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ORIGINAL ARTICLE

Evaluation of Seismic Hazard Scenarios for Selecting Accelerograms in the Structure's Analysis in the Eastern Region of Cuba

Evaluación de escenarios de amenaza sísmica para la selección de acelerogramas en el análisis de estructuras en la región oriental de Cuba

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Abstract

The southeastern region of Cuba exhibits high seismic hazard due to the interaction of the North American and Caribbean tectonic plates. This study proposes a methodology for defining representative seismic scenarios and selecting accelerograms for Nonlinear Dynamic Analysis (NDA) of structures in Cuba. Three scenarios were developed based on active faults (Oriente Fault, secondary reverse faults, and shallow faults), characterized by magnitude, focal mechanism, and distance. Real accelerograms (local and international) were selected and processed using SeismoSoft software, validating their spectral compatibility with the Uniform Hazard Spectrum (UHS) of the Cuban NC 46:2017 standard. The results demonstrate the representativeness of the records in the key structural period range (0,2–1,12 s), with spectral errors <24,5 %. The proposed methodology overcomes the scarcity of strong ground motion records in Cuba and provides a robust framework for selecting input seismic motions, which is essential for seismic engineering studies and the assessment of realistic structural response in the Cuban context.

Keywords: seismic hazard, seismic scenarios, accelerograms, nonlinear dynamic analysis, Uniform Hazard Spectrum

Resumen

La región suroriental de Cuba presenta una elevada amenaza sísmica debido a la interacción de las placas tectónicas de Norteamérica y del Caribe. Este estudio propone una metodología para la definición de escenarios sísmicos representativos y la selección de acelerogramas destinados al Análisis Dinámico No Lineal (ADNL) de estructuras en Cuba. Se desarrollaron tres escenarios basados en fallas activas (falla Oriente, fallas secundarias inversas y fallas someras), caracterizados por magnitud, mecanismo focal y distancia. Se seleccionaron y procesaron acelerogramas reales (locales e internacionales) mediante el software SeismoSoft, validando su compatibilidad espectral con el Espectro de Peligro Uniforme (EPU) de Santiago de Cuba. Los resultados demuestran la representatividad de los registros en el rango de periodos estructurales clave (0,2–1,12 s), con errores espectrales <24,5 %. La metodología propuesta supera la escasez de registros fuertes en Cuba y proporciona un marco robusto para la selección de movimientos sísmicos de entrada, esencial para estudios de ingeniería sísmica y evaluación de la respuesta estructural realista en el contexto cubano.

Palabras clave: amenaza sísmica, escenarios sísmicos, acelerogramas, análisis dinámico no lineal, Espectro de Peligro Uniforme

1. INTRODUCTION

The seismicity of Cuba is determined by the interaction of the North American and Caribbean tectonic plates, whose boundaries host fault systems capable of generating strong earthquakes. This interaction has also originated secondary tectonic structures towards the interior of the country with lower seismic potential. Thus, the seismicity in the national territory has both an interplate origin (at the boundary south of Oriente) and an intraplate origin (towards the interior), as established by Arango (2014). Interplate seismicity represents the greatest hazard for the southeastern region, due to the greater energy accumulation and the magnitude of the events. The Oriente Fault (Bartlett-Caimán) is the most significant structure in this zone, where the highest seismic activity in the country has historically been recorded, with 23 strong earthquakes reported (Chuy, 1999, updated November, 2024). This activity is confirmed by data from the National Seismological Service (SSN), which between January 2024 and May 2025 recorded 15,548 seismic events, whose distribution is shown in Figure 1. The focal mechanisms of the earthquakes recorded here evidence this complex process. Researchers such as Álvarez *et al*. (2016) and Chuy (1999) agree that the maximum expected magnitude on this fault is 7.5 Mw. Table 1 details the historical earthquakes of highest intensity in the area.

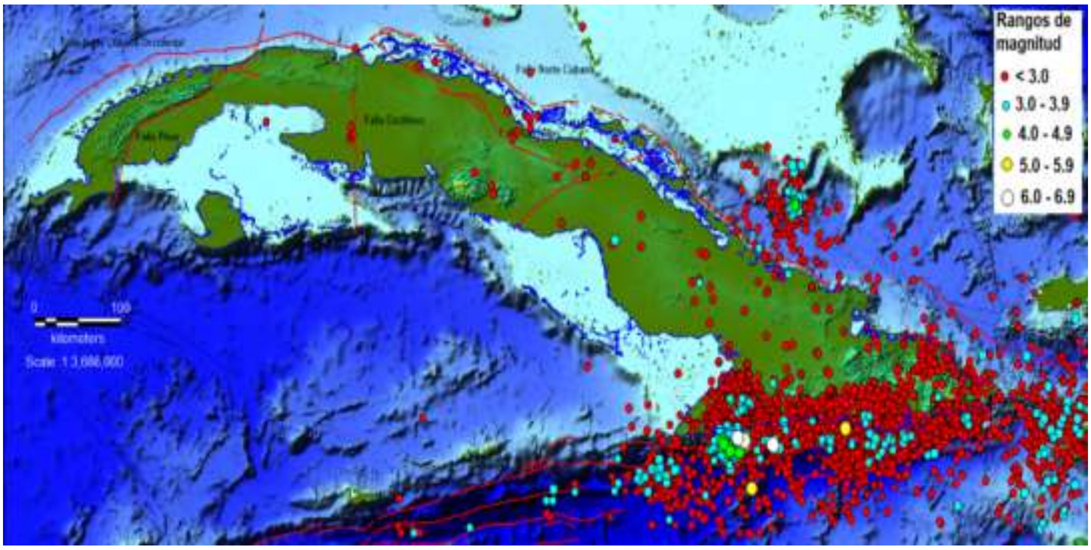

Figure 1. Earthquakes recorded by the SSN from January 2024 to May 2025. Source: SSN, 2025.

Table 1. Historical earthquakes of highest intensity for the study area. Source: Chuy (1999). Updated by CENAIS team (Nov 10/2024)

Year	Month	Day	Time	North Latitude	West Longitude	Ms	H	I	Locality
1766	Jan	12	05:14	(19,80)	(76,10)	(7,6)	(35)	9,0	Santiago de Cuba
1852	Ago	20	14:05	(19,77)	(75,35)	(7,3)	(30)	9,0	Santiago de Cuba
1932	Feb	03	06:15	19,80	75,80	6,75	-	8,0	Santiago de Cuba
2024	Nov	10	11:49	19,77	76,99	6,7	10,0	8,0	Granma

Among the most significant earthquakes are those of 1932 (Ms=6.75; I=VIII) and 1947 (Ms=6.75; I=VII) in Santiago de Cuba, and those of 1976 (Ms=5.7), 1992 (Ms=7.0) and 2024 (Ms=6.7) in Granma province. The city of Santiago de Cuba has endured intensities of up to IX degrees MSK in events of 1766 and 1852. The average recurrence interval for these strong earthquakes is approximately 85 years.

Given that more than 90 years have elapsed since the last strong earthquake of February 3, 1932, this shows the critical need to carry out damage estimation studies in buildings of cities with high seismicity to outline mitigation strategies.

Nonlinear Dynamic Analysis (NDA) currently constitutes a fundamental advanced methodology to evaluate structural behavior under severe earthquakes, whose reliability critically depends on the selection of accelerograms that reliably represent the local seismic hazard, in accordance with international standards such as FEMA P-58 (2018) and ASCE 7-22 (2022).

However, this process is particularly challenging in contexts such as the Cuban one, where the scarcity of strong motion records forces the use of records from other seismic regions. This limitation makes it imperative to adopt a rigorous methodology that allows selecting, adapting, and validating accelerograms, guaranteeing not only their spectral compatibility but also their seismotectonic representativeness, a challenge widely recognized in the specialized literature (Kohrangi *et al*., 2020; Caicedo *et al*., 2023). Consequently, a robust methodological framework is required to overcome these deficiencies and ensure that the inputs used in NDA realistically reflect the seismic hazard conditions of the eastern region of Cuba.

This research has as its main objective to present a comprehensive methodology for the definition of seismic hazard scenarios and the selection of accelerograms for NDA of structures in the eastern region of Cuba. The methodology is based on seismological, geotechnical, and spectral criteria, aligned with international regulations and adapted to the Cuban context.

The results validate the representativeness of the selected accelerograms, providing a solid basis for seismic engineering studies in the country.

2. MATERIALS AND METHODS

2.1. Seismotectonic context and definition of scenarios

The study area is located in the eastern region of Cuba, where the Oriente Fault (transform boundary between the North American and Caribbean plates) represents the most important seismic source (Figure 2). Three hazard scenarios were defined based on active faults (Table 2), considering their seismogenic potential, focal mechanisms, and distance to the city of Santiago de Cuba (Arango, 2014; Cotilla and Córdova, 2010).

Table 2. Seismic hazard scenarios defined for Santiago de Cuba

Scenario	Focal Mechanism	M_w	Dept (km)	Distance (km)	Analogous Records
Oriente Fault	Strike-slip	7,2	10 – 15	20 – 40	Kocaeli (1999), Landers
Secundary Fault	Reverse	6,5	10	< 20	Northridge (1994)

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Shallow Fault	Normal	5,8	5 – 10	10 – 20	Lorca (2011), Cuba 2016

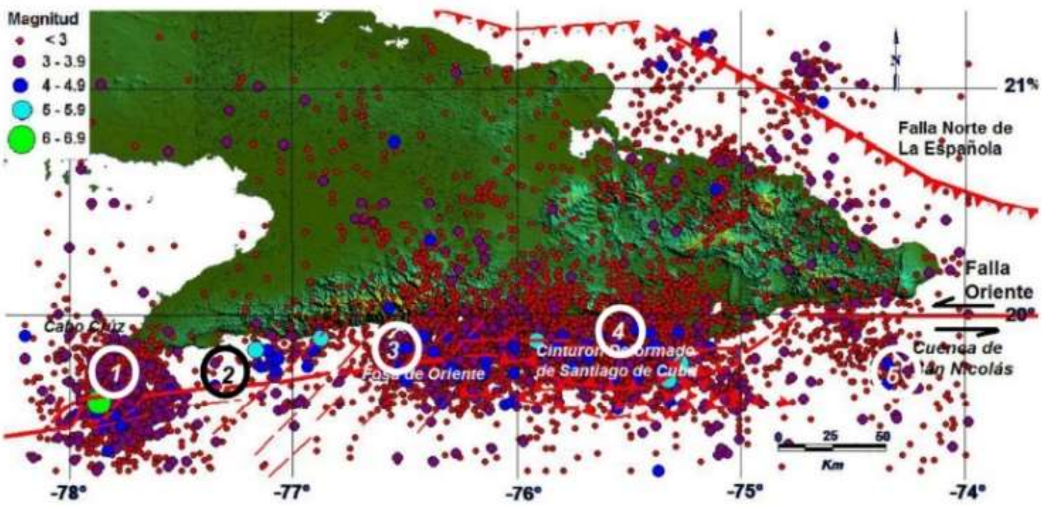

Figure 2. Location of the Oriente Fault. Numbers indicate the main geodynamic elements that characterize the Oriente Fault: 1. Transtension (Cabo Cruz Basin), 2. Pure strike-slip, 3. Extension (Oriente Trough), 4. Transpression (Deformed Belt of Santiago de Cuba). 5. Transtension (San Nicolás Basin). Source: Arango (2014).

2.2. Selection and processing of accelerograms

The selection of accelerograms was governed by strict criteria of spectral compatibility, soil conditions, and seismological parameters (Mw 6.0 – 7.5, distance $\leq$ 50 km). Cuban and international records were used, obtained from consolidated databases (PEER NGA-West2, ESM).

Processing included spectral matching using SeismoMatch software, following internationally validated methodologies (Manfredi *et al.*, 2022; Saracho *et al.*, 2021) and adjusting the records to the Uniform Hazard Spectrum (UHS) of Santiago de Cuba for periods between 0.1 T_1 and 1.5 T_1, with a mean square error $\leq$ 0.30 (Baker, 2011). Key parameters such as PGA, PGV, significant duration (Ds_{5-95}), and Arias intensity were calculated.

2.3. Validation of spectral compatibility

The representativeness of the selected accelerograms was evaluated by comparing the average spectrum of the processed records with the UHS of Santiago de Cuba for the return period of interest. This comparison allowed quantifying the spectral fit in the range of structural periods under analysis by calculating the relative error.

3. RESULTS

3.1. Characterization of accelerograms

The selected accelerograms showed a wide range of intensities (PGA: 0.21–0.84 g; PGV: 33.5–112.4 cm/s) and significant durations (Ds_{5-95}: 14.3–22.5 s), suitable for inducing nonlinear response in structures. The fundamental parameters of the key international records are presented in Table 3, while those of the Cuban earthquakes are detailed in Table 4. The diversity of focal mechanisms (strike-slip and reverse) ensures the representativeness of the seismogenic sources of the region.

Table 3. Parameters of the selected international accelerograms

Earthquake	Mw	Fault type	Mechanism	PGA (g)	PGV (cm/s)	Ds_{5-95} (s)
Kocaeli	7,6	Crustal	Strike-slip	0,42	56,30	22,50
Landers	7,3	Crustal	Strike-slip	0,71	98,70	18,70
El Centro	7,3	Reverse	Reverse	0,35	33,50	14,30
Northridge	6,7	Reverse	Reverse	0,84	112,40	16,90

Table 4. Parameters of the selected Cuban accelerograms

Earthquake	Mw	Focal Mechanism	PGA (g)	PGV (cm/s)	Ds_{5-95} (s)
20/03/2010	5,7	Reverse	0,605	25,74	5,14
17/01/2016	5,1	Reverse	0,217	8,63	3,34
10/11/2024	6,8	Strike-slip	0,420	8,39	14,30

PGA: Peak Ground Acceleration; PGV: Peak Ground Velocity; Ds_{5-95}: Significant duration.

3.2. Spectral compatibility

The response spectrum of the selected records (Figure 3) showed optimal coverage in the key structural period range. The average spectrum of the accelerograms showed a satisfactory fit with the Uniform Hazard Spectrum (UHS) of Santiago de Cuba in the key structural period range (0.2 s – 1.12 s), as evidenced in Figure 4 and quantified in Table 5.

The relative errors at key periods (0.2 s; 0.5 s; 1.12 s) were less than 24.5%, complying with the limits established by the ASCE 7-22 standard (<30 %). Spectral dispersion (standard deviation $\sigma < 0.3$ g) was controlled, ensuring that the records neither underestimate nor overestimate the seismic demand systematically.

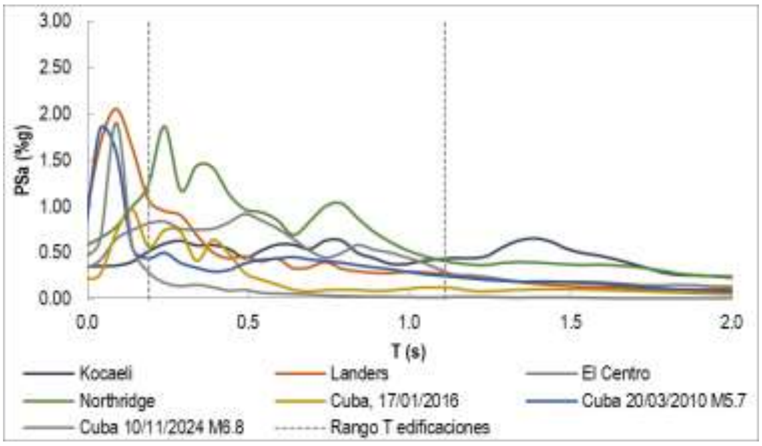

Figure 3. Response spectra of the selected earthquakes. Dashed lines represent the period range of the buildings.

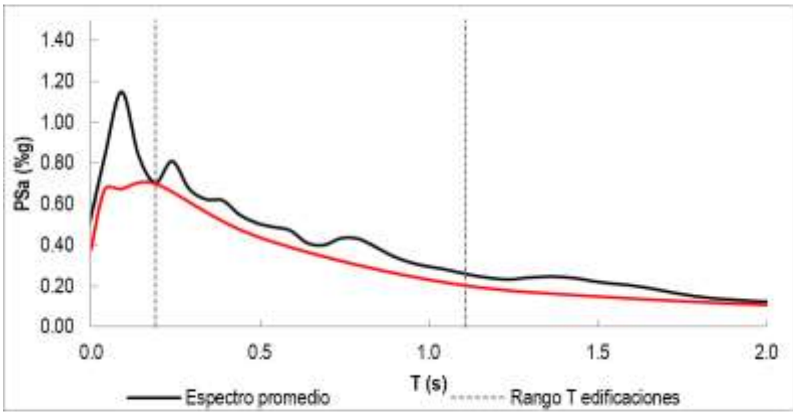

Figure 4. Comparison between the average response spectrum of the selected earthquakes and the uniform hazard spectrum for Santiago de Cuba. Dashed lines represent the period range of the buildings.

Table 5. Spectral comparison between the average of records and the UHS

Period (s)	UHS (g)	Average Spectrum (g)	Relative Error (%)
0,20	0,70	0,68	2,86
0,50	0,44	0,49	11,36
1,12	0,28	0,33	24,50

4. DISCUSSION

The proposed methodology allows overcoming the scarcity of strong seismic records in Cuba by integrating representative local and international records. The selection based on seismotectonically justified scenarios ensures that the accelerograms replicate the essential characteristics of the regional seismic hazard.

The obtained spectral compatibility validates the usefulness of the selected records for NDA, ensuring that the energy and frequency demands in the critical structural period range are representative of the local hazard. The maximum spectral error of 24.5 % is considered acceptable for practical engineering studies, especially in the context of limited data availability.

Limitations of the study include the dependence on scaled international records and the need to expand the Cuban accelerogram database. Future research should incorporate more detailed site effects and validate the methodology with a greater number of recent local records.

5. CONCLUSIONS

- A robust methodology is developed for the definition of seismic hazard scenarios and selection of accelerograms, specific to the context of the eastern region of Cuba, based on seismotectonic and spectral criteria.
- The selected and processed accelerograms show satisfactory spectral compatibility with the Uniform Hazard Spectrum, validating their use for Nonlinear Dynamic Analysis.
- The methodology constitutes an essential tool for the selection of input seismic motions in engineering studies, contributing to a more realistic assessment of structural response in Cuba.

6. ACKNOWLEDGEMENTS

The authors express their most sincere gratitude to Dr.C. Eng. Enrique Diego Arango Arias for his invaluable advice and his fundamental contributions to the knowledge of Cuban seismotectonics, which constituted the scientific basis for the development of this work.

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Additional information

Conflict of interest

The authors declare that there are no conflicts of interest.

Author contributions

KMLC and **GMB**: study conception, data analysis, validation of results, original drafting, revision, correction, and approval of the final version. B**MT**: principal responsible for the definition and justification of seismic scenarios. Revision and approval of the final version of the article.

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ORIGINAL ARTICLE

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Abstract

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Keywords: seismic hazard, seismic scenarios, accelerograms, nonlinear dynamic analysis, Uniform Hazard Spectrum

Resumen

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Palabras clave: amenaza sísmica, escenarios sísmicos, acelerogramas, análisis dinámico no lineal, Espectro de Peligro Uniforme

1. INTRODUCTION

The seismicity of Cuba is determined by the interaction of the North American and Caribbean tectonic plates, whose boundaries host fault systems capable of generating strong earthquakes. This interaction has also originated secondary tectonic structures towards the interior of the country with lower seismic potential. Thus, the seismicity in the national territory has both an interplate origin (at the boundary south of Oriente) and an intraplate origin (towards the interior), as established by Arango (2014). Interplate seismicity represents the greatest hazard for the southeastern region, due to the greater energy accumulation and the magnitude of the events. The Oriente Fault (Bartlett-Caimán) is the most significant structure in this zone, where the highest seismic activity in the country has historically been recorded, with 23 strong earthquakes reported (Chuy, 1999, updated November, 2024). This activity is confirmed by data from the National Seismological Service (SSN), which between January 2024 and May 2025 recorded 15,548 seismic events, whose distribution is shown in Figure 1. The focal mechanisms of the earthquakes recorded here evidence this complex process. Researchers such as Álvarez *et* *al.* (2016) and Chuy (1999) agree that the maximum expected magnitude on this fault is 7.5 Mw. Table 1 details the historical earthquakes of highest intensity in the area.

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Figure 1. Earthquakes recorded by the SSN from January 2024 to May 2025. Source: SSN, 2025.

Table 1. Historical earthquakes of highest intensity for the study area. Source: Chuy (1999). Updated by CENAIS team (Nov 10/2024)

Year	**Month**	**Day**	**Time**	**North Latitude**	**West Longitude**	**Ms**	**H (km)**	**I**	**Locality**
1766	JUN	12	05:14	(19.80)	(76.10)	(7.6)	35	9.0	Santiago de Cuba
1852	AUG	20	14:05	(19.77)	(75.35)	(7.3)	30	9.0	Santiago de Cuba
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2024	NOV	10	11:49	19.77	76.99	6.7	10.0	8.0	Granma

Among the most significant earthquakes are those of 1932 (Ms=6.75; I=VIII) and 1947 (Ms=6.75; I=VII) in Santiago de Cuba, and those of 1976 (Ms=5.7), 1992 (Ms=7.0) and 2024 (Ms=6.7) in Granma province. The city of Santiago de Cuba has endured intensities of up to IX degrees MSK in events of 1766 and 1852. The average recurrence interval for these strong earthquakes is approximately 85 years.

Given that more than 90 years have elapsed since the last strong earthquake of February 3, 1932, this shows the critical need to carry out damage estimation studies in buildings of cities with high seismicity to outline mitigation strategies.

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2. MATERIALS AND METHODS

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Table 2. Seismic hazard scenarios defined for Santiago de Cuba

Scenario	**Focal Mechanism**	**M~w~**	**Depth (km)**	**Distance (km)**	**Analogous Records**
Oriente Fault	Strike-slip	7.2	10 – 15	20 – 40	Kocaeli (1999), Landers (1992)
Secondary Fault	Reverse	6.5	10	< 20	Northridge (1994)
Shallow Faults	Normal	5.8	5 – 10	10 – 20	Lorca (2011), Cuba 2016

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Figure 2. Location of the Oriente Fault. Numbers indicate the main geodynamic elements that characterize the Oriente Fault: 1. Transtension (Cabo Cruz Basin), 2. Pure strike-slip, 3. Extension (Oriente Trough), 4. Transpression (Deformed Belt of Santiago de Cuba). 5. Transtension (San Nicolás Basin). Source: Arango (2014).

8. SELECTION AND PROCESSING OF ACCELEROGRAMS

The selection of accelerograms was governed by strict criteria of spectral compatibility, soil conditions, and seismological parameters (Mw 6.0–7.5, distance ≤ 50 km). Cuban and international records were used, obtained from consolidated databases (PEER NGA-West2, ESM).

Processing included spectral matching using SeismoMatch software, following internationally validated methodologies (Manfredi *et al.,* 2022; Saracho *et al.*, 2021) and adjusting the records to the Uniform Hazard Spectrum (UHS) of Santiago de Cuba for periods between 0.1 T_1 and 1.5 T_1, with a mean square error ≤ 0.30 (Baker, 2011). Key parameters such as PGA, PGV, significant duration (Ds_{5-95}), and Arias intensity were calculated.

3. **Validation of spectral compatibility**

The representativeness of the selected accelerograms was evaluated by comparing the average spectrum of the processed records with the UHS of Santiago de Cuba for the return period of interest. This comparison allowed quantifying the spectral fit in the range of structural periods under analysis by calculating the relative error.

3. RESULTS

    1. Characterization of accelerograms

The selected accelerograms showed a wide range of intensities (PGA: 0.21–0.84 g; PGV: 33.5–112.4 cm/s) and significant durations (Ds_{5-95}: 14.3–22.5 s), suitable for inducing nonlinear response in structures. The fundamental parameters of the key international records are presented in Table 3, while those of the Cuban earthquakes are detailed in Table 4. The diversity of focal mechanisms (strike-slip and reverse) ensures the representativeness of the seismogenic sources of the region.

Table 3. Parameters of the selected international accelerograms

Earthquake	**Mw**	**Fault Type**	**Mechanism**	**PGA (g)**	**PGV (cm/s)**	**Ds_{5-95} (s)**
Kocaeli	7.6	Crustal	Strike-slip	0.42	56.30	22.50
Landers	7.3	Crustal	Strike-slip	0.71	98.70	18.70
El Centro	7.3	Reverse	Reverse	0.35	33.50	14.30
Northridge	6.7	Reverse	Reverse	0.84	112.40	16.90

Table 4. Parameters of the selected Cuban accelerograms

Earthquake	**Mw**	**Focal Mechanism**	**PGA (g)**	**PGV (cm/s)**	**Ds_{5-95} (s)**
03/20/2010	5.7	Reverse	0.605	25.74	5.14
01/17/2016	5.1	Reverse	0.217	8.63	3.34
11/10/2024	6.8	Strike-slip	0.420	8.39	14.30

PGA: Peak Ground Acceleration; PGV: Peak Ground Velocity; Ds_{5-95}: Significant duration.

2. **Spectral compatibility**

The response spectrum of the selected records (Figure 3) showed optimal coverage in the key structural period range. The average spectrum of the accelerograms showed a satisfactory fit with the Uniform Hazard Spectrum (UHS) of Santiago de Cuba in the key structural period range (0.2 s – 1.12 s), as evidenced in Figure 4 and quantified in Table 5.

The relative errors at key periods (0.2 s; 0.5 s; 1.12 s) were less than 24.5 %, complying with the limits established by the ASCE 7-22 standard (<30 %). Spectral dispersion (standard deviation σ < 0.3 g) was controlled, ensuring that the records neither underestimate nor overestimate the seismic demand systematically.

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Figure 3. Response spectra of the selected earthquakes. Dashed lines represent the period range of the buildings.

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Figure 4. Comparison between the average response spectrum of the selected earthquakes and the uniform hazard spectrum for Santiago de Cuba. Dashed lines represent the period range of the buildings.

Table 5. Spectral comparison between the average of records and the UHS

Period (s)	**UHS (g)**	**Average Spectrum (g)**	**Relative Error (%)**
0.20	0.70	0.68	2.86
0.50	0.44	0.49	11.36
1.12	0.28	0.33	24.50

4. DISCUSSION

The proposed methodology allows overcoming the scarcity of strong seismic records in Cuba by integrating representative local and international records. The selection based on seismotectonically justified scenarios ensures that the accelerograms replicate the essential characteristics of the regional seismic hazard.

The obtained spectral compatibility validates the usefulness of the selected records for NDA, ensuring that the energy and frequency demands in the critical structural period range are representative of the local hazard. The maximum spectral error of 24.5 % is considered acceptable for practical engineering studies, especially in the context of limited data availability.

Limitations of the study include the dependence on scaled international records and the need to expand the Cuban accelerogram database. Future research should incorporate more detailed site effects and validate the methodology with a greater number of recent local records.

5. CONCLUSIONS

- A robust methodology is developed for the definition of seismic hazard scenarios and selection of accelerograms, specific to the context of the eastern region of Cuba, based on seismotectonic and spectral criteria.
- The selected and processed accelerograms show satisfactory spectral compatibility with the Uniform Hazard Spectrum, validating their use for Nonlinear Dynamic Analysis.
- The methodology constitutes an essential tool for the selection of input seismic motions in engineering studies, contributing to a more realistic assessment of structural response in Cuba.

6. ACKNOWLEDGEMENTS

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Evaluation of seismic hazard scenarios for the selection of accelerograms in the analysis of structures in the eastern region of Cuba

ORIGINAL ARTICLE

Evaluation of seismic hazard scenarios for selecting accelerograms in the structural analysis of structures in the eastern region of Cuba

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Abstract

The southeastern region of Cuba presents high seismic hazard due to the interaction of the North American and Caribbean tectonic plates. This study proposes a methodology for the definition of representative seismic scenarios and the selection of accelerograms intended for Nonlinear Dynamic Analysis (NDA) of structures in Cuba. Three scenarios were developed based on active faults (Oriente Fault, secondary reverse faults, and shallow faults), characterized by magnitude, focal mechanism, and distance. Real accelerograms (local and international) were selected and processed using SeismoSoft software, validating their spectral compatibility with the Uniform Hazard Spectrum (UHS) of Santiago de Cuba. The results demonstrate the representativeness of the records in the key structural period range (0.2--1.12 s), with spectral errors <24.5%. The proposed methodology overcomes the scarcity of strong motion records in Cuba and provides a robust framework for the selection of input seismic motions, essential for seismic engineering studies and the assessment of realistic structural response in the Cuban context.

Keywords: seismic hazard, seismic scenarios, accelerograms, nonlinear dynamic analysis, Uniform Hazard Spectrum

Resumen

La región suroriental de Cuba presenta una elevada amenaza sísmica debido a la interacción de las placas tectónicas de Norteamérica y del Caribe. Este estudio propone una metodología para la definición de escenarios sísmicos representativos y la selección de acelerogramas destinados al Análisis Dinámico No Lineal (ADNL) de estructuras en Cuba. Se desarrollaron tres escenarios basados en fallas activas (falla Oriente, fallas secundarias inversas y fallas someras), caracterizados por magnitud, mecanismo focal y distancia. Se seleccionaron y procesaron acelerogramas reales (locales e internacionales) mediante el software SeismoSoft, validando su compatibilidad espectral con el Espectro de Peligro Uniforme (EPU) de Santiago de Cuba. Los resultados demuestran la representatividad de los registros en el rango de periodos estructurales clave (0,2--1,12 s), con errores espectrales <24,5 %. La metodología propuesta supera la escasez de registros fuertes en Cuba y proporciona un marco robusto para la selección de movimientos sísmicos de entrada, esencial para estudios de ingeniería sísmica y evaluación de la respuesta estructural realista en el contexto cubano.

Palabras clave: amenaza sísmica, escenarios sísmicos, acelerogramas, análisis dinámico no lineal, Espectro de Peligro Uniforme

1. INTRODUCTION

The seismicity of Cuba is determined by the interaction of the North American and Caribbean tectonic plates, whose boundaries host fault systems capable of generating strong earthquakes. This interaction has also originated secondary tectonic structures towards the interior of the country with lower seismic potential. Thus, the seismicity in the national territory has both an interplate origin (at the boundary south of Oriente) and an intraplate origin (towards the interior), as established by Arango (2014). Interplate seismicity represents the greatest hazard for the southeastern region, due to the greater energy accumulation and the magnitude of the events. The Oriente Fault (Bartlett-Caimán) is the most significant structure in this zone, where the highest seismic activity in the country has historically been recorded, with 23 strong earthquakes reported (Chuy, 1999, updated November 2024). This activity is confirmed by data from the National Seismological Service (SSN), which between January 2024 and May 2025 recorded 15,548 seismic events, whose distribution is shown in Figure 1. The focal mechanisms of the earthquakes recorded here evidence this complex process. Researchers such as Álvarez *et al.* (2016) and Chuy (1999) agree that the maximum expected magnitude on this fault is 7.5 Mw. Table 1 details the historical earthquakes of highest intensity in the area.

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Figure 1. Earthquakes recorded by the SSN from January 2024 to May 2025. Source: SSN, 2025.

Table 1. Historical earthquakes of highest intensity for the study area. Source: Chuy (1999). Updated by CENAIS team (Nov 10, 2024)

Y	M	D	Ti	North Latitude	West Longitude	M	H	(km)	I	Loc
1	JU	1	0	(19.80)	(76.10)	(	35		9	Santi
1	AU	2	1	(19.77)	(75.35)	(	30		9	Santi

Y	M	D	Ti	North Latitude	West Longitude	M	H (km)	I	Loc
1	FE	0	0	19.80	75.80	6.	-	8	Santi
2	N	1	1	19.77	76.99	6.	10.0	8	Gran

Among the most significant earthquakes are those of 1932 (Ms=6.75; I=VIII) and 1947 (Ms=6.75; I=VII) in Santiago de Cuba, and those of 1976 (Ms=5.7), 1992 (Ms=7.0) and 2024 (Ms=6.7) in Granma province. The city of Santiago de Cuba has endured intensities of up to IX degrees

MSK in events of 1766 and 1852. The average recurrence interval for these strong earthquakes is approximately 85 years.

Given that more than 90 years have elapsed since the last strong earthquake of February 3, 1932, this shows the critical need to carry out damage estimation studies in buildings of cities with high seismicity to outline mitigation strategies.

Nonlinear Dynamic Analysis (NDA) currently constitutes a fundamental advanced methodology to evaluate structural behavior under severe earthquakes, whose reliability critically depends on the selection of accelerograms that reliably represent the local seismic hazard, in accordance with international standards such as FEMA P-58 (2018) and ASCE 7-22 (2022).

However, this process is particularly challenging in contexts such as the Cuban one, where the scarcity of strong motion records forces the use of records from other seismic regions. This limitation makes it imperative to adopt a rigorous methodology that allows selecting, adapting, and validating accelerograms, guaranteeing not only their spectral compatibility but also their seismotectonic representativeness, a challenge widely recognized in the specialized literature (Kohrangi *et al*., 2020; Caicedo *et al*., 2023). Consequently, a robust methodological framework is required to overcome these deficiencies and ensure that the inputs used in NDA realistically reflect the seismic hazard conditions of the eastern region of Cuba.

This research has as its main objective to present a comprehensive methodology for the definition of seismic hazard scenarios and the selection of accelerograms for NDA of structures in the eastern region of Cuba. The methodology is based on seismological, geotechnical, and spectral criteria, aligned with international regulations and adapted to the Cuban context.

The results validate the representativeness of the selected accelerograms, providing a solid basis for seismic engineering studies in the country.

2. MATERIALS AND METHODS

2.1. Seismotectonic context and definition of scenarios

The study area is located in the eastern region of Cuba, where the Oriente Fault (transform boundary between the North American and Caribbean plates) represents the most important seismic source (Figure 2). Three hazard scenarios were defined based on active faults (Table 2), considering their seismogenic potential, focal mechanisms, and distance to the city of Santiago de Cuba (Arango, 2014; Cotilla and Córdova, 2010).

Table 2. Seismic hazard scenarios defined for Santiago de Cuba

Scenario	**Focal Mechanism**	**Mw**	**Depth (km)**	**Distance (km)**	**Analogous Records**
Oriente Fault	Strike-slip	7.2	10 -- 15	20 -- 40	Kocaeli (1999), Landers (1992)

Scenario	**Focal Mechanism**	**M~**	**Depth (km)**	**Distance (km)**	**Analogous Records**
Secondary Fault	Reverse	6.5	10	< 20	Northridge (1994)
Shallow Faults	Normal	5.8	5 -- 10	10 -- 20	Lorca (2011), Cuba 2016

https://media/image2.tif{width="5.673942475940508in" height="2.6857141294838147in"}

Figure 2. Location of the Oriente Fault. Numbers indicate the main geodynamic elements that characterize the Oriente Fault: 1. Transtension (Cabo Cruz Basin), 2. Pure strike-slip, 3. Extension (Oriente Trough), 4. Transpression (Deformed Belt of Santiago de Cuba), 5. Transtension (San Nicolás Basin). Source: Arango (2014).

2.2. Selection and processing of accelerograms

The selection of accelerograms was governed by strict criteria of spectral compatibility, soil conditions, and seismological parameters (Mw 6.0--7.5, distance ≤ 50 km). Cuban and international records were used, obtained from consolidated databases (PEER NGA-West2, ESM).

Processing included spectral matching using SeismoMatch software, following internationally validated methodologies (Manfredi *et al*., 2022; Saracho *et al*., 2021) and adjusting the records to the Uniform Hazard Spectrum (UHS) of Santiago de Cuba for periods between 0.1 T_1 and 1.5 T_1, with a mean square error ≤ 0.30 (Baker, 2011). Key parameters such as PGA, PGV, significant duration (Ds_{5-95}), and Arias intensity were calculated.

2.3. Validation of spectral compatibility

The representativeness of the selected accelerograms was evaluated by comparing the average spectrum of the processed records with the UHS of Santiago de Cuba for the return period of interest. This comparison allowed quantifying the spectral fit in the range of structural periods under analysis by calculating the relative error.

3. RESULTS

3.1. Characterization of accelerograms

The selected accelerograms showed a wide range of intensities (PGA: 0.21--0.84 g; PGV: 33.5--112.4 cm/s) and significant durations (Ds_{5-95}: 14.3--22.5 s), suitable for inducing nonlinear response in structures. The fundamental parameters of the key international records are presented in Table 3, while those of the Cuban earthquakes are detailed in Table 4. The diversity of focal mechanisms (strike-slip and reverse) ensures the representativeness of the seismogenic sources of the region.

Table 3. Parameters of the selected international accelerograms

Earthquake	**M**	**Fault Type**	**Mechanism**	**PGA (g)**	**PGV (cm/s)**	**Ds_{5-95} (s)**
Kocaeli	7.	Crustal	Strike-slip	0.42	56.30	22.50
Landers	7.	Crustal	Strike-slip	0.71	98.70	18.70
El Centro	7.	Reverse	Reverse	0.35	33.50	14.30
Northridge	6.	Reverse	Reverse	0.84	112.40	16.90

Table 4. Parameters of the selected Cuban accelerograms

Earthquake	**M**	**Focal Mechanism**	**PGA (g)**	**PGV (cm/s)**	**Ds_{5_95} (s)**
03/20/2010	5.	Reverse	0.605	25.74	5.14
01/17/2016	5.	Reverse	0.217	8.63	3.34
11/10/2024	6.	Strike-slip	0.420	8.39	14.30

PGA: Peak Ground Acceleration; PGV: Peak Ground Velocity; Ds_{5_95}: Significant duration.

3.2. Spectral compatibility

The response spectrum of the selected records (Figure 3) showed optimal coverage in the key structural period range. The average spectrum of the accelerograms showed a satisfactory fit with the Uniform Hazard Spectrum (UHS) of Santiago de Cuba in the key structural period range (0.2 s -- 1.12 s), as evidenced in Figure 4 and quantified in Table 5.

The relative errors at key periods (0.2 s; 0.5 s; 1.12 s) were less than 24.5%, complying with the limits established by the ASCE 7-22 standard (<30%). Spectral dispersion (standard deviation σ < 0.3 g) was controlled, ensuring that the records neither underestimate nor overestimate the seismic demand systematically.

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Period (s)	**UHS (g)**	**Average Spectrum (g)**	**Relative Error (%)**
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