23.11.2025

Response to Reviewer Comments

Manuscript ID: EGUsphere-2024-3488

Title: Critical Evaluation of Strong Ground Motions in Izmir and Implications for Future Earthquake Simulation Results

Dear Editor and Reviewers,

We sincerely thank the Editor and both Reviewers for their thorough evaluation of our manuscript and for the constructive comments that greatly contributed to improving the quality, clarity, and scientific rigor of the study. We carefully reviewed each comment and revised the manuscript accordingly. Major methodological explanations have been expanded, figures and tables have been upgraded for resolution and readability, and several sections—particularly Sections 3 and 4—have been completely rewritten to ensure transparency, reproducibility, and coherence of the analytical framework.

Reviewer comments are shown in blue, while our responses are shown in black. All corresponding changes have been incorporated into the revised manuscript, with clear improvements in methodological description, figure consistency, and overall narrative flow. In the revised manuscript, all changes made in response to reviewer comments are highlighted in yellow for ease of reference.

We are grateful for the reviewers' insightful contributions and believe that the revised manuscript is now significantly strengthened as a result.

Respectfully,

Assist. Prof. Dr. Şahin Çağlar Tuna

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This manuscript tries to evaluate ground motion characteristics and potential ground motions by future earthquake in Izmir city, Turkey. As Turkey is prone to large earthquakes, these evaluations are considered very important. Overall procedure seems probably reasonable, but as is already pointed out by Referee 1 the manuscript needs more explanation/indication and improvement of figure quality. The comments from Referee 1 are right on point, and particularly, I strongly agree with comments 1, 2, 4, 7, 10, 12, 13, 14, 20, 25, 27, 31. In addition, I would like to indicate four major comments. Therefore, I judge this manuscript major revision.

Author Response: We sincerely thank the reviewer for this valuable overall assessment. In line with the reviewer's observations, we conducted a comprehensive revision of the manuscript focusing on both scientific clarity and presentation quality. All comments highlighted by the reviewer—including those specifically emphasized (1, 2, 4, 7, 10, 12, 13, 14, 20, 25, 27, 31)—as well as the full set of comments from Reviewer 1 have been addressed in detail. Substantial improvements were made to strengthen methodological explanations, clarify assumptions, and enhance the consistency of the narrative. In addition, all figures and tables were revised for higher resolution, improved readability, and clearer scientific interpretation. These modifications significantly improve the manuscript's structure, transparency, and technical rigor. We appreciate the reviewer's guidance and believe the revised version satisfactorily resolves the concerns raised.

Major comments:

1. In Section 2, the author seeks for the most appropriate GMPEs for Izmir dataset considering PGA data. However, in Section 4, response spectra are evaluated using the selected GMPEs. Why don't the author evaluate the appropriateness of GMPEs using response spectra? It is necessary to show the validity of use of PGA for the evaluation of GMPEs.

Author Response: Thank you for the comment. We agree that the connection between the PGA-based GMPE evaluation in Section 2 and the spectral analyses in Section 4 must be clearly explained.

Our use of PGA as the primary IM for evaluating GMPE performance follows standard practice in GMPE selection literature, where PGA (or very-short-period Sa) is commonly employed as the first-order discriminator for identifying suitable ground-motion models.

This approach is consistently adopted in NGA-West1/2, Kalkan & Gülkan (2004), Boore et al. (2014), Campbell & Bozorgnia (2014), Karaca et al. (2021), and Huang et al. (2023). The underlying reasons are well established:

- PGA exhibits the lowest model-to-model epistemic variability, providing a stable basis for ranking GMPEs.
- PGA is a directly recorded quantity, whereas spectral ordinates require additional processing steps (baseline correction, filtering, SDOF transformation).
- Short-period spectral accelerations ($T \leq 0.2$ s) are strongly correlated with PGA, a relationship explicitly embedded in many GMPE functional forms.
- GMPEs are best constrained and show the lowest aleatory variability at short periods, while long-period Sa(T) inherently displays much larger dispersion.

Therefore, the use of PGA provides a statistically robust, noise-insensitive, and internationally recognized basis for GMPE screening. Our methodological approach follows this established practice.

Recent studies that adopt a similar two-stage workflow (PGA-based GMPE screening followed by physics-based spectral construction) generally do not perform a full Sa(T)–GMPE residual analysis before defining scenario spectra. Instead, GMPEs are commonly used to establish the median short-period level on rock, while the longer-period spectral shape is adjusted using additional physical considerations such as directivity, basin response, and site-specific amplification. Examples include Huang et al. (2023), Wang et al. (2022), Karaca et al. (2021), and Cetin & Çakır (2023). Although these studies differ in details, their general methodological structure aligns with the approach adopted here.

In Section 4, the selected GMPEs (CB14 and BSSA14) are not used as full spectral predictors. They serve only to:

- define the rock-level hazard (PGA and very-short-period Sa) for the Mw 6.5 deterministic scenario, and
- anchor the short-period portion of the target spectrum.

The long-period portion of the spectrum (1–2 s) is then modified using near-fault directivity and basin-amplification effects, constrained by empirical observations from the 2020 Samos earthquake (Somerville et al., 1997; Shahi & Baker, 2011; Cetin et al., 2022; Cetin et al., 2023).

Thus, Sa(T) in Section 4 is not a GMPE output but a GMPE-anchored, physics-based spectrum that reflects validated site-response behavior.

Finally, Figure 10 provides a meaningful spectral-level consistency check:

- CB14 and BSSA14 median trends align well with the target spectrum at short periods (where GMPEs are most reliable),
- while deviations at longer periods reflect intended physical modifications, not a GMPE inconsistency.

These modifications result from near-fault directivity, basin amplification, and nonlinear SRA behavior validated in Section 3. Therefore, the PGA-based GMPE selection in Section 2 is methodologically consistent with, and fully supportive of, the spectral analyses performed in Section 4.

2. It is difficult to understand how the author actually evaluates the amplification of three stations in Izmir in Section 3, because the description on the method lacks details, the resolution of figures is very low, and the figures do not have appropriate legends and/or captions. As far as I guess from the manuscript, the author obtains the SRA results by inputting ground motion recorded at 3514 site to underground structure model shown in Table 4 and Figure 5. However, underground structure models of 3513, 3522, and 3519 sites shown in Table 4 and Figure 5 do not reach bedrock,

and therefore, I am wondering at which depth the bedrock ground motion is input, which very much affects site amplification.

Author Response: Thank you for the comment. We agree that the original text in Section 3 did not provide sufficient detail regarding how the input rock motion was applied and how the soil columns were defined down to the engineering bedrock. These clarifications have now been fully incorporated into the revised manuscript.

Although Table 4 and Figure 6 present only the upper portions of the soil profiles for readability, each 1D site-response model was constructed using the **f**ull geotechnical and geophysical logs available for the three stations. In DeepSoil, the soil columns were extended down to the engineering bedrock**,** defined as the depth where Vs ≈ 760 m/s, consistent with standard SRA practice. The resulting total model depths are:

- **Station 3513:** ~120 m
- **Station 3519:** ~250 m
- **Station 3522:** ~90 m

The 3514 rock-outcrop motion, which corresponds to the only rock site in the study area (Vs_{30} = 836 m/s), was applied as the within-motion (rock-outcrop boundary) at these bedrock depths in all simulations. This is now explicitly stated in the revised Section 3 to eliminate ambiguity.

To address the reviewer's concern about figure clarity, all figures related to the SRA validation (previous Figures 7–9) have been regenerated at high resolution, legends and axes have been standardized, and captions have been expanded to clearly explain the comparison between recorded and simulated spectra. The previous Figure 5 has been reorganized and updated as the new Figure 6 to more clearly show the subsurface profiles and station layout.

3. The detailed analytic procedure of Section 4 is also vague. Similar to Section 3, the manuscript just names software for analysis and lacks detailed methodology.

Author Response: Thank you for the comment. In response, Section 4 has been completely rewritten, expanded, and reorganized to present a transparent, step-by-step, and fully reproducible procedure. The major improvements are summarized below:

1. Full methodological rewrite of Section 4: The entire section was rewritten to clearly describe how the deterministic scenario, target spectrum, ground-motion selection, spectral matching, and nonlinear response analyses were conducted. All conceptual gaps in the original version have been removed.

2. Clarified justification for the Mw 6.5 scenario: We added a scientific explanation showing that the RADIUS (1997) scenario is consistent with modern tectonic models (EFSM20, ESHM20), confirming that Mw 6.5–6.7 remains a realistic magnitude capability for the İzmir Fault.

3. Rupture directivity and long-period amplification integrated analytically: The revised text now explains:

- the physical mechanism of directivity,
- why it affects 1–2 s periods,
- and how it was identified in the 2020 Samos recordings (1.6–2.1× amplification at Station 3519).

These effects are now explicitly incorporated into target spectrum construction.

4. Step-by-step description of target spectrum development: The manuscript now clearly describes that:

- short-period amplitudes are anchored using CB14 and BSSA14,
- long-period ordinates are shaped using directivity, basin effects, and validated nonlinear site-response results (Section 3),
- the final spectrum envelopes both GMPEs and TEC-2018.

This workflow is now presented as a reproducible analytical process, not just a conceptual description.

5. Ground-motion selection and spectral matching fully detailed: The previous brief reference to SeismoMatch has been replaced with:

- justification of the 0.1–2.0 s matching range,
- Eurocode 8 and PEER-GMSM compatibility requirements,
- explanation of how mean $\pm 1\sigma$ and exceedance rates were evaluated,
- a clear description of how 11 NGA-West2 motions were selected.

6. Explicit link to validated SRA models from Section 3: We clarified that the scenario analyses used the same calibrated DeepSoil models validated with the Samos earthquake.
Additional explanations were added regarding:

- median surface spectra,
- $\pm 1\sigma$ dispersion,
- frequency-dependent amplification at each site.

7. Comprehensive reinterpretation of TEC-based amplification factors: The revised section now provides a clear engineering comparison between:

- simulation-based Site Amplification Ratios (SAR), and
- TEC-2018 factors (F_1 and FS),
  highlighting long-period underestimation and structural implications.

8. Figures fully replaced and upgraded: All figures related to Section 4 (Figures 10–14) were regenerated with:

- high resolution,
- proper legends,

- improved axes,
- detailed captions.

9. Reorganized structure for clarity (Sections 4.1, 4.2, 4.3): The analytical workflow is now clearly separated into:

- target spectrum formulation,
- ground-motion selection and matching,
- nonlinear response results and engineering implications.

These revisions directly resolve the reviewer's concern. Section 4 now presents a complete, rigorous, and reproducible analytical methodology, matching the level of detail expected in performance-based seismic hazard and site-response studies.

4. Appropriate indication and acknowledgements to data resources need to be added. Particularly, data listed in Table 5 includes data from several observation networks or institutes. Acknowledgements to continuous efforts to obtain data support such networks and institutes.

Author Response: Thank you for the comment. We fully agree, and the revised manuscript now includes explicit and detailed attribution to all data sources.

This study utilized two primary datasets:

1. AFAD (Disaster and Emergency Management Authority of Türkiye) – provider of all 2020 Samos Earthquake recordings and the station data used in the site-response validation analyses in Section 3.
2. PEER NGA-West2 Ground Motion Database – provider of the 11 real ground-motion records listed in Table 5, which were used for spectral matching and deterministic scenario analyses in Section 4.

To ensure full transparency and proper credit, we have incorporated the following revisions:

In Section 3, the description of the site-response validation has been rewritten to reflect the updated formulation, where we now state that the 3514 rock-outcrop motion used in the SRA validation was obtained from the AFAD strong-motion network, and that the 2020 Samos Earthquake recordings from AFAD formed the basis of the calibration of the site-response models. This updated text provides clearer context on how and where the reference motion was obtained, fully replacing the earlier brief wording.

In Section 4.1, we specify that all ground-motion records used for spectral matching and scenario simulations were obtained from the PEER NGA-West2 Ground Motion Database.

Finally, the Acknowledgements section has been revised to include the following explicit acknowledgement: "The authors gratefully acknowledge AFAD for providing the strong-motion recordings of the 2020 Samos Earthquake, and the Pacific Earthquake Engineering Research Center (PEER) for maintaining and providing access to the NGA-West2 ground-motion database.

The continuous efforts of these observation networks and contributing institutions are sincerely appreciated."

These revisions ensure that all data providers are appropriately credited and that the updated Section 3 text remains fully consistent with the reviewer response.

Minor comments: - Table 2: Style of fonts needs to be consistent in the table.

Author Response: Thank you for the comment. The table has now been fully revised to ensure consistent font style, size, and formatting throughout.

- p.8, line 166: "The city covers large areas of alluvial soil condition" seems grammatically incorrect. "The city is covered with large areas of alluvial soil condition" may be better.

Author Response: Thank you for the comment. The original sentence has been fully revised for clarity and grammatical correctness. The entire paragraph describing the 2020 Samos Earthquake and the selection of validation sites has been rewritten. The revised text no longer contains the incorrect sentence and now reads (lines 229-234):

"The earthquake occurred on October 30, 2020, with a moment magnitude of Mw = 6.9 and an epicenter located approximately 14 km northeast of the Greek island of Samos, within the Aegean Sea. Despite the offshore origin, the event caused significant structural damage in İzmir, largely attributed to shallow rupture depth and site amplification effects. Numerous strong motion stations across İzmir captured the event (Figure 5), including sites situated on soft alluvial soils and others on rock outcrops, enabling a comparative evaluation of site effects (Kwok et al., 2007; Kramer, 1996)."

- p.9, line 174: "data's" seems grammatically incorrect. "data" may be better.

Author Response: Thank you for the comment. The sentence has been fully revised, and the incorrect phrase "PGA data's" has been removed. The entire methodological description in this section has been rewritten for clarity and scientific accuracy. The revised text now reads (lines 235-245):

"The 1D SRA simulations were conducted by propagating the 3514 rock-outcrop motion—obtained from the AFAD strong-motion network—through the calibrated soil columns at the selected sites. Station 3514, characterized by a Vs_{30} value of 836 m/s, is the only rock site in the study area and therefore provides an appropriate outcrop reference motion for validation purposes.

Four representative locations were selected to capture the geotechnical and geological variability across İzmir:

- Karşıyaka (3519) – basin edge, thick alluvial deposits
- Bayraklı (3513) – deep soft soils with high amplification potential
- Bornova (3522) – moderately deep alluvial layers
- Konak (central district) – urban area with transitional soil conditions

These stations collectively reflect the diversity of soil conditions and shaking characteristics across İzmir, enabling the development of a calibrated and reliable SRA model for subsequent scenario-based simulations."

- Figure 6: It is better to set the same size for top and bottom panels.

Author Response: Thank you for the comment. In the revised manuscript, the original multi-panel Figure 6—showing generic modulus-reduction and damping-ratio curves—has been removed. These curves represent well-established literature models (Seed & Idriss, 1970; Vucetic & Dobry, 1991), and including them was not essential to the presentation of the study's results.

The methodology now cites these references directly in the text:

"Modulus reduction (G/G_{max}) and damping ratio (D) curves were assigned based on soil classification. The Seed and Idriss (1970) model was used for cohesionless soils, while the Vucetic and Dobry (1991) curves were adopted for cohesive soils."

- Table 5: Style of the table needs improvements (distorted aspect ratio of fonts, inconsistent for centering or right-aligning, etc).

Author Response: Thank you for the comment. Table 5 has been completely reformatted in the revised manuscript. All fonts have been standardized, column alignment has been corrected (text centered, numerical fields right-aligned), and row spacing has been normalized. The updated version is now included as Table 6 in the revised manuscript.