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Machine Learning-Based Ground Motion Modeling for Seismic Scenarios in Stable Continental Regions: Lisbon's Case

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Earthquakes remain among the most destructive natural hazards worldwide, affecting over 100 million people in 2020 alone. Lisbon, Portugal, situated in a Stable Continental Region (SCR) and historically devastated by the 1755 earthquake, has made advances in seismic microzonation and structural modeling suited for building design. However, these models may be less effective for guiding emergency response and real-time decision-making following a seismic event.

This study presents the development of a machine learning-based (ML) seismic hazard model tailored to SCRs. Although Ground Motion Prediction Equations (GMPEs) exist for SCRs, ML-based ground motion models remain underutilized in these regions due to sparse high-magnitude data. The proposed model leverages recent advances in ML to improve prediction accuracy and spatial resolution, addressing limitations of traditional methods. To ensure suitability for emergency planning the model is implemented within a Deterministic Seismic Hazard Assessment (DSHA) framework. Notably, no recent DSHA models have been proposed for Lisbon.

The proposed Ground Motion Model (GMM), named XGB2.2G, was trained using the Engineering Strong Motion (ESM) database for events with Mw ≥ 4.5. Most key features (including magnitude (Mw), hypocentral depth, station and epicenter coordinates, and RotD100 Peak Ground Acceleration) were sourced directly from ESM. Additional preprocessing steps included the calculation of epicentral distance (Re), hypocentral distance, and azimuth orientation. Missing Vs_{30} values were imputed from the USGS global Vs_{30} map.

For the source model, earthquake epicenters and magnitudes from the *Instituto Geográfico Nacional* (1969–2024), together with fault data from Quaternary Active Faults Database of Iberia (QAFI), were used to define the highest-Mw probable epicenters for Lisbon city.

The GMM, developed using the XGBoost algorithm, achieved a coefficient of determination (R^2) of 0.84. Model quality was further assessed by using additional performance metrics. In a worst-case magnitude 7.2 earthquake

scenario near the Setúbal Peninsula (~60 km from Lisbon), the XGB2.2G model predicted RotD100 PGA values between 36%g and 41%g in Lisbon, equivalent to Modified Mercalli Intensity (MMI) IX shaking levels, according to the *Instituto Português do Mar e da Atmosfera* (IPMA).This research highlights the effectiveness of ML-based DSHA in SCRs, emphasizing its value for emergency preparedness and scenario-based seismic risk platforms.

Keywords: DSHA, XGBoost, RotD100 PGA, Maximum Credible Earthquake, Vs_{30}