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Advances in Geotechnical Engineering: From Lab and Field Testing to Seismic Risk Assessment

In this issue

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Abstract

This paper presents recent advances by the Research Unit of Soil Dynamics and Geotechnical Earthquake Engineering (SDGEE) in earthquake engineering, seismic hazard assessment, urban scale risk analysis, and soil dynamics. A new seismic zonation for Greece is developed using the Eurocode 8 spectral parameters S_{α} *and* S_{β} *derived from ESHM20, offering a more consistent representation of seismic action than PGA based approaches. At the urban scale, a methodology integrating soil–structure interaction and site amplification into fragility functions and exposure models is implemented within OpenQuake and applied to the 1978 Thessaloniki earthquake, revealing the importance of local soil and foundation conditions in spatial damage patterns. Complementary laboratory studies on gravel–rubber mixtures demonstrate favourable stiffness and damping characteristics that support sustainable geotechnical seismic isolation (GSI) solutions. Together, these developments enhance seismic hazard characterisation, improve risk assessment reliability, and contribute to more resilient built environments. Access the full presentation details in the recorded talk.*

1. Introduction

The Research Unit of Soil Dynamics and Geotechnical Earthquake Engineering (SDGEE) of the School of Civil Engineering at Aristotle University of Thessaloniki, Greece, has a long and worldwide-recognized expertise in earthquake engineering, soil dynamics, engineering seismology, microzonation studies, site effects, and the vulnerability and risk assessment of buildings, infrastructure, lifelines, and cultural heritage.

Within the framework of the ongoing revision of Eurocode 8, SDGEE contributed to the development of a new seismic zonation for Greece based on the spectral parameters S_α and S_β, derived from the European Seismic Hazard Model ESHM20. This approach provides a more refined and physically consistent representation of seismic hazard compared to conventional PGA-based zonation.

At the urban scale, a methodology integrating SSI and site amplification into seismic risk assessment is proposed through site-specific fragility functions and an enhanced exposure taxonomy, enabling implementation within the OpenQuake platform. Application to the 1978 Thessaloniki earthquake scenario demonstrates the influence of local soil and foundation conditions on damage distribution.

Complementary laboratory research investigates the dynamic properties of granular soils and gravel–rubber mixtures using resonant column, cyclic triaxial, and shake table testing, supporting the development of sustainable geotechnical seismic isolation solutions. Overall, the integrated experimental, analytical, and applied research of SDGEE contributes to improved seismic hazard definition, more reliable risk assessment, and enhanced resilience of the built environment.

Through the integration of experimental, analytical, and applied approaches, SDGEE continues to enhance the scientific understanding of seismic behaviour, supporting more resilient urban environments and the protection of critical infrastructure across scales.

2. Recent advances in seismic hazard assessment

In the upcoming revision of Eurocode 8 (EC8), two new seismic action parameters have been introduced to characterise the elastic response spectrum: S_α, which controls the spectral plateau at short periods, and S_β, which is the spectral acceleration at the vibration period of $T_\beta = 1s$ (Figure 1). These parameters replace the single peak ground acceleration (PGA) based definition of seismic action in the current code, providing a more flexible representation of the spectral shape across a wider period range. Significant efforts have been made to align Eurocode 8 with other international seismic codes, such as the NEHRP seismic code provisions in the U.S. (FEMA, 2015).

To implement these parameters in the context of the National Annex of Greece, a new seismic zonation methodology was developed (Pitilakis et al., 2024) based on the 2020 European Seismic Hazard Model, ESHM20 (Danciu et al., 2021). The procedure consisted of deriving maps of S_α and S_β values for a 475-year return period and for rock site conditions, calculated on a uniform grid of approximately 10 × 10 km (Figure 2). Median values within the national territory were extracted and statistically processed to define representative seismic levels, which were then grouped into zones based on the S_α parameter through clustering and applying geographical and population-based criteria. This approach ensures consistency with the European-scale hazard model while maintaining the necessary simplicity for practical implementation in national seismic design regulations.

The outcome of this process is a proposed seismic zonation map for Greece, which defines five seismic zones, each assigned representative values of $S_{\alpha,475}$ and $S_{\beta,475}$, as shown in Figure 3 (Pitilakis et al., 2024). Compared with the existing PGA-based zonation, the new map provides a more refined and scientifically justified characterisation of seismic hazard. The proposal has been submitted for consideration for potential inclusion in the Greek National Annex, which will accompany the revised Eurocode 8.

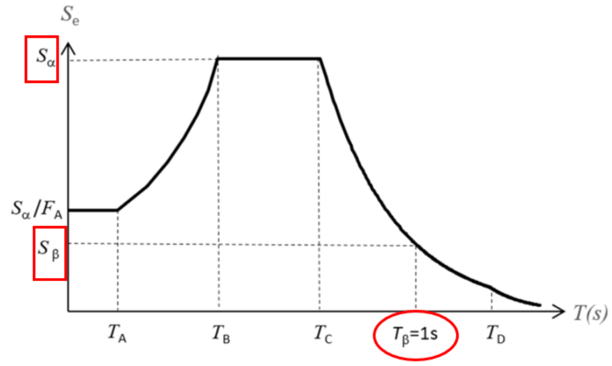


Figure 1: Elastic response spectrum of the revised Eurocode 8 defined by the two new parameters, S_α (short-period spectral plateau) and S_β (spectral acceleration at $T_\beta = 1s$).

3. Urban-scale risk assessment including Soil-Structure Interaction

A methodology is proposed to improve large-scale seismic damage assessment by incorporating site-specific fragility curves, considering soil–structure interaction (SSI) and site amplification (SAmp) effects. As illustrated in Figure 4, the fragility functions are derived and grouped by average shear wave velocity in the top 30 m and by slenderness ratio, serving as proxies for SAmp and SSI effects and allowing direct linkage to site conditions. The exposure model is adjusted to integrate fragility functions through an enhanced taxonomy that incorporates local soil and foundation information in addition to building attributes. A Python tool generates the modified exposure model from global soil and foundation data, with outputs provided in the Natural Hazard Risk Markup Language (NRML) format supported by OpenQuake, offering a solid basis for spatial risk analyses that explicitly consider SSI and SAmp

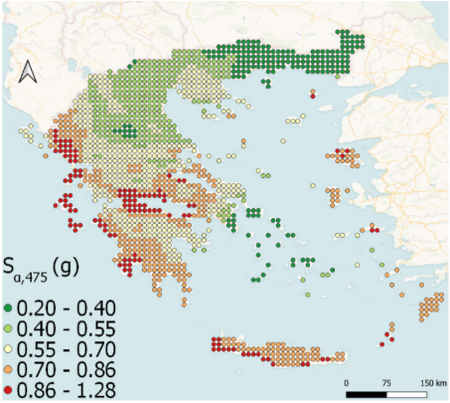


Figure 2: Map of median values of $S_{\alpha,475}$ for Greece, derived from ESHM20 for the commonly used return period of 475 years and for rock conditions on a uniform grid of approximately 10 × 10 km.

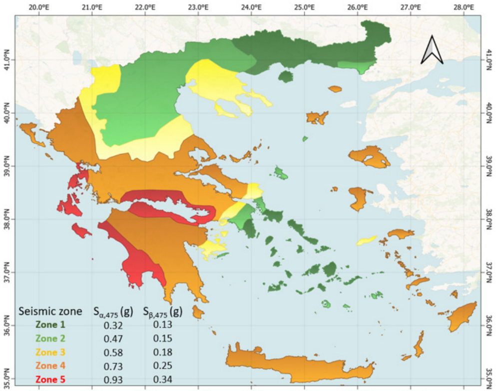


Figure 3: Proposed seismic zonation map of Greece based on the new EC8 parameters. Five seismic zones are defined, each characterised by representative values of $S_{\alpha,475}$ and $S_{\beta,475}$.

(Amendola & Pitilakis, 2022; 2024; Pitilakis et al., 2022).

The objective is to determine whether a more refined approach incorporating SSI and SAmp can impact the final damage calculation. The proposed approach is evaluated by estimating the damage distribution for the Thessaloniki 1978 earthquake scenario using the actual building stock of Thessaloniki. Several maps are presented with aggregated damages at different levels to investigate the spatial variability of SSI and SAmp, and their influence on the resulting damages (e.g, Figure 5).

The estimated physical damages are compared with those obtained using approaches from the existing literature (Figure 6). Using an updated building exposure model makes direct comparison with past observed damages challenging. Nevertheless, incorporating SSI and SAmp in large-scale damage assessment can provide valuable support for strategic decision-making in cities and improve the accuracy of the expected loss assessment due to a seismic event.

Figure 6 presents the estimated total physical damages using our proposed damage assessment approach (SSI + SAmp) and the literature approach (FB-on -rock and -soil), compared to the collected damage data (POST-EQtag) for the specific case of low-rise non-ductile masonry buildings made of stone with unknown technology (referred to as MUR-ST99-LWAL-DNO-H2 according to the GEM taxonomy). For this building type, using the literature approaches (fixed-base-on-rock) does not show good matching

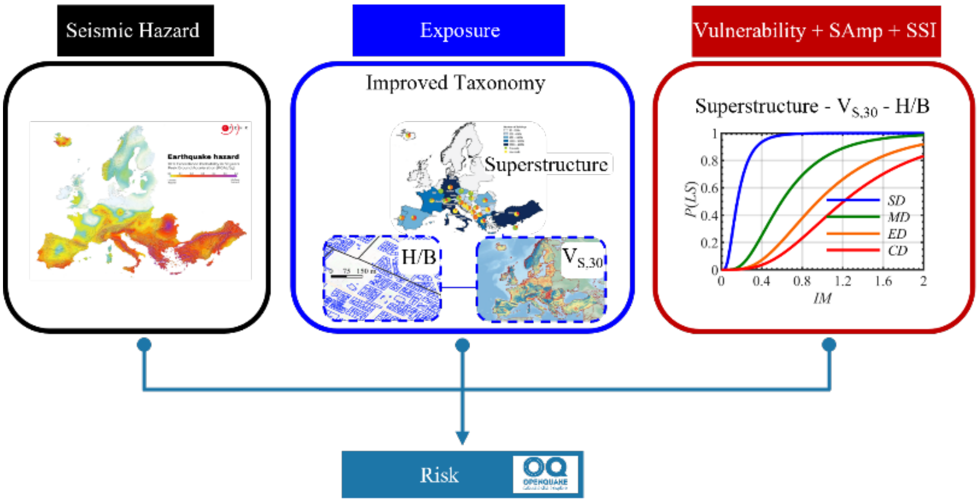


Figure 4: Conceptual framework for urban-scale seismic risk assessment integrating seismic hazard, exposure, and vulnerability, including site amplification (SAmp) and soil–structure interaction (SSI) effects.

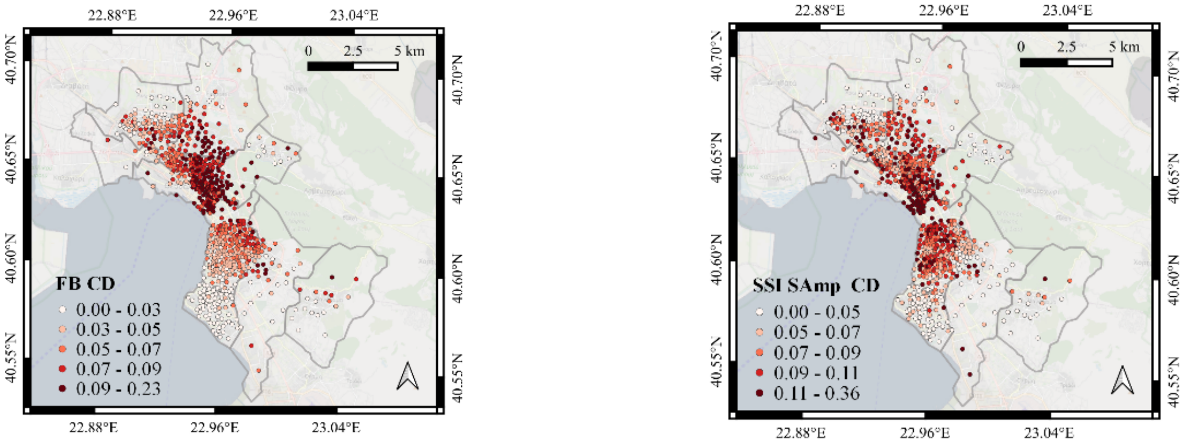
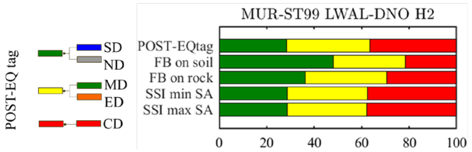


Figure 5: Percentages of buildings experiencing Complete Damage state for the M_W= 6.5, Thessaloniki 1978 earthquake, considering fragility curves for (left) the fixed base and (right) accounting for SSI and SAmp.



Despite the numerous uncertainties, a good comparison is found between the results of the proposed framework and observed damage while the literature approach may lead, to unconservative results.

Figure 6: Comparison of estimated physical damages with collected damage data for the masonry building classes MUR-ST99-LWAL-DNO-H2 for the M_W = 6.5, Thessaloniki 1978 earthquake.

with the observed damages. On the other hand, one should keep in mind that any differences between the results of the proposed framework and the observed damages can be attributed to many parameters, namely, to the differences in the exposure definition between the old (1978) and current exposure models. Nevertheless, the results obtained in this study establish the groundwork for an integrated approach that accounts for both site amplification effects and soil-structure interaction in fragility curves and risk analysis.

4. Soil dynamics testing in the laboratory. Dynamic properties of granular soils mixed with synthetic materials

Modern research shows a significant interest in examining the behaviour of soil materials mixed with granulated rubber from automotive vehicles. Granulated rubber, as a material, exhibits important engineering properties, including its low density, high elasticity, high damping ratio, and high deformability, which have already been included in the American Society for Testing and Material Standards (ASTM-D6270). Importantly, it is also considered as a low-cost material for engineering purposes (Pitilakis et al. 2021). Its behaviour depends mainly on the grain size, which varies from large diameter parts, also known as chips (12-50 mm), to low diameter grains, also known as powder (< 1mm). Figure 7 shows examples of different sizes of granular soils and shredded rubber.

The dynamic properties of the mixtures can be determined in the laboratory. Resonant Column and Cyclic Triaxial Tests are commonly used to estimate the Shear Modulus-Shear Strain-Damping curves (G-γ-D curves), while recent advances enable the derivation of G-γ-D curves from small scale experiments, such as shake table experiments (Pitilakis et al. 2024). Figure 8 shows the sinusoidal time history recording from the excitation of shake table experiments carried out in the laboratory facilities of the SDGEE Unit in the Aristotle University of Thessaloniki, Greece. The shear modulus and damping estimated from shake table tests on gravel soil without granulated rubber are presented in Figure 9a, while Figure

(a) (b) (c) (d)

Figure 7: Different sizes of granular soils and shredded rubber. (a) Gravel Material (D_{50} = 21mm) (b) Rubber Material (D_{50} = 3mm) (c) Gravel Material (D_{50} = 9mm) (d) Rubber Material (D_{50} = 2mm)

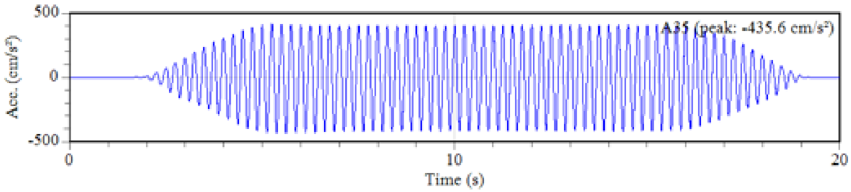


Figure 8: Sinusoidal excitation of the shake table

(a)

(b)

Figure 9: Estimation of Shear Modulus and Damping from shake table experiments

9b shows the corresponding estimates for gravel soil mixed with granulated rubber at a ratio of 80% of mass gravel to 20% of mass rubber.

5. Conclusions

The results presented confirm the added value of adopting advanced seismic modelling approaches that move beyond conventional, simplified assumptions. The use of the new Eurocode 8 spectral parameters enables a more robust and transparent representation of seismic action, while the proposed zonation framework for Greece ensures consistency with European-scale hazard models and practical applicability at the national level.

At the urban scale, explicitly accounting for soil–structure interaction and site amplification leads to measurable differences in damage estimates and spatial damage patterns, highlighting the importance of local soil and foundation conditions in large-scale seismic risk analyses. These effects, often neglected in standard assessments, prove relevant for supporting informed mitigation strategies and urban planning decisions.

Laboratory investigations further demonstrate the potential of innovative granular mixtures, such as gravel–rubber composites, to enhance seismic performance through favourable stiffness and damping characteristics, supporting sustainable geotechnical solutions. Overall, the integration of hazard modelling, risk assessment, and experimental soil dynamics provides a coherent framework for improving seismic resilience of the built environment.

SECED

SECED, The Society for Earthquake and Civil Engineering Dynamics, is the UK national section of the International and European Associations for Earthquake Engineering and is an Associated Society of the Institution of Civil Engineers. It is also sponsored by the Institution of Mechanical Engineers, the Institution of Structural Engineers, and the Geological Society. The Society is also closely associated with the UK Earthquake Engineering Field Investigation Team. The objective of the Society is to promote co-operation in the advancement of knowledge in the fields of earthquake engineering and civil engineering dynamics including blast, impact and other vibration problems.

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SECED Newsletter

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Please contact the Editor of the Newsletter, Fabio Freddi, for further details. This edition of the Newsletter was co-edited by Atif Rasheed, Mohamed Elzeadani, and Ashraf Nayel.

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The 2024 Offshore Seismic Hazard Maps for UK Waters

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Abstract

The 2024 offshore seismic hazard maps for the UK Exclusive Economic Zone update the previous 2002 assessment using improved earthquake catalogues, revised completeness thresholds, multiple seismic source zone models, and a new ground-motion characterisation model. Probabilistic hazard calculations for PGA, $SA_{0.2\,s}$ and $SA_{1.0\,s}$ show generally low to moderate hazard, with higher levels in the northern and southern North Sea and the Irish Sea. Hazard estimates for key carbon capture and storage areas - Acorn, Endurance, and HyNet North West - highlight important regional differences relevant to planning critical infrastructure offshore. These maps provide an up-to-date baseline for natural seismic hazard in UK waters, but do not replace site-specific studies for critical infrastructure. This article summarises the material presented in the evening lecture delivered on the 26th of November 2025. For further details and access to the full presentation, please refer to the recorded talk here.

1. Introduction

In the context of the United Kingdom's (UK's) decarbonisation and net zero carbon policy, the UK continental shelf and, in particular, the North Sea and the Irish Sea have a strategic role in achieving this target with an increasing number of licensed carbon capture and storage (CCS) sites (Figure 1). The presence of historical seismicity, including the largest recorded earthquake in the UK, i.e., the 5.9 moment magnitude(M_W) Dogger Bank earthquake on 7th June 1931 (Versey, 1939; Neilson et al., 1984), near offshore CCS areas, suggests that robust estimates of earthquake hazard are essential for the planning and design of offshore critical infrastructure. Although updated seismic hazard maps for the UK were recently published to inform the National Annex to Eurocode 8 (earthquake-resistant design of structures; Mosca et al., 2022), these maps do not extend offshore and the most recent hazard maps for the offshore regions around the UK were published in 2002 (EQE, 2002). Since then, there have been significant advances in seismic hazard assessment, in particular how to model the ground shaking produced by potential, future earthquakes and capture its uncertainties.

2. Development of the 2024 Offshore Seismic Hazard Model

The British Geological Survey (BGS) developed and published the 2024 offshore seismic hazard models, together with accompanying maps for the UK Exclusive Economic Zone (EEZ), to update the previous maps. The work was funded by the Industrial Decarbonisation Research and Innovation Centre (IDRIC) and was informed at key stages by external experts who reviewed the project's main components. The development of the 2024 offshore hazard model and maps attempted to improve

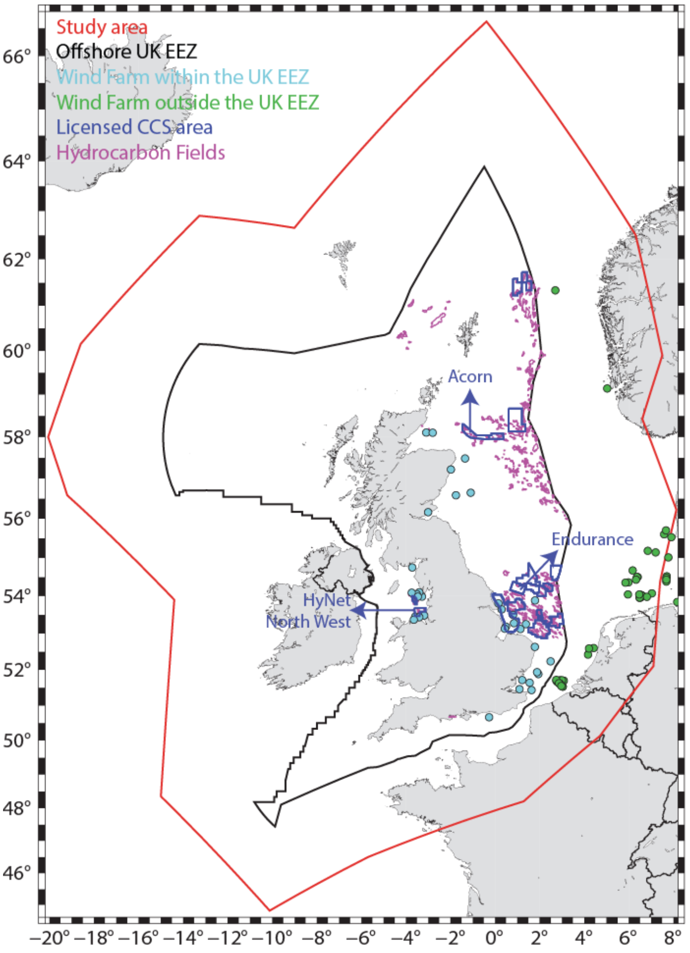

Figure 1: Map of the current UK offshore Exclusive Economic Zone (EEZ; inner polygon), the study area for the development of the project earthquake catalogue and the source zone model (outer polygon) and the locations of the gas and oil hydrocarbon fields, wind farms, and licensing offshore CCS sites as reported by the North Sea Transition Agency.

some of the limitations of the 2020 national seismic hazard model for the UK (Mosca et al., 2022). Therefore, the 2024 offshore model represents an update to the 2020 national hazard model, incorporating the latest data and advances in probabilistic seismic hazard assessment (PSHA) methodologies.

The analysis is based on a comprehensive catalogue of earthquake activity across the region developed by combining existing earthquake catalogues and data from regional and local monitoring agencies. One of the main differences between the 2020 and 2024 seismic hazard models is given by the completeness thresholds for the earthquake catalogue in the offshore regions. A limitation of the 2020 national hazard model was that the completeness thresholds were based on published information and were not tested against observations. To try to understand the magnitude of offshore earthquakes that might be felt by coastal population, we used the intensity prediction equations (IPEs) of Allen et al. (2012) and Musson (2013) to model earthquake intensities for a specific event and the expected magnitude of the earthquakes that might be felt in at least one populated place with an intensity of 3 across the North Sea region. We have found that the magnitude of earthquakes that would be felt increases rapidly with distance offshore. The use of Allen et al. (2012) suggests that earthquakes of magnitude greater than six in the Central North Sea would be felt, whereas events greater than magnitude 5 would be felt by the coastal population, according to Musson (2013). The different results are explained by the different data used to derive the two intensity models (tens of thousands of intensity data from crustal earthquakes worldwide with 5.0-7.9 M_W for Allen et al. (2012) and several hundred intensity data from 326 British earthquakes with 2.0-6.0 M_W for Musson (2013)). The results estimated using the IPE of Musson (2013) agree well with the completeness thresholds in Johnston et al. (1994) for the Continental Shelf and Norway, and therefore have been adopted for the 2024 offshore hazard model.

Another limitation of the 2020 national hazard model was its reliance on a single source zone model (SZM). In the 2024 offshore seismic hazard model, we used four different SZMs to account for different interpretations of the mapped tectonic structures, large-scale deformation, regional stress field, and observed seismicity in the UK and surrounding regions (see Figures 18-21 in Mosca et al., 2024). The first SZM is strongly based on the main structural domains and the distribution of seismicity and corresponds to the SZM developed for the 2020 national seismic hazard model for the UK (Mosca et al., 2022) and the source model for northern France, Belgium, the North Sea, and the Atlantic Ocean used in the 2020 European Seismic Hazard Model in Danciu et al. (2024). The second SZM is based on the regional geological and structural understanding, focusing on zones consistent with known geological structures. This includes rocks of similar type that have undergone the same deformation events and therefore share similar structural trends and should behave similarly in a given stress field. The last two SZMs are from the previous offshore seismic hazard model (EQE, 2002).

To develop the ground motion characterisation (GMC) model, we used a large (for an intraplate region with low levels of seismicity) dataset of homogeneously processed high-quality ground motion recordings for PGA, $SA_{0.2\ s}$, and $SA_{1.0\ s}$ to help select and weight the ground motion models (GMMs) used in the GMC model. This is the first time that such a dataset has been compiled for this region. Although we recognise that the inherent limitations of the dataset (e.g., lack of recordings at near-source distances and for large earthquakes) still make the selection of the GMMs challenging, it represents a valuable database to develop a ground motion backbone model for the UK (Mosca et al., 2023). The GMC model consists of five recently published multiple GMMs considered to be applicable to the region. The GMMs are included in a logic tree where the weights are informed by the fit between observed and modelled ground motions, together with team discussion.

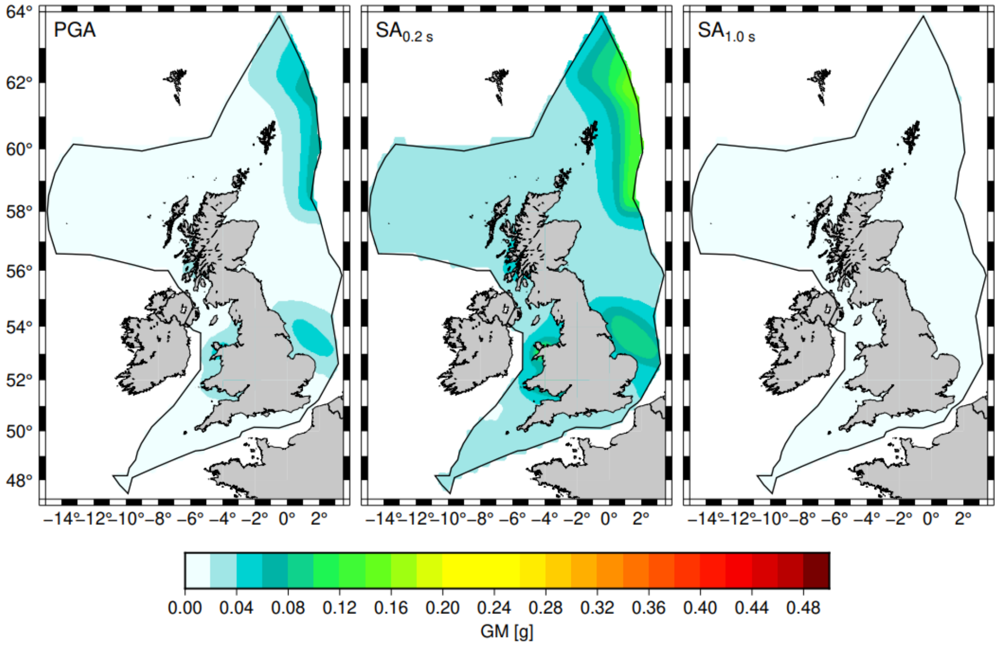

Figure 2: Hazard map for PGA, $SA_{0.2\ s}$ and $SA_{1.0\ s}$ at the 475-year return period. The black polygon describes the UK offshore EEZ.

The GMC model also includes the host-to-target adjustments (HTTAs) and an ergodic global sigma model. The HTTAs account for differences in site conditions between the host regions for which the GMMs were computed and the target regions. It has become common practice to develop separate models for median ground-motion predictions and the aleatory variability, also referred to as sigma model, to avoid the double-counting of the aleatory variability of the ground motion when the sigma model provided by the individual GMPEs is used together with the HTTAs. In this project, we adopted the ergodic global model of Al Atik (2015), which was developed using the NGA (Next Generation Attenuation) -West 2 GMMs that were derived from a large uniformly processed global dataset and are applicable to a large range of magnitudes (from 3.0 to 8.0 or 8.5 M_W).

3. Hazard Results for UK Waters and CCS Sites

We calculated the hazard using a Monte Carlo-based PSHA, in which a large number of artificial catalogues were generated by randomly sampling the probability distributions in the seismic source models. This follows the same methodology used for the latest national seismic hazard maps for the UK. Hazard is calculated for PGA, $SA_{0.2\ s}$,

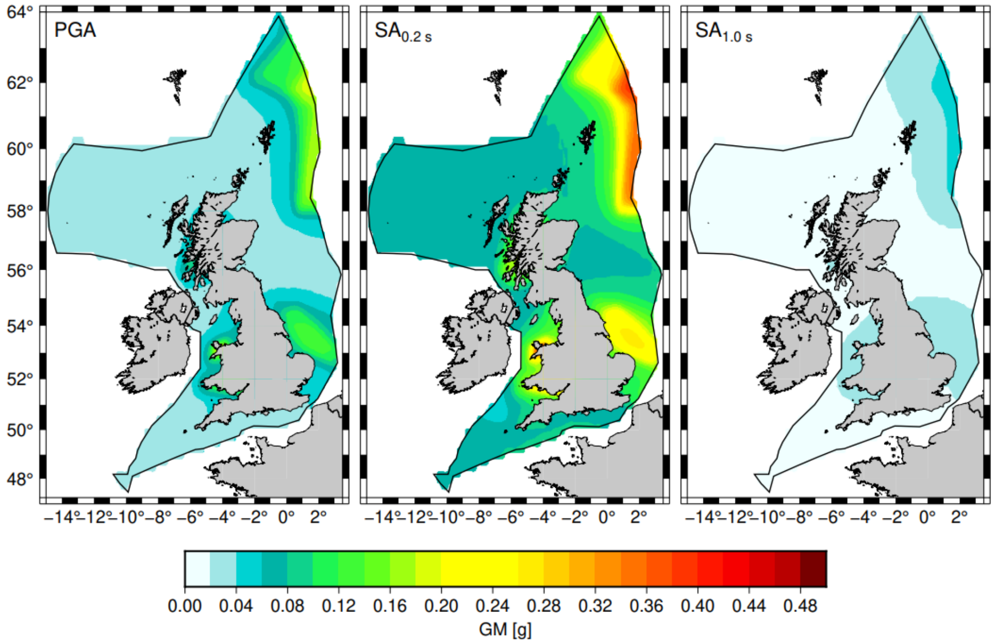

Figure 3: Hazard map for PGA, $SA_{0.2\ s}$ and $SA_{1.0\ s}$ at the 2475-year return period. The black polygon describes the UK offshore EEZ.

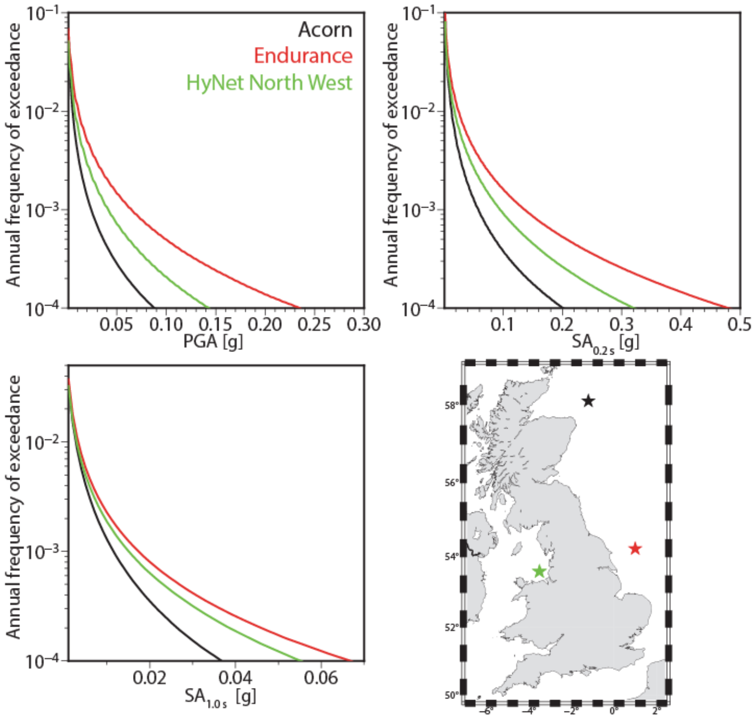

Figure 4: PGA, SA$_{0.2\ s}$ and SA$_{1.0\ s}$ hazard curves for sites in Acorn (black star), Endurance (green star), and the HyNet North West (red star).

and SA$_{1.0\ s}$ for 5% damping and Vs30 (time-averaged shear wave velocity for the top 30 m) of 800 m/s as a proportion of g and for the return periods of 95, 475, 1100, 2475, and 5000 years. This is the first time that maps of the seismic hazard at short (0.2 s) and long periods (1.0 s), which are particularly relevant for offshore structures, have been produced for UK waters. For a return period of 475 years, the PGA hazard is lower than 0.04 g for much of the UK offshore EEZ, except for the Irish Sea close to North Wales, the northern North Sea, and the southern North Sea. The hazard is up to 0.05 g in the region offshore North Wales, 0.07 g in the northern North Sea, and 0.05 g in the southern North Sea. A similar spatial pattern in the hazard is observed at 0.2 s, with the highest hazard in the northern North Sea (0.16 g), with more pronounced variations. At 1.0 s, the hazard is less than 0.02 g, and there is little variation across the UK offshore EEZ (Figure 2). For 2475 years, the northern North Sea, the offshore area near western Scotland, the Irish Sea near Wales, and the southern North Sea have been the areas of highest hazard for PGA and SA0.2. The highest hazard values (0.19 g for PGA and 0.39 g for SA0.2 s) are observed in the northern North Sea (Figure 3).

We also estimated the hazard for selected CCS sites (i.e., Acorn area in the Moray Firth Basin, Endurance site in the Sole Pit Basin, and the HyNet North West storage area in the southeast Irish Sea; Figure 4). We selected these sites because they were the first areas to hold a carbon capture licence issued by the offshore authority, i.e., North Sea Transition Authority. Moreover, they have different levels of seismicity, with the Endurance site located close (between 20-40 km distance) to the largest instrumental recorded earthquake in the UK region, i.e., the 5.9 Mw Dogger Bank earthquake, and the HyNet North West site being close to North Wales, the most seismically active areas of mainland Britain, i.e., North Wales (Mosca et al., 2022, 2024). The Acorn site has the lowest hazard of the three CCS areas, with a PGA hazard value of 0.04 g for a 2475-year return period. The PGA hazard values at Endurance and the HyNet are 0.11 g and 0.07 g for the same return periods. For SA0.2 s, the hazard values for the 2475-year return period increase to 0.10 g at Acorn, 0.23 g at Endurance, and 0.16 g at HyNet (Figure 4).

4. Conclusions

The 2024 offshore maps provide a robust indication of the level of seismic hazard to underpin the planning and design of offshore structures and CCS sites in UK waters, e.g., Acorn and HyNet North West areas. They also help identify regions of high seismic hazard to inform the need for site-specific risk assessments and provide a robust baseline for tectonic seismic activity in UK waters, which can be used to help discriminate any seismicity induced by operations, such as CCS, in the event it occurs. However, it is important to note that these maps are not a substitute for site-specific hazard assessment and high-consequence-of-failure installations (designated CC4-Highest in the new edition of EN1990, 2002). The user must take responsibility for ensuring that the use of the results provided by this study is appropriate for the case in question.

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Seismic-Related Design in East Asia: Practical Lessons from Recent Projects

Honest Tang, Saad Faizi, Yao Wang
Arup, Hong Kong

Abstract

Seismic design of geotechnical and underground structures in low- to moderate-seismicity regions presents specific challenges, particularly in selecting an appropriate level of analytical complexity while maintaining practical and robust design outcomes. This article presents two recent project case studies from East Asia that illustrate how different seismic analysis approaches, ranging from deformation-based pseudo-static methods to advanced dynamic soil–structure interaction analyses, were applied to address non-standard design problems. The first case study examines the seismic response of an underground station by comparing pseudo-static and dynamic time-history analyses, highlighting the conditions under which simplified methods remain reliable and where their limitations emerge (JSCE, 1992; Hashash et al., 2001; Hokmabadi et al., 2024). The second case study focuses on the seismic design of a deep underground diving pool, where strict crack-control requirements and complex soil–structure interaction necessitated verification beyond conventional static design using dynamic analysis (Hokmabadi et al., 2022). Together, these examples demonstrate how targeted use of advanced analysis can support engineering judgement, validate simplified approaches, and inform practical seismic design decisions. Access the full presentation details in the recorded talk.

1. Introduction

In many parts of East Asia, seismic design is increasingly required for projects located in regions of low- to moderate-seismicity. While established codes and simplified analysis methods provide a robust baseline for typical structures, engineers are often faced with non-standard geometries, unusual loading conditions, or stringent performance requirements that challenge conventional practice. In such cases, a key design question is not whether advanced numerical analysis can be performed, but when it is necessary and how its results should be interpreted in a practical design context.

Arup has been involved in a wide range of seismic-related design projects across East Asia, covering underground structures, bridges, energy infrastructure, and specialist facilities (see Figures 1 and 2). These projects have required

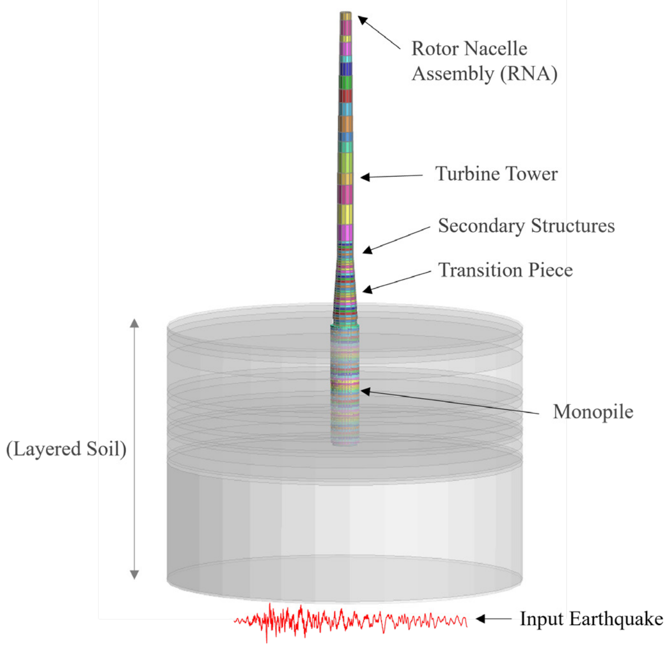


Figure 1: DSSI analysis of an offshore wind turbine supported by a large diameter monopile.

the application of multiple international design standards, including Japanese codes, Eurocode 8, and US standards, alongside project-specific performance-based criteria. In parallel, advanced numerical tools such as dynamic soil–structure interaction (DSSI) analysis have increasingly been used to supplement or validate simplified approaches where conventional methods alone may not provide sufficient confidence (Hokmabadi et al., 2022).

This article presents two case studies that illustrate how seismic analysis methods were selected and applied to address specific engineering challenges, and how the results informed design decisions. Rather than focusing on software tools, the emphasis is placed on the engineering implications, limitations of simplified methods, and practical lessons relevant to design engineers.

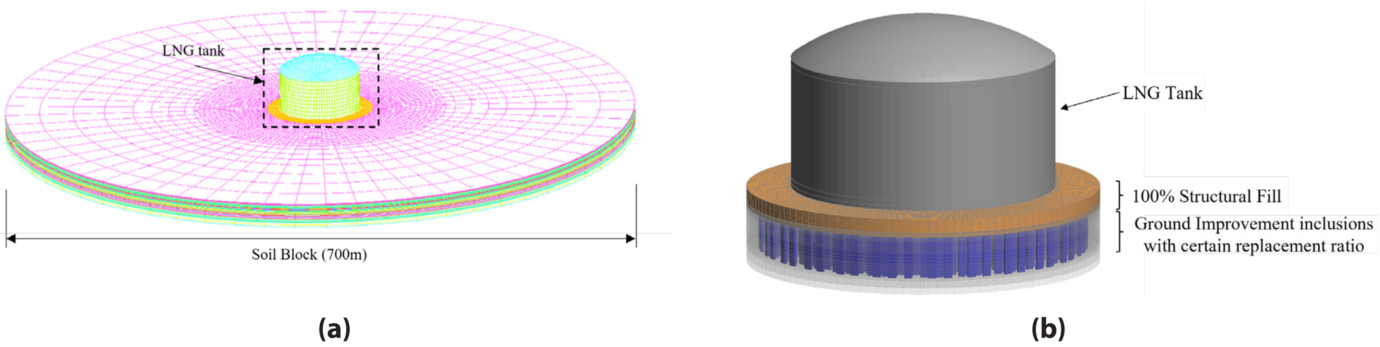
2. Case Study 1: Seismic Analysis of an Underground Station – Pseudo-static versus Dynamic Approaches

The seismic design of underground stations is commonly governed by ground deformation rather than inertial effects, leading to widespread use of deformation-based pseudo-static analysis methods in practice (JSCE, 1992; Hashash et al., 2001). These methods are attractive due to their simplicity and modest computational requirements; however, their reliability under stronger ground motions or atypical loading scenarios is less well understood.

In this case study, an underground station was analysed using both a pseudo-static finite-element approach (Figure 3) and dynamic time-history analysis to evaluate their relative performance (Hokmabadi et al., 2024). Three scenarios were considered: response under the design earthquake, response under increased ground motion, and the influence of additional mass concrete fill within the structure.

Under the design earthquake, the pseudo-static analysis produced bending moments and internal forces that compared reasonably well with the dynamic analysis results. This finding supports the continued use of deformation-based pseudo-static methods for typical underground structures in regions of low- to moderate-seismicity (Hokmabadi et al., 2024). However, when the ground motion increased, discrepancies between the two approaches became more pronounced, particularly in structural elements sensitive to higher deformation demands.

The study also showed that the presence of additional mass concrete fill imposed only minor additional inertial effects on the underground structure for the investigated configuration. This behaviour reflects the strong kinematic constraint provided by the surrounding ground, which limits free vibration compared with surface structures (Hashash et al., 2001; Hokmabadi et al., 2024). These findings highlight the importance of understanding the applicability limits of simplified seismic analysis methods and demonstrate how dynamic analysis can be used selectively to test design robustness under less conventional scenarios.



(a) (b)

Figure 2: DSSI analysis of a large LNG tank in LS-DYNA: (a) overall model setup; (b) ground improvement under LNG tank.

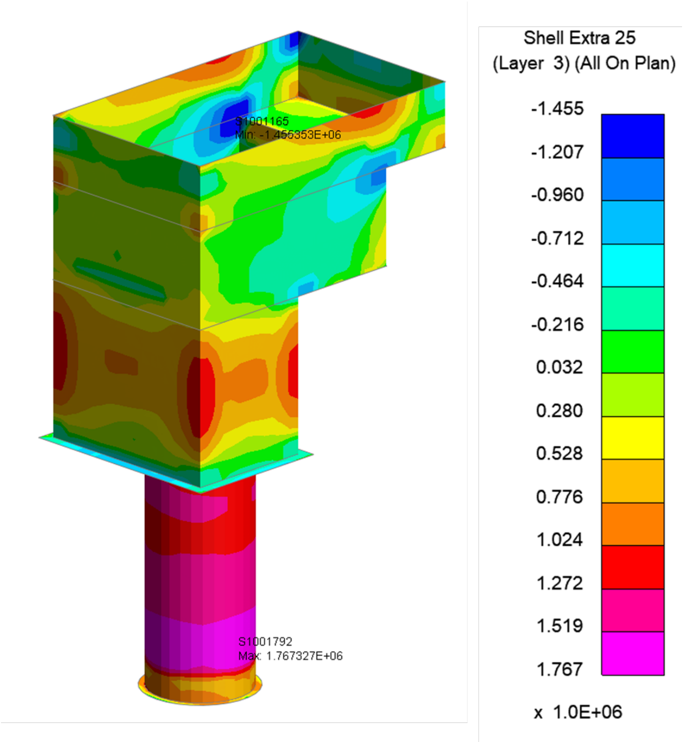


Figure 3: Procedure of the pseudo-static method for seismic analysis.

3. Case Study 2: Seismic Design of a Deep Underground Diving Pool

The seismic design of a deep underground diving pool presents challenges that go beyond those of typical underground structures. In this project, the pool comprised both circular and rectangular sections at significant depth as demonstrated in Figure 4, with strict crack-control requirements and sensitivity to differential ground movement. Conventional static design alone was insufficient to demonstrate adequate seismic performance.

A deformation-based seismic displacement method was adopted as the primary design approach, in which dynamic soil–structure interaction effects were represented through equivalent static actions derived from relative ground displacements, consistent with established practice for underground structures (JSCE, 1992). The design criteria required the pool structure to remain elastic under low-level earthquakes, with additional deformation limits imposed for precautionary and higher-level earthquake actions.

To supplement this approach, dynamic time-history analysis was carried out using a three-dimensional numerical model to provide additional insight into soil–structure interaction and stress distribution (Hokmabadi et al., 2022). Comparison of results showed that the peak ground displacements predicted by the dynamic model were consistent with those assumed in the seismic displacement method, lending confidence to the overall design approach.

While the dynamic analysis required substantially greater modelling effort and input data, it proved valuable in validating critical design assumptions and identifying localised stress concentrations relevant to detailing and crack control. This case study illustrates how advanced analysis can be used efficiently as a design verification and insight tool, rather than as a routine replacement for established simplified methods.

4. Conclusions

The two case studies presented demonstrate that simplified seismic analysis methods remain appropriate for many geotechnical and underground structures in low- to moderate-seismicity regions, provided their limitations are understood (JSCE, 1992; Hashash et al., 2001). Advanced dynamic analysis, when applied selectively, can play a

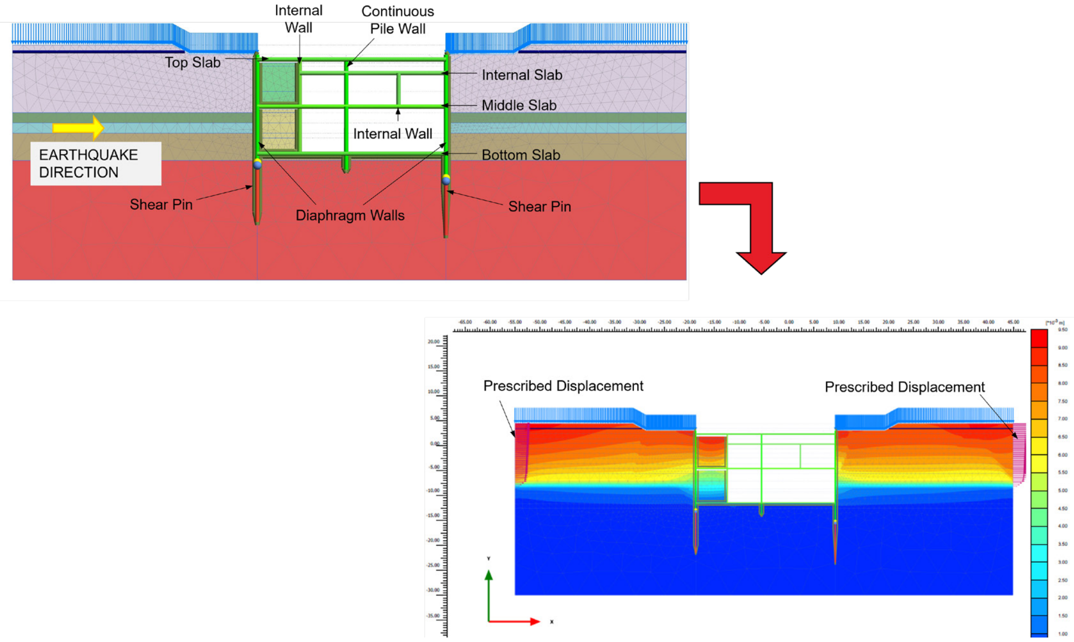


Figure 4: DSSI analysis of the diving pool in LS-DYNA.

valuable role in validating design assumptions, assessing non-standard scenarios, and informing critical design decisions (Hokmabadi et al., 2022; Hokmabadi et al., 2024). For practising engineers, the key is not the routine use of complex tools, but the informed integration of appropriate analysis methods to achieve safe, robust, and practical seismic designs.

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Note: This article draws upon insights presented during the SECED Webinar held on June 11, 2025. For further details and access to the full presentation, please refer to https://www.youtube.com/watch?v=UWoTHB9CMdA.

New Episode of SECED Talks

The SECED Talks podcast, produced by Young SECED, has just released a new episode featuring an insightful conversation with a leading voice in civil and earthquake engineering.

Episode 6 – Sebastian Kaminski: Engineering for International Development

In this episode of the SECED Talks podcast, host **Rafik Nizarali** speaks with **Sebastian Kaminski**, structural engineer at Arup, about his journey into the field of structural and seismic engineering. Sebastian reflects on the experiences that shaped his career path, discussing how his academic background and professional interests led him toward engineering work focused on resilience and societal impact.

The conversation explores Sebastian's involvement in international development projects, highlighting the challenges of designing and implementing engineering solutions in resource-constrained environments. He discusses the importance of context-sensitive design, collaboration with local communities, and the role engineers can play in supporting safer and more resilient infrastructure in developing regions.

The episode also examines a promising sustainable housing solution aimed at addressing the housing crisis in rural communities while improving disaster resilience. By combining low-cost materials with simple yet effective structural concepts, the approach seeks to provide affordable, scalable housing options capable of withstanding natural hazards. The discussion offers valuable insights into how engineering innovation can contribute to both social development and disaster risk reduction.

SECED Outreach in Bristol

Jessica Christie
AtkinsRéalis

On 11th February 2026, the CHAIN: Bristol event took place at the University of the West of England (UWE), bringing together students and early career engineers from across multiple institutions. I was delighted to represent SECED alongside fellow Young Members Maria Liapopoulou and Mohamed Elzeadani, our current Young Memebers Subcommittee (YMSC) Chair. Together, we introduced SECED to students, academics, and professionals, highlighting our Society's mission, activities, and opportunities for involvement.

As part of the technical programme, each institution delivered a presentation. Mohamed spoke on behalf of SECED, presenting his research on the Dynamic Performance of Cement Free Rubberised Concrete in Seismic and Impact Applications. His contribution was well received and reflected the breadth and relevance of our community's ongoing work in earthquake engineering and civil engineering dynamics.

Our engagement continued the following day with a visit to the University of Bristol, where SECED YMSC delivered a structures focused seminar to engineering students. Mohamed opened the session with an introduction to SECED and a presentation on the Structural Performance of Confined Rubberised Alkali Activated Concrete under Compression and Cyclic Loading, followed by Maria's talk, Beyond Intensity: Accounting for Duration and Directionality in Seismic Design. Both talks underscored the importance of advanced seismic research and showcased SECED's strong connection to the academic community.

Across both days of activity, it was encouraging to witness the enthusiasm of students and early career engineers engaging with SECED's work. Our presence helped strengthen ties within the regional engineering community and provided an effective platform for outreach, collaboration, and knowledge sharing. As a Young Member, I was proud to play a role in promoting SECED and supporting its visibility across Bristol and beyond.

Photos form the Bristol visit

Notable Earthquakes
September 2025 – December 2025

Reported by British Geological Survey

Issued by: Davie Galloway, British Geological Survey, February 2026.
Non-British Earthquake Data supplied by: United States Geological Survey.

			Time			Dep	Magnitude			
Year	Day	Mon	UTC	Lat	Lon	km	ML	Mb	Mw	Location
2025	04	SEP	16:56	34.70N	70.76E	16			5.6	HINDU KUSH, AFGHANISTAN
At least 2 people killed, over 50 others injured and over 330 homes destroyed in Kunar province.										
2025	07	SEP	08:49	53.69N	1.37W	27	2.6			PONTEFRACT, WEST YORKSHIRE
2025	09	SEP	18:24	53.27N	3.87E	11	2.9			SOUTHERN NORTH SEA
2025	10	SEP	23:09	54.16N	2.91W	3	1.7			KENTS BANK, CUMBRIA
2025	13	SEP	02:37	53.20N	160.19E	58			7.4	KAMCHATKA (OFFSHORE)
2025	18	SEP	18:58	53.14N	160.72E	27			7.8	KAMCHATKA (OFFSHORE)
Some buildings damaged in and around Petropavlovsk. A tsunami was generated with a maximum wave height of 31 cm recorded at Zhupanovo, Russia.										
2025	30	SEP	13:59	11.16N	124.11E	10			6.9	VISAYAS, PHILIPPINES
At least 79 people killed, over 1,270 others injured, over 10,000 homes and public buildings destroyed and over 185,000 damaged and several landslides occurred on Cebu and Leyte Islands.										
2025	06	OCT	05:30	54.55N	2.50W	12	1.7			ORMSIDE, CUMBRIA
2025	07	OCT	11:05	6.74S	146.84E	98			6.6	PAPUA NEW GUINEA
2025	10	OCT	01:43	7.29N	126.69E	59			7.4	MINDANAO, PHILIPPINES
At least 10 people killed, more than 1,000 others injured and over 39,500 homes and buildings were damaged or destroyed across many provinces in Mindanao. A tsunami with a maximum wave height of 19 cm was generated.										
2025	10	OCT	11:12	7.21N	126.66E	47			6.7	MINDANAO, PHILIPPINES
2025	10	OCT	20:29	60.19S	61.82W	10			7.6	DRAKE PASSAGE
2025	20	OCT	07:25	56.55N	4.54W	5	3.6			PUBIL, PERTH & KINROSS
Felt Aberfeldy, Killin, Pitlochry and Tyndrum (Perth & Kinross), Bridge of Orchy (Argyll & Bute), Fort William Highland) and several other places, mainly from within around 60 km of the epicentre, although reports were also received from further afield including Fife and Lothian (4 EMS).										
2025	20	OCT	07:27	56.54N	4.54W	8	1.7			PUBIL, PERTH & KINROSS
2025	20	OCT	16:29	56.54N	4.56W	3	2.7			PUBIL, PERTH & KINROSS
2025	20	OCT	17:06	56.55N	4.55W	3	3.7			PUBIL, PERTH & KINROSS
Felt Aberfeldy, Killin, Pitlochry and Tyndrum (Perth & Kinross), Bridge of Orchy (Argyll & Bute), Fort William (Highland) and several other places, mainly from within around 60 km of the epicentre, although reports were also received from further afield including Fife and Lothian (4 EMS).										
2025	20	OCT	17:10	56.55N	4.56W	3	2.4			PUBIL, PERTH & KINROSS
2025	22	OCT	04:40	56.11N	5.22W	8	1.9			MINARD, ARGYLL & BUTE
Felt Lochgair and Lochgilphead (3 EMS).										

<table>
<tr><th>Year</th><th>Day</th><th>Mon</th><th>Time
UTC</th><th>Lat</th><th>Lon</th><th>Dep
km</th><th colspan="3">Magnitude</th><th>Location</th></tr>
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<tr><td>2025</td><td>27</td><td>OCT</td><td>12:38</td><td>16.54N</td><td>59.56W</td><td>10</td><td></td><td></td><td>6.5</td><td>LEEWARD ISLANDS</td></tr>
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<tr><td>2025</td><td>02</td><td>NOV</td><td>20:29</td><td>36.59N</td><td>67.48E</td><td>28</td><td></td><td></td><td>6.3</td><td>AFGHANISTAN</td></tr>
<tr><td colspan="11">At least 27 people killed, over 1,170 others injured and some 2,600 buildings destroyed or damaged in Balkh province.</td></tr>
<tr><td>2025</td><td>01</td><td>NOV</td><td>05:21</td><td>58.03N</td><td>0.26E</td><td>10</td><td>1.7</td><td></td><td></td><td>CENTRAL NORTH SEA</td></tr>
<tr><td>2025</td><td>09</td><td>NOV</td><td>08:03</td><td>39.49N</td><td>143.38E</td><td>10</td><td></td><td></td><td>6.8</td><td>OFFSHORE HONSHU, JAPAN</td></tr>
<tr><td colspan="11">A tsunami was generated with a maximum wave height of 20 cm recorded at Kuji and Ofunato, Japan.</td></tr>
<tr><td>2025</td><td>19</td><td>NOV</td><td>06:06</td><td>52.61N</td><td>2.75W</td><td>10</td><td>1.9</td><td></td><td></td><td>LONGNOR, SHROPSHIRE</td></tr>
<tr><td>2025</td><td>21</td><td>NOV</td><td>04:38</td><td>23.86N</td><td>90.54E</td><td>27</td><td></td><td></td><td>5.4</td><td>BANGLADESH</td></tr>
<tr><td colspan="11">At least 10 people killed and some 630 others injured in and around the capital, Dhaka.</td></tr>
<tr><td>2025</td><td>22</td><td>NOV</td><td>04:24</td><td>56.55N</td><td>4.53W</td><td>5</td><td>2.5</td><td></td><td></td><td>PUBIL, PERTH & KINROSS</td></tr>
<tr><td colspan="11">Felt Aberfeldy and Pitlochry (3 EMS).</td></tr>
<tr><td>2025</td><td>24</td><td>NOV</td><td>02:29</td><td>59.04N</td><td>1.19E</td><td>25</td><td>3.2</td><td></td><td></td><td>NORTHERN NORTH SEA</td></tr>
<tr><td>2025</td><td>29</td><td>NOV</td><td>10:41</td><td>56.55N</td><td>4.53W</td><td>4</td><td>3.0</td><td></td><td></td><td>PUBIL, PERTH & KINROSS</td></tr>
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<tr><td>2025</td><td>29</td><td>NOV</td><td>11:32</td><td>56.53N</td><td>4.54W</td><td>3</td><td>1.5</td><td></td><td></td><td>PUBIL, PERTH & KINROSS</td></tr>
<tr><td>2025</td><td>29</td><td>NOV</td><td>17:07</td><td>56.53N</td><td>4.54W</td><td>3</td><td>2.0</td><td></td><td></td><td>PUBIL, PERTH & KINROSS</td></tr>
<tr><td>2025</td><td>03</td><td>DEC</td><td>23:23</td><td>54.17N</td><td>2.84W</td><td>3</td><td>3.2</td><td></td><td></td><td>SILVERDALE, LANCASHIRE</td></tr>
<tr><td colspan="11">Felt Silverdale, Carnforth, Morecambe, Kendal, Milnthorpe, Grange-over-Sands, Lancaster, Kirkby Lonsdale and several other places, mainly from around 25 km from the epicentre (5 EMS).</td></tr>
<tr><td>2025</td><td>05</td><td>DEC</td><td>12:13</td><td>56.35N</td><td>5.26W</td><td>3</td><td>2.4</td><td></td><td></td><td>ANNAT, ARGYLL & BUTE</td></tr>
<tr><td colspan="11">Felt Taynuilt and KilchrenaN (3 EMS).</td></tr>
<tr><td>2025</td><td>06</td><td>DEC</td><td>02:28</td><td>50.41N</td><td>1.01W</td><td>5</td><td>2.1</td><td></td><td></td><td>ENGLISH CHANNEL</td></tr>
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<tr><td>2025</td><td>06</td><td>DEC</td><td>20:41</td><td>60.40N</td><td>139.60W</td><td>17</td><td></td><td></td><td>7.0</td><td>YAKUTAT, ALASKA</td></tr>
<tr><td>2025</td><td>07</td><td>DEC</td><td>16:16</td><td>55.81N</td><td>5.98W</td><td>8</td><td>1.7</td><td></td><td></td><td>JURA, ARGYLL & BUTE</td></tr>
<tr><td>2025</td><td>08</td><td>DEC</td><td>14:15</td><td>41.00N</td><td>142.18E</td><td>45</td><td></td><td></td><td>7.6</td><td>OFFSHORE HONSHU, JAPAN</td></tr>
<tr><td colspan="11">At least 52 people injured and several buildings damaged in Aomori, Iwate and Hokkaido. A tsunami was generated with a maximum wave height of 70 cm, recorded at Kuji, Japan.</td></tr>
<tr><td>2025</td><td>08</td><td>DEC</td><td>21:52</td><td>40.98N</td><td>143.16E</td><td>19</td><td></td><td></td><td>6.6</td><td>OFFSHORE HONSHU, JAPAN</td></tr>
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<tr><td>2025</td><td>19</td><td>DEC</td><td>05:03</td><td>54.16N</td><td>2.85W</td><td>3</td><td>2.4</td><td></td><td></td><td>SILVERDALE, LANCASHIRE</td></tr>
<tr><td colspan="11">Felt Silverdale, Carnforth, Morecambe, Milnthorpe, Grange-over-Sands, Lancaster and several other places, mainly from around 15 km from the epicentre (4 EMS).</td></tr>
<tr><td>2025</td><td>22</td><td>DEC</td><td>10:31</td><td>5.70S</td><td>145.54E</td><td>107</td><td></td><td></td><td>6.5</td><td>PAPUA NEW GUINEA</td></tr>
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			Time			Dep	Magnitude			
Year	Day	Mon	UTC	Lat	Lon	km	ML	Mb	Mw	Location
2025	23	DEC	00:11	57.42N	4.27W	8	1.6			INVERNESS, HIGHLAND
Felt Scaniport, Farr, Errogie and Inverarnie (3 EMS).										
2025	27	DEC	15:05	24.69N	122.05E	63			6.6	TAIWAN
One person killed and several buildings damaged in Taipei.										

Forthcoming Events

Evening Lecture

The 2nd Generation of Eurocode 8 – Key changes and implications for the UK

Professor Ahmed Elghazouli
Ziggy Lubkowski

Hybrid event
29 April 2026 (6:00 pm UTC)

Synopsis

In 2012, the European Commission issued mandate M/515 to amend the existing Eurocodes and extend their scope. This has resulted in the current evolution activities leading to the new Eurocodes and associated National Annexes being published in 2026.

This meeting will focus on the main changes and developments in the 2nd Generation of Eurocode 8 and the implications for the UK. It will include an overview of the development of the National Annexes and supporting published data.

Introduction – 2nd Gen EC8 Development and UK Implementation

- General progress and timeline for EC8 publication
- Activities of CEN TC250/SC8 and BSI/B525/8

Overview of Structural Design and Assessment

- Key changes and additions in different parts of the code
- Outline of main aspects in EN1998 Parts 1-2, 2, 3, 4

Seismic Actions and Design Approaches

- Design Spectra and Actions in Part 1-1
- Force and displacement based approaches

Hazard and Geotechnical Aspects

- European and UK Hazard
- Site Effects in Part 1-1 and Geotechnical Design in Part 5.

About the speaker

Professor Ahmed Elghazouli is Chair of BSI Committee B525/8 on seismic design, a member of BSI Committee B525 on building and civil engineering structures, and a member of the management committee of the European CEN/TC250/SC8 on seismic design. He is a Fellow of the Royal Academy of Engineering (FREng), Fellow of the Institutions of Civil and Structural Engineers (FICE; FIStructE), and a past Chair of SECED.

He has been Head of Structural Engineering at Imperial College London, and has held full-time appointments in industry and academia, including at the University of Edinburgh and at the Hong Kong Polytechnic University, in addition to various other visiting posts.

His main research interests are related to the response of structures to seismic and other extreme loads. He has led numerous research projects and authored more than 500 publications in these areas. He has over 30 years of experience as a specialist design consultant on many important engineering projects worldwide.

Ziggy Lubkowski is a seismic expert and global geo-seismic skills leader at Arup. He is a Fellow of the Institution of Civil Engineers (FICE) and was the past chair of both SECED and EEFIT. His work focuses on advising our clients on the resilience of their assets within the built environment, specifically seismic design, analysis and assessment for the energy, infrastructure, manufacturing and humanitarian sectors.

He has been heavily involved in seismic code development in the UK, the Caribbean, the Middle East and specifically for port structures. He has been a long-standing member of the British Standards Institution Committee B/525/8 focussing on geotechnical aspects and is now deputy chair.

In 2010, he was awarded the Shamsher Prakash prize for excellence in practice of geotechnical earthquake engineering and in 2018, he became a RAEng Visiting Professor in Geotechnical Earthquake Engineering at UCL.

In person attendance

The event will held in-person at the Institution of Civil Engineers. Prior registration is not required. Seats are allocated on a first come, first served basis. We encourage everyone to attend in person if they can.

Join online

Please click on the link here to register to the Zoom meeting online.

Further information

The EEFIT Annual General Meeting (AGM) will begin at 18:00, followed by the SECED AGM at 18:15. The lecture will start at 18:30. The lecture is organised by SECED, and chaired by Dr Damian Grant (Arup). The event is open to all and is free to attend.

Programme:

17:30 - 18:00: Registration and refreshment
18:00 - 18:15: EEFIT Annual General Meeting
18:15 - 18:30: SECED Annual General Meeting
18:30 - 19:30: Lecture: The 2nd Generation of Eurocode 8 – Key changes and implications for the UK
19:30 : Close