Engineering-based Inspection Priority and Damage Calculations using AEBM

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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 elastic spectral acceleration (0.3, 1.0, and 3-sec periods) as well as Instrumental Intensity [7]. At present, three common approaches are being used to 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 4-state discrete output. Herein, we describe the requirements and general procedure for the ShakeCast AEBM framework (Fig.1).

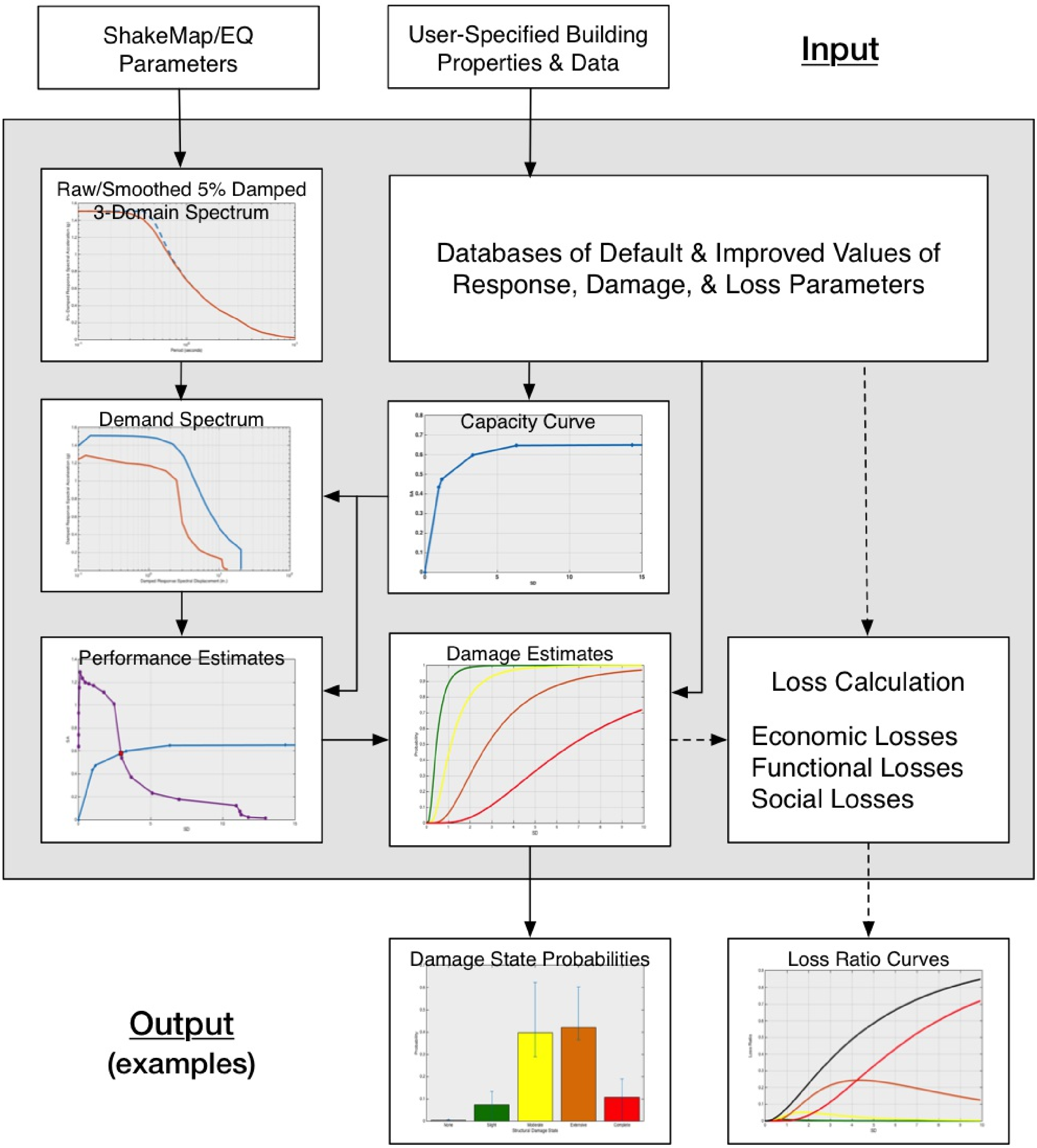

Fig. 1 – ShakeCast Flowchart showing implementation of HAZUS AEBM Methods. Dashed lines indicate loss-related functions and associated output not yet implemented.

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 to 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, that is, prior to the occurrence of an earthquake. The posterior 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.

Implementing ShakeCast facility fragilities is not to be taken lightly. Users can 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 (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.

This real-time AEBM analysis framework is also compatible with the general HAZUS damage methods defined in the current ShakeCast application. 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. It is anticipated and expected that the three tiers of user data and (likely) engineering expertise range from (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 [8] procedure, and (3) advanced, specifically ASCE 41 [9] structural engineering data. Alternatively, users can specify generic or custom fragilities in the standard from of its median (alpha) and lognormal standard deviation deviation (beta) values based for any of the ShakeMap intensity metrics.

Despite the desired users’ levels noted above, several notable ShakeCast implementations are running that 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 [10] rather than specifying or relying on engineering-based damage estimates.

Building Capacity Curve Parameters and Damage-State Medians

For building-specific damage calculations, users need to provide engineering parameters to define the capacity curve parameters 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 list 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 through 5.6 of the HAZUS-MH Technical Manual for different seismic design level. The computed capacity control points are adjusted for the actual building height instead of the general height category (Low-Rise, Mid-Rise, and High-Rise). The above calculations are computed in both the ShakeCast workbook and during the stage of uploading building inventory to the ShakeCast database, that is during system configuration prior to earthquakes (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 [11]) will be 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 during the processing of a ShakeMap.

Building Response Parameters

Peak displacement building response is defined by the intersection of demand spectrum and the capacity curve. The demand spectrum is the 5%-damped spectrum of ground shaking at the building site reduced for effective damping above 5% of critical.

ShakeMap-based "three-domain" Response Spectrum

Contrary to the standard HAZUS method, ShakeCast constructs demand spectra using four ShakeMap ground motion parameters (PGA, and PSA at 0.3, 1.0, and 3.0 seconds). With a standardized response spectrum shape of the Probabilistic Earthquake Seismic Hazard (PESH) 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, Ts, and use an improved estimate of long-period level, TL, to match the frequency content of multi-period demand spectra.

Effective Damping and Demand Spectrum

ShakeCast AEBM computed response parameters include elastic damping and degradation () 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, eff, is defined as the total energy dissipated by the building during peak earthquake response and is the sum of an elastic damping term and a hysteretic damping term associated with post-yield inelastic response. Instead of using amplitude-dependent damping reduction factors in HAZUS (RA at periods of constant acceleration and RV at periods of constant velocity), we adopted a model [12] for a damping scaling factor (DSF) that can be used to adjust the 5% damped response spectrum predicated by the ShakeMap input to demand spectrum. The DSF model captures the influence of duration by including both the magnitude and rupture distance (Rrup) variables in the model.

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 Rrup). The performance point was calculated using straight line interpolation between discrete points of demand spectra and capacity curves at 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. 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 beta's have been included as default for users to select appropriate values of variability for their structural system. Kircher [13] 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 [13] further recommended that revised betas be employed for earthquakes with significant impact (MMI>VI or PGA>0.2 g), 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 that consider uncertainty contributions of nearby seismic station and macroseismic data, inference of the fault location, and the GMPEs employed in shaking estimates developed [14, 15]. Thus, the propagation of these grid-based ShakeMap uncertainties into site-specific HAZUS-based loss calculations is now possible. We can employ both the upper bounds of the damage as well as capacity curves to evaluation the uncertainty in the building performance (Fig.2), and these values can be reported out if so 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).

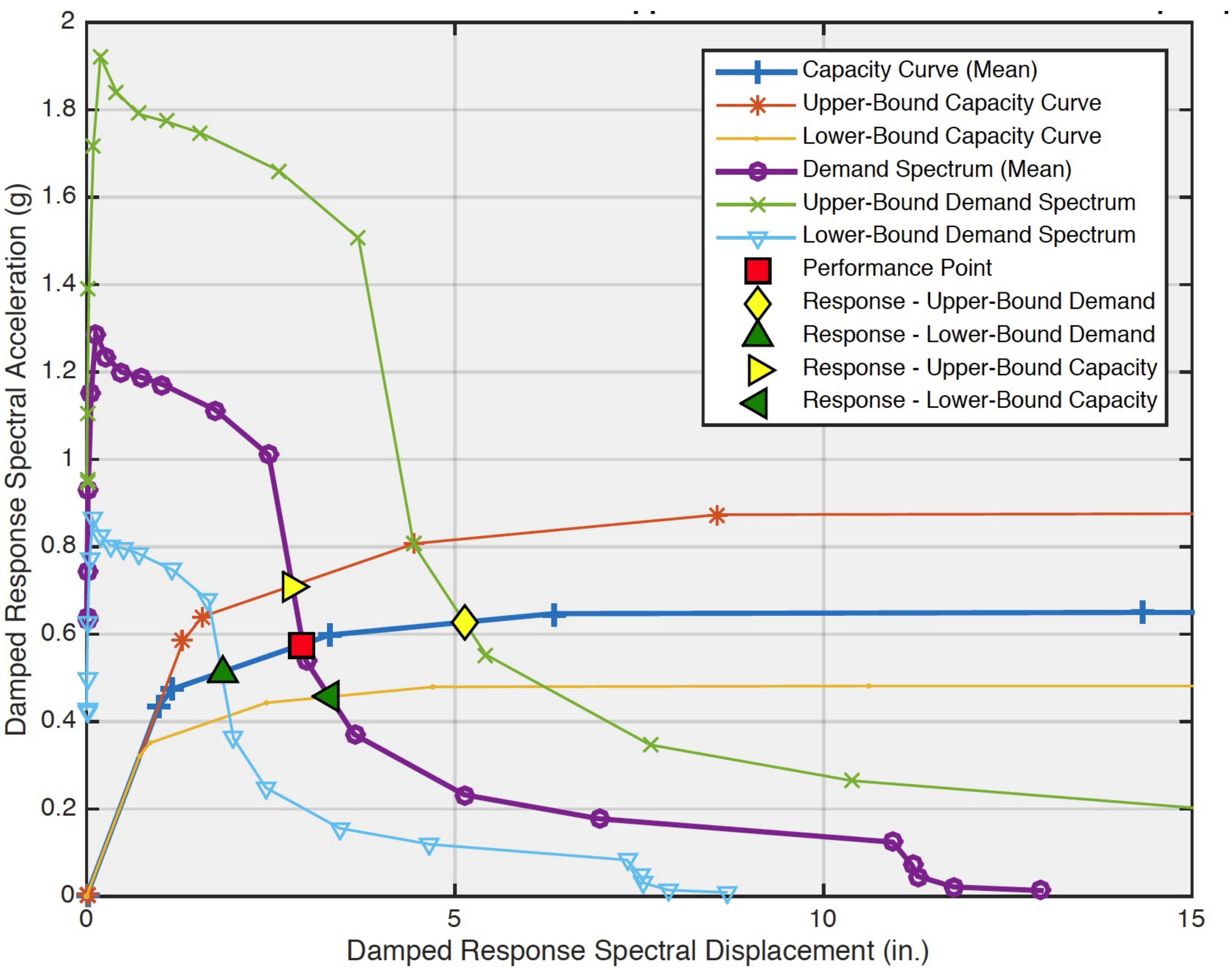

Fig. 2 – HAZUS-MH (AEBM) performance point calculation and intersection of upper and lower bound demand and capacity curves.

Tags: pycast (tag_pycast)