	12.7 %	29	0.74258 g
	N-S	1.2 %	16.2 %	30	0.73549 g
EQ11	E-W	2.3 %	10.1 %	22	0.73522 g
	N-S	2.5 %	11.0 %	11	0.74047 g
EQ12	E-W	2.2 %	14.7 %	21	0.73483 g
	N-S	2.1 %	8.8 %	18	0.73823 g
EQ13	E-W	8.3 %	30.7 %	30	0.76939 g
	N-S	5.2 %	16.5 %	30	0.73597 g
EQ14	E-W	2.8 %	18.7 %	30	0.75170 g
	N-S	5.5 %	33.4 %	30	0.86670 g
EQ15	E-W	1.5 %	14.6 %	10	0.84155 g
	N-S	2.6 %	15.0 %	15	0.78304 g
EQ16	E-W	4.8 %	25.0 %	30	0.73497 g
	N-S	9.1 %	41.8 %	30	0.73613 g
EQ17	E-W	7.3 %	32.2 %	30	0.74578 g
	N-S	2.9 %	16.8 %	30	0.74029 g
EQ18	E-W	1.5 %	13.8 %	28	0.73692 g
	N-S	1.6 %	7.8 %	27	0.81736 g

Continue Table 4. Summary of matched ground motions accelerograms

Earthquakes	Component	Ave. Misfit	Max Misfit	Iterations	Max. Acc (g)
EQ19	E-W	1.2 %	5.1 %	7	0.75420 g
	N-S	1.5 %	15.4 %	30	0.73523 g
EQ20	E-W	2.1 %	10.4 %	14	0.73560 g
	N-S	1.5 %	8.0 %	23	0.73521 g
EQ21	E-W	2.9 %	10.6 %	29	0.73652 g
	N-S	3.4 %	30.8 %	30	0.78296 g
EQ22	E-W	2.9 %	15.2 %	10	0.74238 g
	N-S	2.9 %	15.8 %	16	0.73513 g
EQ23	E-W	7.9 %	30.4 %	30	0.76679 g
	N-S	3.0 %	17.8 %	30	0.74579 g
EQ24	E-W	3.3 %	15.0 %	30	0.74030 g
	N-S	2.2 %	8.9 %	24	0.74669 g
EQ25	E-W	1.2 %	5.5 %	24	0.73712 g
	N-S	1.1 %	7.0 %	25	0.73506 g
EQ26	E-W	1.2 %	11.4 %	17	0.81774 g
	N-S	1.1 %	9.1 %	20	0.75879 g
EQ27	E-W	1.4 %	8.9 %	20	0.73616 g
	N-S	5.3 %	34.6 %	30	0.73506 g
EQ28	E-W	4.2 %	18.0 %	29	0.74096 g
	N-S	1.7 %	12.6 %	22	0.73534 g
EQ29	E-W	1.6 %	13.9 %	23	0.73499 g
	N-S	2.9 %	31.5 %	30	0.73565 g
EQ30	E-W	1.6 %	8.9 %	27	0.73511 g
	N-S	1.3 %	8.5 %	26	0.73542 g

SeismoMatch performs the spectral matching analysis and is regarded as a tool that operates in the time domain. The time domain method is considered more effective than spectral matching in the frequency domain due to its utilization of wavelet. This method alters the original accelerogram in the time domain. Fig. 6 displays a sample of the matched response spectrum for selected ground motions used in this study. The mean matched spectrum provides an improved fit over the period of 0.001 seconds to 4 seconds, though there is a minor peak in the spectrum between 2 and 3 seconds. In summary, considering the average misfit value of the algorithm and the spectral shape of ground motions, Al Atik and Abrahamson's algorithm demonstrates superior performance in spectral matching analysis compared to other techniques.

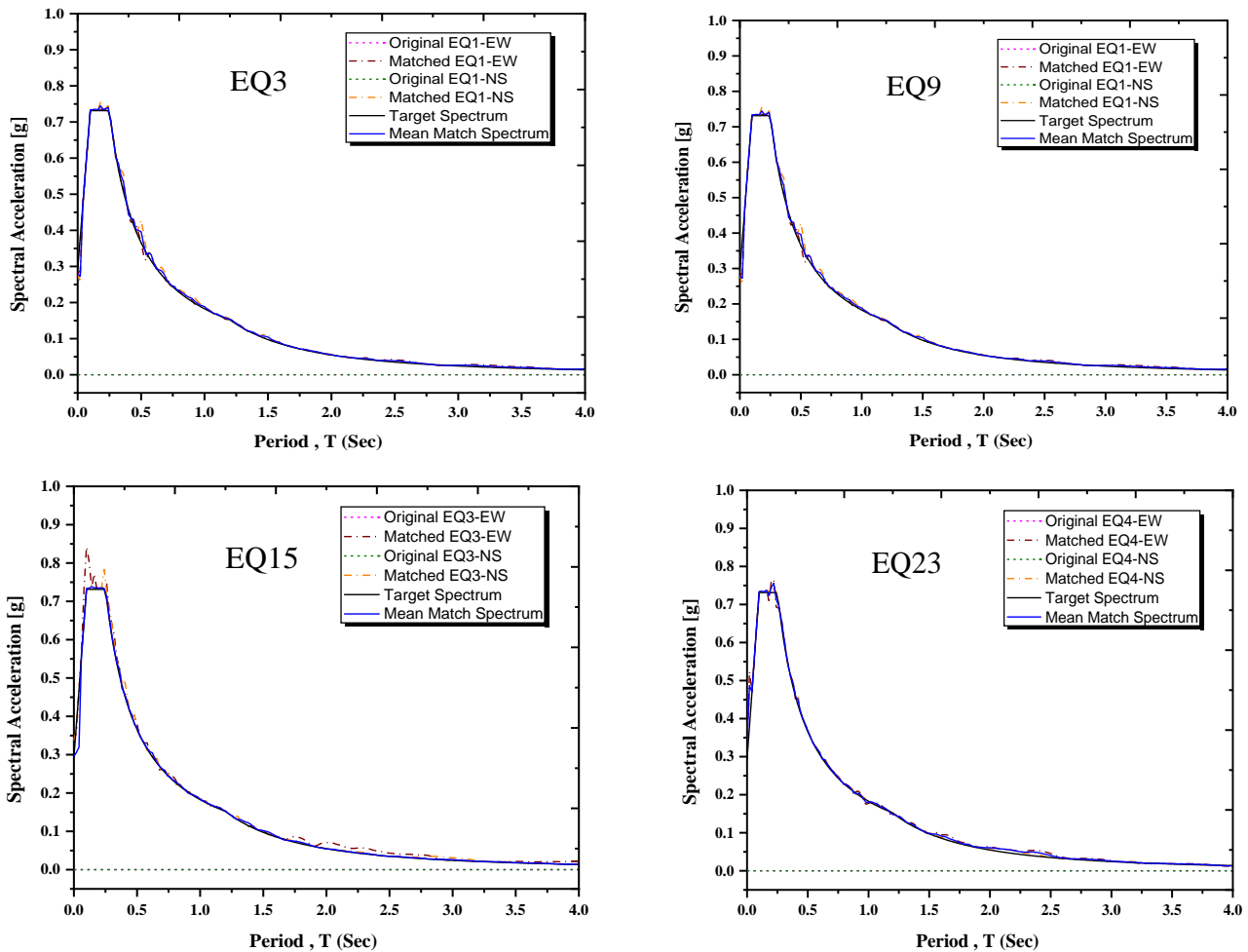
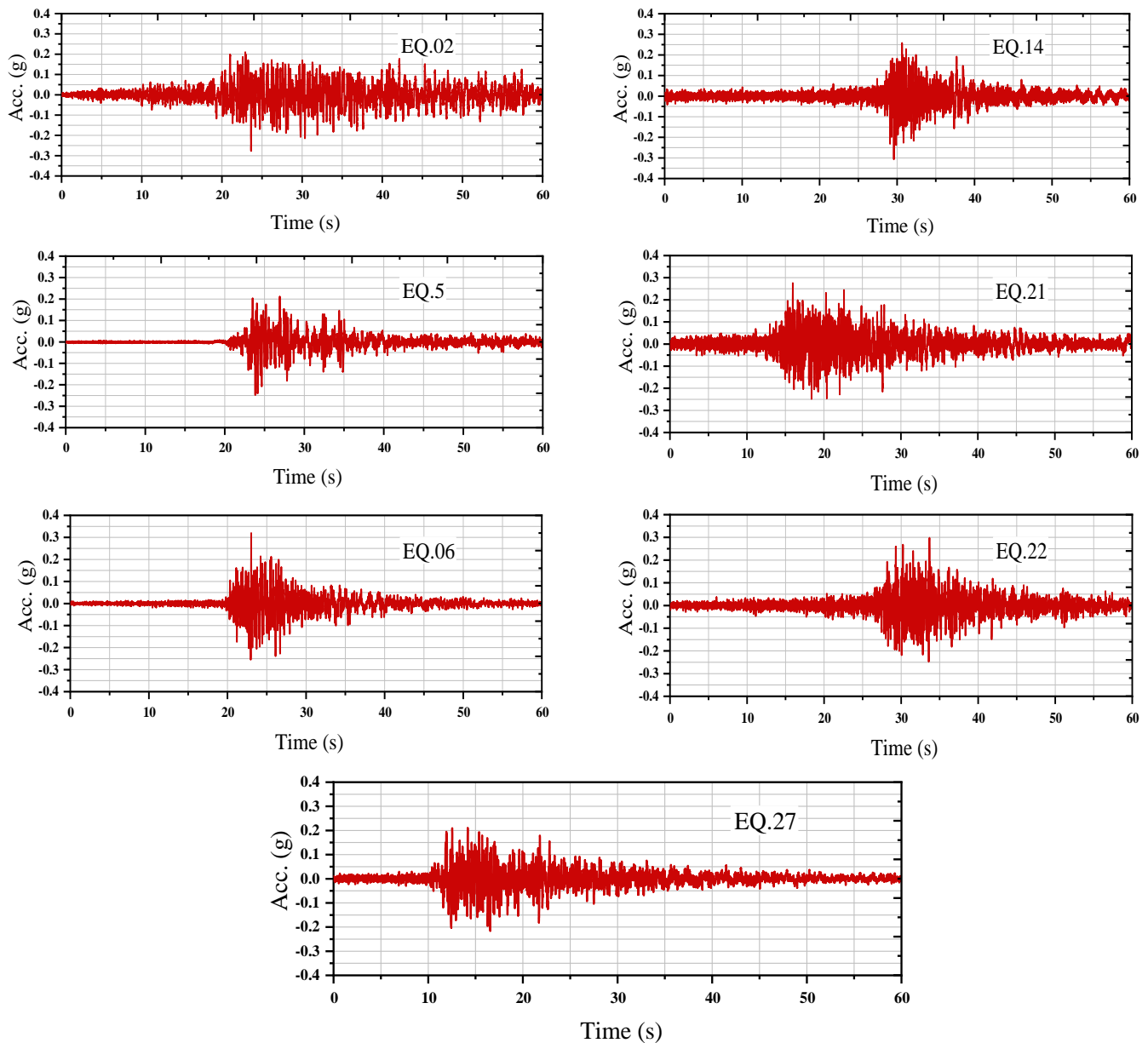


Figure 6. Sample of matched response spectrum for ground motions

Alexander et al. [39] identified three key criteria for spectral matching to preserve the non-stationary characteristics of the original accelerogram: maintaining the overall envelope shape, ensuring consistent Fourier spectra, and accurately reflecting the timing and features of significant pulses. These criteria are essential for preserving the characteristics of the original signal during the matching process. If we assume that maximum acceleration corresponds to the large pulses, we can identify their timing. The matched time histories of selected ground motions with high magnitudes are analyzed, as shown in Fig. 7. The timing of the large pulses closely matches with the original accelerograms. This discrepancy may arise from the phase drift observed during the spectral matching process. Given that the analysis uses unscaled, as-recorded data, this minor drift is considered reasonable.



**Figure 7. Matched time histories of ground motions with high magnitude**

Table 5 presents the comparisons of PGD, PGV, and PGA for both the original and matched ground motions with high magnitude. The three parameters are expected to scale with the amplitude of the accelerograms. The PGA increased at an approximately constant rate compared to the original accelerograms, exhibiting a linear pattern [40]. SeismoMatch using Abrahamson algorithm shows consistent percentages, indicating its suitability as a technique.

Table 5. PGD, PGV, and PGA of original and matched ground motions with high magnitude

Earthquakes	Original			Matched		
	PGD (cm)	PGV (cm/sec)	PGA (g)	PGD (cm)	PGV (cm/sec)	PGA (g)
EQ02	0.01755	0.00152	0.00120	466.33700	16.70454	0.29754
EQ05	0.04800	0.00038	0.00006	317.57700	2.53846	0.39950
EQ06	0.00051	0.00002	0.00009	2.15878	0.11840	0.31981
EQ14	0.07000	0.00160	0.00001	1929.26000	44.33734	0.30700
EQ21	0.08000	0.00157	0.00002	985.78600	23.51230	0.24940
EQ22	0.09900	0.00267	0.00006	466.33700	16.70454	0.29750
EQ27	1.64000	0.04161	0.00008	4127.31000	104.98200	0.21640

## VI. CONCLUSION

Ground motion accelerograms from the National Research Institute of Astronomy and Geophysics in Cairo, Egypt (NRIA) was utilized to obtain selected accelerograms. The selection criteria for these accelerograms were based on the Egyptian Code for Loads and the site's soil characteristics. To derive the optimal input motion for seismic hazard analysis, spectral matching was conducted using SeismoMatch, following the methodology outlined by Al Atik and Abrahamson (2010). The Uniform Hazard Spectra for the site, corresponding to a 475-year return period earthquake, served as the target spectra. The technique developed by Al Atik and Abrahamson yields an average mismatch of 3.10% and a maximum misfit of around 17.07% across all accelerograms. The PGD, PGV, and PGA values obtained from spectral matching exhibit significant variations from the originals due to the scaling of accelerograms amplitude. The results show that SeismoMatch effectively matches the time history response spectra with the target spectrum, nearly achieving perfect alignment. Additionally, the spectral matching analysis indicates that using SeismoMatch software exhibits superior performance in the spectral matching of selected ground motions.

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## REFERENCES

- [1] Bommer, Julian J., and Ana Beatriz Acevedo. "The Use of Real Earthquake Accelerograms as Input to Dynamic Analysis." *Journal of Earthquake Engineering*, vol. 8, spec01, 2004, pp. 43-91.
- [2] Iervolino, Iunio, and Gaetano Manfredi. "A Review of Ground Motion Record Selection Strategies for Dynamic Structural Analysis." *Modern Testing Techniques for Structural Systems: Dynamics and Control*, 2008, pp. 131-163.
- [3] Silva, Walter J., and Kin Lee. WES RASCAL Code for Synthesizing Earthquake Ground Motions. *Department of the Army, US Army Corps of Engineers*, 1987.
- [4] Naeim, Farzad, and Marshall Lew. "On the Use of Design Spectrum Compatible Time Histories." *Earthquake Spectra*, vol. 11, no. 1, 1995, pp. 111-127.
- [5] Lilhanand, K., and W. S. Tseng. "Generation of Synthetic Time Histories Compatible with Multiple-Damping Design Response Spectra." *Structural Mechanics in Reactor Technology*, 1987.
- [6] Lilhanand, Kiat, and Wen S. Tseng. "Development and Application of Realistic Earthquake Time Histories Compatible with Multiple-Damping Design Spectra." *Proceedings of the 9<sup>th</sup> World Conference on Earthquake Engineering*, vol. 2, 1988.
- [7] Abrahamson, N. A. "Non-Stationary Spectral Matching." *Seismological Research Letters*, vol. 63, no. 1, 1992, p. 30.
- [8] Bray, Jonathan D., and Thaleia Travararou. "Simplified Procedure for Estimating Earthquake-Induced Deviatoric Slope Displacements." *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 133, no. 4, 2007, pp. 381-392.
- [9] Athanasopoulos, Adamantia-Maria George. "Select Topics on the Static and Dynamic Response and Performance of Earthen Levees." *University of California, Berkeley*, 2008.
- [10] Rathje, E. M., A. R. Kottke, and W. L. Trent. "Influence of Input Motion and Site Property Variabilities on Seismic Site Response Analysis." *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 136, no. 4, 2010, pp. 607-619.
- [11] Ergun, M., and S. Ates. "Selecting and Scaling Ground Motion Time Histories According to Eurocode 8 and ASCE 7-05." *Earthquakes and Structures*, vol. 5, no. 2, 2013, pp. 129-142.
- [12] Carlson, C. P., D. Zekkos, and J. P. McCormick. "Impact of Time and Frequency Domain Ground Motion Modification on the Response of a SDOF System." *Earthquakes and Structures*, vol. 7, no. 6, 2014, pp. 1283-1301.
- [13] Wood, R. L., and T. C. Hutchinson. "Effects of Ground Motion Scaling on Nonlinear Higher Mode Building Response." *Earthquake and Structures*, vol. 3, no. 6, 2012, pp. 869-887.
- [14] Pavel, F., and R. Vacareanu. "Spatial Correlation of Ground Motions from Vrancea (Romania) Intermediate-Depth Earthquakes." *Bulletin of the Seismological Society of America*, vol. 107, no. 1, 2017, pp. 489-494.
- [15] Makrup, L. "Generating Design Ground Motion by Probabilistic Seismic Hazard Analysis and Code." *Electronic Journal of Geotechnical Engineering*, vol. 22, 2017, pp. 1567-1586.
- [16] Makrup, L., and Y. Muntafi. "Artificial Ground Motion for the Cities of Semarang and Solo, Indonesia Generated Based on Probabilistic Seismic Hazard Analysis and Spectral Matching." *Electronic Journal of Geotechnical Engineering*, vol. 21, no. 21, 2016, pp. 6587-6602.

- [17] Pawirodikromo, W., L. Makrup, M. Teguh, M. Anggit, and B. Suryo. "Bi-directional and Directivity Effect Identifications of Synthetic Ground Motions at Selected Sites in Yogyakarta City, Indonesia." *International Journal of Civil Engineering Technology*, vol. 10, no. 11, 2019, pp. 149–166.
- [18] Saputra, E., and L. Makrup. "Deagregasi Hazard Dan Rekomendasi Ground Motion Sintetik Di Provinsi Riau." *AGREGAT*, vol. 6, no. 1, 2021.
- [19] Pratiwi, D. A. W. W., L. Makrup, and I. Setiawan. "The Structural Dynamic Evaluation of Wadaslintang Dam to the Earthquake Acceleration Based on Indonesian Seismic Code 2019." *American Journal of Civil Engineering*, vol. 10, no. 3, 2022, pp. 125–134.
- [20] Marzuko, M. A., L. Makrup, and M. R. Abdurrazak. "The Effect of the Soil Response on the Change of the Frequency Characteristic of Earthquake Ground Motions." *American Journal of Civil Engineering*, vol. 10, no. 4, 2022, pp. 145–152.
- [21] Hancock, J., J. Watson-Lamprey, N. A. Abrahamson, J. J. Bommer, A. Markatis, E. M. McCoy, and R. Mendis. "An Improved Method of Matching Response Spectra of Recorded Earthquake Ground Motion Using Wavelets." *Journal of Earthquake Engineering*, vol. 10, no. spec01, 2006, pp. 67–89.
- [22] Al Atik, L., and N. Abrahamson. "An Improved Method for Non-stationary Spectral Matching." *Earthquake Spectra*, vol. 26, no. 3, 2010, pp. 601–617.
- [23] Elkady, A. Z., M. A. Seleemah, and F. Ansari. "Structural Response of a Cable-Stayed Bridge Subjected to Lateral Seismic Excitations." *Journal of Civil Structural Health Monitoring*, vol. 8, 2018, pp. 417–430.
- [24] Alshaer, M. F., A. Elkady, M. Sakr, and A. Seleemah. "Enhancing Seismic Performance of Cable-Stayed Bridges Using Tuned Mass Dampers." *Journal of Engineering Research*, vol. 6, no. 2, 2022, pp. 45–49.
- [25] Seleemah, M. A., M. S. Helam, M. A. Abu-alenein, E. B. Hammad, M. S. Goda, A. A. Seleemah, and A. Z. Elkady. "Response of Aswan Cable-Stayed Bridge to Spatial Non-Synchronous Seismic Excitations." *Journal of Engineering and Applied Science*, vol. 69, no. 1, 2022, pp. 70.
- [26] Elkady, A. Z., A. F. Youssef, I. Abuelnadr, D. DePeder, and A. A. Seleemah. "Optimum Location of Seismic Isolation for Manavgat Cable-Stayed Bridge." *International Journal of Advanced Engineering, Management and Science (IJAEMS)*, vol. 9, no. 11, 2023, pp. 39–58.
- [27] Nooraie, M., and F. Behnamfar. "A New Procedure for Selection and Modification of Ground Motion for Nonlinear Dynamic Analysis." *15th World Conference on Earthquake Engineering*, 2012, p. 10.
- [28] Deb, S. K., and G. T. Kumar. "Seismic Damage Assessment of Reinforced Concrete Buildings Using Fuzzy Logic." *13th World Conference on Earthquake Engineering*, Vancouver, BC, Canada, Aug. 2004.
- [29] Cornell, C. A. "Engineering Seismic Risk Analysis." *Bulletin of the Seismological Society of America*, vol. 58, no. 5, 1968, pp. 1583–1606.
- [30] Bommer, J. J., and R. Mendis. "Scaling of Spectral Displacement Ordinates with Damping Ratios." *Earthquake Engineering & Structural Dynamics*, vol. 34, no. 2, 2005, pp. 145–165.
- [31] Field, E. H. "Probabilistic Seismic Hazard Analysis (PSHA): A Primer." 2005.
- [32] Baker, J. W. "Quantitative Classification of Near-Fault Ground Motions Using Wavelet Analysis." *Bulletin of the Seismological Society of America*, vol. 97, no. 5, 2007, pp. 1486–1501.
- [33] National Research Institute of Astronomy and Geophysics (NRIAG). "Seismic Data and Analysis Reports." 2024, <https://www.nriag.sci.eg/>.
- [34] "SEISOMATCH." *Seismosoft*, 2022, <https://www.seismosoft.com/seisomatch>.
- [35] Ozbulut, Osman E., and Stefan Hurlbaeus. "Optimal design of superelastic-friction base isolators for seismic protection of highway bridges against near-field earthquakes." *Earthquake engineering & structural dynamics* 40,3 (2011): 273-291.
- [36] IBC."International Building Code". *International Code Council: Falls Church, VA*, 2000.
- [37] Malhotra, Praveen K. "Strong-motion records for site-specific analysis." *Earthquake Spectra* 19,3 (2003): 557-578.
- [38] Adekristi, A. "Algorithm for Spectral Matching of Earthquake Ground Motions Using Wavelets and Brodyden Updating." *Doctoral Dissertation, Virginia Tech*, 2013.
- [39] Alexander, N. A., A. A. Chanerley, A. J. Crewe, and S. Bhattacharya. "Obtaining Spectrum Matching Time Series Using a Reweighted Volterra Series Algorithm (RVSA)." *Bulletin of the Seismological Society of America*, vol. 104, no. 4, 2014, pp. 1663–1673.
- [40] Zhang, B., Y. Yu, X. Li, and Y. Wang. "Ground Motion Prediction Equation for the Average Horizontal Component of PGA, PGV, and 5% Damped Acceleration Response Spectra at Periods Ranging from 0.033 to 8.0 s in Southwest China." *Soil Dynamics and Earthquake Engineering*, vol. 159, 2022, p. 107297.