COSMOS Ground-Motion Simulation Working Group Workshops #1 and #2

Held online 7-8 June 2022 and 20 October 2022

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Summary

Two workshops were held in response to interest generated from sessions on the use of simulated earthquake ground motions at the 2020 and 2021 Consortium of Organizations for Strong Motion Observation Systems (COSMOS) Technical Sessions. The discussions at the Technical Sessions highlighted desires to promote the use of simulated earthquake ground motions for engineering applications and the need to coordinate efforts to validate and disseminate the data. Our first workshop focused on curating and disseminating simulated earthquake ground-motion data. Our second workshop focused on validating simulated ground-motions for engineering applications. Both workshops included a few invited presentations from providers (ground-motion simulators) and engineering user perspectives followed by open discussions. More than 100 people participated in each of the workshops.

Summary of Key Points

- Numerous groups are generating simulated earthquake ground motions and making them openly available; however, there is very little coordination among groups to provide consistent interfaces for searching and downloading data.
- Participants advocated for a distributed architecture that would allow institutions to host and manage their own data while broadcasting their holdings to a combined catalog.
- Efforts to develop community standards for searching and downloading simulated ground-motion data should leverage the best features from existing efforts.
- More research is needed to develop ground-motion metrics that are tied to structural response characteristics for general situations.
- Validation results should provide a clear, transparent, quantitative assessment of the simulated ground motions.

Next Steps

The workshops confirmed interest in developing international standards and guidelines for curating, disseminating, and validating simulated ground-motion data for engineering applications. The workshops also highlighted challenges associated with (1) simultaneously engaging stakeholders across several continents, (2) potentially archiving and disseminating a wide variety of existing simulated ground-motion data, and (3) a continuously evolving cyberinfrastructure landscape. We plan to:

1. Continue to engage the international community by convening informal and formal gatherings at regularly scheduled scientific meetings;
2. Seek funding for a series of in-person workshops focused on developing international standards and guidelines for curating, disseminating, and validating simulated earthquake ground-motion data; and
3. Form a technical committee that will write the standards and guidelines.

Organization and Logistics

The workshop organizers included Aysegul Askan (Middle East Technical University), Brad Aagaard (U.S. Geological Survey; USGS), Sean Ahdi (USGS), Sanaz Rezaeian (USGS), and Alan Yong (USGS). We advertised the workshop via email and newsletter announcements distributed by COSMOS, the Southern California Earthquake Center, the Pacific Earthquake Engineering Research Center, and the Earthquake Engineering Research Institute. We provided the online meeting information to everyone who registered.

Participants

More than 200 people registered for each of the workshops, and the actual participation rate exceeded 50 percent (210 people participated in the first workshop and 139 people participated in the second workshop), which is consistent or better than many other online workshops. The time of the sessions (late afternoon to evening in Europe and morning to early afternoon in North America) resulted in most of the participants being from Europe and the United States.

Demographic information was not collected from those that registered for the workshop, but demographic information was collected in a user survey organized and implemented by Aysegul Askan (Middle East Technical University) on behalf of COSMOS (see Survey Results section). 49 percent of the respondents identified with seismology or engineering seismology, 26 percent with structural engineering, and 20 percent with geotechnical engineering or engineering geology. Respondents represented the research community (21 percent were research scientists, 21 percent faculty, 25 percent graduate students, 3 percent undergraduate students), practicing engineers (16 percent), and seismic network operations (3 percent). Many respondents indicated they would use simulated ground motions in multiple applications: 60 percent for academic or basic research, 58 percent for probabilistic seismic hazard analysis, 55 percent for ground-motion model development, 49 percent for engineering design and assessment, 38 percent for applied research, 25 percent for engineering practice, and 25 percent for regional loss modeling.

Sessions in Workshop #1: Curation and Dissemination

Examples of simulated earthquake ground-motion datasets

The first session included 11 presentations on ground-motion simulation efforts in Canada, Greece, Italy, Japan, Mexico, New Zealand, Portugal, Turkey, and the United States. Some efforts focus on regional and local seismic hazard maps, which often provide finer scale detail than national maps. Most of the efforts focus on computing ground motions to fill in gaps in the observational record associated with past earthquakes that have few, if any, recordings and potential future earthquakes. Studies often leverage three-dimensional (3D) seismic velocity models when available and usually rely on one-dimensional deterministic or stochastic methods when such seismic velocity models are not available.

The simulations are often validated from the seismological perspective with comparison of waveform features and amplitude metrics using ground-motion records from past earthquakes; simulations are rarely validated using metrics related to engineering applications. Various groups have made their ground-motions publicly available through websites or simple data portals. There is little consistency in the delivery formats and metadata, and only a few groups provide users the ability to search for simulated data based on attributes.

Assessing user needs

A brief survey was created to assess the needs of users of simulated ground-motion data for engineering applications. This survey complements previous surveys done by the SCEC Ground-Motion Simulation Validation Technical Activity Group, which reached about 12 people. The two main objectives of our survey were to:

1. Assess how users want simulated data to be delivered.
2. Learn what features users want to improve future simulations.

A link to the survey was included with workshop announcements and everyone who registered for the workshop was encouraged to complete the survey. A total of 102 responses were received. See the Survey Results section for the compilation of responses.

In terms of dissemination of simulated ground-motion data, the survey indicates the following features would address the desires of most users:

- Search and download interfaces via a web page and web services;

- CSV (or Excel) format for metadata, tabular data, and time series; and
- All three components of motion.

Survey responses demonstrated that suites of simulated ground-motions with the following features would meet the needs of most users:

- 10–100 realizations for each fault rupture;
- Frequency range of 0.1–20 Hz;
- Horizontal resolution in simulation output: 0.1–1 km;
- Vertical resolution in simulation output: 100 m; and
- Output on ground surface and top of stiff soil or soft rock.

Archiving simulated ground-motion data: Data center perspectives

In this session, Carlo Caruzzi provided advice on how to move forward developing international standards for simulated ground-motion data from the perspective of the Observatories and Research Facilities for European Seismology (ORFEUS). Lijam Hagos provided an update on recent and ongoing changes at the Center for Engineering Strong-Motion Data (CESMD), some of which are relevant to disseminating simulated ground-motion data.

Carlo Caruzzi's suggestions included:

- Map standards (file formats and metadata) to user needs, placing emphasis on expected use cases and FAIR (findable, accessible, interoperable, and reusable) data sharing;
- Think global and federated by promoting strategies to access the data via interfaces at the "owner" data center and only download data when necessary;
- Think modern by looking for synergy with high-performance computing in computational seismology and "big data" issues in observational seismology (for example, distributed acoustic sensing and nodal deployments);
- Look for consensus by leveraging existing de-facto standards and develop guidelines that can be adopted and implemented with minimal overhead; and
- Consider how to identify and anticipate new use cases.

Lijam Hagos discussed the recent addition of web services at the CESMD and the web pages for searching for ground-motion records. These web services are more focused on engineering seismology users than International Federation of Digital Seismograph Networks (FDSN) web services. CESMD hosts special ground-motion datasets, which currently consist of custom processing of ground-motion waveforms and flat files with station and waveform metrics for suites of earthquakes. The special datasets could be expanded to include simulated ground-motion data.

Concrete actions towards developing and implementing standards and guidelines for archiving and disseminating simulated ground-motion data

This discussion focused on identifying concrete actions towards achieving our objectives of standardizing access to simulated earthquake ground motions. There was strong consensus that providers of simulated data should provide comprehensive metadata. However, the details were left for future discussion. Participants advocated for including both ground-motion time series and metrics, such as peak acceleration, peak velocity, and spectral acceleration, in the simulated data to be archived and disseminated. Participants also expressed strong support for open access and a central catalog. Initially, the central catalog could be a web page pointing to existing datasets and listing the main attributes of the simulated datasets, such as region of interest, earthquake magnitudes, number of simulations, and frequency range. Even though this workshop did not focus on validation, the topic came up repeatedly in the context of describing the appropriate uses of the simulations and conveying the quality of the simulated data. Participants expressed concerns about ensuring simulated data met minimum quality standards so that it would not be rejected by the engineering community.

Key Points: Curation and Dissemination

- Simulated earthquake data are useful across a range of engineering applications. Scenario earthquakes can be used to explore the resilience of urban regions due to potential earthquakes. Simulated ground motions can augment empirical ground-motion models in hazard analyses and structural response and geotechnical engineering research. Some building codes (for example, Eurocode 8, TBEC 2019, and ASCE 7-22), now include provisions for how to use simulated ground-motion time series in engineering design.
- Numerous groups are generating simulated earthquake ground motions and making them openly available; however, there is very little coordination among groups to provide consistent interfaces for searching and downloading data.
- Interfaces for accessing data continue to change as large data storage and cloud computing technologies advance, and an effort to standardize data access would benefit from consideration of agile approaches that can adapt to changing capabilities and user needs.
- Users expressed support for standard interfaces for searching and downloading simulated ground-motion data, including metadata and delivery formats.
- Participants advocated for a distributed architecture that would allow institutions to host and manage their own data while broadcasting their holdings to a combined catalog, similar to the FDSN registry (https://www.fdsn.org/services/).
- Efforts to develop community standards for searching and downloading simulated ground-motion data should leverage the best features from existing efforts.

Sessions in Workshop #2: Validation

Southern California Earthquake Center Ground-Motion Validation Exercises

Rigorous validation of simulated ground motions is required before hazard analysts, practicing engineers, or regulatory bodies can be confident in their use. A decade ago, validation exercises were mainly limited to comparisons of simulated-to-observed waveforms and median values of spectral accelerations for selected earthquakes. The Southern California Earthquake Center (SCEC) Ground Motion Simulation Validation (GMSV) group was formed to increase coordination between simulation modelers and research engineers with the aim of devising and applying more effective methods for simulation validation.

Sanaz Rezaeian (USGS), Jonathan Stewart (UCLA), and Nico Luco (USGS) summarized lessons learned in over a decade of GMSV activities and studies. Christine Goulet (University of Southern California; SCEC) followed with a short presentation on validation philosophy for future users of simulations. The SCEC GMSV group categorizes different validation methods according to their approach and the metrics considered. Two general validation approaches are to compare validation metrics from simulations to those from historical records or to those from semi-empirical models. Validation metrics are application dependent and consist of ground motion characteristics and structural responses. Key lessons learned are that (1) validation is application-specific, (2) outreach and dissemination efforts could be improved, and (3) much validation-related research remains unexplored. The group is planning a publication summarizing their findings, which will provide a foundation for establishing international guidelines.

The panel discussion highlighted the need for vetted sets of validated and tested simulations that are easily accessible. Engineers would also benefit from formal guidelines that can be incorporated into building codes and provisions.

European and New Zealand Validation Efforts

This session highlighted a few verification and validation efforts in Europe and New Zealand. Luis Dalguer (3Q-Lab) presented a theoretical overview of verification and validation procedures from both earth sciences and engineering perspectives; the procedures involve comparisons against recorded data, empirical ground-motion models, cross-correlation checks of ground motion components, frequency content, and duration of the simulated records. Chiara Smerzini (Politecnico di Milano) outlined a 3-level validation procedure that included comparisons against records of past events, assessment of simulated data for scenario earthquakes, and design and assessment of simulations for engineering applications. Brendon Bradley (University of Canterbury) summarized a validation approach using a two-dimensional matrix describing the spatial extent (generic region to site specific) and complexity of the validation metrics (simple qualitative waveform comparisons to intensity metrics based on elastic single-degree-of-freedom systems to inelastic multiple-degree-of-freedom systems). The presentation included examples from published studies and checklists for developers and users of simulated ground-motion datasets.

The panel discussion raised several important issues related to validation. Participants recognized that a lack of an umbrella organization in most regions impeded efforts to coordinate validation and share best practices. Similarly, regional 3D seismic velocity models do not exist in many regions, so simulated ground-motions incorporating effects from region- and site-specific Earth structure would be difficult to generate. Nevertheless, structural and geotechnical engineers still value alternative approaches that produce less site-specific ground motions.

Key Points: Validation

- Validation of ground-motion simulations applies to the entire workflow for simulating earthquake ground-motions, such as a rupture model, seismic velocity model, seismic wave propagation software, and simulated waveforms. Validation for engineering applications focuses on the simulated waveforms, while recognizing that the accuracy of the waveforms also depends on the upstream components.
- Validation of ground-motion simulations that fill in gaps in the instrumental record by considering anticipated future earthquakes or past earthquakes for which we have relatively few, if any, recordings require special care to minimize uncertainties associated with extrapolation.
- More research is needed to develop ground-motion metrics that are tied to structural response characteristics for general situations.
- Validation results should provide a clear, transparent, quantitative assessment of the simulated ground motions.
- Validation results should be included in the metadata used in searching and disseminating the simulated ground motions.
- Guidelines for validation could include minimum standards for dissemination.

Disclaimers

The survey described in this information product was organized and implemented by Aysegul Askan (Middle East Technical University) on behalf of COSMOS and was not conducted on behalf of the U.S. Geological Survey.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Agenda for Workshop #1: Curation and Dissemination

All dates and times are Pacific Time (UTC-7)

7 June 2022

8:00-8:15 Introduction

8:15-9:25 Session I: Examples of Ground-Motion Simulation Data Sets

8:15-8:25 State of SCEC Simulations and their Dissemination, Christine Goulet (University of Southern California; Southern California Earthquake Center)

8:25-8:35 Simulation Efforts and Database Efforts within the Pacific Earthquake Engineering Research center, Dave McCallen (University of Nevada Reno; Lawrence Berkeley National Laboratory)

8:35-9:05 Summary of Simulation Studies (3 min each)

- Japan, Hiroaki Yamanaka (Tokyo Institute of Technology)
- New Zealand, Brendon Bradley (University of Canterbury)
- Canada, Behzad Hassani (BC Hydro)
- Pacific Northwest, Erin Wirth (USGS)
- Mexico, Leonardo Ramirez Guzman (Universidad Nacional Autónoma de México)
- Italy, Rodolfo Puglia (Istituto Nazionale di Geofisica e Vulcanologia) and Chiara Smerzini (Politecnico di Milano)
- Greece, Basil Margaris (Institute of Engineering Seismology and Earthquake Engineering)
- Portugal, Shaghayegh Karimzadeh (University of Minho)
- Turkey, Aysegul Askan (Middle East Technical University)

9:05-9:30 Discussion

9:30-10:00 Break

10:00- 11:40 Session II: Assessing User Needs

10:00- 10:10 Practicing Structural Engineering Perspectives, C.B. Crouse (AECOM)

10:10- 10:20 Academic Structural Engineering Perspectives, Jack Baker (Stanford University)

10:20-10:30 Geotechnical Engineering Perspectives, Domniki Assimaki (Caltech)

10:30-10:40 Perspectives for Loss and Impact Modeling, Kuanshi Zhong (Stanford University)

10:40-11:00 Summary of COSMOS Survey, Brad Aagaard (USGS)

11:00-11:30 Discussion

8 June 2022

8:00-8:15 Recap of Day 1

8:15- 9:00 Session III: Archiving Ground-Motion Simulation Data: Data Center Perspectives

8:15-8:25 Observatories and Research Facilities for European Seismology (ORFEUS), Carlo Cauzzi (SED & ETH Zurich)

8:25-8:35 Center for Engineering Strong-Motion Data (CESMD), Lijam Hagos (California Geological Survey)

8:35-9:00 Discussion

9:00-9:30 Break

9:30- 11:00 Session IV: Concrete actions towards developing and implementing standards and guidelines for archiving and disseminating simulated ground-motion data

9:30-10:30 Developing standards: Archiving

10:00-10:30 Developing standards: Dissemination

10:30-10:50 Implementing standards

10:50-11:00 Workshop Wrap-up

Agenda for Workshop #2: Validation

All dates and times are Pacific Time (UTC-7)

20 October 2022

9:00-9:15 Introduction, Aysegul Askan (METU)

9:15-10:45 Session I: SCEC Ground-Motion Simulation Validation Efforts

9:15-9:30 Lessons learned from a decade of validation exercises at SCEC, Sanaz Rezaeian (USGS)

9:30-9:45 Validation for ground motion characteristics, past, present, and future direction, Jonathan Stewart (University of California, Los Angeles)

9:45-10:00 Validation for structural responses, past, present, and future direction, Nico Luco (USGS)

10:00-10:15 Validation philosophy for future users of simulations, Christine Goulet (University of Southern California; Southern California Earthquake Center)

10:15-10:45 Panel discussion with Speakers, led by Farzin Zareian (University of California, Irvine) and Nico Luco (USGS)

10:45-11:15 Break

11:15-12:30 Session II: Other Validation Perspectives and Efforts

11:15-11:30 Validation of simulated ground motions from different perspectives: earth sciences and engineering, Luis Dalguer (3Q-Lab)

11:30-11:45 Validation of simulated ground motions in Europe, Chiara Smerzini (Politecnico di Milano)

11:45-12:00 New Zealand User Guidelines, Brendon Bradley (University of Canterbury)

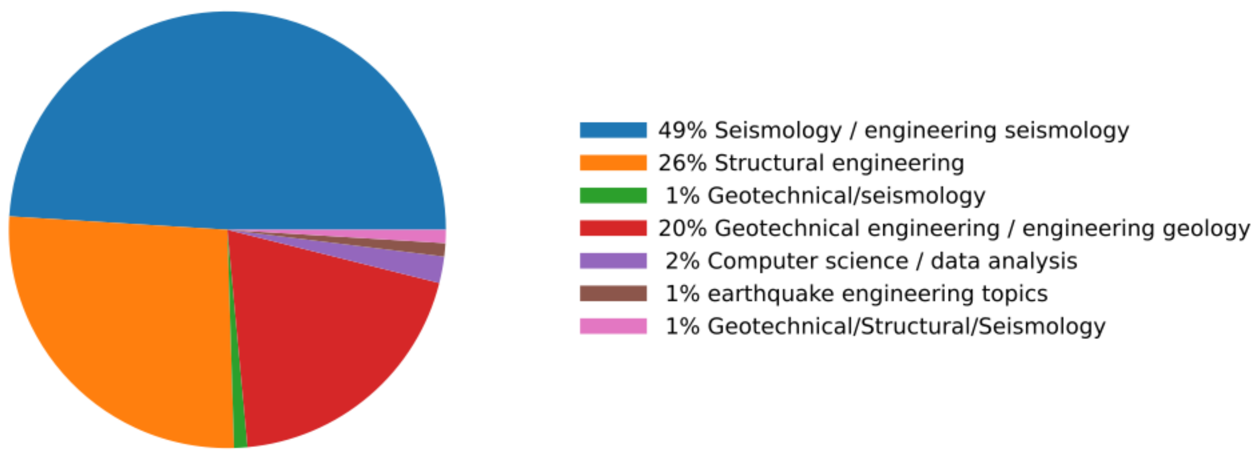
12:00-12:30 Panel discussion with Speakers, led by Ertugrul Taciroglu (University of California, Los Angeles) and Brendon Bradley (University of Canterbury)

12:30-13:00 Discussion and Next Steps by Brad Aagaard (USGS)

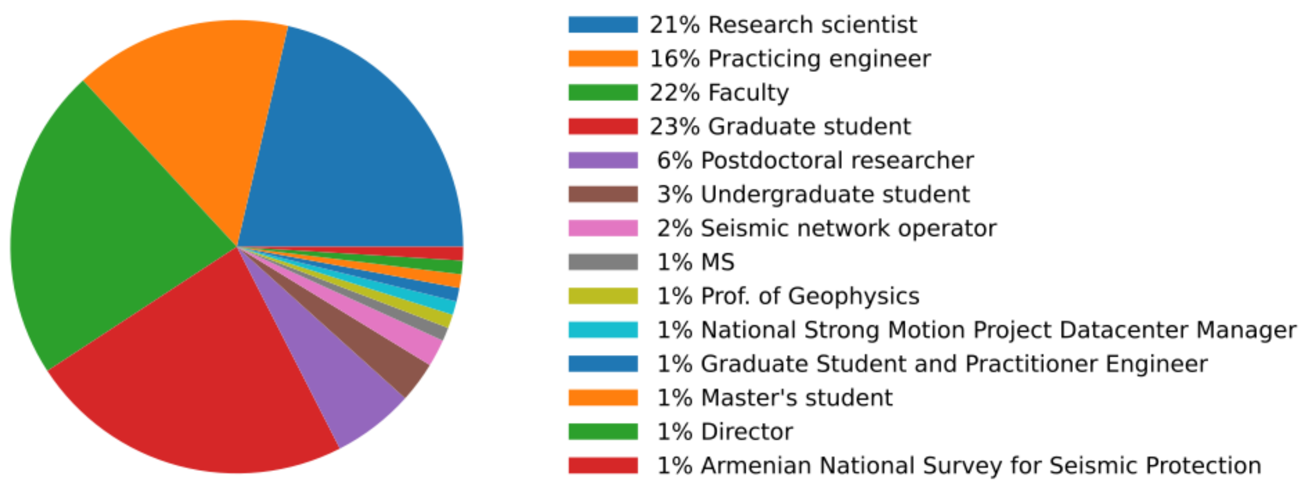
Survey Results

Demographics

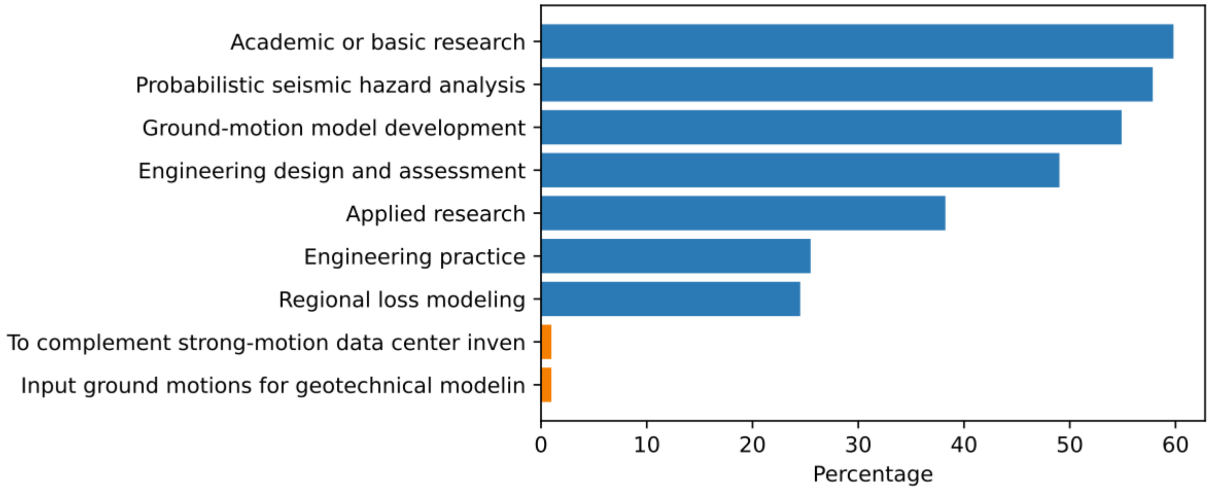
What is your area of interest?



What is your current position?

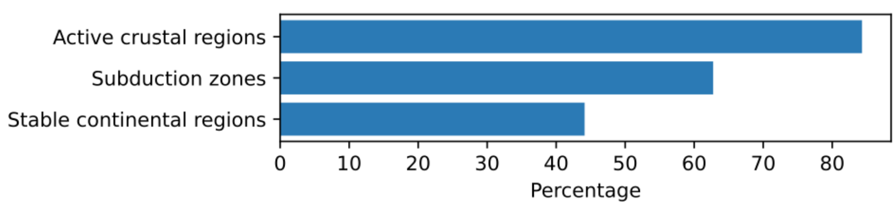


How would you use simulated ground-motion data? Check all that apply. Answers in orange correspond to write-in responses.



60% Academic or basic research
58% Probabilistic seismic hazard analysis
55% Ground-motion model development
49% Engineering design and assessment
38% Applied research
25% Engineering practice
25% Regional loss modeling
1% To complement strong-motion data center inventory
1% Input ground motions for geotechnical modeling

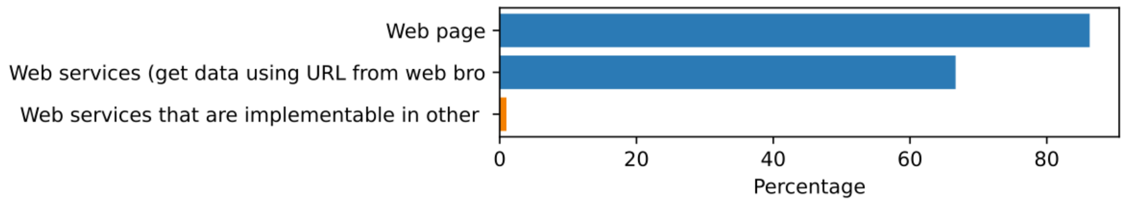
For what tectonic environments do you want simulated ground-motion data? Check all that apply.



84% Active crustal regions
63% Subduction zones
44% Stable continental regions

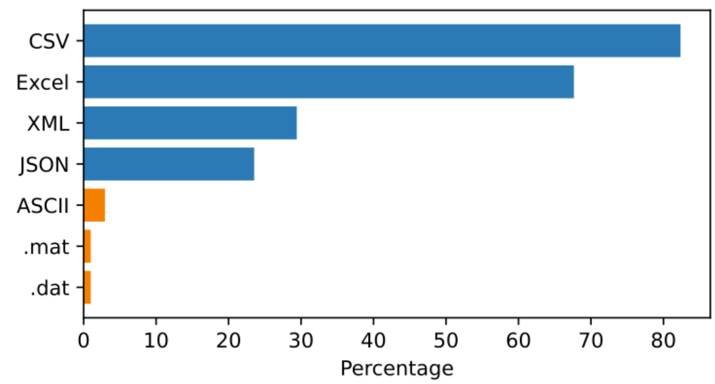
Dissemination

What interface would you use to search and download data? Check all that apply. Answers in orange correspond to write-in responses.



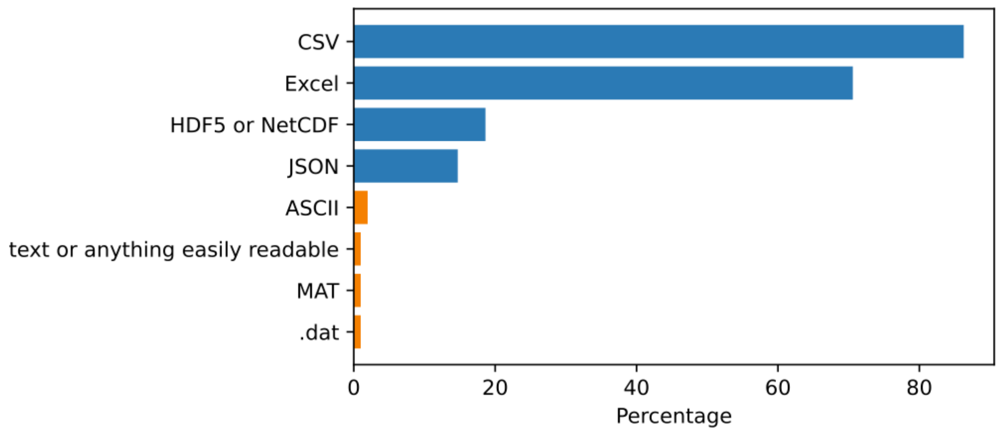
86% Web page
67% Web services (get data using URL from web browser or access using programming languages)
1% Web services that are implementable in other codes for batch query

What data format(s) do you prefer for metadata (for example, authors, dates, descriptions of ground-motion simulation methodology, and seismic velocity models used)? Check all that apply. Answers in orange correspond to write-in responses.



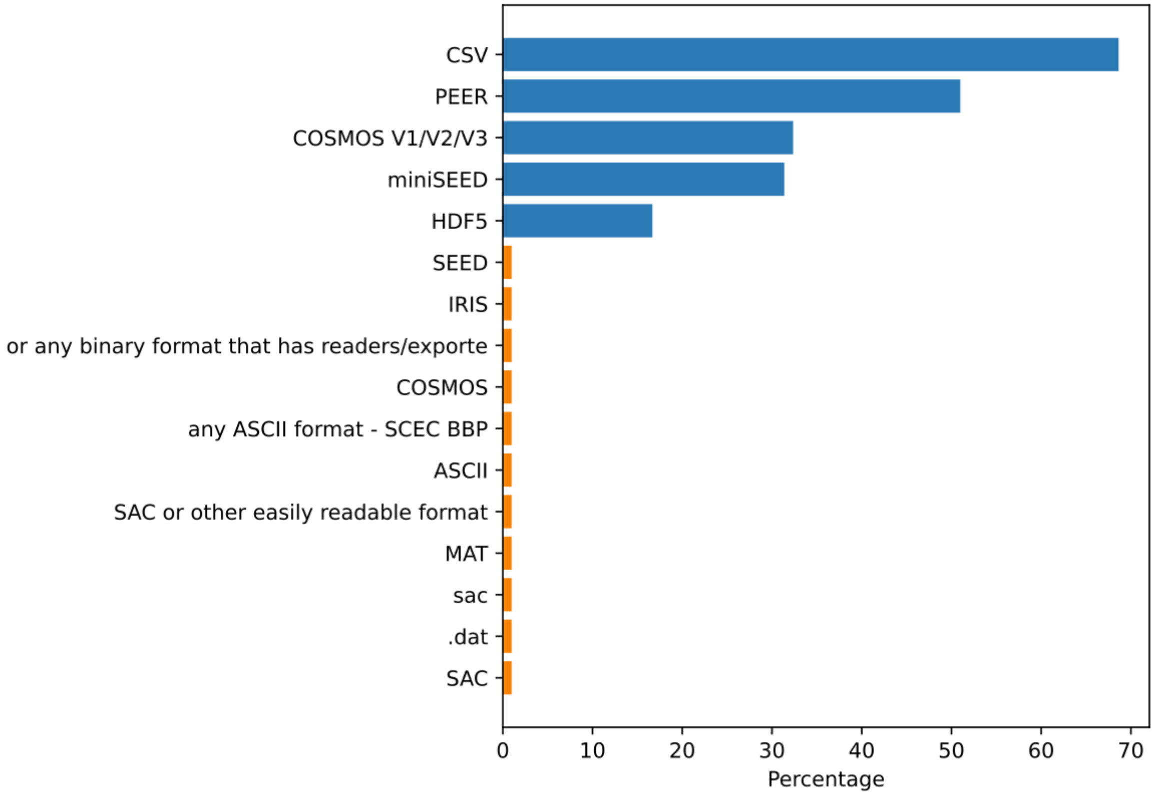
82% CSV
68% Excel
29% XML
24% JSON
3% ASCII
1% .mat
1% .dat

What data format(s) do you prefer for tabular data (for example, tables of peak ground acceleration, peak ground velocity, spectral acceleration)? Check all that apply. Answers in orange correspond to write-in responses.



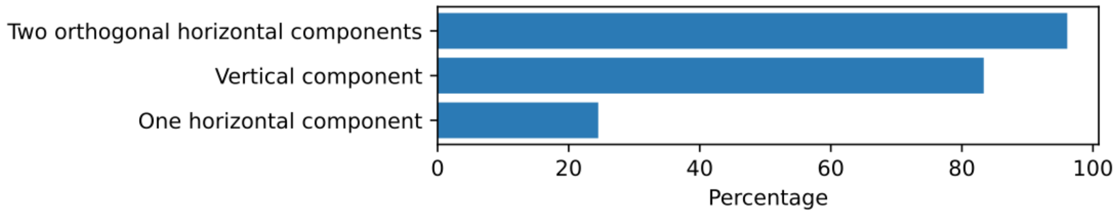
86% CSV
71% Excel
19% HDF5 or NetCDF
15% JSON
2% ASCII
1% text or anything easily readable
1% MAT
1% .dat

Which data format(s) do you prefer for time series? Check all that apply. Answers in orange correspond to write-in responses.



69% CSV
51% PEER
32% COSMOS V1/V2/V3
31% miniSEED
17% HDF5
1% SEED
1% IRIS
1% or any binary format that has readers/exporters available
1% COSMOS
1% any ASCII format - SCEC BBP
1% ASCII
1% SAC or other easily readable format
1% MAT
1% sac
1% .dat
1% SAC

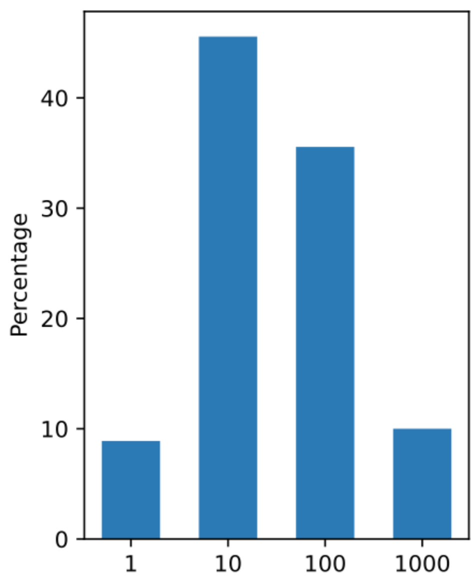
Which component(s) do you need? Check all that apply.



96% Two orthogonal horizontal components
83% Vertical component
25% One horizontal component

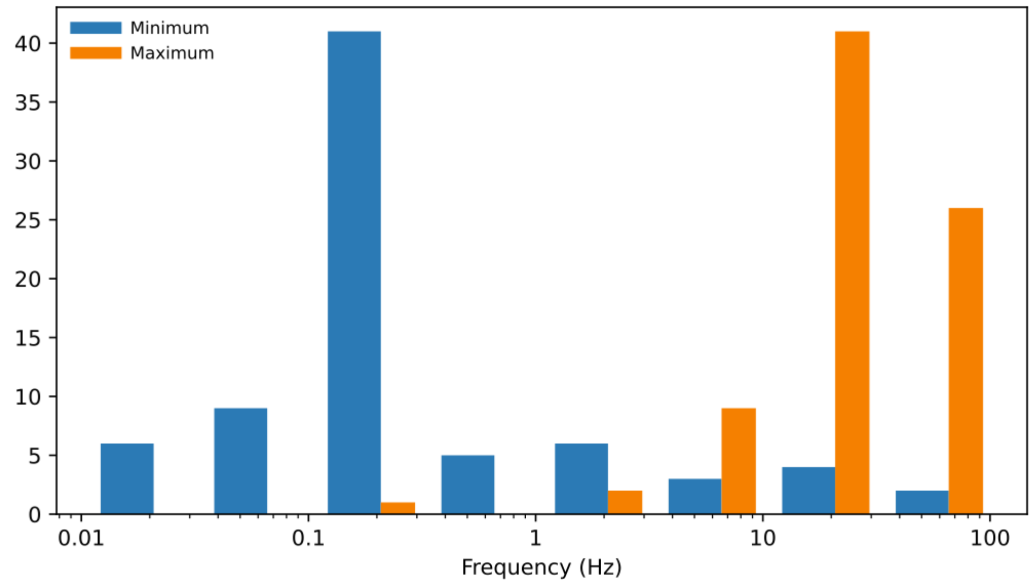
Future Simulations: User Needs

How many earthquake source realizations on a section of a fault do you prefer?



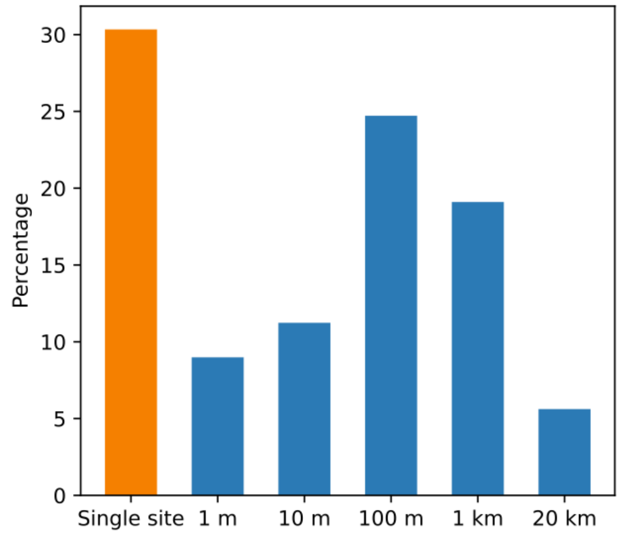
9% 1
46% 10
36% 100
10% 1000

What are the minimum and maximum frequencies you need?



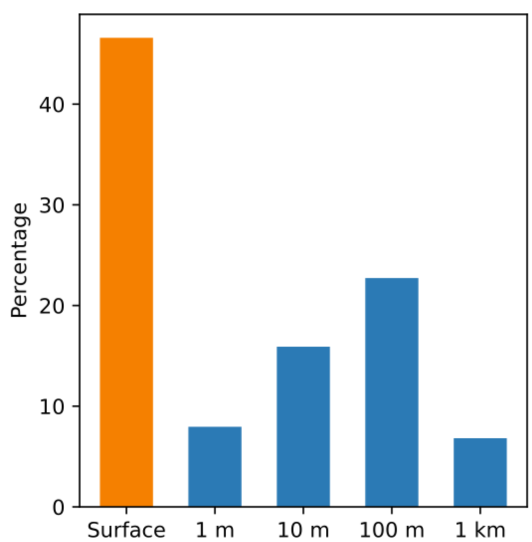
Frequency range (Hz)	Responses for minimum frequency	Responses for maximum frequency
0.01–0.03	6	0
0.03–0.1	9	0
0.1–0.3	41	1
0.3–1	5	0
1–3	6	2
3.0–10	3	9
10–30	4	41
30–100	2	26

What horizontal spatial resolution do you need in simulation output?



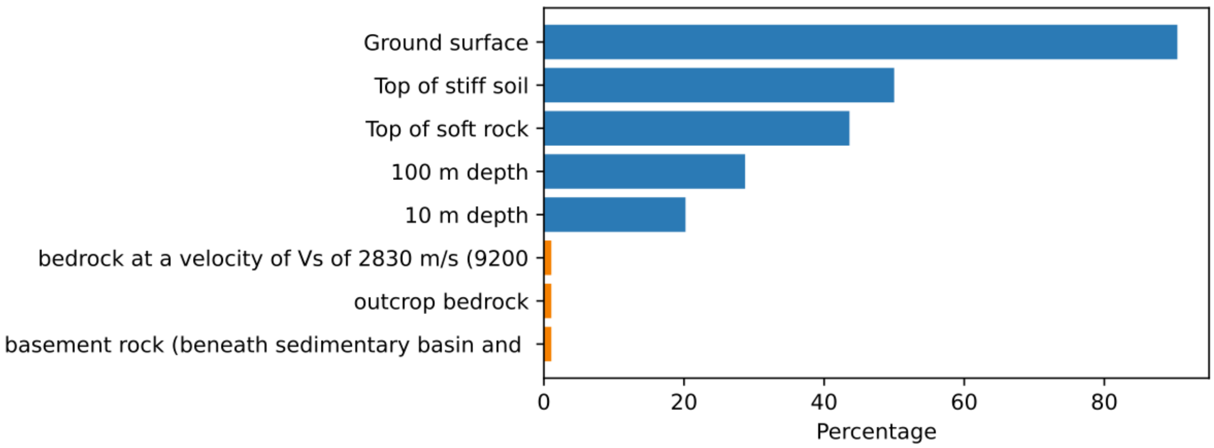
30% Single site
9% 1 m
11% 10 m
25% 100 m
19% 1 km
6% 20 km

What vertical spatial resolution do you need in simulation output?



47% Surface
8% 1 m
16% 10 m
23% 100 m
7% 1 km

At what vertical location do you want ground-motion data? Check all that apply. Answers in orange correspond to write-in responses.



- 90% Ground surface
- 50% Top of stiff soil
- 44% Top of soft rock
- 29% 100 m depth
- 20% 10 m depth
- 1% bedrock at a velocity of Vs of 2830 m/s (9200 ft/s)
- 1% outcrop bedrock
- 1% basement rock (beneath sedimentary basin and in mountain regions)