New Ground Motion Spectral Response Accelerations for Seismic Retrofit of Existing Buildings

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SUMMARY:
An update of the contemporaneous American Society of Civil Engineers (ASCE) standards for seismic evaluation and rehabilitation/retrofit of existing buildings, ASCE 31-03 and 41-06, is nearing completion. As part of the update, the ground motion spectral response accelerations specified by those standards are being re-specified for more consistency with the concept of the recently-updated ground motions for designing *new* buildings that are in ASCE 7-10. The Risk-Targeted Maximum Considered Earthquake ground motions in ASCE 7-10 are defined such that they are expected to result in buildings with relatively uniform collapse risk across the United States (US). Although the re-specified ground motions for existing buildings described herein are not precisely risk-targeted – due to limited availability of fragility curves for retrofitted buildings – we demonstrate that the new ground motions can be expected to result in more uniform risk of collapse and of life endangerment across the US than those specified by ASCE 31-03/41-06.

Keywords: risk-targeted and uniform-hazard ground motion maps for design, retrofit

1. INTRODUCTION

The American Society of Civil Engineers (ASCE) standards for *Seismic Evaluation of Existing Buildings* (ASCE 31-03, 2003) and *Seismic Rehabilitation of Existing Buildings* (ASCE 41-06, 2006) are currently being updated. This ASCE committee work will culminate in a merged standard to be published in 2013 (ASCE 41-13). As part of the update, changes to the ground motion spectral response accelerations specified by ASCE 31-03 and 41-06 have been proposed. This paper summarizes (in Section 1) the ground motion changes proposed for ASCE 41-13, provides (in Section 3) examples of the risks of collapse and of life endangerment that are anticipated to result from rehabilitation/retrofit to these ground motions (as calculated via the risk integration described in Section 2), and discusses (in Section 4) adjustments to the proposed ground motions that would result in precisely uniform risk.

1.1. Ground Motions Specified in ASCE 31-03 and ASCE 41-06

The Basic Safety Objective (BSO) of ASCE 41-06 specifies collapse prevention building performance at the Basic Safety Earthquake 2 (BSE-2) ground motion level, and life safety at the BSE-1 ground motion. The BSE-2 ground motions are equated to the Maximum Considered Earthquake (MCE) ground motions in the latest ASCE 7 standard for designing new buildings. The BSE-1 ground motions are defined as the smaller of uniform-hazard ground motions having a 10% probability of being exceeded in 50 years ("10%-in-50yrs" ground motions) and 2/3 times the aforementioned MCE ("2/3MCE") ground motions. So defined, this BSO was intended to approximate the performance objective of ASCE 7 for new buildings. The philosophy was that retrofits should be done to a level consistent with ASCE 7.

In contrast, the performance level implicit in ASCE 31-03 is less than the BSO of ASCE 41-06. The lesser performance is in keeping with a commonly-held philosophy within the US profession that higher risk of collapse can be accepted for existing buildings because of their generally shorter life spans, as well as the costs associated with seismic retrofit. To accomplish this, the ASCE 31-03 Tier 1 and 2 evaluations use the 2/3MCE or 10%-in-50yrs ground motions in conjunction with somewhat more liberal acceptance criteria than those in ASCE 41-06. The Tier 3 evaluation in ASCE 31-03 points to ASCE 41-06, but specifies ground motions that are 0.75 times the ASCE 41-06 ground motions. The 0.75 reduction factor came from commonly-accepted practice (for over 30 years) codified by many local jurisdictions and from ATC 14 (Applied Technology Council, 1987).

For 34 example US city locations from FEMA P-750 (2009), the MCE spectral response accelerations from the latest edition of ASCE 7 (i.e. ASCE 7-10, 2010) are listed in Table 1.1, for spectral periods of 0.2 and 1.0 seconds. Note that these ground motions in ASCE 7 are now “Risk-Targeted MCE ground motions,” but in this paper we will refer to them as simply “MCE ground motions” for brevity. Also listed in the table are corresponding 10%-in-50yrs uniform-hazard ground motions that are also based on the latest (2008) USGS National Seismic Hazard Maps (Petersen et al, 2008). For consistency with the MCE ground motions in ASCE 7-10, these 10%-in-50yrs ground motions are likewise modified

Table 1.1. Thirty four example city locations from FEMA P-750, their Risk-Targeted MCE ground motions from ASCE 7-10 (S_S and S_1), and their corresponding 10%-in-50yrs ($S_{SUH10\%}$ and $S_{1UH10\%}$), 5%-in-50yrs ($S_{SUH5\%}$ and $S_{1UH5\%}$), and 20%-in-50yrs ($S_{SUH20\%}$ and $S_{1UH20\%}$) uniform-hazard ground motions.

#	Location Name	Lat.	Long.	S_S (*g*)	S_1 (*g*)	$S_{SUH5\%}$	$S_{1UH5\%}$	$S_{SUH10\%}$	$S_{1UH10\%}$	$S_{SUH20\%}$	$S_{1UH20\%}$
1	Los Angeles	34.05	-118.25	2.40	0.84	1.76	0.61	1.26	0.44	0.84	0.30
2	Century City	34.05	-118.40	2.16	0.80	1.60	0.57	1.15	0.41	0.79	0.28
3	Northridge	34.20	-118.55	1.69	0.60	1.46	0.51	1.13	0.40	0.81	0.29
4	Long Beach	33.80	-118.20	1.64	0.62	1.18	0.43	0.84	0.31	0.57	0.21
5	Irvine	33.65	-117.80	1.55	0.57	1.04	0.38	0.75	0.28	0.53	0.20
6	Riverside	33.95	-117.40	1.50	0.60	1.29	0.51	1.04	0.40	0.79	0.30
7	San Bernardino	34.10	-117.30	2.37	1.08	2.39	1.02	1.80	0.75	1.28	0.51
8	San Luis Obispo	35.30	-120.65	1.12	0.43	0.78	0.30	0.56	0.22	0.39	0.15
9	San Diego	32.70	-117.15	1.25	0.48	0.85	0.31	0.51	0.20	0.31	0.13
10	Santa Barbara	34.45	-119.70	2.83	0.99	2.16	0.74	1.49	0.51	0.87	0.31
11	Ventura	34.30	-119.30	2.38	0.90	1.73	0.64	1.23	0.45	0.82	0.30
12	Oakland	37.80	-122.25	1.86	0.75	2.14	0.79	1.66	0.61	1.19	0.43
13	Concord	37.95	-122.00	2.08	0.73	2.06	0.71	1.56	0.53	1.08	0.37
14	Monterey	36.60	-121.90	1.53	0.56	1.11	0.40	0.79	0.29	0.54	0.19
15	Sacramento	38.60	-121.50	0.67	0.29	0.45	0.20	0.35	0.16	0.27	0.12
16	San Francisco	37.75	-122.40	1.50	0.64	1.51	0.62	1.16	0.46	0.85	0.32
17	San Mateo	37.55	-122.30	1.85	0.86	1.71	0.72	1.24	0.50	0.85	0.32
18	San Jose	37.35	-121.90	1.50	0.60	1.58	0.55	1.26	0.44	0.97	0.33
19	Santa Cruz	36.95	-122.05	1.52	0.60	1.23	0.46	0.94	0.34	0.67	0.24
20	Vallejo	38.10	-122.25	1.50	0.60	1.39	0.50	1.12	0.40	0.84	0.30
21	Santa Rosa	38.45	-122.70	2.51	1.04	2.39	0.97	1.67	0.67	1.02	0.40
22	Seattle	47.60	-122.30	1.36	0.53	0.98	0.38	0.71	0.27	0.49	0.18
23	Tacoma	47.25	-122.45	1.30	0.51	0.93	0.37	0.70	0.27	0.49	0.18
24	Everett	48.00	-122.20	1.27	0.48	0.89	0.35	0.64	0.24	0.43	0.16
25	Portland	45.50	-122.65	0.98	0.42	0.71	0.31	0.48	0.20	0.30	0.11
26	Salt Lake City	40.75	-111.90	1.54	0.56	1.07	0.36	0.58	0.19	0.29	0.10
27	Boise	43.60	-116.20	0.31	0.11	0.21	0.07	0.15	0.05	0.10	0.04
28	Reno	39.55	-119.80	1.50	0.52	1.14	0.38	0.82	0.27	0.55	0.18
29	Las Vegas	36.20	-115.15	0.49	0.17	0.33	0.11	0.22	0.08	0.15	0.06
30	St. Louis	38.60	-90.20	0.44	0.17	0.31	0.12	0.19	0.07	0.10	0.03
31	Memphis	35.15	-90.05	1.01	0.35	0.71	0.24	0.35	0.10	0.13	0.04
32	Charleston	32.80	-79.95	1.15	0.37	0.71	0.20	0.31	0.08	0.10	0.03
33	Chicago	41.85	-87.65	0.13	0.06	0.08	0.04	0.05	0.03	0.03	0.01
34	New York	40.75	-74.00	0.28	0.07	0.16	0.04	0.09	0.03	0.04	0.02

for the maximum direction of horizontal spectral response acceleration. That is, they are factors of 1.1 (for 0.2 seconds) and 1.3 (for 1.0 seconds) times larger than the corresponding geometric-mean uniform-hazard ground motions mapped by the USGS. For more information on maximum-direction ground motions, please see FEMA P-750.

1.2. New Ground Motions Proposed for ASCE 41-13

In lieu of the 0.75-times-MCE ground motions specified by ASCE 31-03 Tier 3 for collapse prevention building performance, 5%-in-50yrs uniform-hazard ground motions (but capped by MCE ground motions) have been proposed for ASCE 41-13. In lieu of the 0.75-times-10%-in-50yrs or 0.75-times-2/3MCE ground motions for life safety performance, 20%-in-50yrs ground motions (capped by 2/3MCE ground motions) have been proposed. Although the proposed ground motions for ASCE 41-13 also include unreduced (MCE and 2/3MCE for collapse prevention and life safety, respectively) ground motions for use in retrofitting/evaluating to a level consistent with ASCE 7-10 for new buildings, only the reduced ground motions proposed for ASCE 41-13 are discussed in this paper. Values of the proposed 5%-in-50yrs and 20%-in-50yrs ground motions for the 34 example city locations are listed in Table 1.1.

Ratios of the proposed ASCE 41-13 ground motions to those specified by ASCE 31-03 Tier 3 (hereafter referred to as ASCE 31-03/41-06 ground motions) are shown in Fig. 1.1, only for the short (0.2-second) spectral period for brevity. The corresponding figure for 1.0-second spectral period looks very similar, and its ratios (which can be calculated from the values in Table 1.1) are included in the summaries below.

Recognizing that for ASCE 31-03/41-06 the 10%-in-50yrs ground motions typically govern over (i.e., are smaller than) 2/3MCE, in most of the western US regions (namely Southern California, Pacific Northwest, Intermountain West) the ground motions proposed for ASCE 41-13 are generally only slightly smaller than the corresponding ASCE 31-03/41-06 ground motions, by median ratios for each

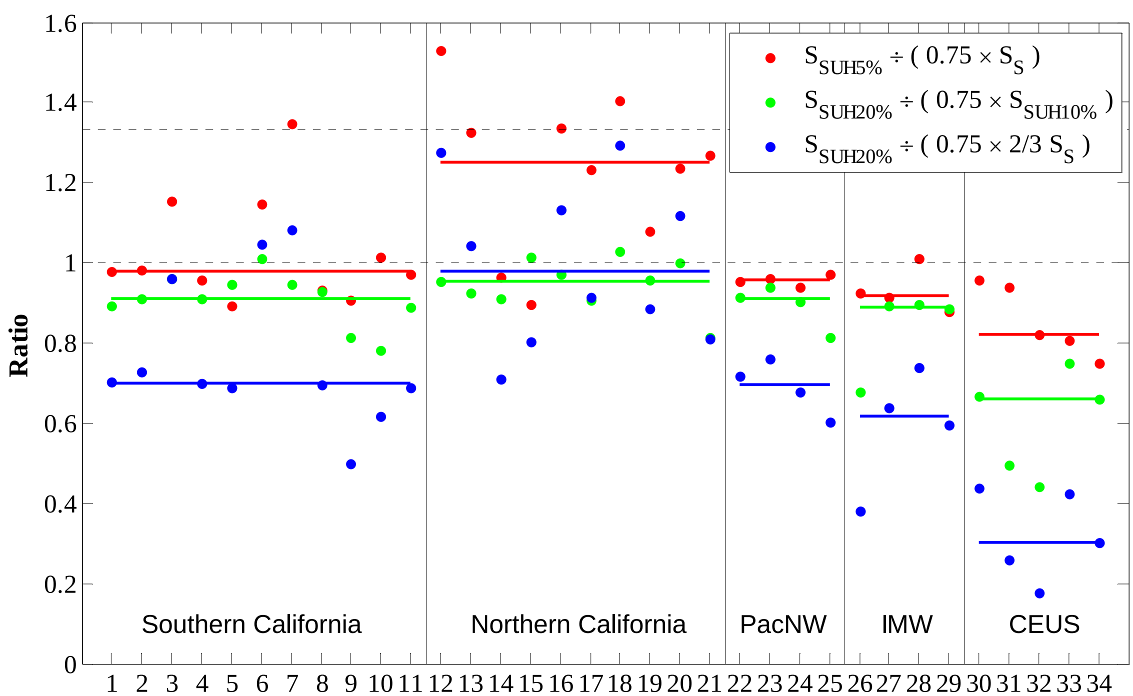

Figure 1.1. Ratios of ground motions proposed for ASCE 41-13 over those specified by ASCE 31-03/41-06, for the 34 example city locations and the short (0.2-second) spectral period. Please see the caption of Table 1.1 for the definitions of $S_{SUH5\%}$, etc. The red/green/blue lines show the median ratio for each region. PacNW = Pacific Northwest, IMW = Inter-Mountain West, CEUS = Central and Eastern US.

region of 0.88 to 0.98. The exception is that in the Northern California region the proposed 5%-in-50yrs ground motions are generally larger (than 0.75 times the MCE ground motions), by a median ratio of about 1.17 to 1.25. This is because eight of the ten MCE ground motions in that region (from ASCE 7-10) are capped by deterministic ground motions.

In contrast, in the Central and Eastern US region, the ground motions proposed for ASCE 41-13 are smaller than the ASCE 31-03/41-06 ground motions by median factors of 0.60 to 0.89 (again recognizing that the 10%-in-50yrs ground motions typically govern for ASCE 31-03/41-06). As will be shown in Section 3, however, the risks of building collapse and endangerment of individual lives that are expected to result from retrofitting to the proposed ground motions are relatively uniform across the US, as compared to the risks resulting from the ground motions of ASCE 31-03/41-06.

2. CALCULATING RISK RESULTING FROM DESIGN GROUND MOTIONS

To calculate the risk of collapse or of endangerment of individual lives that is anticipated for a building designed/retrofitted to a given ground motion level, the so-called risk integral (e.g., ATC 3-06, 1978; McGuire, 2004) can be used. As an early example, this integral was used in ATC 3-06 to compute collapse risks expected to result from designing buildings for uniform-hazard ground motions. Recently, the risk integral was used to revisit these ATC 3-06 computations (Luco et al, 2007) and ultimately derive the new Risk-Targeted MCE ground motions in ASCE 7-10.

2.1. Risk Integral

As expressed in Equation 2.1 for collapse risk, denoted λ[Collapse], the risk integral combines a collapse fragility curve for the building design/retrofit of interest, Pr[Collapse|IM=a], with a ground motion hazard curve for its location, λ[IM>a]. The fragility and hazard curves used in this paper are described in the next two subsections, but in short (and loosely speaking) a fragility curve provides "what-if" conditional probabilities of collapse for a range of potential ground motion intensity measure (IM) values, and a hazard curve provides annualized frequencies of exceeding those IM values. The combination of these curves via the risk integral yields an annualized frequency of collapse of the building design/retrofit at its particular location.

$$\lambda[\mathrm{Collapse}] = \int_0^\infty \Pr[\mathrm{Collapse} \mid \mathrm{IM} = a] \left| \frac{\mathrm{d}\lambda[\mathrm{IM} > a]}{\mathrm{d}a} \right| \mathrm{d}a \qquad (2.1)$$

From λ[Collapse], probabilities of collapse for time horizons like the 50 years used below in Section 3 are commonly calculated using a Poisson probability distribution (e.g., see McGuire, 2004). Probabilities of "endangerment of individual lives" (as phrased in ASCE 7-10) can be calculated analogously.

2.2. Fragility Curves

2.2.1. Collapse prevention

The collapse fragility curves used in this paper are the same generic fragility curves for *new* buildings that were used to derive the Risk-Targeted MCE ground motions in ASCE 7-10, because corresponding fragility curves for retrofitted buildings are not yet available. More specifically, the collapse fragility curves are lognormal cumulative distribution functions (CDF's) with a logarithmic standard deviation (β) value of 0.8 and a 10% probability of building collapse at the collapse-prevention ground motion level for the city location: MCE from ASCE 7-10, 0.75-times-MCE from ASCE 31-03/41-06, or 5%-in-50yrs from ASCE 41-13. It is not unreasonable to assume that a building retrofitted for collapse prevention at a given ground motion level (e.g., 0.75 times MCE) will have the same fragility curve as a new building designed *for that same ground motion level*. This assumption has not yet been confirmed, however.

2.2.2. Life safety

The life-endangerment fragility curves assumed in this paper are also based on ASCE 7-10. Like the collapse fragility curves, they are lognormal CDF's with a β value of 0.8. Instead of the 10% probability at the collapse-prevention ground motion level, the life-endangerment fragility curves have a 12% probability of endangerment of individual lives at the life-safety ground motion level for the city location: 0.75-times-10%-in-50yrs or 0.75-times-2/3MCE from ASCE 31-03/41-06 (whichever is less governs, but both are shown in this paper), or 20%-in-50yrs from ASCE 41-13. Assuming that the life-safety ground motion level for new building design in accordance with ASCE 7-10 is 2/3MCE, the 12% probability is equivalent to the 25% probability of endangerment of individual lives at the MCE ground motion level that is listed in Table C.1.3.1b of ASCE 7-10. That is, for a lognormal CDF with $\beta = 0.8$, 25% probability at the MCE ground motion is equivalent to 12% at the 2/3MCE ground motion.

2.3. Hazard Curves

The ground motion hazard curves used in this paper are the same curves of ground motion level versus annualized frequency of exceedance from the USGS National Seismic Hazard Mapping Project that were used to derive the MCE ground motions in ASCE 7-10, as well as the various uniform-hazard ground motions listed above in Table 1.1. For consistency with the MCE ground motions in ASCE 7-10, the hazard curves are likewise for the maximum direction of horizontal spectral response acceleration. Please see the end of Section 1.1 for more information.

3. RISK RESULTING FROM ASCE 41-13 VERSUS ASCE 41-06/31-03 GROUND MOTIONS

Calculated using the risk integral and fragility/hazard curves described in the preceding section, risk values resulting from the ground motions proposed for ASCE 41-13 versus those specified by ASCE 31-03/41-06 are shown in Figs. 3.1 and 3.2. They are discussed in the two subsections below.

3.1. Collapse Prevention

As seen from Fig. 3.1, the collapse risks expected of a building retrofitted to the 5%-in-50yrs uniform-hazard ground motions proposed for ASCE 41-13 are relatively uniform across the US regions, with median risks ranging only from 1.8% to 2.2% probability of collapse in 50 years. In contrast, the risks resulting from the 0.75-times-MCE ground motions specified by ASCE 31-03/41-06 vary more across the US regions, from median probabilities of collapse in 50 years of 1.6% to 1.9% outside of Northern California, up to 3.5% in Northern California.

For comparison purposes, the new-building collapse risks expected to result from designing to the (Risk-Targeted) MCE ground motions in ASCE 7-10 are also shown in Fig. 3.1. Per the definition of those ground motions, the risks are equal to 1% probability of collapse in 50 years for most city locations. The exceptions are those city locations for which deterministic caps govern the MCE ground motions. For the Northern California region, the deterministic caps result in median risks of 1.5-1.9% in 50 years.

3.2. Life Safety

As seen from Fig. 3.2, the life-endangerment risks resulting from the 20%-in-50yrs uniform-hazard ground motions proposed for ASCE 41-13 are also relatively uniform across the US regions, with median risks ranging only from 9.2% to 11.0% probability of endangerment of individual lives in 50 years. If the Memphis (#31) and Charleston (#32) city locations were removed, the median risks would be slightly more uniform. These two city locations are discussed more below in Section 4.

The risks resulting from the 0.75-times-10%-in-50yrs uniform-hazard ground motions specified by ASCE 31-03/41-06 are also relatively uniform across the US regions, with median risks ranging from

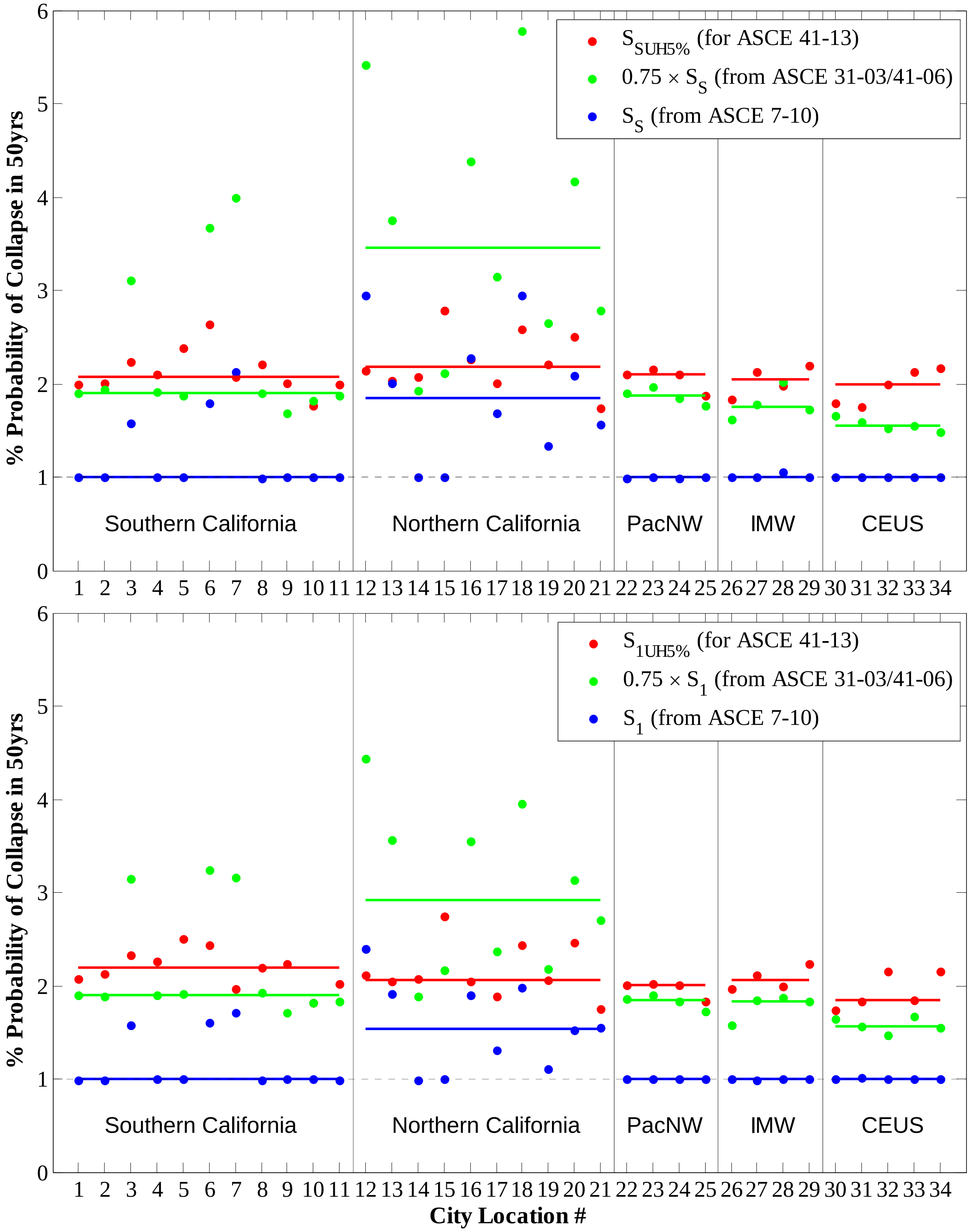

Figure 3.1. Risks of collapse anticipated for a building retrofitted for collapse prevention at the 5%-in-50yrs uniform-hazard ground motions proposed for ASCE 41-13 ($S_{SUH5\%}$ and $S_{1UH5\%}$), versus those expected to result from the 0.75-times-MCE ground motions specified by ASCE 31-03/41-06 ($0.75{\times}S_S$ and $0.75{\times}S_1$). For comparison purposes, also shown are the collapse risks for a new building designed to the (Risk-Targeted) MCE ground motions in ASCE 7-10 (S_S and S_1). Along the lines of Figure 1.1, the red/green/blue lines show the median (e.g., 6th largest value of 11) collapse risks for each region. Please see the caption of Figure 1.1 for an explanation of the PacNW, IMW, and CEUS region abbreviations.

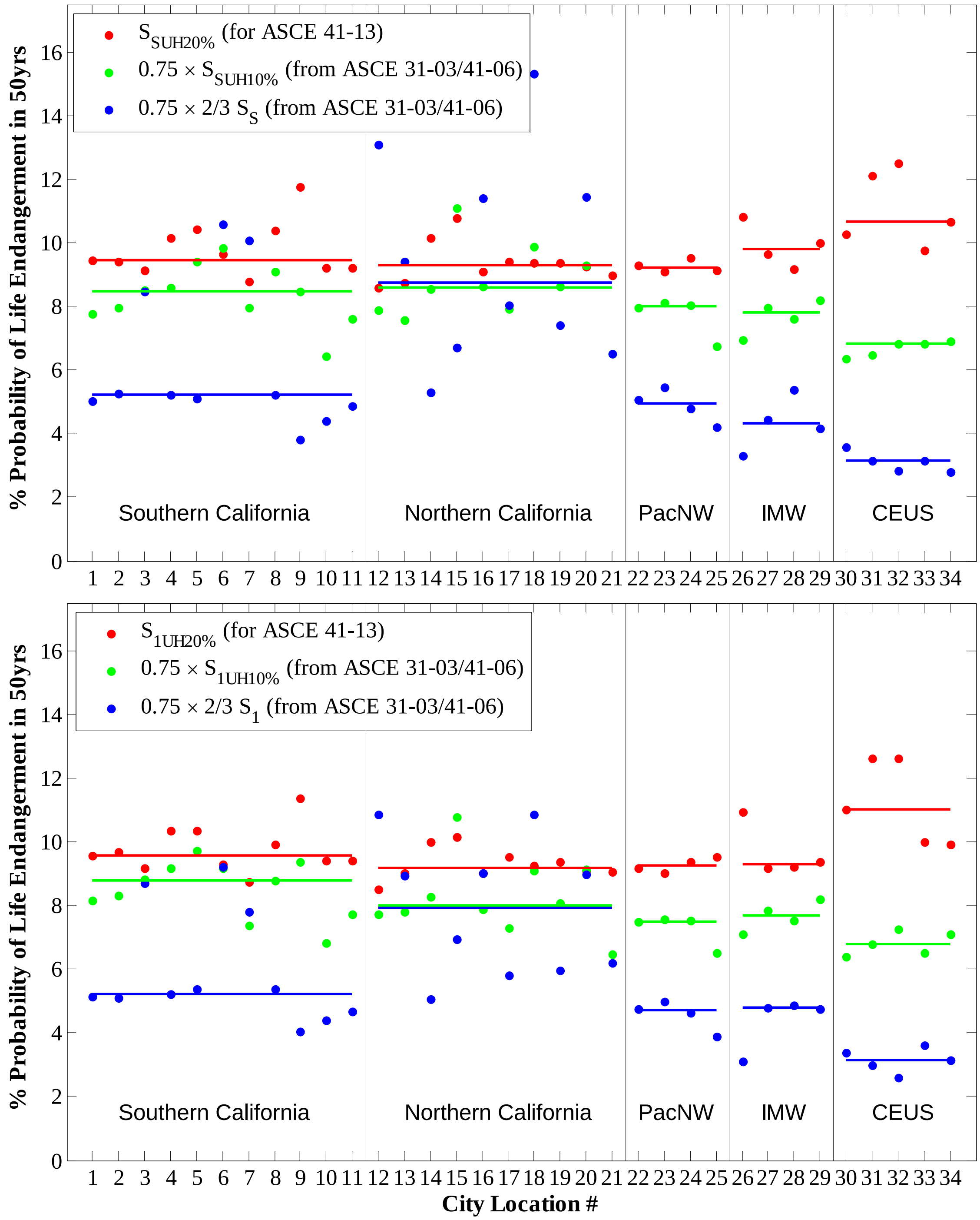

Figure 3.2. Risks of endangering individual lives that are anticipated for buildings retrofitted for life safety at the 20%-in-50yrs uniform-hazard ground motions proposed for ASCE 41-13 ($S_{SUH20\%}$ and $S_{1UH20\%}$), versus those expected to result from the 0.75-times-10%-in-50yrs uniform-hazard ($0.75 \times S_{SUH10\%}$ and $0.75 \times S_{1UH10\%}$) or 0.75-times-2/3MCE ground motions ($0.75 \times 2/3 S_S$ and $0.75 \times 2/3 S_1$) specified by ASCE 31-03/41-06. Please see the caption of Figure 3.1 for explanations of the red/green/blue lines and region abbreviations.

6.8% to 8.8% probability of life endangerment in 50 years. In contrast, the risks resulting from the 0.75-times-2/3MCE ground motions specified by ASCE 31-03/41-06 vary more across the US regions, from medians of 3.1% to 5.2% in 50 years outside of Northern California, up to 8.7% in Northern California.

4. RISK-TARGETED GROUND MOTIONS FOR FUTURE EDITIONS OF ASCE 41?

Although the ground motions proposed for ASCE 41-13 result in more uniform risks of collapse and of life endangerment across the US (as shown in the preceding section) than ASCE 31-03/41-06, it is interesting to investigate how much the proposed ground motions would need to be adjusted in order to result in precisely uniform risks. Analogous adjustments were adopted for the Risk-Targeted MCE ground motions for designing new buildings in ASCE 7-10, not to mention the ground motion level in the ASCE 43-05 (2005) *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*. Of course, the generic fragility curves used in this paper (for retrofitted buildings) are merely based on ASCE 7-10 (for new buildings). Therefore, the "uniform-risk" adjustments presented below for retrofitting existing buildings might change with future research.

4.1. Collapse Prevention (CP)

As discussed above in Section 3.1, the 5%-in-50yrs uniform-hazard ground motions proposed for ASCE 41-13 result in collapse risks of around 2% probability of collapse in 50 years. Also for the 34 example city locations, Fig. 4.1 below shows factors by which these 5%-in-50yrs ground motions would need to be adjusted in order to result in precisely 2% probability of collapse in 50 years. The analogous "risk coefficients" for new buildings (and 1% probability of collapse in 50 years) that are in ASCE 7-10 are also shown in Fig. 4.1, for comparison purposes.

As seen from Fig. 4.1, the risk adjustment factors for the 5%-in-50yrs ground motions ($AF_{RS,5\%}$ and $AF_{R1,5\%}$) are relatively close to unity, ranging only from 0.91 to 1.14. In contrast, the ASCE 7-10 risk coefficients (C_{RS} and C_{R1}) range from 0.79 to 1.13, with several city locations having values less than 0.91.

4.2. Life Safety (LS)

As discussed above in Section 3.2, the 20%-in-50yrs uniform-hazard ground motions proposed for ASCE 41-13 result in life-endangerment risks of around 10% probability of life endangerment in 50 years. The factors by which these uniform-hazard ground motions would need to be adjusted, in order to result in precisely 10% probability of life endangerment in 50 years, are shown in Fig. 4.1.

As seen from Fig. 4.1, the risk adjustment factors for the 20%-in-50yrs ground motions ($AF_{RS,20\%}$ and $AF_{R1,20\%}$) are also relatively close to unity for the city locations other than Memphis and Charleston, ranging only from 0.91 to 1.11. The risk adjustment factors for Memphis and Charleston range from 1.26 to 1.40, however, suggesting that once generic fragility curves for retrofitted buildings are available, perhaps risk-targeted (or uniform-risk) ground motions should be considered for future editions of ASCE 41.

5. CONCLUDING REMARKS

For the nearly-complete update of the ASCE standards for *Seismic Evaluation of Existing Buildings* (ASCE 31-03) and *Seismic Rehabilitation of Existing Buildings* (ASCE 41-06), new ground motion spectral response accelerations have been proposed. In addition to updating to ground motion values that are based on the latest (2008) USGS National Seismic Hazard Maps, the definitions of the ground motion levels specified for rehabilitation/retrofit have been changed. The new ground motions have been accepted, pending a public comment period, for the merged standard to be published in 2013 (ASCE 41-13).

In lieu of the 0.75-times-MCE ground motions specified by ASCE 31-03/41-06 for collapse prevention building performance, 5%-in-50yrs uniform-hazard ground motions (capped by MCE ground motions) have been proposed for ASCE 41-13. In lieu of the 0.75-times-10%-in-50yrs or 0.75-times-2/3MCE ground motions specified by ASCE 31-03/41-06 for life safety performance, 20%-in-

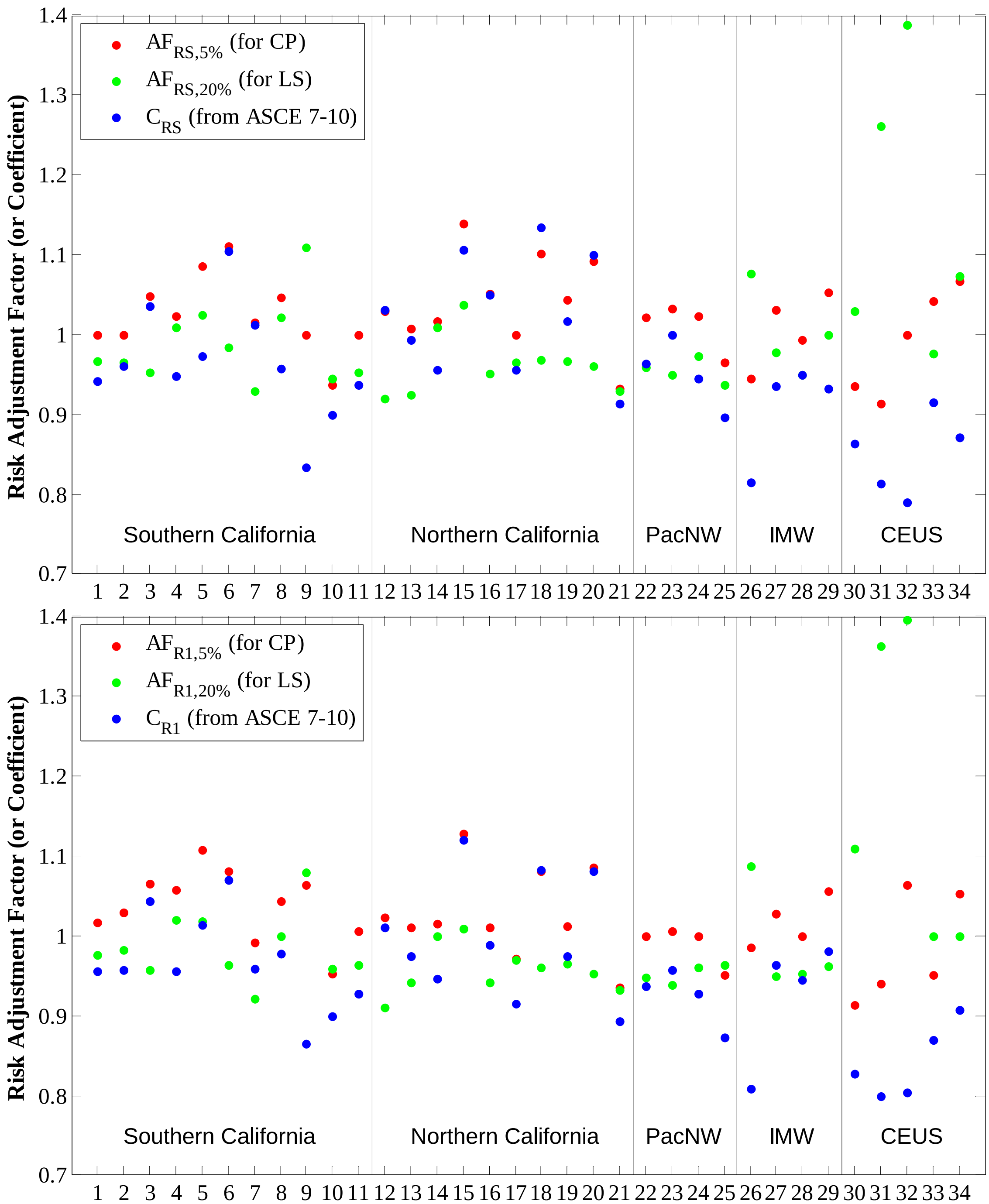

Figure 4.1. Risk adjustment factors for the proposed 5%-in-50yrs and 20%-in-50yrs uniform-hazard ground motions for ASCE 41-13. Adjusting the 5%-in-50yrs ground motions by $AF_{RS,5\%}$ (for 0.2-second spectral response acceleration) and $AF_{R1,5\%}$ (for a spectral period of 1.0 second) would result in a retrofitted building with precisely 2% probability of collapse in 50 years. Adjusting the 20%-in-50yrs ground motions by $AF_{RS,20\%}$ and $AF_{R1,20\%}$ would result in a retrofitted building with precisely 10% probability of endangerment of individual lives. Also shown, for comparison purposes, are the analogous risk coefficients (C_{RS} and C_{R1}) for designing new buildings that are incorporated into the Risk-Targeted MCE ground motions in ASCE 7-10.

50yrs ground motions (capped by 2/3MCE ground motions) have been proposed. In the western US, the proposed ground motions are generally only slightly smaller (by regional median ratios as low as 0.9) than the corresponding ASCE 31-03/41-06 ground motions. In the Northern California region, they are actually somewhat larger, by median ratios of up to 1.25. In contrast, the proposed ground motions are smaller in the Central and Eastern US region, by median ratios as low as 0.6.

Perhaps more importantly, the proposed ground motions are expected to result in retrofitted buildings with more uniform risk of collapse and of endangerment of individual lives across the entire conterminous US, on the order of 2% and 10% probability of collapse and life endangerment in 50 years, respectively. If the proposed ground motions were adjusted in order to precisely result in these two risk levels, the adjustment factors would range from only 0.9 to 1.15 across the 34 city locations considered except Memphis (Tennessee) and Charleston (South Carolina), where the hazard curve shapes are well-known to be distinctive. For those two city locations, the adjustment factors for the proposed 20%-in-50yrs uniform-hazard ground motions would range from 1.25 to 1.4, although for the 5%-in-50yrs ground motions they would fall in the aforementioned narrow 0.9-to-1.15 range. Thus, with these two exceptions, the ground motions proposed for ASCE 41-13 are more consistent (than those specified by ASCE 31-03/41-06) with the concept of the recently-updated Risk-Targeted MCE ground motions in ASCE 7-10. Those ground motions target a 1% probability of collapse in 50 years for a new building (subsequently capped by deterministic ground motions near some major faults).

It is important to keep in mind that the generic fragility curves used in this paper to calculate (via the "risk integral") the risk anticipated for a building retrofitted to the proposed ground motions are based on ASCE 7-10, which is for designing new buildings. We have assumed that the generic fragility curves for buildings retrofitted in accordance with ASCE 41-13 are the same as those for new buildings designed *to the same ground motion levels* in accordance with ASCE 7-10. Although this assumption is not unreasonable, future research is needed to confirm or deny it.

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