Development of a System for Visualization and Management of Information on the Earthquake Performance of Structures

S.A. Mahin, H.A. Faison, V. Terzic & J. Way
Pacific Earthquake Engineering Research Center (PEER), University of California, Berkeley

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SUMMARY:
Progress in realizing the goals of performance-based design has been thwarted due to the lack of data on the behavior of structures, systems and components during past earthquakes. A wealth of data is expected following each new earthquake that occurs. While considerable data is currently being obtained following these events, it is often not gathered in a quantitative manner or stored in databases that will facilitate searches to identify information of importance in the development of improved design and evaluation methods. To rectify this situation, a seismic performance observatory is described herein that is comprised of a federated of distributed databases, a rich set of object classes for quantifying seismic performance, and a user friendly user interface.

Keywords: Post-earthquake information systems, performance-based design, damage, reconnaissance

1. INTRODUCTION

Well-documented information gathered following major earthquakes on the performance of structures is indispensable in assessing and improving design, analysis, construction, and retrofit methods. Moreover, performance-based earthquake engineering (PBEE) methods and other risk reduction methodologies aimed at achieving structural resilience or other defined performance goals depend on the availability of data sets that reliably relate structural response to damage and associated impacts of damage. Similarly, those with responsibilities for emergency response and post-event recovery have needs for a wide variety of well-organized technical data regarding the characteristics of the earthquake, the underlying geology and soil conditions, the nature of the facilities and systems shaken, the types and, if known, causes of observed damages, and remediation efforts that have been made, scheduled or completed.

While almost overwhelming amounts of information have been gathered following recent earthquakes, information relevant to specific research projects, design applications or recovery efforts is often difficult to find and typically not accompanied by adequate metadata or tools to facilitate its analysis and visualization. Thus, there is a need for enhanced tools that will allow the earthquake engineering community to gather and share data and media from various sources and of various types. This information may take a wide variety of forms, ranging from geo-tagged and annotated digital images, video and audio files, satellite images, point clouds, material and soil test results, ground motion and in-structure response recordings, architectural and structural drawings, simple sketches, inspection reports, more detailed engineering and administrative reports, computer models, and so on. These data need to be 1) imported, stored and indexed, 2) sorted and visualized, and 3) analysed, interpreted and deployed in ways that provide value and support to end-users.

To meet this need, a new system for management and visualization of information on the seismic performance of structures is being developed by the PEER to import, search, analyze, and visualize a wide variety of earthquake and earthquake performance related data. The system is intended to provide a flexible, scalable, and robust visualization and management system that can be easily contributed to and accessed by users from around the world via the web.

2. OBJECTIVES

The mission of the Pacific Earthquake Engineering Research Center (PEER) is to develop, validate, and disseminate performance-based seismic design technologies for buildings and infrastructure to meet the diverse economic and safety needs of owners and society. PEER's research defines appropriate performance targets, and develops engineering tools and criteria that can be used by practicing professionals to achieve those targets, such as safety, cost, and post-earthquake functionality. Post-earthquake data is critical to understanding the threshold levels that result in these performance targets. The data and visualization system being developed by PEER will be an important tool to allow researchers, engineers and others to access information useful for designs and analysis utilizing PBEE principles. By synthesizing this data, fragility curves and other resources can be developed that allow engineers to conduct performance-based earthquake engineering (PBEE) assessments. Once this system fills overtime with data, researchers will be able to use it as a database of information that can inform their research.

Clearly, such a collection of information on seismic performance would have a variety of benefits outside of the narrower PBEE research community. These would include benefits to those involved with broader issues in design practice, emergency response, recovery planning, education, and so on.

3. BACKGROUND

The need to carry out post-earthquake reconnaissance, and distil and disseminate lessons learned from observed damages and impacts is well known. Following major earthquakes major reports have been prepared by government agencies, professional and trade organizations, universities and private companies) to document the earthquake and its effects (for example, the 1906 San Francisco (Lawson and Reid, 1908) and 1967 Venezuela (Hanson and Degenkolb, 1968), 1989 Loma Prieta (Astaneh et al, 1989) and other earthquakes). The Learning from Earthquakes program at the Earthquake Engineering Research Institute has produced for more than 4 decades a regular series of detailed reconnaissance reports following major earthquakes around the world (for example, Meehan, 1973). While this information is useful, the fact that it is in written report format makes it difficult to synthesize the information contained and extract quantitative information about the performance of particular types of structures.

With the advent of the Internet much more information is available and easily searchable. In earthquake engineering, several on-line repositories contain considerable digital information about the behaviour of structures in earthquakes. For example, the National Information Service for Earthquake Engineering (NISEE, 2012) has operated a physical and on-line library for nearly than five decades. Currently, this on-line library has nearly 20,000 catalogued digital images of earthquake damage as well as more than 40,000 documents on earthquake engineering. Similar efforts exist worldwide (for example, Fischinger, 2009; NICEE, 2012). In the past decade, other efforts have been developed to help relay information via the Internet to various stakeholders immediately following a seismic event. Some of these provide detailed reports (for example, GEER, 2012) while others resemble bulleting boards where various individuals can centrally post information from the field (for example, EERI, 2012a). In other cases, automated systems are used to provide various groups with automatic information for assistance in emergency response efforts (for example, Shoji et al, 2003 and Wald et al, 2007). Efforts to develop unified network communication middleware (UICDS, 2012) for exchanging information regarding of national emergencies among emergency responders, planners and managers have also been developed and hold promise to promote communications among a broad array of stakeholders. While these efforts provide useful information for the short and long term, they are not developed in the context of a database that can be used to access particular information, or to synthesize and analyse large sets of data to identify causal relations or develop generally applicable fragility information. An effort to develop an earthquake database related to structural performance has been undertaken by NEEScomm, where a spreadsheet like database has been developed for the recent Chile and Hatian earthquakes (NEEScomm, 2012). While such databases are a large step forward, they are collections that are limited in scope so that it is hard to relate damage to ground motion intensity, soil conditions, similar damages in other earthquakes in the same or different locations.

Several efforts have examined the need for quantitative, scalable, robust and extensible databases in the field of earthquake risk mitigation (NRC, 2011; USGS, 2007; EERI, 2003). These generally indicate the need for a comprehensive effort covering a range of natural hazards, as well as gathering data for a broad range of stakeholders, including those interested in the earth science, engineering and architecture, socio-economic impacts, and emergency planning, response and recovery.

4. CURRENT FUNCTIONALITY / FRAMEWORK

While a comprehensive database would be highly desirable, it appears that there is a specific and narrower need for information in support of engineering design and evaluation, with particular emphasis on performance based earthquake engineering and seismic risk assessment. As such, PEER has been developing a public seismic performance observatory database. The system has the functionality to easily import data objects, visualize imported and shared public data, and search data within the observatory database for use immediately following earthquakes or over time during ongoing research efforts, as discussed below.

In developing the seismic performance observatory, a few key concepts were developed. These include: the database should use modern federated (networked) database IT concepts, it should be object oriented so that new features can be easily added without disrupting other features, data may be locally stored but globally shared, a wide variety of data types would be permitted, and the maximum use of commercial software standards and tools would be used to avoid dependence on particular equipment, operating systems and devices. In support of these goals, the user interfaces are being developed as web applications in HTML5 operating from a remote server as well as on a local host.

The observatory is envisioned as an environment for conducting research or other detailed studies. As such, emphasis has been placed on gathering detailed quantitative, and technically oriented information, rather than on gathering vast quantities of less detailed information that might be gathered from social media. However, to facilitate the acquisition of data, substantial attention is being placed on making its input as automatic and simple as possible.

4.1 Importing Data Objects

The system utilizes an object oriented programming approach with a modular configuration that allows it to ingest wide varieties of information and to tag it with metadata. Current classes of objects include earthquake events (name, location, magnitude, etc.), built entities (buildings, bridges, etc.), and damage. Subclasses for earthquake events include: ground motion response (strong motion instrumentation), documents (reconnaissance reports, maps, etc.), etc. Built entities include subclasses associated with: structural configuration, site conditions (drilling logs, Vs30 values), structural components (beam, columns, foundations, etc.), non-structural components (partitions, ceilings, etc.), contents (computers, etc.) and so on. Subclasses for damage include overall damage scales, post-earthquake safety ratings (tags), inspection reports, information on functionality of the facility, as well as specific data on the types and severities of damage associated with particular components or contents, such as spalling, fractures, leaking pipes, functionality, etc.). See Fig. 1 for a few screen shots. Currently, emphasis is on a few of these classes, with the anticipation that other future users will assist by extending or adding object classes. Metadata is input by those initially entering data, but can be augmented or corrected by subsequent users (with a record of all changes, and additions).

Many types of information may be input in addition to short narrative descriptions, including: geo-tagged and annotated digital photographic and video images or point clouds, ground motion and in-structure instrumental records, audio files, digital databases of geotechnical, structural and other measurements, files containing structural drawings, computer analysis models, inspection reports, structural evaluations, reconnaissance reports, etc. Importing tools are being developed to maintain scalability of the system by reducing manual processing.

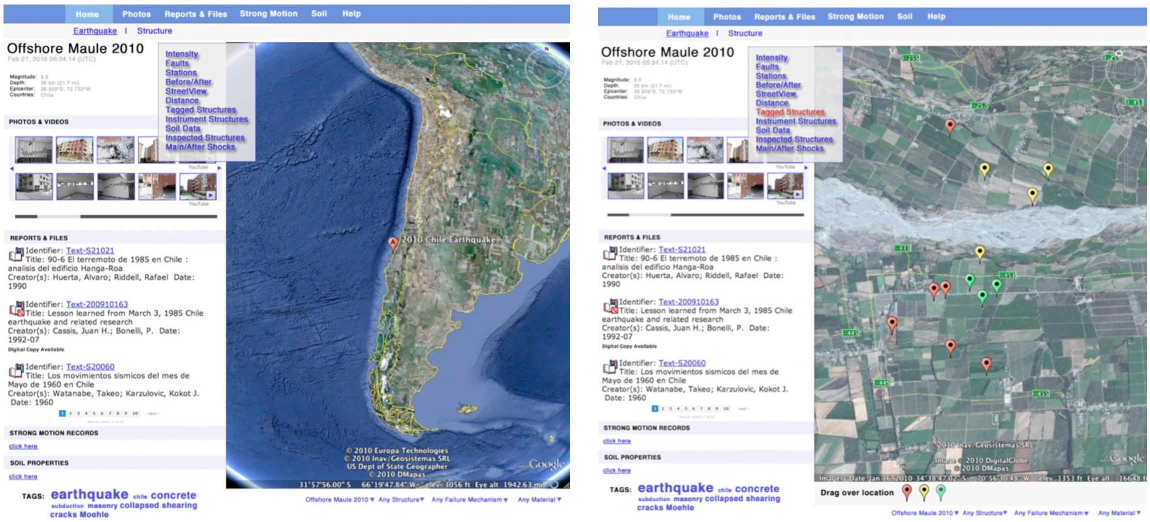

Figure. 1 Screen shots of structural performance observatory GUI showing earthquake event information and building tagging information

Meta data is broadly defined, so that users can search for all information about a particular building, a particular type of structure during a particular earthquake, the behaviour of similar structures over all earthquakes in the database. To ensure that this search functions properly, each data object imported to the database is carefully tagged with metadata, by the person importing the object. Figure 2 shows how the importing system interface allows the user to classify a data element for a building into useful taxonomies that can be used in a database search. This also allows users do define new types of metadata. The taxonomy chosen was developed from a variety of sources to ensure broad applicability and usefulness. These sources include: ATC (2005), EERI (2012b), FEMA (2007), FEMA (2012), GEM (2012).

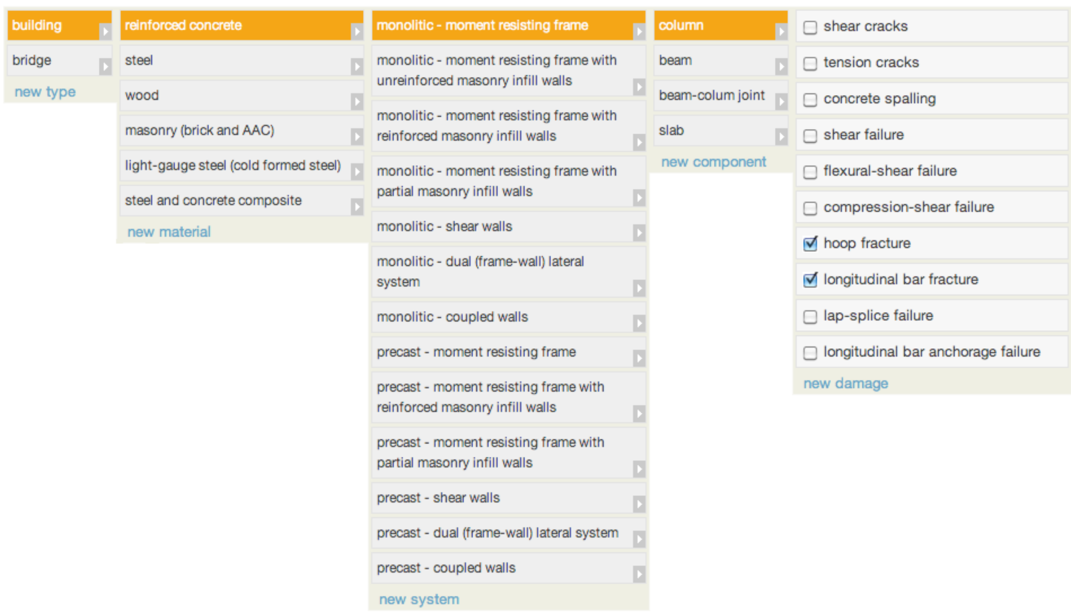

Figure 2. Damage selection for the component of the selected structural system.

Detailed as well as general descriptors of damage are permitted. It is important to recognize in the development of fragility information in support of PBEE, that information on the absence of damage is important to gather. In addition to numeric, descriptive, and narrative descriptions of damage, a wide variety of digital imagery is possible to associate with sites, structures, components and contents.

In addition to allowing users to manually enter data objects, the system can display and search data from other similar databases. The underlying federated database network for the observatory permits information in other databases to be included in the overall assembly of information available to the user. PEER is working to develop partnership agreements with various governments, academic, professional and research organizations to access their databases. For example, information from USGS on earthquake name, location, magnitude, severity of shaking, and so on can be automatically accessed within the seismic performance observatory's GUI. Similarly, information from PEERs existing databases of geotechnical site information, past earthquake records, fragility curves and so on are available. Literature and other on-line documents can also be accessed from within the interface.

Thus, other organizations that develop earthquake specific databases, or specialized databases on particular types of structures, systems and components can participate and benefit from access to other information available in the observatory. By integrating public information from various sources, the system will be able to provide a useful, single-stop resource for researchers in the field after an earthquake doing reconnaissance or for investigating data from earthquakes in the past.

4.2 Visualizing Data

The observatory system leverages currently available visualization technologies and GIS tools (i.e. Google Maps, Google Earth, open source KML, etc.) to allow data to be layered and displayed on a map. Thus, as indicated in Fig. 2, users can view the vicinity of an earthquake from the observatory window, and activate tags and overlays showing fault locations, severity of ground shaking at different sites, epicenter locations, instrument locations (and access records from these instruments when available), soil conditions, emergency inspection tagging reports, field reconnaissance inspection reports, as well as availability of digital images and technical information. Some of this data is available immediately and automatically after the earthquake (i.e. ShakeCast Maps from USGS, etc.).

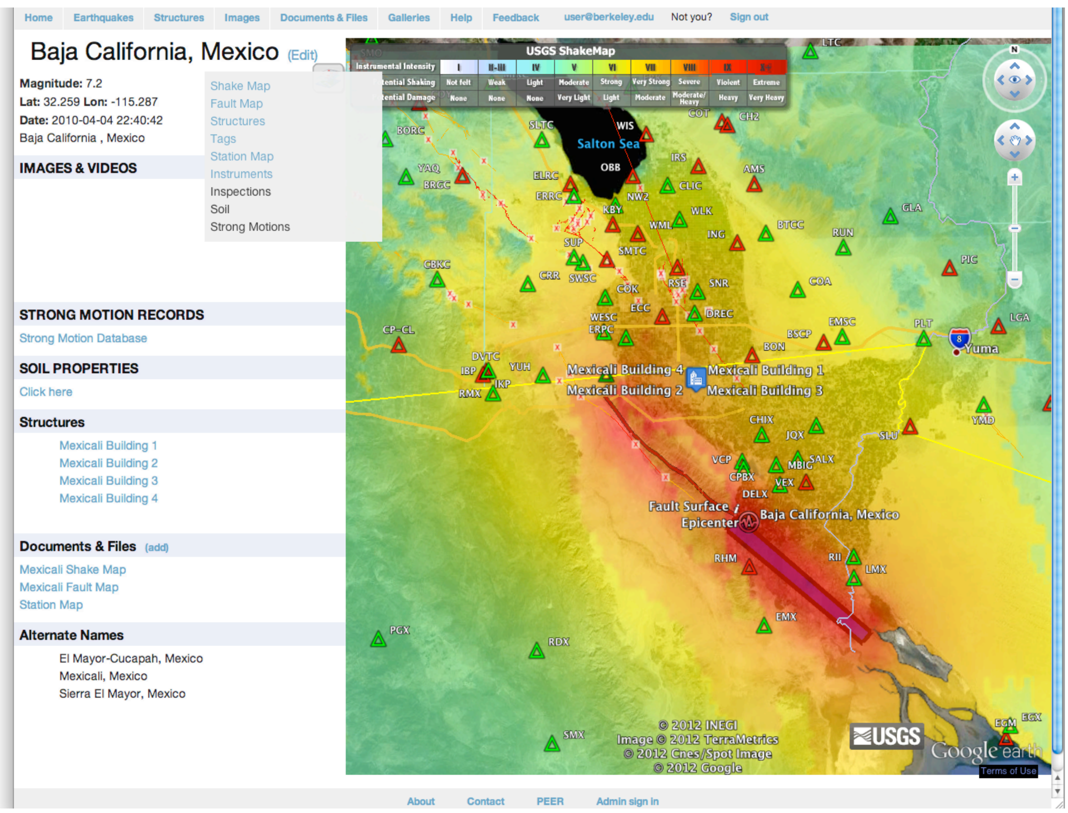

Figure 3. Screenshot of GUI showing various layers of data that were obtained after the 2010 Baja California

Earthquake including the ShakeCast Map, IRIS ground motion stations and fault locations.

By taking advantage of standard web services, users can use tools such as Google Streetview to view images of a neighborhood before, immediately following and after various time intervals (depending on availability). Icons showing locations of available information (photos, reports, etc.) are being enabled for display on Streetview images. See Fig. 4.

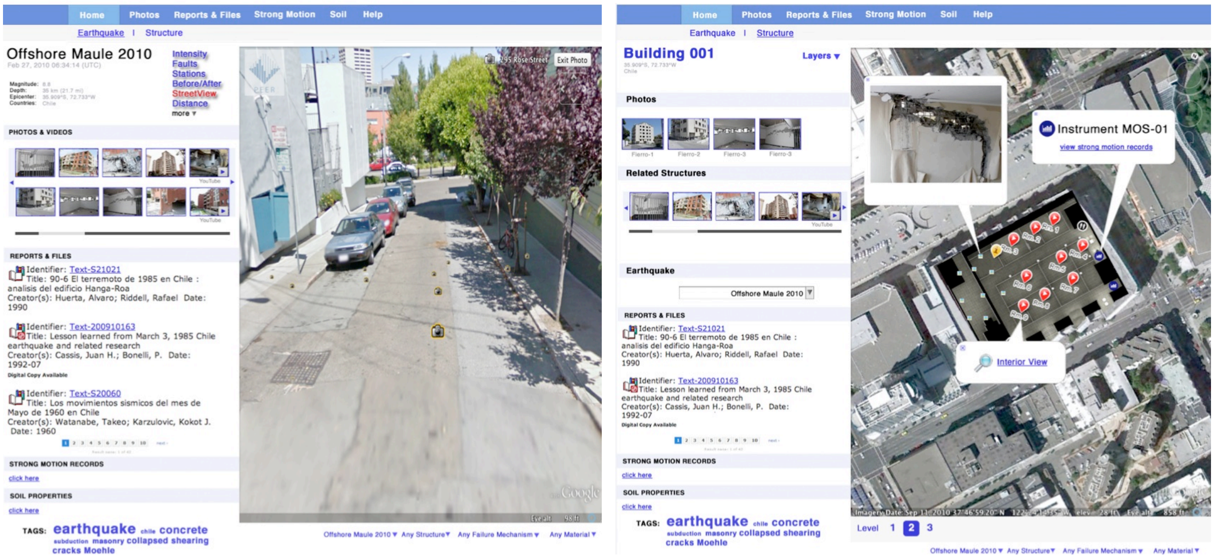

Figure 4. Streetview type images with photo icons and Google Earth with detailed information on available information in building identified.

One of the strategic benefits of this system is that information about particular facilities can be pre-populated into the database in advance of an earthquake. Thus, building drawings, analytical models, construction and inspection reports, and so on can be entered prior to a seismic event. This data can be used as part of inventories of potentially hazardous structures, such as unreinforced masonry buildings, nonductile concrete buildings, buildings with soft first stories, and so on, or of particular types of structures of interest to a research group (steel buildings, tall buildings, hospitals, etc.). As such, these efforts can help in guiding post-earthquake reconnaissance efforts by identifying buildings of interest. Researchers, engineers, and others are encouraged to help with this effort.

Alternate visualization tools, such as 3D models, high-resolution image galleries, and tools using plots/charts/tables, are being considered to perform different types of data analysis that will enrich the user's experience and provide them the capability to search, compile, and gather data in ways that best fit their needs.

4.3 Searching the Data

The seismic performance observatory is intended to be more than just an information repository. It is envisioned as a useful and powerful research tool that relies on robust search capabilities. This search is made possible through the careful meta-data tagging that utilizes the taxonomy structure discussed in the section 3.1, and the use of a formidable database management system that provides long-term data archival capabilities.

One can use the observatory to find available information about a particular facility (soil type, likely intensity of shaking, damage reports from various investigators, photos, reports and so on. In addition, the user can find other related structures of interest (Fig. 5). For example, the user can search by arbitrary combinations of metadata, so that sets of buildings located on certain types of soil conditions, having peak ground accelerations exceeding some threshold or having a particular type of damage can be identified. Similarly, buildings having similar characteristics, such as construction materials, height, age, etc. can also be identified, for one or several earthquakes.

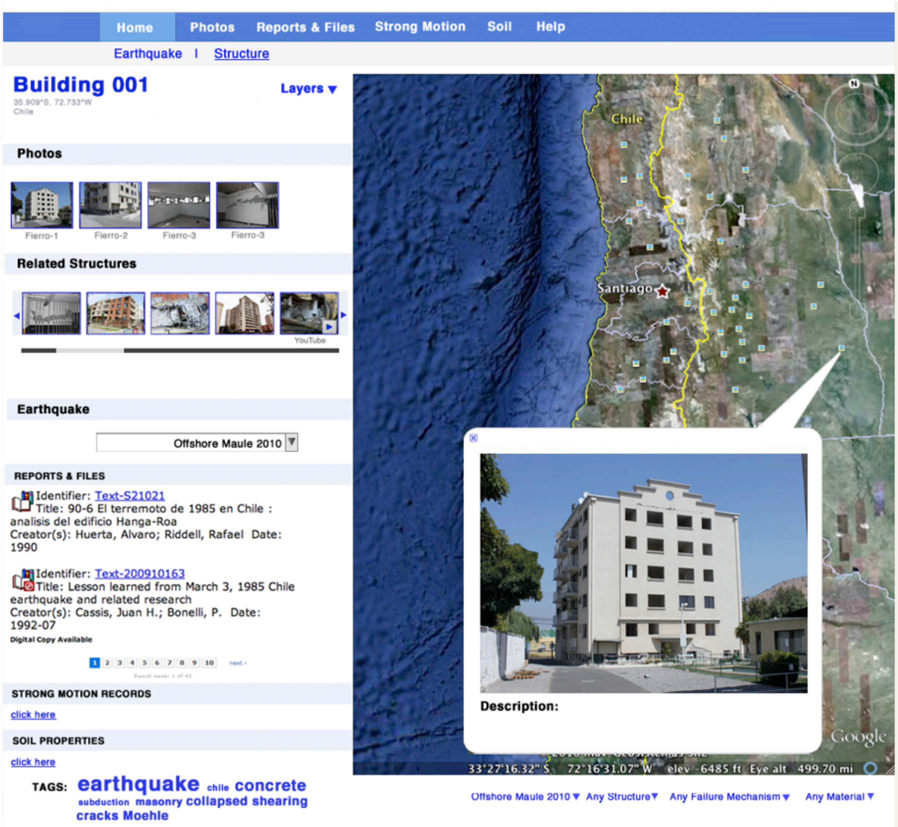

Figure 5. Screenshot of GUI showing the results of a sample search for a specific building.

By having the system have access to various public data sources, the system reach outside of existing organizational boundaries and provides widespread access to information. Furthermore, using the search feature to link archived data with ephemeral data (i.e. news, news photos, announcements) creates a richer search experience and further improves the decision making process for researchers and others involved in post-earthquake research and planning efforts.

5. VISION FOR FUTURE USES

The system is expected to grow over time to include a large amount of data from various earthquakes around the world. Work is currently underway to import existing data from several historic earthquakes, as well as importing pre-earthquake data for communities with high earthquake risk for comparison purposes after future earthquakes. While the uses of this system are both broad and diverse, several scenarios described below outline the expected possible future uses of this system.

5. 1 Scenario #1: Pre-planning earthquake reconnaissance

During earthquake reconnaissance immediately following an earthquake, various teams are deployed into the field to gather data. Often these teams visit the same sites repeatedly. With the use of this system, teams in the field could be deployed strategically to instrumented buildings or bridges that had been pre-populated with information, to areas with the greatest shaking intensity, to areas in the vicinity of seismographs, etc. Similarly, once deployed to the field following an event, investigators would benefit from information in an integrated web based environment as to the types of soil, intensity of shaking, and any information that had been previously uploaded by others. Rather than duplicating information already obtained, field investigators could focus on supplementing and augmenting this information, or inspect other structures.

5.2 Scenario #2: Identifying commonalities leading to seismic vulnerability

One of the more difficult tasks in interpreting post-earthquake data, is collecting, synthesizing and interpreting data about seismic performance from multiple earthquakes. While narrative reports exist on individual earthquakes, and some databases exist for a few earthquakes, it is difficult to examine these as a whole. Thus, care has been taken to facilitate studies by researchers who are hoping to identify common triggers for damage. Searches where investigators can look at similarities of damage in particular types of structures (say 4 story or less nonductile concrete frames) situated on particular types of soil and subjected to similar levels and types of ground shaking. By having such search features, the level of ground shaking that might trigger various levels of damage (empirical fragility curves), or the area of walls as a function of floor area that might preclude structural damage for a given level of shaking, might be identified.

5.3 Scenario #3: Environment for detailed post-earthquake investigations

While many investigators study various aspects of earthquake damage following major events, this information is often lost or ineffectively used. In part, this is because information on these studies is difficult to locate, and in most cases, detailed information, such as structural drawings, photos, computer analysis models, and calculation results are not made available to the public. This information is stored on the investigators hard drive, archived and eventually forgotten. By enabling investigators to carry out their research within personalized layers in the observatory, the investigators will be able to organize and document quantitative data about their project and to release it to the public at the conclusion of their study. In this way, they have an archival means of storing their work, and others can benefit from the detailed findings and data.

6. CONCLUSION

PEER hopes that this system will grow over time through the support of earthquake engineering research and professional communities. Only with the addition of data from future earthquakes and the pre-population of existing data will this system become the useful resource that PEER envisions – a tool that can enable, support and advance performance-based earthquake engineering.

This system has limited scope and is not intended to be able to record all types of information of interest to all members of the earthquake engineering community. However, it is intended that the object oriented programing approach and features built into the observatory will allow community members to add meta data and add classes as needed for broader utility. Moreover, a cornerstone of the observatory is the underlying federated database concept. By establishing more formal agreements, protocols and procedures for data sharing, it is believed that detailed quantitative information for the use of the engineering community can be made available to accelerate progress to realize the goals of performance based design and seismic risk mitigation.

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