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USING SHAKEMAP AND SHAKECAST FOR POST-EARTHQUAKE RESPONSE AND DAMAGE ASSESSMENT

Kuo-Wan Lin[1], David J. Wald[1], and Loren L. Turner[2]

ABSTRACT

The U. S. Geological Survey (USGS) ShakeMap is a well-established tool used to portray the extent of potentially damaging ground shaking following an earthquake. ShakeMap provides spatially varying shaking hazard information which helps in loss estimation, emergency response, and public information about extent of shaking immediately after an earthquake. ShakeCast, short for ShakeMap Broadcast, is a full-featured freely-available software application for rapid post-earthquake response and damage assessment. In addition to real-time notification, ShakeCast also includes routine system testing and earthquake scenario capabilities. The ShakeMap/ShakeCast combined system allows a consistent approach for the evaluation of facility performance using the ShakeMap methodology by combining observations with ground motion predictions and covers major geographic regions and earthquakes, real-time, historical, and scenario, worldwide. The most recent ShakeMap update provides additional metrics of engineering interest, including intensity-based prediction equation, estimated uncertainties in PGA values and Vs30 values, as well as improved detailed processing parameters. The ShakeCast update, a product of the Caltrans-supported ShakeCast research and development, enables association of facilities with specific recording stations, access to new ShakeMap metrics, creation of user-defined metrics, and inclusion of custom fragility modules for populating the user-defined metric and for damage assessment. ShakeMap and ShakeCast software and products are freely available on the Internet at http://earthquake.usgs.gov/shakemap.

Introduction

Situational awareness in the immediate aftermath of a disastrous earthquake is of fundamental importance for effective societal response. While overall disaster management is critical, a successful, organized response is dependent on the collective efforts of the community at large. When a potentially damaging earthquake occurs, businesses, utility and other lifeline managers, emergency responders, and others have an urgent need for information about the impact on their own facilities so they can make informed decisions and take quick actions to ensure safety, restore system functionality, and minimize losses.

[1] U. S. Geological Survey, Denver Federal Center, P.O. Box 25046, MS 966, Denver, Colorado, CO 80225
[2] Senior Transportation Engineer, Caltrans, 5900 Folsom Blvd, Sacramento, CA, 95819

We first provide a brief overview of the combined ShakeMap/ShakeCast software. Next, we address the procedures available for assessing potential damage to users' facilities. Example uses and users are provided to illustrate the range of potential ShakeCast applications. Finally, ongoing development of both ShakeMap and ShakeCast applications and functions are outlined in the Discussions and Conclusions section . While this report provides an overview of the ShakeCast system with emphasis on methods of damage assessment, potential users are encouraged to consult ShakeCast publications for more comprehensive details regarding the system and operation (Wald et al., 2008; Wald and Lin, 2007; Lin and Wald, 2008).

The Shakemap/Shakecast Combined System

The U.S. Geological Survey's (USGS) ShakeMap (Wald et al., 1999b, 2005) is now a well known and widely available tool used to portray the extent and severity of ground shaking following an earthquake. The ShakeMap products have evolved from initial Web display to include high-resolution graphics files, maps made specifically for television, GIS files for direct input into the FEMA's HAZUS (NIBS and FEMA, 2003) loss estimation software, as well as gridded extensible markup language (XML) and Google Earth (KML) data files, all of which are now also automatically generated. ShakeMaps can be used for a wide range of needs, including emergency response, loss estimation, scientific and engineering analyses, and public information. In order to assist critical users to move beyond simply looking at ShakeMap and to begin implementing response protocols, the USGS has developed ShakeCast that utilizes the known shaking distribution in fully automated systems.

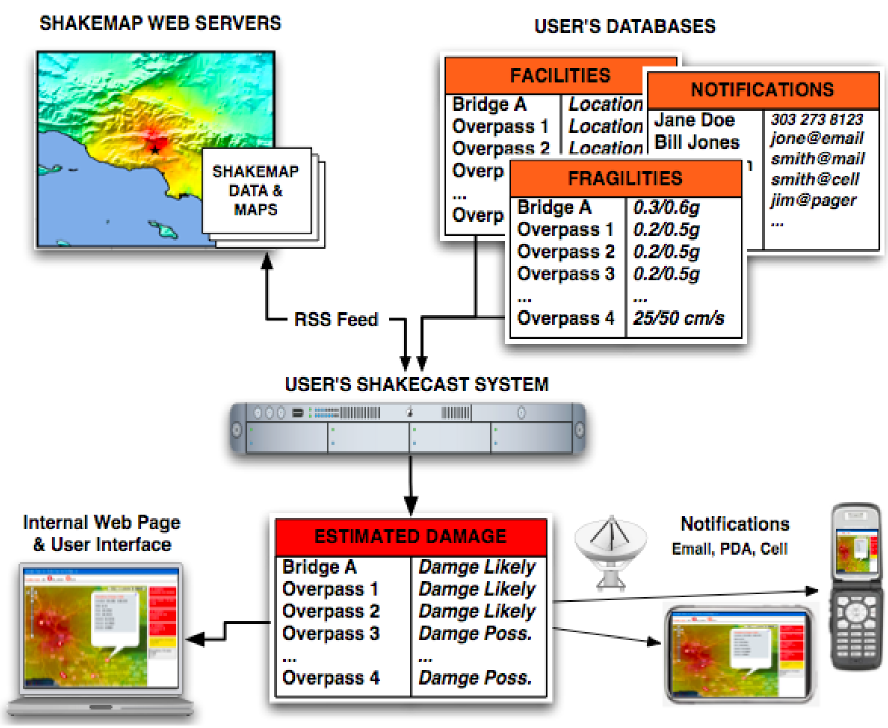

Figure 1. ShakeCast flowchart showing the conceptual flow of USGS ShakeMap data, users' ShakeCast inventory and user databases, and notifications.

ShakeCast (http://earthquake.usgs.gov/shakecast), short for ShakeMap Broadcast, is a fully automated, freely-available open-source system for delivering specific ShakeMap products to critical users and for triggering established post-earthquake response protocols. ShakeCast allows utilities, transportation agencies, and other large organizations to automatically determine the shaking value at their facilities, set thresholds for notification of damage states (typically green, yellow, and red) for each facility and then automatically notify (via pager, cell phone, or email) specified operators, inspectors, and others within their organizations responsible for those particular facilities in order to prioritize inspection and response. A conceptual diagram showing the ShakeMap/ShakeCast flow of data and information is shown in Fig. 1. The basic pre-earthquake set up and post-earthquake response timeline is outlined in Fig. 2.

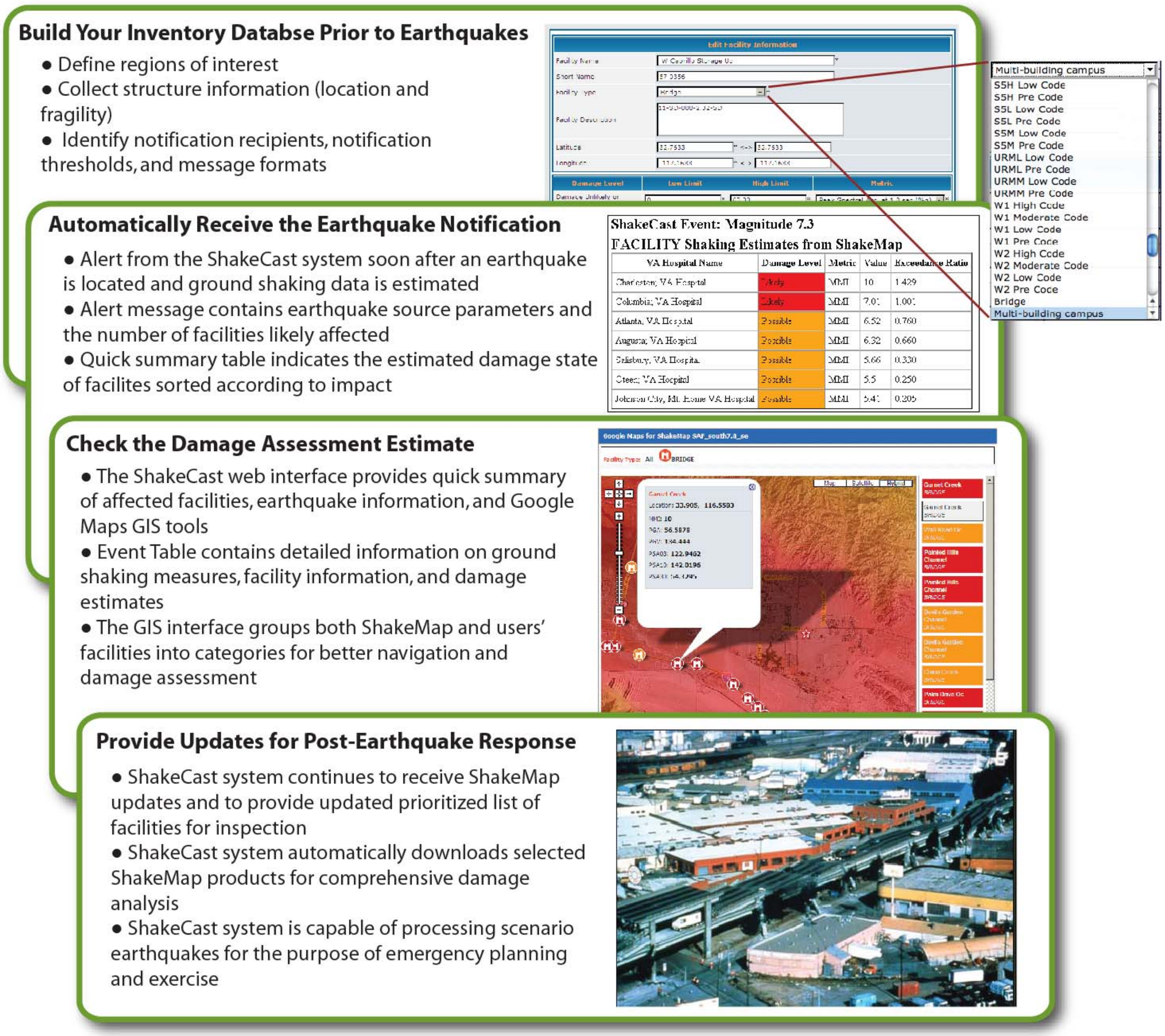

Figure 2. ShakeCast overview from the users' perspective.

ShakeMap-Based Damage Assessments

ShakeCast offers users different options for estimating impact to their facilities and infrastructure, and thus allows different criteria for sending notifications. Simplified damage estimates can be made based on current ShakeMap ground motion parameters, namely peak horizontal ground acceleration (PGA), peak ground velocity, and 5% damped elastic spectral acceleration (0.3, 1.0, and 3-sec periods) as well as Instrumental Intensity (Wald et al., 1999a). This includes damage relationships that can be pre-computed into look-up tables, and produces a multiple-state discrete output. At present, three common approaches are being used to provide users with an indication of damage: HAZUS-based, Intensity-based, and customized damage functions.

Predefined (HAZUS) Structure Types

For users whose portfolio of structures is comprised of common, standard designs, ShakeCast offers a simplified structural damage-state estimation capability adapted from the HAZUS-MH earthquake module (NIBS and FEMA, 2003) with a total of 128 choices of HAZUS model building type and code era. The color-coded alert levels index the likely structural damage state of the facility, in HAZUS terms: green corresponds to HAZUS' undamaged or slight structural damage states, yellow corresponds to moderate structural damage, orange to extensive structural damage, and red to complete structural damage. In ShakeCast, a facility is indicated user-predefined inspection priority or damage levels (i.e., green, yellow, orange, or red) when the PGA is such that there is at least a 50% probability of exceeding the corresponding HAZUS structural damage state and less than a 50% probability of the next-higher HAZUS structural damage state. These PGA values are taken from the HAZUS-MH Technical Manual Table 5.16a-d.

Intensity-Based

For facilities without known damage functions, that contain a variety of structures, or that represent exposed populations (cities, for example), users may simply want to be notified when the shaking reaches or exceeds some predefined intensity level. In this way, users fall back on the average effects described for each Modified Mercalli Intensity (MMI) value. Users select the range of intensities that constitute thresholds of concern (for example, green, yellow and red at intensity ranges MMI $<$ V, V $\leq$ MMI $<$ VII, and MMI $\geq$ VII, respectively) and receive notifications based on ShakeMap Instrumental Intensity values if the trigger thresholds assigned are matched or exceeded at their facility locations. The Intensity-based approach is useful for an organization's preliminary installation of ShakeCast while they further investigate the development of fragility relationships specific to their inventory, perhaps via performance-based earthquake engineering analysis.

Customized Damage Levels

Users who have previously analyzed the fragility of their structures can encode their fragility information in look-up tables that contain discrete ground-motion thresholds between damage states. For instance, as described in the section on the California Department of Transportation (Caltrans) ShakeCast implementation, Caltrans has produced its own set of damage functions that correspond to the specific design details of each California bridge or overpass in its jurisdiction. Each bridge has a unique fragility associated with it in the system's database, based upon bridge damage models originally published by Basöz and Mander and implemented in FEMA's HAZUS software. The fragility models are based upon 1-sec peak-spectral accelerations, and take into account bridge geometry (e.g., span lengths, number of spans, column heights, skew); year of design, construction, and retrofit; and component material types. The results are presented in a context of "inspection prioritization" to avoid any perception that the analysis represents actual damage conditions. Inspection priorities are coded as RED, ORANGE, YELLOW, and GREEN, corresponding to high, medium-high, medium, and low "priority for full engineering assessment."

When a desired measure for assessing potentials of facility damage is not part of the standard ShakeMap metrics or the customized damage levels cannot be pre-computed, users can create a user-defined module with functions for assessing facility damage levels and attach it to the ShakeCast system. Any representative metric in a newly-defined module is automatically generated as part of the ShakeCast process so that it can be used for damage assessment of facilities in real-time. This flexible design will allow, for example, the introduction of new hazard parameters (e.g., duration-based), vector-based combinations of parameters, or more complex damage functions.

Caltrans ShakeCast Implementation

In 2005 the Caltrans initiated a research contract with USGS to develop and implement a Caltrans-specific version of ShakeCast. The net result of this collaboration is release of the ShakeCast Version 2. Caltrans is one of the early adopters of the software and is currently operating ShakeCast (deployed in June 2008), on two redundant servers at the Transportation Laboratory in Sacramento, California, to support a group of responders responsible for post-earthquake bridge inspections. The servers operate 24/7 and rely upon a robust system of Departmental mail servers to distribute notifications. For earthquakes greater than magnitude 4.0, ShakeCast automatically determines the shaking value at the locations of the appropriate subset of over 12,700 bridges and facilities, compares these to pre-established thresholds for each facility, and distributes email messages to specified responders within 15 minutes of the event. The email messages contain general information about the event, a table of bridges sorted by inspection priority, and links to other relevant information. In addition, it automatically generates local products for direct use in Google Earth®, ArcGIS®, and Excel®.

During the test deployment phase of Caltrans ShakeCast, in the July 2008 earthquake of magnitude 5.4 near Chino Hills, only one bridge sustained significant damage. The damage included concrete spalling and transverse displacement of a deck span at the center pier. This was identified in the initial Caltrans ShakeCast notification as the 30th highest inspection priority out of over 300 bridges assessed by the system. A follow-up notification message (based upon more comprehensive ground motion measurements) identified this bridge as the third highest inspection priority out of over 400 bridges assessed (Fig. 3). This event, although not considered major, provided an excellent opportunity to fully exercise ShakeCast capabilities during the test deployment phase and build confidence in the system. The number of subscribed ShakeCast users has steadily increased to over 200 since its deployment.

M 5.4 - 4.0 mi SE of Diamond Bar, CA (ID: 14383980 - 5)

Facility ID	Type	Description	Inspection Priority	Latitude	Longitude	MMI	PGA (%g)	PGV (cm/sec)	PSA03 (%g)	PSA10 (%g)	PSA30 (%g)
53 2078K	BRIDGE	Valley Blvd UC	Medium-High	34.06132815	-117.789393	VI	18.4398	16.3272	34.1435	34.7184	1.9088
53 2078	BRIDGE	Valley Blvd UC	Medium-High	34.06132815	-117.789393	VI	18.4398	16.3272	34.1435	34.7184	1.9088
53 1431	BRIDGE	183Rd Street OC	Low	33.86645555	-118.0504159	V	9.1634	9.1547	16.1002	10.4814	0.9226
53 1711	BRIDGE	183Rd Street UC	Low	33.86542969	-118.0984937	V	10.6026	8.7775	20.8425	10.9765	0.8774
53 1710	BRIDGE	195Th Street OC	Low	33.85333495	-118.0948803	V	11.1974	10.3711	23.0812	13.951	1.0535
53 0446K	BRIDGE	3Rd Street On Ramp UC	Low	34.03278423	-118.1816918	VI	17.9782	12.4222	29.0013	10.2643	0.757
53 0756S	BRIDGE	3Rd Street On-Ramp OC	Low	34.03196462	-118.1841895	VI	17.9782	12.4222	29.0013	10.2643	0.757
55 0218	BRIDGE	Acacia Street UC	Low	33.85394685	-117.8980016	VI	13.7223	13.6304	26.586	13.6263	1.1072
53 1995	BRIDGE	Amelia Avenue OC	Low	34.12001074	-117.8201169	VI	13.8433	11.5879	26.7183	16.1847	1.0873
53 1994	BRIDGE	Amelia Avenue UC	Low	34.12001893	-117.8202896	VI	13.8433	11.5879	26.7183	16.1847	1.0873
53 1949	BRIDGE	Amelia OH	Low	34.10103354	-117.8194318	VI	14.6567	11.5349	27.5691	16.0555	1.08
53 1954	BRIDGE	Arrow Hwy UC	Low	34.1066719	-117.8217228	VI	14.6567	11.5349	27.5691	16.0555	1.08
53 1434	BRIDGE	Artesia Blvd OC	Low	33.87316036	-118.0601826	V	9.4884	8.9648	16.8373	10.6224	0.9109
55 0139	BRIDGE	Artesia Blvd UC	Low	33.87314502	-118.0099393	V	12.4527	11.1869	21.8529	11.7813	1.0032
53 1735	BRIDGE	Artesia Blvd UC	Low	33.87245805	-118.1011756	V	10.6026	8.7775	20.8425	10.9765	0.8774
55 0466	BRIDGE	Associated Rd UC	Low	33.90696799	-117.8818509	VI	18.9134	15.7061	42.6271	12.4998	0.9158
53 1977R	BRIDGE	Auto Centre Drive UC	Low	34.1167	-117.825	VI	15.3083	12.5948	30.5016	15.7231	1.1173
53 1977L	BRIDGE	Auto Centre Drive UC	Low	34.1167	-117.825	VI	15.3083	12.5948	30.5016	15.7231	1.1173
53 1789	BRIDGE	Azusa Ave OC	Low	33.99702061	-117.9312269	VI	18.9468	12.5394	26.2054	14.1799	1.014
55 0670	BRIDGE	Ball Road OC	Low	33.81818638	-117.9181686	VI	13.974	13.1189	27.4383	13.7133	1.1867
55 0524	BRIDGE	Ball Road OC	Low	33.81823356	-117.8764329	V	11.6865	10.6207	24.6269	11.4164	1.0088

Figure 3. Caltrans ShakeCast bridge inspection priority table for the magnitude 5.4, July 2008, Chino Hills, Los Angeles earthquake.

Scenarios and Historic Earthquakes

In addition to real-time notification, an additional benefit of the ShakeMap/ShakeCast combination is its built-in capacity to generate and deliver scenario earthquakes (Fig. 4) for evaluating system performance and response capabilities under earthquake conditions. ShakeMap is now used routinely to generate earthquake scenarios for many users and numerous scenarios are available online for most ShakeMap regions. ShakeCast further allows users to test their response capabilities with the same notification tools that will be available when responding to a real earthquake. ShakeCast can be configured to notify all or just a subset of the users for scenario events, thus scenarios can be practiced at a predetermined level of participation within an organization or group of organizations.

As with scenarios, ShakeCast users can also access and process any historic earthquake run through the Atlas of ShakeMap (Allen et al., 2008) to evaluate either the impact that such an event would have or to assess the level of accuracy with their vulnerability assessments (in comparison to actual impacts due to a historic event). The Atlas database consists of a collection of ~5,500 earthquakes worldwide with input peak ground motions, macroseismic intensity data, and finite-fault information for approximately 600 best constrained recent and historical global earthquakes. The Atlas is regularly updated and provides a consistent and quantitative description of the distribution of shaking intensity for events 1973 to 2008. What's more, by injecting all regional and sufficiently strong ShakeMaps into their local ShakeCast system, a user can evaluate how often and to what degree any of their inventories has been shaken in the past 40 years, a useful analysis that would otherwise be more difficult to make.

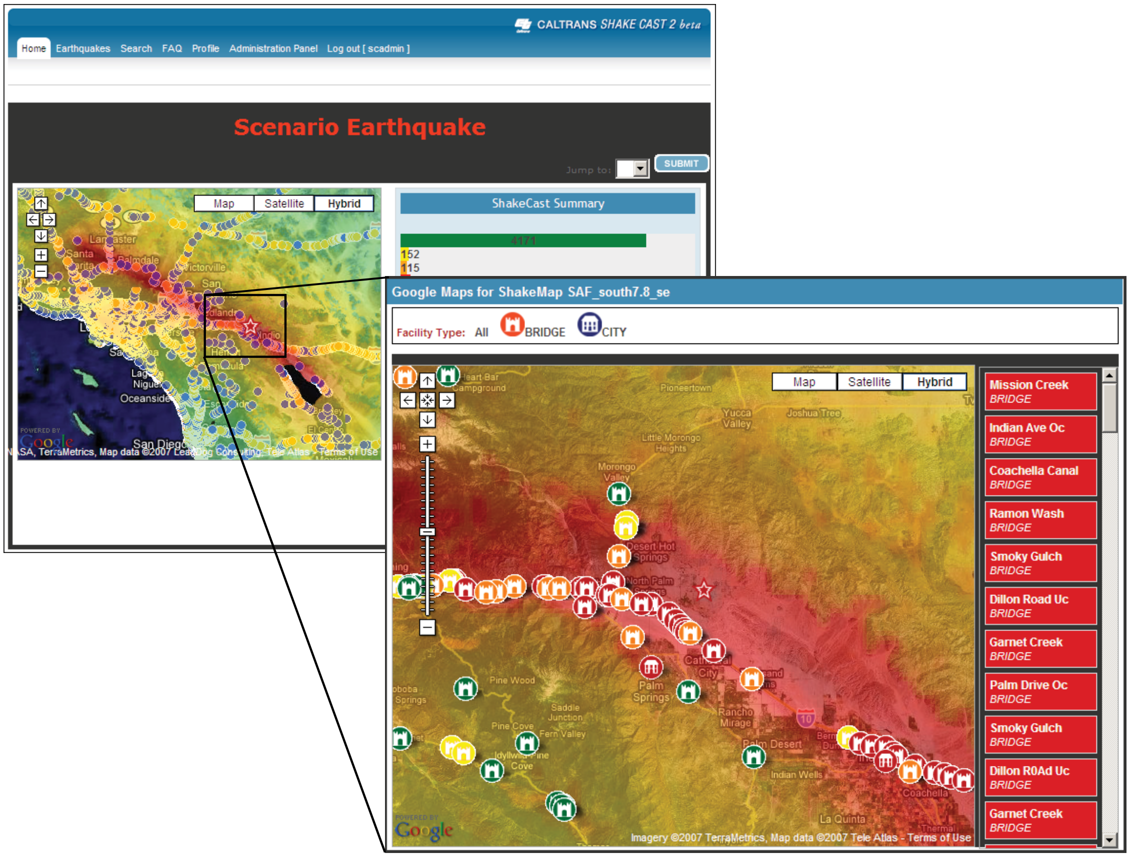

Figure 4. The ShakeCast summary page in mapping mode for the ShakeOut Earthquake Scenario (magnitude 7.8, southern San Andreas fault, California).

System Integration and User Support

As an open technology platform, ShakeCast provides a set of functions for customization and integration with users' earthquake response protocols. Application interaction with ShakeCast can occur at three different levels: simple data exchange using plain file instructions, system function calls and user-defined scripts, and application programming interface (API). Depending on users' needs and the complexity of the hosting environment, automation can usually be achieved with one or multiple pathways of application interactions.

One example of system integration on building information and damage estimates involves the ShakeCast software and the Rapid Observation of Vulnerability and Estimation of Risk (ROVER) project. ROVER is a project for FEMA by SPA Risk LLC, Instrumental Software Technologies, Inc. (ISTI) and Applied Technology Concil (ATC) to design, implement, and enhance FEMA 154 in an open-source, mobile computing environment. ROVER is open-source software and can be adapted to pre-earthquake risk assessment, post-disaster reconnaissance, insurance risk management, among other possibilities. System integration between ShakeCast and ROVER occurs at the API level without modifications to either application. The latest ShakeCast application has built-in support for ROVER and the administrator can update the ShakeCast facility database based on the building information, including their HAZUS fragility settings, inside the ROVER server in pre-event mode. After an earthquake occurs, the ShakeCast system will automatically generate color-tagged damage estimates for ROVER buildings and transfer the results back to the ROVER server.

Another example of system integration regarding ShakeCast facility database and input ground motion estimates can be best presented with the use of USGS NetQuakes devices. The USGS NetQuakes instrument is a new type of digital seismometer that communicates its data to the USGS via the Internet. These instruments connect to a local network using WiFi and use existing broadband connections to transmit data after an earthquake. These seismometers have been designed to be installed in private homes, businesses, public buildings and schools where there is an existing broadband connection to the Internet. The strong-motion data recorded by the NetQuakes instrument is processed by the USGS and is used for creating ShakeMaps. As of October, 2009, about 50 NetQuake instruments were contributing to ShakeMap in the northern California area alone. Thus ShakeCast users with facilities and NetQuakes devices co-located can acquire more accurate ground motion constraints, and therefore better damage estimates, particularly at sites of critical facilities. Fig. 5 shows the data flow among the combined systems of ShakeMap/ShakeCast, ROVER and HAZUS, and NetQuakes,

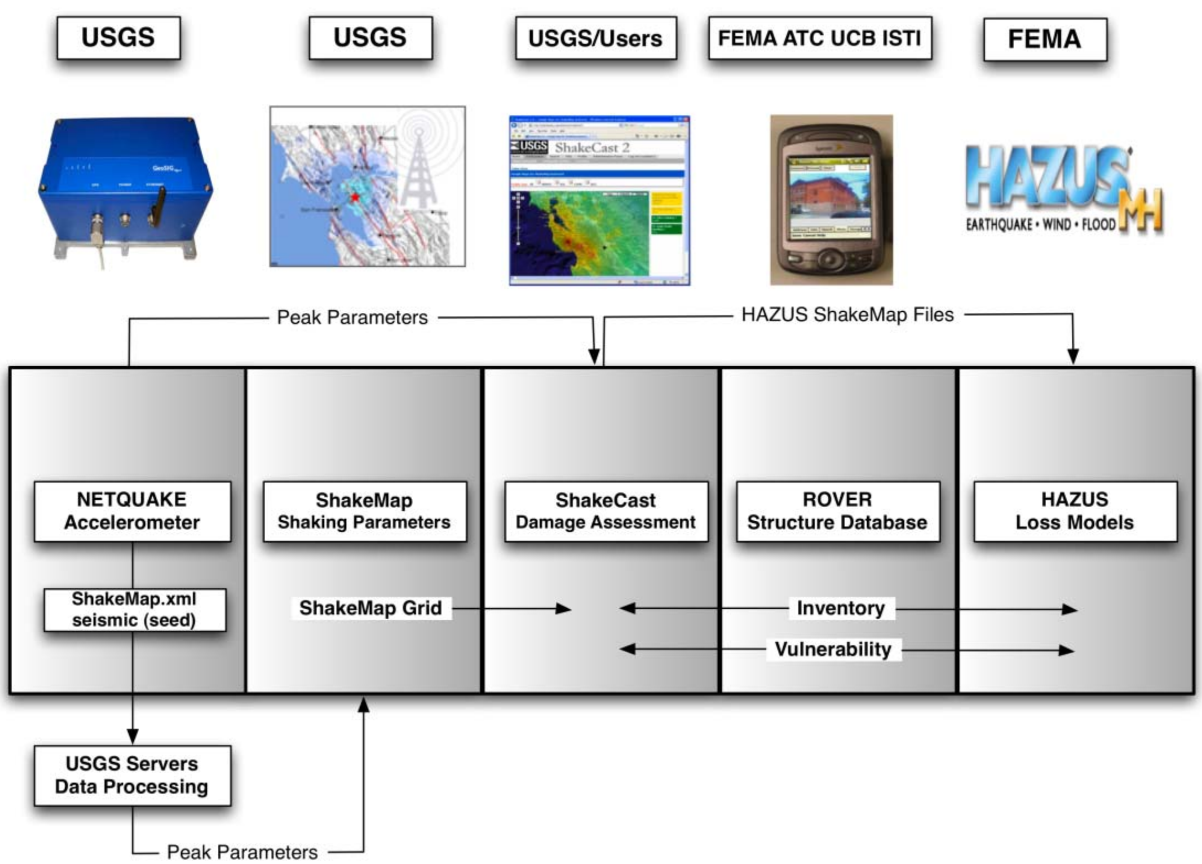

Figure 5. An end-to-end mitigation and response solution using the NetQuakes instruments, the ShakeMap/ShakeCast combined system, ROVER, and FEMA's HAZUS systems.

Since the release of ShakeCast Version 2, the user base has steadily increased with some critical users such as the International Atomic Energy Agency (IAEA) which adapted the application for pre-event planning and post-earthquake response. To accommodate the needs of user support, the USGS Fort Collins Science Center (FORT) IT group is now providing tiered technical support with emphasis on GIS application to all ShakeCast users. Application update and announcement will continue to be disseminated via the USGS web site and the ShakeCast user mailing list.

Discussions and Conclusions

ShakeCast is a simple application that automatically processes the ShakeMaps and provides an opportunity for greatly improving post-earthquake situational awareness among potential users, particularly companies, utilities, and agencies whose earthquake exposure is both widespread and of variable vulnerability. Regular building owners can adopt the ShakeCast default HAZUS fragility settings (or information derived from the ROVER project, for example) to easily establish a system for handling post-earthquke response. Those motivated to take full advantage of the ShakeMap/ShakeCast combination must develop a reasonable evaluation of the fragilities of their inventory, structures and other facilities. It is anticipated that the need to improve the accuracy of estimated damage to a portfolio will further motivate critical utilities and other entities to make rigorous assessments of the range of vulnerabilities of structures and infrastructure within their inventories. Naturally, any such assessments also provide a sound basis for prioritizing mitigation efforts.

Critical facilities can benefit from site-specific recordings rather than relying on ground motions interpolated from ShakeMap from nearby stations. ShakeMaps for different earthquakes come with highly variable constraints from strong-motion stations, and therefore the uncertainties vary not only from event to event, but within the domain of a map for a single earthquake (e.g. Wald et al., 2008). While inherent uncertainties are due to the combined effects of inferring and interpolating ground motions, as well as from probabilistic damage functions, the former can be effectively removed by installing strong motion instruments at the site of interest. On- or near-site instrumentations is commonplace for many bridges, dams and Veteran's Administration (VA) hospitals, for example. ShakeCast was developed with this potential in mind, allowing users to associate facilities with recordings from seismic stations. The estimated ground shaking values by ShakeMap will only be used if recorded data from the designated station is not available for the earthquake. For seamless access to facility parametric data as well as improving overall ShakeMap quality for other users, such site recordings should be telemetered through the same regional network approaches used in ShakeMap, including regional seismic networks of the USGS Advanced National Seismic System (ANSS) and the Center for Engineering Strong Motion Data (CESMD). The exception is for the owner of NetQuakes instrument, which the above processes have been handled by the USGS.

Future efforts are also needed in instrumentation and communications as well as in rapidly assessing multiple channels of free-field and structural-monitoring recordings to better gauge the impact on individual structures. Likewise, more investigation is needed to incorporate the numerical uncertainty values now provided by ShakeMap (Wald et al, 2008) directly into uncertainties in damage assessments (e.g., Luco and Karaca, 2007). The grid-based shaking uncertainty values and detailed processing parameters (selected ground motion prediction equation, finite fault information, and bias corrections, etc.) are already available to ShakeCast users via the ShakeMap grid XML file, but they are typically not used explicitly in computing loss uncertainties.

Finally, we anticipate additional and improved predefined damage functions, not only for structures, but also for pipelines, landslide and liquefaction potential, and other forms of spatially distributed types of "damage" as the use of ShakeCast is expanded. If more comprehensive functions (involving shaking duration, for example) are required for more accurate loss estimates, ShakeMap would need to accommodate these parameters as well.

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