Development and Utilization of USGS ShakeCast for Rapid Post-Earthquake Assessment of Critical Facilities and Infrastructure

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Abstract

The ShakeCast system is an openly available near–real-time post-earthquake information management system. ShakeCast is employed by public and private emergency responders, lifeline operators, and facility engineers to automatically receive and process ShakeMap products for situational awareness, inspection priority, or damage assessment. The success of ShakeCast and its critical-user base mandates improved software usability and functionality. In an effort to make the software more accessible to novice users we have developed a "ShakeCast Workbook," a well-documented Excel-spreadsheet-based user interface that allows users to input notification and inventory data and export files needed for operating the ShakeCast system. Users will be able to select structure fragilities based on a minimum set of user-specified facility data (building location, size, height, use, construction age). "Expert" users will be able to import user-modified structural response properties into the facility inventory associated with the HAZUS Advanced Engineering Building Modules (AEBM). The goal of the ShakeCast system is to provide simplified real-time potential impact and inspection metrics to allow users to institute customized earthquake response protocols. Previously, fragilities were approximated using individual ShakeMap intensity measures (IMs, specifically peak ground acceleration and 0.3- and 1.0-sec spectral accelerations) for each facility, but we are now performing capacity-spectrum-based damage state calculations using a more robust characterization of spectral demand. We are also developing methods for the direct import of ShakeMap's multi-period response spectra in lieu of the assumed three-domain design spectrum (at 0.3 sec for constant acceleration; 1.0 or 3.0 sec for constant velocity and constant displacement at very long response periods). As part of ongoing ShakeCast research and development, we will also explore the use of ShakeMap IM uncertainty estimates and evaluate the assumption of employing multiple damping values rather than the single value (5%) currently employed. Developing and incorporating advanced fragility assignments into the ShakeCast Workbook requires related software modifications and database improvements; these enhancements are part of an extensive rewrite of the ShakeCast application.

Keywords: ShakeCast; ShakeMap; HAZUS, earthquake response; critical infrastructure; critical facilities

1. Introduction

The ShakeCast® system is an openly available near–real-time post-earthquake information management system. ShakeCast is widely used by public and private emergency planners and responders, lifeline utility operators, and facility and transportation engineers [1] to automatically receive and process ShakeMap products for situational awareness, inspection priority, or damage assessment of their own infrastructure. The success of ShakeCast to date and its broad critical-user base mandates improved software usability and functionality, including improved engineering-based damage and loss functions. As a distributed software application, ShakeCast can be installed either "in-house" within a user's network and their physical or virtual operating systems, or more commonly by running an "instance" of the ShakeCast software as a cloud-hosted service after cloning the system disc image provided by U.S. Geological Survey (USGS).

In order to make the software more accessible to novice users—while still utilizing advanced users' technical and engineering background—we have developed a "ShakeCast Workbook," a well-documented Excel-spreadsheet-based user interface. The Workbook allows users to input notification and inventory data and export XML files requisite for operating the ShakeCast system. Users will be able to select structure types from a pre-established library of various facility types (i.e., buildings, bridges, and other structures) based on a minimum set of user-specified facility features (e.g., building location, size, height, use, construction age, etc.). A new version of the Workbook contains "default" values of building properties based on these minimum data, as well as "improved" values of building properties based on additional building information provided by advanced users. Additional building information includes, for example, identification of structural irregularities which can significantly affect building perfomance. Further, "expert" users can develop and import user-created facility types and associated building properties into facility inventories.

The goal of the ShakeCast system is to provide simplified (*green*, *yellow*, *orange* and *red* priority ratings), near–real-time damage and inspection metrics in order to facilitate users' inspection priorities and protocols. To date, fragilities have been approximated using individual ShakeMap intensity measures (IMs; specifically peak ground acceleration (PGA) and 0.3 and 1s spectral accelerations) for each facility rather than performing the full iterative capacity spectrum method calculations to compute the performance point. We have extended this strategy, supplementing the existing ShakeCast Workbook by allowing more advanced structural characteristics for ShakeCast fragility calculations, an approach based on the methods of HAZUS [2] as described in the next section. We have also been considering options for multi-period spectra in lieu of the assumed three-domain design spectrum (0.3 sec marking constant acceleration; 1.0 or 3.0 sec delimiting the constant-velocity to constant-displacement transition). For example, we note that the Kathmandu KATNP record from the 2015 Gorkha, Nepal earthquake provided a reminder of the potential significant inaccuracy of such anchoring: despite having a relatively low PGA (0.18g), KATNP had much higher response accelerations of 0.5g at long periods of 4-5 sec than at shorter periods. With the usually assumed spectral shape, larger long-period spectral response values cannot be accommodated. HAZUS methods would be modified to incorporate multi-period spectra. At this time, discrete values of damage and loss are calculated as a function of spectral demand defined at 0.3, 1.0, and 3.0 sec spectral accelerations.

Making ShakeCast better involves exploring the use of ShakeMap IM uncertainty estimates and evaluating the assumption of employing multiple damping values rather than the single value (5%) currently employed. Developing and incorporating advanced fragility assignments into the ShakeCast Workbook requires related software modifications and database improvements; such enhancements will improve the ShakeCast application.

In the following sections, the engineering-based approaches for determining damage state or inspection priorities are outlined; the ShakeCast Workbook spreadsheet aimed at facilitating users' data management is described; and ongoing developments, including ShakeCast software re-engineering, are detailed. Some recent relevant improvements to the ShakeMap system are also introduced.

2. Background on HAZUS and Related Applications

The methods of the ShakeCast Workbook for calculating building damage and loss are based on the HAZUS earthquake loss estimation approach, originally developed in the 1990s by the Federal Emergency Management Agency (FEMA) for estimating earthquake impacts on large regions [2, 3]. The HAZUS approach is very broad in nature, estimating damage and loss to buildings, critical facilities, and utility and transportation lifelines caused by ground shaking, ground failure, and other (induced) hazards such as fire. Regional loss estimation precludes modeling of individual buildings (because, e.g., there are over 2 million individual buildings in Los Angeles County alone). Rather, aggregate estimates of damage and loss are made for each combination of model building type (i.e., structural system of the building) and building use (i.e., occupancy) by census tract. Model building type (MBT)—defined in terms of construction material (wood, steel, etc.), height (low-, mid-, and high-rise), and seismic design level (based on design vintage)—influences the estimation of peak response during an earthquake and the associated damage to the structure, nonstructural systems, and contents. Building occupancy, defined by the residential, commercial, or industrial use of the building, influences the computation of economic, functional, and social losses (e.g., the nonstructural systems and contents of a hospital are very different and would cost much more to replace or repair than those of a warehouse).

The ShakeCast Workbook relies largely on the methods of the HAZUS Advanced Engineering Building Module (AEBM) Manual [3] for calculating damage and loss to specific buildings (e.g., a portfolio of buildings). While based on the same concepts, model building types, and occupancies as the basic methods of HAZUS [2], the AEBM anticipates that users will have better, building-specific, information. Among other refinements of the basic methods of HAZUS, the AEBM uses the actual height (number of stories) of each building to improve the estimation of peak structural response [4]. Of particular significance, the AEBM allows “expert” users to develop building-specific properties based on “engineering” data, such as calculations of structural capacity and building inspections to identify structural deficiencies. The AEBM methods have been adapted for seismic risk assessment of U.S. Department of Veterans Affairs (VA) hospital buildings [4] and safety evaluation of older California hospital buildings by Office of Statewide Health Planning and Development (OSHPD) [5]. In the VA and OSHPD applications, “engineering” data are based on detailed building evaluation criteria that may now be found in ASCE 41-13 [6].

The HAZUS AEBM methods were also used as the technical basis for a recent update of the rapid visual screening methods of FEMA 154, as described in FEMA 155 [6]. The rapid visual screening methods of FEMA 154, while intentionally not as rigorous as the detailed evaluation criteria of ASCE 41-13, provide a basis to expeditiously develop limited building-specific information. The documentation of the VA and OSHPD HAZUS applications and FEMA 155 provide values of AEBM response and damage parameters for each model building type as a function of the “engineering” data. For example, baseline values of response and damage parameters are modified for those buildings found (by inspection or analysis) to have a “soft-story” to better reflect the poor performance expected for buildings with this type of significant structural irregularity. The ShakeCast Workbook contains databases of baseline and modified values and of each AEBM parameter taken from the documentation of the VA and OSHPD applications and FEMA 155. Baseline values of parameters are used as “default” values for building evaluation when only minimal building information is provided by the user; modified values are used for building evaluation when “engineering data” are provided by the user.

3. Engineering-based Inspection Priority and Damage Estimates

The default setup of ShakeCast offers users different options for assigning inspection priorities to their facilities and infrastructure, and thus allows different criteria for sending automatic notifications. Inspection priorities are based on assessed damage estimates using ShakeMap ground motion parameters, namely peak horizontal ground acceleration, peak ground velocity, and damped spectral accelerations (at 0.3-, 1.0-, and 3.0-sec periods), as well as Instrumental Intensity [7]. At present, three common approaches provide users with an indication of damage: HAZUS-based, intensity-based, and customized damage functions.

Starting with the current ShakeCast (2016 Version 3, or V3) software and later versions, we have implemented building-specific damage functions and inspection prioritizations based on the procedures developed by the HAZUS AEBM. The newly designed ShakeCast AEBM framework utilizes a combination of these measured or estimated ground motion parameters, earthquake source parameters (magnitude and distance), and building capacity information to produce a four-state discrete output. Herein, we describe the requirements and general procedure for the ShakeCast AEBM framework (Fig.1).

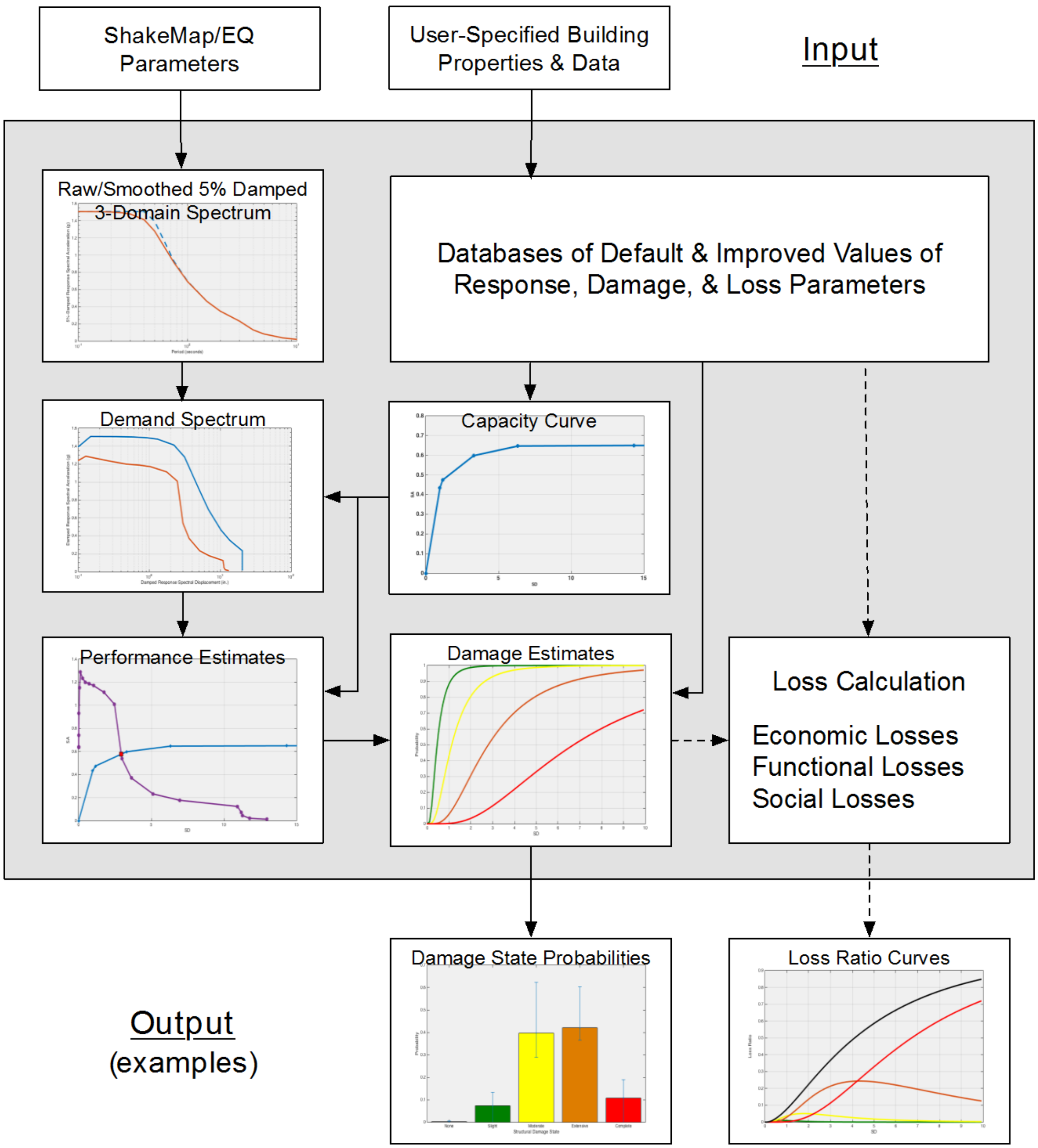

Fig. 1 – ShakeCast Flowchart showing implementation of HAZUS AEBM Methods. Dashed lines indicate loss-related functions and associated output not yet implemented.

There were a number of technical issues to work through when implementing the AEBM framework. As a near–real-time earthquake response application, ShakeCast divides the computation framework into two main areas. The ShakeCast AEBM workbook handles building-specific capacity curve parameters and fragility medians as part of the users' ShakeCast setup and configuration, prior to the occurrence of an earthquake. The second part of the ShakeCast AEBM framework takes place after a ShakeMap becomes available for an earthquake, in order to generate the demand spectra and to analyze building response.

Implementation of ShakeCast facility fragilities is not to be done lightly. Users can select structure types from a pre-established library of various facility types (buildings, bridges, and other structures) based on a minimum set of user-specified facility characteristics (building location, size, height, use, construction age, etc.). The revised ShakeCast Workbook contains "default" values of HAZUS Model Building Types (MBT) based on these minimum data. These defaults can be improved by users who have better information on the lateral-load resisting systems and capacities of their many structures.

This real-time AEBM analysis framework is also compatible with the general HAZUS damage methods defined in the current ShakeCast application [8]. Depending on the quality and completeness of building-specific data provided by the user, ShakeCast supplements default MBT parameters and damage functions in order to take advantage of the new computational framework. There are three tiers of user data and (likely) engineering expertise (1) minimal: no engineering expertise, but the ability to select default fragilities or MBT assignments per structure; (2) moderate: e.g., the FEMA 154/155 Rapid Visual Screening [9] procedure; and (3) advanced: specifically ASCE 41-13 [10] structural engineering data. Alternatively, users can specify generic or custom fragilities in the standard form of its median (alpha) and lognormal standard deviation (beta) values for any of the ShakeMap intensity metrics.

Despite the desired users' levels noted above, several notable ShakeCast implementations employ only default (typically intensity-based) shaking parameters for determining inspection priorities. When combined with users' priorities, these ShakeCast instances benefit the users, despite the lack of detailed structural response parameters. Likewise, regulatory criteria have been often used within the ShakeCast framework for coordinating response or for situational awareness [11], rather than specifying or relying on engineering-based damage estimates. For some organizations, existing regulations or protocols dictate post-event inspections, and these criteria (for instance, PGA design exceedance) can be checked readily with ShakeCast.

3.1. Building Capacity Curve Parameters and Damage-State Medians

For building-specific damage calculations, users need to provide engineering parameters to define the capacity curve and damage-state medians using the ShakeCast AEBM Workbook. If specified, these building parameters will override the default values for the yield and ultimate capacity control points for the selected MBT. Desired parameters include: the building height, seismic design level, design strength, weight pushover modal factor, height pushover modal factor, higher-mode factor, yield strength to design strength factor, ultimate strength to yield strength factor, ductility ratio, and the inter-story drift ratio for each damage state. The basic source of the values of default and improved building data are taken primarily from Veterans Administration (VA) Hospital Risk Assessment adaptation of the HAZUS AEBM, for which structural collapse is based on the California Office of Statewide Health Planning and Development (OSHPD) hospital safety assessment adaptation of the HAZUS AEBM.

For buildings with partial lists of parameters, default values of code building capacity parameters for each of the 36 generic MBTs are extracted from the values given in Tables 5.4–5.6 of the HAZUS-MH Technical Manual for different seismic design level [11]. The computed capacity control points are adjusted for the actual building height instead of the general height category (low-, mid-, and high-rise). The above calculations are computed both in the ShakeCast AEBM Workbook and during the stage of uploading building inventory to the ShakeCast database (that is, during system configuration prior to earthquakes; see Fig. 1). A similar procedure is applicable to the definition of the damage-state median spectral displacement. The default values of inter-story drift ratio (Table 5.8 of the HAZUS-MH Technical Manual [12]) are used to compute the median displacement for each damage state, adjusted to the actual building height. Computation of the damage-state beta for each damage state requires additional earthquake parameters and will be evaluated by ShakeCast during the processing of a ShakeMap.

3.2. Building Response Parameters

Peak displacement building response is defined by the intersection of the demand spectrum and the capacity curve. The demand spectrum is the 5%-damped spectrum of ground shaking at the building site, reduced for effective (surrogate) damping above 5% of critical to mimic inelastic spectral demand.

Contrary to the standard HAZUS method, ShakeCast constructs demand spectra using four ShakeMap ground motion parameters (PGA, and spectral accelerations at 0.3, 1.0, and 3.0 sec). With a standardized response spectrum shape of the Probabilistic Earthquake Seismic Hazard input, three domain transition periods were defined using the ShakeMap input data. Furthermore, the ShakeMap spectral accelerations do not need to be adjusted for soil amplification effects. The three-domain constant-acceleration, velocity, and displacement response spectra are smoothed near the mid-to-long-period transition period, T_S, and use an improved estimate of long-period level, T_L, to match the frequency content of multi-period demand spectra.

ShakeCast AEBM-computed response parameters include damping of an elastic system and degradation (κ) factors that reduce the hysteretic damping and affect intersection capacity and demand. ShakeCast develops an inelastic response (demand) spectrum from the 5%-damped elastic response (ShakeMap input) spectrum. Effective damping, β_{eff}, is defined as the total energy dissipated by the building during peak earthquake response and is the sum of a damping term of elastic system and a hysteresis damping term associated with post-yield inelastic response. Instead of using amplitude-dependent damping reduction factors in HAZUS (R_A at periods of constant acceleration and R_V at periods of constant velocity), we adopted a model [13] for a damping scaling factor (DSF) that can be used to adjust the 5% damped elastic response spectrum predicted by the ShakeMap input to demand spectrum. The DSF model captures the influence of duration by including both the magnitude and rupture distance (R_{rup}) variables in the model.

3.3. Performance Point, Damage-State Probabilities, and Uncertainties

The calculation of the performance point (i.e., peak displacement response) is based on the effective damping of the building, which is a function of the amplitude of response, building elastic and inelastic response properties, and the duration of shaking (estimated using magnitude and R_{rup}). The performance point was calculated using straight-line interpolation between discrete points near the intersection of the demand spectra and capacity curves at each of the 20 response periods (Fig.2).

Building fragility curves are in the format of lognormal probability functions that describe the probability of reaching, or exceeding, structural damage states, given median estimates of spectral response in spectral displacement. These curves take into account the variability and uncertainty associated with capacity curve properties, damage states, and ground shaking. Fragility curves define boundaries between damage states among *Slight*, *Moderate*, *Extensive* and *Complete* damage states (designated by colors green, yellow, orange, and red, respectively). For a given value of spectral displacement response, discrete damage-state probabilities are calculated as the difference of the cumulative probabilities of reaching, or exceeding, successive damage states. The probabilities of a building reaching or exceeding the various damage levels at a given response level sum to 100%.

HAZUS building fragility functions employ lognormal standard deviation parameters, referrred to as "betas." The HAZUS betas describe the total uncertainty of the fragility-curve damage states. The current implementation in ShakeCast accepts three sources of variability associated with the capacity curve, the demand spectrum, and the discrete threshold of each damage state. A pre-populated set of damage-state betas have been included as default for users to select appropriate values of variability for their structural system. Kircher [14] developed ShakeMap-specific betas for HAZUS-MH based on analyses of several loss-data–rich California earthquakes, as a reflection of overall reduced uncertainty of ShakeMap data-constrained shaking estimates compared with HAZUS defaults. Kircher [14] further recommended that revised betas be employed for earthquakes with significant impact (Modified Mercalli Intensity, MMI > VI or PGA > 0.2g), specifically when ShakeMap (peak-component motions [7]) maps are used in loss estimation.

However, substantial efforts to quantify and provide frequency-dependent ground motion uncertainties as a function of ShakeMap grid location have been made that consider nearby seismic station and macroseismic data, inference of the fault location, and the GMPEs employed in shaking estimates developed [15, 16]. Thus, the propagation of these grid-based ShakeMap uncertainties into site-specific HAZUS-based loss calculations is now possible. We can employ the upper bounds of the damage as well as the capacity curves to evaluate the uncertainty in the building performance (Fig.2), and these values can be reported out if desired by the user. The convolution process that combines the contributions from the demand spectrum and the building capacity is non-trivial; instead, ShakeCast uses a simple strategy that accounts for the upper and lower bounds of both demand spectrum and capacity curves to estimate the total uncertainty range of individual facility damage states (Fig.2).

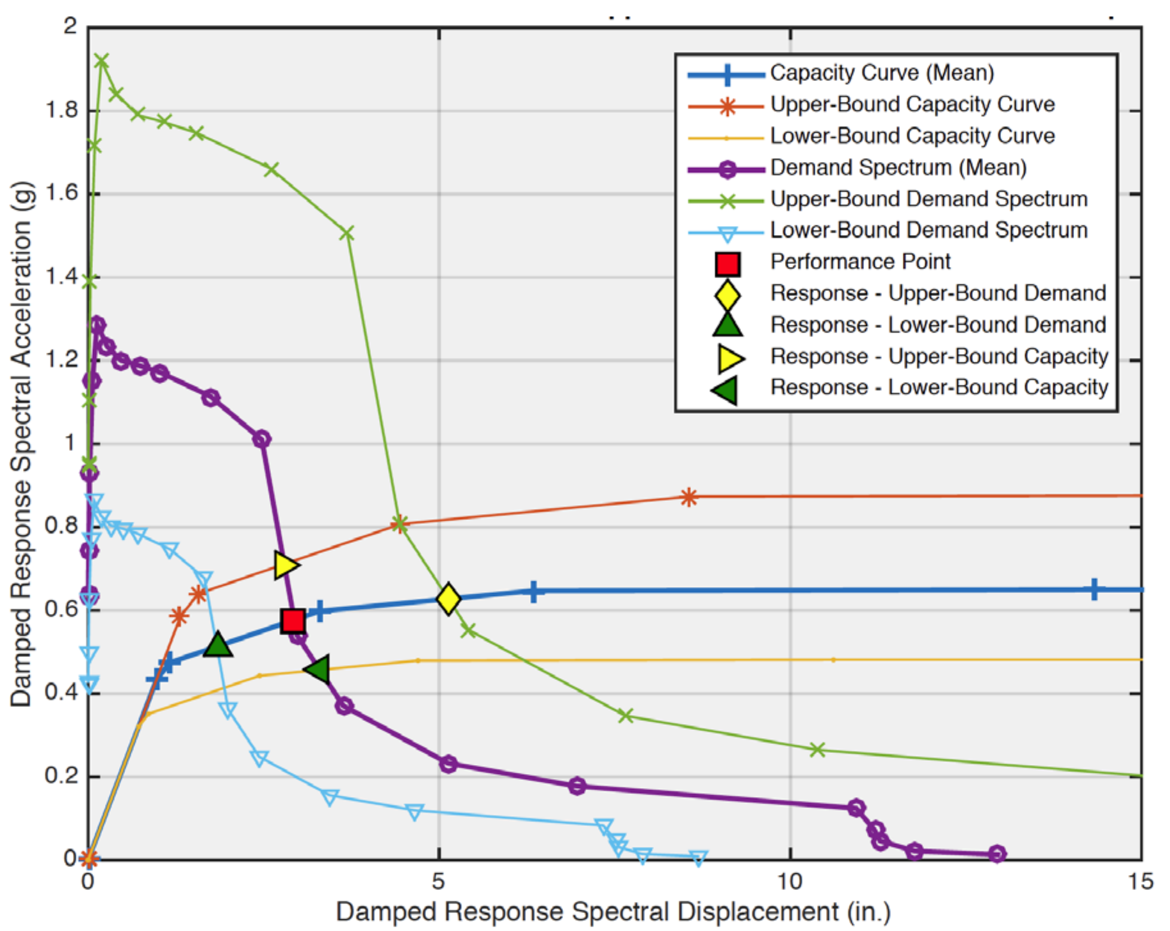

Fig. 2 – HAZUS-MH (AEBM) performance point calculation and intersection of upper and lower bound demand and capacity curves.

4. ShakeCast Inventory Workbook

The ShakeCast Inventory Workbook is a collection of Excel® spreadsheets used to bridge the gap between users' data and the ShakeCast application (Fig.3). It allows users to collect their facility, notification group, and user information in a single location. Once the data have been collected, a customized function generates a master XML file that contains all the information needed for the user's ShakeCast instance. Data are validated as they are entered into the workbook, and malformed data are not exported. This ensures that data with the potential to corrupt the ShakeCast database will not be uploaded to the application.

The Workbook also serves as a stepping stone among Versions 2–4 of ShakeCast. It has the ability to import CSV and configuration files, which were used to upload data to V2. CSV files containing facility data can be exported from V2 and imported to the inventory workbook. This workbook will remain compatible with future versions of ShakeCast to ensure that installations of new software will be hassle-free.

A revision to the Workbook has been developed in the form of a spreadsheet specifically designed for the inclusion of building-specific HAZUS AEBM structural parameters. This spreadsheet is completely separable from the rest of the workbook, allowing users with the required information to take advantage of the AEBM without distracting users with less-detailed inventories.

A Workbook lookup table is currently used to store MBT information. This table is editable by advanced users to allow for access to customizable MBTs. New MBTs can also be created with user-defined fragilities. For the users' convenience, fragility values can be changed on a case-by-case basis as well. The Workbook also provides tables of default values of the various (and numerous) HAZUS parameters compiled primarily from the VA seismic risk application of the HAZUS AEBM and FEMA 155, and provides documentation of HAZUS AEBM parameter references and/or methods used to develop parameters (not given directly in the References).

Map & Display			Facility Fragility Parameters													
			Select from library of default HAZUS models to auto-populate fragility parameters, *or* enter fragility parameters manually													
Latitude Facility latitude (decimal degrees, north) More Info	Longitude Facility longitude (decimal degrees, east) More Info	HTML Snippet Contents will be formatted into html for display on ShakeCast website More Info	HAZUS Model Building Type Label Select label from the drop-down list. Select USER_DEFINED to manually enter fragility parameters More Info	HAZUS Model Building Type Description This field is automatically populated based on the HAZUS Model Building Type Label field selection	METRIC	METRIC:ALPHA:GREEN	METRIC:BETA:GREEN	METRIC3	METRIC:ALPHA:YELLOW	METRIC:BETA:YELLOW	METRIC4	METRIC:ALPHA:ORANGE	METRIC:BETA:ORANGE	METRIC5	METRIC:ALPHA:RED	METRIC:BETA:RED
41.6	-124.1	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	100	0.6	PSA10	120	0.6	PSA10	170	0.6
41.6	-124.1	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	98.5226	0.6	PSA10	120.417	0.6	PSA10	164.204	0.6
41.6	-124.1	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	94.3077	0.6	PSA10	136.222	0.6	PSA10	167.658	0.6
41.8	-124.1	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	100	0.6	PSA10	120	0.6	PSA10	170	0.6
41.8	-124.1	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	97.5739	0.6	PSA10	140.94	0.6	PSA10	173.465	0.6
41.8	-124.0	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	94.8966	0.6	PSA10	115.985	0.6	PSA10	158.161	0.6
41.9	-123.9	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	99.1382	0.6	PSA10	121.169	0.6	PSA10	165.23	0.6
41.9	-123.8	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	100	0.6	PSA10	120	0.6	PSA10	170	0.6
41.9	-123.8	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	104.85	0.6	PSA10	128.15	0.6	PSA10	174.75	0.6
41.9	-123.8	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	98.2815	0.6	PSA10	135.137	0.6	PSA10	208.848	0.6
41.9	-123.9	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	93.0021	0.6	PSA10	113.669	0.6	PSA10	155.003	0.6
41.9	-124.1	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	100	0.6	PSA10	120	0.6	PSA10	170	0.6
41.8	-124.2	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	100	0.6	PSA10	137.5	0.6	PSA10	212.5	0.6
41.9	-124.1	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	104.85	0.6	PSA10	128.15	0.6	PSA10	174.75	0.6
42.0	-124.2	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	90.507	0.6	PSA10	108.608	0.6	PSA10	153.862	0.6
41.6	-124.1	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	116.034	0.6	PSA10	141.82	0.6	PSA10	193.391	0.6
41.5	-124.0	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	91.7689	0.6	PSA10	112.162	0.6	PSA10	152.948	0.6
41.5	-124.0	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	84.0056	0.6	PSA10	102.673	0.6	PSA10	140.009	0.6
41.5	-124.0	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	88.2506	0.6	PSA10	107.862	0.6	PSA10	147.084	0.6
41.5	-124.0	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	97.425	0.6	PSA10	119.075	0.6	PSA10	162.375	0.6
41.5	-124.0	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	100	0.6	PSA10	120	0.6	PSA10	170	0.6
41.8	-124.0	<table border="0" cellpad	USER_DEFINED	Modified HAZUS Bridge Fragility	PSA10	10	0.6	PSA10	81.9243	0.6	PSA10	100.13	0.6	PSA10	136.541	0.6

Fig. 3 – Snapshot of the ShakeCast "Workbook". Users' structure inventory and notification databases can be developed in this Excel spreadsheet and exported as XML files for direct import into their ShakeCast software instance.

5. ShakeCast Software

The official release of ShakeCast V3 was in late 2015. However, the ShakeCast team (contact: shakecast-help@usgs.gov) is deeply entrenched in the development of ShakeCast V4. This revision of the ShakeCast code is being built from scratch with the goals of being more accessible to the average user and demanding less IT support. In comparison to previous versions, V4 will have a more succinct architecture, a leaner set of features, and a highly developed user interface.

5.1. Software Development (*pyCast*)

ShakeCast V4 and on—as well as newer versions of USGS's ShakeMap, "Did You Feel It?", and PAGER systems—are being developed in Python due to its functionality and near-ubiquity in computer science courses and academia. As such, the new development has been coined *pyCast* and can be found on GitHub and Python's package manager by this name. Our development of *pyCast* is within the GitHub framework; thus, any GitHub user can contribute to the development or submit feature requests in the form of "issues". ShakeCast V4 development can be followed on GitHub (http://usgs.github.io/shakecast).

Since ShakeCast is a distributed application, pyCast will utilize more-portable application technologies. This includes the usage of SQLite as the default database and a pure Python webserver. The web interface will be improved upon as well; a powerful interface for pyCast is being created using Angular2/jQuery/Bootstrap. Our aim is to be more intuitive and include new features that both general users and administrators will find helpful, based on best practices in software development. Many of the modifications are based on direct user feedback, feature requests, and culling of vestigial functions.

5.2. Cloud Services

As a primarily distributed application, ShakeCast is employed by most users in a cloud computing environment [17]. ShakeCast can currently be acquired by requesting access to the ShakeCast base image on Amazon Web Services (AWS, Amazon's cloud), but our cloud presence required accommodation for Government cloud-computing mandates. The USGS and the Department of the Interior (DOI) have created their own cloud environments (the USGS Cloud Hosting Service, CHS, and the DOI Cloud), so we have moved existing applications off AWS and into an internal cloud. Any significant policy or cloud implementation changes will be reported via the ShakeCast Newsletter and blog (http://usgs.github.io/shakecast/news).

5.3. Dynamic Documentation

The documentation for pyCast will be available online through GitHub, employing markdown language and the Sphinx template consistent with recent ShakeMap documentation [7]. This revised documentation strategy allows the ShakeCast team to keep the documentation current and ensures that all users are getting the same up-to-date information. This documentation will include information for general users, administrators, and developers who would like to contribute to the pyCast software.

6. Related ShakeMap Developments

Several upgrades to the USGS ShakeMap system are noteworthy, particularly as they pertain to ShakeCast. Improvements have been made to (1) event-specific metadata, product archiving, and technical documentation; (2) additional gridded parameters (including interpolated rock-motion shaking estimates); and (3) improved ground motion characterization, including multiply-weighted GMPEs, spatial variability characterization and improved directivity functions. In addition, systematic collections of scenarios and historical ShakeMaps have been revised. From a ShakeCast user's perspective, these updates provide more opportunities for systematic ShakeCast testing and evaluation. The enhanced ShakeMap metadata are available for ShakeCast users (providing details as to which GMPEs were employed in a particular ShakeMap and what inter-event bias values were computed, for example). Characterizing spatial variability of shaking will allow for probabilistic loss estimates with tools like HAZUS and ShakeCast (and other loss models) to account for both shaking and fragility function uncertainties, as well as their frequency-dependent spatial correlations. More details about these updates are provided and kept up-to-date online [7].

Allstadt et al. [18] further describe model testing and improvements to USGS's near–real-time capability to estimate the spatial distribution of the probability of landslides and liquefaction. These efforts are being made in conjunction with ShakeCast development to ensure full functional compatibility within ShakeCast. For example, a geospatial grid comparable to the ShakeMap shaking estimates (the *grid.xml* file used by ShakeCast) includes the ground failure probabilities. ShakeCast can access this secondary hazard grid and use it to assign likelihood of landslides and liquefaction at users' facilities. Like ShakeMap, there are substantial uncertainties associated with such estimates that depend on both degree of the shaking constraints and ground failure model sufficiency at specific locations.

6. Conclusions

As part of ongoing ShakeCast research and development, we have enhanced functionality, updated the code base, and improved the user interface. The engineering-based approaches for determining damage state (or inspection priorities) have been improved, implementing the interactive HAZUS capacity spectrum method and HAZUS Advanced Engineering Building Module (AEBM). Incorporating more advanced fragility assignments into the ShakeCast required related software modifications and database improvements, part of an extensive rewrite of the ShakeCast application. An enhanced ShakeCast Workbook, an Excel spreadsheet, exports users' data into ShakeCast and allows for more intuitive management of facilties, fragilities, users, and notifications, as well as ShakeCast configurations. Users can select structure fragilities based on a minimum set of user-specified facility features (building location, size, height, use, construction age, etc.) and "expert" users can import user-modified structural response properties into facility inventory associated with the HAZUS Advanced Engineering Building Modules (AEBM).

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