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ADJUSTING PORTFOLIO LOSS ESTIMATES IN LIGHT OF UPDATE TO THE EARTHQUAKE HAZARD MODEL IN CALIFORNIA

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Abstract

This study presents two heuristic approaches to adjust the California earthquake occurrence rates in the commercial catastrophe models based on the new Uniform California Earthquake Rupture Forecast (UCERF3) time-dependent model. The UCERF3 model was developed by the 2014 Working Group on California Earthquake Probabilities and incorporates updated earthquake catalogs, new smoothed seismicity algorithms and inputs, combined fault and geodetic based slip-rate models, and more comprehensive earthquake rupture models. The time-dependent (TD) rates in UCERF3 reveal significant model changes compared to the previous forecast (UCERF2) upon which the current catastrophe earthquake loss models for the United States are developed. Changes partly originate from the inclusion of multifault ruptures, where earthquakes are no longer confined to separate, individual faults, but rather can occasionally rupture multiple faults simultaneously. The impact of model changes in terms of earthquake rates –including multifault rupture effects– on the projected short-term and long-term modeled losses for selected portfolios in the United States are estimated in this study. Two rate adjustment approaches are examined: (1) uniform application of the averaged earthquake rate changes over all groups of faults in different regions of California; and (2) application of fault-by-fault rate adjustment for each event within the catastrophe models' stochastic event sets. The results from two approaches are compared by performing a set of sensitivity tests on portfolio level loss estimates. The second approach directly employs the multifault rupture effects and is shown to be more reliable to estimate the projected loss changes.

Keywords: UCERF3; time-dependent earthquake rate; portfolio loss estimate; catastrophe models

1. Introduction

The 2014 Working Group on California Earthquake Probabilities (WGCEP2014) developed the third Uniform California Earthquake Rupture Forecast (UCERF3) time-independent (TI) [1, 2] and time-dependent (TD) models [3]. The UCERF3-TD included the effect of elastic-rebound theory in which a smaller rupture probability is given to the fault after experiencing a large rupture and the probability rises with time as the result of tectonic stress reaccumulation. Compared to its preceding version (i.e., UCERF2) [4, 5] the UCERF3-TD employed the relaxation of fault segmentation assumptions and also encompassed multifault rupture effects.

The 2014 U.S. Geological Survey National Seismic Hazard Maps (2014 USGS NSHMs) incorporated the updated earthquake catalogs, new ground-motion models (GMMs), and new slip-rate and earthquake rupture models [6]. Compared to the 2008 NSHMs model [7], the probabilistic ground motions changed across the entire regions of the U.S. by ±10-20% [8]. In the Western U.S. including the greater California region, UCERF3-TI and the new NGA-West2 GMMs [9] with broader uncertainties were employed in 2014 NSHMs.

The current generation of major commercial catastrophe (CAT) loss models for the United States are developed based on the 2008 USGS NSHMs [7] including the UCERF2 earthquake rupture models [4, 5] for California. An enhanced seismic hazard module in light of UCERF3 [3] and 2014 USGS NSHMs [6] has the potential to improve the estimates of earthquake-induced loses. There are three major elements of update to the seismic hazard: (1) changes to fault rupture and occurrence rates resulting from the inclusion of multifault ruptures; (2) changes to the ground-motion intensity estimations as the result of using new ground-motion models; and (3) update of the local site conditions. Considering a reference site condition between models, the authors investigate the effect of updates to the earthquake rates and GMMs.

Fig. 1 presents a flowchart showing the propagation of changes before event loss tables are updated.

In this study, we adjust the modeled portfolio loss estimates at different return periods based on the UCERF3 update of the California earthquake rates. In the following two sections, we briefly discussed the key changes on the UCERF3 and 2014 USGS NSHMs. Subsequently, we propose two approaches to adjust the earthquake rates of the CAT models to approximately consider the earthquake rate changes in California. Finally, we present the estimated portfolio loss changes resulting from our two methods.

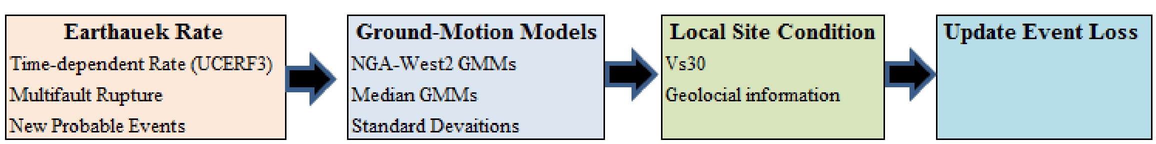


Fig. 1 – The main hazard components in CAT models which influence the updated event loss

2. The 2014 USGS Seismic Hazard Map for California

The 2014 update of USGS national seismic hazard map [6] is based on the updated seismological and geological information including new probable locations, magnitudes and rates for future earthquakes. It also employs new ground-motion models to estimate the level of ground shaking at a site. The new time-independent rupture forecast model of UCERF3 and NGA-West2 GMMs are implemented in the California part of the 2014 NSHMs. Petersen et al. (2014) discussed a summary of changes to the seismic source and GMMs [8]. Fig. 2 presents the ratio of spectral accelerations at 0.2s (SA0.2s) for 2% probability of exceedance in 50 years (2475 return period) between 2008 and 2014 maps along with disaggregation to earthquake rate, seismicity model, and GMMs.

The northern part of California (particularly, in Central Valley and parts of San Andreas) generally shows higher levels of spectral accelerations in the 2014 update. The effect of new faults, changes to slip rates, and multifault ruptures defined in UCERF3 are shown in Fig. 2b. The disaggregation to the UCERF3 smoothing seismicity model and the new NGA-West2 GMMs are shown in Fig. 2c and Fig. 2d, respectively.

Rezaeian et al. (2014) performed sensitivity analysis to investigate the impact of new NGA-West2 GMMs in active tectonic region for shallow crustal earthquakes [10]. The new GMMs present higher attenuation rate at far distances. At near-to-fault distances (up to about 10 km) and for strike-slip faults a slight increase is observed on the 2014 over 2008 GMM combinations. Similarly, for mid-range distances (up to about 50 km) the median 2014 GMM combination shows a small increase for large earthquake magnitudes. In general, the 2014 weighted combination of NGA-West2 GMMs displays lower median intensities for mid-to-far distances, yet higher standard deviations of ground shaking. The combined effects resulted in relatively small changes (5-20%) over the 2008 model in the probabilistic ground motions in the western U.S. As discussed earlier, the new GMMs estimate higher ground shaking intensities for large earthquakes on the strike-slip faults. Having comprised relatively high occurance rates for majority of faults in California compared to the western U.S. the probabilistic ground motions are mostly influenced by the larger aleatory uncertainties of NGA-West2 GMMs, hence, higher probabilistic ground shaking intensities in CA are observed [10].

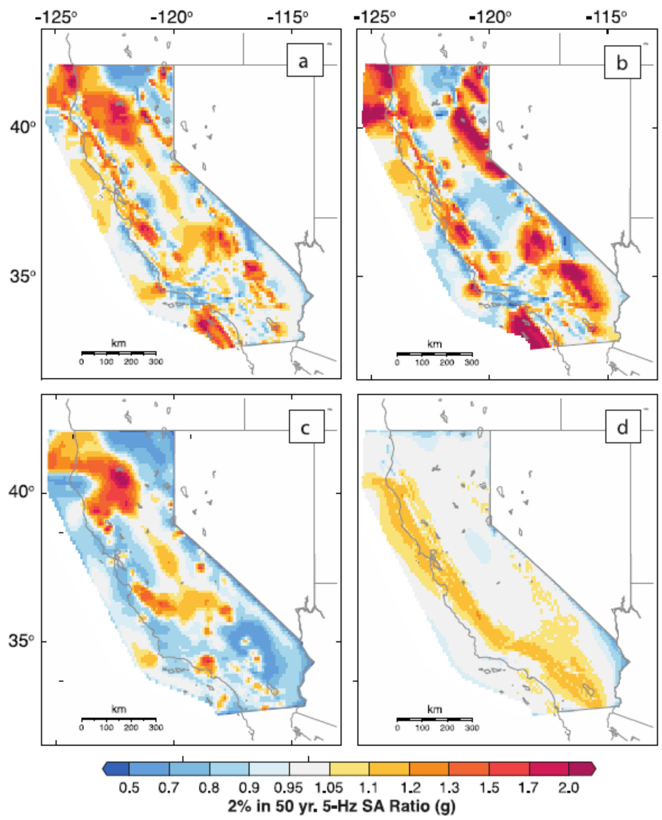


Fig. 2 – The 2014/2008 ratio maps for 2500-year return period SA0.2s. The subplots display impacts of (a) overall comparison of new source model, (b) changes in fault model in UCERF3, (c) changes in the seismicity-based model and background seismicity, and (d) new NGA-West2 GMMs (Source: Petersen et al., 2014 [8]).

3. The New Uniform California Earthquake Rupture Forecast

Inclusion of multifault ruptures and the relaxation of fault segmentation assumptions are two key attainments of the third version of the uniform California earthquake rupture forecast (i.e., UCERF3) [3] over the previous model UCERF2 [4, 5]. Consequently, UCERF3 considers significantly larger number of fault-based earthquakes than UCERF2 (250,000 including multifault ruptures vs. about 10,000, respectively) [11]. In addition, over 1440 alternative logic-tree branches are deployed to represent the epistemic uncertainties in UCERF3-TD. As the result of such model improvement and considering the entire California region, the mean rupture time for earthquake magnitudes greater than or equal to 6.7 (M ≥ 6.7) decreased about 30%, while for M ≥ 8.0 the occurrence rates increased by about 20%. In terms of likelihood of experiencing events, the 30-year probability of exceedance (PE) for M ≥ 6.7 remains almost close to one (≥ 0.99). For M ≥ 8.0, the 30-year PE is 7% which shows an increase by about 50% over UCERF2 as the result of inclusion of multifault rupture and rate changes of large faults [11]. However, this likelihood varies by region in the state. In addition, the probability participation of each individual fault is also dissimilar. For major faults in California, Fig. 3 shows the 30-year probability of exceedance for M ≥ 6.7.

As noted, the USGS implemented the time-independent UCERF2 and UCERF3 model for 2008 and 2014 NSHMs, respectively. The time-dependency impact of earthquake rates on the probabilistic ground motion is represented by *gain* (time-dependent divided by time-independent ratio map). The 2% in 50yrs PGA gain map in CA (not shown here) demonstrates that TD/TI gain in UCERF3 is more significant then the same gain in UCERF2. Fig. 4 shows the 30-year participation probability for M ≥ 7.7 based on UCERF3 and UCERF2 models. More areas of CA participate to M ≥ 7.7 events in UCERF3 which is another indication of the differences in the earthquake rate models.

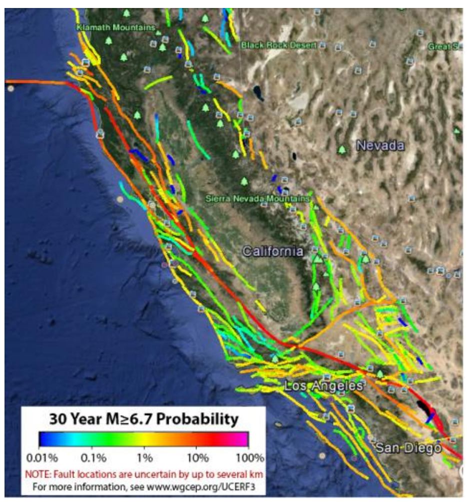


Fig. 3 – The 30-yrs M ≥ 6.7 time-dependent probabilities of individual faults of CA following UCERF3 model (developed using the supplementary KMZ file from the UCERF3 website).

4. Earthquake Rate Adjustment Algorithms

The existing commercial catastrophe earthquake models implemented the UCERF2 and 2008 USGS NSHMs on the earthquake hazard module in CA. Our focus in this study has been to update event rates of the CAT models in light of UCERF3-TD earthquake rates in order to enhance the estimate the portfolio earthquake-related losses. The following describes two approaches employed in this regard:

4.1 Rate Adjustment using the Regional Factors

For this algorithm, the event rates of CAT models are updated by using regional adjustment factors given in UCERF3-TD model document [3, Table 7]. The regional factors are UCERF3 /UCERF2 mean ratios (hereafter referred as U3 /U2) of the 30-year participation probabilities in different regions of California at several magnitude bins. The regions are defined as North California, South California, San Francisco and Los Angeles. Table 1 summarizes the employed ratios.

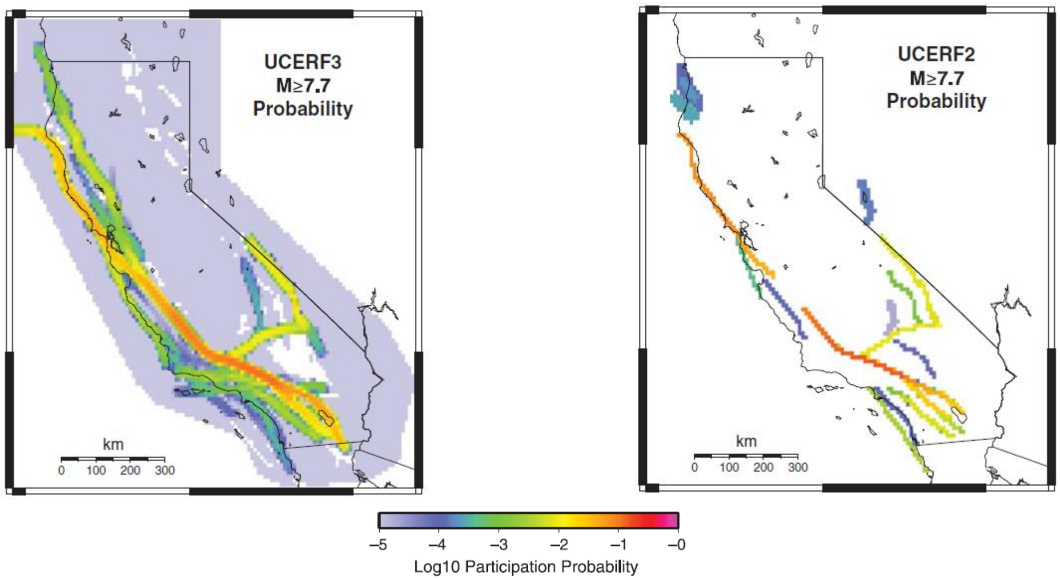


Fig. 4 – The 30-yrs M ≥ 7.7 participation probability in CA based on the (left) UCERF3 and (right) UCERF2 time-dependent model (Source: Filed et al., 2015 [3]).

In this approach, the stochastic events are clustered based on their corresponding magnitude and associated fault locations. For each event, the 30-year exceedance probability (P_t) is calculated using the Poisson distribution as shown in Eq. (1). To represent the probability based on UCERF3, the probability is multiplied by the corresponding adjustment factor from Table 1. The updated annual event rate is then back-calculated from Eq. (1). The flowchart of the proposed algorithm is given in Fig. 5.

$$P_t = 1 - e^{-rt} \tag{1}$$

where t is time interval (here, 30 years) and r is the annual rate. Having the updated event rates in the Event Loss Table (ELT), the average annual loss (AAL) and probable maximum loss (PML) at different return periods are estimated.

Table 1 – The 30 year participation probability for California (Source: Table 7, Field et al, 2015 [3])

Region	**M***	**U3/U2**	**Region**	**M***	**U3/U2**
North. California	6.0	1.00	San Francisco	6.0	1.02
	6.7	0.99		6.7	1.08
	7.0	1.00		7.0	1.27
	7.5	1.05		7.5	1.61
	7.7	0.87		7.7	1.24
	8.0	1.41		8.0	1.95
South California	6.0	1.00	Los Angeles	6.0	1.01
	6.7	0.96		6.7	0.76
	7.0	0.90		7.0	0.70
	7.5	0.93		7.5	0.87
	7.7	1.06		7.7	1.01
	8.0	2.47		8.0	2.51

*Magnitude (M) represents the minimum threshold value

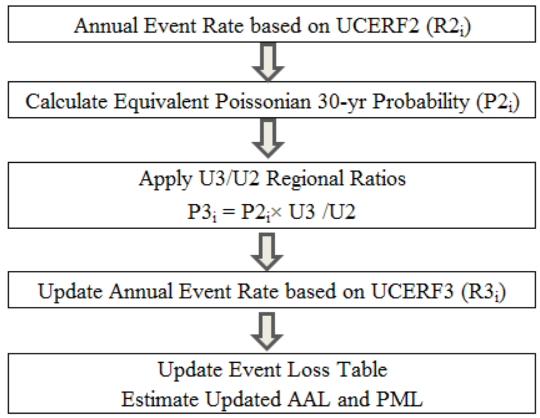


Fig. 5 – The algorithm to update event rates using regional adjustment factors of UCERF3-TD model.

4.2 Individual Fault-based Rate Adjustment

In the fault-based rate adjustment approach, event rates are updated by magnitude-dependent factors computed on each fault. The flowchart of the methodology is shown in Fig. 6. In this approach, the 30-year participation probability and its associated (UCERF3 / UCERF2) ratios for a desired fault at different magnitude bins are calculated. In this regard, we incorporated the supplementary documents provided on the UCERF3-TD website. The ratios represent the fault-based adjustment factors which will be multiplied by the corresponding event rate of catastrophe models (based on magnitude and fault name).

In the proposed heuristic, the event rates in the stochastic event sets are updated fault-by-fault; resulting in more accuracy compared to the first approach. We also add new events to the ELT in case the fault in UCERF3 is capable of producing larger magnitudes than the maximums represented by UCERF2 and the CAT models. The new event losses are estimated by fitting a statistical model relating the losses to the magnitude on the investigated fault. The updated occurrence rates and losses are incorporated to update portfolio loss estimates. The results for a few sample faults are given in the following section.

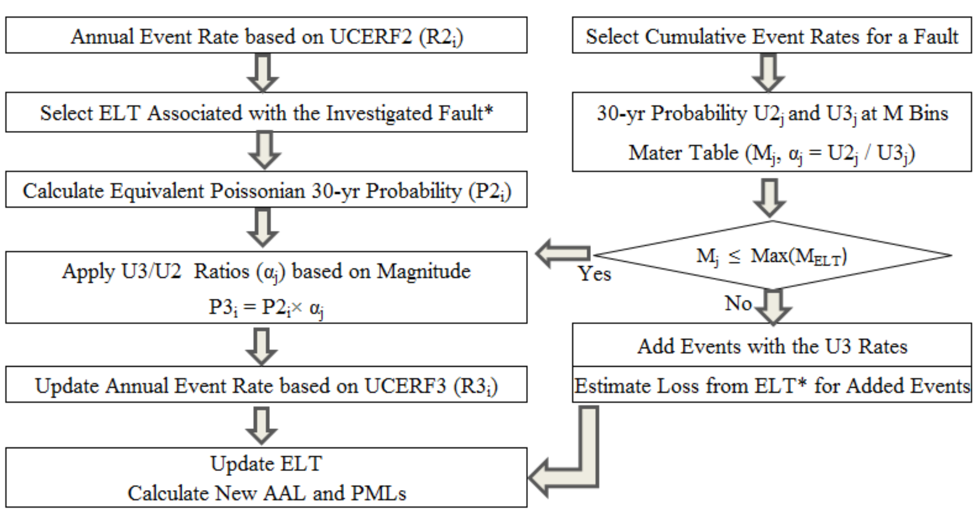


Fig. 6 – The flowchart of updating the event rates using the fault-based approach.

5. Case Studies: Portfolio Loss Adjustments

In this section, the impact of changes to event rates on the portfolio AAL as well as short-term and long-term PML estimates is investigated on two CAT models. Fig. 7 compares the adjusted cumulative occurrence rates resulting from the two proposed approaches on CAT model-1 for three representative faults in California. The example faults are Calaveras and Hayward-Roger Creeks in Northern CA (San Francisco area) and Puente Hills fault in Los Angeles area. Clearly, the adjusted rates resulting from the fault-based approach can follow the targeted UCERF3 curves more closely than the adjusted curves offered by the regional approach.

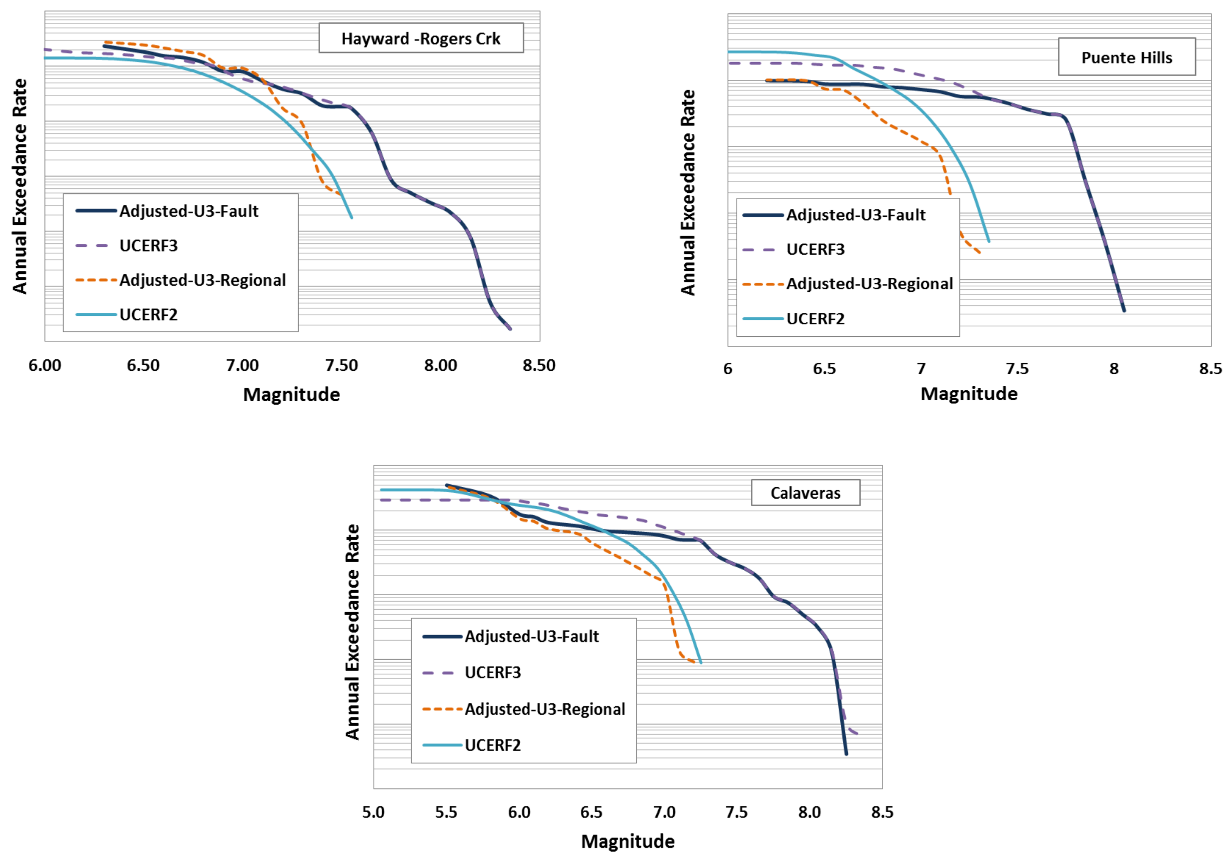
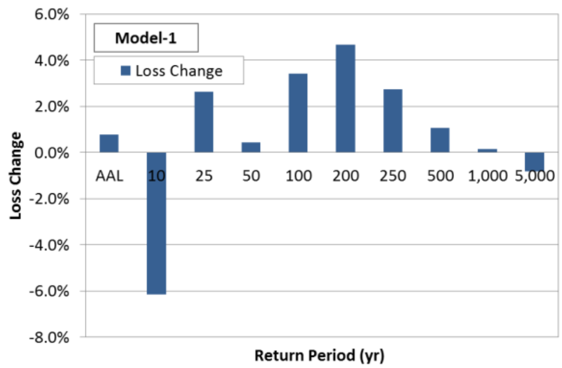


Fig. 7 – Comparing the magnitude-frequency curves from the two proposed adjustment methods for three faults in California. Model-1's magnitude-frequency curve is represented by the UCERF2 curve.

Fig. 8 shows the PML and AAL portfolio loss changes by using the regional adjustment approach on the two CAT models (Model-1 and Model-2). The regional adjustment approach results in similar trends on loss changes of both CAT models. Note than the shown effects are portfolio-specific as the spatial distribution of exposure influences the observed loss changes. Nevertheless, shown results offer the expected order of changes for a portfolio which is spread over the entire state of California.



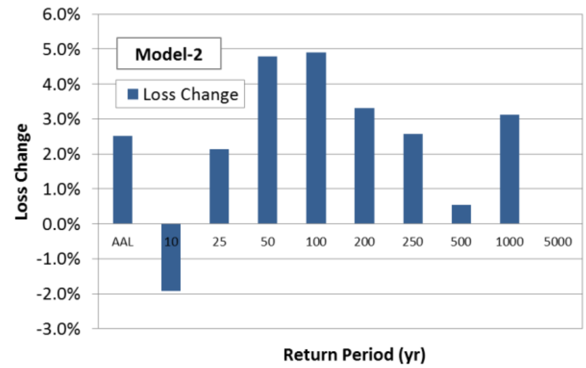


Fig. 8 – The percentage of AAL and PML loss changes using the regional rate adjustment approach from two CAT models.

Fig. 9 compares the changes in AAL and PML losses associated with updates to individual three Calaveras, Hayward-Roger Creeks and Puente Hills faults for the CAT model-1. The differences between the two approaches are evident for individual faults as well, although as evidenced by Fig. 7, the results from the fault-based approach seem to better conform to the targeted UCERF3 changes. For example, differences between loss changes form the two approaches in Calaveras fault are significant. On the other hand, a significant increase (the biggest increase among main faults) on the $M \geq 6.7$ probability was observed in the UCERF3 (in about three times larger) compared with UCERF2 in the Calaveras fault.

The rate updates on Calaveras and Hayward-Roger Creek faults have an impact on losses associated with the exposure in the Northern CA (particularly in greater San Francisco area), while it is the Southern CA losses (particularly in greater Los Angles) which are influenced by updates to the Puente Hills fault. It is interesting to note that Southern CA experiences a decrease in AAL for this particular portfolio as the result of updates to the Puente Hills fault. Fig. 10 combines the impact from rate adjustments to the three faults. This figure presents a better loss change representation on the state level; however, from impact of just abovementioned three faults. In other word, a portion of ELT associated with the three faults is considered in this figure–compared to Fig. 8 where the thorough ELT is employed– to estimate loss changes.

The fault-based approach is implemented to estimate portfolio loss changes as the result of occurrence rate adjustment of major A-Type faults in California. The faults included South and North San Andreas, Calaveras, Hayward Roger Creek, Garlock, and Elsinore. The associated fault segments are listed in Table 2. The portfolio AAL and PMLs losses and loss changes are shown in Fig. 11. It should be noted that despite Fig. 9 and Fig. 10, loss changes in Fig. 11 are calculated by considering the complete event loss table. In other words, the updated rate is used for events associated with A-type faults; however, for events other than A-type faults the original occurrence rate of vendor model is implemented. To compare the results with the regional-based approach, we repeated the analysis by substituting the original occurrence rate of A-type faults with the regional adjusted ones. Similarly, for all other events in ELT the original rate is used. We observed the results from two approaches have almost the same trend–but different values. The overall increase in AAL and PMLs as the result of A-Fault type rate adjustment is observed. The observation is in line with the expectation of rate increase in Northern California and spatial distribution of majority of important A-type faults. To fully investigate the portfolio loss changes in California a comprehensive rate adjustment includes rate update of all major faults (including B-Type faults) are also required.

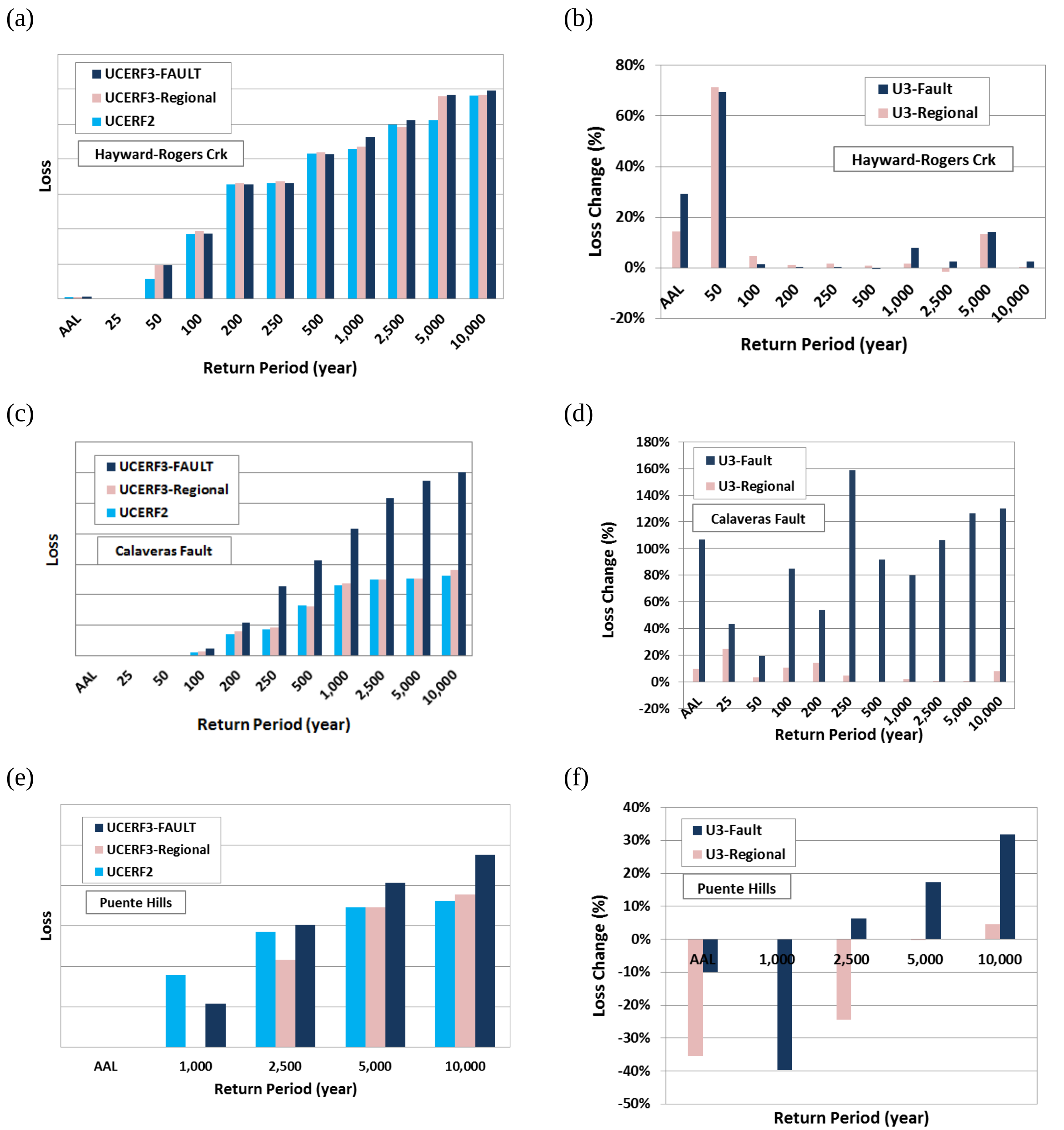


Fig. 9 – The AAL and PML losses (left column) and loss changes (right column) from Model-1 using the two adjustment approaches. Subplots represent losses that caused by events from (top) Hayward-Roger Creeks, (middle) Calaveras, and (bottom) Puente Hills faults.

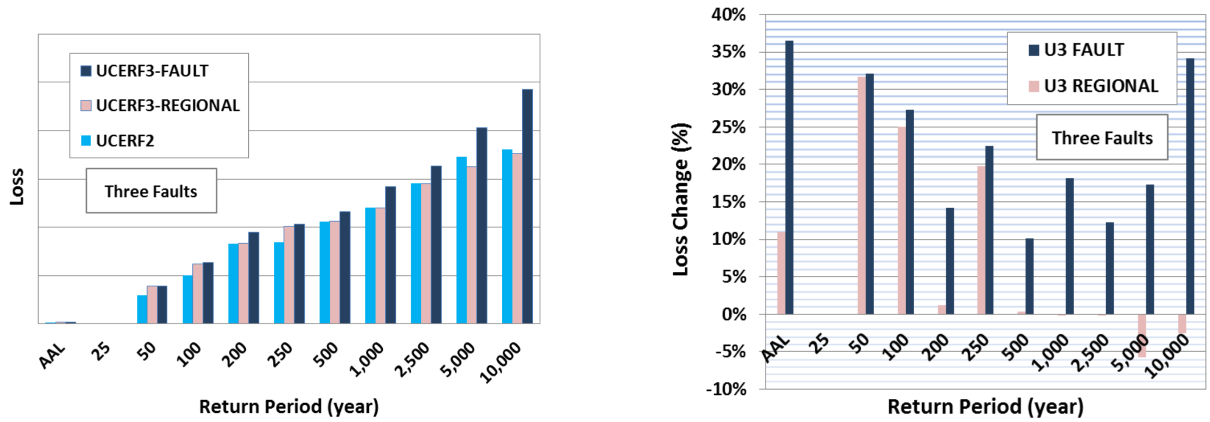


Fig. 10 – The AAL and PML loss and loss changes compared to the modeled losses by Model-1 considering all three investigated faults (Calaveras, Puente Hills, and Hayward-Rogers Creeks).

Table 2 – The major A-Type faults and their sections considered for the fault-based approach analysis.

Fault Name	**Sections**
South San Andreas	San Andreas (Parkfield), San Andreas (Cholame) rev, San Andreas (Carrizo) rev, San Andreas (Big Bend), San Andreas (Mojave North), San Andreas (Mojave South), San Andreas (San Bernardino N), San Andreas (San Bernardino S), San Andreas (San Gorgonio Pass-Garnet Hill), San Andreas (North Branch Mill Creek), and San Andreas (Coachella) rev
North San Andreas	San Andreas (Offshore) 2011 CFM, San Andreas (North Coast) 2011 CFM, San Andreas (Peninsula) 2011 CFM, and San Andreas (Santa Cruz Mts) 2011 CFM
Calaveras	Calaveras (North) 2011 CFM, Calaveras (Central) 2011 CFM, Calaveras (South) 2011 CFM
Hayward Roger Creek	Rodgers Creek—Healdsburg 2011 CFM, Hayward (No) 2011 CFM, Hayward (So) 2011 CFM
San Jacinto	San Jacinto (San Bernardino), San Jacinto (San Jacinto Valley) rev, San Jacinto (Stepovers Combined), San Jacinto (Anza) rev, San Jacinto (Clark) rev, San Jacinto (Coyote Creek), San Jacinto (Borrego), San Jacinto (Superstition Mountain)
Elsinore	Whittier alt 1, Elsinore (Glen Ivy) rev, Elsinore (Stepovers Combined), Elsinore (Temecula) rev, Elsinore (Julian), Elsinore (Coyote Mountains)
Garlock	Garlock (East), Garlock (Central), Garlock (West)

5. Conclusions

The commercial catastrophe loss models are based on the UCERF2 earthquake rupture model and 2008 USGS NSHMs in California. In light of update to the rupture models (UCERF3) in CA, two alternative earthquake rate adjustment methods are proposed to update the event rates, and subsequently, modeled losses of CAT models. The first approach employs the magnitude-dependent regional adjustment factors over all groups of faults in California. In the second method, event rates associated with each individual fault are adjusted by incorporating the magnitude-dependent adjustment factors computed on the investigated fault.

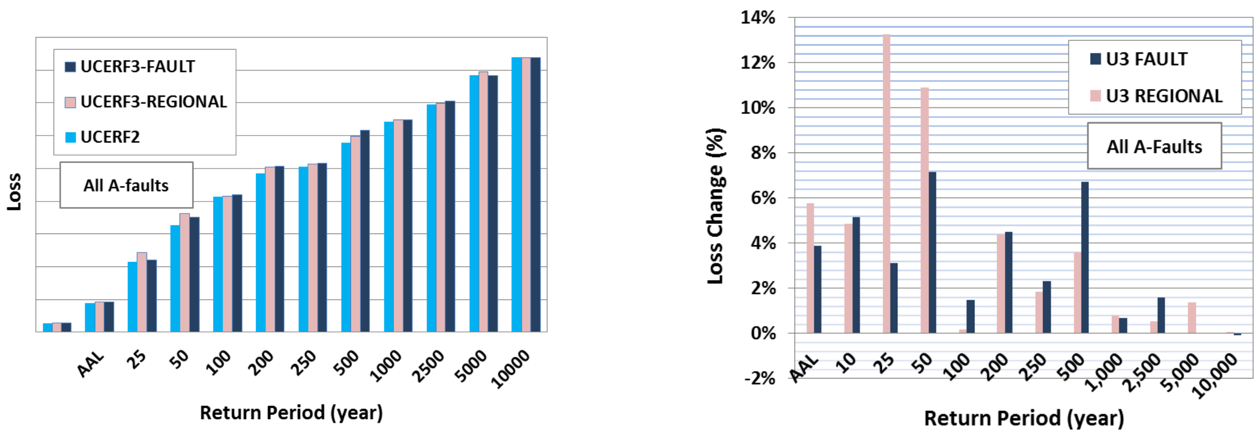


Fig. 11 – The portfolio loss changes from modifications of occurrence rate of Type-A-faults in California.

In addition, it explicitly employs the multifault rupture effects to update the CAT models' stochastic event set. Although the fault-based approach requires much more detailed adjustment which necessitates extensive computational efforts, sensitivity analyses show its superior performance in conforming to UCERF3. Using the regional modification approach, we observed a slight increase in the average annual loss of CA for a portfolio covering both northern and southern parts of the state. In addition, the probable maximum losses experience a decrease at very short return period and an increase at longer return periods. The detailed modification analysis over all main faults (Type-A and Type-B faults in California) is required to fully investigate the portfolio loss change across the state. In this study, we have not considered the impact of new ground-motion models on the loss estimate. Future study will investigate the effect of new NGA-West2 GMMs (incorporated in the 2014 USGS NSHMs) on the portfolio loss change to complement the current study.

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Disclaimer

All results and findings presented in this paper are the opinion of the authors and do not reflect the views of AIG.

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