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Seismic post-disaster site characterization, diagnosis, and modelling using geophysics coupled with innovative portable geotechnical penetrometers (iDCPT)

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ABSTRACT: This study investigates the combined use of the Instrumented Dynamic Cone Penetrometer (iDCPT), Multichannel Analysis of Surface Waves (MASW), Horizontal-to-Vertical Spectral Ratio (HVSR), and Microtremor Array Method (MAM) for high-resolution geotechnical and geophysical assessment of earthquake-affected sites. The proposed methodology was applied to two liquefaction-prone regions: Mala Gorica (Croatia), impacted by the 2020 Petrinja earthquake (M_w 6.4), and Gölbaşı (Türkiye), severely affected by the 2023 Türkiye–Syria earthquakes ($M_w \geq 7.5$). In both cases, iDCPT data were systematically compared with available CPT results, enabling reliable soil profiling and calibration. Moreover, the integration of geophysical MASW and HVSR measurements allowed for 1D and 2D subsurface modeling, capturing both vertical stratigraphy and lateral variability. The results, of which only a few are presented here, underline the efficiency and relevance of these lightweight, complementary techniques for post-seismic site investigations, especially in logistically constrained environments.

KEYWORDS: Soil liquefaction, Petrinja (Croatia), Gölbaşı (Türkiye), Dynamic Cone Penetrometer (iDCPT), MASW, HVSR

1 INTRODUCTION

In civil and earthquake engineering, seismic activity and its effects on infrastructure remain among the most extensively studied topics. A growing body of research focuses on understanding key mechanisms such as soil liquefaction, lateral spreading, and the critical role of spatial soil variability in seismic response. Consequently, in the aftermath of major seismic events, post-earthquake reconnaissance missions are generally conducted by international organizations and research institutions. These missions aim not only to assess the extent and nature of structural and geotechnical damage, but also to collect high-resolution field data related to surface soil conditions, which are essential for understanding site-specific seismic responses and then for improving predictive models.

Over the last fifteen years, Europe has experienced several major seismic events, including the 2020 Petrinja earthquake in Croatia in Dec. 2020 (M_w~6.4) and, even more catastrophic, the Türkiye–Syria earthquakes in Feb. 2023 ($M_w \geq 7.5$). Both events resulted in considerable structural damage and human casualties, prompting extensive geotechnical reconnaissance efforts afterwards to assess and characterize the dynamic behavior of surface soils in the affected regions. In both cases, significant ground movements were observed in specific areas, attributed to soil liquefaction phenomena and its various consequences including differential settlements, lateral spreading and ground subsidence.

In this context, two investigation campaigns were conducted between 2022 and 2024 on selected sites in Croatia and Türkiye with a lot of liquefaction occurrences. In Petrinja (Croatia), geotechnical and geophysical investigations were carried out in the epicentral area in 2022 and 2024 at different sites between Mala Gorica and Brest along the Kupa riverbanks. In Türkiye, the choice fell on the town of Gölbaşı, close to Adiyaman and affected by significant settlements due to soil bearing capacity deficiencies consecutive to liquefaction (Çetin et al. 2024b & 2025). This mission, organized in collaboration with French and Turkish national organizations, took place in spring 2024 aimed to collect data to characterize shallow soil through geophysical methods combined with innovative portable geotechnical penetrometers, in order to complement the information previously gathered during other larger international post-seismic surveys in the town of Gölbaşı.

In this paper, we provide a concise outline of the geotechnical and geophysical equipment used, as well as the campaigns conducted at both areas (Croatia and Türkiye), with a primary focus on the most recent campaign carried out in Gölbaşı town. However it should be noted that the campaign in Petrinja area (Croatia), is mainly utilized here to refine correlations between geotechnical and geophysical tests, aiming to quantify the vertical and horizontal variability at Gölbaşı site and presented hereafter. Furthermore, as all the soundings and subsurface geophysics were implemented between 2022 and 2024 in Croatia or in May 2024 in Türkiye, we bear in mind that the soil condition is no longer the one which existed before or just after the earthquakes.

2 OVERVIEW OF USED METHODS

In post-disaster missions, portable methods that provide precise and reproducible measurements both in depth and spatially are crucial. While geophysical methods allow investigation of large soil volumes, they often lack sufficient vertical resolution, whereas geotechnical soundings offer highly accurate point measurements. Given restricted access to affected areas and logistical constraints related to transportation, combining subsurface geophysical techniques (MASW, HVSR) with portable instrumented dynamic cone penetrometers (iDCPT) enables rapid, reliable, and cost-effective site characterization (Sastre et al. 2021; Villavicencio et al. 2011).

Figure 1. Illustration of portable geotechnical and geophysical test (a) HVSR, (b) iDCPT (Panda), (c-d) iDCPT (Panda) and 2DMASW measurements Illustrations of iDCPT (Panda®) and 2DMASW measurements carried out at Gölbaşı, (Türkiye) in May 2024.

2.1 *Portable geotechnical test (iDCPT)*

iDCPT can probe the soil to depths of 10-15 meters even more with soft soils. Notably, the French iDCPT, such as the Panda (Figure 1), provides a versatile and cost-effective solution enabling the collection of large volumes of data directly on site.

The fundamental operating principle presented in Benz et al. (2024) is the measurement of dynamic cone resistance *qd* as the key parameter. Numerous studies have demonstrated its capabilities and its strong correlation with cone resistance q_c from CPT tests, as well as with the blow count from SPT. Recent research has also shown that their instrumentation combined with wave equation analysis significantly enhances the application and interpretation of dynamic penetrometer data. For instance, Benz et al. (2021) have demonstrated that reliable estimates of soil resistance, shear wave velocity, and soil modulus can be obtained using iDCPT. The main advantage lies in the ability to rapidly perform numerous tests across various locations, making it particularly well-suited for efficient post-disaster site characterization. The equipment weighs 20 kg and enables real-time recording of the cone resistance profile. More detailed descriptions of these tools can be found in the provided literature.

2.2 *Geophysical test : 2D-MASW, MAM and HVSR*

Surface geophysical methods such as 2D MASW (Multichannel Analysis of Surface Waves), MAM (Microtremor Array Method) and HVSR (Horizontal-to-Vertical Spectral Ratio) are also lightweight, portable, and well-adapted techniques for use in post-disaster environments. These non-invasive methods enable the investigation of subsoil conditions over large areas with limited logistical constraints.

2D MASW is an active seismic technique that analyzes the dispersion of surface waves generated by a controlled source (Figure 1). By recording wavefields across a linear array of geophones and performing a 2D inversion, MASW provides spatially continuous shear wave velocity (*Vs*) profiles. It is especially effective in identifying lateral and vertical changes in soil stiffness and detecting near-surface heterogeneities.

MAM is a passive seismic technique that uses ambient microtremors recorded over small arrays to analyze surface wave dispersion. Unlike MASW, which is depth-limited by source energy and array length, MAM is capable of investigating deeper soil structures, making it an effective complement for identifying deeper velocity layering and constraining *Vs* profiles in thick sedimentary basins.

HVSR is another passive seismic technique based on ambient vibrations. It computes the ratio of horizontal-to-vertical spectral amplitudes to measure resonance frequencies associated with seismic impedance contrasts. HVSR technique is usually used to retrieve the soil fundamental resonance frequency and is particularly useful for estimating the depth to bedrock or major lithological interfaces from single-point measurements, even in urban or difficult-to-access areas.

By combining 2D MASW, MAM and HVSR, with high-performance iDCPT, a multi-scale and complementary characterization of the subsurface can then be reached. This integrated approach leverages the spatial coverage and depth penetration of geophysical methods with the vertical precision of geotechnical testing, resulting in a robust, rapid, and cost-effective framework for assessing soil conditions.

3 SITES PRESENTATION AND FIELD TESTS

3.1 *Mala Gorika, Petrinja, Croatia*

The Petrinja–Sisak region in Croatia is located at the junction between the southwestern Pannonian Basin and the northern Internal Dinarides and crossed by the Petrinja fault system which caused the Kupa valley earthquake in 1909 (mainshock Ms ~ 5.75-6) and the M_w 6.4 Petrinja earthquake. These two events produced liquefaction with, for the more recent, an abundance of sand blows along the Kupa, Sava, and Glina rivers in Holocene alluvial sediments. The liquefaction phenomena caused widespread ground deformation and structural damage. Ejecta was documented both in open areas and near residential buildings. In free-field conditions, the ejection was often accompanied by significant ground fissuring, and within built-up areas, ejecta contributed to differential settlements, cracks in foundations, as well as contamination of water wells. In addition, in specific areas, lateral spreading led to ground and building fissures, rupture of underground pipelines and damage to road surfaces.

The Mala Gorica area, located in the epicenter zone, is representative enough of conditions typical of liquefaction-prone environments. Recent investigations have revealed a characteristic soil profile: from the surface with alluvial sediments saturated by the shallow water table of the river's aquifer, which consist of approximately 3 meters of clayey silts, overlying at least 3 meters of sandy layers, themselves underlain by gravels and coarse sands (Luong et al., 2022).

3.1.1 *Field test carried out in Mala Gorica*

Between 2022 and 2024, 3 field investigation campaigns were conducted into different zones of interest (example with Site D presented in Figure 2). The first, carried out in autumn 2022, included iDCPT, trenches, borehole drilling, Ground Penetrating Radar (GPR), MASW survey and Electrical Resistivity Tomography (ERT).

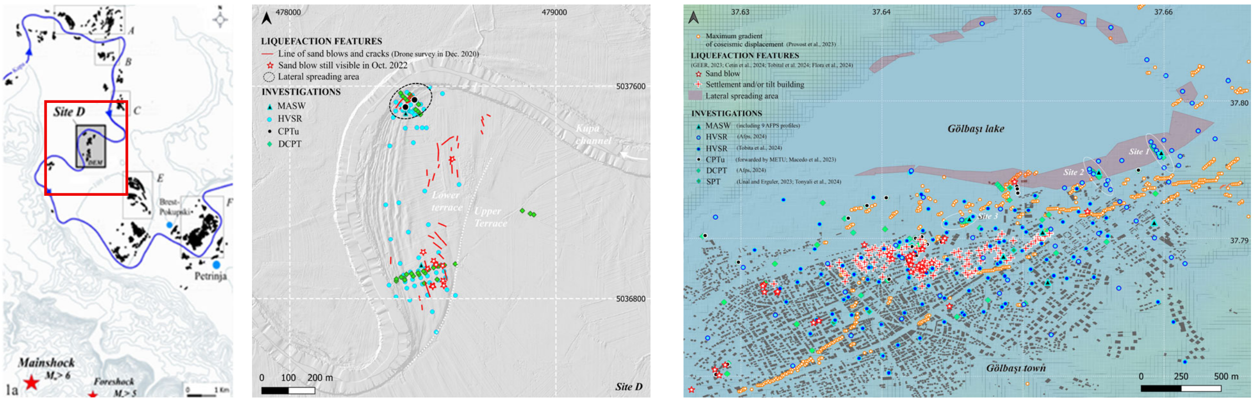

Figure 2. Investigations carried out in (left) site D at Mala Gorica (Petrinja, Croatia) - Lidar image before the earthquake (HGI-CGS), and (right) Location of investigations in Gölbaşı (Türkiye) and liquefaction evidence collected after the earthquakes (Mw ≥ 7.5).

The second and third campaign, conducted in Sept. 2023 and April 2024, focused respectively on HVSR measurements and more advanced investigations, CPT and Cyclic PMT tests, additional iDCPT, and geophysical methods including 2D MASW and MAM. One of the main objectives of this latest study is to expand the comparative test database (iDCPT, Vs, CPT, and Cyclic PMT results), enabling robust data integration and aggregation to refine surface soil prediction models and improve site characterization in post-seismic contexts.

3.2 *Gölbaşı, Adıyaman, Türkiye*

Spanning the eponymous depression that stretches for around 30 km along a branch of the active East Anatolian Fault (EAFZ), the town of Gölbaşı suffered heavy human and material losses during the Feb. 2023 earthquake, particularly the lower town between altitudes of 880m and 910m above sea level (absl), which is mainly built on Quaternary alluvial and lacustrine soils. The tectonic activity along the EAFZ causes a subsidence of this basin at a rate of ~10 mm/year, while the displacement rates along the Erkenek and Pazarcık segments are slightly lower, ~7.5 mm/year (Yönlü et al. 2013; Moug et al. 2023; Çetin et al. 2024b; Moss et al. 2025).

This region had already been severely impacted by several large-magnitude earthquakes in the past, as identified in Duman et al. (2018). The strongest earthquake recorded in the area were the 6th of Feb. 2023, firstly the Pazarcık earthquake ($M_w = 7.8$) followed then by Elbistan earthquake ($M_w = 7.6$) some hours later, with both mainshocks at a focal depth of 8.6 km and 7 km, respectively. Afterwards, there were more than 400 aftershocks with magnitudes greater than 4. Intensive damage was observed in buildings, transportation systems, earth structures, harbors, gas, water, and electricity lifelines as described in the numerous post-earthquakes reports as in Çetin et al. (2023) or Moug et al. (2023).

Regarding more specially Gölbaşı, about 60 % of the buildings in city center collapsed and most of the remaining structures were severely damaged (Çetin et al., 2024b; Moss et al., 2025). Widespread liquefaction-induced ground deformations (settlement, lateral spreading) occurred in the city and near Lake Gölbaşı, causing tilting and overturning of buildings, especially those with 5-7 stories. Additionally, surface fault ruptures from left-lateral strike-slip movement were clearly observed through the city (Figure 2).

3.2.1 *Field test carried out in Golbasi*

In spring 2024, a five-day investigation campaign was carried out in Gölbaşı by a team of seven researchers. Test locations were strategically selected based on the spatial distribution of ground deformations and structural damage observed immediately after the earthquake. Particular attention was given to three specific sites (Site 1 to 3 in Figure 2) where clear evidence of lateral spreading had been documented for sites 1 & 2 especially. At these locations, a higher density of iDCPT and geophysical tests was performed enabling both detailed assessment of the near-surface soil layers and correlations between cone resistance (q_d) and shear wave velocity (Vs).

A total of 9 2D-MASW/MAM profiles, 74 HVSR points and 61 iDCPT tests were performed. Each iDCPT included torque measurements at every rod advancement increment to evaluate the influence of skin friction. The torque values remained consistently low (< 6 Nm), confirming minimal shaft resistance along rod and ensuring the reliability of qd readings.

In addition, before and after the field campaign, an in-depth review of published data was conducted for the Gölbaşı area and allowed us to compile a dataset including 31 CPT/CPTu soundings, 9 SPT, 4 MASW Profiles and 136 HVSR measurements, all mainly presented in Ünal & Ergüler (2023), Çetin et al. (2024a & 2024b), Flora et al. (2024), Milev et al. (2024), Moss et al. (2025), Moug et al. (2024), Tonyali et al. (2024) or downloadable via data depot (CPT data set through Macedo et al. 2024 and HVSR data set through Tobita et al. 2024) or even sent by the METU Ankara (9 CPTu carried out in Fall 2023). These data contributed to a broader understanding of the subsurface conditions as a reference framework for the interpretation and validation of the newly acquired results (Figure 2).

Across both study sites in the respective countries (Croatia and Türkiye), all measurements were fully georeferenced, enabling precise spatial integration and facilitating detailed mapping and correlations.

4 DATA ANALYSIS AND SOIL SPATIAL MODELING

The main objective of building geophysical and geotechnical test databases on disaster-affected sites is to collect, cross-analyze, compare and establish on-site correlations. This approach enhances the amount of useful information extracted and contributes to a better understanding of the surface soil behavior, while providing estimates of the key geotechnical parameters relevant for liquefaction studies. Firstly, after organizing and structuring all available data, we propose a correlation analysis between the main measured parameters. Subsequently, we focus on the spatial distribution of measurements and the modeling of the spatial variability of the inferred properties.

The results presented herein are primarily derived from the city of Gölbaşı, where the highest concentration of tests was performed. Data from the Mala Gorica (Croatia) are just used here to further refine the correlations between geotechnical and geophysical measurements.

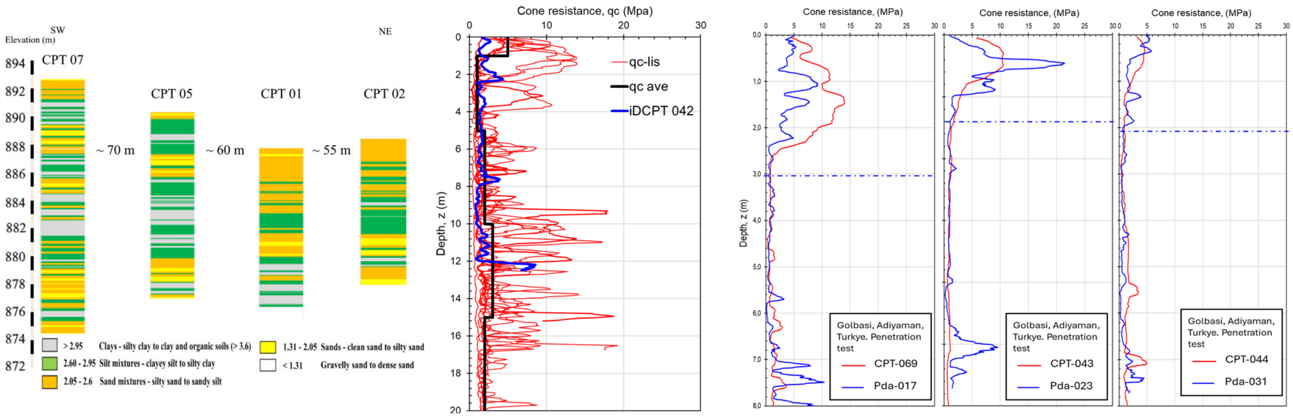

Figure 3. (left) Soil variability based on Soil Behavior Type (SBT) from CPTs in downtown Gölbaşı; (middle) Comparison of CPT and IDCPT profiles showing strong vertical resistance variation; and (right) Dynamic (IDCPT) vs. static (CPT) cone resistance comparison in Gölbaşı, Türkiye.

4.1 *Gölbaşı's soil profiles*

The soil profiles identified across Gölbaşı city exhibit significant spatial variability, both in terms of nature and stratigraphy (Figure 3). While surface layers are often predominantly composed of fine-grained soils (clays) with varying plasticity (CL to CH), several studies have reported the presence of liquefiable layers interbedded with thick clay deposits - potentially explaining the numerous sand ejecta (sand boils) observed immediately after the earthquake (Çetin et al. 2024a). This variability reflects the diverse depositional sequences and sediment sources characteristic of alluvial and lacustrine sedimentation environment. Remarkably, many of the soil properties do not meet conventional criteria for liquefaction susceptibility; yet evidence of liquefaction was documented at several locations across the city. Groundwater depth was generally observed to range between 0 and 4 meters across the study area, near to the lake.

4.2 *Gölbaşı's penetration test results and comparison*

iDCPT were spatially distributed to ensure broad coverage of the study area. A dense set of iDCPT was co-located with 2DMASW/MAM seismic profiles to enhance near-surface soil characterization and enable robust q_d-V_s correlation (Sites 1 to 3, cf. Figure 2). CPT and iDCPT were further cross analyzed to enrich the integrated geotechnical dataset. CPT and iDCPT results reveal significant vertical variability in soil cone resistance (Figure 3). Near the surface (0–1 m), resistance values reach ~5 MPa, followed by a sharp decrease to around ~1 MPa between 1-5 m. Between 5-10 m, resistance increases to an average of 2 MPa, peaking at 3 MPa between 10-15 m, before declining again to 2 MPa in the 15–20 m range. This highlights the spatial and stratigraphic heterogeneity of the subsurface materials, as illustrated in Figure 3, which presents both CPT profiles and the deepest iDCPT measurements. Figure 3 presents 3 examples of penetration resistance profiles obtained using the iDCPT and CPT performed in close proximity to one another. The results show a good agreement between the two methods, while also highlighting the higher vertical resolution of stratigraphic variations captured by iDCPT. This enhanced sensitivity is primarily attributed to the smaller tip diameter (22 mm), which induces less disturbance and homogenization of the surrounding soil compared to CPT.

The comparative analysis of penetration resistance from iDCPT and CPT indicates a strong correlation across the studied sites. Despite the variability, both methods reflect similar trends in near-surface mechanical behavior. Notably low resistances were recorded at several locations, supporting the hypothesis of widespread susceptibility to liquefaction given the observed groundwater levels and soil texture.

Figure 4 show the established correlations between iDCPT and CPT measurements, derived from datasets collected in Gölbaşı and Mala Gorica, and benchmarked against literature proposal. These findings validate the potential of iDCPT as a portable and cost-effective proxy for CPT in post-seismic investigations. This figure also presents the experimental *qd-Vs* relationship, which shows a good agreement.

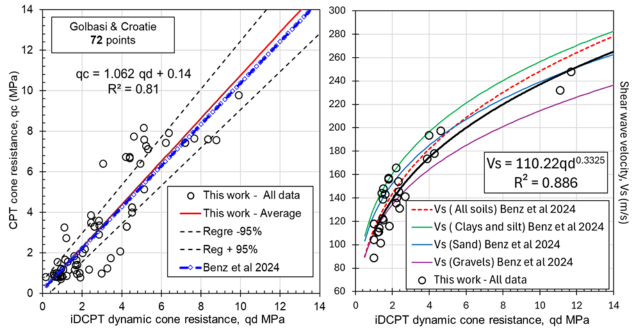

Figure 4. (left) iDCPT-CPT cone resistances relationship, and (right) *qd-Vs* relationship from Gölbaşı (Türkiye)and Mala Gorica (Croatia)

4.3 *Gölbaşı's geophysical results*

4.3.1 *HVSR measurements*

HVSR acquisition was made with *SmartSolo* stations in 3 components and for recordings lasting from 30 minutes to several hours during the night. After processing and removal of anthropogenic noise, 3 resonant frequencies peaks (Figure 5) have been identified on a site-wide scale and in line with previous HVSR results (Tobita et al. 2024). The dominant frequency (f_0) corresponds to a deep interface, presumably the bedrock (Eocene limestone as described in Yönlü et al. 2013) and varies between 0.5 Hz and 0.3 Hz with azimuths in the direction of the basin axis subparallel to that of the EAFZ.

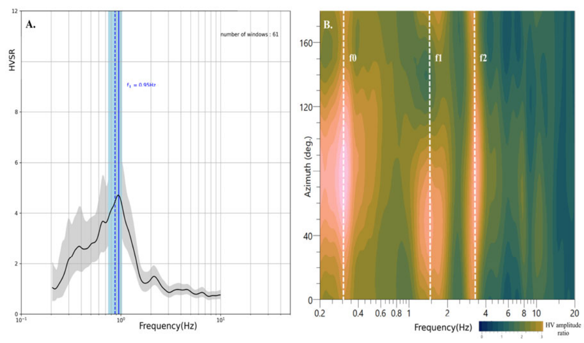

Figure 5. Examples of HVSR results. (a). HVSR curve (f_1 peak, station n°50_04) and (b) Directional resonances (station n°51_08).

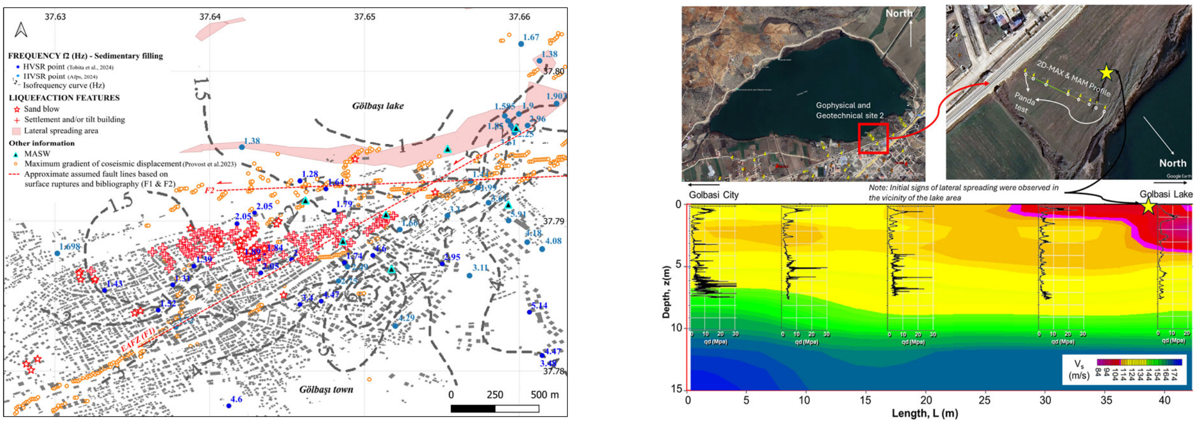

Figure 6. (left) Sketch of superficial sedimentary filling in frequency (Hz) below Gölbaşı town, and (right) 2 MASW profile and iDCPT at site 2 in a lateral spreading area. Gölbaşı (Türkiye).

The second frequency peak (f_1) around 0.95 Hz (Figure 5.a) ranges between 0.7 Hz and 1.5 Hz. This peak f_1, present throughout the entire Gölbaşı basin, displays variable azimuths in the vicinity of the EAFZ fault and requires further analysis. The latter frequency peak (f_2), which decreases in amplitude regularly from the hills located above 920 absl ($f_2 > 5$ Hz) to the shores of lake at 880-890 m absl up to 1.3 Hz (Figure 6), can be linked with the sedimentary infill probably Holocene in age and increasing in thickness from the hills towards the lake, which is consistent with the geological context and aligns with findings reported by other researchers. The number of f_2 values is limited enough to analyze the polarizations (example given in Figure 5.b).

Figure 6 pinpoints that the liquefaction occurrences or their consequences would seem to be spatially distributed below f_2 values of 2-3 Hz from a certain thickness of sedimentary fill. However, building damage including those caused by liquefaction would also spread out partly along the EAFZ that runs Gölbaşı town in a south-west to north-east direction. In this regard, it should be noted that surface ruptures and aerial images underlines at least 2 segments of faults which played in Feb. 2023, one corresponding to a part of segment EAFZ (F1 in Figure 6) and another left-lateral strike-slip, approximately north-south direction and passing near the shores of the lake (F2 in Figure 5) as well detailed in Pucci et al. (2025).

4.3.2 *2D MASW and MAM results*

In the lower part of the town and along the lake shore, shear wave velocity measurements indicate *Vs* values of approximately ~ 150 m/s down to a depth of 15 m. By integrating 2D-MASW and MAM techniques, the average velocity over the full investigated depth (~ 45 m) is estimated around 174 m/s. The computed $V_{S,30}$ for sites 1 to 3 (cf. Figure 3) values range from ~ 155 m/s to 178 m/s, classifying them predominantly as site class E (soft soil conditions). By cross-referencing the *Vs* values with HVSR measurements (frequency peak f_2 (Figure 6) indicates a sediment thickness near the lake shore greater than 30 m.

2D MASW profiles, conducted at key locations which exhibited evidence of lateral spreading, have allowed for the identification of "decompression" zones. To improve the robustness of the Vs inversions, a substantial number of iDCPT were then performed along each profile. Figure 6 illustrates results from site 2 and shows a "decompression" zone, corroborated by a marked reduction in tip resistance within the top 5 meters, indicative of near-surface weakening likely induced by lateral ground displacement.

Furthermore, empirical correlations have been developed between q_d and *Vs* values derived at the three sites 1 to 3. These datasets have also been complemented by additional measurements from Mala Gorica (Croatia) and benchmarked against reference correlations available in the literature (Benz et al. 2024) (see Figure 4). Despite notable scatter, the results largely fell within the expected trend envelopes and the derived relationship will be subsequently used to spatially interpolate *Vs* values across the broader Gölbaşı area, enhancing the resolution of seismic site characterization.

4.4 *Gölbaşı's soil modeling and site variability analysis*

The vertical and horizontal variability of both *qd* and *qc* has been evaluated using statistical indicators such as Shannon entropy index which captures vertically fluctuations in soil resistance along depth profiles (Figure 7).

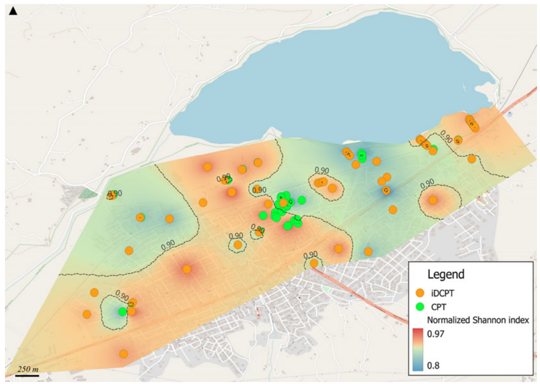

Figure 7. Cone resistance variability obtained from iDCPT and CPT test. Normalized Shannon Index - Gölbaşı (Türkiye).

Horizontal variability has also been assessed using the Horizontal Variability Index (HVI) as proposed by Sastre et al. (2021). Both indicators provide a robust framework for characterizing subsurface heterogeneity, thereby enhancing the interpretation of near-surface soil behavior across the investigated area. Spatial modeling of the obtained values has been conducted using classical kriging interpolation.

5 CONCLUSIONS

This study presents and highlights the feasibility and effectiveness of combining portable, rapid-deployment techniques for post-seismic site characterization in difficult-to-access environments. Field campaigns were conducted in two earthquake-affected regions - Mala Gorica (Croatia) and, more extensively, Gölbaşı (Türkiye) - using lightweight equipment including an instrumented dynamic cone penetrometer (iDCPT), surface-wave analysis (MASW), and ambient noise methods (MAM and HVSR).

In Gölbaşı, the collected data reveal significant vertical and lateral variability in subsurface conditions, reflecting the heterogeneous nature of the alluvial and lacustrine sedimentary deposits, predominant in the lower part of the town. Three resonance frequency peaks have been identified on a city-wide scale, one of which reflects presumably the bed rock interface (f_0) at around 0.36 Hz, another (f_1) at around 0.95 Hz whose directional resonances seem to be disrupted in the vicinity of the EAFZ line trace, and a third (f_2) up to 1 Hz, varying and corresponding to the increasing sedimentary thickening from the hills to lake's shores. This first analysis should be confirmed and corroborated with other data.

In the lower part of the town, the soil is generally characterized by low to medium stiffness, with average shear-wave velocities below 150 m/s in the top 10 meters and cone resistance values around 2 MPa. The iDCPT reached a maximum depth of 12.5 m, while the integration of MASW and MAM allowed for shear-wave velocity profiling up to 45 m. In these investigated areas of Gölbaşı, the average $V_{s,30}$ values below 180 m/s, corresponds to very soft soil and confirms the unfavorable geotechnical conditions.

Cross-correlation of iDCPT with CPT and MASW measurements (*Vs*) showed strong agreement, reinforcing the reliability and added value of the iDCPT as a diagnostic tool in post-seismic reconnaissance. iDCPT log obtained is a high-resolution and discretized signal, enabling statistical analysis of both vertical and horizontal homogeneity. This provides powerful insights for geotechnical engineers and researchers who require reliable, low-cost soil data with minimal logistical constraints. This integrative and cost-effective approach enables a detailed characterization of site conditions, which is essential for assessing liquefaction susceptibility or ground failure mechanisms such as lateral spread.

Looking forward, future investigations could benefit from correlating these geotechnical and geophysical measurements with complementary portable technologies—such as LiDAR or UAV-based imaging - to better understand the mechanisms of structural collapse, ground deformation, and lateral spreading. Such multi-sensor strategies hold great promises for improving the accuracy and comprehensiveness of post-disaster assessments, particularly in challenging logistical contexts.

Finally, 3D probabilistic modeling of soil indicators within the upper soil layers represents a promising avenue for further research based on the collected dataset.

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