ESG7

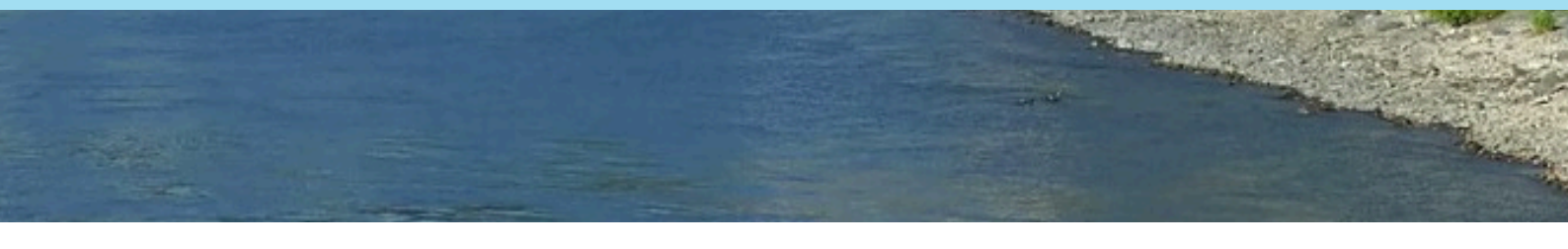
7th IASPEI/ IAEE International Symposium on the Effects of Surface Geology on seismic motion



OCTOBER 19-21 2026

GRENOBLE / FRANCE

BOOK OF ABSTRACTS



Monday, October 19, 2026

8h30-9h30 ***Registration & welcome coffee***

9h30-10h00 ***Opening ceremony***

Session A1 : Keynotes I

Chairmen: S. Matsushima & C. Cornou

10h00-10h45 **Genesis and the history of the series of ESG symposia**

Introduction lecture *The IAEE-IASPEI Joint Working Group and previous ESG organizers*

10h45-11h30 **O01 - The 2026 Joyner Memorial Lecture on Seismic Wave Propagation in Complex Geological Domains: From Site Effects in Ground Motion to Diffuse Fields in Passive Seismology**

Keynote lecture ***F. J. Sánchez-Sesma***

11h30-13h30 : Lunch break & poster session *(lunch in the same hall as the poster session)*

(Topics: past earthquakes, source characteristics, damages, ground motion models, PSHA, non-linearity, site characterization & ground structure imaging; sessions A3 & B1)

Session A2 : Recent damaging earthquakes

Chairmen: F. Bonilla & A. Yong

13h30-14h15 **O02 - Unprecedented site effects observed at a couple of sites in the Noto peninsula, Japan, during the 2024 Noto peninsulia earthquake of Mw7.4: large amplification, long duration, and strong nonlinearity**

Keynote lecture ***H. Kawase****, K. Nakano, E. Ito, H. Yamanaka, Z. Wang, and S. Matsushima*

14h15-14h45 **O03 - What the Ground Revealed: Insights into Near-Fault Site Effects from Two Contrasting Geological Settings During the 2026 La Guaira, Venezuela Earthquake**

Keynote lecture ***F. Pinto****, D. Pizarro, F. Rojas, R. Boroschek, C. Pastén, F. Ochoa, P. Heresi, J. Felipe Beltran, R. Herrera, L. Quintero*

Session A3 : Large past earthquakes and site amplification at regional scale

Chairmen: J. Régnier & TBA

14h45-15h00 **O04 - Ground motion characteristics and basin amplification from the Mw 7.7 Myanmar earthquake recorded in northern and central Thailand**

N. Poovarodom*, A. Jirasakjamroonsri, P. Likhitsuwan, A. Apakarin, and P. Warnitchai*

15h00-15h15 *(PhD student presentation)* **O05 - Application of Seismic Interferometry to Continuous Strong-Motion Records Observed in Affected Areas of the 2023 Southeastern Turkey Earthquake**

T. Ono*, H. Yamanaka, S. Tsuno, N. Takai , M. Yoshimi, H. Miyake, O. Özel, O. Tuna Özmen, D. Çaka, P. Duran, M. Safa Arslan, Ş. Bariş, A. Askan, and G. Tanırcan*

15h15-15h30 **O06 - Directional Nonlinear Site Response: Evidence From The 2011 Mw 9.0 Tohoku Earthquake**

C. Pastén*, J. Bustos, P. Heresi, S. Ruiz, and L. F. Bonilla*

15h30-16h00 : Coffee break

16h00-16h15 **O07 - An Extreme Peak Ground Acceleration Of 1.14 G At The Csob Station (Campi Flegrei, Italy): Site And Instrumentation Insights**

	***L. Nardone**, C. Martino, M. Orazi, F. Liguoro, A. Tramelli, V. Convertito, M. G. Soldovieri, M. Carandente, S. Madonna, A. Benincasa and A. Caputo*
16h15-16h30	**O08 - Regional and Site-Specific Site Effects in the Northeastern United States** ***L. Baise**, E. Meyer, J. Kaklamanos , and A. Abbas*
16h30-16h45	**O09 - Seismic bedrock as a reference : extracting hard-rock ground motions and predicting regional amplification** ***M. Pilz** and F. Cotton*
16h45-17h00	**O10 - Accounting for site effects significantly reduces uncertainties in earthquake stress parameters** *C. Ji and **R. J. Archuleta***
17h00-17h15 *(PhD student presentation)*	**O11 - Site term estimation in Europe using the late coda of weak motion earthquake recordings** ***L. Schreiner**, H. Pedersen, N. Shapiro, F. Cotton, and S. R. Kotha*
17h15-17h30	**O12 - Installation Effects of Seismological Stations on Seismic Recordings: the Impact of Depth, Near-Vertical Topography, Buildings, and Coupling Configurations** ***P. Rischette**, F. Hollender, V. Perron, N. Theodoulidis, Z. Roumelioti, P. Traversa, M. Cushing, P-Y. Bard, A. Bou Nassif , E. Maufroy, E. Chaljub, M. Buscetti, I. Douste-Bacqué, A. Konidaris*

17h30-19h00 : Poster session (A3 & B1)

(Topics: past earthquakes, source characteristics, damages, ground motion models, PSHA, non-linearity, site characterization & ground structure imaging)

Tuesday, October 20, 2026

Session B1 : Microtremor & site response

Chairmen : E. Chaljub & M. Yoshimi

08h30-09h15 **Keynote lecture**	**O01 - H/V spectral ratios: consensus reached and debated issues after four decades of investigations** ***P.-Y. Bard***
09h15-09h30	**O02 - 3D numerical simulations of ambient seismic noise: disentangling source distribution and lateral heterogeneity effects on H/V amplitude and polarization** ***D. Gregor**, E. Chaljub, M. Wathelet , F. Hollender, V. Perron and F. de Martin*
09h30-09h45	**O03 - Site Amplification Estimates From Empirical And Numerical Methods In Italy** ***S. Hailemikael**, G. Cultrera, G. Lanzano, C. Barnaba, G. Laurenzano, M. R. Gallipoli, G. Martini, A. Peloso, S. Sgobba, F. Pacor*
09h45-10h00	**O04 - Review of Site Response Modeling Conditional On HVSR** ***J. P. Stewart**, Francisco Javier G. Ornelas , Christopher A. de la Torre, Tristan E. Buckreis , Chukwuebuka C. Nweke , and Scott J. Brandenberg*

10h00-10h30 : Coffee break

10h30-10h45	**O05 - Region-Specific Amplification Hazard Mapping of Metro Vancouver, British Columbia, Canada** ***S. Molnar,** A. Bilson Darko, H. Ghofrani, M. Salsabili, N. Gómez Jaramillo, and 35 project team members*
10h45-11h00	**O06 - Assessment of site amplification factors from the non-reference site approach – a case study of the Taipei basin** ***C.-H. Kuo** and Yi-Jei Chen*

Session B2 : Benchmark I

Chairmen : M. Wathelet & S. Tsuno

11h00-12h00	**O07 - OSCAR (One Station methods for site ChARacterisation) benchmark** ***E. Chatziagnostou,** F. Hollender, C. Cornou, P.-Y. Bard, S. Foti, N. Theodoulidis, V. Perron, H. Kawase, F. Sánchez-Sesma, E. Chaljub, D. Gregor, A. Aaskan, and the 61 participants of the benchmark (list in appendix)*

12h00-13h30 : Lunch break & poster session (lunch in same hall as the poster session)

(Topics: seismic microzonation, H/V, site characterization, DAS, new methods & data, OSCAR benchmark; sessions B1, B2, B3, B4)

Session B3: DAS for site characterization & site response

Chairmen: D. Mercerat & M. Mazanec

13h30-14h00 **Keynote lecture**	**O08 - Fibre optic sensing in Geosciences: state of the art and future** **P. *Jousset***
14h00-14h30 **Keynote lecture**	**O09 - DAS Site Characterization: Opportunities and Challenges** ***B. Cox***

14h30-14h45	**O10 - Development Of The Subsurface Velocity Structure Model And Source Monitoring Technology Utilizing Fiber Optic Sensing** ***S. Naito**, H. Nakamura, H. Fujiwara, H. Suzuki, N. Ogawa, K. Sakurai, M. Takebe, H. Saito, K. Ochi and H. Ishige*
14h45-15h00	**O11 - Ambient noise interferometry applied to das arrays: seasonal site monitoring in a quiet marsh floodplain** ***S. Ayjaz Mohammed**, L. F. Bonilla, C. Gélis, E. Stutzmann, Le Tang, E. Bertrand, S. Hok, M. Lehujeur, D. Le-paroux, Y. Boussafir, Y. Capdeville, O. Durand, G. Gugole, L. Saussaye*

15h00-15h30 : Coffee break

Session B4 : New observations, data & methods for site amplification and characterization

Chairmen. E. Youssef & TBA

15h30-15h45	**O12 - Detecting seasonal variations of seismic site response: testing in the NE Hokkaido, Japan** ***A. Haendel**, L. C. Malatesta, M. Pilz, D. Litwin, and F. Cotton*
15h45-16h00 (PhD student presentation)	**O13 - Unveiling Type Of Fiber And Coupling Conditions Effects On Distributed Fiber Optic Sensing** ***V. Carrillo-Barra**, D. Mercerat, V. Brémaud, A. Sladen, O. Sèbe, A. Vallage, J.-P. Ampuero*
16h00-16h15 (PhD student presentation)	**O14 - An adapted P-wave seismogram approach for direct Vs30 estimation in Greece** ***E. Pappa**, C. Papazachos, N. Chatzis, N. Theodoulidis, F. Hollender*
16h15-16h30 (PhD student presentation)	**O15 - Soil-Compaction Rates From PS-Insar As A Proxy For Resonance Period Inferred In Various Sedimentary Valleys** ***V. Schindelholz**, A. Cheaib, E. Maufroy, C. Cornou, E. Pathier, J. Régnier, A. Roullé, V. Perron, F. Hollender, H. Jomard, G. Laurenzano and P. Klin*
16h30-16h45 (PhD student presentation)	**O16 - A method for estimating complex broadband frequency response functions and generating virtual seismograms** ***R. Amiri Fard**, S. Parolai, F. Panzera, F. Romanelli*

16h45-19h00	**Poster session (B1, B2, B3 & B4)** *(Topics: seismic microzonation, H/V, site characterization, DAS, new methods & data, OS-CAR benchmark)*

19h00-22h30 : GALA DINER

(Bus departure for the Gala diner : 18h30 and 18h45)

Wednesday, October 21, 2026

Session C1 : Machine-learning site effects

Chairmen : F. Gatti & K. Hayashi

08h30-09h15 **Keynote lecture**

O01 - Searching in the Data: Machine-learning Site Effects for Characterisation and Ground Motion Synthesis

D. Assimaki

09h15-09h30

O02 - Development of machine learning model to estimate site amplification factors using microtremor time histories

***Y. Anda**, F. Nagashima and S. Matsushima*

09h30-09h45

O03 - Recent efforts to predict site effects from microtremor horizontal-to-vertical spectral ratios with artificial intelligence

***J. P. Vantassel**, A. Rodriguez-Marek, B. Anbazhagan, K. Sharma Wagle and A. Kottke*

09h45-10h00

O04 - Characterization And Identification Of Site Effects Through Multivariate Statistical Analysis

***G. Cultrera**, A. Mercuri, F. Panzera, S. Sgobba, P. Bergamo*

10h00-10h30 : Coffee break

10h30-10h45

O05 - Ai-Based Quality Check And Interpretation Of Microtremor H/V Curves

***S. Castellaro**, L. Dal Compare*

10h45-11h00

O06 - Transferability of Machine-Learning Models for Site Response Prediction using mHVSR and its Derived Peak Parameters

***F. Javier G. Ornelas**, C. A. de la Torre, T. E. Buckreis, C. C. Nweke, S. J. Brandenberg, J. P. Stewart, L. M. Wotherspoon 7, A. C. Stolte*

Session C2: Benchmark II

Chairmen : J.-F. Semblat & E. Chaljub

11h00-12h00

O07 - BEnchmark of 3D Numerical simulations on TOpographic Site (BENTO)

***A. Bou Nassif**, E. Chaljub, E. Maufroy, D. Gregor, F. Hollender, P.-Y. Bard, E. El Haber, V. Perron, P. Rischette, E. M. Cushing, C. Cornou, N. Glinsky, M. Galis, P. Moczo, N. Babaadam, J. Kristek, M. Kristekova, R. Hu, W. Zhang, X. Chen, S. Miyanaga, N. Yamada, S. Tsuno, H. Yamanaka, C. Bourdeau, K. Kato, A. Chakraborty, H. Goto, Y. Mitsuhashi, A. Nakatsuji, A. Imtiaz, M. Koroni, L. Ermert, K. Kasamatsu, T. Hikita, Y. Tomozawa, P. Klin, R. Puglia, F. Linsalata, C. Smerzini, M. Vanini, F. De Martin, V. Soto Moncada, F. Lopez Caballero, and Z. Ye*

12h00-13h00 : Lunch break

13h00-14h30 : Poster session (C1, C2 & C3)

(Topics: BENTO Benchmark, ground motion simulation, machine learning)

Session C3 : Ground motion simulation

Chairmen : F. De Martin & M. Koroni

14h30-14h45

(PhD student presentation)

O08 - Study on estimating love wave phase velocity using translational and rotational motions in 3D subsurface structure based on numerical simulation

***Y. T. Chou** , S. Matsushima, and F. Nagashima*

14h45-15h00

O09 - Revisiting the Translational And Rotational Motion In A Semi-Infinite Layer In The Time, Frequency And Time-Frequency Domains

	***P. Moczo**, P.-Y. Bard, N. Babaadam, J. Kristek, M. Kristekova, and M. Galis*
15h00-15h15	**O10 - Physics-Based Simulation And Analysis Of Near-Fault Ground Motion For The 2021 Mw 6.1 Yangbi, China Earthquake** ***R. Wen**, C. Li, M. Vanini, R. Paolucci, H. Wang, S. Qiang, and Y. Ren*
15h15-15h30	**O11 - Towards Physics-Based Seismic Ground Motion And Site-City Interaction In Urban Areas: A Case Study In Mexico City** ***R. Paolucci**, S. Sangaraju, and V. M. Hernández-Aguirre*
15h30-15h45	**O12 - Frequency- and component-dependent topographic effects on ground-motion in the Swiss Rhône Valley** ***M. Koroni**, L. Ermert, P. Bergamo, J. Sunny, D. Fäh*
15h45-16h00	**O13 - Benchmarking Finite-Difference Simulations Of Surface-To-Borehole Spectral Amplification In 3D Scattering Media** ***I. Oprsal**, M. Hallo, D. Fäh, M. Labuta, J. Burjanek*
16h00-16h15	**O14 - Ground motion study in central Wajima, Japan, based on three-dimensional finite difference method considering soil nonlinearity** ***H. Nakagawa**, Y. Masuyama, and M. Nagano*
16h15-16h30 (PhD student presentation)	**O15 - Basin amplification factors from 3-D physics-based ground motion simulations in Kahramanmaras** ***B. Bilgen** and A. Askan*

16h30-17h00 : Coffee break

17h00-17h15	**O16 - Ground motion variability in Israel: insights from M7 regional simulations on the dead sea fault system** *N. Shachrur, C. Porat-Dekel, R. Kamai and **M. Tsesarsky***
17h15-17h30 (PhD student presentation)	**O17 - Characterization of ground motion variability in the Kyoto basin using physics-based ground motion simulations** ***T. Yadanar**, S. Matsushima, and F. Nagashima*
17h30-17h45 (PhD student presentation)	**O18 - Deterministic Numerical Modelling Of Wave Propagation During The Main Aftershocks Of Le Teil Earthquake (November 2019, ArdÈChe, France) And Characterization Of Associated Uncertainties** ***A. Gounelle**, F. de Martin, E. Chaljub, F. Lavoué, D. Do Couto, E. M. Cushing, C. Gélis*

Session C4 : Round table

17h45-18h30	***ESG scientific perspectives*** ***Session chairs***
18h30-19h00	***Closing Ceremony***

POSTER SESSION

Monday, October 19, 2026

Session A3

P01 Strong Motion Characteristics in the source Area of the 2024 Noto Peninsula Earthquake (Mw7.6), Japan.
Tomotaka Iwata, Kimiyuki Asano and Haruko Sekiguchi

P02 Strong-motion characteristics and ground-motion directionality at Armenia, Colombia : a comparison of the 1999 and 2026 earthquakes
Carlos Lozano, Fernando Lopez-Caballero, Malcon Celorio, Juan Reyes

P03 Preliminary Investigation Of High-Frequency Attenuation Parameter (Kappa) In The Noto Peninsula: Characteristics Before And After The 2024 Noto Earthquake.
Hiroaki Sato

P04 Long Period Ground Motions In The Osaka Basin In Southwest Japan During Recent Large Earthquakes.
Kimiyuki Asano

P05 Reconstruction Of Damage Inventory 30 Years After The 1996 Annecy Earthquake (Mw 4.9) In The French Alps, According To The Ems-98 Scale, And Comparison With Epicentral Source And Site Effects.
Emeline Maufroy, Pauline Rampon, Mathieu Causse, Christophe Sira, Valentin Schindelholz, Vincent Perron, Fabrice Hollender, Cécile Cornou, and Hervé Jomard

P06 Spatial Distribution Of Microtremor Horizontal-To-Vertical Spectral Ratios In Wajima And Suzu Cities: Implications For Building Damage During The 2024 Noto Peninsula Earthquake.
Hiroki Yamanaka, Shinichi Matsushima, Fumiaki Nagasihma, Eri Ito, and Hiroshi Kawase

P07 Towards Predicting Site Effects In The French West Indies At A Regional Scale.
Yoann Legendre, Hussein Shible, Coline Biserta, Didier Bertil, Agathe Roullé, Samuel Auclair, Pierre Gehl, Romain Guidez, Anne Lemoine, Caterina Negulescu, Roxanne Rusch

P08 Site Effects Mapping At Regional Scale In Mayotte Island.
Roullé Agathe, Raingeard Anne, Legendre Yoann, Rusch Roxanne, Reninger Pierre-Alexandre, Beaubois Florent, Dectot Grégoire, Sadeski Ludivine, Bitri Adnan

P09 Empirical Site Amplification In Deep Sedimentary Basins In The Kansai Region Of Japan.
Miroslav Hallo, Kimiyuki Asano, Haruko Sekiguchi, and Tomotaka Iwata

P10 Site Amplification Characteristics In Machino Town, Wajima, Japan Derived From Temporary Aftershock Observations.
Hiroyuki Kosaka, Seiji Tsuno, Masahiro Korenaga, Hiroaki Yamanaka, Hiroe Miyake, Towa Ohno, and Kotomi Iwamoto

P11 Influence Of Seawater On Seismic Ground Motion Observed At The Seafloor
Misa Moriwaki, Seiji Tsuno, and Masahiro Korenaga

P12 Investigation Of Site Amplification Characteristics Using Surface Wave And Microtremor Array Measurements At Aftershock Observation Stations In Wajima City, Japan.
Michiko Shigefuji, T ai Nobuo, Seiji Tsuno, Hiroaki Yamanaka, Masahiro Korenaga, Hiroe Miyake, Hiroyuki Kosaka, Kimiyuki Asano, Kosuke Chimoto, and Tatsuo Kanno

P13 Spatial Variation Of Empirical Site Amplification Factors In Japanese Ports And Their Predictability By Microtremor Observation
Yosuke Nagasaka and Atsushi Nozu

P14 Geophysical Investigation Of Amorgos Island (Cyclades, Greece) And Its Unexpected Response To The 1956 Santorini Earthquake.
Andy Combey, Diego Mercerat, Vasiliki Kouskouna and Frédérique Leclerc

P15 Site Amplification Study For The Santorini Volcanic Island Using Data From The Dense Santoarray Network.
Nikos Chatzis, Costas Papazachos, Costas Gkogkas and Evi Pappa

P16 Towards Next-Generation Regional And Urban Site Amplification Models: Leveraging Cross-Disciplinary Approaches And Multi-Sensor (Including Smartphone) Data Fusion.
Fabrice Cotton, Remy Bossu, Francesco Finazzi, Karina Loviknes, and Graeme Weatherill

P17 Local Site Effects In Petropavlovsk-Kamchatsky And Surroundings During The Kamchatka Earthquake Of 29 July, 2025.
Olga Pavlenko, Danila Chebrov

P18 Seismic Wave Amplification In Sandy Barriers Of The Gulf Of CÁDiz: The Case Of Isla Cristina (Huelva, Spain) And Potential Cascading Geological Hazards.
David Amador Luna, Albert Macau, Beatriz Zapico, José Miguel Pellicer, Manuel Vázquez Boza, Carlos Merino, José Manuel Torres, Encarnación García-Navarro and Francisco M. Alonso-Chaves

P20 A Bayesian Framework For Near-Fault Ground Motion Reconstruction From In-Situ Observation: Case Study Of The 2019 Le Teil Earthquake.
Hongyi Su, Mathieu Causse, Cécile Cornou, Sébastien Hok and Céline Gélis

P21 On The Seismic Moment Dependency Of Source-Controlled Fmax.
Kenta Kobayashi and Hitoshi Morikawa

P22 Depth Dependency Of Stress Drop In Strong Motion Generation Areas For Interplate Earthquakes In Japan.
Susumu Kurahashi, Ken Miyakoshi and Kojiro Irikura

P23 Source Characteristics Of The 2023 Elbistan, Türkiye, Earthquake (Mw 7.7) Based On A Joint Inversion Of Strong-Motion Waveforms And Satellite-Based Geodetic Data.
Yujia Guo, Ken Miyakoshi, and Kazuhiro Somei

P24 Source Characterization Of The 2023 Kahramanmaraş, TÜRkiye, Earthquake Using Strong Motion And Geodetic Data.
Kazuhiro Somei, Ken Miyakoshi, Yujia Guo, and Yasuhiro Matsumoto

P25 Source Spectral Characteristics Of Long-Period Ground Motion Inferred From The F-Net Broad Band Strong Ground Motion Records.
Ken Hatayama

P26 Long-Period Ground Motions Generated In Shallow Zone Above Seismogenic Zone For Inland Crustal Earthquakes With Surface Ruptures.
Ken Miyakoshi, Yujia Guo, Kazuhiro Somei, Susumu Kurahashi, Yasuhiro Matsumoto, Naoto Inoue, Takashi Kumamoto, Katsuhiro Kamae, and Kojiro Irikura

P27 Surface Ground-Motion Variability Due To Source Variability For Improved Site-Specific Seismic Hazard Assessment.
Zishu Ye, Karim Tarbali and Fernando Lopez Caballero

P28 Site Response Changes During Strong Earthquake Shaking: Recent Case Studies From Japan.
Yadab P. Dhakal and Takashi Kunugi

P29 Understanding Nonlinear Soil Response Using Velocity And Frequency Changes: Examples From Iwate Prefecture, Japan.
Alessandra Schibuola, Ssu-Ting Lai, Luis Fabián Bonilla, Eléonore Stutzmann, Martin Schimmel

P30 Characterizing Linear And Nonlinear Site Responses Using Single-Station Time-Frequency Analysis Across Multiple Regions.
Ssu-Ting Lai, Alessandra Schibuola, Luis Fabian Bonilla, Karina Lovkines, Dino Bindi and Fabrice Cotton

P31 Evaluating Nonlinear Site Response Using Deconvolution-Based Seismic Interferometry In Kik-Net Vertical Arrays.
Alessandra Schibuola, and Stefano Parolai

P32 Towards A Correction Of Downhole Station To Ec8 Reference Rock Outcrop Ground Motion For Kik-Net Sites Considering Nonlinear Soil Behavior.
Joya El Hitti, Julie Régnier, Céline Gélis, Luca Lenti

P33 Impact Of Equivalent-Linear Relationships For Nonlinear Soil Behavior On The Amplification Of Seismic Ground Motion.
Eleni Koufoudi, Martin Koller, and François Dunand

P34 Case Study Of A Combined Assessment Of Seismic And Liquefaction Hazards Using Different Approaches.
Cyril Gomes

P35 Multi-Output Gaussian Processes For Nonlinear Site Amplification With Cross-Period Correlation.
Victor M. Hernández-Aguirre and Rajesh Rupakhety

P36 Probabilistic Seismic Hazard Assessment For Mainland France.
Judith Marinière, Céline Beauval, Sofía López Ordoñez, S. Lambotte, T. Bonami, F. Masson, L. Jeandet, S. Mazzotti, H. Jomard, P. Georges, S.R. Kotha, M. Métois, A. Periollat, F. Hollender, E. Maufroy

P37 Probabilistic Seismic Hazard Assessment For The French Islands In The Lesser Antilles.
Sofía López-Ordóñez, Céline Beauval, Judith Marinière, Marion Alloncle, Didier Bertil, Jordane Corbeau, Océane Foix, O'Leary González, Roser Hoste-Colomer, Hervé Jomard, Sreeram Reddy Kotha, Anne Lemoine, Aurore Laurendeau, Emeline Maufroy, Stéphane Mazzotti, Mélody Philippon, Agathe Roullé, Claudio Satriano, Jean-Marie Saurel, Hussein Shible

P38 Local Gmpe Calibration And Non-Ergodic Seismic Hazard In The Cyclades: A Three-Stage Bayesian Framework And Its Implications For Psha.
Ziya Cekinmez, Olga-Joan Ktenidou, and Laurentiu Danciu

P39 Evaluating Sampling Strategies For Convolution-Based Integration Of Site Effects In Partially Non-Ergodic Psha
Haifa Tebib, Angeliki Lessi-Cheimariou, Manuela Daví and Iain Tromans

P40 On Ergodicity In Hybrid Broadband Ground Motion Simulations.
Srihari Sangaraju, and Sreeram Reddy Kotha

P41 Probabilistic Seismic Hazard Analysis At Depth For Deep Geological Repositories.
Louison Laruelle, Marco Pilz, Fabrice Cotton, and Oliver Heidbach

P42 Uncertainty Projected Mapping Of Site-Response Across Europe: A Case Study In France.
Anirban Chakraborty and Sreeram Reddy Kotha

P43 Toward An Attenuation Proxy: Adapting A European Gmm To The Fourier Domain And Investigating Spatial Variability In France.
Pauline Georges, Sreeram Reddy Kotha and Emmanuel Chaljub

P44 Regionalized And Non-Ergodic Gmms For Crustal Earthquakes In Northern Vietnam.
Van Bang Phung, Norman Abrahamson, Chun-Hsiang Kuo, Bor-Shouh Huang, Nguyen Cong Nghia, and Le Minh Nguyen

P45 Extracting Ground Motion Time Series At The Seismological Bedrock Reference Horizon.
Marco Pilz and Fabrice Cotton

P46 Identifying Reference Sites: Methodologies And Applications In Mainland China REN Yefei
Yefei Ren, Xuesong Wang, Ye Liu and Ruizhi Wen

P47 Advancing Trans-Dimensional Bayesian Inversion For Earthquake Hazard Prediction.
Charlotte Motuzas, Sheri Molnar and Stan Dosso

P48 Site Effects Of West Texas Earthquakes Through Stochastic Inversions For Source, Path And Site Parameters.
Alexandros Savvaidis, Bartik Pandel, Ellen M. Rathje, and Albert R. Kottke

P49 Evaluation Of The Regionality Of Site Amplification For The Eastern Tibetan Plateau Zone Of China: Insights From Both The Shear-Wave Velocity Profiles And Strong Motion Records.
Ruibin Hou

P50 Empirical Site Amplification Factors In Central Italy Region Through Generalized Inversion Technology On Strong Ground Motions.
Wu Shuanglan, Ren Yonglin, Nozu Atsushi, Zhong Zilan, Nagasaka Yosuke, Zhang Yi, Ueda Kyohei, Chen Guoxing

P51 Impact Of Seismic Station Housing On Ground Motion Models Uncertainties And Variability
Paola Traversa, Fabrice Hollender, Pauline Rischette, Margaux Buscetti, and Vincent Perron

Session B1

P52 A Revised Vs30 Map For Italy Integrating Topographic And Lithological Proxies With Extensive Vs30 Measurements.
Giulio Brunelli, Sara Sgobba, Giovanni Lanzano and Lucia Luzi

P53 Site Characterization Of The Israeli Seismic Network Stations
Ronnie Kamai, Gopala Krishna Roda, and Gony Yagoda-Biran

P54 Systematic Site Characterization Of Epos-France Seismological Stations Using Surface-Wave Methods.
Fabrice Hollender, Rémy Burlot, Eirini Chatzianagnostou, Pauline Rischette, Emeline Maufroy, Cécile Cornou and many other contributions

P55 On The Importance Of Explicitly Accounting For Sensor Self-Noise In Ground Motion Measurements, With A Particular Focus On Ambient-Noise H/V Analysis
Fabrice Hollender, Pauline Rischette, Vincent Perron

P56 Designing A National Soil Class Map For Switzerland Through Integrated Geophysical, Geological And Geotechnical Data.
Janneke van Ginkel, Paulina Janusz, Anastasiia Shynkarenko and Paolo Bergamo

P57 Deep Characterizarion Of Seismic Stations Using Strongmotion Records
Felipe Leyton

P58 Empirical Amplification Functions For Sicily By Using 20-Years Of Seismic Recordings.
Giuseppe Orefice, Laura Cataldi, Valerio Poggi, Paolo Bergamo, Giuseppina Tusa, Alfio Marco Borzì, Andrea Cannata and Francesco Panzera

P59 Empirical Amplification Factors In Campi Flegrei Area From Ground Motion Models Residuals.
Giovanni Lanzano, Tommaso Castelbarco, Lucia Nardone, Giovanna Cultrera, Gaetano Riccio, Maurizio Vassallo, Antonella Bobbio, Francesca Pacor, INGV Flegrei Team

P60 Geologic Classification Of Mhvsr Peaks In New Zealand
Liam Wotherspoon, Andrew Stolte, Anna Kaiser, Elena Manea and Chris de la Torre

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Camilo I. Pinilla-Ramos, Douglas S. Dreger, Arben Pitarka, Norman A. Abrahamson, Robert E. Kayen and Pablo Castellanos-Nash

List of OSCAR benchmark participants

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THE 2026 JOYNER MEMORIAL LECTURE ON SEISMIC WAVE PROPAGATION IN COMPLEX GEOLOGICAL DOMAINS: FROM SITE EFFECTS IN GROUND MOTION TO DIFFUSE FIELDS IN PASSIVE SEISMOLOGY

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ABSTRACT

This Lecture emerges from decades of research on seismic waves in complex geological media to assess ground motion, from strong shaking to weak ambient vibrations such as microtremors and seismic noise. It is dedicated to William B. Joyner, who bridged the gap between seismologists and engineers to achieve an earthquake-resilient society. Personally, the 1985 Michoacán earthquake (Mw 8.1), which caused catastrophic damage in Mexico City, was a key motivation. The Random Vibration Theory, reformulated by Boore and Joyner, helped us to craft the Mexico City building code, which incorpo-rated Fourier spectrum as a design concept. The seismic hazard is a big puzzle; we take little pieces and try to solve each. The Indirect Boundary Element Method (IBEM) enabled studying the seismic response of topographic features and alluvial valleys to educate the intuition. The need for a geomorphological description is evident. Diffuse fields allowed us to establish the exact retrieval of Green's functions from noise cross-correlations. This leads to a theory for the H/V spectral ratio to model ambient seismic noise measurements and infer subsurface layered structures. However, including lateral irregularity is a major challenge. Preliminary results suggest it is possible to spot from H/V results zones that may trap energy in earthquakes.

Keywords: seismic ground motion, wave propagation, site effect, earthquake engineering

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UNPRECEDENTED SITE EFFECTS OBSERVED AT A COUPLE OF SITES IN THE NOTO PENINSULA, JAPAN, DURING THE 2024 NOTO PENINSULA EARTHQUAKE OF MW7.4: LARGE AMPLIFICATION, LONG DURATION, AND STRONG NONLINEARITY

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ABSTRACT

On January 1, 2024, the Mw7.4 Noto Peninsula earthquake occurred in the northern part of the Noto Peninsula in Japan. The shaking caused significant damage to wooden houses in rural cities and towns, particularly in Wajima City and Suzu City. We conducted the generalized inversion analysis of observed weak motions to isolate site amplification factors for the S-wave portions as well as the whole waves. We found that two stations in both cities have extraordinarily large horizontal site amplification factors of 80 to 100 times in the frequency range of 1 Hz or less. These values cannot be explained by any simple 1D structures. To delineate the site effects of the deep basins beneath these extraordinarily large HSAF sites, we conducted linear-array and areal single-station microtremor measurements in both cities. We also conducted two-step GIT analysis to delineate nonlinear site amplification factors during the mainshock. All pieces of evidence support the 3D resonance hypothesis.

Keywords: Strong motion, 3D resonance, Nonlinearity, Sedimentary rock, Generalized inversion

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WHAT THE GROUND REVEALED: INSIGHTS INTO NEAR-FAULT SITE EFFECTS FROM TWO CONTRASTING GEOLOGICAL SETTINGS DURING THE 2026 LA GUAIRA, VENEZUELA EARTHQUAKE

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ABSTRACT

The June 24, 2026 La Guaira earthquake produced sharply contrasting responses across two geological settings in north-central Venezuela. In the Caracas sedimentary basin, severe damage concentrated in deeper, long-period sectors, repeating patterns observed in 1967 and indicating persistent basin and site effects. Along the La Guaira coast, near-fault shaking interacted with local soil conditions and geomorphology. The Catia La Mar Pleistocene terrace exhibited slope instability, foundation distress, distributed deformation, and possible topographic effects. At Caraballeda, saturated distal alluvial-fan deposits were associated with site effects, liquefaction, lateral spreading, settlement, and widespread permanent deformation.

Keywords: Near-fault effects, site effects, basin effects, ground deformation, soil dynamics

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GROUND MOTION CHARACTERISTICS AND BASIN AMPLIFICATION FROM THE MW 7.7 MYANMAR EARTHQUAKE RECORDED IN NORTHERN AND CENTRAL THAILAND

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ABSTRACT

The Mw 7.7 Myanmar earthquake of 28 March 2025 generated widespread shaking across Thailand and produced pronounced long-period ground motions in deep sedimentary basins despite source-to-site distances exceeding 1000 km. This study examines the characteristics of recorded motions in northern and central Thailand, with emphasis on the Chiang Mai and Bangkok Basins. Ground motion records, spectral accelerations, and attenuation characteristics are analyzed together with subsurface basin conditions derived from microtremor investigations. The results show clear amplification and prolonged shaking within both basins, particularly in the long-period range. In Chiang Mai, stations above deeper basement structures recorded systematically larger motions than stations with comparable Vs30 but shallower basement depths. In Bangkok, spectral amplitudes in the 2–6 s period range exceeded surrounding reference motions by more than an order of magnitude. The observations demonstrate the dominant influence of deep basin geometry on long-period seismic response, highlighting the importance of incorporating basin-scale geological effects into seismic hazard assessment and urban earthquake resilience planning in Thailand.

Keywords: Basin amplification, Long-period ground motion, Distant large earthquakes, Mw 7.7 Myanmar earthquake, Thailand

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APPLICATION OF SEISMIC INTERFEROMETRY TO CONTINUOUS STRONG-MOTION RECORDS OBSERVED IN AFFECTED AREAS OF THE 2023 SOUTHEASTERN TURKEY EARTHQUAKE

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ABSTRACT

Tomographic analysis was conducted using surface-wave group velocities estimated from cross-correlation analysis of continuous strong-motion records obtained at the temporary stations in Antakya, a sedimentary basin, that was one of the areas most severely affected by the 2023 southeastern Turkey earthquake. The tomographic maps of Rayleigh-wave group velocities at periods of 0.3–3.0 s show that the northwestern part of the plain has lower group velocities than other areas. The dispersion curves of Rayleigh-wave group velocities in each cell were inverted to obtain 1D S-wave velocity profiles, and amplification factors for S-wave were subsequently calculated using them. The spatial distribution of amplification factors shows a clear contrast between the basin and the surrounding areas, with a band of high amplification in the northern part of the basin that corresponds to regions of severe building damage. These results suggest that deep subsurface structures may have contributed to the earthquake damage.

Keywords: the 2023 Southeastern Turkey Earthquake, Seismic Interferometry,
Temporary Strong-Motion Observation, S-wave Velocity Structures, Antakya region

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DIRECTIONAL NONLINEAR SITE RESPONSE: EVIDENCE FROM THE 2011 MW 9.0 TOHOKU EARTHQUAKE

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ABSTRACT

Soils respond with nonlinear behavior during strong ground motions, resulting in a reduction of the site predominant frequency and changes in amplification. However, the directional variability of non-linearity has been overlooked. In this study, we analyze more than 3000 seismic records from three KiK-net stations in Ibaraki Prefecture, Japan, including the 2011 Mw 9.0 Tohoku Earthquake. The predominant frequency is evaluated as a function of peak ground velocity (PGV), commonly adopted as an intensity measure related to soil shear strain. The reference peak ground velocity (PGV_{ref}) is defined to relate frequency changes to seismic intensity and is estimated using a Bayesian framework. Results show a systematic reduction in frequency with increasing PGV, a trend observed in all directions with different magnitudes. The results suggest that the site's nonlinear response exhibits directionality, associated with the influence of local geomorphology on wave propagation.

Keywords: Site period, nonlinear soil behavior, stiffness degradation

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AN EXTREME PEAK GROUND ACCELERATION OF 1.14 G AT THE CSOB STATION (CAMPI FLEGREI, ITALY): SITE AND INSTRUMENTATION INSIGHTS

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ABSTRACT

Located in southern Italy, the Campi Flegrei caldera is one of the most active and closely monitored volcanic regions worldwide, representing a key natural laboratory for studying seismic phenomena, particularly in light of the recent increase in seismicity culminating in the 13 March 2025, Md 4.6, earthquake. This study investigates the ground motion generated by this event, with particular focus on the CSOB station, where an exceptional Peak Ground Acceleration (PGA) of 1.14*g* was recorded. Instrumental and seismological investigations, including HVSR analysis and site characterization, were conducted to assess the origin of this extreme unusual value. Results highlight the role of local geological conditions and directional effects in amplifying ground motion, while no significant long-term changes in seismic noise were observed. These findings indicate that site conditions, rather than source effects, primarily controlled the recorded ground motion and provide important insights for seismic monitoring and hazard assessment.

Keywords: Peak Ground Acceleration, local site effect, Campi Flegrei Caldera

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REGIONAL AND SITE-SPECIFIC SITE EFFECTS IN THE NORTHEASTERN UNITED STATES

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ABSTRACT

In this paper, we will discuss lessons learned from the unique site effects in the Northeastern United States, leveraging regional and site-specific data. We are motivated by observed spatial patterns in the site-to-site residuals from the NGA-East ground-motion models and U.S. Geological Survey "Did You Feel It?" intensity data for the 2024 **M** 4.8 Tewksbury, New Jersey, earthquake. Geomorphic provinces can be used in ground-motion models to reduce the observed regional biases, and their use can be linked to the crustal velocity structure differences in New England and New York. Beyond regional trends, local site effects are observed and evaluated with detailed site characterization. In the Northeastern United States, glaciation results in strong resonant conditions, which are observed as strong site amplification patterns across a range of sedimentary structures. In addition, there is evidence of topographic effects in the observed shaking, which is confirmed with detailed site characterization at an example site. To capture the observed behavior, we propose linear site-effects models for use in ground motion models for the region.

Keywords: site effects, intensity, Did You Feel It?, ground motion models, residual analysis

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SEISMIC BEDROCK AS A REFERENCE: EXTRACTING HARD-ROCK GROUND MOTIONS AND PREDICTING REGIONAL AMPLIFICATION

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ABSTRACT

Reliable seismic hazard assessment requires accurate (hard-)rock ground-motions. A common approach involves applying generic or site-specific corrections to surface recordings to mitigate the influence of site effects and to infer the corresponding bedrock motion. However, these corrections typically do not account for phase differences (i.e., variations in the temporal characteristics) between the surface and bedrock ground motions. Here we present a complex-valued deconvolution procedure based on the Generalized Inversion Technique (GIT) to generate a homogeneous database of time series representative of outcrop bedrock conditions at a reference observation site. This procedure incorporates a site-specific phase correction to account for differences in mean ground-motion arrival times. Following validation with KiK-net data in Japan, the procedure was extended to a large European dataset for improved ground motion modelling, encompassing recordings from a diverse range of seismological environments. The resulting database comprises over 50,000 time series derived at more than 1,400 stations across Europe. This comprehensive dataset offers significant potential for both the refinement of existing ground-motion models and the derivation of robust site-to-site residuals, enabling improved characterization of site amplification factors as well as harmonized and more accurate assessments of seismic hazard at regional and local scales.

Keywords: Site effects, deconvolution, reference ground motion, duration

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ACCOUNTING FOR SITE EFFECTS SIGNIFICANTLY REDUCES UNCERTAINTIES IN EARTHQUAKE STRESS PARAMETERS

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ABSTRACT

Retrieving the source spectra from seismic record requires the knowledge of surface geology. We account for site amplification effects using generic sediment models inferred from Vs30s and the quarter-wavelength approximation. We employ a novel strategy combining grid search with statistical analysis to search for the optimal frequency-dependent crustal attenuation model as well as the site attenuation parameter κ_0 for each site. The site effects relative to reference sites are further refined using an iterative algorithm. We evaluate the results using records from independent events within the same earthquake sequence. We find: a) although the perturbation of the inverted κ_0 is negligible, significant uncertainties exist in predicted site amplifications; b) when using the mean site response as the reference, updating the site responses does not significantly affect the mean spectra and stress parameter $\Delta\sigma_c$. However, variations of reconstructed source spectra are significantly reduced, validating the results. Solutions still carry the uncertainty associated with reference sites.

Keywords: Vs30, reference site, stress parameter, uncertainty, earthquake engineering

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SITE TERM ESTIMATION IN EUROPE USING THE LATE CODA OF WEAK MOTION EARTHQUAKE RECORDINGS

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ABSTRACT

Seismic risk assessments at a regional scale require empirical site-response maps of regional scale. However, spatial sparseness of seismic data limits reliable measurement of the frequency dependent site term. This study addresses uneven station and event distribution, by analysing weak-motion sensor recordings of European crustal earthquakes over the past 20 years. We exploit the coda wavefield, dominated by multiply scattered waves, to estimate vertical and horizontal site terms relative to a reference station. We obtain measurements at large epicentral distances by focusing on the late coda, including the coda of the crustally guided Lg wave. This approach enables robust site term measurement across nine frequency bands from 0.7-9.5Hz for up to 3337 stations in Europe. Furthermore, we combine these measurements with proxies such as slope and geological data, to create continuous site term maps of Europe. We also show that the vertical site term can be used as a proxy for the horizontal site term with a variance reduction much higher than other proxies. Our method is robust and makes it possible to reliably estimate site terms across wide areas with varying levels of seismicity, including low seismicity areas.

Keywords: Site Term, Weak-Motion Sensor, Coda Wave, Europe

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INSTALLATION EFFECTS OF SEISMOLOGICAL STATIONS ON SEISMIC RECORDINGS: THE IMPACT OF DEPTH, NEAR-VERTICAL TOPOGRAPHY, BUILDINGS, AND COUPLING CONFIGURATIONS

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ABSTRACT

Seismic hazard assessment relies on ground-motion recordings assumed to represent free-field conditions. However, installation conditions of seismological stations often deviate from this ideal configuration, potentially biasing the recordings. This study investigates the influence of installation modalities -including sensor depth, short-wavelength topography, buildings, and coupling devices- on recorded ground motion. Experiments conducted in Greece and France, comprising recordings of low-to moderate-magnitude earthquakes and ambient noise measurements, are analyzed to quantify these effects. Results show frequency-dependent amplifications and deamplifications, particularly above 5– 10 Hz depending on installation conditions. Operational correction tools, such as station-to-free-field (S2FF) functions, are proposed. Installation effects are also assessed on response spectra, magnitude estimates, and delta kappa, introducing significant biases. Incorporating installation-specific terms in ground-motion models (GMM) reduces aleatory variability by 20–30%. Based on these findings, practical recommendations are proposed for station installation, along with guidelines to improve metadata standardization and completeness.

Keywords: Seismic station installation, Ground motion recordings, Free-field condition

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STRONG MOTION CHARACTERISTICS IN THE SOURCE AREA OF THE 2024 NOTO PENINSULA EARTHQUAKE (M_W7.6), JAPAN

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ABSTRACT

The 2024 Noto Peninsula Earthquake ($M_W7.6$) struck strongly the Oku-Noto area, central Japan, resulting severe damage. We discuss the characteristics of the strong ground motions based on the observed records in the damaged area. One characteristic feature of the records in the Oku-Noto area is their long duration. This is likely because the area is located on the hanging wall side of the long source fault of reverse type with a complex rupture process. Another feature is that multiple velocity records in severely damaged areas within small basins showed predominant periods of approximately 2-3 seconds, which are closely associated with damage to residential buildings and houses. Those ground motions with the predominant periods of 2-3 seconds was generated by seismic amplification due to shallow structures, including nonlinear response.

Keywords: The 2024 Noto peninsula earthquake (Mw7.6), strong motion, source effect, site effect, non-linear site response

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STRONG-MOTION CHARACTERISTICS AND GROUND-MOTION DIRECTIONALITY AT ARMENIA, COLOMBIA: A COMPARISON OF THE 1999 AND 2026 EARTHQUAKES

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ABSTRACT

Armenia, Colombia, was affected by the 25 January 1999 Córdoba–Quindío M_L 6.3 earthquake, and on 10 August 2026 by the Mw 7.4 San José del Palmar deep intraslab event. The ARMEC station is the only one with records of both earthquakes, enabling a direct comparison using corrected three-component records, peak ground-motion measures, 5%-damped response spectra, empirical horizontal-to-vertical ratios (EHVR), and rotation-independent spectral measures. The 1999 event produced larger PGA and PGV than the 2026 event, with site response concentrated near T≈0.5 s and an EHVR peak near 2 Hz in both cases. Despite lower amplitude, the 2026 record shows stronger directional amplification at T=1.0 s (RotD100/RotD50≈1.41 versus ≈1.07 in 1999), and the maximum-response orientation shifts between events, showing that directionality depends on source-path-site interaction rather than a fixed azimuth. RotD100/RotD50 also departs from published models, and the vertical-to-horizontal ratio exceeds the Fan et al. (2026) model at long periods in 1999.

Keywords: Armenia; strong motion; site response; RotD100/RotD50; VHSR

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PRELIMINARY INVESTIGATION OF HIGH-FREQUENCY ATTENUATION PARAMETER (KAPPA) IN THE NOTO PENINSULA: CHARACTERISTICS BEFORE AND AFTER THE 2024 NOTO EARTHQUAKE

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ABSTRACT

This study investigates the characteristics of strong ground motions and high-frequency attenuation in the Noto Peninsula during the 2024 Noto Peninsula Earthquake (Mj 7.6) and the associated seismic sequence. Peak ground accelerations (PGAs) recorded at K-NET and KiK-net surface stations in the peninsula are first examined, and their distance attenuation characteristics are compared with an existing empirical attenuation relation. Site-specific high-frequency attenuation parameters (kappa, κ) are then estimated from pre-mainshock records using S-wave acceleration Fourier amplitude spectra in the 11–30 Hz frequency range, and the reference site term κ0 is derived at each station from regression of κ with epicentral distance. The spatial distribution of κ0 is analyzed together with the time-averaged shear-wave velocity in the upper 30 m (V_{S30}). Furthermore, κ values for the mainshock and post-mainshock events are compared with the pre-mainshock κ–distance regression to examine possible changes in attenuation behavior, with particular attention to the station ISK006, which recorded PGAs exceeding 2 g. Finally, high-frequency attenuation characteristics at KiK-net borehole stations are evaluated to discuss the suitability of hard-rock records for kappa estimation.

Keywords: High-frequency attenuation, Kappa, nonlinear site effect, 2024 Noto earthquake

The 7th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion
Grenoble (France), 19-21 October 2026

LONG PERIOD GROUND MOTIONS IN THE OSAKA BASIN IN SOUTHWEST JAPAN DURING RECENT LARGE EARTHQUAKES

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ABSTRACT

The Osaka sedimentary basin in Japan has been the subject of extensive research regarding long-period and long-duration ground motions for decades. In particular, long-period ground motions with periods of 5–7 s have been significantly amplified in the lowlands surrounding Osaka Bay during past large earthquakes. This study compiled ground motion records of large earthquakes ($M_{JMA} > 6.5$) occurring between 2000 and 2025, utilizing data from various networks. A comparative analysis revealed, for instance, the long-period ground motions during the 2024 Hyuga-nada earthquake were significantly weaker than those of the 2016 Kumamoto earthquake, despite their similar magnitudes, distances and back-azimuth directions. Statistical analysis of the mean and variability of the peak periods in the pseudo-velocity response spectra (pSv) was performed at each station. The resonance periods at each station remain relatively stable, although certain stations exhibit inter-event variability.

Keywords: long-period ground motion, resonance period, Osaka Basin

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RECONSTRUCTION OF DAMAGE INVENTORY 30 YEARS AFTER THE 1996 ANNECY EARTHQUAKE (Mw 4.9) IN THE FRENCH ALPS, ACCORDING TO THE EMS-98 SCALE, AND COMPARISON WITH EPICENTRAL SOURCE AND SITE EFFECTS

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ABSTRACT

This reconstruction exercise of the damage caused by the 1996 Annecy earthquake (Mw 4.9) in the French Alps exploits macroseismic data collected at the time by the BCSF. It consists of more than a thousand individual forms filled out by people affected by the earthquake in their residences in the epicentral area. Each form is analyzed to convert people's description into a damage inventory made for scientific applications. This extended abstract describes the conversion process from testimony to degrees of damage and vulnerability of the affected building according to the EMS-98 scale. We are interested in this earthquake because it has similar characteristics to two recent damaging earthquakes in mainland France (Le Teil and La Laigne earthquakes, 2019 and 2023 respectively). The obtained damage inventory will bring insight on the rupture and site-effect processes that were poorly documented at the time of the earthquake (no nearby seismological recordings in 1996).

Keywords: earthquake damage, EMS-98, macroseismic intensities, source rupture, site effects.

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SPATIAL DISTRIBUTION OF MICROTREMOR HORIZONTAL-TO-VERTICAL SPECTRAL RATIOS IN WAJIMA AND SUZU CITIES: IMPLICATIONS FOR BUILDING DAMAGE DURING THE 2024 NOTO PENINSULA EARTHQUAKE

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ABSTRACT

As part of a larger project to estimate subsurface structures and simulate strong ground motion and building damage caused by the 2024 Noto peninsula earthquake, this study aims to clarify the local site characteristics. We conducted extensive microtremor observations to determine the spatial distribution of the Microtremor Horizontal-to-Vertical Spectral Ratios (MHVRs) and estimate the Rayleigh wave phase velocity. We performed both single-station and array microtremor observations. Array observations were conducted at five sites in Wajima and three sites in Suzu, using seven-sensor circular arrays and single-station observations were conducted at 77 and 52 points in Wajima and Suzu, respectively. Regarding MHVRs, both Wajima and Suzu Cities exhibited peaks in two distinct frequency bands. For the Rayleigh wave phase velocities, values of approximately 150 to 2100 m/s were obtained in Wajima City, while Suzu City yielded two separate ranges: 750 to 1150 m/s and 800 to 1600 m/s.

Keywords: 2024 Noto Peninsula Earthquake, Microtremor, Horizontal-to-Vertical Spectral Ratio, Wajima City, Suzu City

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TOWARDS PREDICTING SITE EFFECTS IN THE FRENCH WEST INDIES AT A REGIONAL SCALE

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ABSTRACT

The French West Indies, located in a highly active subduction zone, are the most seismically active French territories, where site effects play a key role in amplifying ground motion, particularly due to weathered volcanic formations. Because direct soil measurements are sparse, seismic microzonation studies are typically used to infer lithological site effects by defining homogeneous geological units and assigning them geophysical properties (e.g., Bour et al., 1998; LeBrun et al., 2004; Régnier et al., 2020; Vessia et al., 2021). In this work, we extend this approach by producing a regional V_{S30} proxy map for the French West Indies, based on a reinterpretation of geological and geomorphological units combined with existing seismic microzonation data, seismic velocity profiles (332 points) and H/V measurements (1,942 points). These maps are intended to support rapid ground-motion estimation and preliminary seismic damage assessment, with future perspectives focusing on validation and refinement using additional observations such as strong-motion records.

Keywords: French West Indies, site effects, V_{S30}

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SITE EFFECTS MAPPING AT REGIONAL SCALE IN MAYOTTE ISLAND

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ABSTRACT

Mayotte island, located in the Comoros archipelago, is prone to moderate seismic hazard and extensive site effects due to the tropical weathering of the volcanic superficial deposits. To take into account site effects impact in local risk mitigation policies, we aimed at producing a site effects map based on EC8 soil classification in the whole island. The poor spatial distribution of the available ground geophysical data led us to use airborne electromagnetic (AEM) data to access dense information on the lithology and thickness of the superficial geological layers, so that to obtain reliable EC8 site proxies. This study shows the relevancy of AEM data for site effects estimation in Mayotte context and presents the methodology we used to build a site effects map on three pilot sites.

Keywords: seismic hazard, airborne data, site effect, Mayotte, volcanic geology

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EMPIRICAL SITE AMPLIFICATION IN DEEP SEDIMENTARY BASINS IN THE KANSAI REGION OF JAPAN

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ABSTRACT

Earthquake shaking is significantly influenced by site amplification caused by near-surface layers, especially in deep sedimentary basin areas like Osaka, Kyoto, and Nara in Southwest Japan. This study evaluates empirical site amplification functions (0.08–30 Hz) using spectral inversion from 227 regional earthquakes. We analyzed data from 454 sites across the Kansai region, utilizing K-NET, KiK-net, JMA, CEORKA, and DPRI strong-motion monitoring networks. Our spectral inversion framework incorporates a Brune-type source model, frequency-dependent attenuation, and azimuthal dependence of the source radiation. Based on dense spatial coverage, we constructed regional empirical amplification maps for periods between 0.1 and 5 s. Results demonstrate that long-period amplification (5 s) is concentrated in areas with deep sedimentary basin (>1.5 km). Intermediate periods (1–2 s) dominate central Osaka, Nara, and southern Kyoto basins, while short-period amplification (0.1–0.2 s) is widespread in Nara and Kyoto. The longest amplified periods correlate with local bedrock depth.

Keywords: site effect, empirical amplification, spectral inversion, earthquake motions, Japan

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SITE AMPLIFICATION CHARACTERISTICS IN MACHINO TOWN, WAJIMA, JAPAN DERIVED FROM TEMPORARY AFTERSHOCK OBSERVATIONS

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ABSTRACT

During the 2024 Noto Peninsula Earthquake (Mw 7.5), severe damage occurred mainly in the Noto region, where small towns are distributed over small-size basins. Previous studies have shown that, in such small basins in the Noto region, site amplification can vary locally even within the same basin and can reach extremely large levels. To investigate this variability in Machino town, Wajima, Japan, which is situated on a small-size basin in the Noto region, temporary aftershock observations were conducted at 17 sites in 2025. This study presents spatial variations in site amplification across Machino town based on these records. The results indicate that dominant frequencies vary depending on location within the basin and that large amplification occurs over a broad frequency range, which likely contributed to the severe damage.

Keywords: site amplification characteristics, temporary aftershock observations, small-size basin, earthquake ground motion, Noto Peninsula

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INFLUENCE OF SEAWATER ON SEISMIC GROUND MOTION OBSERVED AT THE SEAFLOOR

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ABSTRACT

To utilize ocean-bottom seismometer (OBS) data in earthquake early warning (EEW) systems for railways, it is crucial to understand the amplification characteristics and the effects of seawater on observed ground motion at the seafloor. This study examined spectral ratios of ground motion between land and seafloor, using S-net, Japan. We demonstrated that distinct troughs appear in the P-wave spectral ratio due to the transmission of P-waves into the seawater at the seafloor. The trough frequency varies with water depth according to the quarter-wavelength rule. Furthermore, analysis of time history waveforms from OBS data revealed that the observed P-wave phase at the seafloor is affected by sea-surface-reflected P-waves, and this influence varies with OBS water depth. These findings indicate potential factors that may degrade warning accuracy when applying the existing method to OBSs. Accounting for these effects will enable the development of reliable EEW systems utilizing P-wave data from OBSs.

Keywords: Earthquake early warning, Ocean-bottom seismometer, P-wave, Amplification characteristics, Multiple reflection theory

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INVESTIGATION OF SITE AMPLIFICATION CHARACTERISTICS USING SURFACE WAVE AND MICROTREMOR ARRAY MEASUREMENTS AT AFTERSHOCK OBSERVATION STATIONS IN WAJIMA CITY, JAPAN

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ABSTRACT

Strong ground motions during the 2024 Noto Peninsula earthquake showed significant spatial variation in Wajima City, Ishikawa Prefecture, suggesting strong local site effects. To investigate the subsurface structure at temporary aftershock observation stations, microtremor array surveys and surface wave surveys were conducted to obtain Rayleigh wave phase velocities. S-wave velocity structures beneath the temporary stations along a survey line connecting permanent stations were estimated. The results indicate that sites located on sedimentary layers exhibit amplification of approximately 10 times around 1 Hz. These findings suggest significant lateral variation in site amplification characteristics within a limited area.

Keywords: 2024 Noto Peninsula earthquake, Wajima City, Site effects, Microtremor measurement, Surface wave survey

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SPATIAL VARIATION OF EMPIRICAL SITE AMPLIFICATION FACTORS IN JAPANESE PORTS AND THEIR PREDICTABILITY BY MICROTREMOR OBSERVATION

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ABSTRACT

Evaluating site factors at the exact location of interest is important because site effects vary significantly even within a small area. We conducted temporary seismic and microtremor observations at three Japanese ports damaged by recent large earthquakes to compare site amplification factors (SAFs) with nearby permanent stations and to examine their relationship with microtremor H/V (MHV). The observation results showed large variations between the temporary sites and the neighboring sites, indicating that using strong-motion records from nearby stations can cause overestimation or underestimation at the exact damaged site. Comparisons of relative MHVs and SAFs showed a good correlation around the fundamental frequencies at two ports with clear peaks, while a weak correlation at another port with a relatively flat peak. These results suggest that there are cases where the relative MHV can serve as a proxy for relative SAF.

Keywords: site amplification factor, seismic observation, microtremor

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GEOPHYSICAL INVESTIGATION OF AMORGOS ISLAND (CYCLADES, GREECE) AND ITS UNEXPECTED RESPONSE TO THE 1956 SANTORINI EARTHQUAKE

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ABSTRACT

On 9 July 1956, a major ~Ms7.4 earthquake struck the southeastern Cyclades, followed thirteen minutes later by a Ms 7.0 event. Despite its proximity to the epicenter, Amorgos Island appears to have experienced limited damage compared to Santorini. However, 70 years later, available information remains sparse and sometimes contradictory, preventing a clear understanding of near-field ground-motion effects. We conducted therefore the first combined passive and active geophysical survey on Amorgos, aiming to characterize site response and compare it with reported macroseismic intensities. Results show no significant site amplification, either within sedimentary formations or associated with the rugged topography of the island. Furthermore, fundamental ground frequencies do not match the relatively high natural frequencies of traditional Cycladic buildings (>8 Hz), reducing the likelihood of soil-structure resonance. These findings suggest that Amorgos' geological setting plays a key role in its unexpectedly weak seismic response to such a major event.

Keywords: Ambient noise measurements, historical earthquake, site effects, seismic response, Cyclades

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SITE AMPLIFICATION STUDY FOR THE SANTORINI VOLCANIC ISLAND USING DATA FROM THE DENSE SANTOARRAY NETWORK

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ABSTRACT

We present a quantitative assessment of site-effects for Santorini island, a geologically complex region, characterized by the presence of pyroclastic deposits and lava flows above a metamorphic basement, as well as strong topography. Ground motion amplification is investigated using the Standard Spectral Ratio (SSR) method applied to earthquake recordings from temporary and permanent seismic networks, including the dense temporary SantorArray network during the 2025 Santorini–Amorgos unrest. An automated processing workflow is developed to compute SSR curves for 150+ sites, allowing to compute a continuous 2D transfer function over almost the entire Santorini island complex. Results are validated against manually processed SSR results and compared with ambient noise HVSR analysis, showing a consistent spatial pattern for fundamental frequencies. The results indicate strong spectral amplifications (>5) for a wide range of frequencies, with high-frequency amplification (f>5Hz) near shallow basement outcrops, while lower-frequency amplifications dominate in areas of thick volcanic deposits.

Keywords: Site effects, Transfer function, SSR, HVSR, Santorini island, volcanic deposits

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TOWARDS NEXT-GENERATION REGIONAL AND URBAN SITE AMPLIFICATION MODELS: LEVERAGING CROSS-DISCIPLINARY APPROACHES AND MULTI-SENSOR (INCLUDING SMARTPHONE) DATA FUSION

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Regional and large urban seismic hazard and risk assessments require robust characterization of site amplification, yet the scarcity of site-specific measurements remains a major limitation. Three major developments create an opportunity for a new generation of amplification models: (1) the exponentially growing number of stations recording many earthquakes, (2) advances in surface geology and critical-zone models from hydrology and geomorphology, and (3) the widespread use of smartphones and apps (e.g., EQN, LastQuake) that increase measurement density in urban areas. We show that the rapid growth of seismic stations enables direct estimation of site amplification (site-to-site residuals) and the use of ground-motion model (GMM) residuals to quantify correlations between observed amplification and mappable proxies such as topographic slope, geological era, and geomorphologically inferred sediment thickness. These correlations support empirical amplification models calibrated to regional-scale parameters, avoiding uncertainties introduced when VS30 is inferred from slope and then applied in conventional GMMs. We present key findings from applications in Japan and Europe and show how the framework can be extended by integrating proxies from other disciplines. In particular, we evaluate the predictive skill of sediment-thickness proxies relative to traditional metrics. Geological era combined with slope yields the largest reduction in site-to-site variability, while geomorphological sediment thickness performs comparably to slope-derived VS30 and often slightly better than slope alone. These results highlight the value of integrating geological and geomorphological information and the potential of globally or regionally inferred sediment-thickness datasets—developed outside engineering seismology—to improve hazard assessments. We further demonstrate that crowdsourced smartphone accelerometric data can provide dense, high-resolution constraints on site amplification in urban areas. Using statistical spatial modelling and measurements from the Earthquake Network citizen science initiative, we map site amplification at high spatial resolution. Together, these advances point toward a new generation of regional and urban amplification maps that integrate multiple proxies and diverse data sources. We illustrate associated epistemic uncertainties, evaluate model performance through reductions in GMM aleatory variability, and clarify the specific needs of regional amplification models compared to site-secific or code-based approaches, outlining the datasets and observations needed to further reduce uncertainty.

Keywords: *amplification model, urban studies, data fusion, smartphone*

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LOCAL SITE EFFECTS IN PETROPAVLOVSK-KAMCHATSKY AND ITS SURROUNDINGS DURING THE KAMCHATKA EARTHQUAKE OF JULY, 30, 2025

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In our previous studies, regional characteristics of radiation and propagation of seismic waves during typical subduction-type earthquakes in Kuril-Kamchatka seismogenic zone have been estimated. Regional parameters of radiation and propagation of seismic waves were estimated by comparing simulations of earthquake records with data recorded by stations of Kamchatka Strong Motion Network. Acceleration time histories of strong earthquakes (Mw = 6.8–7.5, depths h ~45–55 km) that occurred near the eastern coast of Kamchatka in 1992–1993 were simulated at rock and soil sites located at distances of 67–195 km.

In the calculations, the source spectra and the estimates of frequency-dependent attenuation $Q(f)\sim 200f^{0.3}$ and geometrical spreading $1/r$ obtained earlier for Kamchatka were used. Local seismic-wave amplification was estimated based on shallow geophysical site investigations and deep crustal seismic explorations, and parameters defining the shapes of the waveforms, the duration, etc. were selected, showing the best-fit to the observations. The obtained set of estimated parameters describes all the studied earthquakes well. Based on the waveforms of the acceleration time histories, models of slip distribution over the fault planes were constructed. Station PET can be considered as a reference rock station having the minimum site effects. The intensity of ground motion at other stations was higher than at PET due to the soil response and topographic effects. At soil stations INS, AER, and DCH, the parameters of soil profiles (homogeneous pyroclastic deposits) were estimated, and nonlinear models of their behavior during strong motion were constructed. At stations located on the hilltops and slopes, topographic effects were identified and evaluated.

Numerous strong motion records obtained during the last Kamchatka earthquake of July, 30, 2025 (Mw=8.8, h ~43.7 km) confirmed the previously obtained estimates of parameters of radiation and propagation of seismic waves, and allowed us to study local site effects at a larger number of stations in Kamchatka. At rock station PET, the intensity of motion was 2-3 times lower than at soil stations and stations located on the hilltops and slopes. The soils in Petropavlovsk-Kamchatsky mainly represent thick layers (~100-200 m) of rather dense pyroclastic deposits (Vs ~600 m/s), formed during the eruptions of proto-Avacha volcano 35-40 thousand years ago; they and do not significantly amplify seismic waves. Mainly, site effects and amplification of seismic waves are related to the effects of surface topography and topography of internal boundaries.

Keywords: strong earthquakes in Kamchatka, stochastic simulations, parameters of radiation and propagation of seismic waves, homogeneous pyroclastic soil layers, topographic effects

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Grenoble (France), 19-21 October 2026

SEISMIC WAVE AMPLIFICATION IN SANDY BARRIERS OF THE GULF OF CÁDIZ: THE CASE OF ISLA CRISTINA (HUELVA, SPAIN) AND POTENTIAL CASCADING GEOLOGICAL HAZARDS

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The Gulf of Cádiz is one of the European regions with the highest potential for cascading geological hazards, associated with the Azores–Gibraltar Fracture Zone. High-magnitude earthquakes (≥8.5) are capable of generating tsunamis with wave heights exceeding 15 m, and historical seismicity provides documented evidence of soil liquefaction in this region. Isla Cristina (Huelva, Spain) is located on the eastern margin of the Guadiana River delta, in the southwestern Iberian Peninsula. Most of its urban area lies at elevations of 3–4 m above sea level, with a water table at or near the surface. This study investigates the subsurface architecture of Isla Cristina using surface geological data, geotechnical boreholes, and seismic ambient recordings analysed through the horizontal-to-vertical spectral ratio (HVSR) method at 34 measurement sites. The HVSR results show low uncertainty and allow the determination of soil fundamental frequencies ranging from 3.18 to 0.71 Hz, as well as the depth to the mechanical bedrock along several transverse profiles. Bedrock depth increases southward, reaching elevations of up to −130 m. In all cases, HVSR curves display H/V peak amplitudes ≥4, locally exceeding values of 8. In addition, some records reveal a secondary peak (H/V ≥2), typically the higher-frequency peak is associated with the shallow architecture of sandy barrier deposits.Our results also provide new insights into the Neogene and Quaternary evolution of the westernmost Guadalquivir Basin along the Isla Cristina transect, which directly influences the mechanical soil response. The presence of previously unidentified faults is inferred, exhibiting vertical offsets of several tens of meters. The downthrown blocks coincide spatially with the development of the Guadiana delta. These structures are interpreted as kilometre-scale active faults, southward-dipping and parallel to the basin margin, which controlled the distribution of major Quaternary sedimentary depocenters.

The geological and geophysical results have three direct applications for seismic risk analysis. First, the identification of local faults provides evidence for an additional near-field seismic source, refining the definition of the expected seismic action. Second, the characterisation of sediment thickness, impedance contrasts and basin geometry informs how incoming seismic waves are amplified or attenuated, further constraining site-specific ground motion. Third, the detailed soil profile derived from HVSR and borehole data supports soil–structure interaction assessments, enabling the evaluation of resonance conditions and the spatial variability of seismic demand on buildings and infrastructure. Comparable tectono-sedimentary configurations, and thus similar implications, occur in other coastal and deltaic regions affected by active tectonics worldwide.

Keywords: seismic vulnerability, delta and barrier island, HVSR method, soil fundamental frequency, Gulf of Cádiz.

A BAYESIAN FRAMEWORK FOR NEAR-FAULT GROUND MOTION RECONSTRUCTION FROM IN-SITU OBSERVATION: CASE STUDY OF THE 2019 LE TEIL EARTHQUAKE

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ABSTRACT

Near-fault ground motion (NFGM) is critical for seismic hazard assessment, yet near-fault strong-motion records are often unavailable, particularly for earthquakes on previously unknown faults. The surface-rupturing 2019 Mw 4.9 Le Teil earthquake in southeastern France highlights this issue. Although no instruments captured the motion near the fault, extensive in-situ observations (e.g., broken rocks, displaced grave slabs, and building damage) were documented due to the shallow nature of the event. We propose a Bayesian framework to constrain NFGM using such observations. First, we generate prior NFGMs from thousands of stochastic kinematic source models, partly constrained by observational data, including InSAR-derived slip distribution, corner frequency from far-field seismological data and rise time from empirical scaling laws. Next, simulated ground motions are used to model observable effects and compared with field data to compute a likelihood function. We finally update the posterior distribution of NFGM and perform random forest analyses to reveal the most influential input source parameters.

Keywords: near-fault ground motion, Bayesian framework, kinematic source modelling, graveslab, building damage, Le Teil earthquake, site effect

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ON THE SEISMIC MOMENT DEPENDENCY OF SOURCE-CONTROLLED f_{max}

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ABSTRACT

High-frequency spectral decay (HFSD) is observed in acceleration Fourier spectra of earthquake ground motions, whereas the omega-square model predicts flat behavior at high frequencies. HFSD has been commonly attributed to near-surface sedimentary effects; however, observed seismic records suggest the existence of source-controlled $f_{\max}$. We previously proposed a hypothesis that source-controlled $f_{\max}$ corresponds to the highest corner frequency of the source spectrum associated with the slip velocity function. As part of a series of related studies, this paper discusses the magnitude dependence of source-controlled $f_{\max}$ observed in earthquake ground motions. Observed $f_{\max}$ exhibits a weak magnitude dependence that deviates from self-similar scaling. Although rise time and final slip are generally considered to follow self-similar scaling, the slip velocity function cannot be fully characterized only by these parameters. The possible existence of an additional parameter related to the initial pulse of the slip velocity function may explain the weak magnitude dependence of source-controlled $f_{\max}$. This suggests that the proposed hypothesis may provide a plausible explanation for the magnitude dependence of $f_{\max}$ observed in earthquake ground motions.

Keywords: High-Frequency Spectral Decay, source-controlled fmax, seismic moment dependency

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DEPTH DEPENDENCY OF STRESS DROP IN STRONG MOTION GENERATION AREAS FOR INTERPLATE EARTHQUAKES IN JAPAN

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ABSTRACT

We examined the depth dependence of stress drop of SMGAs in twelve interplate earthquakes in Japan (M_w 6.0–9.1). The Strong Motion Generation Areas (SMGAs) of the interplate earthquakes were estimated using the empirical Green's function method. The combined areas of SMGAs estimated in this study were smaller than that predicted by the empirical scaling relationship for asperity areas, but slightly larger than that predicted by the empirical scaling relationship for SMGAs. The estimated stress drops of the SMGAs do not appear to show a clear dependence on the focal depth or seismic moment within the focal-depth range (23.7–66.5km) in this study.

Keywords: Strong Motion Generation Area (SMGA), stress drop, interplate earthquake

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SOURCE CHARACTERISTICS OF THE 2023 ELBISTAN, TÜRKIYE, EARTHQUAKE (*M*w 7.7) BASED ON A JOINT INVERSION OF STRONG-MOTION WAVEFORMS AND SATELLITE-BASED GEODETIC DATA

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ABSTRACT

A joint inversion of near-field strong-motion waveforms (0.05–0.2 Hz) and satellite-based geodetic data resolved the coseismic slip distribution of the Elbistan earthquake (*M*w 7.7), the second event of the 2023 Türkiye earthquake doublet. Large (~6 m) shallow slip, including slip within sedimentary rock above the seismic bedrock, was resolved along the Çardak Fault and is likely responsible for the observed surface offsets and near-fault long-period ground motions. We suggest that the magnitude of surface offsets reflects the depth distribution of subsurface slip.

Keywords: 2023 Türkiye earthquake doublet, near-fault long-period ground motion, surface offset, kinematic source model, source scaling relationship

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SOURCE CHARACTERIZATION OF THE 2023 KAHRAMANMARAŞ, TÜRKIYE, EARTHQUAKE USING STRONG MOTION AND GEODETIC DATA

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ABSTRACT

The 2023 Kahramanmaraş earthquake was used to validate the Irikura Recipe. A characterized source model was constructed based on the heterogeneous slip distribution from waveform inversion and SMGA patches from broadband ground-motion simulation. LMGAs were incorporated for validation against geodetic data. The model showed overall good agreement between the observed and calculated surface displacements and velocity waveforms. The relative positioning of the LMGA and SMGA is an important issue for future study.

Keywords: 2023 Kahramanmaraş earthquake, source characterization, strong motion, geodetic data

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SOURCE SPECTRAL CHARACTERISTICS OF LONG-PERIOD GROUND MOTION INFERRED FROM THE F-NET BROAD BAND STRONG GROUND MOTION RECORDS

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ABSTRACT

Source spectral characteristics of long-period (3 to 20 s) ground motion were examined by the spectral inversion analyses for the NIED F-net broad-band strong ground motion records. The F-net stations are located basically on rock sites. Analyzed were 1,718 records (20 Hz sampling) obtained at 70 stations from 46 earthquakes with Mw6.5 or above that occurred between 2003 and 2020 in and around Japan. The observed acceleration spectra for the inverted data were calculated not for the S-wave main ground motion but for almost the whole ground motion. Comparison of the inverted acceleration source spectra shows no differences in the flat levels (3 to 6 s) between the inland earthquakes and the subduction-zone earthquakes. Among the source spectra of the inland earthquakes, the 2016 Kumamoto earthquake is almost twice as high as the other inland earthquakes, probably reflecting that it occurred with accompanying surface rupture.

Keywords: long-period ground motion, source spectra, F-net

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LONG-PERIOD GROUND MOTIONS GENERATED IN SHALLOW ZONE ABOVE SEISMOGENIC ZONE FOR INLAND CRUSTAL EARTHQUAKES WITH SURFACE RUPTURES

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ABSTRACT

Large shallow slips play a key role in generating long-period ground motions near faults during inland crustal earthquakes with surface ruptures. In this study, we investigated the source slip characteristics of the shallow zone (3 km depth), interpreted as a weak layer with low S-wave velocities (3 km/s), to improve the recipe for broadband ground-motion simulations in Japan. We compiled source inversion results and long-period motion generation area (LMGA) models for six earthquakes with surface ruptures (M_w 6.5) and examined slip and source-time functions in the shallow zone. Our findings suggest that incorporating large-slip areas in the shallow zone using a smoothed ramp-like time function, with a slip of ~2 times the overall average slip and a slip duration of ~2 s or longer, is essential for reproducing large long-period ground motions near the fault.

Keywords: Fault displacement, Strong ground motion, Source scaling relationship, Shallow zone, Long-period motion generation area (LMGA)

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SURFACE GROUND-MOTION VARIABILITY DUE TO SOURCE VARIABILITY FOR IMPROVED SITE-SPECIFIC SEISMIC HAZARD ASSESSMENT

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The accurate characterization of site-specific ground motion requires a comprehensive treatment of source, path and site effects. Empirical ground-motion models, which are developed basing on past recorded events, adopt simplified representations of these three components and suffer from a paucity of near-fault recordings for large-magnitude events. Even where near-fault records are available, they rarely correspond to the specific fault and magnitude of interest. As a result, empirical models exhibit significant variability even for scenarios with similar magnitudes and distances, and the estimated uncertainty cannot be easily reduced. Physics-based numerical simulations offer an alternative framework in which the rupture and wave propagation parameters are modeled explicitly, and the ground motion variabilities can be quantified by perturbing these parameters.

In this study, we focus on the impact of slip heterogeneity on low-frequency site-specific ground motions. The slip distribution on a fault is highly heterogeneous, with asperities whose location, size and number control directivity effects and spatial ground-motion patterns, especially in the near-fault region. Our aim is to isolate and quantify the source contribution to the variability of ground-motion intensity measures arising from heterogeneous slips. To achieve this goal, we adopt a source-to-site, physics-based simulation workflow in which fault geometry, hypocenter and a three-dimensional velocity model are kept fixed for a given scenario, while only the slip distribution is varied. Kinematic rupture realizations are generated using the Graves and Pitarka (2016) method, and three-component ground motion simulation are carried out using spectral element method implemented in SEM3D codebase.

A simple one-dimensional site-effect operator is then applied to obtain site-specific response spectra and other intensity measures. For each scenario and recording/site, we derive a set of intensity measures, including acceleration response spectra, peak ground velocity, duration and cumulative absolute velocity, and quantify their variability across the ensemble of slip realizations. Preliminary results show that varying the slip distribution alone can produce substantial variability in low-frequency ground motion intensity measures, especially at near-fault region. Even for a given fault geometry, hypocenter and the three-dimensional velocity model, the variability in ground-motion simulation results is significant and should be treated as source contribution. These results underscore that the detailed characterization of slip heterogeneity is a key driver of the near-fault ground-motion properties and should be explicitly accounted for when using such simulations as input for site-specific design spectra, hazard assessments and subsequent site-response analyses.

Keywords: ground-motion variability, source heterogeneity, slip distribution

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SITE RESPONSE CHANGES DURING STRONG EARTHQUAKE SHAKING: RECENT CASE STUDIES FROM JAPAN

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ABSTRACT

We analyzed surface-to-borehole (S/B) spectral ratios of ground-motion records at selected sites during three earthquakes: the 2011 Mw 9.1 Tohoku-oki earthquake, the 2016 Mw 7.1 Kumamoto earthquake, and the 2024 Mw 7.5 Noto Peninsula earthquake. The mean S/B spectral ratios of weak motions from prior earthquakes showed distinct peak frequencies and spectral shapes at all sites, indicating differing local site geology. Compared with the mean spectral ratios at a site, reductions in higher-frequency spectral ratios and shifts in the predominant frequencies observed during the earthquakes were correlated with changes in input motions at the site. Soon after the strong shaking subsided, the spectral ratios around the lowest predominant frequency recovered to their pre-mainshock levels, whereas those at frequencies mostly above 10 Hz did not. The borehole sensors were in rocks at depths of 100-252 m. Detailed instrumentation at shallower depths may help further understand site response behavior.

Keywords: Strong ground motions, Nonlinear site response and recovery, KiK-net

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UNDERSTANDING NONLINEAR SOIL RESPONSE USING VELOCITY AND FREQUENCY CHANGES: EXAMPLES FROM IWATE PREFECTURE, JAPAN

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ABSTRACT

Local geological conditions strongly shape earthquake ground motion, especially during strong shaking when near-surface materials behave nonlinearly. Under these conditions, reductions in shear modulus and changes in damping can substantially alter site response. Here, we present illustrative examples from one K-NET station and one KiK-net station in Iwate Prefecture, Japan, drawn from a broader dataset of earthquake records spanning 2000-2022. We apply a combination of time-domain methods, seismic interferometry by deconvolution and phase cross-correlation, together with a frequency-domain approach based on stacked Stockwell power spectral density, to both surface and surface-borehole data. The selected examples consistently show coseismic decreases in shear-wave velocity and resonance frequency with increasing shaking intensity. These reductions are detectable even at moderate ground-motion levels and become more pronounced at higher intensities. Comparisons between surface and surface-borehole observations further emphasize the dominant role of shallow layers in driving nonlinear site response.

Keywords: nonlinear soil response, earthquake ground motion, Japan

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CHARACTERIZING LINEAR AND NONLINEAR SITE RESPONSES USING SINGLE-STATION TIME-FREQUENCY ANALYSIS ACROSS MULTIPLE REGIONS

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ABSTRACT

By integrating observations from Japan, Türkiye, and Taiwan—regions where large earthquakes have revealed complex local amplification effects—we investigate the key characteristics of both linear and nonlinear site response. We apply time-frequency analysis on single-station recordings spanning from weak to strong motions to extract linear and nonlinear resonance frequencies. The method does not rely on a reference site. Common observational patterns from these regions indicate that nonlinear site effects can become significant even at moderate shaking levels and that nonlinear site response is highly site-specific, with strong variability governed by local geological conditions. Overall, these results emphasize the complex nature of site response: both linear and nonlinear site behaviors are primarily controlled by local geology, while nonlinear characteristics exhibit strong variability across frequency bands even within the same site, making them more challenging to characterize.

Keywords: seismic motion, site effect, nonlinear site effect, Japan, Türkiye, Taiwan

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EVALUATING NONLINEAR SITE RESPONSE USING DECONVOLUTION-BASED SEISMIC INTERFEROMETRY IN KIK-NET VERTICAL ARRAYS

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ABSTRACT

Vertical arrays are widely used to estimate site response, but borehole recordings may be affected by interference between incident and surface-reflected waves, which can bias the definition of the input motion. In this study, we explore deconvolution-based seismic interferometry as a tool to investigate nonlinear site response in KiK-net vertical arrays. Although the method is based on linear wave-propagation assumptions, we use it to assess how nonlinear soil behavior modifies the retrieved impulse response and the associated borehole-interference pattern. The approach separates the upgoing and downgoing contributions in the impulse response and reconstructs an estimate of the incident motion at depth. A 1D numerical test and a first application to station MYGH10 show delayed arrivals and a shift of spectral features toward lower frequencies under nonlinear conditions. These preliminary results suggest that the method can help identify interference changes associated with nonlinear site response in vertical-array data.

Keywords: seismic interferometry by deconvolution, nonlinear site response, KiK-net strong motion data, vertical seismic array

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TOWARDS A CORRECTION OF DOWNHOLE STATION TO EC8 REFER-
ENCE ROCK OUTCROP GROUND MOTION FOR KIK-NET SITES CON-
SIDERING NONLINEAR SOIL BEHAVIOR

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ABSTRACT

This study aims to improve Eurocode 8 reference rock response spectra by accounting for nonlinear soil behavior using KiK-net vertical array data. Because borehole depth and impedance contrast vary strongly across the network, downhole recordings are first corrected to a common outcrop rock reference using the borehole-to-outcrop method by Cadet et al. (2012). The method is illustrated for the KiK-net site AKTH04, where strong-motion results show the expected nonlinear effects: am-plification shifts toward lower frequencies and decreases at high frequencies. Corrected outcrop site responses are also compared with generalized inversion technique (GIT) estimates referenced to hard rock. Despite some amplitude differences, both approaches show satisfactory agreement. These results will support the development of empirical corrections useful to define EC8 spectra that better represent nonlinear site response under moderate-to-strong earthquakes.

Keywords: Site effects, nonlinearity, KiK-net, reference rock site, Eurocode 8

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IMPACT OF EQUIVALENT-LINEAR RELATIONSHIPS FOR NONLINEAR SOIL BEHAVIOR ON THE AMPLIFICATION OF SEISMIC GROUND MOTION

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ABSTRACT

Nonlinear soil behavior may significantly influence seismic site response and is therefore critical in estimating response spectra in microzonation studies. Overestimation of nonlinear soil behavior in sedimentary sites may reduce predicted surface amplification, leading to non-conservative spectra.

This study evaluates the sensitivity of ground motion amplification to nonlinear soil behavior modeled using equivalent-linear constitutive equations, through 1D and 2D numerical simulations. Three Swiss sedimentary sites are considered: Nyon (shallow deposits, tens of meters), Yverdon (intermediate deep deposits, approximately 100 m), and Chablais (deep deposits, several hundred meters). The equivalent-linear relationships considered include those proposed by Ishibashi&Zhang (1993), Seed&Idriss (1970), and Wang&Stokoe (2022).

Results show that earlier relationships, i.e. Ishibashi&Zhang (1993) and Seed&Idriss (1970), generally predict lower amplification than Wang&Stokoe (2022). The underestimation depends on deposit thickness: it remains below approximately 10 % for shallow sites but can reach about 20 % for intermediate to deep deposits. Discrepancies are most pronounced near the fundamental natural period of the site and at shorter periods.

Keywords: sedimentary site, nonlinear soil behavior, amplification

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CASE STUDY OF A COMBINED ASSESSMENT OF SEISMIC AND LIQUEFACTION HAZARDS USING DIFFERENT APPROACHES

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ABSTRACT

Within the framework of a site-specific probabilistic seismic hazard assessment (PSHA) and liquefaction hazard analysis, this paper presents a comparative case study for a site located in South-East France. Seismic input motions are defined at different return periods and propagated through one-dimensional site response analysis (1D-SRA) to account for local soil conditions. Liquefaction hazard is then evaluated using several approaches, including the semi-empirical NCEER procedure with varying levels of site-specific input, a dynamic approach based on 1D-SRA in effective stress, and a probabilistic liquefaction hazard assessment (PLHA) following recent developments proposed by Ordaz et al. (2023). The comparison highlights the strong influence of site-specific seismic inputs and depth-dependent loading on liquefaction outcomes, and illustrates the added value and limitations of complementary numerical and probabilistic approaches. The results also provide insight into how PLHA can be integrated consistently with PSHA and 1D-SRA to support the definition of performance-or risk-based protection objectives.

Keywords: Seismic hazard, Site response, liquefaction hazard, probabilistic approaches, engineering
practice

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MULTI-OUTPUT GAUSSIAN PROCESSES FOR NONLINEAR SITE AMPLIFICATION WITH CROSS-PERIOD CORRELATION

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Incorporating nonlinear site response into probabilistic seismic hazard assessment (PSHA) is computationally demanding when uncertain site conditions and intensity levels must be explored, and when response metrics must remain mutually consistent across oscillator periods relevant to structural performance. This contribution presents a multi-output Gaussian Process Regression (GPR) surrogate model that emulates site-amplified response spectra obtained from one-dimensional equivalent-linear site response analyses (LESRA). The focus is on an efficient, probabilistically consistent representation of site effects that preserves spectral-shape coherence across periods of engineering interest.

A training database is constructed from thousands of LESRA simulations considering uncertain site conditions and using input records spanning a large variability in earthquake scenario parameters. From each simulation spectral accelerations are computed at selected oscillator periods from the input motion, $\mathbf{Y}^{input}$, and the surface motion, $\mathbf{Y}^{site}$, in log units. The period set is chosen to capture both the short-period range important for higher-mode response (e.g., $T \approx 0.5$ s) and the long-period range relevant for flexible systems (e.g., $T \approx 3.5$ s), while covering intermediate periods to describe the full spectral shape. Each LESRA simulation is summarized by an input vector

$$\mathbf{x} = [Y^{input}, M, \ln R, \epsilon_r, \boldsymbol{\theta}_{site}],$$

where T_{ref} is a reference period (e.g., 1 s), M and R describe event size and distance, ϵ_r represents an within-event residual term to retain record-to-record variability, and $\boldsymbol{\theta}_{site}$ collects site descriptors controlling amplification and nonlinearity (e.g., proxies for impedance contrast and modulus-reduction/damping behavior). A multi-output GP prior is then assumed:

$$\mathbf{Y}^{site}(\mathbf{x}) \sim \mathcal{GP}(\mathbf{m}(\mathbf{x}), \mathbf{K}_T \otimes k(\mathbf{x}, \mathbf{x}')),$$

with a low-order mean function $\mathbf{m}(\mathbf{x})$, a squared-exponential kernel $k(\mathbf{x}, \mathbf{x}')$in the input space, and an inter-period covariance matrix $\mathbf{K}_T$that captures coupling between oscillator periods. The Kronecker (separable) covariance structure is central: it preserves spectral-shape consistency across periods while keeping training and prediction efficient even for many T_k. Model hyperparameters (kernel lengthscales, signal and noise variances, and $\mathbf{K}_T$ parameters) are learned by maximizing the log marginal likelihood using gradient-based optimization.

The resulting surrogate rapidly predicts the full surface response spectrum along with its inter-period uncertainty structure, enabling nonlinear site effects to be propagated through PSHA workflows without repeated site-response simulations and without sacrificing coherence of the predicted spectral shape.

Keywords: Gaussian process regression, site effects, seismic hazard, surrogate model.

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PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR MAINLAND FRANCE

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ABSTRACT

In the context of the update of the Eurocode, the research project Alceste, financed by the French Ministry of the Environment and Sustainable Development, aims to build a seismic hazard model for mainland France. For the first time, the academic community in France is working on delivering the inputs (earthquake catalog and delineation of seismogenic area source zones), and building a community source model for quantifying PSHA at the scale of the entire country. Work is in progress, and hazard results are due by the end of 2026.

Keywords: source model, probabilistic seismic hazard, metropolitan France, Eurocode 8

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PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR THE FRENCH ISLANDS IN THE LESSER ANTILLES

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The ATLAS research project aims to estimate probabilistic seismic hazard for the French islands in the Caribbean under the auspices of the Ministry of the Environment and Sustainable Development (department on risk-prevention - DGPR). The islands Guadeloupe, Martinique, Saint Martin, and Saint Barthélemy, are located in the Lesser Antilles subduction zone. Estimating probabilistic seismic hazard in this region is challenging. The subduction megathrust has been seismically quiet over the last century. Geodetic studies find very low coupling along the interface (van Rijsingen et al. 2022), whereas corals' analyses indicate that the megathrust might be locked at depth (Philibosian et al. 2022). We build a set of source models to account for the uncertainty on earthquake occurrence probabilities. Based on the Foix et al. (2025) source zone delineation, the upper-plate seismicity is modeled through area sources or gridded seismicity combined with crustal faults for which a slip rate estimate exists; interface seismicity is modeled through a three-dimensional subducting fault plane; while inslab seismicity is modeled through a fully three-dimensional dipping slab. Preliminary hazard calculations indicate that, assuming weak coupling at the interface, hazard levels at island sites are controlled by upper-plate sources hosting the islands and by inslab sources located below the islands at depths around 100 km. Overall, our strategy consists of identifying uncertainties at each stage, both in the data and in the methods, and quantifying their impact on hazard estimates in order to identify which assumptions and parameters control the hazard and should be incorporated into the logic tree. Complete seismic hazard models are due by the end of 2026.

Keywords: Guadeloupe, Martinique, PSHA, Earthquake Forecast, Seismic Hazard Levels.

LOCAL GMPE CALIBRATION AND NON-ERGODIC SEISMIC HAZARD IN THE CYCLADES: A THREE-STAGE BAYESIAN FRAMEWORK AND ITS IMPLICATIONS FOR PSHA

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Abstract

We summarise a paired study on ground motion and seismic hazard in the Cyclades following the 2025 Amorgos offshore sequence. A three-stage Bayesian framework is used to locally recalibrate the Boore et al. (2021) Greece GMPE from 2,880 records at 17 stations, reducing total aleatory uncertainty by 20–25% via HVSR-informed site refinement. Four logic-tree branches (rock, modified rock, ESHM20 proxy-site, HVSR non-ergodic) are then propagated through PSHA at the same stations. The ESHM20 and non-ergodic branches disagree in a station-specific, sign-changing way that persists across return periods and within individual islands. A forthcoming companion paper will extend the work into seismic risk.

Keywords: GMPE calibration; non-ergodic PSHA; HVSR site characterization; logic-tree comparison; Cyclades

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EVALUATING SAMPLING STRATEGIES FOR CONVOLUTION-BASED INTEGRATION OF SITE EFFECTS IN PARTIALLY NON–ERGODIC PSHA

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ABSTRACT

Reliable seismic hazard estimation requires accounting for local site effects that standard GMPE site terms cannot fully capture. Advanced approaches overcome this by combining rock hazard results with amplification factors from site response analysis. This can be done analytically using the rock hazard curve or through the more time-efficient convolution method, which discretely samples the rock hazard and provides a close approximation to analytical solutions.

This study examines how surface hazard estimates depend on the sampling strategy used in the convolution approach. Using results from a site-specific PSHA, we compare surface hazard percentiles obtained by convolving SRA-based AFs with: (i) a single rock hazard percentile, (ii) five rock percentiles, and (iii) 1000 rock hazard curves sampled from the full logic tree. Results from approach (i) are shown to be a good approximation to results from approach (iii), demonstrating it to be a computationally efficient alternative for sites with limited nonlinearity.

Keywords: PSHA, site effects, convolution approach, site response, resampling

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ON ERGODICITY IN HYBRID BROADBAND GROUND MOTION SIMULATIONS

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ABSTRACT

Regional-scale hybrid broadband ground-motion simulations can complement existing recordings by improving the completeness of available datasets. Ground-motion models may benefit from such combined datasets to partially relax ergodicity and reduce uncertainties in site-specific predictions. These simulations combine low-frequency physics-based simulations with high-frequency components predicted by artificial neural networks (ANNs). However, their performance depends on training data, which often lack accurate site metadata or commonly used site proxies. This study investigates alternative proxies that can explain site-response variability by analyzing site-to-site residuals (δS2S) at 571 Italian stations. Principal component analysis of δS2S showed that two components explain 92% of the variability. The first correlates with measured $V_{S,30}$, and mean HVSR amplitude, whereas the second correlates with site's fundamental frequency and ratio of HVSR amplitude at high and low frequencies. Results indicate that easily obtainable HVSR metrics are promising proxies for ANN training and broadband simulations, particularly in data-limited regions such as France.

Keywords: Physics-based earthquake ground motion simulation, site effect, hybrid broadband ground
motion, GMM, artificial neural network

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PROBABILISTIC SEISMIC HAZARD ANALYSIS AT DEPTH FOR DEEP GEOLOGICAL REPOSITORIES

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ABSTRACT

The long-term safety assessment of deep geological repositories (DGRs) for radioactive waste poses challenges that are not adequately addressed by the established probabilistic seismic hazard assessment approach. The current regulation for site selection process in Germany relies on surface-based ground motion metrics and return periods designed for structural engineering, which are inconsistent with the relevant depth, timescales, and failure mechanisms of a DGR. This study develops a probabilistic seismic hazard framework tailored to subsurface conditions by introducing ground motion prediction equations calibrated to lower-lithospheric hard-rock reference conditions at depth. We use a new database of deconvolved seismic records constructed using a complex generalized inversion technique that accounts for both amplitude and phase. We plan on integrating the model into a probabilistic seismic hazard analysis for Germany and Europe, exploring different probability–time window combinations up to one million years. The results highlight substantial differences in hazard patterns compared to standard approaches, with important implications for repository siting and regulatory criteria.

Keywords: Deep geological repository, Probabilistic seismic hazard analysis, Site effects, Long-term hazard assessment

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UNCERTAINTY PROJECTED MAPPING OF SITE-RESPONSE ACROSS EUROPE: A CASE STUDY IN FRANCE

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ABSTRACT

National and continental seismic risk assessments frequently rely on topographical and geological proxies to interpolate site responses, a practice that often yields inaccurate predictions and identical uncertainty at every location, irrespective of the availability and variability of site-specific observations. Uncertainty Projected Mapping (UPM) provides a powerful data-driven alternative by providing adaptive spatial resolution of site-response with maps of epistemic uncertainty and aleatory variability. Despite these advantages, the large computational demands of current UPM implementation have restricted its use to local and regional datasets. In this work, we present an optimized, high-performance UPM implementation in Python capable of handling very large datasets and scaling to national and continental domains. We demonstrate this capability using site-specific residuals from the EPOS dataset to generate dynamically updatable site-response and uncertainty maps for France and neighboring regions.

Keywords: site-response, Bayesian inferencing, seismic hazard and risk, EPOS, EPOS-France

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TOWARD AN ATTENUATION PROXY: ADAPTING A EUROPEAN GMM TO THE FOURIER DOMAIN AND INVESTIGATING SPATIAL VARIABILITY IN FRANCE

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ABSTRACT

The intrinsic characteristics and irregularities of the medium through which waves travel cause attenuation, a process known as absorption and scattering. Estimating attenuation is necessary for magnitude estimation and hazard assessment. Despite numerous studies, modelling attenuation is difficult because it depends on the path, making it challenging to extract from a seismic network. Furthermore, the interdependence between magnitude estimation and attenuation complicates the problem. Generally, attenuation is considered to decrease only with distance; however many studies show variation in three dimensions (3D). For this reason, a ground-motion model (GMM) based on the analysis of response spectra records has been constructed for shallow crustal earthquakes in Europe. The objective is to model attenuation more accurately and determine spatial variation. This GMM is based on a large amount of low-magnitude data, enabling accurate grid regionalisation for attenuation to be used. In addition, the model has been modified to estimate attenuation more accurately. To analyse the ground response directly, the model is adapted using Fourier amplitude data. These models are partially non-ergodic GMM with regionalised attenuation for Europe. However, as the model is data-driven, while many earthquakes are recorded in Greece, Italy and the Alps, where seismicity is high, there may be a lack of data in other countries or regions, where seismicity is low, such as the Paris Basin in France and northern Europe. Therefore, the model cannot be extrapolated to these regions, and hazard assessments cannot be regionalised. Only the average value for Europe can be used. To solve this problem, a better understanding of the attenuation phenomenon is required. Identifying parameters, known as proxies, that can explain attenuation would enable them to be used to extrapolate attenuation in regions where data is scarce. The focus is on France, where data is widely available. The regionalised attenuation model derived from the GMM is compared with attenuation tomography. This step provides a better understanding of attenuation variations across France. The attenuation is then correlated with geophysical and geological parameters in order to estimate a proxy. Ultimately, this work could improve GMM modelling and, consequently, hazard assessment.

Keywords: attenuation, ground-motion model, seismic hazard assessment, proxy

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REGIONALIZED AND NON-ERGODIC GMMS FOR CRUSTAL EARTHQUAKES IN NORTHERN VIETNAM

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ABSTRACT

This study presents a two-step approach that localizes the global ASK14 ground motion model to Northern Vietnam (NVN) and then extends it with a non-ergodic framework. For the regionalization of an ergodic model, we adapt the global ASK14 using mixed-effects regression with a local dataset comparing 1903 recordings from 229 shallow crustal earthquakes with M_W between 3.0 and 5.9, recorded at 82 stations from 2005 to 2022. We adjust the scaling for small magnitude events and refine the distance-attenuation terms to better match NVN data. At the same time, due to a lack of data, we keep ASK14's behavior for larger magnitudes and short distances to avoid unrealistic extrapolation. We also update the magnitude-dependent standard deviation terms using within-event and between-event residuals so the model better reflects the observed data for NVN earthquakes. Regarding the site term, since the site conditions of those NVN stations are unknown, we use the earthquake horizontal-to-vertical spectral ratio (eHVSR) to estimate V_{S30} at those stations, and site amplification factors for periods are calibrated using local data. The non-ergodic model extends further by allowing the model coefficients to vary across space. Using the Bayesian hierarchical framework, the non-ergodic coefficients were derived by modeling the residuals of the ergodic model and associating them with source, path, and site components in Gaussian processes. Semi-variograms for each period help determine correlation lengths and variances, and we find that this non-ergodic modeling reduces aleatory variability at T = 0.01s by about 28% (down to 0.72 ln units compared to the ergodic value of 1.0 ln units). The residuals show no significant trends with magnitude, distance, or V_{S30}, indicating that the non-ergodic model effectively captures the main physical effects. Overall, both the new ergodic and non-ergodic GMMs can provide more accurate and less uncertain hazard estimates for Northern Vietnam than directly adopting a global GMM. The two-step method provides a practical template for adapting a global GMM to regions with limited ground-motion data.

Keywords: ergodic GMM, non-ergodic GMM, eHVSR, V_{S30}, semi-variogram

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EXTRACTING GROUND MOTION TIME SERIES AT THE SEISMOLGICAL BEDROCK REFERENCE HORIZON

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Reliable site-specific seismic hazard assessment requires accurate bedrock ground-motion estimates. A common approach involves applying generic or site-specific corrections to surface recordings to mitigate the influence of site effects and to infer the corresponding bedrock motion. However, these corrections typically do not account for phase differences (i.e., variations in the temporal characteristics) between surface and bedrock responses. Here we present a complex-valued deconvolution procedure based on the Generalized Inversion Technique (GIT) to generate a homogeneous database of time series representative of outcrop bedrock conditions at a reference observation site. This procedure incorporates a site-specific phase correction to account for differences in mean ground-motion arrival times.

For validation, we initially selected 90 Kiban-Kyoshin network (KiK-net) surface-downhole sites characterized by insignificant velocity contrasts beneath the downhole sensor which are also located at sufficient depth to avoid substantial interference from downgoing waves. Following assessment of the effectiveness of the deconvolved waveforms through comparison with recorded downhole time series and a confirmation of the robust removal of complex-valued site effects, we applied the procedure to a large European dataset. The resulting database of homogeneous ground motions comprises over 180,000 time series from 4,596 earthquakes across Europe, enabling refinement of existing ground-motion models and derivation of site-to-site residuals for improved seismic hazard characterization.

Keywords: Site effects, deconvolution, reference ground motion, amplification

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IDENTIFYING REFERENCE SITES: METHODOLOGIES AND APPLICATIONS IN MAINLAND CHINA

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ABSTRACT

This study proposes a multi-proxy methodology for identifying reference sites, addressing the challenge of selecting suitable references in site-effect analysis, generalized spectral inversion, and ground-motion simulation. Leveraging extensive datasets in China, we defined five evaluation proxies-V_{S30}, surface geology, slope, terrain classification, and HVSR from strong-motion records—and assigned weights to establish a standardized procedure. Applying this framework to 1,450 strong-motion stations, we preliminarily identified 38 candidate sites. Robustness was confirmed via sensitivity tests on proxy weights, and reliability was validated using site-to-site residuals ($\delta S2S_s$). Ultimately, 18 stations were confirmed as reference sites, establishing a replicable, nationwide technical framework for future reference site selection.

Keywords: reference sites, V_{S30}, surface geology, topography and landforms, HVSR

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ADVANCING TRANS-DIMENSIONAL BAYESIAN INVERSION FOR EARTHQUAKE HAZARD PREDICTION

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ABSTRACT

This study outlines a newly developed software routine for joint trans-dimensional Bayesian (jTD-B) inversion, used to estimate probabilistic layered earth models depicting elastic soil parameters from the combination of surface-wave dispersion and microtremor horizontal-to-vertical spectral ratio (MHVSR) curves. Bayesian trans-dimensional inversion is accomplished using the reversible-jump Markov Chain Monte Carlo (rjMCMC) algorithm augmented with parallel tempering and principal-component reparameterization to efficiently and thoroughly investigate the parameter space. The jTD-B inversion routine estimates unbiased probability distributions of model parameters needed for predicting ground motion for hazard analysis and earthquake site response numerical modelling. The advancements made in this routine allow for trans-dimensional and Bayesian predictive models which exploit the complimentary site information within dispersion and MHVSR data obtained through low-cost microtremor recordings. This routine and its probabilistic models of the subsurface represent vital contributions to reliable and meaningful prediction of ground shaking and additional site effects in future earthquake events.

Keywords: Geophysical Inversion, Seismic Hazard, Seismic Amplification, Microtremor Horizontal-to-Vertical Spectral Ratio, Trans-Dimensional Inversion.

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Grenoble (France), 19-21 October 2026

SITE EFFECTS OF WEST TEXAS EARTHQUAKES THROUGH STOCHASTIC INVERSIONS FOR SOURCE, PATH AND SITE PARAMETERS

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ABSTRACT

This study utilizes recorded ground motions from West Texas to evaluate the source, path, and site effects in this region. We analyze the Fourier amplitude spectra from 354 earthquakes in the Delaware basin recorded by the TexNet seismic network at 49 sites. The magnitudes range from ~3.0 to 5.0, with hypocentral distances up to 300 km. Using a Bayesian parametric inversion on 6,479 records, we simulate the spectra as a combination of source, path, and site effects from a stochastic point-source model. The inverted moment magnitudes were comparable to catalog values, and the stress parameter ($\Delta\sigma$) ranged from 5 to 134 bar, increasing with magnitude. Geometrical spreading yielded a near-field γ of 1.15 and Q(f) = 837f^0.59. The inverted site amplification functions revealed six distinct clusters of response. The high-frequency decay parameter (κ) ranged from 0.005 to 0.056 s, with systematic variation with cluster and location.

Keywords: West Texas, stochastic inversion, site effects, induced seismicity

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EVALUATION OF THE REGIONALITY OF SITE AMPLIFICATION FOR THE EASTERN TIBETAN PLATEAU ZONE OF CHINA: INSIGHTS FROM BOTH THE SHEAR-WAVE VELOCITY PROFILES AND STRONG MOTION RECORDS

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Site response prediction is an important component of ground motion model development and is influenced by regional variations in geological structure and local soil conditions. In historical ground motion models for China, the regional dependence of site amplification has generally not been considered, possibly due to the lack of sufficient ground motion records and shear-wave velocity (V_S) profiles. In this study, we compiled a reasonably large database consisting of 2,150 records from 375 sites in the eastern Tibetan Plateau of China, among which 320 sites have borehole V_S profiles. We first present the regional variability of V_S profiles for three different geological units, namely the Loess Plateau, the West Sichuan Plateau, and the Yunnan–Guizhou Plateau, all of which are seismically active regions in western China. We then evaluate the influence of this variability on site response using both one-dimensional (1D) theoretical and empirical methods. The results show that site response is highly region dependent. Site amplification in the Loess Plateau and the West Sichuan Plateau is dominated by short periods, with amplification in the Loess Plateau being significantly larger than that in the West Sichuan Plateau. This difference is possibly attributable to the relatively thin surface soil layers, as indicated by the V_S profiles. In contrast, site amplification in the Yunnan–Guizhou Plateau is significant at long periods, which can be attributed to deep soft soils within sediment-filled valleys and basins. Based on these findings, regional site amplification factors are recommended for inclusion in future ground motion models.

Keywords: Seismic site response; Regionality; Eastern Tibetan Plateau; Loess soil; Ground motion model

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EMPIRICAL SITE AMPLIFICATION FACTORS IN CENTRAL ITALY REGION THROUGH GENERALIZED INVERSION TECHNOLOGY ON STRONG GROUND MOTIONS

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Site amplification effects represent a critical component in strong ground motion studies, as they can significantly modify seismic waves propagating through near-surface geological layers and substantially influence the intensity of shaking experienced at the ground surface. This study applies the generalized inversion technique (GIT) to a comprehensive dataset comprising approximately 18,000 strong-motion records from nearly 580 earthquakes in the central Italy region. The dataset, primarily sourced from the Italian Accelerometric Archive (ITACA) and the Engineering Strong-Motion (ESM) database, encompasses both moderate and strong ground motions recorded at a dense network of stations. Using non-parametric GIT, we decompose the observed Fourier amplitude spectra into source, propagation path, and site contributions. The inversion provides empirical site amplification functions relative to a reference rock site condition, together with source spectra and frequency-dependent attenuation parameters, including the quality factor Q(f). The obtained site amplification factors show considerable spatial variability across central Italy, consistent with the diverse subsurface conditions ranging from stiff rock to soft soil deposits. The reliability and robustness of the GIT-derived site effects are further assessed through comparisons with independent site amplification estimates from previous studies in the region, as well as with the high-frequency attenuation parameter κ derived from the recorded accelerograms. These findings improve the characterization of local site response in this highly seismically active area and offer valuable empirical constraints for regional seismic hazard assessment and the development of ground-motion prediction models in central Italy.

Keywords: site amplification factor, strong ground motion, central Italy region, source, Q value

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IMPACT OF SEISMIC STATION HOUSING ON GROUND MOTION MODELS UNCERTAINTIES AND VARIABILITY

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ABSTRACT

In the framework of ground motion and seismic hazard assessment, the use of ground motions recorded in low-to-moderate seismic regions has recently grown in popularity. These records allow for example to adjust existing Ground Motion Models (GMMs) developed in active regions of the world to the local context, to develop specific non-ergodic GMM or to perform Generalized Inversions (GIT) and assess seismological parameters. When developing GMMs, it is generally assumed that ground motions are recorded at free-field condition, i.e. at the ground surface and far enough from any structure or construction that could interact with and affect the recorded motion. However, there is a wide variety of sensor installation configurations and conditions worldwide. Information about seismic station installation conditions (housing, type of soil-sensor coupling…) is however most often lacking in ground motion databases. The results of a Bayesian update of the Kotha et al. (2020, 2022) European GMM using the EPOS-France ground motion dataset (Buscetti et al., 2024) and the BELSHAKE dataset (Vanneste and Onvani, 2024) highlight that the use of both, accelerometric and broadband records in France may lead to larger site-to-site variability with respect to the use of accelerometric data only (Kotha and Traversa, 2024), possibly due to the different installation conditions. With the objectives of identifying possible biases and robustly characterizing GMM variabilities, this work illustrates the benefit of accounting for station installation information in the development of empirical GMMs. The results highlight that a significant portion of the site-related variability in the GMM is due to the variety of sensor installation modalities and conditions inventoried in France. Accounting for it allows to improve the description of the GMM variability by an enhanced separation of repeatable and aleatoric effects. Overall, this contributes to the improvement of seismic hazard studies accuracy.

Keywords: Ground Motion Models, Site-To-Site Variability, Sensor Installation Conditions

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A REVISED VS30 MAP FOR ITALY INTEGRATING TOPOGRAPHIC AND LITHOLOGICAL PROXIES WITH EXTENSIVE VS30 MEASUREMENTS

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ABSTRACT

Vs30 is widely used to describe near-surface site conditions in ground motion models (GMMs), seismic hazard assessment and shaking scenarios, but direct measurements are unevenly distributed. This work presents a Vs30 model for Italy obtained by combining an extensive national database of more than 15,000 shear-wave velocity profiles with topographic and lithological information. Several topographic proxies and national lithological maps were examined to identify the most robust predictors. For the final model two proxies were used: the slope at 150 m resolution and a revised lithological classification derived from the ISPRA map. Different modelling strategies are adopted for rocks, soils and pyroclastic deposits, including linear, piecewise and mean-based models. Spatially correlated residuals are interpolated by geostatistical analysis and added to the regression predictions. The resulting model provides a spatially continuous and locally constrained representation of Vs30 variability across Italy.

Keywords: seismic motion, site effect, earthquake engineering, Vs30

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SITE CHARACTERIZATION OF THE ISRAELI SEISMIC NETWORK STATIONS

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ABSTRACT

We describe an ongoing site-characterization effort which started ten years ago, aimed at characterizing the 119 seismic stations of the new Israeli Seismic Network. The site characterization efforts include both field measurements as well as analysis of ground motion data recorded by the seismic stations themselves. The shallow shear-wave velocity profile is measured at 83 stations using a variety of surface-wave geophysical methods. The peak amplification frequency, $f_{peak,}$ is estimated through an HVSR analysis, using both microtremors as well as earthquakes. Finally, the high-frequency attenuation – kappa – is also estimated for all stations, using the f_{peak} to determine the frequency band.

Keywords: Site Characterization, V_{S30}, HVSR, kappa, f_{peak}

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SYSTEMATIC SITE CHARACTERIZATION OF EPOS-FRANCE SEISMOLOGICAL STATIONS USING SURFACE-WAVE METHODS

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ABSTRACT

The characterization of seismic stations is a key prerequisite for the optimal use of ground-motion recordings in seismic hazard and engineering applications. In France, a systematic effort to characterize the stations of the EPOS-France network, including both the RAP accelerometric network and the RLBP broadband network, has been ongoing since 2012. An initial dataset of 33 stations was presented in Hollender et al. (2018). Since then, this effort has been continuously expanded, reaching more than 100 stations in mainland France, with additional sites characterized in the French West Indies. This contribution presents an updated synthesis of this large-scale characterization program. The adopted methodology relies on a consistent framework combining Horizontal-to-Vertical Spectral Ratio (HVSR), Ambient Vibration Array (AVA), and Multichannel Analysis of Surface Waves (MASW) measurements. These complementary datasets are jointly interpreted through inversion procedures based on the acceptable-misfit approach, allowing for robust estimation of shear-wave velocity profiles and associated uncertainties. The results highlight the benefit of systematic, non-invasive characterization using large-aperture arrays, enabling investigation depths up to several hundred meters to about 1 km. The resulting dataset significantly improves the quality and consistency of site metadata for French seismic stations, providing a solid basis for future developments such as online dissemination platforms and data-driven approaches for uncharacterized sites.

Keywords: Seismological station characterization, EPOS-France, Surface-wave methods.

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ON THE IMPORTANCE OF EXPLICITLY ACCOUNTING FOR SENSOR SELF-NOISE IN GROUND MOTION MEASUREMENTS, WITH A PARTICULAR FOCUS ON AMBIENT-NOISE H/V ANALYSIS

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ABSTRACT

The quality of ground motion measurements, whether from ambient vibrations or earthquakes, depends on both the signal level at the site and the instrumental self-noise of the sensors. Reliable measurements require that the signal significantly exceeds self-noise over the frequency band of interest. In this study, we present a systematic characterization of the self-noise of sensors commonly used in geophysics, including broadband seismometers, accelerometers, and low-cost instruments. The analysis is based on co-located measurements using the three-sensor method of Sleeman (2006), allowing instrumental noise to be estimated independently of the seismic signal. Through several examples, we show that sensor selection must be guided not only by the method used, but also by the actual ambient vibration level and the frequency range of interest. Sensors commonly considered suitable may become inadequate when ambient noise levels are too low relative to their self-noise. We therefore recommend systematically comparing the power spectral densities of recorded signals with sensor self-noise levels. Applications to H/V analyses demonstrate that insufficient signal-to-noise ratios can lead to apparently stable and well-defined H/V curves that are in fact artefacts, controlled in part by instrumental noise. This highlights the limitations of interpreting H/V curves based solely on their visual quality. These results go beyond the usual distinction between accelerometers and seismometers, and call for a more quantitative approach to instrumental validation, explicitly incorporating sensor self-noise into ambient vibration analysis, in complement to current SESAME guidelines.

Keywords: Ambient vibration, Sensor self-noise, H/V spectral ratio.

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DESIGNING A NATIONAL SOIL CLASS MAP FOR SWITZERLAND THROUGH INTEGRATED GEOPHYSICAL, GEOLOGICAL, AND GEOTECHNICAL DATA

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ABSTRACT

This project aims to develop a homogeneous, nationwide map of seismic soil classes for Switzerland, aligned with the revised second-generation Eurocode 8 (EC8). Existing cantonal maps are heterogeneous and largely based on only geological descriptions, limiting their ability to capture geophysical controls on site amplification.
The updated EC8 framework requires parameters such as the average shear-wave velocity of the sedimentary cover ($v_{s,H}$) and the depth to engineering bedrock (H_{800}), motivating a consistent, data-driven approach. Here, we present two key components of the ongoing workflow. First, SPT and CPT datasets are linked to shear-wave velocity profiles to derive empirical relationships within the EC8 framework. Second, machine learning techniques are applied to predict velocity parameters from HVSR measurements and mapped covariates. These models are applied to >3000 HVSR measurements across Switzerland. The final maps of V_{S30}, $v_{s,H}$, and H_{800} will provide a consistent basis for seismic soil classification and hazard assessment.

Keywords: seismic site classification, earthquake engineering, soil classes, Eurocode 8

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DEEP CHARACTERIZARION OF SEISMIC STATIONS USING STRONGMOTION RECORDS

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In recent years, the number of seismic stations deployed all over the world has increase notably, enabling the recording of large numbers of strongmotion accelerograms. While being a source of significant information for the community, this data losses its relevance if sites are not properly characterized. In this study, I propose to retrieve deep 1D S wave velocity (Vs) profile using only strongmotion records from the respective station. I analyze data from moderate earthquakes, retrieving parameters such as horizontal-to-vertical spectral ratios of vertically incident body waves (eHVSR) and noise (nHVSR), and Rayleigh wave's ellipticity & phase velocity. Results show a larger sensitivity to deeper parts of the Vs profiles, mainly restricted to hundreds of meters. This information

Keywords: deep Vs profiles, strongmotion records, site characterization

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EMPIRICAL AMPLIFICATION FUNCTIONS FOR SICILY BY USING 20-YEARS OF SEISMIC RECORDINGS

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ABSTRACT

Sicily is one of the Italian regions with the highest seismic hazard. Its geological and seismotectonic setting strongly influences local seismic amplification. We present site amplification functions obtained for a set of seismic stations in Sicily through the Generalized Inversion Technique (GIT) using a parametric approach. GIT separates source, path, and site effects by fitting observed spectra with a predefined functional model and deriving station amplification functions from residuals. GIT was performed on local earthquakes ($2.0 \leq M_L \leq 4.5$, depth ≤ 30 km) recorded between 2006 and 2024 by the Rete Sismica Italiana (RSN, code IV by INGV). The reliability of the results is assessed, where possible, through comparison with the ITACA database in terms of amplification functions. Results are also compared with HVSR curves derived from one hour of seismic noise. This dataset can be used to develop regional seismic amplification maps and for seismic hazard applications.

Keywords: Generalized Inversion Technique GIT, Sicily, Amplification function.

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EMPIRICAL AMPLIFICATION FACTORS IN CAMPI FLEGREI AREA FROM GROUND MOTION MODELS RESIDUALS

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ABSTRACT

This note presents the empirical estimation of the amplification factor (AF) at the seismic stations installed in the Campi Flegrei area and is part of the seismological activities of the Level III Microzonation Plan in the area. AF values for PGA, PGV and three period intervals of the acceleration response spectrum are available for 43 stations – both accelerometric and velocimetric – belonging to both permanent and temporary networks installed in the Campi Flegrei area.

Keywords: amplification factors, seismic motion, site effect, earthquake engineering, Campi Flegrei, Seismic Microzonation.

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GEOLOGIC CLASSIFICATION OF MHVSR PEAKS IN NEW ZEALAND

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ABSTRACT

This paper presents the geologic classification of microtremor horizontal-to-vertical spectral ratio (mHVSR) peaks at GeoNet strong motion station locations across New Zealand. A consistent field methodology using the same equipment and a common processing approach was used to develop mHVSR curves for each site. mHVSR peaks, or the lack thereof, were associated with geologic layer interfaces through an iterative review of site geotechnical data, geologic conditions and wider regional mHVSR trends. Two or more mHVSR peaks were present at 70% of the stations, representing various different impedance contrast combinations. For half of the stations, the peak with the largest amplitude was associated with a layer interface that was not the soil-rock interface typically associated with the fundamental site period. Results highlight the diverse site conditions across the GeoNet network, the insight that mHVSR testing can provide when used in conjunction with geologic/geotechnical data, and the complex nature of seismic site classification.

Keywords: horizontal-to-vertical spectra ratio, site classification, impedance contrast, geologic conditions

Relationships Between Site Amplification and Measured and Inferred Site Parameters in New Zealand

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Abstract:

The performance of the built environment during earthquakes is strongly influenced by local and regional variations in ground conditions, which affect both the amplitude and frequency content of ground motions. Developing models to predict these local features is a key ingredient for the modelling of the seismic hazard and risk

To achieve this, we compiled an extensive database of relevant site parameters at 582 GeoNet seismic stations, derived from seismic data (ambient noise and earthquake recordings), geological and topographical maps, as well as site parameters included in the NZ-strong-motion database (Wotherspoon et al., 2024). Additionally, the NZ backbone model proposed by Atkinson (2024) was used to compute PSA site-to-site variability within the period range of 0.05 to 10 seconds, utilizing a comprehensive dataset of ground motion parameters from Manea et al. (2024). We then evaluated the robustness of correlations between site parameters and earthquake site-to-site variability to assess their performance both individually and in combination.

Among measured parameters, V_{S30} shows the best performance at short periods, while T0 is more effective at longer periods. Inferred parameters such as slope, curvature and relief perform similarly, although they may capture different aspects of site-to-site variability. In conclusion, while different geological and topographical proxies are effective for estimating site amplification at a regional scale, measured site parameters such as T_0, V_{S30} and HVSR are also needed to capture the variability of site response at the local level.

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A 100-METER-RESOLUTION SITE-CONDITION MAP OF CHINA BASED ON SURFACE GEOLOGY AND BEDROCK DEPTH

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Accurate site classification maps are crucial for updating seismic zoning maps by accounting for site effects. When direct field measurements are impractical, proxy-based methods are commonly used to estimate V_{S30}, a key site-condition parameter. This study developed a novel hybrid model integrating surface geology and subsurface bedrock depth to predict V_{S30}. Using a nationwide database of 10,650 boreholes and combining 1:500,000 geological maps with 100-meter-resolution bedrock depth data, we produced high-resolution (100 m) V_{S30} and site classification maps for China. Validation showed the model's strong national applicability, with site classification accuracies of 79.38% (Class II), 73.90% (Class III), and 67.75% (Class IV). In plain areas, it outperformed slope-based methods in differentiating between Class II/III (NEHRP C/D) sites. Our hybrid model advances the accuracy of proxy-based V_{S30} estimation, and the resulting maps provide valuable input for seismic hazard zonation.

Keywords: shear wave velocity; site parameter; site condition; geological data; bedrock

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IMAGING LATERAL HETEROGENEITY USING BAYESIAN AMBIENT NOISE SURFACE WAVE TOMOGRAPHY TO ESTIMATE SITE EFFECTS

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ABSTRACT

Developing site-independent and accurate methods to estimate seismic amplification with uncertainty is key in site response assessment. In this work, we propose to evaluate site effects using a few weeks of ambient noise recordings by combining Bayesian Ambient Noise Surface Wave Tomography (BANSWT) and seismic wave propagation modelling. We will develop this new approach using data recorded by 400 nodes deployed in a 10 km by 10 km area in the Rhône Valley, near the Tricastin nuclear power plant. So far we have extracted group velocity measurements from ambient noise cross-correlation. They are consistent with the known local geology. Next step will be to apply BANSWT to retrieve a 3D shear wave velocity model with uncertainties on shear wave velocity and probability of the presence of interfaces at depth.

Keywords: site effects, ambient noise, Bayesien inversions, surface wave tomography, sedimentary basins

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ESTIMATION OF DETAILED SHALLOW S-WAVE VELOCITY STRUCTURE USING SURFACE WAVE EXPLORATION WITH HIGH-DENSITY LINEAR ARRAY IN KUMAMOTO CITY, JAPAN

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ABSTRACT

To evaluate detailed shallow S-wave velocity (Vs) structures, we conducted surface wave exploration using a high-density linear array in Kumamoto City, Japan. Because the observed waveforms generated by a weight-drop source were contaminated by reflected waves at high frequencies, Rayleigh wave dispersion curves were extracted up to 80 Hz, including both the fundamental and higher modes. A genetic algorithm was applied to invert for the Vs structure. The results show that inversion using only the fundamental mode is insufficient to accurately estimate the subsurface structure, particularly the depth of the deepest layer. In contrast, incorporating higher modes significantly improves estimation accuracy and yields results consistent with the PS logging data. Sensitivity analysis indicates that higher modes contribute to the estimation of deeper layer boundaries, while also providing constraints on shallow layers. These results indicate the importance of incorporating higher mode dispersion data for reliable characterization of shallow Vs structures.

Keywords: Rayleigh wave, multi-mode, high-density linear array, shallow S-wave velocity structure

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ESTIMATING SUBSURFACE VELOCITY STRUCTURE OF THE MIYAZAKI PLAIN BASED ON MICROTREMOR OBSERVATIONS

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ABSTRACT

The purpose of this study is to estimate the subsurface velocity structure of the Miyazaki plain, Japan, using microtremor records. We conducted single-station microtremor observation and microtremor array measurements in the Miyazaki plain. We calculated microtremor horizontal-to-vertical spectral ratios (MHVRs) from the single-station records. The results show that the peak frequencies of MHVRs in the northwestern and southeastern parts are higher than other regions. Next, we calculated Rayleigh wave phase velocities for 1-5 Hz. At the array site closest to coast among our array observations, the phase velocity in the high frequency range was faster than that of other array sites. We conducted inversion analysis using the MHVRs and Rayleigh wave phase velocity. As a result, the first and second layer of the resulting model from inversion analysis in the area of northeastern parts to southwestern parts are deeper than other areas.

Keywords: Miyazaki plain, microtremor, horizontal-to-vertical spectral ratio, Rayleigh wave phase velocity, subsurface velocity structure

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GRAVITY-CONSTRAINED SHEAR-WAVE VELOCITY MODEL OF THE MEJILLONES BASIN, NORTHERN CHILE

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ABSTRACT

In Chile, seismicity is primarily controlled by the subduction of the Nazca Plate beneath the South American Plate; however, shallow crustal faults can also generate significant earthquakes, as in the case of the Mejillones Fault (MF) in northern Chile. The city of Mejillones is located above one of the deepest known sedimentary basins in the country, intersected by this active N–S structure. This study presents an extended geophysical characterization of the Mejillones Peninsula basin based on seismic and gravimetric data. Ambient noise measurements, array techniques, and active seismic surveys were used to constrain shear-wave velocity structures, while gravity data were used to infer basin geometry and depth to bedrock. The integrated interpretation reveals a sedimentary sequence reaching depths of up to ~900 m, with marked lateral variations. It also enabled a gravity-constrained shear-wave velocity model, providing a consistent basis for future seismic hazard assessment through numerical modeling.

Keywords: Sedimentary basin, Mejillones Peninsula, Gravimetry, Surface waves methods.

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EVALUATION OF RAYLEIGH WAVE PHASE VELOCITIES USING MICROTREMOR ARRAY MEASUREMENTS NEAR PS LOGGING SITES IN THE KATHMANDU VALLEY

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ABSTRACT

The Kathmandu Valley in Nepal is an intermountain sedimentary basin filled with thick Quaternary lacustrine deposits, which significantly amplify seismic ground motions. The sediment thickness exceeds 600–650 m in the central part of the basin, and such deep soft sediments played a crucial role in the spatial distribution of damage during the 2015 Gorkha earthquake (M_w 7.8). In this study, phase velocities of Rayleigh waves are estimated using microtremor array measurements conducted at several sites in the Kathmandu Valley. Phase velocities are obtained using the spatial autocorrelation (SPAC) method with multiple array configurations. The obtained dispersion curves cover a wide frequency range depending on array size and site conditions. Comparisons with PS logging data at nearby borehole sites indicate that the observed phase velocities are generally consistent with shallow subsurface conditions. These results demonstrate the applicability of microtremor array measurements for evaluating site conditions in the Kathmandu Valley.

Keywords: Kathmandu Valley, Microtremor array measurement, Velocity structure

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OUTLINE OF GEOMETRIES OF SEDIMENTARY FILLING IN THE NORTH-EASTERN PART OF GÖLBAŞI BASIN (TÜRKIYE) BASED ON GEOPHYSICAL INVESTIGATIONS

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ABSTRACT

This work presents an outline of geometries of sedimentary filling of the north-east part of pull apart basin along the East Anatolian Fault (EAFZ) in Türkiye from geophysical investigations (HVSR, MASW) performed in the wake of the 6 February 2023 Kahramanmaraş earthquakes. The first event of magnitude ~7.7/7.8; known as the Pazarcik earthquake, severely affected Gölbaşı town situated on Holocene soils within this basin and between two EAFZ fault segments. The context and the research methodology are briefly introduced before discussing the geophysical results followed then by an overview of sedimentary filling that raises questions regarding fault geometry or ground motion amplification within this basin as well.

Keywords: Pull-apart basin, East Anatolian Fault, Gölbaşı (Türkiye), HVSR, MASW

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PASSIVE SEISMIC INVESTIGATION OF MADDHAPARA GRANITE MINE, BANGLADESH: A CASE STUDY OF A SITE WITH KNOWN BEDROCK DEPTH

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ABSTRACT

Obtaining the shear-wave velocity profile of the shallow underground by inversion of single-station estimates, such as H/V curves or Rayleigh wave ellipticity curves, is tempting. However, due to the inherent trade-off between depth and shear-wave velocity values, the inversion of H/V or Rayleigh wave ellipticity curves alone leads to ambiguous results. We show an example of Maddhapara Granite Mine, an underground hard-rock mine in Bangladesh, where the seismic bedrock depth is about 110 to 120 m. We performed passive seismic measurements to obtain Love and Rayleigh wave dispersion curves and Rayleigh wave ellipticity curves. Inversions using different sets of the measured data curves show that a combined inversion of dispersion and ellipticity data yields the most realistic results, while an inversion of ellipticity data alone gives unrealistic results. Additional constraints, such as dispersion curves or the fixing of the seismic bedrock depth, are necessary to obtain unique results for the inversion of ellipticity curves.

Keywords: Rayleigh wave ellipticity, Rayleigh wave dispersion curve, Love wave dispersion curve, shear-wave velocity profile, bedrock depth

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ESTIMATION OF SHALLOW TO DEEP SUBSURFACE STRUCTURES IN CENTRAL WAJIMA, ISHIKAWA PREFECTURE, JAPAN, USING MICROTREMOR OBSERVATIONS

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ABSTRACT

To investigate the relationship between subsurface soil structure and ground motion characteristics, we conducted microtremor measurements in central Wajima City, Ishikawa Prefecture. Microtremor array surveys were carried out using both small (radius of 1 m) and medium-sized arrays (side length 50– 600 m), allowing estimation of the subsurface structure from shallow (tens of meters) to deeper parts (up to ~1 km). The results revealed that soft sedimentary layers (Vs < 200 m/s) are widely distributed in the downtown area. The seismic bedrock (Vs ~ 3000 m/s) is shallower at the city's western edge, whereas our results indicate that the deeper subsurface structure (Vs = 400–3000 m/s) is similar between the downtown area and the eastern hills where no soft surface layers are present. Microtremor horizontal-to-vertical spectral ratios (MHVSRs) derived from single-point measurements exhibited distinct regional variations and provided useful insights into the spatial variation of deep ground structures across the study area.

Keywords: 2024 Noto Peninsula Earthquake, Microtremor, Site Amplification

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IMAGING THE BEDROCK AT THE URBAN SCALE USING AUTOCORRELATIONS: THE QUITO BASIN CASE STUDY

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ABSTRACT

Quito (Ecuador), located in a sedimentary basin, is exposed to a high seismic hazard due to its proximity to the Pacific subduction zone and active crustal faults. Using autocorrelation analysis, we retrieved body-wave reflections in this study, allowing us to map the deep, complex geological structures under the city. We compute autocorrelation functions at 10 stations distributed along a profile across the basin to image the bedrock geometry using P-coda earthquakes from regional seismicity. The results demonstrate that the autocorrelation technique is valuable for imaging structures at depth in urban environments where other geophysical imaging methods cannot be applied. We propose a new interpretation of the resonance frequencies measured in the basin and present a comprehensive image of the bedrock beneath the city. Keywords: seismic interferometry, seismic noise, site effects, body and surface waves.

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SEISMIC TOMOGRAPHY FOR CRUSTAL IMAGING BENEATH NSUKKA, IFE, AND KADUNA SEISMIC STATIONS IN NIGERIA.

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ABSTRACT

The crust and upper-mantle structures beneath the Nsukka, Ife, and Kaduna seismic stations in Nigeria have been studied using data from the 2009 earthquake recorded at these three stations. The study aims to use seismic tomography to create high-resolution images of the crustal structure beneath Nsukka, Ife, and Kaduna, enhancing understanding of the tectonic framework, aiding seismic hazard assessment, and supporting geoscientific and infrastructural development. The method involves modeling body waveforms—the Primary (P) and Secondary (S) phases—from the 2009 earthquake, whose epicenter was located in the South Western Nigeria, using the global crust model Crust2loc, the earthquake's epicenter, and the coordinates of the recording stations at IFE, KADUNA, and NSUKKA. The Python algorithm applies wave propagation theory, which uses the distance and travel-time as a function of ray parameters, to determine crustal properties such as depths and velocities from a single earthquake event. Results indicate that the Moho depths beneath these stations are approximately 35 km, 39 km, and 29 km, respectively. The earthquake's hypocentral depth is relatively shallow, with a maximum of 39 km from the Earth's surface to the mantle, indicating that the September 2009 event occurred within the thin upper crust of Nigeria. The study also determined the Moho depths, or the discontinuity between the upper mantle and lower crust, beneath the seismic stations in Ife, Kaduna, and Nsukka. Additionally, the study obtained parameters such as compressional and shear wave velocities (Vp and Vs) and their ratio (Vp/Vs), which are useful for mineral and oil exploration. This technique, implemented in this innovative research in Nigeria, can be used to estimate Moho depths across different regions in Nigeria using available seismic stations. Keywords: Nigeria, Tomography, Crust-upper mantle structure, Moho depth, Vp and Vs,

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OPENAMP: AN OPEN-SOURCE SITE AMPLIFICATION DATABASE TO UNLOCK THE POTENTIAL OF MACHINE LEARNING

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OpenAmp is an open-source, consistently curated, high-quality database of earthquake site amplification functions derived from instrumental recordings, accompanied by a comprehensive suite of site metadata, for 1,742 K-NET and KiK-net strong-motion recording sites in Japan. The site metadata builds upon the site database of Zhu et al. (2021) and introduces several new parameters, including the site-specific spectral decay parameter (κ0), the standard deviation of the horizontal-to-vertical spectral ratio of earthquake recordings (σHV), and site dimensionality index (I1D3D). A distinctive feature of OpenAmp is the inclusion, for the first time, of a diverse set of vector-based parameters and proxies, including quarter-wavelength velocity (Vs,qwl), and frequency- and scale-dependent topographic metrics. The (linear) site amplification functions are derived from weak-motion recordings using a generalized inversion technique in the Fourier domain, and their correlations with various site data are also presented. OpenAmp is unapparelled in its quality, scale, and completeness by any existing databases. It enables a wide range of applications, including optimal site parameterization, development and benchmarking of site-specific or geospatial amplification models, and testing novel ideas. Ultimately, OpenAmp has the potential to significantly advance data-driven approaches for modeling near-surface effects in seismic hazard assessments. The database and associated resources can be freely accessed via: https://doi.org/10.25398/rd.northumbria.29649008

Keywords: earthquake, site amplification, database, machine learning, hazard

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BASIN SITE EFFECTS AND GROUND MOTION AMPLIFICATION IN SOUTHEASTERN FRANCE

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ABSTRACT

The Mw 4.9 Le Teil earthquake (11 November 2019, lower Rhône Valley, France) posed a significant seismic hazard challenge due to its proximity to the Cruas and Tricastin nuclear power plants and the scarcity of observational data in this low-to-moderate seismicity region. This study extends previous 3D physics-based simulations with the spectral element code SPEED by substantially revising the subsurface velocity model, integrating new geological and geophysical data. Validation against seismic station recordings confirms strong agreement. Building on this framework, additional hypothetical scenarios are presented, demonstrating the potential of physics-based simulations as a robust alternative to empirical Ground Motion Models in data-sparse environments.

Keywords: Physics-based numerical simulation, Seismic wave propagation, Data-sparse regions, Ground motion variability, alluvial basin

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H/V SPECTRAL RATIOS: A FOUR DECADE OVERVIEW – CONSENSUS REACHED AND DEBATED ISSUES

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ABSTRACT

The two basic references which launched the HVSR technique were published 55 years and 37 years ago, respectively (Nogoshi & Igarashi, 1971; Nakamura, 1989). Since then, the method has spread worldwide and has been used for wider and wider types of applications; it has generated a lot of investigations and discussions on its theoretical basis, the kind of information that may be retrieved from MHVSR and EHVSR curves (from microtremor or earthquake recordings), and the optimal processing techniques to be used to obtain reliable and reproducible results. This presentation presents a quick overview of the legacy of these two foundation papers, as analysed through a collection of close to 3000 papers indexed in the "web of science" and "OpenAlex" bibliometric tools, which explicitly quote at least one of those two papers. After a short introduction presenting the paper collection, a quick overview of the various uses of the HVSR technique, together with their geographical and temporal distributions, emphasizes the remarkable spread of this technique in different communities worldwide. A methodological section discusses the different types of physical interpretations successively considered over those four to five decades, and the consequences on the subsoil information that could be extracted with adhoc processing. This review allows to list a series of findings with can be considered rather consensual, on what can, or cannot, be reliably extracted from HVSR curves (from fundamental frequency to velocity profile, or actual site amplification). There are however a number of still (widely) open issues, requiring further investigations to improve the methodological reliability and the routine practice of HVSR processing, depending on the expected outcomes.

Keywords: H/V ratio, microtremor, earthquakes, diffuse field theory, Rayleigh wave ellipticity, site amplification

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3D NUMERICAL SIMULATIONS OF AMBIENT SEISMIC NOISE: DISENTANGLING SOURCE DISTRIBUTION AND LATERAL HETEROGENEITY EFFECTS ON H/V AMPLITUDE AND POLARIZATION

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ABSTRACT

Ambient seismic noise *H V* spectral ratios are widely used for site characterization, yet their interpretation remains challenging in complex geological settings where both lateral heterogeneities and variations in noise source distributions may significantly affect the measurements. Here, we investigate the sensitivity of *H V* amplitude and polarization to these coupled effects using direct 3D numerical simulations of ambient seismic noise.

This study is motivated by repeated observations of strong temporal variability in *H V* measurements at the station S14 in the Mygdonian sedimentary basin (northern Greece), where large day-night variations in amplitude (see Fig. 4(b)), polarization, and occasionally peak frequency were reported. The station (denoted by red star in Fig. 1) is located above a blind fault separating a shallow northern basin from a deeper southern basin, suggesting that both local structure and changes in noise source distributions contribute to the observed variability.

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SITE AMPLIFICATION ESTIMATES FROM EMPIRICAL AND NUMERICAL METHODS IN ITALY

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ABSTRACT

Developing site amplification models for large areas is increasingly relevant for seismic hazard assessment. In this study, we compiled a dataset of empirical amplification estimates for more than 1000 Italian sites obtained by Standard Spectral Ratio (SSR), Generalized Inversion Technique (GIT) and site-to-site ground motion residuals (S2S). Then, we developed a quantitative framework to evaluate their mutual consistency and fit with predictions from an existing national site-amplification model based on 1D simulations. Results show a high correlation between empirical estimates, indicating that different methods consistently capture relative amplification levels. In Central Italy, observed systematic discrepancies stem primarily from the choice of reference ground motion and can be resolved by scaling the estimates to a common reference. In contrast, 1D simulation-based estimates correlate poorly with empirical data and fail to capture the range of amplification levels. These findings suggest that amplification models should be grounded on empirical data.

Keywords: seismic ground-motion, site effects, amplification factor, 1D simulation

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REVIEW OF SITE RESPONSE MODELING CONDITIONAL ON HVSR

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ABSTRACT

Frequency-dependent horizontal-to-vertical spectral ratios (HVSRs) of three-component recordings can provide useful information on site resonant frequencies, which may be useful for predicting site response. Despite this potential, HVSR-conditioned site response models have not been adopted in the ground motion models most often employed for ground motion prediction in the United States and most global regions. We suggest that this stems from HVSR data resources being unavailable to support model development until recently, ongoing questions related to how HVSR should be measured and interpreted, and lack of consensus on how HVSR data should be utilized for site response prediction. Despite those challenges, we argue that the stage is set for future implementation of HVSR-conditioned models because a public dataset is now available, it is increasingly recognized that models should be conditioned on microtremor-based HVSR (mHVSR), and several modeling approaches have appeared in recent literature. This brief article focuses on site response modeling approaches, which include machine learning methods, models conditioned on mHVSR ordinates, and models conditioned on attributes of mHVSR peaks (i.e., peak frequency, amplitude, and width) or the lack of peaks.

Keywords: Site response, microtremors, HVSR

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Grenoble (France), 19-21 October 2026

REGION-SPECIFIC AMPLIFICATION HAZARD MAPPING OF METRO VANCOUVER, BRITISH COLUMBIA, CANADA

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ABSTRACT

The Metro Vancouver seismic microzonation mapping project is a decade-long (2017-2027) project to produce region-specific seismic hazard maps that capture earthquake site and basin effects. These Metro-Vancouver-specific probabilistic seismic hazard maps are developed using the 6th Canadian seismic hazard model at 2% and 10% probability of exceedance in 50 years risk levels. Comprehensive Level 2 seismic microzonation mapping of 7 key earthquake shaking susceptibility measures are generated including thickness of post-glacial or Quaternary sediments, Vs_{30}, and resonance period of post-glacial or Quaternary sediments. Level 3 seismic microzonation mapping of shaking amplification hazard is then generated efficiently from tri-parameter shaking susceptibility mapping (the zonation) based on ground motions predicted from 1D site response analyses performed using selected earthquake waveforms scaled to the uniform hazard spectrum of each seismic source at the two chosen return periods to provide site amplification factors at 6 selected spectral periods (amplification values for mapping). At long spectral periods (≥ 2 seconds), ground motions are predicted from physics-based 3D wave propagation simulations of large-magnitude scenario earthquake ruptures within regional 3D velocity models (60 km depth) to provide basin-only amplification factors to multiply with the determined site amplification factors at locations where the average basin depth is greater than the average basin depth for a given Vs_{30} at the applicable 2 and 5 second spectral periods. The suite of 29 seismic microzonation maps of western Metro Vancouver were published in 2024, and extension to eastern Metro Vancouver is underway (2024 - 2027).

Keywords: site amplification, basin effect, seismic microzonation, hazard mapping, Vancouver

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Grenoble (France), 19-21 October 2026

ASSESSMENT OF SITE AMPLIFICATION FACTORS FROM THE NON-REFERENCE SITE APPROACH - A CASE STUDY OF THE TAIPEI BASIN

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ABSTRACT

The Non-reference Site Approach (NSA) has emerged as a flexible framework for evaluating frequency-dependent site amplification without requiring a nearby reference rock station. We apply the NSA using the stations in northern Taiwan to assess linear site amplification factors (SAFs) in and around the Taipei Basin. We use a simplified ground-motion prediction equation based on generic rock conditions and adopt a well-developed GMM for Taiwan to evaluate within-event residuals between observed RotD50 pseudo-spectral accelerations and model predictions for each station and period. The median within-event residual at each site is then interpreted as a linear, frequency-dependent SAF, from which the dominant frequency (f_0) and amplification factor (A_0) for each station can be derived. Our results reveal that stations inside the basin generally exhibit low dominant frequencies (approximately 0.4–1.5 Hz) and significant amplifications (about 3–6), whereas stations along the basin edge and outside the basin show higher dominant frequencies and smaller amplifications. These patterns align with previous understandings of sediment thickness and shear-wave velocity structure and match the earlier dominant frequency distribution obtained from microtremor observations. The NSA-derived results yield a non-ergodic SAF, which more accurately captures site-specific amplification behavior than an SAF predicted by an ergodic GMM. Our results show comparable spectral shape between NSA-derived SAFs and earthquake horizontal-to-vertical spectral ratios (eHVSR) at most stations, indicating that the NSA reasonably captures the linear component of site response. Furthermore, the agreement between the two independent approaches supports the NSA as an alternative approach to understanding the site amplification behavior at a site. Spatial distributions of dominant frequency and amplification factors within the Taipei Basin, corresponding to a uniform engineering bedrock, are then derived using the NSA method. The result confirms significant long-period amplification, especially in the western sector, suggesting that the current seismic design spectra may underestimate the effects of basin amplification at longer periods.

Keywords: site amplification factor, Non-reference Site Approach, eHVSR, Taipei Basin

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OSCAR BENCHMARK: ONE−STATION METHODS FOR SITE CHARACTERIZATION BENCHMARK

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Reliable characterization of site conditions is a key component of seismic hazard assessment and earthquake engineering. While a wide range of single-station methods has been proposed to infer subsurface shear-wave velocity (Vs) structures from ambient noise and earthquake recordings, their performance and robustness strongly depend on the available data, processing choices, and a priori constraints. The OSCAR Benchmark (One-Station methods for Site ChARacterisation) has been designed to systematically evaluate and compare single-station site-characterization approaches under controlled and progressively informed conditions. The benchmark is structured into three successive phases**,** each introducing additional levels of information in order to investigate how different types of prior knowledge influence inversion stability, uncertainty, and reliability. Phase 1 focuses on minimal-information scenarios, where participants rely primarily on seismic recordings, ambient noise and/or earthquakes recordings, and their preferred processing and inversion strategies, while Phase 2 is divided into two sub-phases, in which increasing amounts of near-surface and geological information are provided, such as partial shear-wave velocity constraints (e.g., shallow or deepest range of Vs estimates) and well-characterized reference profiles. Phase 3 is conceived as an exploratory and flexible stage**,** intended to further investigate the limits and adaptability of single-station methods. By comparing inversion results across phases, sites, and methodological families, the OSCAR Benchmark aims to investigate how the amount and nature of site-related prior information provided to the participants influence inversion outcomes, enabling a systematic evaluation of how additional constraints reduce non-uniqueness and improve robustness, as well as an assessment of inter-method variability, sensitivity to prior assumptions, and trade-offs between model complexity and stability. The ultimate objective of OSCAR is to synthesize these findings into practical, evidence-based guidelines for single-station site characterization, to provide recommendations on optimal processing strategies, inversion setups, and the most informative forms of a priori information, with the goal of promoting more reliable, transparent, and reproducible site-condition assessments in both research and applied contexts.

Keywords: site characterization, inversion, single-station methods, site effects, shear-wave velocity profiles.

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FIBRE OPTIC SENSING : STATE OF THE ART AND PERSPECTIVES

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ABSTRACT

Fibre optic sensing has experienced a tremendous development in the two recent decades, provided by the photonic scientists' ability to manipulate light better and the availability of more powerful com-puters. Initially used by oil and gas industry in boreholes, fibre optic sensing developed applications in Geosciences through a couple of key studies, which demonstrated that existing fibre optic cables in telecom infrastructures can be transformed in thousands of strain and temperature sensors. This opened the path to probing ground subsurface for an ever-increasing number of applications, e.g., seismology, submarine studies, landslides detection, volcanology, glaciology, sink hole detection and many others. This paper aims at providing a short introduction on fibre optic sensing highlighting few principles and at illustrating applications in seismology, volcanology, and urban environment.

Keywords: fibre optic sensing

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Grenoble (France), 19-21 October 2026

DISTRIBUTED ACOUSTIC SENSING (DAS)-BASED SITE CHARACTERIZATION: OPPORTUNITIES AND CHALLENGES

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ABSTRACT

Distributed acoustic sensing (DAS) offers a transformative approach to seismic monitoring and subsurface characterization by providing densely sampled measurements over kilometer-scale fiber-optic arrays. However, realizing its potential requires addressing challenges associated with issues such as fiber installation in diverse geologic environments, frequency-dependent measurement interpretation, waveform quality, and horizontal-component inversion. This study examines opportunities and challenges through two recent field experiments involving ~1.4 km DAS arrays with co-located nodal stations: one focused on subsurface imaging and fault characterization, and the other on vibration monitoring associated with critical infrastructure. The studies highlight practical challenges associated with phase errors in high-strain DAS measurements and strain-to-velocity conversions for applications based on conventional seismic ground-motion metrics. Furthermore, a semi-automatic radial-component predominant-mode surface wave inversion is applied to address the directional nature of DAS measurements and automate mode selection across densely sampled subarrays. The results highlight both the potential of DAS and the need for continued research on DAS-specific acquisition, processing, and inversion strategies.

Keywords: Distributed acoustic sensing (DAS), Subsurface Imaging, Site Characterization

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DEVELOPMENT OF THE SUBSURFACE VELOCITY STRUCTURE MODEL AND SOURCE MONITORING TECHNOLOGY UTILIZING FIBER OPTIC SENSING

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ABSTRACT

A new technology has been developed to monitor the subsurface velocity structure by using optical fiber cables as high-density sensors. At the test site in Tsukuba, DAS observations using horizontal and vertical optical fibers are conducted to investigate the effect of cable installation direction on data quality. Measurement records showed that the data quality of horizontal optical fibers was good, but it was confirmed that weak signals could not be measured with borehole optical fibers if the coupling with the borehole wall was insufficient. Furthermore, observations were conducted using dark fiber in the Kinugawa area to obtain records of earthquakes, microtremors, and vibrator excitations. The results showed that different data were obtained depending on the location of the vibration source and the direction of the cable, demonstrating its applicability to estimating the subsurface velocity structure.

Keywords: Distributed Acoustic Sensing, velocity structure model, high-density observation, earthquake monitoring, real-time data processing

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AMBIENT NOISE INTERFEROMETRY APPLIED TO DAS ARRAYS:

SEASONAL SITE MONITORING IN A QUIET MARSH FLOODPLAIN

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ABSTRACT

Distributed Acoustic Sensing (DAS) is an emerging seismic measurement technology, capable of providing dense strain measurements along a fiber-optic cable at local scales while remaining unobtrusive, making it particularly attractive for long-term site monitoring without repeated deployment. Since the strain measurements are averaged over a sliding gauge length rather than being point measurements like with geophones, there is a need to test its limitations in near-surface imaging and monitoring. In the context of the IMADAS project, we conduct seasonal DAS measurement campaigns in a marsh floodplain of the Loire estuary where we deploy a fiber optic cable and forty 3C geophones. In this work, we first calibrate the DAS recordings using colocated 3C nodes. We then apply seismic interferometry based on Phase cross-correlations to ambient noise recordings during the summer and winter seasons to a linear segment of the dense array. Based on our results, we discuss the seasonal variation of both subsurface dispersion properties and characteristics of the noise wavefield.

Keywords: DAS; ambient seismic noise; phase cross-correlation; soil monitoring; near-surface imaging

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DETECTING SEASONAL VARIATIONS OF SEISMIC SITE RESPONSE: TESTING IN NE HOKKAIDO, JAPAN

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ABSTRACT

Near-surface materials can be sensitive to environmental changes, such as rainfall or temperature fluctuations. For example, seasonal changes in shear-wave velocity have been documented for at least 20 years and are typically derived from continuous seismic noise data. Little research has been conducted into how such velocity changes affect earthquake seismic site response, which is generally considered to be static. In this study, we use earthquake data recorded at KiK-net stations in NE Hokkaido, Japan, to show that at select sites the entire site response (over the entire frequency band) shows seasonal cyclic variations up to a factor of two to three. The variations reflect environmental changes, in particular the winter period of continuous sub-zero temperatures. Our focus is on developing methods to detect and quantify these seasonal variations in site response and on identifying the meteorological and atmospheric parameters that best explain and track these changes over time.

Keywords: site effects, seasonal variations, Japan

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UNVEILING TYPE OF FIBER AND COUPLING CONDITIONS EFFECTS ON DISTRIBUTED FIBER OPTIC SENSING

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ABSTRACT

Distributed Acoustic Sensing (DAS) is a novel technology widely used in geoscience in the last years, with the advantage or leveraging the existing fiber-optic infrastructure to study deformation processes, but compared to traditional sensors its instrumental response remains unclear. In order to understand how DAS measurements are influenced or not by the nature of the fiber optic cable and its coupling we analyze data from two active seismic experiments deployed at the Low-Noise Underground Laboratory (LSBB, *Laboratoire Souterrain à Bas Bruit*), in redundant set-ups, long and short scale and low and high frequency seismic sources, comparing different deployment conditions. Our results reveal significant discrepancies in the recorded data depending on the coupling conditions, and differences in the performance of different types of cables, which should be considered at the moment of design a DAS acquisition in order to preserve a good sensitivity and cost-efficiency.

Keywords: Coupling, fiber-optics, DAS, strain-rate, active seismic.

AN ADAPTED P-WAVE SEISMOGRAM APPROACH FOR DIRECT V ESTIMATION IN GREECE
S30

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ABSTRACT

We apply the P-Seismogram (Ni et al., 2014) method to estimate the V_{S30} at several Greek stations, exhibiting different local site effects, based on availability reference velocity models. The method uses the first P-wave arrival recorded on the vertical and radial component to estimate the corresponding amplitude ratio. We derive the V_{SZ} and propose a direct estimation of V_{S30} by determining for each waveform the depth extend, z, to which V_{SZ} refers to. This is expressed as $z = V_{SZ}\ \tau_p$, where τ_p is the source time function. We measure τ_p for each P-arrival and compute corresponding depth. Statistical processing of the z-V_{SZ} dataset allows us to directly obtain V_{SZ} for a depth of 30m, i.e. a V_{S30}^{Pseis} value. Application of this approach to selected stations with available reference V_{S30} values shows a good agreement of V_{S30}^{Pseis} estimates with the reference values, verifying the potential of the proposed approach.

Keywords: V_{S30}, P-wave Seismogram Method, Greek Stations, Local Site Effects

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SOIL-COMPACTION RATES FROM PS-INSAR AS A FUTURE PROXY FOR RESONANCE PERIODS INFERRED IN VARIOUS SEDIMENTARY VALLEYS

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ABSTRACT

In sedimentary basins, the site effect resulting from the impedance contrast between the sediments and the bedrock can lead to an increase in the intensity of the seismic motion. Assessing this site effect is important in the seismic regulations and therefore the need to accurately measure site parameters is in-creasing. Using the case of two valleys in France where the sedimentary site effect is well known, we illustrate that it is possible to retrieve the resonance period (T_0) from the long-term displacement rate of the ground, as measured by InSAR, leading the way to a new proxy to obtain T_0 at a high spatial res-olution. We will need to confirm and characterize this relationship across a wide range of sedimentary contexts before we can establish a new proxy; in this first step, we also show that such a proxy will have to include information about the rigidity of the sediments.

Keywords: sedimentary site effect, sediment compaction, InSAR, fundamental-resonance period, proxy

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A METHOD FOR ESTIMATING COMPLEX BROADBAND FREQUENCY RESPONSE FUNCTIONS AND GENERATING VIRTUAL SEISMOGRAMS

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ABSTRACT

Accurate seismic hazard assessment and earthquake-resistant design rely on reliable estimates of local site response. However, existing empirical and numerical methods are limited in regions of low-to-moderate seismicity. The standard spectral ratio (SSR) method requires numerous earthquake records, while the horizontal-to-vertical spectral ratio (HVSR), both using earthquake or seismic noise recordings, fails to estimate the site response. The reference spectral ratio method, when applied to seismic noise, may also be biased by the distribution of anthropogenic noise sources. Moreover, these approaches neglect the complex nature of site response and the cross-coupling between motion components. This study proposes a novel method to estimate a broadband complex site response function using only seismic noise and to generate virtual seismograms for different earthquake azimuths. The methodology combines an extended hybrid standard spectral ratio with a cross-coupling inversion approach to capture the broadband frequency-dependent behavior of the complex site response function. Application to Kefalonia Island shows strong agreement with SSR, while the generated virtual seismograms closely reproduce observed ground motions.

Keywords: Seismic noise interferometry, Complex site response function, Virtual seismogram, earthquake engineering,

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ASSESSING THE ROBUSTNESS AND RELIABILITY OF SINGLE-STATION FULL MICROTREMOR HORIZONTAL-TO-VERTICAL SPECTRAL RATIO INVERSION IN SEISMIC SITE CHARACTERIZATION: RESULTS FROM THE OSCAR BENCHMARK

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ABSTRACT

Passive seismic techniques, particularly the microtremor single-station horizontal-to-vertical spectral ratio (mHVSR) method, have proven highly effective for seismic site characterization due to their efficiency, low cost, and applicability across diverse geological settings. Within the OSCAR Benchmark framework, ambient vibration data from five sites were processed to derive mHVSR curves. The full mHVSR spectra were then inverted, following the Phase 1 and Phase 2a protocols, to estimate shear-wave velocity (Vs) profiles at each station in the blind test. In Phase 1, the inversion was performed without incorporating prior information. In Phase 2a, constraints were introduced based on available knowledge of near-surface geology, together with provided estimates of shear-wave velocity for the shallow subsurface layers. The results demonstrate that incorporating such constraints reduces the non-uniqueness of the inversion.

Keywords: Seismic site characterization, Site effect, Full H/V inversion, Soil Class, Vs30

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SEISMIC SITE CHARACTERIZATION VIA ONE-STATION INVERSION METHODS: RESULTS FROM OSCAR BENCHMARK

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ABSTRACT

This study presents the results of the OSCAR Benchmark (One-Station methods for site ChARacterisation Benchmark), an initiative designed to evaluate the performance of site characterization methods using single-station techniques. The research evaluates the impact of increasing stratigraphic constraints on seismic site characterization through the inversion of H/V spectral ratios. Using five study sites (XX01–XX05) as benchmarks, we compare three levels of methodological refinement: an unconstrained preliminary model (Phase 1), a constrained geological model (Phase 2a), and a high-resolution, multi-layer model (Phase 2b). Results demonstrate that unconstrained inversions (Phase 1) systematically overestimate subsoil stiffness, often misclassifying sites by masking sedimentary covers. Conversely, Phases 2a and 2b, through stratigraphic data integration, effectively resolve shallow impedance contrasts and capture low-velocity gradients. High-resolution modeling is essential for accurate Vs30 estimation and seismic classification (Eurocode 8/NTC 2018), preventing underestimation of seismic design actions. Keywords: ESG7, Seismic Site Characterization, Velocity Profiles, Single-station Inversion methods

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OSCAR BENCHMARK: WESTERN UNIVERSITY APPROACH

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ABSTRACT

This investigation seeks to examine new approaches for MHVSR inversion using the popular Geopsy inversion routine, Dinver, within the bounds of the OSCAR Benchmark Project. An emphasis is placed on how S-wave boundaries of each layer contribute to model misfit associated with blind inversion of MHVSR curves. In addition, critical input data selection using a Python MHVSR curve clustering algorithm is compared to Geopsy's native curve processing, to reduce user bias within the window selection stage. Using an iterative processing workflow in Phase I where velocity model parameterization ranges are incrementally increased as a method to tackle the blind and non-unique nature of the inverse solutions within the parameter space was highly successful at generating applicable minimum misfit models. Given further site information in Phase II regarding layer thickness or initial S-wave velocity, permitted refinement of the applicable suite of minimum misfit models to refine the most likely subsurface profile(s).

Keywords: Geophysical Inversion, Seismic Hazard, Seismic Amplification, Microtremor Horizontal-
to-Vertical Spectral Ratio, OSCAR Benchmark Project.

The 7th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion
Grenoble (France), 19-21 October 2026

PRELIMINARY RESULTS ON EPISTEMIC UNCERTAINTY ESTIMATION FOR SHALLOW VS STRUCTURES USING MULTIPLE INVERSION TECHNIQUES IN A SUBGROUP WITHIN THE ESG7 OSCAR BLIND PREDICTION EXERCISE

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ABSTRACT

We participated in the ESG7 OSCAR blind prediction with four modelers, each using their own methods and strategies to assess Vs structures at six sites. The sites' identities were undisclosed, but some geological information, layering, partial Vs, and thickness were provided at various stages. The methods used comprised a diffuse field assumption (DFA) for the microtremor horizontal-to-vertical spectral ratio (mHVSR) with supervised inversion based on Vs from the dominant-frequency-to-Vs30 relation; a DFA for mHVSR with simulated annealing; a DFA for mHVSR with reversible jump Markov chain Monte Carlo; and a 1D Haskell method for the earthquake horizontal-to-vertical spectral ratio combined with a genetic algorithm. Monitoring the inversion results at each step showed how epistemic uncertainty changed as new types of information were introduced. This understanding can inform future applications by helping decision-makers gauge the level of epistemic uncertainty that can be managed within limited budgets.

Keywords: ESG7, OSCAR Blind Prediction, Epistemic Uncertainty, diffuse field assumption, 1D Haskell

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Grenoble (France), 19-21 October 2026

USE OF HV-INV SOFTWARE ON THE OSCAR BENCHMARK

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ABSTRACT

The goal of the OSCAR benchmark is to evaluate different single-station methods used to calculate the shear-wave velocity profiles. Our team has joined this benchmark to test the HV-Inv software, which has been used in a few previous studies. HV-Inv is a computer code for forward modelling and inversion of H/V spectral ratios based on the diffuse field assumption.

This paper describes the software and the procedure used to process the data submitted from all sites. Subsequently, the main results obtained are presented, analyzing the discrepancies observed during the different phases of the benchmark. Finally, some conclusions and lessons learned during the OSCAR benchmark are detailed.

Keywords: HV-Inv, HV Inversion, Soil fundamental frequency, Shear-Wave Velocity Characterization

The 7th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion
Grenoble (France), 19-21 October 2026

SITE CHARACTERIZATION BY INVERSION OF RAYLEIGH WAVE ELLIPTICITY ESTIMATED FROM AMBIENT SEISMIC VIBRATIONS IN THE FRAMEWORK OF THE OSCAR BENCHMARK

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ABSTRACT

Seismic waves can be amplified by near-surface geological conditions. The assessment of such local site effects is therefore important for seismic hazard assessment. It is tempting to use single-station measurements, such as H/V or Rayleigh wave ellipticity curves, for site characterization. The inherent trade-off between depth and shear-wave velocity values, however, leads to ambiguous results if such single-station data are inverted without additional constraints. The OSCAR (One-Station methods for site ChARacterisation) benchmark of the ESG7 symposium on the Effects of Surface Geology on Strong Motions invited research groups to analyze and invert single-station data, in a first phase without additional information and, in further phases, with increasing amounts of additional information. The goal of the benchmark is to assess what type of additional information is actually needed and how it affects the obtained results. By analyzing the data provided for the six OSCAR test sites, we obtain Rayleigh wave ellipticity curves and invert them to obtain shear-wave velocity profiles of the underground. The results show that the additional information provided in phase 2a is not sufficient for realistic results, and that the information in phase 2b, which mainly consist of near-surface velocity profiles down to 15 m depth, actually improves the inversion results and reduces the variability of the obtained velocity profiles. Nevertheless, the accuracy of the obtained velocity profiles can only be assessed once the reference results of the different sites are available.

Keywords: ESG7 OSCAR benchmark, site characterization, Rayleigh wave ellipticity

The 7th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion
Grenoble (France), 19-21 October 2026

OSCAR BENCHMARK: INVERTING OF SINGLE-STATION ELLIPTICITY CURVES USING MULTIZONAL TRANSDIMENSIONAL INVERSION.

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ABSTRACT

This extended abstract summarizes the methodology used to perform inversion of single-station seismic recordings for six sites within the OSCAR benchmark. The benchmark aims to evaluate the potential of single-station ambient vibration and earthquake recordings for deriving reliable shear-wave velocity (Vs) profiles. In the first step, we compared the H/V curves calculated using earthquakes and ambient vibrations. This offered us a first insight into the characteristics of different sites and helped to estimate the frequency ranges appropriate for further inversion. From the selected data, we computed Rayleigh-wave ellipticity curves using the RayDec algorithm and used the multizonal transdimensional Bayesian inversion tool Neopsy to derive velocity profiles. The results show that the inclusion of prior information can improve the agreement with the target shallow velocity structure at some sites, while deeper interfaces remain poorly constrained due to the limited resolution and penetration depth of single-station ellipticity data.

Keywords: ESG7, OSCAR, Neopsy, RayDec, H/V, ambient vibrations, inversion

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INVERSION OF HORIZONTAL-TO-VERTICAL SPECTRAL RATIO OF MICROTREMORS AND EARTHQUAKES FOR OSCAR BENCHMARK

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ABSTRACT

We participated in OSCAR for evaluating the performance of single-station methods for seismological site condition characterization. We identified one velocity structure based on HVR of microtremors and the other one based on HVR of earthquakes for each of the five target sites. For microtremor HVR inversion, HVRs using distributed microtremor records were calculated by applying the anti-triggering filter and a linear scale smoothing. Then, the microtremor HVRs were inverted based on the diffuse field concept for microtremors. The velocity structures above the seismic bedrock were considered. For earthquake HVR inversion, HVRs using 40 s including S-wave of all distributed ground motions were calculated. Then, the earthquake HVRs were inverted based on the diffuse field concept for earthquakes. Basically, ten or five layers above the seismic bedrock was assumed. The identified velocity structures for microtremor and earthquake HVRs reproduced their target HVRs well in all the requested exercise phases.

Keywords: OSCAR, HVR, Microtremor, Earthquake, Diffuse field concept

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OSCAR BENCHMARK TEST: JOINT INVERSION OF EARTHQUAKE AND MICROTREMOR H/V SPECTRAL RATIOS

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ABSTRACT

A joint inversion of the earthquake H/V spectral ratio (EHVR) and the microtremor H/V spectral ratio (MHVR) was performed for the OSCAR benchmark test based on diffuse field theory. The theoretical EHVR and MHVR were calculated using the formulations of Kawase et al., 2011 and García-Jerez et al., 2013, respectively. Subsurface structures were estimated using a Hybrid Heuristic Search algorithm combining a genetic algorithm and simulated annealing. Broad search ranges resulted in unstable convergence, whereas fixing the S-wave velocities of the deep layers improved the inversion stability. The optimal models reproduced the observed EHVR and MHVR at most sites. Comparison with observed group velocity dispersion curves also showed reasonable agreement, demonstrating the applicability of the proposed joint inversion approach.

Keywords: Microtremor H/V spectral ratio, Earthquake H/V spectral ratio, Diffuse field theory

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JOINT INVERSION OF ELLIPTICITY, HVSR, AND P-WAVE SEISMOGRAM DATA USING THE NEIGHBORHOOD ALGORITHM AND SIMULATED ANNEALING METHODS

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ABSTRACT

We investigate the potential of jointly inverting single-station noise and earthquake data to constrain the 1D S-wave velocity (Vs) structure in the context of the OSCAR blind benchmark. Different joint-inversion schemes and methods were tested during the three phases of the OSCAR benchmark for six unknown sites. The corresponding Vs models were also independently estimated using the P-wave Seismogram (PWS) method from earthquake recordings. Selected PWS-derived Vsz values were incorporated into joint-inversion schemes together with ambient noise data to evaluate their contribution to reducing model non-uniqueness and improving the robustness of the estimated Vs models. The resulting models show generally good agreement between the Neighborhood Algorithm (NA) and Simulated Annealing(SA) inversion methods,with the largest discrepancies observed for the first OSCAR phase, when no prior constraints were available. Model consistency improves as additional geological and geophysical constraints are introduced in later OSCAR phases, highlighting the value of combining complementary single-station data to reduce inversion uncertainty.

Keywords: OSCAR benchmark, Joint inversion, Simulated Annealing, Neighborhood Algorithm, single-station data, P-wave Seismogram

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EFFICIENT MCMC SAMPLING FOR NON-UNIQUE HVSR INVERSION IN THE OSCAR SITE RESPONSE BENCHMARK

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ABSTRACT

Horizontal-to-vertical spectral ratios (HVSR) and Rayleigh-wave ellipticity curves constrain shallow shear-wave velocity structure. Yet, their inversion is strongly non-unique. In the Rayleigh-ellipticity limit, co-scaling velocities and interface depths can produce identical curves. This ambiguity creates long, correlated posterior probability structures that are inefficiently sampled by one-parameter-at-a-time Markov chain Monte Carlo (MCMC) methods. We use simulated inversion benchmarks to assess the efficiency of principal-component covariance rotated model parameter perturbations within MCMC. Despite the overhead cost of estimating parameter rotations, principal-component rotations yield far more effective samples for the same MCMC iteration count, even when compared to favorable examples of standard sampling chains that start at the true model with tuned proposal widths. This work highlights how efficiently sampling the non-unique, correlated posterior is essential for site-response uncertainty analysis.

Keywords: site response; HVSR; Rayleigh ellipticity; Bayesian inversion; MCMC

SPATIAL SAMPLING AND SENSOR COMPLEMENTARITY IN A CO-LOCATED DAS–3C NODAL SURVEY

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ABSTRACT

Distributed acoustic sensing (DAS) and three-component (3C) nodes provide complementary views of near-surface wavefields. We present a co-located active–passive experiment using a 150 m buried fibre and eight 3C nodes at Velemín, Czech Republic. Ambient spectra, repeated hammer impacts and phase-shift images were compared over a common 140 m aperture. DAS used a 10 m gauge length and 5 m channel spacing; nodes were spaced at 20 m. DAS provided densely sampled observations, whereas nodes provided component-resolved particle motion and generally higher receiver-level SNR. Retaining only DAS channels at nodal positions increased phase-shift ambiguity under identical aperture and processing, showing receiver spacing to be a major contributor. Differences persisted at spatially matched positions, consistent with sensing quantity, gauge-length averaging, coupling and instrument response. The experiment illustrates both the sampling advantage of DAS and the complementary role of sparse 3C nodes in site characterization. Keywords: distributed acoustic sensing, surface waves, nodal sensors, spatial sampling, site characterization

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NEAR-SURFACE SHEAR WAVE VELOCITY PROFILING USING LONG-RANGE DAS: A PARAMETRIC STUDY ON THE COMBINED INFLUENCE OF OPTICAL AND COUPLING EFFECTS FROM NUMERICAL AND FIELD DATA

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ABSTRACT

This study shows that pulse width (PW) effects are critical for DAS near-surface (< 50m) applications (e.g. Vs30), and that typical PW values (> 3m) required for long-range (> 20 Km) DAS survey may seriously impede the retrieval of high frequency dispersion needed for near-surface Vs imaging using active MASW survey. On the other hand, GL effects are not dominant. Our results also show that bad ground coupling of the fiber optic as well as intrinsic sensitivity of DAS data, leads to poor sensitivity to high frequencies dispersion and may lead to artifacts which are exacerbated with the increase of PW and GL values. Thus, near-surface Vs profiling using long-range DAS on existing telecom fiber optic infrastructure is possible, but limited resolution is expected for the first 5-10 m depth for most geological settings.

Keywords: DAS, MASW, Vs30, soil classification

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IMADAS PROJECT: IMAGING AND MONITORING THE NEAR SUBSURFACE USING DAS AND GEOPHONES MEASUREMENTS

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ABSTRACT

Distributed Acoustic Sensing (DAS) is an emerging technology that offers unprecedented spatial and temporal resolution. However, unlike conventional seismic sensors, DAS measures longitudinal strain rate along an optical fiber rather than three-component ground velocity. Within the ASNR–CNRS IMADAS project, we aim to assess the potential and limitations of DAS for near-surface monitoring and imaging. To this end, we conducted four one-week field campaigns combining DAS and geophone measurements in two environments: a marsh in Couëron (France) and a levee in La Riche (France). In addition, semi-permanent geophone nodes were deployed at both sites. This study first presents the experimental setups implemented at these locations. We then analyze temporal variations in soil properties using the Horizontal-to-Vertical Spectral Ratio (HVSR) method applied to the semi-permanent nodes, interpreting these variations in terms of changes in soil water content. Finally, we compare surface-wave velocities derived from geophone nodes and DAS measurements in the marsh environment. This work provides a foundation for subsequent, more detailed analyses.

Keywords: DAS measurements, near subsurface imaging, near surface monitoring, site effects, levee

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LARGE SCALE ASSESSMENT OF RAILWAY SITE CONDITIONS USING RESONANCE FREQUENCIES FROM DAS DATA (ESG7)

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ABSTRACT

Modern French railway network is equipped with optical fifibers dedicated to telecommunication pur-poses, among which some remain unused. These so-called dark fifibers can be exploited using Dis-tributed Acoustic Sensing technology (DAS) to provide an effective tool for rapid assessment and long-term monitoring of site conditions along railways tracks. We present a methodology applied to a 19 km long DAS array operating under normal railway traffific conditions, highlighting the capability to perform continuous spatial analysis at kilometer scale with measurements every 4.9 meters. Despite the limited coupling associated with the on-conduit installation, corresponding to the standard opera-tional conditions without any modifification to the existing infrastructure, time windows selected before and after train passages allow the extraction of the resonance frequencies (f_R) at each DAS channel, overcoming the low signal-to-noise ratio of the installation setup. Variations of f_R along the railway reflflect changes in near-surface soil conditions, related either to shear wave velocity or to variation in impedance contrast depth, with rapid spatial variation observed in karstic areas over only a few tens of meters. The novelty of this work lies in the use of f_R as a stable and repeatable site parameter derived from DAS data on a large scale. While this information does not quantify site amplifification, it provides direct information on the frequency ranges that may be preferentially amplifified. This makes them well suited for long-term monitoring and for tracking temporal or spatial changes in site conditions under linear infrastructures, and for supporting future strategies to manage infrastructure evolution and time-dependent variability.

Keywords: Distributed Acoustic Sensing, site characterization, resonance frequencies

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NUMERICAL SIMULATION OF DAS TRAIN-INDUCED SEISMIC SIGNALS FOR SUBSURFACE MONITORING IN SHALLOW KARSTIC ENVIRONMENT

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ABSTRACT

Train-induced seismic signals are increasingly recognized as valuable sources of information for passive seismic monitoring of the shallow subsurface over large areas with minimal environmental impact. Repeatable train signals provide a continuous tool for observing and detecting geomechanical subsurface variations along railway infrastructure. In particular, the presence of shallow karstic cavities can alter near-surface mechanical behavior and lead to sudden collapse of surficial earth material, affecting the stability and performance of railway infrastructure. In this study, we use seismic signals generated by passing trains, recorded on fiber-optic cables, to monitor spatio-temporal variations of subsurface geomechanical properties over long distances beneath railways. To better understand the signature of DAS (Distributed Acoustic Sensing) fiber-optic data, we numerically simulate train-induced signals using a spectral-element method, assuming track sleepers excited by the passage of train wheels. We provide an estimate of the parameters controlling variations in fiber-optic strain records (e.g., train speed, train length, railway regularity, soil stiffness). We found that simulated signals with irregular sleeper positions (i.e., railway irregularity) are the best to fit the time and spectral signatures of the observed ones.

Keywords: Numerical simulation, Seismic wave propagation, Distributed Acoustic Sensing, Train signals.

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Grenoble (France), 19-21 October 2026

CHARACTERISTICS OF EARTHQUAKE GROUND MOTIONS EXCITED IN THE SMALL BASIN EDGE USING DISTRIBUTED ACOUSTIC SENSING DATA

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ABSTRACT

The extreme site amplifications in the small basin were observed during the 2024 Noto Peninsula earthquake, Japan (Mw 7.5). Therefore, to investigate the mechanism of the extreme site amplifications larger than several tens, we performed the aftershock observations using the distributed acoustic sensing in the small basin (Width of the basin: about 1.3 km) of Machino town, Wajima, Japan. In this area, we have performed the temporary aftershock observations using 17 accelerometers with an interval distance of about 100 m. We also perfomred the seismic survey with the artificial source excited by clashing brocks in the electric discharge crushing device along the measurement line of fiber optic cable. As for the earthquake ground motions, we clearly confirmed the seismic waves propagating from the basin edge after S-wave arrivals.

Keywords: Earthquake ground motion, Basin edge, Distributed acoustic sensing data, Artificial source, Noto Peninsula

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Grenoble (France), 19-21 October 2026

GRADIENT-DRIVEN LOCAL STRUCTURE IMAGING WITH DISTRIBUTED ACOUSTIC SENSING

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We show a novel approach for imaging the local velocity structure that combines gradient-driven amplitude estimation with distributed acoustic sensing. It aims to provide a flexible and effective solution for shallow subsurface imaging in complex, heterogeneous structures, especially in urban underground spaces that contain cavities, isolated rocks, and pipes. Under the plane wave assumption, the first-order time and spatial derivatives of the strain rate of surface waves satisfy the one-dimensional plan wave equation at every single frequency. It enables determination of the local surface-wave phase velocity from the amplitude ratio of the time derivative of the strain rate to its spatial gradient. As a result, a pair of adjacent channels can provide a local one-dimensional velocity structure, enabling high lateral spatial resolution. We construct models that incorporate various velocity anomalies, using numerical simulations and field experiments to evaluate the effectiveness of this new approach. The results indicate that the local phase velocity of the Rayleigh wave, obtained from the amplitude ratio, can accurately locate the anomaly in the horizontal space, and that surface-wave inversion provides depth resolution. This high-density channel observation, based on fiber-optic sensing technology, enables high-precision gradient estimation. This technological advancement opens up new possibilities for underground imaging using optical communication cables and for future exploration of urban underground areas.

Keywords: Distributed Acoustic Sensing, Gradient Estimation, Seismic imaging

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Grenoble (France), 19-21 October 2026

HYBRID AMBIENT VIBRATION ARRAYS MIXING OPTICAL FIBER AND THREE-COMPONENT VELOCIMETERS : APPLICATION TO ARGOSTOLI TEST SITE (GREECE)

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In-situ measures of shear-wave velocity (Vs) profiles versus depth inside dense urban areas are not always possible from a logistical point of view. Dense ambient vibration arrays, that are cost effective and efficient in open-field areas, suffer from a number of limitations in city centers. Emerging Distributed Dynamic Strain Sensing (DDSS) technology transforms an optical fiber into a line of horizontal seismic strain sensors. The omnipresence of telecommunication networks now available in most cities may appear as a wonderful opportunity to acquire Vs profiles in harsh environments of prime concern for mitigating seismic risk. Though DDSS comes with an unprecedented dense spatial sampling, it provides only one horizontal component which restrains the decomposition of horizontal wavefields, made of mixtures of Love and Rayleigh wave, that can be achieved with classical velocimeter three-component arrays. This limitation can be circumvented by a controlled diversity of orientations of the fiber paths. However telecommunication networks where obviously not deployed for this purpose and they generally follow straight lines with only few localized turns. The separation of Love and Rayleigh waves with a single orientation of the fiber might be possible if a few three-component velocimeters are added. In this work, we implement a three-component frequency-wavenumber processing that can accept velocimeter and strain sensors in a single array. In 2023, a 1.2 km-long tight fiber was buried in Koutavos park (Argostoli, Greece), a site that has been already investigated by various technics for more than ten years. Along and around the fiber path 51 three-component nodes were also buried. Ten days of continuous recording are available. In 2025, the same fiber was also instrumented for a longer period (2 months) and with a different distribution of nodes. These datasets are used to evaluate the quality of the strain signal by integration between pairs of velocimeters located along straight fiber segments. Various fiber segments and selections of three-component sensors are combined to test the potentialities and the limitations of such an approach.

Keywords: site effect, ambient vibrations, array processing, frequency-wavenumber, optical
fiber, distributed dynamic strain sensing

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Grenoble (France), 19-21 October 2026

EFFECTS OF 3D VELOCITY STRUCTURES ON HVSR

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ABSTRACT

The horizontal-to-vertical spectral ratio (HVSR) is a widely used technique for estimating the fundamental site period (Ts), a key parameter in seismic microzonation. However, in the presence of significant lateral heterogeneities, subsurface velocity structures become inherently 3D, and their influence on HVSR remains an open research problem. To improve the understanding of these effects, relatively dense ambient seismic noise (ASN) measurements were conducted at selected sites in Mexico City to capture spatial variations in HVSR. Under the diffuse field assumption (DFA), the ASN is considered diffuse, preliminary interpretations of lateral irregularity effects are derived. Complementary numerical simulations are performed using the Indirect Boundary Element Method (IBEM), which enables efficient computation of HVSR in media with complex geometries. The results reveal clear directional and spatially dependent behaviors associated with subsurface interface morphology, highlighting the sensitivity of HVSR to 3D structural effects.

Keywords: site effect, directional HVSR, 3D effects

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QUANTIFYING THE IMPACT OF SUBSURFACE STRUCTURES ON AZIMUTHAL SITE RESPONSE VARIABILITY

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ABSTRACT

Surface-to-borehole spectral ratios (SBSRs) directly capture site amplification, yet their interevent variability is usually treated as random noise in seismic hazard analysis. Using KiK-net records from 693 stations (about 150,000 records), this study separates SBSR variability into an azimuth-dependent systematic component and a residual random component. Co-llocated earthquake pairs were used to estimate random variability, whereas pairs with contrasting back-azimuths were used to estimate total variability; the difference in variance defines the systematic component. The two components are comparable over a wide frequency range. To characterize them, random variability is modeled by a common curve in normalized frequency f/f_0, while systematic variability is screened by three dominant site indicators: EHVR peak frequency, S-wave velocity at the borehole depth, and surrounding terrain anisotropy. These results suggest that azimuthal SBSR variability provides a practical constraint on subsurface heterogeneity and site-response uncertainty.

Keywords: surface-to-borehole spectral ratio, systematic variability, random variability, azimuthal dependence, site response

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EXTREME SITE EFFECTS AND THREE-DIMENSIONAL RESONANCE IN MAAR VOLCANOES

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ABSTRACT

Maar volcanoes exhibit three-dimensional resonance with significant amplification of ground motion at the resonance frequencies of individual oscillation modes. By applying a suite of methods to ambient seismic noise, we can quantify this amplification relative to the surrounding bedrock and construct synthetic seismic noise models of the maar diatreme. Matching the modeled resonance frequencies and amplification ratios to the observed values allows us to estimate the physical properties of the maar. In addition, we can determine the polarization of particle motion for the fundamental mode across the entire maar and infer the elongation of the diatreme. This elongation commonly reflects the regional tectonic setting, thereby improving our understanding of the geological genesis of the volcanic structure.

Keywords: ambient vibration, site effect, spectral analysis, maar, 3D numerical modelling

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CHARACTERIZING THE SEISMIC RESPONSE OF AN EARTHEN DAM USING DENSE AMBIENT VIBRATION SURVEY

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ABSTRACT

Earth-filled dams are highly vulnerable to earthquake damage, making accurate characterization of their seismic response essential. We present a dense seismic survey of the Horka earthen dam (West Bohemia, Czechia) to estimate its in situ dynamic behavior. Reference stations on engineering bedrock and multiple stations along the crest, mid-height, toe, and abutments reveal strong three-dimensional resonances caused by the velocity contrast between dam infill and surrounding rock. Ambient vibrations were analyzed using Site-to-Reference Spectral Ratio (SRSR), Frequency Domain Decomposition (FDD), Horizontal-to-Vertical Spectral Ratio (HVSR), and polarization analysis (PA). While closely spaced vibration modes complicate FDD-based modal separation, SRSR robustly resolves the fundamental and higher modes, which show predominantly symmetrical shapes and strong vertical components limiting HVSR applicability. Shear-wave velocity profiles from MASW constrained a three-dimensional numerical model, whose simulated response agrees with observations and provides a foundation for future nonlinear dynamic analyses.

Keywords: ambient vibrations, site effect, spectral analysis, MASW, earthen dam, numerical modelling

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DEVIATION OF RAYLEIGH WAVE DISPERSION IN DIPPING MEDIA FROM HORIZONTAL STRATIFICATION

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ABSTRACT

Microtremor array exploration is a widely adopted technique for estimating subsurface velocity structures. However, this method relies on the fundamental assumption that the subsurface consists of a horizontally stratified medium. This study focuses specifically on ground structures with dipping interface, aiming to clarify the propagation characteristics of surface waves in such environments. We numerically reproduced microtremor fields in two-dimensional ground models with a dipping interface to investigate surface wave propagation characteristics. The microtremor fields were simulated by the random superposition of pre-calculated Green's functions. To evaluate the effects of interface inclination, models with various dipping angles were constructed. The SPAC method was then applied to the simulated microtremors of each model to evaluate Rayleigh wave phase velocities. The results suggest that Rayleigh wave propagation characteristics correlate relatively well with the local velocity structure directly beneath the observation array.

Keywords: dipping structure, microtremor array method, Rayleigh wave, surface wave dispersion, finite element method

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HORIZONTAL SITE AMPLIFICATION FACTORS AT SITES IN THE NOTO PENINSULA, JAPAN, WITH 3D RESONANCE DERIVED FROM MICROTREMOR HORIZONTAL-TO-VERTICAL SPECTRAL RATIOS

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ABSTRACT

On January 1, 2024, the Noto Peninsula Earthquake (Mw7.4) occurred, causing extensive damage to municipalities in the northern part of the Noto Peninsula. In particular, in Wajima City and Suzu City, damages were quite severe. It is our urgent need to elucidate the factors contributing to this phenomenon. In this study, we present the results of site amplification characteristics estimated using generalized inversion technique and the VACF method for horizontal-to-vertical spectral ratios of earthquakes and microtremors measured at a couple of sites in and out of the heavily damaged areas. We also report the results of the analysis on the areal microtremor observations conducted inside these two cities. We found that we cannot explain the observed very large site amplifications in both horizontal and vertical components without considering 2D/3D resonance of deep basins in these cities.

Keywords: Horizontal-to-vertical ratio, Vertical amplification, 3D resonance, Sedimentary rock

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THE SITE-SPECIFIC SEISMIC RESPONSE IN THE URBAN ENVIRONMENT – EMPIRICAL ASSESSMENT OF THE STRUCTURE EFFECT FROM A SEISMIC BOREHOLE ARRAY IN SWITZERLAND

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ABSTRACT

Seismic instrument housing can strongly influence recorded ground motion. Sensors installed near or within buildings may show changes in amplitude and frequency content compared to free-field conditions, complicating the assessment of local site effects. This is particularly relevant in urban areas, where free-field installations are often not feasible. Understanding and separating the effects of soil– structure interaction and local geology is therefore essential. In this study, we compare seismic recordings from a borehole array in Visp (Switzerland), before and after the construction of a 6-storey building above the site. The region is characterized by strong amplification and complex site effects. Results from earthquake data show a significant impact of the structure, including a reduction of surface amplification by a factor of 2–6 above 2 Hz and an increase in high-frequency attenuation. These effects are likely caused by wave scattering and filtering by the building and its deep foundation.

Keywords: site amplification, attenuation, soil-structure interactions, seismic borehole array, seismic station housing

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MICROTREMOR H/V SPECTRAL RATIO AROUND BURIED ACTIVE FAULT AND ITS IMPLICATIONS FOR SITE RESPONSE: CASE OF NISHIYAMA FAULT IN KYUSHU, JAPAN

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ABSTRACT

Microtremor observations were conducted around the northern tip of the Nishiyama Fault to investigate buried structures beneath the adjacent plain. An initial reconnaissance microtremor survey suggested lateral variations in subsurface structure. Guided by these results, an approximately 300-m-long S-wave seismic reflection survey was carried out and revealed several discontinuities interpreted as faults. Borehole drilling conducted in parallel further supports this interpretation. Subsequently, dense microtremor measurements were conducted along multiple lines oriented perpendicular to the expected fault strike to constrain the spatial extent of the inferred structures. The peak frequency of the microtremor H/V spectral ratio (MHVR) shows a clear spatial contrast, with higher values (> 4 Hz) on the northeastern side and lower values (< 2 Hz) on the southwestern side, concentrated within narrow transition zones. These zones are interpreted as two NW–SE trending buried faults extending beneath the plain, with a vertical displacement component. The sharp lateral variation in MHVR peak frequency indicates strong heterogeneity in site response over short distances, suggesting that ground motion near the inferred fault zones may be highly variable and complex. These results demonstrate that MHVR analysis can effectively capture abrupt structural changes associated with buried faults and provide a practical framework for linking subsurface structure to reliable earthquake ground motion prediction.

Keywords: microtremor H/V spectral ratio, active fault, S-wave reflection survey

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AMBIENT VIBRATION TECHNIQUES FOR SEISMOLOGICAL CHARACTERIZATION OF THE PERNICANA FAULT AT ETNA VOLCANO, ITALY

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ABSTRACT

The seismic response of fault zones is essential for understanding near-fault ground shaking in tectonically active regions. In this study, we investigate three sectors of the Pernicana Fault (PF), located on the northeastern flank of Mt. Etna, using a suite of ambient vibration techniques. We combine HVSR, time-frequency polarization analysis, and shear-wave velocity profiles derived from passive and active surface-wave methods. Ambient-vibration measurements were collected along linear transects across the PFS, enabling detailed mapping of resonance frequencies and directional dependence of ground motion. Dispersion curves obtained from passive and active data were jointly inverted, together with Rayleigh-wave ellipticity. The resulting velocity profiles were used to convert HVSR resonance frequencies into four geophysical cross-sections. Overall, the integration of HVSR, polarization analysis, and multimethod surface-wave inversion provides a robust seismological characterization of the PFS zone. The results illuminate its near-surface structure, highlighting the occurrence of directional amplification linked to fault geometry.

Keywords: Ambient vibrations, seismic site effects, Pernicana Fault, Etna volcano

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REVISITING HVSR PROCESSING AND INVERSION: LIMITATIONS, CHALLENGES, AND NEW METHODOLOGICAL TOOLS

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ABSTRACT

Leveraging passive seismic ambient noise is a low-cost approach for investigating the subsurface. Three-component seismograms recorded at single stations are commonly processed using Nakamura's method to obtain spectral ratio curves, whose main peak corresponds to the local resonance frequency. Despite its conceptual simplicity, HVSR processing involves several subjective choices, often guided more by operator experience than by standardized procedures. Moreover, data may be collected under suboptimal conditions, for example across sites with complex topography or in the presence of significant anthropogenic transients. As inversion may be strongly biased in the absence of sufficient prior information, it is desirable to devise tools that facilitate interpretation and expand the range of information that can be extracted directly from the data alone. This contribution illustrates novel data processing and visualization strategies implemented in the open-source OpenHVSR Processing Toolkit to address these challenges.

Keywords: HVSR, seismic noise, microtremor, processing, directionality

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MODE-BASED NONPARAMETRIC STATISTICS AND DIRECTIONAL DIAGNOSTICS FOR AMBIENT NOISE HORIZONTAL-TO-VERTICAL SPECTRAL RATIOS

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ABSTRACT

Ambient-noise horizontal-to-vertical spectral ratios (HVSRs) are commonly summarized by lognormal statistics, although window-wise amplitudes and principal directions can be skewed or multimodal. We present a nonparametric alternative in which the representative amplitude is the mode of a kernel-density estimate (KDE) evaluated in the linear amplitude domain, and uncertainty is described by a highest-density interval (HDI). The same distributional view is extended to directional diagnostics based on the principal horizontal direction. A near-lognormal hvsrpy benchmark shows that the KDE mode is close to the lognormal mode and exposes the small upward bias of the geometric mean. A structurally complex Rotmoos site shows the opposite regime: competing amplitude and direction modes make the conventional lognormal median fall between physically meaningful branches. The proposed mode-based curves and HDIs preserve the dominant branches and provide practical diagnostics for data weighting and one-dimensional inversion assumptions.

Keywords: ambient-noise H/V, kernel density estimation, lognormal statistics, directional site effects, inversion weighting

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EXTENSIVE MULTISCALE MAPPING OF 1D SEISMIC AMPLIFICATION EFFECTS BASED ON GEOLOGICAL DATA

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Extensive seismic hazard assessment including the effect of local seismo-stratigraphical conditions is a basic tool for seismic risk estimates. A novel physically based procedure is proposed for using geological maps to estimate expected seismic amplification effects relative to spectral ordinates of engineering interest. Automatic spatial analysis based of geological maps at different scales, their interpretation in terms of engineering/geological units, statistical data relative to seismic and geotechnical properties of geological bodies and linear equivalent numerical modelling are combined to determine the probability distribution of expected amplification effects by accounting for uncertainty affecting the relevant parameters. Information provided by geological data at the different scales is combined within a coherent Bayesian approach. Resulting estimates of possible amplification effects and of relevant uncertainty are then combined with the reference probabilistic seismic hazard estimates to obtain a comprehensive hazard map to be used for land planning purposes and risk evaluations. The feasibility of the proposed approach and the possible outcomes are discussed in the case of the Tuscany Region in Central Italy.

Keywords: seismic hazard; 1D amplification effects; Geological Data; seismic microzonation

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CHARACTERIZATION OF SITE EFFECTS IN THE ULAANBAATAR BASIN, MONGOLIA

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ABSTRACT

This study investigates seismic site effects associated with the sedimentary basin underlying Ulaanbaatar, Mongolia, with the aim of quantifying their influence on ground-motion amplitude, dominant frequency, and duration. The analysis is based on weak-motion earthquake recordings from 32 stations and ambient noise measurements from 104 sites, complemented by microtremor array observations. Shear-wave velocity profiles were derived from frequency–wavenumber (f–k) analysis, and geological, geophysical, gravity, and borehole data were integrated into a GIS-based three-dimensional model of the basin. The study shows consistent dominant frequencies (2–5 Hz) from both SSR and H/V methods, while SSR gives higher amplification for weak motion. Two-dimensional modeling highlights the strong influence of basin geometry, especially sediment–bedrock interfaces, on amplification patterns. Ground-motion duration is mainly controlled by one-dimensional site amplification, with additional contributions from basin-edge effects and surface waves. Arias intensity analysis indicates frequency-dependent duration effects beyond simple resonance.

Keywords: Site effect, Microzoning, Standard Spectral Ratio, HV ratio, Basin effect, Seismic wave duration

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TEMPORAL VARIABILITY OF MICROTREMOR HVSR MEASUREMENTS AND THE INFLUENCE OF ENVIRONMENTAL AND ANTHROPOGENIC FACTORS

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ABSTRACT

The microtremor Horizontal-to-Vertical Spectral Ratio (mHVSR) method is a rapid and cost-effective approach for estimating the fundamental (resonant) frequency, f_0, of a site. Since its popularization by Nakamura (1989), the technique has been widely used globally for site-specific and regional-scale geophysical surveys. In recent years, several research groups have proposed extending mHVSR applications to directly predict frequency-dependent site response. This raises an important question regarding the stability and reliability of mHVSR amplitude when derived from short-term deployments (e.g., the commonly used 1-hour recordings).

This extended abstract summarizes the work of Daish et al. (2026), which used one year of continuous microtremor recordings from 36 permanently installed broadband seismometers distributed across Southern California, to generate hourly mHVSR curves for every hour of the year. Statistical analyses are performed to assess the temporal stability of mHVSR amplitudes. Resonant peaks are identified and evaluated using the SESAME criteria, enabling quantification of temporal variability in derived peak metrics and the probability of identifying a “true” peak from any given one-hour deployment. Statistics are also computed for specific times within a week (e.g., all Mondays at 1 a.m. across the year) to investigate the influence of anthropogenic and environmental patterns, such as traffic cycles and diurnal effects. Finally, we examine how geomorphic and geologic setting, as well as population density, influence the temporal variability of mHVSR characteristics. These results help define the conditions under which mHVSR amplitude can be considered a reliable proxy for frequency-dependent site response.

Keywords: Temporal variability, mHVSR, site response, seismic site characterization

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Grenoble (France), 19-21 October 2026

TEMPORAL AND SPATIAL VARIATIONS OF SEISMIC NOISE IN AN URBAN ENVIRONMENT: THE CASE STUDY OF ROME

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ABSTRACT

This study presents an analysis of temporal and spatial variations of ambient seismic noise recorded within the city of Rome (Italy). The investigation was based on data acquired by a temporary network of 24 seismic stations installed between January and April 2021. Data recording coincided with mobility restrictions and activity limitations imposed during the COVID-19 pandemic. This exceptional context offered a unique experimental opportunity to isolate and quantify the impact of anthropogenic activity on the background seismic noise. Additionally, the seismic data were correlated with various meteorological parameters, including pressure, temperature, wind speed, and humidity, as well as tidal information.

Keywords: urban seismology, site effect, statistical analysis, environmental data, seismic network.

The 7th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion
Grenoble (France), 19-21 October 2026

QUANTIFYING THE TIME-DEPENDENT EVOLUTION OF HVSR FEATURES FOR SITE RESPONSE MODELING

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ABSTRACT

The horizontal-to-vertical spectral ratio (HVSR) derived from three-component seismometer recordings of either microtremor or earthquake recordings has been widely used for seismic site characterization to estimate the fundamental resonant site period. Additionally, HVSR is a cost-effective means to characterize subsurface impedance contrasts and thereby infer sediment thickness, without the need of extensive invasive site characterization data. Conventional applications often reduce HVSR to a single stationary scalar proxies (e.g., the peak frequency) implicitly assuming one-dimensional layering and a temporally diffuse wavefield. However, deviations in HVSR spectral shape for different time segments, such as secondary peaks, ambiguous peaks or amplitude variability, reflect the influence of lateral heterogeneity, basin-edge effects, and transient ambient sources. To advance the use of HVSR in site response modeling, we investigate a potential framework for quantifying both stationary and time-dependent features. In this study, we first characterize frequency-domain descriptors, including peak frequency, bandwidth, number of spectral peaks, and azimuthal dependence of peaks, which serve as a baseline for characterizing resonance strength and dimensionality. To capture temporal evolution of these features, Stockwell transform–based time–frequency analysis is applied to over 250 sites in Southern California to evaluate the temporal persistence of HVSR features. Persistent frequency ridges are hypothesized to represent robust site resonance, while intermittent peaks reflect source variability or localized scattering. Application to Southern California sites demonstrates that time-dependent HVSR metrics highlight differences between basin interiors, basin edges, and transition zones, even when peak frequencies are similar. This framework enables HVSR to move beyond static proxies, offering a suite of time-varying and direction-sensitive features that capture basin complexity, support improved site condition classification, and provide a principled basis for assessing when HVSR constitutes a reliable proxy for site response.

Keywords: horizontal-to-vertical spectral ratio, seismic site effects, time-frequency analysis, azimuthal-temporal effects, Stockwell transform, temporal variability

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MONITORING THE EFFECTS OF BLAST DENSIFICATION IN A RENATURED OPENCAST LIGNITE MINE IN EASTERN GERMANY BY REPEATED PASSIVE SEISMIC MEASUREMENTS

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During the exploitation of the Lusatian coalfields in Eastern Germany, the lignite was extracted and the remaining material redeposited in the mines, leaving large areas of unconsolidated soft sediments. The renaturalization of the area creates the Lusatian Lake District, a chain of artificial lakes extending about 80 km from east to west. The rising groundwater levels increase the liquefaction hazard in the unconsolidated areas. These areas therefore need a soil improvement before they can be used for other purposes. Blast densification has proven to be an effective way of compacting the soil.

In a test site located in the opencast mine Sedlitz, where the sediments were deposited in the 1960s, different geophysical methods were assessed for their ability to complement the more classical methods to monitor the effectiveness of the compaction efforts. The first measurements took place in 2023, before the blast densification, and subsequent measurements followed in 2024 and 2025 to monitor the evolution after the compaction.

One of the tested methods were passive seismic measurements. We performed them in two array configurations at the exact same locations during each of the measurement campaigns. The first array consists of 16 sensors in a spiral-galaxy configuration with inter-station distances between 3.4 m and 157 m, the second array of 13 sensors, also in a spiral-galaxy configuration with inter-station distances between 4.0 m and 90 m. Using the array recordings, Rayleigh and Love wave dispersion curves were obtained with different methods. Using the single-station recordings, H/V and Rayleigh wave ellipticity curves were analyzed. The different data curves were then inverted for the shear-wave velocity profiles of the sedimentary layers.

The H/V measurements show a very prominent peak at about 0.6 Hz, which does not change over the years. The data inversion shows that this peak is connected to a velocity contrast in about 100 m depth. The dispersion curves show a decrease in velocity for Love and Rayleigh waves from 2023 to 2024, which can be attributed to velocity reductions in the topmost 20 m. They are highest in the near-surface layers. We interpret them as related with non-linear effects resulting of the strong shaking and the depression of the surface induced by the compaction blasts and possibly the destruction of the inter-particle cementation formed in the sediments since their deposition.

Keywords: blast densification, H/V, surface waves, Rayleigh wave dispersion curves, Love wave dispersion curves

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ENHANCING MICROZONATION THROUGH COMBINED EMPIRICAL APPROACHES: APPLICATION ACROSS THREE FRENCH ALPINE URBAN AREAS (GRENOBLE, ANNECY AND NICE)

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ABSTRACT

Site-Specific Seismic Hazard Assessment (SSHA) is a best practice for evaluating seismic hazard in critical or densely populated areas, but accurately capturing site response across broad frequencies and high spatial resolution remains challenging. This study proposes an empirical framework in three steps: (1) estimating site response at regional scale relative to reference conditions using generalized GIT inversions on earthquakes; (2) extending low-frequency coverage (0.05–1 Hz) using spectral ratios from teleseismic P-coda (SSRc); and (3) assessing site response at high resolution through the hybrid SSRh method applied to ambient noise. Applied within the EMISSER project in Annecy, Grenoble, and Nice, the approach shows strong agreement between GIT and SSRc results. Despite urban conditions, SSRh reliably reproduces earthquake-based estimates, enabling consistent, high-resolution SSHA for improved seismic risk mitigation. Keywords: Seismic Hazard, Site-specific, Site effects, Ambient noise, Microzonation, Array processing

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TESTING THE HYBRID STANDARD SPECTRAL RATIO METHOD IN THE NORCIA SEDIMENTARY BASINS, ITALY

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ABSTRACT

Seismic site response is a key factor in the assessment of local seismic hazards, particularly in sedimentary basins where ground motion can be significantly modified by near-surface geology. In this study, we analyze data collected in the Norcia basin, characterized by sediment thickness exceeding 200 m and reaching up to 600 m, by comparing the Standard Spectral Ratio (SSR), the noise-based SSR (SSRn), and a hybrid method (SSRh). The SSR method, based on earthquake recordings, provides reliable results but requires a large dataset of seismic event recordings, while SSRn, which uses ambient noise, is more versatile but sensitive to noise source distribution. The SSRh approach combines both methods to overcome these limitations. Results show a good agreement between SSR and SSRh, with the SSRh generally showing slightly higher amplification values, especially in areas with thicker sediments. These findings confirm that SSRh is a promising tool for site response evaluation.

Keywords: seismic site responses, seismic risk, SSRh method, sedimentary basin, Norcia case study.

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PRELIMINARY RESULTS FROM THE GRANDE ARRAY PROJECT: A TEMPORARY SEISMIC NETWORK IN THE CENTRAL APENNINES

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ABSTRACT

The Central Apennines region (Italy) is regularly affected by seismic activity. In 2009, a Mw 6.1 earthquake occurred near L'Aquila city. To improve our understanding of the structure and dynamics of seismogenic fault zones in Central Apennines, we conducted the GRANDE (hi**G**h **R**esolution im**A**ging of **N**ormal faults **D**amage zon**E**s) experiment. We deployed nine dense linear arrays of seismic nodes crossing two well studied fault damage zones at the surface (Campo Imperatore and Monte Marine fault systems). Previous geophysical and geological surveys precisely characterized these fault damage zones down to depths of a few tens of meters (Cortinovis et al. 2024; Fondriest et al. 2020). However, the downward extent of fault-related damage remains poorly understood.

Keywords: nodal arrays; fault structure; damage zone

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The Site Effect Laboratory (Lab ESITO) of the Istituto Nazionale di Geofisica e Vulcanologia (INGV): An Integrated Infrastructure from Local Studies to Transnational Access

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Abstract

The evaluation of local site effects is a fundamental component of seismic hazard assessment. The Site Effect Laboratory (Lab ESITO), established by the Istituto Nazionale di Geofisica e Vulcanologia (INGV), provides a distributed, specialized infrastructure for multi-scale investigations of local seismic amplification. This paper outlines the laboratory's capabilities, ranging from high-precision instrumentation to specialized analytical software (e.g. HVNEA), and details its critical role in emergency response (EMERSITO) and transnational access programs (TNA-MEET).

Keywords: site effect, seismic motion, earthquake engineering, nodal arrays, laboratory

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Grenoble (France), 19-21 October 2026

ADVANCING THE VERTICAL SEISMIC DESIGN SPECTRUM IN TAIWAN

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ABSTRACT

The vertical design response spectrum has been required as half or two-thirds of the horizontal design response spectrum in the current seismic design code in Taiwan. However, analyses of seismic observation data from selected Taiwan ground motion records limited to events with moment magnitudes of 6.5 or greater and source-to-site distances less than 30 km indicate that the vertical-to-horizontal (V/H) spectral ratio at short periods often exceeds two-thirds and exhibits clear period dependency. This study reviews and develops a vertical design response spectrum for Taiwan, using high-quality seismic records and ground motion empirical models for Taiwan. The proposed spectrum is defined by the site-adjusted horizontal spectral acceleration coefficient at short periods. The V/H spectral ratio is approximately 0.72 at 0.1 periods. The proposed vertical design response spectrum differs from the recommendations of current seismic design codes but more accurately represents the vertical seismic characteristics unique to Taiwan.

Keywords: vertical design spectrum, V/H spectral ratio, nonlinear site effect, vertical ground motion

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SITE-SPECIFIC DESIGN GROUND MOTIONS THAT HAVE BEEN USED SINCE 2007 IN THE DESIGN STANDARD FOR JAPANESE PORT STRUCTURES

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ABSTRACT

The design standard for Japanese port structures (OCDI, 2025, https://ocdi.or.jp/en/download4) is unique in a sense that it requires the use of site-specific design ground motions. It does not include any “standard” response spectrum to be used in the design. Instead, it fully utilizes GIT-based site amplification factors. Both for the level-1 and level-2 ground motions, the evaluation of the site amplification factor is necessary. The design standard recommends to evaluate the site amplification factor based on earthquake observations. Because of the uniqueness of the design standard, it will be worthwhile introducing the main features of the standard. The presentation will include the examples of site amplification factors, the examples of design ground motions, comparisons with observed ground motions during recent damaging earthquakes, and how microtremor observations come into play within this framework.

Keywords: design ground motion, site effect, earthquake observation, microtremor observation, Fourier-spectrum based PSHA

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INTEGRATION OF NON-ERGODIC SITE RESPONSE INTO NEHRP PROVISIONS & ASCE-7

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ABSTRACT

Site response effects are accounted for in the development of risk-targeted maximum considered earthquake (MCE_R) ground motions in two ways: (1) as site factors incorporated within ground-motion models, as implemented in the National Seismic Hazard Model, and (2) from the use of site response analyses that model wave propagation through a geotechnical model of the project site. Site response analyses are the subject of Section 21.1 in the NEHRP Provisions and the ASCE-7 Standard. As part of a provisions update cycle concluding in Fall 2026 for the NEHRP Provisions and 2028 for ASCE-7, Section 21.1 was rewritten to permit the use of probabilistic methods for combining site response with reference site ground motions, as well as to incorporate significant improvements related to parameter selection, uncertainty evaluation, and analytical approaches. Included within the updates are procedures that allow for the use of non-ergodic (site-specific) site response, including guardrails.

Keywords: Site response, non-ergodic, seismic design, building codes

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THE ROLE OF F_0 IN EUROCODE 8 SITE CLASSIFICATION: A NEW PATHWAY FOR SITE EFFECT ASSESSMENT USING SINGLE-STATION AMBIENT VIBRATION

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ABSTRACT

The upcoming Eurocode 8 update revises soil classification, shifting from V_{s30}, $V_{...}$, and rock sub-stratum thickness to a system based on the average shear wave velocity ($V_{s...}$) down to V_{800} (depth where Vs exceeds 800 m/s, capped at 30 m). If V_{800} is unavailable, classification can use the soil's fun-damental resonance frequency (f_0) and V_{sH} (averageVs over the depth of investigation between at least 10 m capped at 30 m, excluding bedrock). This revision aligns with international codes (e.g., New Zealand, Japan) by introducing f_0 for site classification, enabling cost-effective geophysical methods like single-station ambient vibration recordings (HVSR). We propose comparing site classifications using f_0 across regulatory codes, then analyzing response spectra for site classes defined by f_0 and V_{sH}, alongside alternative spectra based on V_{s30} and f_0 (Cadet et al., 2012). A predictive model to es-timate Vs30 using $V_{s...}$ and f0, enabling direct comparisons between actual and upcoming Eurocode 8 (EC8) site categorizations. he upcoming regulatory response spectra align with KiK-net empirical data, but discrepancies at high accelerations due to nonlinear soil behavior will be addressed in future work.

Keywords: HVSR, Eurocode 8, site classification

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THE LOWER VAR VALLEY: A NATURAL LABORATORY FOR ESTIMATING THE SPATIAL VARIABILITY OF SEISMIC SITE RESPONSE

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ABSTRACT

The Lower Var Valley (LVV), located between Nice and Saint-Laurent-du-Var, is a National Priority Zone (OIN – Eco-Vallée) driving sustainable development on the French Riviera. This 2 km-wide flu-vial sedimentary basin exhibits site effects during earthquakes and lies in the most seismically active area of metropolitan France, with a reference peak ground acceleration of 1.6 m/s² on rock. A 3D geological model was developed using borehole logs and ambient vibration recordings, defining elastic soil properties and basin geometry, but excluding non-linear soil behavior. Uncertainties in ge-ometry and soil properties remain poorly quantified. This natural laboratory is used to evaluate approaches for estimating uncertainty and spatial variability in key factors influencing seismic response, such as the fundamental soil frequency (f□) and strati-graphic log distribution. Two methods are explored: (1) a random field model of f□ using Bayesian compressive sensing–Karhunen-Loève expansion, and (2) machine learning applied to log stratigra-phy to define typical soil layers and interpolate lithological data.

Keywords: Lower Var Valley, Nice, Site repsonse variability

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DENSE SEISMIC NETWORK IN THE CAMPI FLEGREI (ITALY) VOLCANIC AREA FOR SEISMIC MICROZONATION

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ABSTRACT

Seismological measurements for seismic microzonation are inherently challenging in densely urbanized, active volcanic areas. This research, conducted under the Italian Civil Protection's Extraordinary Plan to mitigate seismic risk in the Campi Flegrei caldera (Italy), aimed to assess subsoil characteristics and seismic wave velocities to inform microzonation studies. We conducted a dense, month-long seismic survey (starting in late February 2025) across Pozzuoli, Bacoli, and Naples municipalities, deploying 60 seismic nodes and five seismic arrays for shear-wave velocity profiling. The nodes potentially recorded 370 earthquakes, with magnitudes up to 4.6. As expected in an urban environment, high noise levels were observed, with short-period variations linked to anthropogenic sources. Horizontal-to-Vertical Spectral Ratios were computed using data from nodes and complementary network stations, totaling 151 measurement points. Preliminary findings reveal a heterogeneous seismic response governed by the volcanic history of the caldera.

Keywords: seismic microzonation, site effect, nodal arrays, urban seismology, volcanic seismic hazard

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1D SEISMIC VELOCITY MODELS FROM DENSE ARRAYS WITHIN THE CAMPI FLEGREI SEISMIC MICROZONATION PROJECT

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ABSTRACT

The Campi Flegrei caldera (Italy) is currently affected by an ongoing bradyseismic crisis characterized by ground uplift and frequent shallow seismicity. Within the framework of the DL140 emergency program, five dense seismic arrays were deployed to investigate the shallow subsurface structure and support Level 3 seismic microzonation activities. Ambient seismic noise data were analyzed using both array-based techniques and spectral ratios to assess local site response and constrain subsurface velocity structure. Joint inversion of dispersion curves and H/V spectral ratios allowed the reconstruction of 1D shear-wave velocity models, revealing significant spatial variability and the presence of high-velocity layers consistent with lava-like volcanic lithologies. The results highlight pronounced heterogeneity in seismic wave propagation across the caldera, emphasizing the complexity of near-surface structure in this active volcanic and urban environment.

Keywords: seismic microzonation, array technique, 1D velocity model

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RECORD SELECTION FOR SEISMIC MICROZONATION STUDIES IN CAMPI FLEGREI AREA

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ABSTRACT

This study outlines methodology and results achieved in selecting accelerograms for seismic site response analysis in the Campi Flegrei area, as part of the activities of the Level III Microzonation Plan for three municipalities (Pozzuoli, Bacoli and eastern Naples). The procedure developed is specific to this unique area and has led to the definition of two sets of input accelerograms: one consistent with local volcanic-tectonic ground motion and the other in line with current seismic regulations.

Keywords: record selection, seismic motion, site effect, earthquake engineering, Campi Flegrei

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SEISMIC SITE CLASSIFICATION AND MICROZONATION IN MEKNES CITY (MOROCCO) USING HVSR METHOD

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ABSTRACT

Seismic site classification and microzonation are important approaches for seismic risk assessment. This study applies the horizontal to vertical spectral ratio (HVSR) method, based on ambient noise measurements, in the urban area of Meknes, northern Morocco. A total of 210 measurement points were analyzed to estimate the resonance frequency (F_0), derive S-wave velocityprofiles, and calculate V_{S30} in the upper 30 m. The data quality and reliability of the HVSR curves were carefully checked before interpretation. Theresults show clear spatialvariations in seismic response. Basedon F_0 values, the study area was divided into three microzones: low, medium, and high frequency zones. The V_{S30} values range from245 to 1142 m/s, with an average of 624m/s, correspondingto NEHRP classes B, C, and D and Eurocode 8classes A, B, and C. This is the first HVSR studyconducted in the region.

Keywords: Microzonation, seismic motion, site effect, resonance frequency

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USING SPECTRAL AMPLIFICATIONS FROM STRONG MOTION STATION ARRAYS FOR ENGINEERING SITE RESPONSE ANALYSIS THROUGH RANDOM VIBRATION THEORY

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Earthquake records collected at dense arrays of strong-motion stations are often utilized in microzonation studies to evaluate the changes in site response due to variability in site conditions across a region. These studies typically begin with calculating Fourier spectral amplifications and then transition to performing engineering site response analyses. It has proven difficult to utilize Fourier spectral amplifications to define the appropriate elastic response spectra for a site or sites. A past study utilized a database of 95 events to calculate Fourier spectral amplifications at 35 strong-motion stations in Anchorage, Alaska using the generalized inversion technique (GIT). Estimated response spectra have been evaluated at each site by applying those Fourier spectral amplifications to a response spectrum of a reference station through random vibration theory (RVT). Correction factors are also applied within the approach to account for nonlinear site effects. The method provided a coherent and straightforward way to use GIT-derived Fourier spectral amplifications to directly estimate site-specific response spectra, accounting for nonlinear site effects and without requiring engineering characterization of subsurface soil conditions. The authors have evaluated the use of this method to estimate site response from another dense array of strong-motion stations with moderate to large earthquakes have occurred, including the M_w 6.3, 2009 L'Aquila earthquake in Italy,. The results from this study indicate that the method of using GIT-derived Fourier spectral amplifications provides an effective method of estimating site response across a network of stations provided that rock site motions are utilized to develop spectral amplifications. One of the major benefits of this method is that the site response is directly measured utilizing moderate earthquakes to predict site amplifications for future large earthquakes and allows the opportunity to avoid the standard challenges and limitations of one-dimensional site response analysis.

Keywords: site effect, generalized inversion technique, site response analysis, strong-motion
station arrays

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INTEGRATING AMBIENT NOISE, EARTHQUAKE RECORDINGS, GEOPHYSICAL DATA AND GRAVIMETRY FOR LOCAL SEISMIC RESPONSE MAPPING IN ROVERETO

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ABSTRACT

This study presents a comprehensive investigation of Local Seismic Response (LSR) in the Rovereto area (northern Italy), an alpine valley characterized by asymmetric geometry, complex morphology, and heterogeneous Quaternary sediments featuring high impedance contrasts relative to the underlying bedrock. Although the region is classified as having moderate seismic hazard on rock sites, ground motion amplification due to local geological conditions can significantly increase it. To characterize LSR in the study area, we adopted a multidisciplinary approach integrating ambient noise measurements, earthquake recordings from a temporary seismic network, geophysical surveys, and gravimetric data. HVSR analysis at more than 200 ambient noise recording points reveals pronounced lateral variability of resonance frequencies, with values below 1 Hz along the valley axis, consistent with sediment thicknesses up to approximately 200 m. Earthquake data from 30 stations were processed using the Generalized Inversion Technique and show amplification values of around 10 at low frequencies (<2 Hz) for the stations in the valley. Independent geophysical and gravimetric measurements allowed us to constrain the bedrock geometry and the velocity structure in the valley highlighting the key role of buried valley morphology and 2D and 3D effects in controlling LSR.

Keywords: HVSR, GIT, MASW, Seismic Reflection Profiles, Gravimetry, Alpine valley

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QUANTIFYING SEISMIC AMPLIFICATION EFFECTS IN MEXICO CITY'S TRANSITION ZONE: INSIGHTS FROM A 3D VS MODEL DERIVED BY AMBIENT NOISE TOMOGRAPHY AND HVSR

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ABSTRACT

The September 19, 2017, earthquake (Mw 7.1) revealed that 3D subsurface irregularities in the clay deposits of Mexico City drive extreme seismic amplification. This study uses Ambient Noise Interferometry in a non-urbanized area to isolate the seismic response of lacustrine clays ($\beta_1 \approx 150$ m/s) and their interaction with volcanic bedrock. Our 3D Vs model identified significant topographical relief (7-12 m) correlating with high HVSR amplifications, confirming that 1D models underestimate localized risk. These findings from an undisturbed site provide a critical benchmark for understanding the coupled effects of differential subsidence and ground motion when modern infrastructure and colonial heritage sites are superimposed on similar geological settings. This study establishes a methodological baseline for deconvolving the effects of urbanization from natural soil-structure interactions, thereby enhancing seismic risk reduction in complex, high-contrast urban environments.

Keywords: Ambient Noise Interferometry, 3D Vs Structure, Bedrock Irregularity

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SITE RESPONSE ESTIMATES IN A SECTOR OF THE EASTERN PO PLAIN (NE ITALY)

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ABSTRACT

This study investigates the local site response in a sector of the Po Plain around Ferrara (NE Italy), characterized by flat topography. Earthquake and ambient noise recordings from seismological networks deployed since the 2012 seismic sequence were analyzed at multiple stations. A comparative analysis of earthquake and noise horizontal-to-vertical spectral ratios (EHV and NHV) was carried out to evaluate the ability of ambient noise to identify site resonance frequencies and assess the reliability of site response estimates based solely on noise measurements. These data were integrated with geological and geophysical information, including Vs profiles, to develop a comprehensive 3D subsurface model. This model provides the basis for numerical simulations that generate synthetic seismograms, which are systematically compared with observed earthquake recordings through an iterative refinement process to constrain the most realistic subsurface structure.

Keywords: Seismic motion, alluvial deposits, site effect, numerical modelling

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ASSESSMENT OF THE FUNDAMENTAL FREQUENCY OF AN EARTH DAM THROUGH DIFFERENT METHODOLOGIES

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ABSTRACT

The fundamental frequency represents a key parameter for the assessment of the seismic response of earth dams. In the present work, empirical (HVSR, SSR), analytical (shear beam model), and numerical (FLAC2D) approaches are compared to investigate this parameter for Camastra dam. Results highlight that simplified analytical models provide reliable prediction of the fundamental frequency, justifying its use in the preliminary design stages as well as for screening analyses, preliminary assessments of dynamic response, and consistency checks against more advanced numerical models. However, 2D numerical modelling remains essential for an accurate evaluation of the overall dynamic ground-dam system response, as it correctly integrates also the influence of the foundation soils.

Keywords: earth dam; fundamental frequency, empirical, analytical and numerical approaches

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CHARACTERIZING AND CLASSIFYING SHALLOW GEOLOGICAL FORMATIONS IN CAMEROON USING FULL MICROTREMOR H/V METHOD

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ABSTRACT

A non-invasive single-station microtremor horizontal-to-vertical (H/V) spectral ratio technique was applied to investigate the local site conditions in Cameroon. Site characterization was achieved through the computation of microtremor H/V spectral ratios, identification of site fundamental frequencies, inversion of full H/V spectra to derive shear-wave velocity (VS) profiles, and classification of the sites in accordance with established seismic design codes. The Cameroon passive-source seismic experiment, consisted of 32 three-component broadband seismometers deployed across the country. For each station, H/V spectral ratios were calculated within a frequency band of 0.2–20 Hz. The variations in the site fundamental frequencies and the H/V maximum amplitude reflect strong site effects linked to differences in sediment thickness and indicate the potential for considerable amplification of seismic ground motion during earthquakes. The full H/V spectra were inverted to obtain VS profiles for each station. VS30 indicate soil classes C through A as defined by Eurocode 8.

Keywords: Seismic site characterization, Site classification, Site effects, Full H/V inversion, V -f predictive equation
S30 0

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PROGRESS IN VS PROFILE ESTIMATION IN LAKE LUCERNE (SWITZERLAND) USING INVERSION OF FULL MICROTREMOR HORIZONTAL-TO-VERTICAL SPECTRAL RATIOS AND PHASE VELOCITY DISPERSION CURVES FROM OCEAN BOTTOM SEISMOMETERS

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ABSTRACT

Shear-wave velocity (Vs) structure is a key parameter for evaluating seismic hazard in offshore environments, where earthquake-triggered processes such as slope failures and tsunamis may occur. A seismological campaign conducted in Lake Lucerne (Switzerland) between 2018 and 2020 investigated the seismic response of subaqueous slopes composed of unconsolidated sediments. Ocean Bottom Seismometers were deployed as both single stations and small-aperture arrays. Ambient noise recordings were used to derive H/V spectral ratio curves, revealing clear site responses between 0.5 and 20 Hz. In parallel, array data provided dispersion curves of Scholte and Love waves. These datasets were jointly inverted to obtain Vs profiles, while single-station inversions were applied where array data were unavailable. The inversion framework incorporates full-wavefield contributions and explicitly accounts for water-sediment coupling. The results demonstrate that OBS-based ambient vibration methods provide reliable constraints on subsurface structure, improving seismic hazard assessment in lacustrine environments.

Keywords: Seismic site characterization offshore, Ocean Bottom Seismometer, Site effect, Full H/V inversion

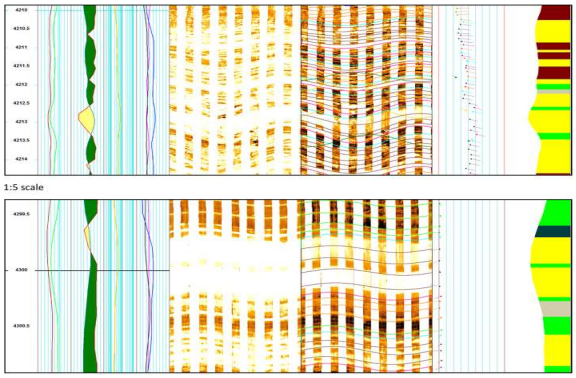
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QUANTITATIVE FRACTURE AND FAULT CHARACTERIZATION IN A FRACTURED RESERVOIR USING HIGH-RESOLUTION QUANTA GEO BOREHOLE IMAGING CASE OF MARSOUIN-1: BIR ALLAH FIELD

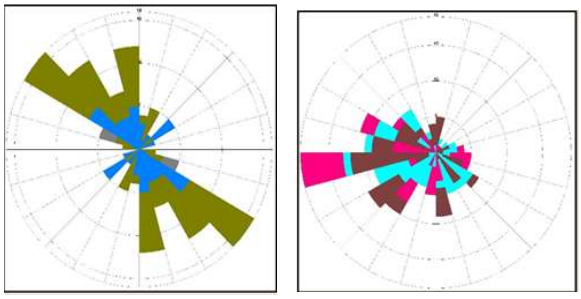
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The northwest African Atlantic margin is characterized by a series of Cretaceous rift–sag basins formed during progressive continental breakup, resulting in a structurally segmented subsurface architecture dominated by tilted fault blocks, growth strata, and later-stage compactional drape. However, the characterization of subsurface fracture systems in the region has been limited by sparse well control, minimal core data, and the resolution constraints of legacy borehole imaging tools. The Marsouin prospect, located in Block 8 offshore Mauritania within the Bir Allah area, is situated in a structurally complex Cretaceous rift setting. The Marsouin-1 exploration well targeted Lower Cenomanian and Albian channelized reservoirs but was terminated prematurely due to unexpected overpressure. This study applies high-resolution Quanta Geo borehole micro-resistivity imaging to quantitatively characterize the structural architecture of the Upper Cenomanian to Lower Albian interval in Marsouin-1. Unlike conventional FMI/FMS tools, Quanta Geo provides continuous 360° circumferential coverage at sub-millimeter resolution, enabling precise measurement of bedding dips, fracture attributes, minor fault geometries, and soft-sediment deformation features, while minimizing borehole bias effects. Resistive fractures predominantly strike NW–SE to E–W, whereas conductive fractures are mainly oriented NNE–SSW to NE–SW. Minor faults exhibit scattered NE–SW and WNW–ESE trends with predominantly normal but locally reverse apparent offsets (Fig, 2). Borehole breakouts further provide constraints on the contemporary stress regime. Together, these observations demonstrate that fracture–fault architecture is strongly domain-controlled and mechanically stratified, with important implications for reservoir connectivity, permeability anisotropy, and fluid flow behavior. The study highlights the value of high-resolution borehole imaging for refining structural models and reducing uncertainty in fractured reservoir evaluation along the Mauritanian offshore margin.

Keywords: MSGBC Basin, Quanta Geo Borehole, FMI, fault blocks, channelized reservoirs



Fig, 1: Clear sandstone open hole log response, intersected by a Fault.



Fig, 2: NW-SE rose histogram striking deformed beds

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Grenoble (France), 19-21 October 2026

THREE-COMPONENT ARRAYS FOR SEISMIC AMBIENT VIBRATIONS

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ABSTRACT

Thousands of ambient vibration arrays have been deployed across a wide range of geological settings since the pioneering work of Aki in 1957. Although most acquisitions rely on three-component sensors, the horizontal components have rarely been fully exploited beyond standard spectral ratio analyses. Over the past fifteen years, several high-resolution three-component frequency–wavenumber (3C-FK) methods have been developed to better exploit the full wavefield. Among them, the All-component Rayleigh Direct Steering (ARDS) method provides unprecedented retrieval of signed Rayleigh-wave ellipticity. This feature offers a major advantage for higher-mode separation, as modes can be tracked in a three-dimensional space (frequency–wavenumber–ellipticity) rather than in the conventional frequency–wavenumber domain. Compared to earlier approaches (e.g. RTBF), the sensitivity to incoherent noise is controlled not by its absolute level but by its relative distribution between horizontal and vertical components. The direct-steering concept can also be extended to the retrieval of Love-wave dispersion curves. In this study, we present an application of 3C-FK processing methods (RTBF, ARDS) to the characterization of station ZELS(Rhine valley, France). Particular emphasis is placed on the key role of retrieving the sign and the amplitude of Rayleigh-wave ellipticity. This information enables a more reliable identification of mode jumps and, consequently, helps prevent major errors in the inversion of dispersion curves into subsurface velocity profiles. Regarding Love waves, we compare standard transverse high-resolution FK processing with LDS2 and LDS3 approaches derived from the ARDS framework.

Keywords: Site effets, Ambient Vibrations, Array processing, Frequency-wavenuber, Three components.

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Grenoble (France), 19-21 October 2026

AN ATTEMPT TO EXTEND THE SPAC METHOD FOR ESTIMATING RAYLEIGH WAVE ATTENUATION COEFFICIENTS

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ABSTRACT

Subsurface velocity and attenuation structures are essential for the accurate evaluation of seismic ground motion at a site. To estimate the velocity structure, microtremor array exploration methods, such as the spatial autocorrelation (SPAC) method, are frequently employed. However, methodologies extending this technique to estimate attenuation structure have yet to be fully established. Therefore, we propose a new method for estimating Rayleigh-wave attenuation coefficients from microtremor recordings by combining our previously developed SPAC-based theory with an optimisation algorithm. Its performance was verified using synthetic data generated from simple dispersion and attenuation coefficient curves. In this verification, we compared three optimisation algorithms: the BFGS method, CMA-ES and Differential Evolution, and found Differential Evolution to be the most suitable. Furthermore, we discovered that the sensitivity of attenuation estimation using this method varies with wavelength, suggesting that measurements using multiple array sizes are necessary.

Keywords: microtremor, Rayleigh wave, spatial auto-correlation method, attenuation.

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Grenoble (France), 19-21 October 2026

REVISITING THE KUMAMOTO BLIND TEST: SHALLOW Vs REANALYSIS AND SOURCE-DEPTH EFFECTS ON ACTIVE SURFACE-WAVE MODES

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ABSTRACT

We revisited the Kumamoto blind-test site seismic experiment using two post-ESG6 developments. First, the discrepancy is reduced between the original PS-logging profile and the shallow velocities inferred by many surface-wave participants after a new picking of the shallow S-wave arrivals in the PS-logging data. In the reanalysis, peak picks were replaced by onset picks in the shallowest interval (< 10 m), increasing the near-surface Vs from about 95-100 m/s to about 130 m/s and bringing the logging result closer to the passive seismic dispersion inversion results. Second, new forward modeling with the revised velocity model shows that placing the active source just below the free surface better reproduces the observed active MASW dispersion data, where higher modes dominate and the fundamental mode is weak or absent. We infer that hammer-plate coupling may act as a slightly buried source and should be considered when interpreting active surface-wave data at Kumamoto and similar sites.

Keywords: Kumamoto, surface waves, MASW, PS logging, active-source seismic

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Grenoble (France), 19-21 October 2026

TWO-STATION DISPERSION ANALYSIS METHOD AS TOOL FOR PRACTICAL NEAR-SURFACE CHARACTERIZATION AND LATERAL HETEROGENEITIES EVALUATION

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ABSTRACT

Seismic site characterization for near-surface seismic response evaluation today typically relies on multichannel surface-wave surveys and single-station measurements with the aim of inferring the 1D subsoil structure from dispersion curves (DC) and HVSR curves, requiring relatively large instrument deployment. In this work, we propose a standardized two-station protocol, based on two 3-component receivers recording seismic ambient noise, as a rapid approach for subsurface characterization, potentially applicable extensively in seismic microzonation campaigns. The use of only two stations allows the simultaneous retrieval of dispersion curves and HVSR from the same dataset, also allowing for the evaluation of two key aspects which are the azimuthal distribution of noise sources and the lateral homogeneity of the site, fundamental conditions for obtaining reliable and high-quality estimates. A fast simplified DC and HVSR inversion procedure is also presented, which provides robust velocity models in the absence of prior information, suitable as a preliminary site assessment or as starting model for more refined inversions. The method is tested on three known sites showing consistent and reliable results.

Keywords: two-station methods, surface-wave, ambient seismic noise, near-surface heterogeneity

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FAST ESTIMATION OF BEDROCK DEPTH AND TIME-WEIGHTED AVERAGE V_S FOR SEISMIC SITE CLASSIFICATION AND ITS LIMITATIONS

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ABSTRACT

The depth to engineering bedrock (h) and the time average shear-wave velocity ($V_{S,h}$) of overlying deposits are key parameters for the evaluation of seismic site response and are included in several building codes as seismic classification proxies. This work aims to test the application of an integrated approach that combines a wavelength-depth transformation of Surface Waves (SW) data and the fundamental frequency (f_0) from Horizontal to Vertical Spectra Ratio (HVSR) to directly estimate h and $V_{S,h}$ without a formal inversion. This approach is applied on a large suite of synthetic V_S profiles, covering a wide range of realistic ground models which are representative of different conditions of engineering interest. Results show the potential of the proposed approach for normally dispersive and relatively uniform profiles. Greater discrepancies were instead observed, particularly in the h estimates, as profile heterogeneity increases, therefore suggesting some applicability limits.

Keywords: Surface Wave tests, HVSR, seismic site characterization, seismic bedrock.

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POTENTIAL AND LIMITS OF THE P-WAVE POLARIZATION METHOD TO DETERMINE SUBSURFACE SHEAR-WAVE VELOCITY: NUMERICAL SIMULATIONS AND APPLICATION TO THE GRENOBLE SITE, FRANCE.

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ABSTRACT

The P-wave polarization method provides a promising non-invasive single-station approach to estimate subsurface shear-wave velocity ($\beta_{\theta\theta}$) and β_{30} from earthquake recordings. Based on the radial-to-vertical ratio of the first P-wave arrival, this method has been applied in several seismically active regions. Yet, many aspects remain insufficiently understood in moderate-seismicity contexts. In this study, we conduct numerical sensitivity tests using 1D wave propagation simulations inspired by the well-characterized OGFO station in Grenoble, France. We test three velocity models and evaluate the influence of source duration, incident angle, signal-to-noise ratio, and bandpass filtering on $\beta_{\theta\theta}$ estimates. We then apply the method to 46 earthquake recordings from the OGFO station. Direct measurement of the P-wave pulse duration from time-series significantly reduces estimation errors, and bandpass filtering allows building a depth-dependent velocity profile. β_{30} is estimated with less than 5% error relative to the reference model.

Keywords: *P-wave polarization, shear-wave velocity, β_{30}, seismic site characterization, Grenoble*

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A BENCHMARK PROCEDURE TO ESTIMATE SITE EFFECT ON VERTICAL-TO-HORIZONTAL SPECTRUM RATIO USING SITE RESPONSE ANALYSIS

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ABSTRACT

While earthquake engineering conventionally adopts a fixed vertical-to-horizontal (V/H) response spectral ratio, these ratios vary significantly with site conditions. This study proposes a benchmark procedure to estimate site-dependent V/H ratios using site response analyses. The methodology involves developing compressive wave velocity (Vp) profiles from measured shear wave velocity (Vs) profiles and groundwater table depth. Surface V/H ratios are calculated from separate vertical and horizontal site response analyses, utilizing Vp and Vs along with their respective nonlinear curves. The proposed analysis procedure, validated by comparing the obtained V/H ratios with empirical ratios established for similar site conditions, can be applied to various site conditions.

Keywords: Vertical-to-Horizontal Spectrum Ratio, Site Effect, Site Response Analysis, Vertical Ground Motion, Ground Water Table

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THE SSR TECHNIQUE APPLIED ON TELESEISMIC P-CODA WAVES AS A COMPLEMENTARY APPROACH FOR SITE RESPONSE ASSESSMENT AT LOW FREQUENCY EVEN IN LOW SEISMICITY AREAS

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ABSTRACT

Site spectral Amplification Factor (SAF) is essential for estimating seismic hazard at a given location. Several empirical approaches have been developed during recent decades, typically relying on local earthquake recordings and on the availability of a nearby reference-station. These requirements introduce significant limitations, particularly in low-seismicity regions and/or in areas where suitable nearby reference-site records are not available. Addressing these challenges, this study proposes a new SAF estimation technique utilizing tele-seismic large-magnitude earthquake records and distant reference-stations. Specifically, the Standard Spectral Ratio applied to long-duration P-coda waveforms (SSRp) is used to derive the SAF of a target station relative to a short or long-distance reference-station. Here, SSRp for 260 stations across France were computed based on 329 tele-seismic events occurred worldwide, at distances up to ~10,000km. Good agreement is observed between SSRp results and SAFs derived from GIT application, for the frequency range 0.05-2Hz, when target-to-reference distance ranges between 0 and 120km.

Keywords: Site-effect, SSRp, tele-seismic records, long-distance reference-station

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NUMERICAL EVALUATION OF THE RELATIONSHIP BETWEEN THE STANDARD DEVIATION OF GROUP DELAY TIME IN THE FREQUENCY DOMAIN AND THAT OF GROUND-MOTION ARRIVAL TIMES IN THE TIME DOMAIN

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ABSTRACT

Group delay time is associated with the temporal characteristics of ground motions and has been widely utilized worldwide in applications such as the generation of simulated ground motions. Mean group delay time defined in the frequency domain can be analytically shown to be equivalent to the mean arrival time defined in the time domain. However, the standard deviation (or variance) of group delay time and that of arrival times are not mathematically equivalent. In this study, we computed the difference term between the two variances using a large dataset of observed strong-motion records from Japanese strong-motion observation networks and quantitatively evaluated the difference term. As a result, the mean and standard deviation of the difference term were evaluated at each frequency. Furthermore, its dependence on source-to-site distance, magnitude, and significant duration was examined.

Keywords: ground motions, group delay time, arrival time, standard deviation

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TIME-FREQUENCY TRANSFER FUNCTION - A NEW TOOL FOR ANALYSING SITE EFFECTS

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ABSTRACT

Fourier transfer functions are indispensable for describing seismic site amplification, but their amplitude spectra collapse the whole response into frequency and therefore hide the time of origin of individual wavefield contributions. We present the time-frequency transfer function, TFTF(t,f), defined as the time-frequency representation of the impulse response. Using a continuous wavelet transform based on the Morlet wavelet, TFTF extends the standard transfer-function concept to show how frequency content of resonant, scattered and laterally propagating surface-wave components evolve in time. The formulation is demonstrated on the SH response of a semi-infinite sedimentary layer. Compared with FTF, TFTF separates early vertical resonance from later Love-wave modes generated at the vertical discontinuity and allows measurement of the related, frequency dependent, prolongation of motion.

Keywords: site effects; transfer function; time-frequency; wavelet; surface waves

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Grenoble (France), 19-21 October 2026

APPLICABILITY OF DYNAMIC MODE DECOMPOSITION WITH CONTROL TO VERTICAL ARRAY GROUND MOTION RECORDS

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ABSTRACT

This study evaluates the applicability of Dynamic Mode Decomposition with control (DMDc) and its time-delay embedded extension (Hankel DMDc) to real vertical array ground motion records. An extensive dataset comprising approximately 1,000 ground motion records from four observation sites is used, each consisting of two horizontal components (NS and EW) simultaneously recorded at the ground surface and at a subsurface sensor. The models are assessed based on one-step reconstruction of surface motions from subsurface inputs using the same dataset. Results show that Hankel DMDc consistently improves reconstruction accuracy compared to DMDc and static models, although its performance exhibits significant variability across sites, records, and model configuration. In the frequency domain, Hankel DMDc reproduces the dominant peak frequencies of the observed surface-to-subsurface spectral ratio, whereas discrepancies in amplitude remain. These findings indicate that the model captures the dominant spectral characteristics of ground motion response, while limitations in reproducing amplification levels persist.

Keywords: Dynamic Mode Decomposition with Control (DMDc), Time-Delay Embedding, Vertical Array Ground Motion Records, Data-Driven Modeling

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Two-dimensional Burridge – Knopoff Model with time-dependent friction and varying Pressure

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Numerical study of the dynamics of an earthquake remains today only asset to understand this phenomenon. 2D and 3D dynamics of the internal structure of the Earth's crust as well as the seismic wave provides a better understanding of the earthquake. Friction coefficient as well as the presence of a fluid play a preponderant role in the dynamics of the propagation of seismic waves. In this work, we used the two-dimensional Burridge-Knopoff model of an earthquake taking into account the time-dependent of the friction coefficient and the presence of a fluid with variable pressure. After numerical resold, we find that seismic wave propagates with countable number of periods. The temperature profile indicates that the temperature is proportional to both velocity and displacement. In addition, beyond a certain depth ($L \approx 100\ km$), the energy produced by friction has no longer impact on the dynamics of the system. Our study also makes it possible to highlight the transitional phase (a stick) which exists between two periods of different amplitudes. In absence of fluid and when the coefficient of friction is constant, the system oscillates indefinitely with a multiplicity of periods while approaching a chaotic and indeterminist system. The variation of frequency of vibration of wave, which affects the coefficient of friction, shows that, the system vibrates with at least two periods (stick-slip), always separated from a transient phase (a stick) characteristic of seismic manifestations. Thus, our approach can now be taken into account during seismic forecasting method.

Keywords: *displacement; seismic energy; pressure ratio; ratio of temperature; coefficient of friction.*

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DOES ONGOING STRONG SUBSIDENCE AFFECT RESONANCE PERIODS IN MEXICO CITY?

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Abstract

Mexico City is undergoing dramatic subsidence due to groundwater usage and building. In the long term, this alters the properties of the sedimentary basin and may thus affect its response to seismic ground motion. We investigate time-dependent horizontal-to-vertical spectral ratios in order to investigate possible changes in resonance periods and amplitudes at a seismic network covering sites within and outside Mexico City, both in the sedimentary basin and at surrounding hill sites. Our preliminary results suggest that sediment resonance shows systematic temporal changes, such as seasonal variation and a drop in the frequency of resonance following the 2017 Puebla earthquake.

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INFLUENCE OF SUBSURFACE POROSITY AND PERMEABILITY ON LOCAL SEISMIC RESPONSE

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ABSTRACT

This study investigates the influence of subsurface porosity and permeability on local seismic response, focusing on their role in thermal response and fault dynamics. While these parameters govern material stiffness and fluid circulation, their impact on seismic cycles remains critical. We used a single-degree-of-freedom spring–block model incorporating frictional forces and thermal pressurisation. The governing equations for fault dynamics, energy balance, and fluid conservation were solved using a fourth-order Runge–Kutta algorithm. Our results demonstrate that permeability and porosity exert opposite effects: reduced permeability and increased porosity amplify both seismic slip and thermal energy production, while lengthening earthquake recurrence intervals. Specifically, high porosity reduces mechanical strength, while low permeability promotes pore pressure build-up, enhancing deformation. These findings explain contrasting seismic responses in geologically similar areas. Integrating these physical properties into hazard models is essential for improving site-effect predictions and refining earthquake-resistant construction standards to strengthen infrastructure resilience.

Keywords: Permeability, porosity, mechanical strength, seismic slip, seismic cycle

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Grenoble (France), 19-21 October 2026

SITE AMPLIFICATION FACTORS ESTIMATED FROM MICROTREMOR H/V AT THE NILE DELTA BASIN OF EGYPT: NEW SITE-SPECIFIC EMPIRICAL CORRECTION

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It has been a long-standing subject of investigation into how to delineate site amplification factors (SAFs) at a target site based onvarious types of microtremor measurements. This paper aims to provide a practical yet physically rational solution for that difficult task.Since SAFs contribute significantly tofuture planned engineering practices, particularlyat sites onthick and soft basin sediments, we delineated the empirical and theoretical SAFs (ESAFs and TSAFs,respectively) at 103 single-station microtremor survey points along three North-South lines crossing the entireNile Delta0basin area in Egypt.We successfully derived a new empirical correction ratiospecifictothe regionby averaging the ratios betweenthe microtremor horizontal-to-vertical spectral ratios (MHVSRs) and TSAFs. The correlation between TSAFs and the corrected TSAFs (cTSAFs) was reproduced by directly multiplying the observed MHVSRs by this correction ratio. This strong correlation accurately reproduces both low-fundamental frequency modes (0.1 to 1.0 Hz) and higher-frequency modes (1.0 to 3510.0 Hz), which are crucial for local urban landscapes in the Nile Delta characterized by low-rise buildings. Furthermore, the effectiveness of the cTSAFs,derived solely from MHVSRs, was confirmed through example recalculations. The dominance of low fundamental frequency modes in ESAFs stems from their strong dependence on MHVSRs, which mainly consist of surface waves. Although we found interesting comparability between the current correction ratio and pioneering 40previous ratios by Kawase et al. (2019), the current new empirical correction ratio is site-specific and suitable for any future planned engineering practices in the Nile Delta basin. Developing a regional correction ratio applicable across seismic-prone sites without in-site records remains a challenge.

Keywords: Site amplification factor; Microtremor inversion; H/V ratio; Nile Delta; Empirical correction ratio; Earthquake 48ground motion

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Grenoble (France), 19-21 October 2026

A DYNAMICAL LENS ON SEISMIC SITE RESPONSE THROUGH STRUCTURED RANDOMNESS, DYNAMICAL COHERENCE, AND ORDINAL PATTERNS

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Abstract

Conventional site-effect analysis interprets seismic wavefields through amplitude-based descriptors—spectral ratios, power spectral density, and energy coherence—that reduce a dynamic process to a static energy distribution, discarding temporal organisation: the memory and intermittency that govern site response under complex excitation. We introduce an ordinal-pattern framework $\Phi = (\square, \square, \square)$ encoding pattern diversity, statistical organisation, and temporal memory. Invariant under amplitude transforms, Φ enables dynamical coherence $\square_{\Phi}$—the mean pairwise cosine similarity of Φ-triplets across a seismic network—measuring whether stations share the same evolving dynamical state, not merely similar energy levels. On 260 synthetic simulations spanning eight dynamical regimes, KΦ recovers approximately 3× more network structure than classical energy coherence. Φ-based spatial maps resolve source-driven organisation absent from amplitude fields. The framework is calibration-free and directly applicable to dense-array datasets.

Keywords: Dynamical Coherence, Ordinal Patterns, Structured Randomness, Site-effect Analysis, Complex System

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Grenoble (France), 19-21 October 2026

EFFECTS OF FAULTS SYSTEM NEAR PSKEM DAM IN UZBEKISTAN ON SEISMIC MOTION AND DAM STABILITY (ESG7)

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Effects of fault systems on seismic motion modeling and seismic loading will be presented for the Pskem dam located in Uzbekistan. The surface geometry of the faults, their segmentation, and the distance to the Pskem dam are the main parameters necessary for seismic hazard assessment (SHA) of the Pskem dam under seismic impacts. The methodology for synthesizing seismic motions is based on the 3D analytical solutions of Bykovtsev-Kramarovsky (1987 and 1989) for faults with multiple segmentation. It is based on a kinematic description of the displacement function on the fault, taking into account all possible combinations of the three components of the displacement vector. The methodology was presented at ESG4 in the publication of Bykovtsev-Kasymov (2011) for seismic hazard assessment of the Diablo Canyon nuclear power plant area, located approximately 1 km from the new Shoreline fault zone, divided into three segments based on differences in the geological manifestation of surface and near-surface faults in the Central part of Coastal California. The Karzhantau, Northern Ugam, Ugam-Maydontol, and Pskem fault systems are located in close proximity to the planned Pskem dam in Uzbekistan. The Karzhantau strike-slip fault is 88km long, consists of 25 rectilinear segments, and the minimum distance to the Pskem dam site is 1 km. The Ugam-Maydontol thrust fault is 102 km long, consists of 13 segments, and the minimum distance to the Pskem dam site is 4 km. The Northern Ugam strike-slip/thrust fault is 70 km long, consists of 7 segments, and the minimum distance from the Northern Ugam fault to the Pskem dam site is 15 km. The Pskem strike-slip/thrust fault is 109 km long and consists of 31 segments; the minimum distance from the Pskem fault to the Pskem dam site is 9 km. Mathematical methods of fracture mechanics and J-integral calculation methods were used to estimate the location of possible new seismic events near the Pskem dam. Simulated seismic motions and seismic loads were used to calculate the stability of the dams under seismic impacts initiated in the fault system located near the Pskem dam. The licensed software package Geo-Studio-2025.1. was used for these calculations, which allows for the assessment of filtration and stability of dams before and after earthquakes using initial static, linear dynamic, and nonlinear dynamic analyses. The licensed software "Calculation of synthesized seismic effects from earthquakes of various types and faults with different directions of movement along the faults within 10 km of the fault zone (BAS-KDB-1)" was used to analyze seismic records of displacements, velocities, and accelerations. This software was registered in the State Register of Software Products of the Republic of Uzbekistan on August 6, 2024. Keywords: faults system segmentations, seismic motion, fracture mechanics, dam stability, earthquake engineering.

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SEARCHING IN THE DATA: MACHINE-LEARNING SITE EFFECTS FOR GROUND MOTION CHARACTERISATION AND SYNTHESIS

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ABSTRACT

Site and basin effects are the most persistent source of unexplained variability in ground-motion prediction, and the data that constrain them are scattered across geotechnical boreholes, sonic logs, regional velocity models and, increasingly, very large physics-based simulation databases. This paper summarises three recent efforts that search in these data with machine learning: a Gaussian-process (GP) correction to the SCEC CVM-S4.26 shear-wave velocity model of the Los Angeles Basin trained on 691 velocity profiles; a scalable non-ergodic ground-motion model that learns systematic site and path terms from 207 million CyberShake simulations and reduces prediction error by more than 50% at unseen sites; and GMFlow, a function-space generative model that synthesises spatially coherent regional wavefields about 10,000 times faster than 3D simulation. Together they outline a hybrid paradigm in which physics-based simulation provides spatial completeness and data-driven models supply the resolution and realism that regional velocity models and ergodic GMMs cannot.

Keywords: site effects, Gaussian process, non-ergodic GMM, generative model, velocity model

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DEVELOPMENT OF MACHINE LEARNING MODEL TO ESTIMATE SITE AMPLIFICATION FACTORS USING MICROTREMOR TIME HISTORIES

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ABSTRACT

Site amplification factors (SAFs) have large impact on ground motions and seismic damage. Although SAFs are dependent to subsurface structures at target sites, the purpose of this study is to develop a machine learning model for estimating SAFs directly from time histories of microtremors without investigating the subsurface structure. We adopted Deep Neural Network (DNN) with Attention mechanism for our machine learning model. Target SAFs were estimated by Generalized Inversion Technique using earthquake records observed in whole of Japan. We focused on the frequency range of 0.1 to 20 Hz at 124 sites where we have observed microtremors. The k-fold cross validation for 10 folds was performed assigning all sites to the test dataset once. The developed machine learning model reproduces the SAFs of the training and validation datasets well, and estimates the SAFs of the test dataset fairly well.

Keywords: machine learning, site amplification factor, microtremor, time history

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RECENT EFFORTS TO PREDICT SITE EFFECTS FROM MICROTREMOR HORIZONTAL-TO-VERTICAL SPECTRAL RATIOS WITH ARTIFICIAL INTELLIGENCE

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ABSTRACT

The accurate prediction of site effects is essential for understanding the influence of surface geology on seismic motion. Traditionally, ground motion models (GMMs) have parameterized the estimation of site effects with the time-averaged shear wave velocity in the upper 30 m (V_{S30}). However, as direct measurements of V_{S30} are expensive, many ground motion stations do not have a measured V_{S30}, but instead are estimated through regional proxies. While these regional proxies provide a tractable solution, they have limited resolution and can struggle at the site-specific scale. In response, we propose that microtremor horizontal-to-vertical spectral ratio (mHVSR) measurements that are rapid and inexpensive to collect can be used as a site-specific proxy for V_{S30} and for the direct estimation of GMM site terms. To determine if mHVSR could be used as a site-specific proxy for V_{S30}, we aggregated a globally-sourced dataset of 2861 mHVSR measurements with high-quality, co-located V_{S30} measurements and used artificial intelligence (AI) to train a set of open-weight models to predict V_{S30} from mHVSR. The best performing AI model, which used the full mHVSR lognormal median curve as input, showed strong predictive performance, achieving a coefficient of determination (R^2) of 0.82 on the model's testing set, and outperforming a recently developed model to predict V_{S30} from remote sensing data (R^2 of 0.72 compared to 0.09). This success prompted the investigation of whether the mHVSR median curve could be used to estimate GMM site terms directly. To determine if mHVSR could be used as a proxy for site terms, we first developed a dataset of 1105 mHVSR measurements co-located with stations from the Next Generation Attenuation West-3 (NGA-West3) database with site term estimates. We then developed two data-driven models to predict site terms from mHVSR, the first uses only the mHVSR median curve and the second uses both the mHVSR median curve and the V_{S30} estimated from mHVSR. When evaluated on a testing dataset, these models demonstrate near-equivalent performance - similar site-to-site residuals ($\phi_{2\square}$) at all frequencies - to a traditional V_{S30}-based model. These efforts demonstrate that fusing mHVSR and AI can enable new advancements in seismic site characterization and the estimation of site effects.

Keywords: ambient noise, HVSR, site effects, data-driven

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CHARACTERIZATION AND IDENTIFICATION OF SITE EFFECTS THROUGH MULTIVARIATE STATISTICAL ANALYSIS

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ABSTRACT

This study presents the results of an in-depth multivariate statistical analysis on site characterization information for the Italian seismic network, collected in CRISP (http://crisp.ingv.it) and ITACA (https://itaca.mi.ingv.it/ItacaNet_40/) databases. The main goal is to develop a robust methodology for identifying and quantifying site effects, by uncovering the complex relationships and statistical correlations between geological, geophysical, topographical, and seismological variables. Recognizing that site effects arise from complex interaction of multiple factors, we apply advanced statistical analysis (e.g., canonical correlation) to identify the minimum, most effective, and sensitive set of geophysical and geological proxies that can predict the site amplification functions and be used as robust indicators of site effect. The results of this analysis offer a scientific basis for a more accurate and predictive seismic site classification that incorporates geological and topographical complexity beyond simple V_{S30} criteria.

Keywords: Statistical analysis, Site effect, Site characterization, CRISP database, Italian seismic network

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AI-BASED QUALITY CHECK AND INTERPRETATION OF MICROTREMOR H/V CURVES

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ABSTRACT

Single-station ambient noise measurements, analyzed through the Horizontal-to-Vertical spectral ratio, are widely applied in seismic hazard assessment and in stratigraphic reconstructions of the subsurface. In mining exploration and other applied geophysics contexts, large-scale surveys often involve hundreds of measurements to support preliminary bedrock mapping. Under these conditions, there is a strong need for tools that can rapidly evaluate the quality of collected data and guide users - expert or not - in their interpretation. To address this need, we developed and trained a supervised feed-forward neural network to classify different sections of microtremor spectra into seven categories: normal, 1D resonance, 2D/3D resonance, artifact, velocity inversion, data requiring cleaning, and malfunctioning sensor. The training dataset comprised 3000 examples from over 20 years of field measurements in diverse geological and environmental settings, processed with consistent windowing, smoothing, and spectral normalization procedures. By analyzing both the individual spectral components and the H/V curve within selected frequency intervals, the neural net produces a probability-based classification for each interval, which can be aggregated into a synthetic quality assessment - accept, reject, or reanalyze - based on predefined criteria. Testing on unseen data yielded an accuracy of about 80–82%, with the main classification challenge being the distinction between 2D/3D resonances and artifacts due to their spectral similarities. The neural net proved robust to changes in instrument type, analysis window length, and smoothing parameters. This approach offers an alternative to fixed-threshold guidelines such as the SESAME (2004) criteria.

Keywords: neural networks, HVSR, H/V, soil resonance

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TRANSFERABILITY OF MACHINE-LEARNING MODELS FOR SITE RESPONSE PREDICTION USING MHVSR AND ITS DERIVED PEAK PARAMETERS

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ABSTRACT

Accurate prediction of seismic site effects is one of the most significant opportunities for uncertainty reduction in seismic hazard analysis. Microtremor horizontal-to-vertical spectral ratio (mHVSR) measurements offer an appealing, low-cost supplement to ground-motion recordings for characterizing frequency-dependent site amplification. However, the extent to which models developed in one geographic, tectonic, and geologic context can be transferred to another is largely unknown. This study evaluates the transferability of several machine-learning-based models for predicting site response from mHVSR and its derived peak parameters, in combination with various other site metrics. The models were trained using a database of 678 sites with co-located earthquake observations and mHVSR measurements across the state of California (CA) and adjacent regions. This presentation will describe their application to a database of 221 sites in New Zealand (NZ).

The machine-learning models use a Random Forest regressor. The highest order model is trained using the full mHVSR curve (HVSR amplitude as a function of frequency), enabling the algorithm to capture complex, nonlinear patterns without explicit parametrization, albeit with reduced interpretability and transparency. The remaining models rely on different suites of derived mHVSR features, including the peak frequency and amplitude, offering a reduced-dimension representation of the mHVSR curve, as well as other commonly used site proxies such as the time-averaged shear-wave velocity in the upper 30 meters (V_{S30}), and the depths to velocity iso-surfaces $z_{1.0}$ and $z_{2.5}$.

The performance of the models in the two regions is compared and discussed. The Random Forest hyperparameters were tuned to reduce overfitting and improve transferability to datasets and regions not included in the training process. Overall, the models show potential for reducing uncertainty in predictions of linear site response. Compared to a conventional regression-based model conditioned on V_{S30}, uncertainty reductions of up to 0.125 natural log units were achieved at long periods in the training region (CA), and up to 0.1 over a narrower long-period range in the testing region (NZ).

Keywords: Machine learning models, transferability, mHVSR, site response prediction

BENTO: AN INTERNATIONAL BENCHMARK FOR 3D NUMERICAL SIMULATIONS OF SEISMIC-WAVE PROPAGATION OVER COMPLEX TOPOGRAPHY

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ABSTRACT

Topographic site effects can significantly modify the ground motion during earthquakes. Although three-dimensional numerical simulations of seismic-wave propagation have become the primary tool for investigating these phenomena, no international benchmark has ever been dedicated to assess their reliability over realistic or complex topographic sites. The BEnchmark of 3D Numerical simulations on TOpographic Sites (BENTO) addresses this gap by providing a common framework for evaluating numerical methods under identical model setups. Thirteen international

teams participated using various numerical methods. The benchmark is organized into several complementary phases: a verification phase that evaluates the consistency and accuracy of numerical solutions on both canonical and realistic topographies, and a validation phase that assesses their capability to reproduce actual field observations. Standardized post-processing procedures and common quantitative evaluation metrics ensure objective intercomparison of all submitted simulation results. BENTO establishes the first

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VERIFICATION OF 3D NUMERICAL SIMULATIONS OF SEISMIC-WAVE PROPAGATION USING CANONICAL TOPOGRAPHIES: RESULTS FROM THE BENTO BENCHMARK

BENTO Team[1]

[1] The complete list of BENTO organizing and participating teams is provided in the first companion abstract entitled "BENTO: An International Benchmark for 3D Numerical Simulations of Seismic-Wave Propagation over Complex Topography".

ABSTRACT

The first verification phase of the BEnchmark of 3D Numerical Simulations on TOpographic Sites (BENTO) assesses the consistency and numerical accuracy of three-dimensional simulations of seismic-wave propagation in a homogeneous medium with idealized surface topographies. Four canonical topographic configurations with 2D and 3D geometries were designed: a 3D Gaussian hill, a 2D Gaussian ridge, two 2D triangular ridges, and a 2D steep scarp. A broad frequency range was considered to capture the full range of topographic effects, for seismic-wavelengths down to one fifth of the maximum topographic relief. 12 teams submitted results obtained with codes implementing different numerical methods, including the Finite-Difference Method, Finite-Element Method, Spectral-Element Method, and Discontinuous Galerkin Method. Among the submitted solutions, three show excellent agreement on the full frequency range considered, while six only partly match the reference, mainly because of insufficient computational resources or an incorrect implementation of the plane-wave excitation required for some benchmark cases. The remaining solutions are considered unacceptable owing to implementation errors. The results presented in this contribution demonstrate that, despite its apparent simplicity, Phase 1 of the BENTO benchmark constitutes a demanding qualification stage before addressing the more realistic topographic configurations considered in Phase 2.

Keywords: Topographic site effects; Numerical simulations; Seismic-wave propagation; verification on canonical topographies

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VERIFICATION OF 3D NUMERICAL SIMULATIONS OF SEISMIC WAVE PROPAGATION AT REAL TOPOGRAPHIC SITES: RESULTS FROM THE BENTO BENCHMARK

BENTO Team[1]

[1] The complete list of BENTO organizing and participating teams is provided in the first companion abstract entitled "BENTO: An International Benchmark for 3D Numerical Simulations of Seismic Wave Propagation over Complex Topography".

ABSTRACT

The second verification phase of the BEnchmark of 3D Numerical simulations on TOpographic Sites (BENTO) extends the analysis from canonical topographic configurations to realistic topographic settings. This phase assesses the consistency of the results from numerical simulations performed by different teams under identical input parameters, focusing on two real and representative sites in Cephalonia (Greece): the ArgoScarp escarpment and the Mount Ainos massif. These two cases provide complementary scales of topographic complexity, from small-scale features (where topographic effect is marked at high frequencies) to large-scale structures (where topographic effect is marked at intermediate frequencies). The comparison of submitted numerical solutions highlights the increased difficulty of realistic geometries compared to canonical test cases. Differences between simulation results are primarily controlled by the representation of the free surface, mesh resolution, and computational domain size. Good agreement is obtained when the topographic geometry is accurately represented and sufficiently resolved by the mesh, ensuring that receivers are correctly positioned relative to key morphological features. However, local discrepancies can appear, particularly near sharp morphological transitions (e.g., scarp toes), and can significantly affect wavefields and topographic amplification functions. These results emphasize the importance of accurate geometric representation of the topographic transitions, and of appropriate discretization strategies when modelling wave propagation over real topography.

Keywords: Topographic site effects; 3D numerical simulations; Seismic wave propagation; Verification of numerical simulations

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VALIDATION OF 3D NUMERICAL SIMULATIONS OF SEISMIC-WAVE PROPAGATION OVER REAL TOPOGRAPHIES: PRELIMINARY RESULTS FROM THE BENTO BENCHMARK

BENTO Team[1]

[1] The complete list of BENTO organizing and participating teams is provided in the first companion abstract entitled "BENTO: An International Benchmark for 3D Numerical Simulations of Seismic-Wave Propagation over Complex Topography".

ABSTRACT

The validation phase of the BEnchmark of 3D Numerical simulations on TOpographic Sites (BENTO) evaluates the ability of numerical simulations to reproduce observed topographic site effects in sharp topographic environments. The two instrumented sites in Cephalonia (Greece), ArgoScarp and Mount Ainos, used for the BENTO second verification phase, provide earthquake datasets for comparison with numerical predictions. Preliminary results at ArgoScarp show good agreement between observed and simulated amplification patterns, with both datasets reproducing strong de-amplification at the cliff base and moderate amplification at the crest. A second validation exercise, currently underway, investigates the influence of seismic illumination (the dependence of topographic amplification on slope orientation relative to incoming waves) using representative virtual earthquake sources at different azimuths from the topographic sites. Together, these results provide the first validation framework for three-dimensional numerical simulations of seismic-wave propagation over complex topography.

Keywords: Topographic site effects; 3D numerical simulations; Validation of numerical simulations; Earthquake recordings on topographies

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STUDY ON ESTIMATING LOVE WAVE PHASE VELOCITY USING TRANSLATIONAL AND ROTATIONAL MOTIONS IN 3D SUBSURFACE STRUCTURE BASED ON NUMERICAL SIMULATION

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ABSTRACT

Detailed subsurface velocity structures are essential to understand how surface topography and heterogeneous subsurface velocity structures affect ground motion. Microtremor survey methods (e.g., FK and SPAC methods) are the commonly used to estimate subsurface velocity structure but since these methods assume laterally homogeneous structure, the analytic results will be an apparent ‘averaged’ result. Recently, a method based on the correlation between translational and rotational motions at an observation station, the AR method, shows potential to obtain subsurface velocity structure. However, the capability of this method is still not clear. In this study, we synthesized waveforms using random point sources distributed on model surfaces based on Green’s function and spectral element method, considering homogeneous and heterogeneous subsurface structure models. We applied the AR method to the synthetic waveforms and estimated Love wave phase velocities and back azimuths of the sources and compared the results with those based on traditional microtremor survey methods.

Keywords: heterogeneous subsurface structure, rotational motion, phase velocity, microtremor, spectral element method

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REVISITING THE TRANSLATIONAL AND ROTATIONAL MOTION IN A SEMI-INFINITE LAYER IN THE TIME, FREQUENCY AND TIME-FREQUENCY DOMAINS

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ABSTRACT

The least investigated ground-shaking site effects are those related to lateral boundaries of sedimentary layer despite consistent macroseismic observations of significant increase in damage intensity on “stripes” located along strong lateral discontinuities. We consider a semi-infinite layer as a canonical model for many real situations with sediments relatively sharply laterally bounded or with abrupt change of sediment thickness. We investigate numerically simulated seismic motions for vertically incident SH, SV and P waves using a novel time-frequency transfer functions. Sharp peaks of the rates of rotational motion and axial strain across the lateral discontinuity, together with the well-known basin-edge effects for translational motion, are found to be the key site effects of the laterally bounded sedimentary layer. At larger distances from the discontinuity, the decay of rotational motion and axial strain at larger distances is controlled by the attenuation in sediments.

Keywords: Basin-edge site effects, Numerical modelling, Translational motion, Rotational motion, Axial strain

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PHYSICS-BASED SIMULATION AND ANALYSIS OF NEAR-FAULT GROUND MOTION FOR THE 2021 M_W 6.1 YANGBI, CHINA EARTHQUAKE

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ABSTRACT

Physics-based simulation (PBS) is increasingly used to model near-fault ground motions for seismic hazard assessment. This study employs a PBS approach to simulate and analysis ground motions from the M_W 6.1 Yangbi earthquake. A comprehensive three-dimensional numerical model was constructed by integrating a crustal velocity structure and a kinematic rupture model to capture the near-fault complexity. The simulations show good agreement with recorded data in amplitude and spatial pattern. Simulated peak ground velocity and displacement (PGD) at bedrock are approximately 8 cms^{-1} and 4 cm, respectively, with the highest intensities in the southeastern Yangbi County due to unilateral rupture directivity. Time- and frequency-domain comparisons confirm general waveform agreement, though local differences may stem from unaccounted site effects or simplifications in the regional velocity model. The analysis reproduces key near-fault characteristics, including velocity pulses and permanent displacement, providing insight into the spatial shaking variability near the source. Furthermore, topography is found to amplify ground motions by a factor of ~2 at periods of 0.5 s and 1.0 s relative to a flat-reference model. These results highlight the value of PBS in complementing empirical records, particularly in regions with complex geology and topography, offering a reliable tool for ground motion prediction and improved hazard assessment in similar tectonic settings.

Keywords: Physics-based simulation, Near-fault ground motion, Yangbi earthquake, Topography effect, Seismic hazard assessment

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TOWARDS PHYSICS-BASED SEISMIC GROUND MOTION AND SITE-CITY INTERACTION IN URBAN AREAS: A CASE STUDY IN MEXICO CITY

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ABSTRACT

Traditional urban earthquake-impact assessments rely mainly on empirical ground-motion models and fragility curves. These methods are fast and fit naturally within probabilistic risk frameworks, but they can yield unrealistic results when strong-motion data are sparse, especially for large, near-fault earthquakes or geologically complex regions. Empirical fragility curves may also be biased because they are often calibrated using non-site-specific shaking scenarios and intensity measures that are not fully efficient or sufficient. This contribution proposes a physics-based alternative that couples earthquake source modeling, 3D wave propagation, soil-structure interaction, and simplified nonlinear building models representing structural capacity curves. The goal is to create an end-to-end framework linking the rupture process to urban structural response more realistically. The approach has been implemented in the SPEED code developed at Politecnico di Milano. An illustrative application simulates earthquake scenarios in Mexico City, including source effects, basin wave propagation, and nonlinear site-city interaction among high-rise building groups.

Keywords: Physics-based earthquake ground motion simulation, site-city interaction, physics-based seismic damage scenarios, high-performance computing.

Frequency- and component-dependent topographic effects on ground-motion in the Swiss Rhône Valley

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Abstract

We present 3-D spectral-element simulations of seismic wave propagation in the Swiss Rhône Valley to quantify how Alpine topography modifies ground motion when basin geometry is held fixed. Three local earthquakes (M_W 3.0–4.5) are modelled in topographic and flat-surface configurations that preserve the sedimentary basin identically, with ground motion sampled at real network stations and a uniform synthetic 2×2 km grid for spatially unbiased statistics. Frequency-band Topo/Flat spectral ratios reveal a systematic component asymmetry: at exposed mountain positions, horizontal motion is de-amplified across the dominant low-to-intermediate bands (0.80–0.97x at 0.05–0.50 Hz) while vertical motion is amplified across all bands (1.16–2.32x). The asymmetry is consistent with topography-induced SV-to-Rayleigh mode conversion at the free surface, and the qualitative shift in mountain horizontal medians between station populations identifies a structural sampling bias in real seismic networks for topographic site characterisation.

Keywords: topographic effects; ground motion modelling; spectral-element method; alpine valley.

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Grenoble (France), 19-21 October 2026

BENCHMARKING FINITE-DIFFERENCE SIMULATIONS OF SURFACE-TO-BOREHOLE SPECTRAL AMPLIFICATION IN 3D SCATTERING MEDIA

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ABSTRACT

Surface-to-depth spectral amplification for frequencies above 1Hz constitutes a fundamental description of local site response, linking ground motion recorded at depth to that observed at the free surface. At sites equipped with borehole seismic arrays, this transfer function can be constrained empirically through surface-to-borehole (S/B) spectral ratios derived from multiple regional earthquake records. However, robust prediction remains impeded by limited resolution of near-surface velocity heterogeneity and by simplifying theoretical assumptions that inadequately represent the complexity of the high-frequency wave field. In particular, classical 1D plane SH-wave formulations commonly yield narrow, high-amplitude resonance peaks that are not supported by empirical observations. Building on recent advances incorporating stochastic variability into 1D site-response models, we extend the modeling to fully three-dimensional media. We adopt finite-difference simulations of the full wave field in finely discretized 3D subsurface models with smoothed interfaces and spatially correlated random heterogeneities. This approach naturally accounts for scattering and mode conversion, and produces surface-to-depth amplification functions that lack the unrealistically sharp spectral features characteristic of simplified 1D theories. We apply the proposed strategy to sites with borehole instrumentation that exhibit both predominantly 1D resonance behavior and more complex site effects. Modeled S/B spectral ratios are compared with empirical estimates from selected test sites in Japan (KiK-net stations) and Switzerland (National Seismic Networks of Switzerland stations), representing underground installations in both hard rock and softened sedimentary formations. The results demonstrate that realistic prediction of high-frequency underground ground motion is feasible when 3D scattering and the mechanical properties of the surrounding formations are explicitly considered. Our findings emphasize that predictions of site-specific amplification are governed primarily by theoretical modeling assumptions rather than by uncertainties in seismic property estimates, and they underscore the relevance of full-wave field 3D modeling for the seismic hazard assessment of underground structures and deep engineered facilities..

Keywords: Surface-to-borehole spectral amplification, near-surface heterogeneity and seismic scattering, high-frequency 3D finite-difference modeling, underground ground-motion prediction, seismic hazard assessment

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GROUND MOTION STUDY IN CENTRAL WAJIMA, JAPAN, BASED ON THREE-DIMENSIONAL FINITE DIFFERENCE METHOD CONSIDERING SOIL NONLINEARITY

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ABSTRACT

The authors introduced a three-dimensional finite difference method (FDM) considering soil nonlinearity and its application to strong ground motions in the central Wajima area during the 2024 Noto Peninsula Earthquake occurred in Ishikawa Prefecture, Japan. First, the FDM accounting for soil nonlinearity was briefly described herein. A verification test of the FDM was then conducted through numerical calculations for a three-dimensional irregular subsurface structure to compare velocity waveforms with those computed by a three-dimensional finite element method. Next, we constructed a simple three-dimensional soil model with an irregular subsurface structure, based on geotechnical investigations, to better understand the ground motion characteristics in the area during the mainshock. It was confirmed that numerical calculations could reproduce the nonlinear soil response observed in strong motion records. It was also found that further investigation is needed using a more detailed ground model that accounts for both vertical and horizontal directions in the area.

Keywords: Soil Nonlinearity, Irregular Subsurface Structure, Finite Difference Method

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BASIN AMPLIFICATION FACTORS FROM 3-D PHYSICS-BASED GROUND MOTION SIMULATIONS IN KAHRAMANMARAŞ

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ABSTRACT

This study presents the 3-D physics-based ground motion simulation of the February 6, 2023, Mw 7.8 Pazarcık earthquake using the spectral elements method to quantify basin amplification in the Amik, Adana, and Kahramanmaraş basins. Utilizing a high-resolution source inversion and a V_{S30}-dependent velocity model, simulations were conducted by using the SPECFEM3D Cartesian software. The model was validated against recorded data by calculating the goodness-of-fit scores of each station. After validating the model, period-dependent basin amplification factors (BAFs) were found by defining a randomized grid of stations inside of these basins. The ratio of the spectral acceleration for stations inside the basin to the nearby rock station reveals the amplification. The BAFs are validated by comparing them to basin amplification seen in the real records. Results indicate that simulated BAFs successfully envelope real data.

Keywords: physics-based, spectral elements, basin amplification, finite fault, velocity model

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GROUND MOTION VARIABILITY IN ISRAEL: INSIGHTS FROM M 7 REGIONAL SIMULATIONS ON THE DEAD SEA FAULT SYSTEM

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ABSTRACT

The Dead Sea Fault (DSF) is the primary source of seismicity in the Eastern Mediterranean, with a proven historical record of destructive earthquakes. In Israel, a limited instrumental record (1983-present) hinders the development of a locally constrained empirical GMM. We simulate ground motions for nine Mw 7 scenarios on major segments of the DSF using a detailed 3D geological velocity model, yielding a database of ~32,000 three-component synthetic seismograms. The simulations reveal pronounced basin-controlled amplification, strong rupture directivity, and marked directionality of horizontal ground motions. Near-fault pulse-like motions are frequently observed, with dominant pulse periods of 2–6 s. Regression analyses using a simplified ground-motion model show that, while established directivity predictors capture component-specific effects, significant positive residuals persist in deep sedimentary basins, indicating additional amplification mechanisms not represented by conventional site parameters. Our results demonstrate the critical role of three-dimensional basin and rupture effects along the DSF and highlight the need for nonergodic, region-specific ground-motion models. The synthetic database developed here provides a foundational step toward such models in data-limited tectonic environments.

Keywords: Physics-based simulations, Dead Sea Fault, Basins, Rupture directivity

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CHARACTERIZATION OF GROUND MOTION VARIABILITY IN THE KYOTO BASIN USING PHYSICS-BASED GROUND MOTION SIMULATIONS

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ABSTRACT

Accurate ground motion estimation and uncertainty quantification are vital for seismic hazard assessment. This study aims to characterize ground motion variability to develop an approach to integrate ground motion variability based on physics-based simulations into Probabilistic Seismic Hazard Analysis (PSHA). We first focused on the Hanaore Fault in the Kyoto basin, Japan and simulated ground motion due to a JMA magnitude 7.3 earthquake using a hybrid approach by combining 3D finite difference method and stochastic Green's function method for 243 scenarios. Peak ground velocity on the engineering bedrock was compared with Ground Motion Model (GMM) results. While both methods yield comparable results, the hybrid approach shows reduced variability at fault distances around 10 km. Analysis of the Geometric Coefficient of Variation reveals that ground motion variability is sensitive to both fault proximity and subsurface basin structure, providing a basis for understanding modeling uncertainty.

Keywords: GMM, Physics-based simulations, PGV, ground motion variability, Kyoto basin

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DETERMINISTIC NUMERICAL MODELLING OF WAVE PROPAGATION DURING THE MAIN AFTERSHOCKS OF LE TEIL EARTHQUAKE (NOVEMBER 2019, ARDÈCHE, FRANCE) AND CHARACTERIZATION OF ASSOCIATED UNCERTAINTIES

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ABSTRACT

On November 11, 2019, a magnitude Mw = 4.9 earthquake shook Le Teil town (Ardeche, France). This extremely shallow earthquake happened in a region of complex geology, featuring lithological interfaces with strong impedance contrasts. Numerical modeling helps assess how such structures influence local seismic hazard, but geophysical models often rely on uncertain data. Therefore, improving hazard knowledge requires identifying and studying all uncertainty sources to quantify their impact on the seismic signal. To this end, we perform a detailed variance-based global sensitivity analysis built upon 4096 simulations of the two main aftershocks of Le Teil earthquake. We estimate the effect of bedrock complexity to be up to 70%, highlighting the importance of accounting for it.

Keywords: earth ground motion, site effect, sensitivity analysis, seismic hazard, numerical models

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ALTERNATIVE MODELS FOR SITE RESPONSE CONDITIONED ON MHVSR FOR CALIFORNIA SITES

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Traditional site response components of ergodic ground motion models (GMMs) are conditioned using simple site parameters such as the time-averaged shear-wave velocity in the upper 30 m (V_{S30}) and depths to shear-wave velocity isosurfaces (e.g., $z_{1.0}$). These parameters, however, do not adequately capture site-specific resonances or other frequency-dependent site effects, which can lead to biased predictions. Microtremor-based horizontal-to-vertical spectral ratios (mHVSR), derived from ambient-noise recordings, offer a practical means to evaluate these effects and have the potential to reduce uncertainty in GMMs. We develop three different types of models that incorporate mHVSR-derived features, alongside traditional site parameters (e.g., V_{S30}), using a dataset of 685 sites in California and adjacent regions (Ornelas et al. 2025). This presentation will describe the development and comparison between the different models.

The models developed as part of this study include: (1) a peak-based model derived using parameterized peaks from mHVSR (i.e., parameterized by peak frequency, amplitude, and width), focused on the dominant resonant frequency, compared to parameterized peaks from site-to-site residuals from earthquake observations and an ergodic ground-motion model (Boore et al., 2014) (2) an ordinate-based model conditioned on each individual mHVSR frequency-based ordinate compared to each site response ordinate at each oscillator period(e.g., mHVSR ordinates at 2 Hz compared to site response ordinates at T = 0.5 sec); and (3) two machine learning models that are built on a random forest regressor conditioned on a suite of mHVSR peak parameters (e.g., amplitude, frequency, width), as well as of soil parameters (e.g., V_{S30}, $z_{1.0}$, $z_{2.5}$), and spectral ordinates (e.g., the entire mHVSR spectrum).

Model performance is assessed using a 20% validation subset and compared across the various models. All models produce notable reductions in site-to-site variability (ϕ_{S2S}) compared to a baseline linear site amplification model. However, the goal of this evaluation goes beyond developing a ground motion model; it seeks to understand why certain model features or factors are more effective at predicting site response. Additionally, we explore how machine learning models, by capturing complex, hidden patterns, achieve superior accuracy compared to traditional physics-based approaches, which, though more interpretable, cannot identify these intricate features. Our objective is to pinpoint which parameters contribute to improved performance and to understand the reasons behind their effectiveness. The results of this study highlight the potential of integrating mHVSR-derived attributes into site response models, providing a promising framework for site response prediction in regions with limited instrumental data.

Keywords: horizontal-to-vertical spectral ratio, site response, ground motion model, random forest, machine learning

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DATA-DRIVEN SITE CHARACTERIZATION BASED ON FULL-SHAPE H/V SPECTRAL RATIOS

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In earthquake engineering and seismology, a commonly used approach for estimating near-surface soil structure—such as the depth-dependent S-wave velocity structure—is based on the predominant frequency of the microtremor horizontal-to-vertical spectral ratio (H/V spectral ratio, HVSR). Numerous studies have demonstrated the usefulness of this approach for site characterization. However, the HVSR spectrum is likely to contain information on subsurface structure that extends beyond the predominant frequency alone.

The objective of this study is to propose a novel framework in which the entire shape of the microtremor HVSR is treated as image data and linked to subsurface soil structure through deep learning. By focusing on the fact that the HVSR shape varies systematically from site to site— analogous to a site-specific spectral fingerprint—we aim to estimate near-surface ground structure at microtremor observation sites directly from the full spectral shape of the HVSR.

A convolutional neural network (CNN), which is well suited for image-recognition problems, is employed to learn the relationship between HVSR spectral shapes and corresponding ground structures. Through the extraction of characteristic patterns shared by HVSRs and subsurface structures with similar properties, the proposed approach enables investigation of the key features of near-surface soil structure that control the shape of the H/V spectral ratio.

Machine learning techniques have increasingly been applied in seismology and earthquake engineering (e.g., Tsunekawa, 1997; Emami et al., 1996; Yanase and Maruyama, 2019; Kubo et al., 2020). In previous studies, the authors explored the applicability of deep learning using color-image representations of HVSRs for site classification (Tobita et al., 2022; Tobita and Yamamoto, 2023; Tobita and Taniguchi, 2024; Takada and Tobita, 2024). Using on the order of ten thousand HVSR waveforms, these studies demonstrated that observation sites could be classified with high accuracy based solely on HVSR information. Building on these results, the present study extends the approach by utilizing a substantially larger dataset derived from K-NET, the Japanese nationwide strong-motion observation network, to construct a deep learning model for site classification and identification based on full-shape HVSR characteristics.

Keywords: surface ground structure, convolutional neural network (CNN), H/V spectrum ratio (HVSR)

Physics-Based Numerical Simulations Of Earthquake Ground Motions In The Volcanic Area Of Campi Flegrei, Southern Italy

Roberto Paolucci

This presentation introduces 3D physics-based numerical simulations of seismic wave propagation within the Campi Flegrei area. This is a large and active volcanic area located near Napoli, in Southern Italy. Since 2018, the region has experienced a significant rise in both earthquake frequency and magnitude. Given the lack of large-magnitude recorded events, physics-based numerical simulations can be utilized to produce physically consistent ground-motion scenarios. The open-source spectral element code SPEED has been implemented to perform the numerical simulations. A three-dimensional model with lateral dimensions of 30 × 30 km and a depth of 8.1 km was developed. The resolution of the numerical model was set so as to be sufficient to propagate frequencies up to about 10 Hz. The velocity model used in the simulations is a linear approximation of the 1D average model with a Vs starting from 600 m/s on the surface. Site effects analysis using the HVSR approach — performed on a set of 32 seismic events with magnitudes ranging from Mw 3.0 to 3.94 — shows a flat HVSR curve at most stations. For validation, a circular rupture is adopted and simulations were performed for the three recorded events: Md 4.4 (20 May 2024), Md 4.2 (27 September 2023), and Md 3.9 (16 February 2025). The results indicate that the simulation can reproduce the main features of the observed data in both the time and frequency domains, as well as the attenuation trends in peak ground-motion values.

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MACHINE LEARNING MODEL FOR NATIONAL SCALE V_{S30} MAPPING BASED ON A NEW V_{S30} DATABASE IN ISRAEL

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ABSTRACT

This study integrates a newly compiled database of over 500 quality-controlled Vs profiles with proxy-based analysis and high-resolution mapping. A high-resolution national V_{S30} map is developed using a machine learning model which captures non-linear interactions between geology and geomorphology, and kriging of residuals which improves local accuracy and provides uncertainty estimates. Ultimately, this study offers a transferable framework for assessing ground motion controls in diverse tectonic and lithological regions.

Keywords: Vs_{30} mapping, machine learning, kriging

INTRODUCTION

Among the various parameters used to characterize site effects in building codes, ground motion models and other engineering applications, the time-averaged shear-wave velocity in the top 30 meters (V_{S30}) remains the most widely adopted metric for over 30 years.

While direct in situ measurements of V_{S30} are preferred, they are often cost-prohibitive for small projects, or impractical for national-scale mapping. Consequently, proxy-based approaches have become the standard for regional estimation. Common proxies include terrain-based parameters such as slope, and geomorphological or geological classifications. Recent research suggests that integrating multiple proxy families can improve predictive accuracy due to the complementary nature of terrain and geological variables. In recent years, Machine Learning (ML) has emerged as a powerful tool for modeling the complex, non-linear interactions between these geospatial predictors, often outperforming traditional empirical models.

In this study, an integrated framework for V_{S30} characterization in Israel is presented. An ML-based predictive model is developed, and kriging of spatially correlated residuals is applied to generate a high-resolution national V_{S30} map.

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A MACHINE LEARNING-BASED Vs–N CORRELATION FOR BASEL INCORPORATING SOIL COMPOSITION

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ABSTRACT

Reliable characterization of subsurface soil properties is essential in geotechnical engineering. Shear-wave velocity (Vs) measurements are often sparse, whereas Standard Penetration Test (SPT) data are widely available from boreholes, motivating the use of Vs–N correlations to estimate Vs where direct measurements are absent. Existing correlations are typically region-specific and neglect compositional variability, limiting their applicability in complex geological settings. This study develops a Basel-specific Vs–N framework using machine learning applied to 879 quality-controlled SPT profiles paired with geophysically constrained Vs data across 140 km² of urban area. Log–log regression in (Vs, N, depth) space reveals a clear bimodal data structure rather than a single planar trend. Two regression surfaces are fitted to the two populations, and a Random Forest classifier trained on grain-size fractions, depth and morphological indicators successfully assigns SPT records to the appropriate regime. Grain-size composition emerges as the dominant predictor of regime membership in the Basel subsurface.

Keywords: Basel, machine learning, microzonation, shear-wave velocity, Standard Penetration Test

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APPLICATION OF THE SCULPT UNSTRUCTURED HEXAHEDRAL MESHER TO BENTO TOPOGRAPHIC SITE MODELS

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ABSTRACT

To better understand the impact of topographic site effects on seismic ground motion, the international Benchmark of 3D Numerical Simulations on TOpographic Sites (BENTO) was launched to compare seismic wave propagation simulations performed by different numerical modelling methods on real sites with complex topographic relief. All numerical methods require a discretized representation of the computational domain in the form of a 3D grid or mesh. In the presence of irregular topography, the free-surface boundary cannot be accurately represented by structured grids/meshes, making unstructured meshes the preferred choice. For computational meshes, the most common three-dimensional element types are tetrahedra and hexahedra. Owing to the input mesh requirements of applied spectral-finite element solver EFISPEC3D (De Martin et al. 2013, Chaljub et al. 2015, Maufroy et al. 2015), we employ hexahedral meshes, which offer high computational efficiency but are considerably more challenging to generate. This contribution presents the application of the SCULPT unstructured hexahedral mesher to complex topographic site models. Keywords: Computational seismology, Numerical modelling

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CGFD3D CURVILINEAR-GRID FINITE-DIFFERENCE MODELLING FOR THE BENTO BENCHMARK

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ABSTRACT

Team 01 (SUSTech) used CGFD3D, a three-dimensional curvilinear-grid finite-difference solver, in the BENTO benchmark. CGFD3D advances the first-order velocity-stress system on a collocated grid using biased DRP/opt MacCormack spatial operators and fourth-order, four-stage Runge-Kutta time integration, with traction-image treatment of the free surface and ADE CFS-PML at the outer boundaries. The preprocessing workflow crops terrain, applies edge-only smoothing, constructs source-aware body-fitted grids, maps prescribed media by equivalent-medium averaging, and converts benchmark sources into normalized Gaussian spatial distributions. Can01-04 verification simulations showed generally good agreement with the reference solutions, including Category A results for Can01-03 in Workshop 1. For Val01, parabolic grid generation for steep ARGOscarp geometry and S-wave-impedance scaling of plane-wave loading removed systematic amplitude underestimation. Val02 double-couple simulations use separate source treatment and event-specific grid and medium construction; no cross-team Val02 comparison is yet available.

Keywords: BENTO benchmark, curvilinear grid, finite difference, topography, seismic simulation

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3D NUMERICAL MODELING OF THE SEISMIC RESPONSE OF THE CEPHALONIA AREA (GREECE) USING FLAC CODE, WITHIN THE FRAMEWORK OF THE BENTO BENCHMARK

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ABSTRACT

Numerical simulations are widely applied to study the influence of slope morphology and subsurface lithology on seismic ground motion, especially in regions lacking instrumental data. However, three-dimensional dynamic modeling remains computationally expensive, limiting its application to restricted domains. Optimizing numerical model design therefore requires balancing accuracy and efficiency. Within the international BENTO benchmark, 3D finite-difference simulations were conducted using FLAC (Itasca) over a large domain to investigate the effect of small-scale topographic heterogeneities on seismic response. The model covers several kilometers, including the Argo-Scarp area (Cephalonia, Greece), while resolving frequencies up to 30 Hz. Digital elevation models of varying resolution were used to generate STL surfaces via Python scripts. These were imported into FLAC3D to build structured hexahedral meshes conforming to topography. A series of models with different spatial resolutions was developed to assess their impact on ground-motion metrics, including PGV and spectral amplification.

Keywords: numerical simulation, topographic site effects, mesh resolution.

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FINITE-DIFFERENCE SIMULATIONS OF TOPOGRAPHIC SITE EFFECTS FOR BENTO

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ABSTRACT

We performed 3D seismic wave simulations for BENTO using a finite-difference method (FDM). This paper presents the numerical methodology and computational conditions. Results for the Validation Phase case (Val01-Ia) are presented, and the effects of topographic representation on simulated waveforms and amplification characteristics are examined through comparison with the reference results. The results show that direct-wave amplitudes are reproduced reasonably well when the differences in topographic representation are small, whereas larger discrepancies occur at stations associated with greater elevation differences. In contrast, discrepancies in later arrivals and amplification characteristics suggest that topographically generated surface waves are influenced not only by topographic representation but also by grid resolution. These findings highlight the importance of accurate topographic modeling and appropriate grid spacing for reliable simulation of topographic effects on seismic wave propagation.

Keywords: finite difference method, seismic wave propagation, topographic effect, topographic amplification, surface wave

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3D FINITE ELEMENT SIMULATION OF TOPOGRAPHY: MODELING STRATEGIES FOR THE BENTO BENCHMARK

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ABSTRACT

Understanding topographic site effects remains challenging due to scarce empirical data. However, advancements in high-performance computing and high-resolution digital elevation models have made 3D numerical simulations pivotal for analyzing these responses. To ensure consistency across different numerical methods, the BENTO benchmark was organized. Participating as Team 10, we uniquely applied the Finite Element Method (FEM). The benchmark featured ambitious computational goals: smaller-scale canonical models targeted a high frequency threshold of 200 Hz, whereas real-topography models involved massive spatial scales at 20 Hz. Under limited computational resources, our simulation results proved satisfactory: they aligned closely with reference solutions for quasi-3D canonical shapes, but for fully 3D topography they exhibited reduced accuracy at higher frequencies due to coarse-mesh numerical dispersion and residual boundary reflections. This work evaluates how our modeling strategies—specifically meshing scheme, domain extent and boundary condition, optimizing model dimensionality, and element type—balanced computational constraints with accuracy.

Keywords: Finite element method, 3D numerical simulation, Topographic site effect, BENTO

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VERIFICATION OF PLANE-WAVE SOURCE IMPLEMENTATION IN SEM3D USING THE BENTO BENCHMARK

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Plane waves are commonly required in numerical seismic simulations for a wide range of applications, including site response. In the spectral element code SEM3D, incident plane waves are generated using an extended kinematic source formulation, in which a reduced grid of sub-sources radiates coherently to approximate an ideal plane-wave solution. While this approach is routinely used, it has not yet been systematically verified within a controlled benchmark framework. In principle, the most consistent representation of an incident plane wave in a spectral element method would be obtained by injecting a source term at every Gauss-Lobatto-Legendre (GLL) point of a horizontal plane in order to preserve the spectral accuracy. However, such an approach would be computationally expensive and impractical for large-scale simulations. In this study, the BENTO benchmark (BEnchmark of 3D Numerical simulations on TOpographic sites) is used as a reference configuration. A systematic sensitivity analysis is performed by varying sub-source spacing, source depth, and lateral extent. Numerical results are evaluated against the analytical characteristics of a plane wave in a homogeneous elastic medium, focusing on the phase coherence, amplitude and energy metrics, and wavefront arrival at the free surface, in order to recommend practical parameter ranges that enable an efficient and reliable plane-wave approximation in SEM3D.

Keywords: BENTO benchmark, spectral element method, SEM3D, Plane-wave approximation

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HIGH-FREQUENCY NUMERICAL SIMULATIONS OF TOPOGRAPHIC SITE EFFECTS BY A DISCONTINUOUS GALERKIN 3D PARALLEL SOLVER – CONTRIBUTION TO THE BENTO BENCHMARK

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ABSTRACT

Here are some results from the Team 4's contribution to the first validation phase of Bento Benchmark. Simulations are based on a discontinuous finite element solver applied to unstructured tetrahedral meshes. Both real sites under study require an accurate representation of the topography or the processing of large areas, leading to compromises between accuracy and computational capacity, which are discussed as well as suggestions for improvement.

Keywords: seismic motion, site effect, numerical simulation, benchmark

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AMPLITUDE SCALING AND STF TREATMENT IN TOPOGRAPHIC BENCHMARK SIMULATIONS WITH SALVUS

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ABSTRACT

We report on the implementation of BENTO (BEnchmark of Numerical simulations on TOpographic sites) canonical benchmark cases using Salvus, a spectral-element solver developed by Mondaic AG. The benchmark suite at the verification stage comprises four topographic configurations: a Gaussian hill, a Gaussian ridge, triangular ridges with varying opening angles, and a sloppy scarp with multiple source sub-cases. Achieving amplitude consistency between simulated and reference ground-motion fields required three systematic corrections specific to the Salvus implementation: (1) temporal differentiation of the displacement-format source-time function to conform to Salvus force-rate convention, (2) 1/N scaling of distributed point sources used to construct incident plane waves, and (3) boundary condition design adapted to the symmetry properties of each source configuration, within the resolved frequency band of each mesh. With these corrections applied, simulated amplitude ratios match reference solutions across all benchmark cases. The corrected workflow constitutes a validated and transferable methodology for high-frequency spectral-element simulations over topographic terrain.

Keywords: spectral-element method, source-time function, amplitude scaling, plane-wave simulation, topographic site effects.

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VERIFICATION OF GROUND MOTION SIMULATION CODE AND TOPOGRAPHIC EFFECT ON SPATIAL CHARACTERISTICS OF MOTIONS

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ABSTRACT

We participated in the BENTO project, demonstrating sufficient computational accuracy of our simulation code for evaluating seismic ground motions. Currently, we are conducting a case study at the KiK-net station in Rikuzentakata, Japan (IWTH27) to investigate the topographic influence on the seismic motions. By temporarily deploying 20 accelerometers around IWTH27, it was indicated that the three-dimensional (3D) distribution of topsoil contributes to the amplification factor of the ground motions, alongside the topographic effect. The simulation, using a simple 3D S-wave velocity structure model around IWTH27, showed that the focusing effect amplifies motions at the top of slopes and subsurface. When the focusing effect is combined with topsoil amplification at the top of slopes, they provide significantly large amplitudes at specific frequencies.

Keywords: BENTO, Simulation, Verification, Temporarily observation, Topographic effect

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WAVENUMBER LIMITATION OF MEDIUM AND ACCURACY OF THE FINITE-DIFFERENCE MODELING OF SITE EFFECTS

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ABSTRACT

Material interfaces play crucial role in forming seismic motion in local surface sedimentary structures and contributing to strong site effects of earthquakes. A proper implementation of material interfaces in numerical modelling of seismic wave propagation and seismic motion is therefore of great importance. Although this has been well known for some time, insufficient attention has been paid to consequences of spatial discretization in the wavenumber domain. Mittet (2017) and Moczo et al. (2022) demonstrated that a model of the medium must be wavenumber-limited by a wavenumber k smaller than the Nyquist wavenumber. Mittet (2021), Valovcan et al. (2024) and Kristek et al. (2025) proved that the wavefield (numerically simulated or exact) in a medium limited by wavenumber k can only be accurate up to half this wavenumber. This has significant consequence for practical FD modelling of site effects in realistic models of local structures.

Keywords: site effects, numerical modelling, finite-difference, accuracy

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NUMERICAL TESTING OF PROXIES FROM EUROCODE8 AND FROM RECENT STUDIES FOR TOPOGRAPHIC SITE EFFECT: THE CASE STUDY OF SIENA (CENTRAL ITALY)

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ABSTRACT

Current seismic regulations, such as Eurocode 8, define topographic ground motion amplification using simplified parameters based on idealized two-dimensional configurations. These estimates often lack empirical validation and frequently prove impractical for systematic application. This research evaluates the effectiveness of such regulatory parameters alongside new morphometric proxies through an automated workflow integrating GIS-based analysis and 2D/3D numerical modeling. The city of Siena (Central Italy), characterized by complex morphology over a predominantly homogeneous subsoil, is utilized as a benchmark case study. Results from 2D analyses indicate that while regulatory parameters may provide a first-order estimate of average amplification, they fail to capture the full range of directional and frequency-dependent effects produced by complex morphologies. To address these limitations, this study validates advanced proxies related to terrain curvature through comprehensive 3D numerical simulations, ultimately providing a more reliable, automated, and objective tool for seismic microzonation.

Keywords: topographic seismic amplification; seismic code; morphometric analysis; GIS; 3D numerical modeling.

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EVALUATION OF SPECTRAL AMPLIFICATION USING HIGH-DENSITY TEMPORARY SEISMIC OBSERVATION DATA AT CAPE TAPPI, AOMORI PREFECTURE, JAPAN

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ABSTRACT

To evaluate the effects of topography on earthquake ground motions using topographic indices, we conducted temporary seismic observations at 13 sites on Cape Tappi, Aomori Prefecture, Japan, where there are small capes with complex topography, including valleys and cliffs. To clarify the amplification characteristics during earthquakes, we analyze spectral amplification factors and particle motions of earthquake ground motions. These results showed that amplifications differ in the frequency range of 2 to 20 Hz, and particle motions have directional bias between the NS and EW components. Furthermore, to evaluate their relationship with topographic features, we adopted the azimuth of the epicenter, evaluation, and slope as topographic indices. We found that the amplification characteristics depend on the direction of incoming seismic waves, and steep elevation differences strongly influence earthquake ground motions. We also found that the amplifications in the frequency range of 5 to 10 Hz have a relatively high correlation with the slope angle defined within a 160 m × 160 m area around each observation site.

Keywords: Seismic observation, Topography, Amplification factor, Source direction, Elevation, Slope

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QUANTIFYING THE CONTRIBUTION OF TOPOGRAPHY TO AZIMUTHAL VARIABILITY IN AMBIENT NOISE HVSR: OBSERVATIONS AND 3-D NUMERICAL TESTS

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The physical origin of azimuthal variability in ambient noise horizontal-to-vertical spectral ratios (HVSR), and in particular the contribution of local topography, remains debated. Here, we quantitatively test to what extent "pure" topographic geometry can explain observed HVSR directionality. We analyze broadband ambient noise recordings from 161 strong-motion stations in California and the central United States. Rotational HVSR and time-domain horizontal polarization attributes are evaluated across eight frequency bands. Significant and stable HVSR directionality is identified at 41 stations (25%) using combined criteria on amplification clarity, polarization stability, and azimuthal HVSR contrast. Multi-scale terrain analysis shows that directional HVSR is not restricted to pronounced relief (only 11 of 30 "significant-topography" sites exhibit it) and also occurs in gentle topography. Moreover, among the few stations consistently approximable as 2-D ridges across scales, most show no significant directionality, suggesting that classic 2-D ridge expectations do not directly transfer to complex sites. To isolate the topographic contribution, we select a subset of ridge and upper-slope stations with significant directionality and run 3-D spectral-element (SPECFEM3D) simulations with realistic topography and randomized noise sources; simulations and analyses are ongoing. Using identical metrics for observations and simulations, we will quantify an upper bound on topography-only directionality in terms of (i) directionality strength and (ii) preferred-orientation agreement in 0.1-4 Hz, and discuss implications for ESG7 exercises on topographic effects and HVSR-based site-characterization benchmarks.

Keywords: ambient noise; HVSR; directionality; topographic effects; SPECFEM3D

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URBAN SCATTERING AND ATTENUATION: FROM NUMERICAL SIMULATIONS TO REAL URBAN ENVIRONMENTS.

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ABSTRACT

Urban environments are increasingly recognized as complex resonant media capable of modifying seis-mic wave propagation over multiple spatial and frequency scales. Recent numerical and experimental studies have led to the development of a unifified attenuation framework describing these effects in terms of scattering and attenuation. The present work synthesizes this recently introduced framework and presents its fifirst application to ambient-noise observations in the city of Quito (Ecuador). Pre-liminary results reveal frequency-dependent band-gap-like features, suggesting selective wave fifiltering associated with the urban environment. These observations provide a fifirst step toward extending the framework from controlled numerical and experimental settings to real cities, with implications for the characterization seismic ground motion and seismic monitoring.

Keywords: urban attenuation and scattering, mean free path, site-city interaction and seismic ambient noise.

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IMPROVED REGION-SPECIFIC PHYSICS-BASED GROUND-MOTION SIMULATION USING 1D SITE RESPONSE

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ABSTRACT

Accurate characterization of site-specific ground motion in sedimentary basins requires site-representative models of the source, path, and site effects. In this study, the Mw 6.0 2012 event in the Po Plain, Italy, is analyzed using kinematic rupture models generated based on Graves and Pitarka (2010) method, three-dimensional wave propagation using the SEM3D codebase, and a 1D equivalent linear site-response operator. The comparisons with the recorded ground motions show that physics-based simulations (PBS) without an explicit site-response operator systematically underestimate the ground-motion amplitudes. However, the spatial distribution of intensity-measure bias indicates that a single 1D soil column model cannot represent the heterogeneous site conditions across the region. The results suggest that 1D site-response treatment can improve 3D PBS when the local profile is representative; therefore, reliable regional applications require more region- and site-specific velocity models, i.e., a challenge that needs to be overcome empirically (i.e., gathering geological and geophysical data) and numerically (probabilistic modelling of heterogenous media).

Keywords: physics-based ground-motion simulation, site response, velocity model, Po Plain

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EFFECTS OF LINEAR AND NONLINEAR SITE RESPONSE ON PULSE-LIKE GROUND MOTION: PERSPECTIVE FROM A STOCHASTIC FINITE-FAULT SIMULATION APPROACH FOR THE 2023 MW 7.8 TÜRKIYE EARTHQUAKE

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ABSTRACT

During the 2023 Mw 7.8 Türkiye earthquake, 28 pulse-like VP velocities were observed near the fault, with notable differences at three stations within 3 km, especially at Antakya, which recorded the second-largest PGV (station 3123). The PGV and Tp varied two to three times across stations. We removed coseismic static offset via baseline correction and fling-step removal, then simulated the directivity pulse with a velocity-pulse procedure (Huang et al., 2024a). Using stochastic finite-fault ground motion simulation and linear site response based on empirical transfer functions, we identified significant soil nonlinearity at station 3123. Applying the proxy for shear modulus reduction (fsp; Castro-Cruz et al., 2020), the Tp shifted from 3.6 s (linear) to 2.6 s (nonlinear), closer to the observed value. The PGV doubled due to linear site response, with the threefold PGV at station 3123 linked to linear response and super-shear behavior; soil nonlinearity caused a Tp shift and a PGV reduction.

Keywords: pulse-like ground motion, soil nonlinearity, 2023 Turkiye earthquake, finite-fault simulation

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A HYBRID GROUND MOTION SIMULATION MODEL: APPLICATION ON THE AD 551 MOUNT LEBANON THRUST FAULT HISTORICAL EARTHQUAKE

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ABSTRACT

Ground motion time series are required for many applications in seismology and earthquake engineer-ing. However, recorded ground motions from large earthquakes in the near field are scarce, which motivates ground motion simulation. While several hybrid methods for simulating broadband ground motions exist in the literature, most simulate low- and high-frequency components separately. However, observations from recorded ground motions indicate that these components are temporally correlated and share consistent envelope characteristics. In this study, we develop a hybrid simulation approach in which the low-frequency components are simulated using a physics-based model, and the high-fre-quency components are simulated using a stochastic site-based model conditioned on the earthquake scenario and the characteristics of the low-frequency components. We verify our model by comparing simulated ground motions with recorded ground motions. Finally, we present an application of our model to simulate ground motions from the AD 551 historical earthquake on the Mount Lebanon Thrust fault.

Keywords: ground motion simulation, hybrid simulations, historical earthquakes.

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SITE-SPECIFIC WAVE PROPAGATION MODELS BASED ON INTERPOLATED EMPIRICAL GREEN'S FUNCTIONS: APPLICATION TO NEAR-FAULT GROUND MOTION PREDICTION AND KINEMATIC RUPTURE INVERSION

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ABSTRACT

Near-fault ground-motion prediction remains challenging because high-frequency motions are highly sensitive to poorly resolved crustal heterogeneities, while inferred rupture models are also affected by wave-propagation uncertainties. Empirical Green's Functions (EGFs), derived from small nearby earthquakes, offer an attractive alternative because they naturally capture path and site effects. However, suitable EGFs rarely exist for all locations of a large rupture and must therefore be corrected or spatially interpolated. Here, we investigate a cluster-based EGF approach using nearly 1000 small earthquakes with magnitudes ranging from 2.5 to 4.5 recorded during the 2016-2017 Central Italy seismic sequence and apply it to the 2016 Mw 6.5 Norcia earthquake. Cluster-derived EGFs and numerical Green's functions computed from a 1D velocity model are evaluated against selected reference events located close to the modeled fault plane. We also assess the influence of uncertainties in EGF source parameters during the waveform deconvolution process used to extract the impulse response from the EGF recordings.

Keywords: strong-ground motion prediction, kinematic source inversion, Empirical Green's Functions

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DATA-DRIVEN CLUSTERING OF 1D, 3D SIMULATIONS AND OBSERVED H/V RATIOS TO CONTRIBUTE TO SEISMIC MICROZONATION IN THE GRENOBLE BASIN

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ABSTRACT

The Grenoble valley exhibits strong site effects due to the complexity of its 3D sedimentary structure. To better characterize this hazard, we are developing a seismic digital twin, based on the spectral-element method code (EFISPEC3D), combining 1D/3D simulations, observed H/V ratios, and calibrated EC8 response spectra. A clustering pipeline based on k-means and deep learning–derived representations is used to identify zones with homogeneous seismic response. The results are consistent with key geological parameters, particularly sediment thickness. This methodology provides a foundation for more robust probabilistic seismic microzonation.

Keywords: clustering analysis, seismic microzonation, 3D site effects, H/V spectral ratios, 1D and 3D response spectra.

A VARIANCE-BASED GLOBAL SENSITIVITY ANALYSIS OF SITE EFFECTS IN THE GRENOBLE BASIN (FRENCH ALPS)

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ABSTRACT

The Grenoble basin, located in the French Alps, exhibits complex seismic wave propagation due to its one kilometer thick sedimentary layers and surrounding high massifs. Understanding site effffects in such alpine valleys is essential for reliable seismic microzonation. This study investigates the basin's seismic response using 3D simulations for frequencies up to 2 Hz. A variance-based global sensitivity analysis is conducted to examine the inflfluence of uncertain parameters, including velocity gradients and attenuation properties in sediments and weath-ered bedrock. Parameter ranges are constrained using dispersion-curve inversions, borehole data, and empirical relations. For each confifiguration, the basin response is computed using vertically incident plane-wave excitation. Sensitivity indices are evaluated mainly for peak ground displacement to identify the dominant factors controlling amplifification. The results demonstrate that PGD variability is primarily governed by shear-wave velocity structure in the sediments, with a non-negligible contribution from bedrock properties.

Keywords: 3D site effffects, global sensitivity analysis, uncertainty, 3D modelling, alpine valleys.

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IMPACT OF SMALL-SCALE HETEROGENEITIES ON SURFACE GROUND MOTION VARIABILITY: NUMERICAL 1D AND 2D SENSITIVITY ANALYSIS

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ABSTRACT

Spatial variability of surface ground motion (SVGM) can be impacted by multiple factors, including source characteristics, wave propagation, and site-specific conditions such as basin geometry, topography, and stratigraphy. This study focuses on local scales—from centimeters to several hundred meters—and, more specifically, on small-scale heterogeneities within a basin or across soil layers near the site of interest. To represent this variability, soil stiffness - expressed via shear wave velocity - is modeled as a two-dimensional random field characterized by its correlation length and coefficient of variation. Numerical simulations are performed on a 2D domain to capture scattering effects and local wave diffraction, with ground motion computed at closely spaced points along the surface. These results are compared to conventional 1D soil column analyses, with the objectives of analyzing the impact and of deriving equivalent linear damping parameters for simplified models. The analysis considers multiple output parameters in both time and frequency domains, including Arias intensity, significant duration, peak ground acceleration (PGA), peak ground velocity (PGV), and response spectra at 1 and 10 Hz. Furthermore, we compute the out-of-bag importance of the input parameters to understand which parameter has the largest impact on the surface ground motion variability. This approach provides a comprehensive understanding of how small-scale soil variability affects ground motion characteristics.

Keywords: spatial variability, random field, local site conditions, ground motion characteristics, numerical simulations

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A COMPREHENSIVE SENSITIVITY ANALYSIS OF 1D SITE RESPONSE: QUANTIFYING THE IMPACT OF INPUT PARAMETER UNCERTAINTY ON OUTPUT METRICS

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ABSTRACT

Accurate prediction of site response is dependent on the reliability of subsurface characterization; however, inherent uncertainties in geotechnical properties often pose significant challenges. This study aims to quantify how variabilities in input soil parameters propagate to surface ground motion metrics and to identify the governing parameters under different seismic loading conditions. A representative 6-layer soil profile is utilized as the base model. To rigorously model parameter uncertainty, Latin Hypercube Sampling (LHS) is employed to generate 300 unique soil profile scenarios, introducing statistical variations in shear wave velocity (V_s), layer thickness (H), and unit weight (γ). One-dimensional equivalent-linear site response analyses are conducted for each scenario using a real earthquake record (Mw=4.3) to represent linear soil behavior, and a scaled version to investigate the stability of sensitivities under non-linear conditions. A robust statistical framework is applied to interpret the output data. Spearman rank correlation matrices are generated to identify global dependencies between input parameters and output metrics such as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), predominant period (T_0), Spectral Acceleration (S_a), and amplification factors. Furthermore, regression-based Tornado diagrams and Spider plots are utilized to rank the relative importance of each input parameter and to visualize the magnitude of their impact on the system response. The results indicate that under linear conditions, the output variability is primarily controlled by the impedance contrast, specifically the shear wave velocity of shallow layers. However, comparative analyses with the scaled motion reveals that as the soil enters the non-linear range, the hierarchy of parameter importance shifts. This study highlights that input parameter uncertainty does not affect output metrics uniformly, and the identification of critical parameters is essential for reliable probabilistic seismic hazard assessments.

Keywords: site effect, sensitivity analysis, Latin Hypercube Sampling, Tornado diagram, 1D site response analysis

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MODELING OF EARTHQUAKE OCCURRENCE SCENARIOS AND GROUND MOTION SEQUENCES OVER THE SERVICE LIFE OF A BUILDING FOR ASSESSING LIFETIME SEISMIC RESILIENCE

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ABSTRACT

To contribute to the evaluation of the lifetime seismic resilience of buildings, this study investigates a method for establishing earthquake occurrence scenarios and ground motion sequences that account for time-dependent seismic activity during a building's service life. Focusing on the Tokyo metropolitan area, two 100-year earthquake scenarios were developed: one based on stochastic modeling of past seismic activity and another assuming the recurrence of historical earthquake sequences. The results demonstrated that structural responses vary depending on structural characteristics, even when common earthquake scenarios and locations are used. Furthermore, this study highlighted that for sequential earthquake scenarios, it is crucial to evaluate performance from the perspectives of both maximum response and cumulative response.

Keywords: earthquake occurrence scenario, service life, ground motion, Tokyo metropolitan area, seismic resilience

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CONSTRAINING SITE RESPONSE IN A COMPLEX BASIN USING AMBIENT VIBRATIONS, NUMERICAL MODELLING, AND LARGE-N SEISMIC OBSERVATIONS

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ABSTRACT

The West Bohemia region, the most seismically active area in Czechia, provides an opportunity to study site effects in a geologically complex setting. Ambient vibration measurements, including single-station and array configurations, were used to investigate subsurface structure in the Cheb Basin, with a focus on basin-edge effects. Approximately 300 temporary seismic stations are currently deployed in the region within the large-N experiment ELISE, providing a dense dataset for future analysis. The interpretation is supported by finite-difference simulations of ambient noise wavefields in three-dimensional velocity models. Comparison between observed and synthetic data allows assessment of the influence of basin geometry on the H/V response.

Keywords: Seismic site effects, Subsurface imaging, Ambient seismic noise, Sedimentary basins, Seismic hazard assessment

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SEISMIC SITE EFFECTS IN BEIRUT (LEBANON): INSIGHTS FROM 3D GROUND MOTION SIMULATIONS

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ABSTRACT

Site effects caused by complex 2D/3D site geometries and highly heterogeneous soils cannot be fully captured by traditional 1D ground response analyses. These effects influence earthquake ground motion, leading to amplification/deamplification, duration lengthening, and spatial variability of surface ground motion. In this study, we investigate how complex surface geology and topography affect ground motion characteristics in Beirut, Lebanon. We build a detailed 3D velocity model of the city and its suburbs, incorporating geological, geophysical, and topographical data to reveal large variations in shear-wave velocity structure and seismic bedrock depth. We then conduct 3D numerical simulations of seismic wave propagation using spectral-element methods, assuming horizontally polarized SH plane waves. We validate our 3D velocity model by comparing simulated and observed site amplifications. Using several ground motion indicators, we identify significant spatial variation of surface ground motion, large site amplification, and associated duration lengthening of seismic shaking caused by 2D/3D site effects throughout the city.

Keywords: Numerical simulation, Seismic wave propagation, Site effects, Shear-wave velocity, Beirut (Lebanon).

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INTERACTION BETWEEN INCOMING AND TRAPPED WAVES IN A 3D NON-LINEAR ELLIPSOIDAL BASIN

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ABSTRACT

This study presents a fully 3D numerical framework for simulating seismic wave propagation in heterogeneous basins, explicitly incorporating non-linear soil behavior via the Iwan elastoplastic model. The approach is implemented using a high-order parallel 3D discontinuous Galerkin finite element solver. By utilizing a series of double-couple point sources across a range of seismic moments, we demonstrate that the interaction between basin geometry and non-linear effects significantly alters surface ground motion. Additionally, this research quantifies how transfer functions are modified in response to varying incoming wave amplitudes.

Keywords: seismic motion, site effect, numerical simulation, nonlinear heterogeneous medium, elastoplastic model

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IMPACT OF SEDIMENTARY BASINS ON RUPTURE-INDUCED GROUND MOTION VARIABILITY

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ABSTRACT

Sedimentary basins are commonly treated as site effects independent of the seismic source. However, in near-fault conditions, rupture characteristics can significantly influence the incoming wavefield. This study uses 3D numerical simulations to investigate how the presence of a sedimentary basin modifies rupture-induced ground motion. Variability is quantified from an ensemble of rupture realizations and compared between simulations with and without the basin. Results show that the basin increases variability near its edges, redistributes it spatially, and reduces it in the basin center at its resonance frequency. These findings indicate that basin response depends not only on local structure but also on source characteristics, highlighting the importance of source–site interactions in ground motion prediction.

Keywords: Ground motion variability, Sedimentary basins, Site effects, 3D numerical modeling

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SEISMIC RESPONSE AT A GRAVITATIONAL SLOPE DEFORMATION BASED ON SURFACE WAVE METHODS AND NUMERICAL SIMULATION

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ABSTRACT

We carried out a multi-channel analysis of surface waves (MASW), microtremor array measurements (MAM), and single station three-component microtremor measurements on a slope and base of the gravitational slope deformation in Nagano prefecture Japan. Clear dispersion curves were observed and S-wave velocity (Vs) profiles down to approximately 30 m deep were analyzed. Resultant Vs profiles delineated a low Vs layer of 15~20 m thickness in the middle of the gravitational slope deformation. Difference of surface ground motion from a natural earthquake between the deformation area and base was reasonably consistent with the estimated Vs profiles and the results of numerical simulation.

Keywords: site amplification, landslide, surface wave methods, horizontal-to-vertical spectral ratio, finite-difference method

Numerical analyses of 3D seismic site response in the Norcia sedimentary basin (Central Italy)

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The Norcia basin, located in the central Apennines, is a Quaternary intermontane depression that has been repeatedly impacted by major seismic events, most notably the Mw 6.5 earthquake of 30 October 2016. Its intricate geological framework, consisting of lacustrine, palustrine, alluvial and conglomeratic deposits resting on a carbonate basement, makes the area an excellent natural laboratory for studying three-dimensional seismic site amplification effects. Within the INGV PD-GEMME project, we developed an integrated geological and geophysical model of the basin by combining new field data, including MASW profiles, passive seismic arrays, and stratigraphic boreholes, with information from previous investigations (*e.g.*, Bindi *et al*. 2011, https://doi.org/10.1007/s10518-011-9273-3; Di Giulio *et al*. 2020, https://doi.org/10.1016/j.enggeo.2020.105501) and seismic microzonation studies (Center for Seismic Microzonation and its applications, https://www.centromicrozonazionesismica.it/en/).

This model has been implemented in two physics-based numerical frameworks: SPEED (http://speed.mox.polimi.it/), which uses the spectral element method, and FLAC3D (https://itascasoftware.com/products/flac3d/), based on the finite difference method.

Although both codes can efficiently handle non-linear simulations, a model validation is carried out in the linear domain using weak-motion data from the temporary seismic network 3H-2009, that recorded numerous events from the 2009 L'Aquila sequence.

These results clearly show that the geometry of the basin, and the heterogeneity of the sediments, together with the velocity structure of the bedrock, play a key role in the characterization of the amplification patterns of the basin, especially within the 0.5-8 Hz frequency range. These findings are particularly important for the interpretation of the amplification features observed in the latest seismic sequences.

Ongoing and future work aims to further improve the agreement between simulated and observed ground motions, in particular when non-linear behaviour comes into play.

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EFFECTS OF NEAR-SURFACE GEOLOGY IN ITALY: EVALUATION TROUGH STOCHASTIC SIMULATIONS

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ABSTRACT

The present contribution shows results from large scale stochastic simulations of local seismic response. The massive set of stochastic simulations was performed to obtain seismic hazard estimates at large scale (i.e. regional and national scales). The simulations made it possible to: i) implement an automated and scalable workflow for running large numbers of 1D site response analyses for seismic microzonation; ii) produce preliminary probabilistic maps of seismic hazard, including site amplification effects, even in areas with limited site-specific investigations; iii) ensure reproducibility, resource-efficient parallelization, and robust recovery of incomplete runs on Linux-based HPC environments. A total of 21,135 seismic stratigraphic columns were selected as representative profiles for the entire Italian territory. A set of 53 seismic inputs (time response spectra) derived from national hazard models was used as input motion. Keywords: site effects, stochastic simulation, near-surface geology, engineering geological units, high performance computing

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NUMERICAL INVESTIGATION OF HVSR RESPONSE FOR SHALLOW HETEROGENEOUS GEOLOGICAL BODIES

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ABSTRACT

This study investigates the response of horizontal-to-vertical spectral ratios (HVSRs) to shallow heterogeneous geological bodies and evaluates their link with site amplification using numerically simulated seismic ambient noise. Randomly distributed surface sources are generated to approximate a diffuse wavefield, and their stability is examined before HVSR computation. Ambient-noise records are then simulated for representative models, including slopes, undulating interfaces, sedimentary basins, cavities and boulders. The resulting HVSR peak frequencies and amplitudes are compared with theoretical site amplification factors and the known geometries of anomalous bodies. The study aims to clarify whether HVSR peak frequency can provide robust indicators of shallow structural variation and whether HVSR amplitude can be used as a constrained proxy, rather than a direct estimate, of amplification. The results provide guidance for applying HVSR to seismic microzonation and engineering detection of three-dimensional shallow anomalies.

Keywords: HVSR, site effects, numerical simulation, seismic ambient noise, shallow geological anomaly

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IMPACT OF MULTIPLE DEEPLY EMBEDDED STRUCTURES ON THE DEVELOPMENT OF SURFACE WAVES IN A SEDIMENTARY BASIN.

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ABSTRACT

Seismic ground motion at the surface is strongly influenced by local geological conditions and subsurface structures. In sedimentary basins, surface waves generated from incoming body waves reflectong at the borders may highly contribute to observed seismic motion, particularly at low frequencies. In parallel, nuclear facilities are characterized by large and deeply embedded foundations that interact with the propagating wave field. When several structures are present, their combined influence can lead to complex site–city interaction effects. This study investigates the impact of multiple deeply embedded structures on the generation and propagation of surface waves within a sedimentary basin using two-dimensional numerical simulations. Seismic wave propagation is modeled with the finite-element code aode_aster. Surface waves are explicitly extracted from the simulated wave field using the Normalized Inner Product (NIP) method. The influence of embedded obstacles on surface wave amplitudes, spatial distribution, and frequency content is analyzed for different configurations.

Keywords: surface waves; sedimentary basin; embedded foundations; site–city interaction; numerical simulation

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INFERENCE OF CAVITIES WITH WAVEFIELDS UNDER DIFFERENT SEISMIC INCIDENCE ANGLES THROUGH NUMERICAL MODELLING

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ABSTRACT

The presence of underground cavities can significantly influence seismic wave propagation, with relevant effects on ground response and local seismic hazard. Previous studies have shown how geometry, depth and cavity size can affect seismic behavior. In addition, the incident angle of seismic waves is an important parameter controlling site amplification as its variations lead to different dynamic response patterns. Multilayered soil conditions can also significantly modulate seismic-wave propagation, influencing amplification and attenuation characteristics of ground motion. However, studies focusing on the effects of seismic-wave incidence angle in single-layered sites containing underground cavities remain limited. Therefore, this study employs a single-layer model with a medium-sized circular cavity to analyse the seismic response under vertically and obliquely incident wave fronts. A two-dimensional numerical modeling (2D) under linear elastic conditions is carried out through FLAC2D.

Keywords: Local Seismic Response, numerical modeling, wave incident angle.

The 7th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion
Grenoble (France), 19-21 October 2026

DYNAMIC BEHAVIOUR OF AN EARTH DAM USING GEOPHYSICAL TESTING AND EMPIRICAL, ANALYTICAL AND NUMERICAL APPROACHES

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The seismic safety of earth dams is a critical issue, especially in countries like Italy, where many large dams are located in moderate-to-high seismic hazard zones were originally designed without specific seismic criteria. Recent earthquakes have highlighted the complexity of their dynamic behavior. One key parameter in evaluating the seismic response is the fundamental frequency (f_0) of the dam. However, direct acquisition of this parameter is often limited by the high cost and risks of invasive testing on such structures.

In this paper a comprehensive approach by combining monitoring data from HSVR technique, field investigations including surface and borehole geophysical testing, analytical methods (shear beam model), and advanced finite difference-based numerical simulations is afforded for a well-documented earth dam located in Southern Italy. The objective is to compare empirical, analytical, and numerical estimates of f_0 to assess the applicability and accuracy of each method, and to enhance current modelling strategies.

The expected results will significantly improve the understanding of embankment dam behaviour during earthquakes and provide validated, transferable methodologies for seismic safety assessment.

Keywords: earth dam, dynamic behaviour, fundamental frequency, empirical, analytical and numerical methods

The 7th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion
Grenoble (France), 19-21 October 2026

ANALYSIS OF SIMULATED WAVEFIELD FOR BASIN STRUCTURE MODEL REFINEMENT

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ABSTRACT

This study proposes a method for refining basin structure models by analyzing misfits between observed and simulated waveforms. Focusing on direct and multiply reflected phases in the period range around 1 s, three-dimensional semblance analysis is applied to simulated wavefields to trace propagation paths. Differences in polarization and arrival time between observations and simulations are interpreted as deviations in basement geometry. Based on this interpretation, an inversion framework combining corrected incidence directions and ray tracing is developed. The proposed method can recover the depth and inclination of the basement. The method is applied to the 2018 Northern Osaka earthquake. At station OSKP45, the estimated refraction point is inferred to be located approximately 150 m southeast of the original model prediction at a depth of about 1450 m, with a strike of ~20° and a dip of ~10°. These results demonstrate the feasibility of the proposed framework for basin structure model refinement. Future work will extend the method to multiple stations to achieve spatially distributed corrections.

Keywords: sedimentary basin structure model, strong motion, multiple reflection

The 7th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion
Grenoble (France), 19-21 October 2026

SOLVING NON-LINEAR SOIL-STRUCTURE INTERACTION PROBLEMS WITH A COMPLETE WAVE REGIME. APPLICATION TO THE UPLIFTING OF A SIMPLIFIED STRUCTURE ON A MAT FOUNDATION

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We present a methodology to model non-linear soil-structure (SSI) problems with a full wave regime. In the common engineering practice, seismic motion is injected into the base of the structure in the form of three independent accelerograms. However, this method may not be adequate in several cases as it fails to represent salient features of 3D wave propagation and, in particular, the effect of surface waves. When seismic excitation induces a rocking motion in the structure, the stresses at the foundation edges may exceed soil strength and the opposite edges might uplift from the ground surface. Therefore, it is essential to develop a methodology that accounts for non-linearities of the SSI problem. The methodology we implemented is based on a weak coupling between the Thin Layer Method (TLM) and the Finite Element Method (FEM). The TLM is used to determine the site response in the frequency domain, and the FEM analysis solves the SSI problem in the time domain. The coupling between the two numerical methods is ensured thanks to the Domain Reduction Method (DRM). We apply this methodology to the problem of the uplifting of a simplified structure on a homogeneous half-space subject to an incident Rayleigh wave. The methodology is nonetheless generic and can be applied to more complex non-linear SSI problems. We highlight the efficiency of the frequency domain calculation to inject any seismic signal in the model.

Keywords: uplift, surface waves, non-linear soil-structure interaction, domain reduction method

The 7th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion
Grenoble (France), 19-21 October 2026

ANALYSIS OF THE AZIMUTHAL DEPENDENCY OF THE HVSR SPECTRA IN COMPLEX 3D VELOCITY STRUCTURES USING NUMERICAL MODELING

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ABSTRACT

Using numerical modeling, we evaluate the azimuthal dependence of Horizontal-to-Vertical Spectral Ratio (HVSR) by comparing wave fields propagated through 1D layered and 3D velocity structures. We determine optimal source-component combinations to model ambient noise that best explain observations at a test site. Simulations use four source locations with different source-receiver azimuths to assess wave propagation effects on HVSR. Results show source configuration strongly affects HVSR amplitude across all structures. Sites over 1D layered models exhibit stable HVSR spectral shapes across all azimuths, whereas 3D structures show strong azimuth-dependent spectral variations, with the predominant frequency sometimes varying with source-to-site azimuth. We propose a methodology using 2D seismic array analysis and wavenumber-domain filtering to identify HVSR spectral fluctuations as a function of azimuth. These findings have implications for constraining site terms in ground-motion modeling.

Keywords: HVSR, complex velocity structures, azimuthal-dependency of wave fields

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