CALIFORNIA ENERGY COMMISSION

Knowledge Transfer Report

Performance-Based Earthquake Engineering Assessment Tool for Natural Gas Storage and Pipeline Systems

Agreement Number: PIR-18-003

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Natural Gas Research and Development Program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with RD&D entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater natural gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency.
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity.
- Energy-Related Environmental Research
- Natural Gas-Related Transportation.

Knowledge Transfer Report is an interim report for the Performance-Based Earthquake Engineering Assessment Tool for Natural Gas Storage and Pipeline Systems project (PIR-18-003) conducted by the University of California, Berkeley. The information from this project contributes to the Energy Research and Development Division's Natural Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

ABSTRACT

This report is one of a series of reports documenting the methods and findings of a multi-year, multi-disciplinary project conducted by the Pacific Earthquake Engineering Research Center (PEER) with the Lawrence Berkeley National Laboratory (LBNL), and funded by the California Energy Commission (CEC). The overall project is titled "*Performance-based Earthquake Engineering Assessment Tool for Natural Gas Storage and Pipeline Systems*" henceforth referred to as the "*OpenSRA* Project."

The overall goal of the *OpenSRA* project is to create an open-source research-based seismic risk assessment tool for natural gas infrastructure that can be used by utility stakeholders to better understand state-wide risks, prioritize mitigation, plan new gas infrastructure, and help focus post-earthquake repair work.

The project team includes researchers from LBNL, UC Berkeley, UC San Diego, University of Nevada Reno, the NHERI SimCenter at UC Berkeley, and Slate Geotechnical Consultants and its subcontractors Lettis Consultants International (LCI) and Thomas O'Rourke. Focused research to advance the seismic risk assessment tool was conducted by Task Groups, each addressing a particular area of study and expertise, and collaborating with the other Task Groups.

This report presents the approaches used to disseminate the project's technical research and software development, and it describes the materials created and released that highlight the key project outcomes.

Keywords: knowledge, technical, transfer, communications, outreach

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Introduction

This report is one of a series of reports documenting the methods and findings of a multi-year, multi-disciplinary project conducted by the Pacific Earthquake Engineering Research Center (PEER) with the Lawrence Berkeley National Laboratory (LBNL) and funded by the California Energy Commission (CEC). The overall project is titled "*Performance-based Earthquake Engineering Assessment Tool for Natural Gas Storage and Pipeline Systems*" henceforth referred to as the "*OpenSRA* Project."

The overall goal of the *OpenSRA* project is to create an open-source research-based seismic risk assessment tool for natural gas infrastructure that can be used by utility stakeholders to better understand state-wide risks, prioritize mitigation, plan new gas infrastructure, and help focus post-earthquake repair work. This is achieved by conducting user-driven research to develop a comprehensive quantitative seismic risk methodology using probabilistic data to evaluate and manage the seismic risk for natural gas storage and pipeline systems.

The project team includes researchers from LBNL, UC Berkeley, UC San Diego, University of Nevada Reno, the NHERI SimCenter at UC Berkeley, and Slate Geotechnical Consultants and its subcontractors Lettis Consultants International (LCI) and Thomas O'Rourke. Focused research to advance the seismic risk assessment tool was conducted by Task Groups, each addressing a particular area of study and expertise, and collaborating with the other Task Groups.

This report presents the approaches used to disseminate the project's technical research and software development, and it describes the materials created and released that highlight the key project outcomes.

Goal of Knowledge Transfer

The primary result of this project is the user-friendly open-source seismic risk software for natural gas pipelines and storage facilities called *OpenSRA*. Through securing comments and feedback from industry users and decision makers, *OpenSRA* addresses several of the concerns associated with the ad hoc manner in which current seismic risk assessments of natural gas pipelines and storage facilities are performed.

When implemented appropriately, this new software technology and the research it incorporates can ultimately benefit the public with increased reliability in seismic risk assessments and the post-calculation allocation of resources. These goals can be attained when the technology and knowledge is transferred from the project team to a broader audience, so that the software can be effectively utilized.

Software Utilization

Open-source software development enables users to understand the framework and algorithm processes behind the assessment software. Options to use pre-existing or user-specific data enable the users to create scenario assessments with changing parameters so that decisions based on plausible conditions can be evaluated and prioritized.

Soliciting and receiving feedback from industry operators and consultants is critical for the adoption of *OpenSRA* software. Aligning project priorities with the needs of the users facilitates adoption of the software by the industry.

Advancing Knowledge and Practice

OpenSRA software incorporated advancements in seismic hazard analysis. It also incorporates focused research that was conducted on gas infrastructure capacities for above-ground components and systems as well as below-ground wells and caprocks.

Computational simulations using *OpenSRA* for validation or decision-making studies advances research and practice in network system reliability.

Project Benefits

When *OpenSRA* is applied appropriately for mitigation purposes, *OpenSRA* enables utility decision-makers to effectively allocate resources to transmission systems, which supports system reliability and safety.

Approach

A fundamental task in the knowledge transfer plan was to identify the audience based on project benefits to that audience. Another basic task was to create a visual and written description of the project in the form of a logo and very brief description; these two identifiers would be used consistently in any communication about the project. A project website was established so that all project information, publications, and products would be located in a single electronic repository.

The knowledge transfer plan was designed to align with the *OpenSRA* project developments. For each project milestone accomplishment anticipated, complementary activities and material that was needed to effectively communicate, support, and transfer the technical information to the intended audience, was identified. The content of this material, communication messages, and dissemination process was created by the *OpenSRA* team, and it utilized PEER's established communication platforms: website, electronic newsletters, and social media channels.

Project deliverables to the funding agency include the *OpenSRA* software and user manuals, interim project reports ("CEC reports"), project fact sheets, and benefits questionnaires. Additional products were identified by the project team to support the technical transfer efforts. These products and their intended purposes are as follows.

1. One-page summary of each CEC report. Produced for a general audience as an introduction to the CEC report and the *OpenSRA* project.
2. Posters summarizing each research task and results. Produced for a technical research audience to advance the state of knowledge.
3. Presentations provided at conferences and technical meetings. Produced for the audience typically in attendance, as an introduction and engagement to the *OpenSRA* project or to advance the state of knowledge.

4. News articles for *OpenSRA* project-related activities. Produced and disseminated for a general audience as an introduction to the *OpenSRA* project or to advance the state of knowledge.
5. Technical research reports for each research task, to be submitted to PEER for publication. Produced for a technical research audience to advance the state of knowledge.
6. User survey for the User-workshop. Produced for an industry owner utility user audience to secure feedback about *OpenSRA* software and its implementation.

During the project's development, meetings were held with a Technical Advisory Committee (TAC) which is composed of representatives of user utilities such as SoCalGas and PG&E. These TAC meetings yielded useful input and feedback which have been considered and adopted where possible into the software framework and user interface to improve useability and effectiveness of the tool.

A user-workshop, designed to facilitate the use and application of *OpenSRA* software, was held on January 11, 2013 at UC Berkeley. The targeted audience for the workshop was utility owners and users. The workshop program opened with an introductory overview of the *OpenSRA* project, research conducted and incorporated into the program, and software features. The overview presentation was followed by several hours in a computer lab, where participants were able to use the software in several hands-on demonstrations. Project team members were readily available to assist and answer operational and research-oriented questions. The workshop concluded with a poster session where attendees could discuss the project with members of the team while viewing posters that summarized the technical research and results that were incorporated into *OpenSRA*.

Notification about the workshop and its value for attendees was shared with the TAC and project team members, with the encouragement to invite colleagues who have specific interests in risk assessment of networks. Broader outreach to the PEER community was extended via the PEER electronic newsletter and PEER's social media accounts.

Because the emphasis of the workshop was to demonstrate the software's ease of use through hands-on examples in the computer lab, in-person attendance was strongly encouraged. However, due to storms and travel irregularities from an FAA shutdown that day, some utility personnel could not attend because they needed to be responsive to the "all-hands-on-deck" commitment to the public for system reliability. Therefore, for registrants who could not attend in person, the initial overview portion of the workshop was broadcast live and the recording was made available a few days later. To follow up with utility personnel who could not attend the workshop, future meetings have been scheduled.

Attendees were invited to provide anonymous input and feedback about *OpenSRA* and the workshop in an online survey. Connection to the survey was provided in a QR code on the program agenda which was announced several times during the workshop day. A follow-up email to registrants with a link to the survey was also distributed a few days after the workshop.

Results

The primary modes for knowledge transfer throughout the duration of this project were the use of electronic media and in-person meetings. Project programmatic metrics related to data collection, outreach and project execution are associated with performance metrics for the website and the workshop engagement.

The number of clicks on a website is an indicator of the broad exposure of the project. Website tracking data obtained in November 2022 for the previous 3 months shows 845 hits for that quarter, which exceeds the initial performance goal by a factor of more than 33. This high metric can be attributed to the consistent use of the project website hyperlink in nearly all communication announcements, as well as to the large audience base that the communications are transmitted to.

The number of User Workshop participants indicates interest in the project from prospective users and engaged researchers. Excluding team members, 50 people registered for the workshop, which exceeds the target performance goal of 20. Despite the external conditions that prevented many participants from attending, 14 non-project members participated in the hands-on demonstration in the computer lab, and engagement during the workshop was extremely high, with many comments, suggestions, and responses conveyed between the participants and developer team.

Securing comments and feedback from industry users and decision-makers is critical to the alignment of the project and its effective implementation. Feedback was received during project TAC meetings and during the User workshop and subsequent survey.

The TAC meetings with industry operators and users provided discussions where input and feedback from TAC members were helpful. Given the focused timeframe of the project, some examples of input for the initial software launch that were incorporated included:

- Focus on transmission lines, not distribution or service laterals.
- Focus on wells tress and vertical tanks at storage facilities.
- Remove Java from *OpenSRA* due to compatibility issues.
- Software security review will be extensive.

The knowledge transfer plan for the *OpenSRA* project was implemented at the inception of the project with the establishment of project website (https://peer.berkeley.edu/opensra) which serves as a single central repository where all the project information, publications, and products are located. A visual identity and short written description of the project was developed and used consistently as each project milestone was announced. Research progress and results were presented in technical conferences and workshops. Project reports summarizing research accomplishments were published by the CEC and announced to the utility and research communities. All project milestones were disseminated with the use of electronic and online media platforms with messaging that is consistent and focused. The message reaches an expanded audience when colleague organizations re-broadcast the original announcement.

CHAPTER 1: Introduction

This report is one of a series of reports documenting the methods and findings of a multi-year, multi-disciplinary project conducted by the Pacific Earthquake Engineering Research Center (PEER) with the Lawrence Berkeley National Laboratory (LBNL) and funded by the California Energy Commission (CEC). The overall project is titled "*Performance-based Earthquake Engineering Assessment Tool for Natural Gas Storage and Pipeline Systems*" henceforth referred to as the "*OpenSRA* Project."

The overall goal of the *OpenSRA* project is to create an open-source research-based seismic risk assessment tool for natural gas infrastructure that can be used by utility stakeholders to better understand state-wide risks, prioritize mitigation, plan new gas infrastructure, and help focus post-earthquake repair work. . This is achieved by conducting user-driven research to develop a comprehensive quantitative seismic risk methodology using probabilistic data to evaluate and manage the seismic risk for natural gas storage and pipeline systems.

The probabilistic seismic risk tool developed in this project follows the widely-accepted risk methodology of Dr. A. Cornell (Cornell, 1968). A seismic source characterization is used to develop a suite of earthquake scenarios with associated rates of occurrence to represent the seismic hazard. Fault ruptures and the resulting ground deformation are generated for each earthquake scenario to represent the seismic loading, which includes a map of ground motion parameters. This scenario-based seismic parameter map is overlaid on the infrastructure system and the seismic loading combined with the capacities of the infrastructure to calculate the seismic performance of the natural gas system for the scenario. By repeating the process for all scenarios in the suite, the tool can evaluate the seismic risk to the system.

A user-driven research approach was used to develop *OpenSRA* to be easily usable by regulators and utilities, and to include updated models and methods for the seismic demands and capacities that control the seismic risk for natural gas systems. The project includes several innovative approaches that improve the basic methodology and distinguish this project's approach from standard approaches currently used. Current risk studies developed by the utilities use risk scoring approaches that are highly subjective and qualitative. They do not properly incorporate the uncertainties in the seismic demand and in the fragility of the system and its components. Targeted research was conducted in this project to improve the characterization of uncertainty of key inputs to the seismic risk assessment tool. The seismic risk methodology employed in this project provides quantitative estimates of the probabilistic seismic risk. For risk-informed decision-making processes, the reliability of the risk estimates needs to be considered because this can be significant, particularly for large rare earthquakes.

The project team includes researchers from LBNL, UC Berkeley, UC San Diego, University of Nevada Reno, the NHERI SimCenter at UC Berkeley, and Slate Geotechnical Consultants and its subcontractors Lettis Consultants International (LCI) and Thomas O'Rourke. Focused research to advance the seismic risk assessment tool was conducted by Task Groups, each

addressing a particular area of study and expertise, and collaborating with the other Task Groups. The Task Groups are as follows:

- Task A: Fault Displacement
- Task B: Liquefaction-induced deformation and seismically induced slope displacement
- Task C: Performance of natural gas storage well casings and caprock
- Task D: Performance of gas storage and pipeline system surface infrastructure
- Task E: Smart gas infrastructure sensing of wells and pipeline connections performance
- Task F: Synthesis of component fragilities into a system performance model

This report describes the approaches used to disseminate the project's technical research and software development, and it presents highlights of the key outcomes of the project as a whole.

Goals of Knowledge Transfer

The primary result of this project is the user-friendly open-source seismic risk software for natural gas pipelines and storage facilities called *OpenSRA*. The *OpenSRA* software addresses several of the concerns associated with the ad hoc manner in which current seismic risk assessments of natural gas pipelines and storage facilities are performed. The components of knowledge transfer follow what was outlined in the Knowledge Transfer Plan submitted to CEC in March 2020. These steps include communication with utility owners, utilizing PEER's electronic dissemination methods, and presenting at conferences and workshops.

When implemented appropriately, this new software technology and the research it incorporates will benefit the public with increased reliability and allocation of resources. This can be achieved when the technology and knowledge is transferred from the project team to a broader audience with the goal that end users understand the capabilities of the software and see the benefits of the analysis on mitigation and future resource allocation.

The following report outlines the goals of knowledge transfer, the process in which it occurred, the results and outcomes throughout the project, and lessons learned on how to better communicate between entities during projects of this size.

Software Utilization

Soliciting and receiving feedback from industry operators and consultants is critical for the adoption of *OpenSRA* software. Aligning project priorities with the needs of the users facilitates adoption of the software by industry users. Some of the needs include open-source code, easy-to-use user interface, and the ability to run fast computations on a desktop computer.

Open-source software development enables users to understand the framework and algorithm processes behind the assessment software. Options to use pre-existing or user-specific data enable the users to create scenario assessments with changing parameters so that decisions based on plausible conditions can be evaluated and prioritized. The tool's graphical user interface for input and output eliminates the need for special programming skills, and enables the user to easily input data and understand analysis results. Finally, computation time is greatly reduced with the application of Polynomial Chaos method.

Advancing Knowledge and Practice

OpenSRA software incorporates advancements in seismic hazard analysis through the use of Polynomial Chaos (decreasing computation time) and also incorporates focused research that was conducted to estimate the fragility of different gas infrastructure. This project also included validation of the software with existing facilities in California. Sharing this information with utility owners, operators, and researchers will elevate the engineering community's knowledge and practice, and it will serve as a basis for further development.

Benefits of Knowledge Transfer

The features listed in the previous sections "Software Utilization" and "Advancing Knowledge and Practice" are incorporated in *OpenSRA* software. Interfacing with the gas utility owners and operators, as well as with the research and practitioner community has resulted in fruitful discussions that provided guidance and focus to the development of *OpenSRA*. Thus, when *OpenSRA* is applied appropriately for mitigation purposes, it enables utility decision-makers to effectively allocate resources to transmission systems, which supports system reliability and safety.

CHAPTER 2:
Approach

The knowledge transfer plan was designed to align with the *OpenSRA* project developments. The team identified complementary activities adjacent to each project milestone to effectively communicate, support, and transfer the technical information to the intended audience. The *OpenSRA* team created the content of this material, communication messages, and the dissemination process. The team specifically utilized PEER's established communication platforms including their website, electronic newsletters, and social media channels.

The following sections outlined the knowledge transfer goals (i.e. products, audiences to reach, etc.), the mechanisms of transferring the knowledge, and finally in-person interactions between the project team and end-users.

Technology Transfer Fundamentals

At the onset of the project, the team identified specific audiences, products, and goals to achieve sufficient technology transfer to the industry. Part of this technology transfer plan started with discussing these components with the Technical Advisory Committee (TAC) and project team. The first step of these discussions was to identify the audiences that needed information, the second was to raise awareness through branding and dissemination of information, and finally identifying specific products to complement project milestones.

Audience

Communicating and disseminating information that is meaningful requires an understanding of who the recipient audience is. For the *OpenSRA* project, three audiences were identified and categorized based on how the software will help them. These three audiences are as follows:

- Industry owner utility user - *OpenSRA* provides a formal, rigorous process for risk assessment in an open-source platform. The software enables users to analyze a myriad of probabilistic and deterministic scenarios so that decisions and allocation of resources can be effectively implemented.
- Academic researcher - *OpenSRA* incorporates new research that advances knowledge in the engineering sciences, computational methods, simulation framework.
- General audience - When applied appropriately for mitigation purposes, *OpenSRA* enables utility decision-makers to effectively allocate resources to transmission systems, which supports system reliability and safety.

Branding and Website

As stated previously, the primary result of this project is the user-friendly open-source seismic risk assessment, *OpenSRA*, software for natural gas pipelines and storage facilities. A graphical logo, shown in Figure 1, was established at the project's inception for the project's visual identity. This logo has been used to help raise awareness for the project, as well as begin brand recognition within the industry.

Figure 1: *OpenSRA* Logo

Additionally, the following two statements were composed for consistent messaging about the project's purpose.

- The project "Performance-Based Earthquake Engineering Assessment Tool for Natural Gas Storage and Pipeline Systems," henceforth referred to as the "*OpenSRA* Project," is a multi-year study to develop open-source seismic risk assessment tools for natural gas infrastructure.
- *OpenSRA* is a new open-source seismic risk assessment software tool for gas utility regulators and owners that will enable them to strategically address challenges posed by the risk from earthquake-induced hazards.

With branding, one of the goals of this project is to make information readily accessible. To aid in this, the *OpenSRA* project website at https://peer.berkeley.edu/opensra was established at the beginning of the project. This project website is the repository of information for the entire project, and it includes the project's purpose, vision, publications and products, research scope and teams, sponsor and supporters, and related news about presentations to outside organizations. *OpenSRA* software will be available to the public from the project website, and PEER has committed to maintaining and supporting the software.

Products

Project deliverables to the funding agency include the *OpenSRA* software and user manuals, interim project reports ("CEC reports"), project fact sheets, and benefits questionnaires.

The project team identified additional complementary products to support the technical transfer efforts, some of which are outlined in the Knowledge Transfer Plan. These products and their intended purposes are as follows:

1. At the onset of the project a website was created to give *OpenSRA* a platform, and broadcast the research efforts (https://peer.berkeley.edu/opensra).
2. The *OpenSRA* team created a GitHub site where the code is currently located and all future releases will be published (https://github.com/OpenSRA).
3. One-page summary of each CEC report. These summaries were produced for a general audience as an introduction to the CEC report and the *OpenSRA* project.
4. Posters summarizing each research task and results. These were produced for a technical research audience to showcase the models created and summarized for use within the software.

5. Presentations provided at conferences and technical meetings. These were produced for the audience in attendance, as an introduction to the *OpenSRA* project or to highlight the technical aspects of *OpenSRA* in greater detail.
6. News articles for *OpenSRA* project-related activities. These were produced and disseminated for a general audience to create awareness for the project and promote the software for later use.
7. Technical research reports for each research task, to be submitted to PEER for publication. These are produced for a technical research audience to advance the state of knowledge and to further discuss the more technical aspects of the research components for the project.
8. User survey for the User Workshop. This was designed to secure feedback, from the industry owner utility user audience, about *OpenSRA* software and its implementation.

Process of Knowledge Transfer

The complementary products outlined above helped to document and track the progress of the project and software development as a whole. As each project milestone was reached, a process to disseminate the information was employed. The process started by creating a repository of information where the product could be found, and it was followed by a campaign to boost the information to the appropriate audience group. Announcements about project progress always included a hyperlink to the project website as another source of information.

Website Repository and Code Hosting Platforms

A brief description of the *OpenSRA* project website was outlined in "Branding and Website." The project website is the repository where all of the project information and products are located. For example, deliverables and complementary products identified above are located in "Publications and Products" (https://peer.berkeley.edu/opensra/publications-and-products), and presentations that have been made at conferences and workshops can be found on the project website under "Related News" (https://peer.berkeley.edu/opensra/related-news). The project website is continuously updated with the research goals, tasks, findings, and development of *OpenSRA*, and the software will be available to the public from the project website.

The development of *OpenSRA* is based on the principles and culture of open-source coding; this practice is characterized by anticipating collaborations and continued incorporation of user-driven features. In order to support this practice, an *OpenSRA* site was established on GitHub which is a code-hosting and development site. *OpenSRA* code is currently located on GitHub and all future releases will be published from this site (https://github.com/OpenSRA).

Electronic media and news

Developments during the *OpenSRA* project were announced in news articles on the PEER website homepage and announced through PEER's electronic media. For example, as interim project reports were published by the CEC, news articles that included a link to a short one-page summary and to the longer report (published on the *OpenSRA* project website) were posted on the PEER website. This was followed by PEER broadcasting this news in its e-mail

newsletters with more than 3500 subscribers and social media channels LinkedIn (https://www.linkedin.com/company/peer-pacific-earthquake-engineering-research-center/), Twitter (https://twitter.com/PEER_Center), and Facebook (https://www.facebook.com/peerctr) with a combined audience of more than 26,000 followers. An additional benefit of the social media channels is that the natural gas community, e.g., SoCalGas and CEC, are also "followers" of the PEER social media channels and occasionally re-post *OpenSRA* news, as shown in Figure 2. Additionally, project team members, e.g., Slate Geotechnical Consultants and the NHERI SimCenter, were able to re-broadcast the PEER announcements, thereby extending the audience base.

Figure 2: Social Media Re-posting Expands Audience

"Save the date" announcement is re-posted by the CEC on Twitter.

PEER's news articles, electronic newsletter, and social media channels were also used to broadcast engagement at in-person conferences and meetings as well as to announce the user workshop.

Publications

In addition to the interim project reports written for the CEC, the project team is writing technical research reports that will be published by PEER. PEER research reports are typically comprehensive in scope and this enables the research community to share extensive information about research approaches and results. The PEER report series (https://peer.berkeley.edu/peer-reports) is widely used and cited by the research community, and this project's series of reports is anticipated to foster additional research knowledge that can be utilized by the natural gas industry.

The project team is writing research articles for technical journals. The format of these articles is much shorter than a PEER research report, and they focus on a specific aspect of research.

As part of PEER's ongoing commitment to support *OpenSRA*, PEER will announce the publication of each report or journal article with a news article on the PEER website homepage, in the *OpenSRA* project website, in the email newsletter, and through social media posts.

In-person Engagement

In-person activities included meetings with the TAC, presentations at conferences with the goal of engaging and informing other researchers and users of the project's progress, and the User Workshop.

Technical Advisory Committee

During the project's development, meetings were held with a Technical Advisory Committee (TAC) which is composed of representatives from CEC, California Geologic Energy Management Division (CalGEM), California Public Utilities Commission (CPUC), and user utilities such as SoCalGas and PG&E. The TAC helped set the project team's research objectives, provided insights into industry technical needs, and asked probing questions.

These TAC meetings yielded useful input and feedback which have been considered and adopted where possible into the software framework and user interface to improve useability and effectiveness of the tool. Notification of the upcoming user workshop was shared with TAC, encouraging them to share this development with their colleagues and take advantage of early priority registration.

Project team members and TAC members are ambassadors for the project, and benefits of their in-person presentations include networking with engaged audience members.

Conferences and Meetings

During the development of *OpenSRA*, presentations about the project, research basis, and applications were made at workshops and conferences targeted to other researchers, practitioners, stakeholders, and users. Many of these engagements and presentation files are on the project website at https://peer.berkeley.edu/opensra/related-news and listed below.

- 2023 – User Workshop - January 11, 2023
- 2022 – TAC Meeting - February 14, 2022
- 2022 – PEER Researchers' Workshop, September 19, 2022
  Session: "Regional-scale Simulation"
  Presentation: "Seismic Risk Assessment Tool for Natural Gas Storage and Transmission Systems" – Jennie Watson-Lamprey
- 2022 – 12th National Conference on Earthquake Engineering (12NCEE)
  Special Session: "S.S.13 Seismic Risk Assessment Methodologies and Open-Source Tools for Natural Gas Infrastructure – June 28, 2022
  Presentations:

"Introduction" - Barry Zheng
"Methods for Numerically Efficient Estimation of Seismic Risk for Distributed Systems" - Norman Abrahamson
"Impacts of Geo-Spatial Data Resolution on the Uncertainty of Liquefaction-Induced Displacement Estimates" - Jonathan Bray
"The Value of Sensing for Performance-based Earthquake Engineering Assessment of Buried Pipeline Systems" - Peter Hubbard
"Seismic Risk Assessment Methodologies and Open-Source Tools for Natural Gas Infrastructure" - Barry Zheng
"In-plane and Out-of-plane Cyclic Tests on Welded Steel Pipe Tee Joints" - Elide Pantoli
"Fault Displacement Hazard Initiative and Hazard Mapping for California" - Stephen Thompson

- 2022 – ASCE Lifelines Conference – February 9, 2022
  Presentation: "Open-Source Seismic Risk Assessment (OpenSRA) Tool for Natural Gas Infrastructure: Development and Early Results" – Barry Zheng
- 2021 – PEER Researchers' Workshop, August 16, 2021
  Session: "Networks"
  Presentation: "Seismic Risk Assessment Tool for Natural Gas Storage and Transmission Systems" – Jonathan Bray
- 2021 – Disaster Resilient Infrastructure, June 2021
  The Tunneling Podcast
  Presentation: "Disaster Resilient Infrastructure" – Thomas O'Rourke
- 2021 – TAC Meetings - February 24 and August 27, 2021
- 2020 – TAC Meetings - February 28 and August 28, 2020
- 2019 – PEER Researchers' Workshop, August 27, 2019
  Session: "Collaborative Projects"
  Presentation: "CEC Project – Seismic Risk Assessment Tool for Natural Gas Storage and Transmission Systems – Overview" – Jonathan Bray

Conference proceedings for the 2022 – 12th National Conference on Earthquake Engineering (12NCEE) are listed below.

- Bain C., Bray J. (2022). Impacts of Geo-Spatial Data Resolution on the Uncertainty of Liquefaction-Induced Displacement Estimates. Seismic Risk Methodologies and Open-Source Tools for Natural Gas Infrastructure (11007). 12NCEE Proceedings, September 2022. https://12ncee.org/program/proceedings, Accessed February 2, 2023
- Hubbard P.G., Wang J., Xu T., Soga K. (2022). The value of sensing for performance-based earthquake engineering assessment of natural gas pipelines and facility systems. Seismic Risk Methodologies and Open-Source Tools for Natural Gas Infrastructure (103564). 12NCEE Proceedings, September 2022. https://12ncee.org/program/proceedings, Accessed February 2, 2023
- Pantoli E., Hutchinson T. (2022). In-plane and out-of-plane cyclic tests on welded steel pipe tee joints. Seismic Risk Methodologies and Open-Source Tools for Natural Gas

Infrastructure (10396). 12NCEE Proceedings, September 2022. https://12ncee.org/program/proceedings, Accessed February 2, 2023

- Sarmiento A., Thompson S., Bozorgnia Y., Bubeck A., Madugo D., Zandieh A. (2022). Fault Displacement Hazard Initiative and Hazard Mapping for California. Seismic Risk Methodologies and Open-Source Tools for Natural Gas Infrastructure (11035). 12NCEE Proceedings, September 2022. https://12ncee.org/program/proceedings, Accessed February 2, 2023

User Workshop and Survey

A User Workshop, designed to facilitate the use and application of *OpenSRA* software, was held on January 11, 2023 at UC Berkeley. The targeted audience for the workshop was utility owners and users. The workshop program opened with an introductory overview of the *OpenSRA* project, research conducted and incorporated into the program, and software features. The overview presentation was followed by several hours in a computer lab, shown in Figure 3, where participants were able to use the software in several hands-on demonstrations. Project team members were readily available to assist and answer operational and research-oriented questions. The workshop concluded with a poster session where attendees could discuss the project with members of the team while viewing posters that summarized the technical research and results that were incorporated into *OpenSRA*.

Figure 3: User-Workshop

Hands-on demonstration of *OpenSRA* software in the computer lab.

Notification about the workshop and its value for attendees was shared with the TAC and project team members, with the encouragement to invite colleagues who have specific interests in risk assessment of networks. Broader outreach to the PEER community was extended via the PEER electronic newsletter and PEER's social media accounts.

Because the emphasis of the workshop was to demonstrate the software's ease of use through hands-on examples in the computer lab, in-person attendance was strongly encouraged. However due to severe weather conditions, some utility personnel could not attend because they needed to be responsive to the "all-hands-on-deck" commitment to the public for system reliability. Therefore, for registrants who could not attend in person, the initial overview portion of the workshop was broadcast live and the recording was made available a few days later. To follow up with utility personnel who could not attend the workshop, future meetings have been scheduled.

Attendees were invited to provide anonymous input and feedback about *OpenSRA* at the workshop through an online survey. Connection to the survey was provided in a QR code on the program agenda which was announced several times during the workshop day. A follow-up email to registrants with a link to the survey was also distributed a few days after the workshop. Survey results are presented in Chapter 3 and Appendix A.

CHAPTER 3:
Results

The primary modes for knowledge transfer were the use of electronic media and in-person meetings. Project programmatic metrics related to data collection, outreach and project execution are associated with performance metrics for the website and the workshop engagement.

Metrics

The approach outlined in Chapter 2 describes the dissemination of project information through products and announcements of those products. The announcements consistently included the *OpenSRA* project website hyperlink. Therefore, the number of clicks ("hits") on the project website are an indicator of the level of interest in the project. Additionally, the number of User Workshop attendees indicates interest in the project from prospective users and engaged researchers.

Project Website

The number of website hits is an indicator of the broad exposure of the project. The initial target performance goal for this metric is 100 hits per year. Website tracking data obtained for the 3-1/2-year project duration shows 2351 pageviews, with 1872 unique pageviews. The rate of website hits significantly increased recently - tracking data obtained in November 2022 for the previous 3 months shows 845 hits for that quarter, which exceeds the initial performance goal by a factor of more than 33. This high metric can be attributed to the consistent use of the project website hyperlink in nearly all communication announcements, as well as to the regular stream of project announcements that was disseminated to a large audience base.

Workshop Participants

The number of workshop participants demonstrates the interest in and broad use of *OpenSRA* software. The initial target performance goal for this metric is 20, excluding project team members. Excluding team members, 50 people registered for the workshop. However, many registrants were not able to attend in person due to storms and travel irregularities from an FAA shutdown that day. A video recording of the introductory overview of the *OpenSRA* project, research conducted and incorporated into the program, and software features was emailed to all registrants. Despite the external conditions that prevented many participants from attending, 14 non-project members participated in the hands-on demonstration in the computer lab.

Input and Feedback

Securing comments and feedback from industry users and decision-makers is critical to the alignment of the project and its effective implementation. Feedback was received during project TAC meetings and during the User Workshop and subsequent survey.

The TAC meetings with industry operators and users provided discussions where input and feedback from TAC members were helpful. Given the focused timeframe of the project, some examples of input for the initial software launch included:

- Focus on transmission lines, not distribution or service laterals.
- Focus on wells tress and vertical tanks at storage facilities.
- Remove Java from *OpenSRA* due to compatibility issues.
- Software security review will be extensive.

The User Workshop survey had a low respondent rate; of the 6 respondents, 2 were not on the research or development team. Despite this small sample size, results from the survey are presented. The engagement during the workshop was extremely high, with many comments, suggestions, and responses conveyed between the participants and developer team.

Responses to questions from 2 non-team members were "relevant/very relevant," "satisfied/very satisfied," "agree/strongly agree," indicating a high level of positive feedback; there were no responses in the neutral or negative categories. Key take-aways from the workshop were "great integration of various comments into one toolkit" and "the demonstration of the computational tools was very useful." Additionally, the workshop fulfilled their objective of learning about the "demonstration of the computational tool" and learning about "the software interface and basic functionality." They indicated that the workshop information was relevant and helpful to their specialty, and important *OpenSRA* features were the open-source executable and incorporation of fragility functions for components, systems, wells and caprock.

Additional results from the workshop survey, including all respondents, are presented in Appendix A.

CHAPTER 4:
Conclusions

The knowledge transfer plan for the *OpenSRA* project was implemented at the inception of the project with the establishment of project website (https://peer.berkeley.edu/opensra) which serves as a single central repository where all the project information, publications, and products are located. A visual identity and short written description of the project was developed and used consistently as each project milestone was announced. Research progress and results were presented in technical conferences and workshops. Project reports summarizing research accomplishments were published by the CEC and announced to the utility industry and research communities. All project milestones have been disseminated with the use of electronic and online media platforms with messaging that is consistent and focused. The message reaches an expanded audience when colleague organizations re-broadcast the original announcement.

It was especially beneficial for the project team to interact with the TAC that was comprised of decision-making and utility organizations. Input and feedback from the TAC helped to focus the project team's research and software development efforts.

The knowledge transfer plan successfully supports the project efforts that result in the emergence of the *OpenSRA* software tool.

As the development of *OpenSRA* progresses, additional project metrics would be appropriate in order to evaluate the uptake and utilization of the software, and the knowledge transfer plan would incorporate those metric goals. Additional activities in future knowledge transfer plans could include the following.

- Tracking the number of downloads of the software and user manual.
- Training workshops for utility users and consultants.
- User forums where questions and guidance can be provided.
- Forums where software features can be requested from users.
- Documentation of research case studies utilizing the software for demonstration purposes.

GLOSSARY OR LIST OF ACRONYMS

Term	Definition
CalGEM	California Geologic Energy Management Division
CEC	California Energy Commission
CPUC	California Public Utilities Commission
PEER	Pacific Earthquake Engineering Research Center
PG&E	Pacific Gas and Electric Company
SoCalGas	Southern California Gas Company
TAC	Technical Advisory Committee

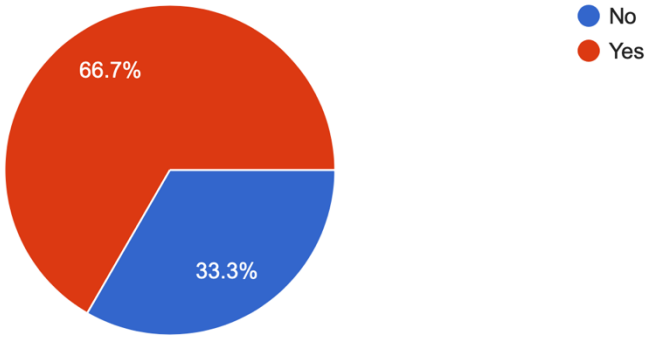
REFERENCES

Cornell, C.A. (1968), Eng Seis Risk Analysis, Bull. Seismo. Soc. Am., V58(5), 1583-1606, doi: 10.1785/BSSA0580051583.

APPENDIX A:
User Workshop Survey

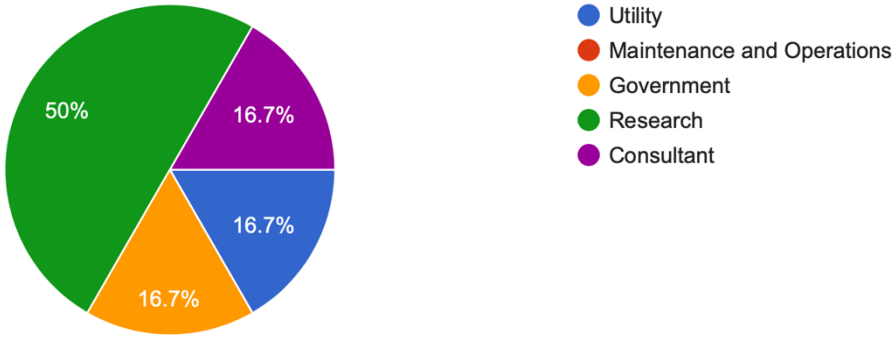
Are you a member of the OpenSRA project team? (If you are on the TAC, please respond "no.")

6 responses



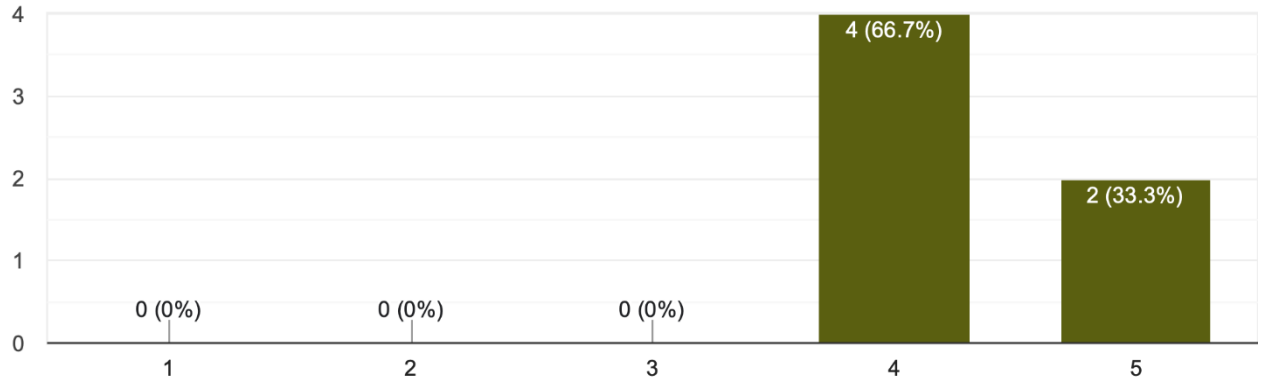
Your specialty

6 responses



How relevant and helpful do you think the workshop information was for your specialty?

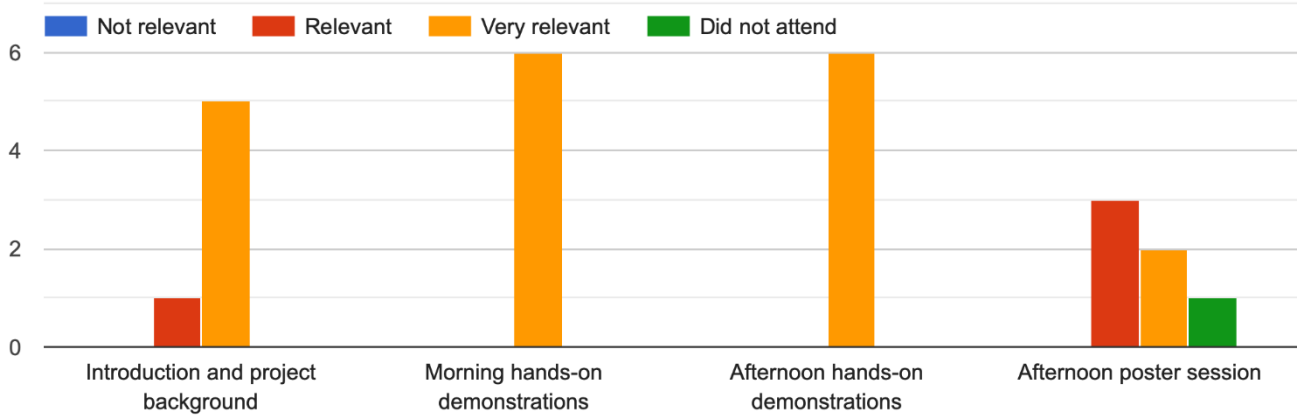
6 responses



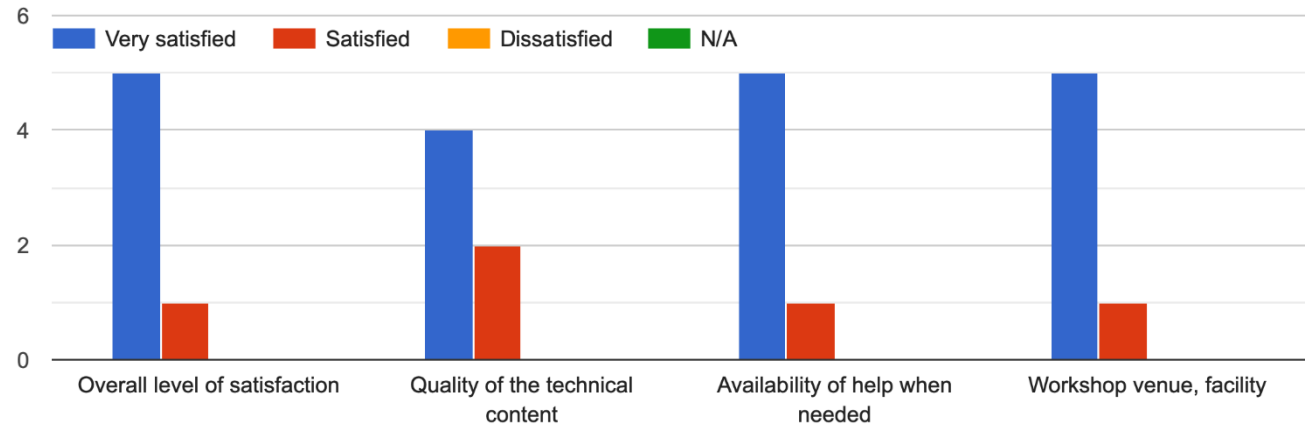
What were your key take-aways from this event?5 responses

- "The research group obviously put a lot of effort into developing a user friendly interface to assess seismic risk to pipeline infrastructure.
- Latest layout and use of opensra
- Great progress but shows a lot more testing needed
- Great integration of various comments into one toolkit
- The demonstration of the computational tool was very useful."

Which sessions did you find most relevant?



Please indicate your level of satisfaction with the Workshop



What were you hoping to learn or gain from the Workshop?6 responses

- "how to use the software
- How to use the new software
- Updates and status of the integration of the teams research into opensra
- how to run software
- The software interface and basic functionality
- Demonstration of the computational tool."

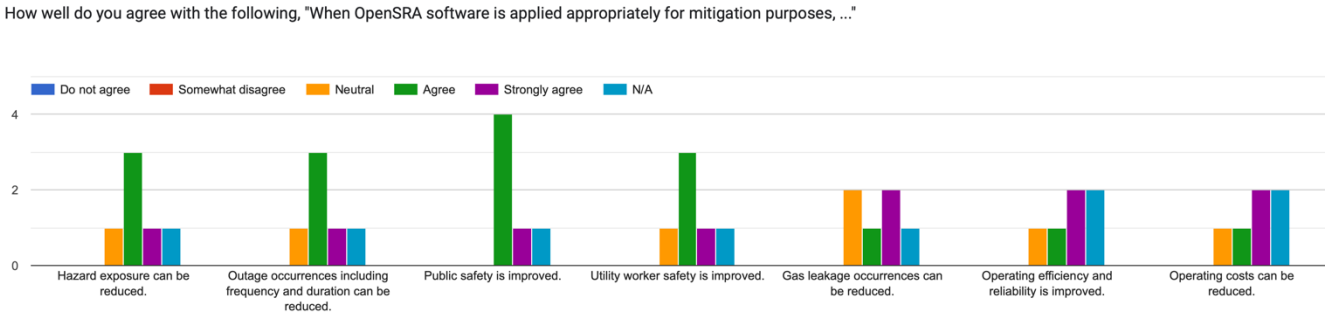
Did the Workshop deliver what you expected? Why or why not?6 responses

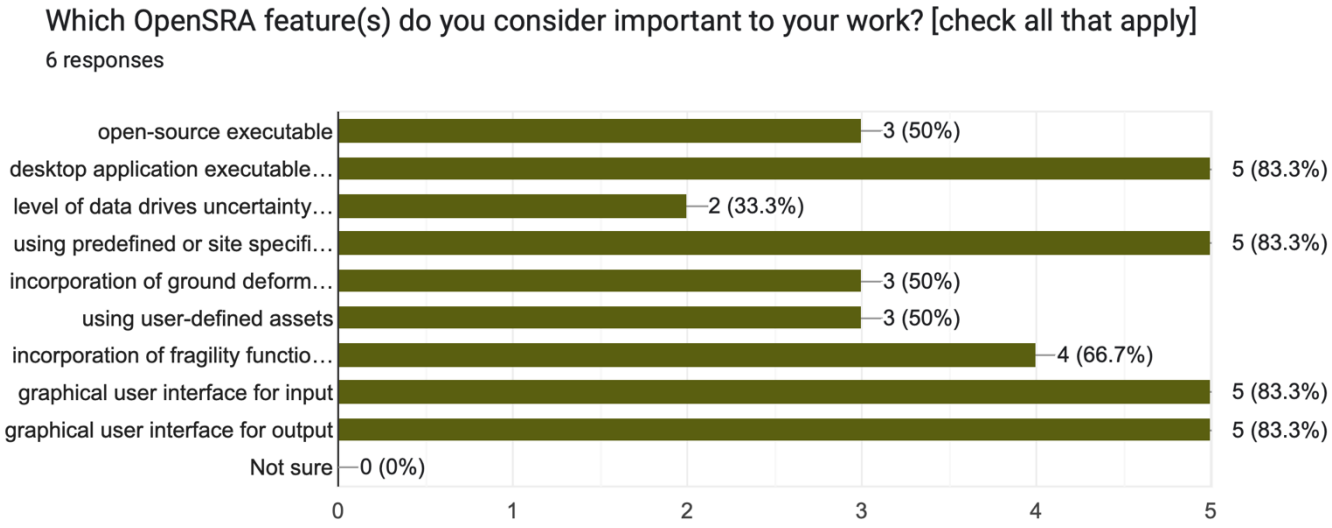
- "Yes
- yes
- Yes, they did a great job of showing off the software and patiently answering questions
- good start"

Overall, what was the *most* useful, interesting, and/or engaging aspect about this Workshop? What was the *least* useful aspect? Please explain your answers.6 responses

- "hands-on demo
- I enjoyed talking with the other participants to see how they would use the software
- Most useful were hands on work with the latest code - great job on the examples; least useful poster session (but it may be useful for some…)
- spending time with Barry and Jon on issues
- The hands on demonstrations are the most useful part. Hopefully more industrial end users will be engaged.

- The computational tool”





Thank you very much for your thoughts. Please share any additional comments or feedback you have about the workshop or the *OpenSRA* software.2 responses

- “The Haywired scenerio (Mw 7.25 on Hayward-Rodgers Creek) would have been good example to look at today
- Great work team!”