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ENHANCED RAPID VISUAL SCREENING (E-RVS) METHOD FOR PRIORITIZATION OF SEISMIC RETROFITS IN OREGON

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Overview

FEMA's rapid visual screening (RVS) procedure was developed to identify, inventory, and rank buildings that are potentially seismically hazardous. The RVS procedure was published in 1988 (FEMA, 1988a) and has been widely used throughout the United States to evaluate thousands of buildings. The RVS procedure was updated in 2002 (FEMA, 2002a) to incorporate technical advancements in earthquake engineering and seismic hazard analysis.

The stated purpose of RVS is to classify buildings as either "those acceptable as to risk to life safety or those that may be seismically hazardous" (FEMA, 2002a). RVS final scores are a quantitative measure of the degree of life safety risk posed by a building because RVS scores are a quantitative measure of the probability of collapse and collapse is the predominant determinant of life safety risk for buildings. RVS scores are useful in the evaluation of life safety risk and in the prioritization of seismic retrofit programs for populations of buildings. The RVS procedure was designed to be the preliminary screening phase of a multi-phase procedure for identifying potentially hazardous buildings. Buildings identified as potentially hazardous by the RVS procedure should be analyzed in more detail by an experienced seismic design professional.

Technical review of the rapid visual screening methodology

This report reviews the technical underpinnings of the RVS procedure, with emphasis on the mathematical relationships between RVS scores and the probabilities of building collapse, use of several types of seismic hazard data, and suggestions for using RVS final scores for initial prioritization of seismic retrofits for a large population of public educational buildings in Oregon.

Our technical review of the existing RVS methodology has concluded that:

1. The use of seismicity regions, rather than site-specific seismic hazard data, for the RVS procedure substantially reduces the accuracy of RVS results because RVS calculations use levels of ground motion which differ from the levels of ground motion at all sites except those where ground motions are at the median value for a seismicity region. Thus, RVS final scores are systematically shifted and overestimate the level of risk for locations with below-median ground motions and underestimate risk for locations with above-median ground motions. This conclusion holds for either of the two RVS seismic hazard methods (using the seismicity region maps by county or determining the seismicity region from site-specific data). As shown by examples, the probability of collapse at the site-specific maximum considered earthquake (MCE) (i.e., at two thirds of the 2% probability of exceedance in 50-year peak ground accelerations) varies by at least a factor of 8 within a single county and by factors of at least 20 to 60 for the moderate and high seismicity regions overall; none of this variation is considered by the existing RVS methodology. The definition of MCE, herein referred to as two thirds of the 2% in 50-year ground motion, conforms to the usage in the RVS calculations (see section 6.2 in FEMA [2002b]).
2. In some cases, the combinations of RVS score modifiers result in final scores that are mathematically out of bounds: the final scores correspond to probabilities of reaching the complete damage state or probabilities of collapse which exceed one. These irregularities in score modifiers affect the relative risk assigned to various buildings (i.e., the final score) and also affect which buildings are deemed to be above or below any defined cut-off score and thus directly affect the buildings for which additional study is recommended.
3. The RVS score modifiers for soil types C, D, and E appear to substantially overcorrect for soil effects in comparison to the soil factors in the 2003 International Building Code (International Code Council, 2002).
4. The logarithmic relationship between final scores and the probability of collapse makes RVS results somewhat difficult to interpret, especially for less technical users.

In combination, the above limitations of the existing RVS methodology, most dramatically the use of seismicity regions which encompass broad ranges of seismic hazard levels, substantially limit the accuracy of RVS results.

From a public policy perspective, the use of seismicity regions in the RVS procedure produces inaccurate results: seismic risk is systematically overestimated for locations with local MCEs below the median values for a seismicity region and seismic risk is systematically underestimated for locations with local MCEs above the median values for the seismicity regions. This oversimplification in the RVS procedure is not corrected in the FEMA method by using local seismic hazard data to determine the appropriate RVS seismicity region.

To the extent that RVS scores are used to evaluate populations of buildings and to prioritize detailed evaluations and seismic retrofits, these limitations of the existing RVS procedure will result in substantially less than optimum allocation of mitigation funds and risk reduction actions. The RVS results will tend to overencourage retrofits in lower hazard areas and to underencourage retrofits in higher hazard areas, within a given RVS seismicity region.

DOGAMI E-RVS method: Enhancements to RVS

To improve the accuracy and usefulness of RVS results, we have developed an enhanced RVS methodology called the E-RVS methodology. Using the E-RVS method, Complete Damage (CODA) and Life Safety Risk Index (LSRI) scores are derived. The E-RVS method:

1. Improves the accuracy of seismic hazard data by using site-specific MCEs rather than median MCEs for broad seismicity regions,
2. Reduces the effects of out of bounds RVS final scores, by avoiding interpretation of RVS final scores that are not physically meaningful (i.e., the final score must correspond to the probability of the complete damage state ≤ 1.0),
3. Adjusts the RVS soil-rock score modifiers to yield results which are consistent with the 2003 IBC (International Code Council, 2002) soil factors.
4. Makes results easier to understand by non-technical users by using linear rather than logarithmic scales for results.

Example printouts of E-RVS results developed using the Oregon Seismic Hazard Calculator and the Oregon E-RVS calculator are provided.

The DOGAMI E-RVS methodology makes improvements in the RVS methodology but does not address all areas where improvements can be made. In the final section of this paper, we make specific suggestions for further enhancements to the RVS and E-RVS methodologies.

The Oregon University System (OUS) funded the development of the E-RVS method, under the leadership of Robert Simonton, OUS director of capital construction planning and budget.

1.0. RAPID VISUAL SCREENING PROCEDURE

1.1. Overview and concepts

The rapid visual screening (RVS) procedure was developed by the Federal Emergency Management Agency (FEMA) to identify, inventory, and rank buildings that are potentially seismically hazardous. FEMA's RVS procedure was first published in two volumes in 1988 as FEMA 154 and FEMA 155 (FEMA, 1988a, 1988b). In the nearly 20 years since its publication, RVS has been widely used to evaluate thousands of buildings in many seismically active regions of the United States.

The RVS procedure was developed for a broad audience, including building officials and inspectors and public- and private-sector building owners. The procedure was designed to be the preliminary screening phase of a multi-phase procedure for identifying potentially hazardous buildings. Buildings identified as potentially hazardous by the RVS procedure should be analyzed in more detail by an experienced seismic design professional.

RVS uses a method based on a "sidewalk survey" of a building: visual inspection of the building from the exterior and, if possible, from the interior to identify the primary structural lateral load resisting system(s) and structural materials. From this survey a building type (Table 1) is assigned (FEMA, 2002a).

Because RVS is designed to be performed from the street, with interior inspection not always possible and structural details not always evident without plan inspection or field testing, hazardous details will not always be visible and some seismically hazardous buildings may not be identified as such. Conversely, some buildings initially identified by RVS as potentially hazardous may prove to be seismically adequate upon more detailed evaluation.

The RVS procedure assigns a basic structural hazard (BSH) score to a building on the basis of the identified primary structural lateral load resisting system and on the seismicity region defined for the county in which a building is located. Then, the BSH score is modified by several score modifiers related to seismic performance attributes of the building and the soil-rock type to obtain a final score. The BSH score, score modifiers, and final score are all related mathematically to the estimated probability that a building will collapse under severe ground shaking levels equivalent to those currently used for the seismic design of new buildings.

The intended use of the RVS procedure is to screen a population of buildings on the basis of a cut-off value for the final score, *S*, which is used to divide screened buildings into two categories that are expected to:

- Have acceptable seismic performance, or
- May be seismically hazardous and should be studied further.

A RVS final score of 2.0 is suggested as a typical cut-off value. Mathematically, a final score of 2.0 means an estimated 1% chance of collapse at the defined level of ground shaking (two thirds of the 2% probability of exceedance in 50-year peak ground accelerations) for the seismicity region of the county in which the building is located.

Table 1. Federal Emergency Management Agency building types (FEMA, 2002a).

Building Type	Description	Building Type	Desscription
W1	Light wood-frame residential and commercial buildings ≤ 5,000 sq. ft.	C1	Concrete moment-resisting frame buildings
W2	Light wood-frame buildings > 5,000 sq. ft.	C2	Concrete shear-wall buildings
S1	Steel moment-resisting frame buildings	C3	Concrete frame buildings with unreinforced masonry infill walls
S2	Braced steel frame buildings	PC1	Tilt-up buildings
S3	Light metal buildings	PC2	Precast concrete frame buildings
S4	Steel frame buildings with cast-in-place concrete shear walls	RM1	Reinforced masonry buildings with flexible floor and roof diaphragms
S5	Steel frame buildings with unreinforced masonry infill walls	RM2	Reinforced masonry buildings with rigid floor and roof diaphragms
		URM	Unreinforced masonry bearing-wall buildings

1.2. FEMA 154 and 155 second editions

The second editions of the FEMA 154 and 155 reports were published in 2002 (FEMA, 2002a and 2002b). This revision of the RVS evaluation methodology included:

1. collection of users' feedback on the RVS procedure,
2. review of updated information on the seismic performance of buildings, including a detailed review of HAZUS, the natural hazard loss estimation methodology software (FEMA, 2006, and earlier editions) fragility curves and the relationship between the RVS results and the detailed seismic evaluation procedures in FEMA 310 (FEMA, 1998) which is now superseded by ASCE 31 (ASCE, 2003),
3. a user workshop to learn about the problems and successes of organizations that had used the original RVS procedure, and
4. revision and updating of technical methods in the first editions of FEMA 154 and FEMA 155.

The second edition of the RVS procedure included updated Basic Structural Hazard Scores and score modifiers, drawing on HAZUS fragility curves (FEMA, 2006, and earlier editions) rather than on ATC-13 damage functions (ATC, 1985), and updated the seismic hazard data. All references in this document to RVS, FEMA 154, and FEMA 155 apply to the second editions (FEMA, 2002a, 2002b).

1.3. Rapid visual screening mathematics

Basic structural hazard scores (BSH), score modifiers (SMs), and final score, *S*, are all measures of seismic damage potential for the building under evaluation. More precisely, the BSH is defined as the negative of the base 10 log of the probability that the building will collapse at the level of ground shaking corresponding to the maximum considered earthquake (MCE) (FEMA 155, equation 6-1 [FEMA, 2002b]):

$$\text{BSH} = -\log_{10}(P_{\text{collapse}} \text{ given the MCE}) \qquad (1)$$

The definition of the MCE as two thirds of the 2% in 50-year ground motion conforms to the usage in the RVS calculations (FEMA, 2002b, section 6.2). The BSH is a generic score for a building class type and is modified for a specific building by score modifiers (SMs) specific to that building to arrive at a final structural score, *S*. That is (FEMA 155, equation 6-2 [FEMA, 2002b]):

$$S = \text{BSH} \pm \text{SMs} \qquad (2)$$

Similarly, for a specific building,

$$S = -\log_{10}(P_{\text{collapse}} \text{ given the MCE}) \qquad (3)$$

Or, equivalently,

$$(P_{\text{collapse}} \text{ given the MCE}) = 10^{-S} \qquad (4)$$

For example, a final score, *S*, of 2.0 means that the calculated probability of building collapse at the maximum considered earthquake is (10^{-2}) or 0.01 (i.e., a 1% chance of collapse). For reference, calculated probabilities of collapse at the MCE corresponding to final scores between 4.0 and 0.0 are shown in Table 2.

If RVS mathematical results are interpreted literally, then a building with a final score of 3.0 has a factor of ten lower probability of collapse at the MCE than does a building with a final score of 2.0. Similarly, a building with a final score of 1.0 is 10 times more likely to collapse at the MCE than a building with a final score of 2.0.

Table 2. Calculated probabilities of collapse versus final score, *S*.

Final Score, *S*	Probability of Collapse[1]
4.0	0.01%
3.5	0.03%
3.0	0.10%
2.5	0.32%
2.0	1.00%
1.5	3.16%
1.0	10%
0.5	32%
0.0	100%

[1] At the maximum considered earthquake (MCE).

More realistically, RVS results should be interpreted in the context of its intended purpose as a preliminary screening tool. The final scores are best interpreted as approximate measures of the relative risk between buildings. Nevertheless, it is important that final scores be as accurate as possible and that systematic errors in final scores be scrupulously avoided. Furthermore, detailed analysis of the final scores is important to make FEMA and users aware of the present shortcomings and to provide motivation and guidance for future improvements. Indeed, FEMA has already begun to implement some of the improvements suggested in this paper (Y. Wang, personal communications, March 2007).

RVS final scores define a seismic fragility curve for the complete damage state of a building. Fragility curves have two parameters for the complete damage state: a median peak ground acceleration (PGA) and beta (the lognormal dispersion parameter in the fragility curve), which determine the probability of being in the complete damage state at any PGA level. Specifying any two of the three parameters: median PGA, beta, or P_{complete} at any PGA level mathematically determines the third parameter. For E-RVS, the final score is mathematically equivalent to the P_{collapse} which in turn determines the $P_{\text{complete damage state}}$ via the HAZUS relationship between these two parameters (as shown in Table 3). Then, we simply use the HAZUS beta and the RVS P_{collapse}, which determines P_{complete}, to determine a unique median PGA for the complete damage state. That is, the RVS final score determines a unique median PGA for the complete damage state, using the HAZUS beta value and the HAZUS relationship in Table 3. This methodology is simply an application of the well-accepted, extensively peer reviewed, HAZUS fragility curve relationships, along with application of the RVS definition of the final score as $-\log_{10}(P_{\text{collapse}})$.

The probability of collapse at the RVS-defined MCE and the probability of being in the complete damage state at the MCE are directly linked because RVS uses the HAZUS (FEMA, 2006) relationship between the probability of collapse and the probability of being in the complete damage state. The HAZUS (FEMA, 2006) relationship between these probabilities is summarized in Table 3. The same HAZUS relationships were included in earlier versions of HAZUS used in the 2002 RVS methodology. For a given RVS final score, the median PGA for the complete damage state is mathematically determined by the probability of collapse at the RVS-defined MCE, the corresponding probability of the complete damage state at the MCE and the HAZUS value for beta.

Given the relationships expressed in equations 1–4, fragility curves for the complete damage state can be calculated from RVS final scores, using the HAZUS (FEMA, 2006) value of 0.64 for beta (the lognormal dispersion parameter in the fragility curve). In the technical evaluation of the RVS procedure in the following section, we use the fragility curve parameters found in Tables 5-16a through 5-16d of the HAZUS Technical Manual, which is included on the HAZUS DVD (FEMA, 2006).

Table 3. Probability of collapse given the complete damage state (HAZUS relationship used by rapid visual screening).

	Probability of Collapse		
Building Type	**Low-Rise**	**Mid-Rise**	**High-Rise**
W1	0.03	NA	NA
W2	0.03	NA	NA
S1	0.08	0.05	0.03
S2	0.08	0.05	0.03
S3	0.03	NA	NA
S4	0.08	0.05	0.03
S5	0.08	0.05	0.03
C1	0.13	0.10	0.05
C2	0.13	0.10	0.05
C3	0.15	0.13	0.10
PC1	0.15	NA	NA
PC2	0.15	0.13	0.10
RM1	0.13	0.10	NA
RM2	0.13	0.10	0.05
URM	0.15	0.15	NA

NA means not applicable for this building type.

2.0. TECHNICAL EVALUATION OF RAPID VISUAL SCREENING PROCEDURES

Our review of the technical assumptions, data, and mathematical calculations included in the RVS procedure (Wang and Goettel, 2006) concluded that:

1. Using seismicity regions rather than site-specific seismic hazard data for the RVS procedure substantially reduces the accuracy of RVS results.
2. In some cases, combinations of RVS score modifiers result in final scores that are mathematically out of bounds: the final scores correspond to probabilities of reaching the complete damage state or probabilities of collapse that exceed 1.0.
3. RVS score modifiers for soil types C, D, and E appear to overcorrect for soil effects in comparison with soil factors in the International Building Code 2003 (International Code Council, 2002).
4. The logarithmic relationship between final score and the probability of collapse at the maximum considered earthquake (MCE) makes results somewhat difficult to interpret, especially for less technical users.

The technical details of these four aspects of the RVS procedure are reviewed below. The intent of this analysis is not to criticize the RVS procedure but to understand the limitations of the existing RVS procedure in order to make enhancements to the RVS procedure so that we can achieve more accurate results for prioritizing seismic retrofits within Oregon.

Table 4. Rapid visual screening (RVS) seismicity regions.

Region	Spectral Acceleration Response[1]: Short-Period S_S (0.2 s)	Spectral Acceleration Response[1]: Long-Period S_l (1.0 s)	Corresponding PGA Values[2,3]
Low	<0.167 g	<0.067 g	<0.067 g
Moderate	0.167–0.500 g	0.067–0.200 g	0.067–0.200 g
High	>0.500 g	>0.200 g	0.200–1.600 g

[1] Response in horizontal direction.
[2] Peak ground acceleration (PGA) values calculated as S_S divided by a factor of 2.5.
[3] Maximum PGA value for high seismicity region calculated using the maximum S_S value in FEMA 155 (2002b) Figure 6-3.

2.1.1. RVS seismicity regions by county

The RVS county seismicity region classification is based on the *highest* seismicity location in each county. Twenty-two counties in western and southern Oregon are in the high seismicity region (FEMA, 2002b), while 14 counties in north-central and northeastern Oregon are in the moderate seismicity region. The RVS seismicity region classification for Oregon counties is as shown in Table 5.

2.1. RVS seismicity regions

The RVS methodology defines three seismicity regions for the United States, as shown in Table 4. Each county is placed into a single seismicity region.

The RVS procedure uses separate evaluation forms for Basic Structural Hazard Score and score modifiers for the three seismicity regions defined above. These seismicity regions are in ranges defined by two thirds of the spectral acceleration values with a 2% chance of exceedance in 50 years. The data source for these data is FEMA 310 (FEMA, 1998).

In the RVS procedure, the seismicity region for a given location can be determined in two ways:

- By reference to seismicity maps by county, or
- From USGS seismic hazard data for specific locations by zip code or by latitude-longitude pairs.

Table 5. Oregon counties by seismicity region.

Moderate Seismicity Region		High Seismicity Region	
Baker	Morrow	Benton	Lake
Crook	Sherman	Clackamas	Lane
Deschutes	Umatilla	Clatsop	Lincoln
Gilliam	Union	Columbia	Linn
Grant	Wallowa	Coos	Malheur
Hood River	Wasco	Curry	Marion
Jefferson	Wheeler	Douglas	Multnomah
		Harney	Polk
		Jackson	Tillamook
		Josephine	Washington
		Klamath	Yamhill

Using the highest seismicity location in each county to determine the seismicity region for the entire county substantially reduces the accuracy of RVS results, especially in counties with a large variation in level of seismic hazard.

The effect of the variation in level of seismic hazard within a single county is illustrated by the Lane County example shown in Figure 1 and Table 6. We consider three hypothetical identical buildings with identical RVS scores in eastern, central, and western Lane County. Using the RVS procedure, the assigned level of seismic risk is identical for each building, regardless of location within Lane County. However, when variation in local seismic hazard is considered, the level of seismic risk (i.e., calculated probability of collapse) at the local MCE (two thirds of the 2% in 50-year ground motion) varies by a factor of 8 between eastern and western Lane County.

The median PGA value for the complete damage state (0.82 g) is uniquely determined from the RVS final score of 2.0. A median PGA value of 0.82 and a beta value of 0.64 yield a probability of the complete damage state of 7.7% at 0.328 g. The HAZUS relationship between the complete damage state and the probability of collapse for a C1 building (13% probability of collapse if the complete damage is reached; see Table 3) yields the 1.0% probability of collapse at 0.328 g, which matches the RVS results exactly.

Figure 1. Variation in assigned seismic hazard level within Lane County, Oregon. (left) The RVS seismicity classification by county system assigns the entire county the same classification on the basis of the the highest seismicity location. (right) Schematic of real variation of seismic hazard levels, with the seismic hazard decreasing markedly from west (red) to east (blue).

Table 6. Rapid visual screening (RVS) results for three sites in Lane County, Oregon, using county-wide versus site-specific seismic hazard levels.

Location	Florence	Eugene	McKenzie Bridge
Building Type	C1	C1	C1
RVS final score, *S*	2.0	2.0	2.0
Probability of collapse at MCE (0.328 g)	**1.0%**	**1.0%**	**1.0%**
Probability of complete damage state at MCE	**7.7%**	**7.7%**	**7.7%**
Inferred median PGA for complete damage	0.82 g	0.82 g	0.82 g
Site-specific MCE	0.41 g	0.26 g	0.21 g
Probability of collapse at site-specific MCE	**1.8%**	**0.5%**	**0.2%**
Probability of complete damage state at site-specific MCE	**14.2%**	**3.5%**	**1.8%**
Corresponding *S* value (yields calculated probability of collapse)	1.7	2.3	2.6

MCE is maximum considered earthquake. PGA is peak ground acceleration. The median value for the complete damage state was inferred from the probability of the complete damage state at the MCE, corresponding to the RVS final score of 2.0, using the standard HAZUS (FEMA, 2006) beta value of 0.64. Then, the probability of complete damage at the local MCE was calculated from this fragility curve and the site-specific MCE. Finally, the corresponding *S* value that yields the calculated probability of collapse was calculated, using the RVS definition of final score, *S*, as shown in section 1.3.

These mathematical relationships are illustrated in Figure 2, which shows $P_{complete}$ and $P_{collapse}$ for a C1 building in the high seismicity region. As shown in Figure 2, a final score of 2.0, which means a $P_{collapse}$ of 1% at 0.328 g in the high seismicity region, corresponds to a median PGA for the complete damage state of 0.82 g. That is, this value yields a $P_{collapse}$ of 1% and a $P_{complete}$ of 7.7% as shown in Table 6. The ratio of $P_{collapse}$ to $P_{complete}$ of 13% is determined from the HAZUS relationship for C1 low-rise buildings as shown in Table 3.

The variation in RVS results within Lane County is rather dramatic, a factor of 8 in the calculated probability of collapse, even though the level of seismic hazard (local MCE) varies by only a factor of 2 between Florence and McKenzie Bridge, in western and eastern Lane County, respectively.

The variation in local seismic hazard shown above for Lane County is only about one quarter of the total variation in local seismic hazard within the RVS high seismicity region, as discussed in the following section. Thus, the above dispersion in RVS results for Lane County reflects only about one quarter of the total dispersion within the high seismicity region.

2.1.2. RVS seismicity region by zip code or by latitude-longitude pairs

FEMA 154 (FEMA, 2002a) notes that the second suggested method, based on USGS seismic hazard data for specific locations by zip code or latitude/longitude, is preferred as it allows the user to determine the *RVS seismicity region* on the basis of a more precisely specified location. This method requires a user to access the USGS Earthquake Hazards Program Custom Mapping and Analysis Tools web page (http://earthquake.usgs.gov/research/hazmaps/interactive/index.php) and to select "Hazard values by zip code" or "Hazard values by latitude longitude" pairs. Corresponding local seismic hazard data are displayed. The returned seismic hazard data using latitude-longitude values include values for peak ground accelerations (PGA) and for spectral accelerations (SA) (0.2 s period) and SA (1.0 s period) for 2% and 10% probability of exceedance in 50 years (USGS, 2002).

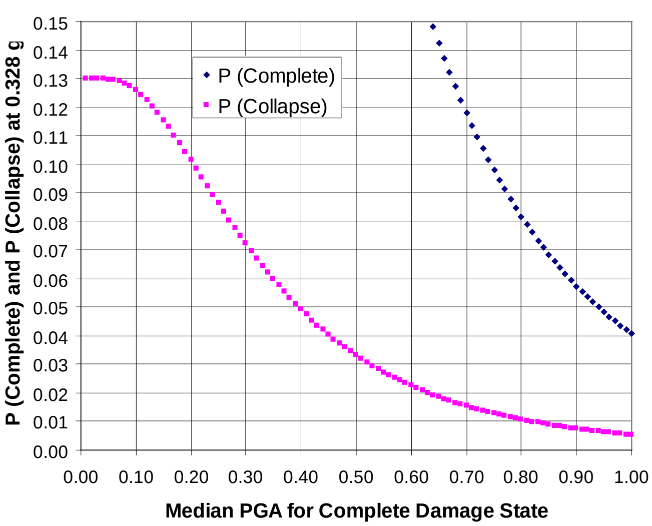


Figure 2. Relationship between fragility curve data (median peak ground acceleration [PGA] for the complete damage state) and $P_{complete}$ and $P_{collapse}$ at 0.328 g.

To determine the appropriate RVS seismicity region for a specified location, we multiply the 0.2 s and 1.0 s SA values with 2% exceedance probability in 50 years by two thirds and then compare the results to the seismicity regions shown in Table 4. These probabilistic SA values (including the two-thirds multiplier) correspond to the ground motions specified for detailed building seismic evaluations in FEMA 310, *Handbook for the Seismic Evaluation of Buildings—A Prestandard* (FEMA, 1998) and ASCE 31-03 *Seismic Evaluation of Existing Buildings* (ASCE, 2003).

Determining a RVS seismicity region using data for a specified location is an improvement over the method of assigning seismicity region for an entire county based on the highest seismic hazard for the county. However, selecting an appropriate seismicity region does *not* correct the inaccuracies which arise from the wide variation in seismic hazard levels within a given seismicity region.

As shown in Table 4, seismic hazard levels within the moderate and high seismicity regions vary by factors of 3 and 8, respectively. These very broad ranges of seismic hazard levels within a seismicity region have substantial effects on RVS results — even larger than those discussed above for the variation in seismic hazard level within Lane County.

The effects of variation in seismic hazard level within a seismicity region (moderate and high) are evaluated by the following examples which consider identical buildings with local MCEs (two thirds of the 2% in 50 year ground motions) equal to the low, median, and high values for RVS moderate and high seismicity regions. Median PGA values for the moderate and high seismicity regions (two thirds of the 2% in 50-year ground motion) are 0.104 g and 0.328 g, respectively.

These median values were taken from the median S_s values for the seismicity regions (FEMA 155, Table 6.3 [FEMA, 2002b]), which are two thirds of the 2% in 50-year ground motion values, with PGA values calculated as the S_s values divided by a factor of 2.5. The results of these sample calculations are shown in Table 7 and Table 8.

Table 7 and Table 8 demonstrate that example buildings having fragility curves with median PGA values for the complete damage state of 0.82 g (high seismicity region) and 0.26 g (moderate seismicity region) with HAZUS (FEMA, 2006) betas of 0.64 yield calculated probabilities of collapse of 1% at the median PGA value for each seismicity region. These results match the RVS results at the median PGA for each seismicity region.

The results in Table 6 show a wide variation in calculated probabilities of collapse at the low and high

Table 7. Variation in rapid visual screening (RVS) final score with seismic hazard level within the full range of ground motions in the high seismicity region.

	Variation in maximum considered earthquake (MCE) within the high seismicity region		
Date or Result	**Low PGA**	**Median PGA**	**High PGA**
Building type	C1	C1	C1
RVS final score, *S*	2.0	2.0	2.0
Probability of collapse at MCE (0.328 g)	1.0%	1.0%	1.0%
Probability of complete damage state at MCE	7.7%	7.7%	7.7%
Median PGA for complete damage[1]	0.82 g	0.82 g	0.82 g
Site-specific MCE (two thirds of 2% in 50-year value)	0.20	0.33	1.60
Probability of collapse at **site-specific** MCE	0.2%	1.0%	11.1%
Probability of complete damage state at **site-specific** MCE	1.4%	7.7%	85.3%
Corresponding *S* value (yields calculated probability of collapse)	2.7	2.0	1.0

[1] This median peak ground acceleration (PGA) for the complete damage state and the HAZUS beta value of 0.64 yield a probability of collapse at 0.328 g (the median PGA level for the high seismicity region) of 1%, which matches the results of an RVS final score of 2.0.

Table 8. Variation in rapid visual screening (RVS) final score with seismic hazard level within the full range of ground motions in the moderate seismicity region.

	Variation in maximum considered earthquake (MCE) within the moderate seismicity region		
Date or Result	**Low PGA**	**Median PGA**	**High PGA**
Building type	C1	C1	C1
RVS final score, *S*	2.0	2.0	2.0
Probability of collapse at MCE (0.104 g)	1.0%	1.0%	1.0%
Probability of complete damage state at MCE	7.7%	7.7%	7.7%
Median PGA for complete damage[1]	0.26 g	0.26 g	0.26 g
Site-specific MCE (two thirds of 2% in 50-year value)	0.07	0.10	0.20
Probability of collapse at **site-specific** MCE	0.2%	1.0%	4.5%
Probability of complete damage state at **site-specific** MCE	1.7%	7.7%	34.3%
Corresponding *S* value (yields calculated probability of collapse)	2.6	2.0	1.4

[1] This median peak ground acceleration (PGA) for the complete damage state and the HAZUS beta value of 0.64 yield a probability of collapse at 0.104 g (the median PGA level for the moderate seismicity region) of 1%, which matches the results of an RVS final score of 2.0.

PGA values for the seismicity regions. For the high seismicity region, the calculated probabilities of collapse vary by a factor of about 60 between sites at the low and high end of the range of seismic hazard level within the high seismicity region. For the moderate seismicity region, the calculated probabilities of collapse vary by a factor of about 20 between sites at the low and high end of seismic hazard level within the moderate seismicity region.

In the RVS procedure, the inferred level of risk for the sample buildings in each seismicity region would be identical, with no consideration of the variation in level of seismic hazard within each seismicity region. The above example calculations demonstrate that the actual level of risk varies by large factors (about 60 and about 20 in above examples) and thus that the RVS results are substantially limited in accuracy. For other buildings with different fragility curves, the factors by which the actual level of risk differs over the range of seismic hazard levels will vary.

To the extent that RVS scores are used to evaluate populations of buildings and to prioritize detailed evaluations and seismic retrofits, these limitations of the existing RVS procedure will result in substantially less than optimum allocation of mitigation funds and risk reduction actions. Use of RVS results will tend to result in too many retrofits in lower hazard areas and too few retrofits in higher hazard areas, within a given RVS seismicity region.

Fortunately, this deficiency in the existing RVS procedure can be corrected by calculating RVS results using site-specific seismic hazard data, rather than calculating RVS results by seismicity region. An enhanced RVS method, which includes this modification, is discussed in section 3 of this report.

2.2. RVS final scores

As given in section 1.3, equation 1, RVS final scores are explicitly the probability of collapse, given the MCE, as defined by the RVS methodology (FEMA 155, equation 6-1 [FEMA, 2002b]):

$$\text{BSH} = -\log_{10} (P_{\text{complete}} \text{ given the MCE})$$

Given that the probability of collapse cannot exceed 1.0 (100% probability of collapse), the minimum physically meaningful RVS final score is zero. As shown in Table 9, there are many combinations of RVS score modifiers that result in RVS final scores below 0.0

Table 9. Rapid visual screening (RVS) basic structural hazard scores and minimum possible final scores.

Building Type	Low Seismicity Region			Moderate Seismicity Region			High Seismicity Region		
	BSH	Min SM	Min *S*	BSH	Min SM	Min *S*	BSH	Min SM	Min *S*
W1	7.4	-6.6	0.8	5.2	–5.2	0.0	4.4	–3.0	1.4
W2	6.0	–5.8	0.2	4.8	–5.5	–0.7	3.8	–4.3	–0.5
S1	4.6	–4.8	–0.2	3.6	–4.5	–0.9	2.8	–3.7	–0.9
S2	4.8	–4.8	0.0	3.6	–4.5	–0.9	3.0	–4.0	–1.0
S3	4.6	–2.8	1.8	3.8	–2.5	1.3	3.2	–2.1	1.1
S4	4.8	–5.0	–0.2	3.6	–4.5	–0.9	2.8	–3.5	–0.7
S5	5.0	–5.0	0.0	3.6	–4.3	–0.7	2.0	–2.5	–0.5
C1	4.4	–4.3	0.1	3.0	–5.1	–2.1	2.5	–4.4	–1.9
C2	4.8	–5.0	–0.2	3.6	–4.5	–0.9	2.8	–3.3	–0.5
C3	4.4	–5.2	–0.8	3.2	–5.1	–1.9	1.6	–2.5	–0.9
PC1	4.4	–2.6	1.8	3.2	–2.3	0.9	2.6	–1.7	0.9
PC2	4.6	–4.5	0.1	3.2	–4.0	–0.8	2.4	–3.5	–1.1
RM1	4.8	–4.6	0.2	3.6	–4.5	–0.9	2.8	–2.9	–0.1
RM2	4.6	–4.1	0.5	3.4	–4.0	–0.6	2.8	–2.9	–0.1
URM	4.6	–4.3	0.3	3.4	–4.4	–1.0	1.8	–2.5	–0.7

BSH is the RVS basic structural hazard score. Min SM is the lowest possible combination of score modifiers. Min *S* is the minimum possible RVS final score. Red shading highlights Min *S* values below 0.0; such scores are not physically meaningful.

(cells shaded red). Of the 45 combinations of building type and seismicity region used in RVS, 28 combinations can have final scores below 0.0. Such scores are not physically meaningful.

In the RVS methodology, probabilities of collapse are calculated in a two-step process: 1) the probability of the complete damage state is calculated, then 2) the probability of collapse if the complete damage state is reached is estimated from the HAZUS (FEMA, 2006) relationship. The probability of collapse if the complete damage state is reached ranges from 0.03 to 0.15 for various building types and combinations of low-, mid-, and high-rise buildings (see section 1.3, Table 3). A more rigorous bound on physically meaningful RVS final scores is that the probability of the complete damage state cannot exceed 1.0 (100% probability). Thus, physically meaningful RVS final scores cannot be lower than the values shown in Table 10.

Comparison of Table 9 and Table 10 indicates that for nearly all possible combinations of RVS building types and seismicity regions, the lowest possible RVS final score is lower than the physically meaningful limit (probability of complete damage state = 1.0).

Table 10. Minimum credible rapid visual screening (RVS) final scores for building types.[1]

Building Type	Minimum Credible Final Score, *S*		
	Low-Rise	Mid-Rise	High-Rise
W1	1.52	NA	NA
W2	1.52	NA	NA
S1	1.10	1.30	1.52
S2	1.10	1.30	1.52
S3	1.52	NA	NA
S4	1.10	1.30	1.52
S5	1.10	1.30	1.52
C1	0.89	1.00	1.30
C2	0.89	1.00	1.30
C3	0.82	0.89	1.00
PC1	0.82	NA	NA
PC2	0.82	0.89	1.00
RM1	0.89	1.00	NA
RM2	0.89	1.00	1.30
URM	0.82	0.82	NA

[1] Probability of complete damage state is 1.0. NA means not applicable for this building type.

Possible explanations for these problematic RVS final scores include:

- The individual score modifiers are very large in many cases, and
- The basic structural hazard score (BSH) and the score modifiers (SMs) are combined linearly to obtain the final score, *S*.

The following examples help illustrate some of the apparent difficulties with the present RVS score modifiers.

1. Score modifiers for “vertical irregularity” range from −1.0 to −4.0, for various building types and seismicity regions. These score modifiers correspond to increases in the probability of collapse at the MCE by factors ranging from 10 to 10,000. These very large increases may or may not be reasonable for major structural irregularities such as a markedly soft first story, but are almost certainly not reasonable for minor or trivial vertical irregularities.
2. Score modifiers for “plan irregularity” are −0.8 for the low seismicity region and −0.5 for the moderate and high seismicity regions for all building types. These score modifiers correspond to increases in the probability of collapse at the MCE by factors of 6.31 and 3.16 for the low and moderate-high seismicity regions, respectively. These substantial increases may be reasonable for major structural irregularities such as very irregular plans with pronounced re-entrant shapes but are almost certainly not reasonable for minor or trivial plan irregularities.

3. To illustrate complications arising from simple linear combination of score modifiers, we consider a C1 building in the moderate seismicity region. Possible score modifiers are shown in Table 11. Selection of these score modifiers individually corresponds to increasing the probability of collapse at the MCE by factors ranging from 3.16 to 100. In combination, selection of all four modifiers increases the corresponding probability of collapse by a factor of more than 125,000.

Table 11. Linear combination of score modifiers for building type C1 in the moderate seismicity region.

Score Modifier (SM)		Multiplicative Factor
Modifier	Value	
Vertical irregularity	–2.0	100
Plan irregularity	–0.5	3.16
Pre-code	–1.0	10
Soil type E	–1.6	39.81
Total	–5.1	125,893

The above example is dramatic, but is not the most extreme possible example. Some possible combinations of score modifiers correspond to increases in the probability of collapse at the MCE by factors of more than 10^6.

Mathematically, there are many alternative ways to combine score modifiers that would be more sophisticated than the simple linear combination used in RVS. For example, score modifiers could be applied by root mean square. Or, the first score modifier could be applied to the BSH, then the mathematical impact of subsequent score modifiers could be systematically adjusted in proportion to the magnitude of the adjustments already made by previous score modifiers. Furthermore, when more than one modifier is selected, more detailed engineering judgment could be applied to determine the most likely governing modifiers for each structural building type. Such possible enhancements to the RVS methodology are beyond the present effort and would require a detailed upgrade of the existing RVS methodology. (See section 5.2 for comments on possible enhancements to RVS.)

At first glance, it might appear that the above mathematical irregularities in RVS final scores and score modifiers might not substantially affect the intended use of RVS, which is to identify a subset of the screened buildings with final scores below a user-defined cut-off score (often 2.0) that are then subjected to further study. The out-of-bounds final scores are all below 2.0.

The apparent irregularities in RVS score modifiers and final scores also affect the relative risk (i.e., final score) assigned to various buildings and strongly affect which buildings are deemed above or below any defined cut-off score. These irregularities are significant and the above results suggest that a thorough review and updating of the score modifiers and the mathematical way in which individual score modifiers are combined may be warranted to improve the accuracy and meaningfulness of RVS results. This possible improvement in the RVS methodology is addressed further in section 5.2.

2.3. RVS soil factors

The score modifiers for soil types C, D, and E are among the largest score modifiers in the RVS method. These score modifiers for soil type have a large influence on the final score, *S*, on the overall interpretation of RVS results and thus on any risk reduction priorities based on RVS results. Because of the importance of the score modifiers for soil types, we evaluate these modifiers quantitatively and compare them to the IBC 2003 (International Code Council, 2002) soil factors.

2.3.1. RVS soil-rock factors

RVS final scores include score modifiers for soil types C, D, and E. These score modifiers for the 15 building types are shown in Table 12 for the moderate and high seismicity regions.

Per the RVS methodology, these score modifiers are directly related to the probability of collapse at the MCE (maximum considered earthquake) via the RVS relationship given in section 1.3, equation 3:

$$S = -\log_{10} (P_{\text{collapse}} \text{ given the MCE})$$

These score modifiers for soil types C, D, and E correspond to the multiplicative factors for the increase in the probability of collapse given the MCE shown in Table 13. As noted above, these factors also apply to

Table 12. Rapid visual screening (RVS) final score modifiers for soil types C, D, and E.[1]

Seismicity Region	Soil Type	Building Type														
		W1	W2	S1	S2	S3	S4	S5	C1	C2	C3	PC1	PC2	RM1	RM2	URM
High	C	0.0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
High	D	0.0	0.8	0.6	0.6	0.6	0.6	0.4	0.6	0.6	0.4	0.6	0.6	0.6	0.6	0.6
High	E	0.0	0.8	1.2	1.2	1.0	1.2	0.8	1.2	0.8	0.8	0.4	1.2	0.4	0.6	0.8
Moderate	C	0.2	0.8	0.6	0.8	0.6	0.8	0.8	0.6	0.8	0.6	0.6	0.6	0.8	0.6	0.4
Moderate	D	0.6	1.2	1.0	1.2	1.0	1.2	1.2	1.0	1.2	1.0	1.0	1.2	1.2	1.2	0.8
Moderate	E	1.2	1.8	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6

[1] Excerpted from RVS data collection forms (FEMA 154, Appendix B, pages 79-80 [FEMA, 2002a]).

the probability of being in the complete damage state, which is linked to the probability of collapse in RVS by the HAZUS (FEMA, 2006) relationship shown in Table 3.

As shown in Table 13, the RVS score modifiers for soils correspond to large increases in the probability of collapse at the MCE, with score modifiers of −1.0 or larger corresponding to increases in P_{collapse} by a factor of 10 or more.

These RVS soil factors differ both conceptually and mathematically from the soil factors in the 2003 IBC (International Code Council, 2002).

First, the RVS (FEMA, 2002a) soil factors are constant for a given building type and seismicity region: values do not vary with the level of ground motion. This is an important difference, because 2003 IBC values vary markedly with the level of ground motion. For example, at high levels of ground motion, IBC factors are 1.0 (no amplification) for soil types C and D and 0.9 (deamplification) for soil type E. In contrast, RVS score modifiers for these soil types correspond to large increases in risk (probability of collapse) for these soil types.

Second, the magnitudes of the RVS soil-rock factors appear large in absolute terms as illustrated by the inferred multiplicative factors for the complete damage state as shown above.

Table 13. Increase in P_{collapse} for score modifiers for soil types.

RVS Soil Modifier	Multiplicative Factor[1]
−1.80	63
−1.60	40
−1.20	16
−1.00	10
−0.80	6
−0.60	4
−0.40	2.5
−0.20	1.6

[1] Increase in P_{collapse}, which is also equal to the increase in P_{complete} via the HAZUS (FEMA, 2006) fragility curve relationships.

Table 14. International Building Code soil-rock factors.[1]

Site (Soil) Class	Mapped Spectral Response Acceleration at Short Periods (S_s)				
	$S_S \leq 0.25$	**$S_S = 0.50$**	**$S_S = 0.75$**	**$S_S = 1.00$**	**$S_S \geq 1.25$**
A - hard rock	0.8	0.8	0.8	0.9	0.8
B - rock	1.0	1.0	1.0	1.1	1.0
C - very dense soil and soft rock	1.2	1.2	1.1	1.0	1.0
D - stiff soil profile	1.6	1.4	1.2	1.1	1.0
E - soft soil profile	2.5	1.7	1.2	0.9	0.9
F	see note	see note	see note	see note	see note

[1] Modified from Table 1615.1.2(1) (IBC, 2003). Values of site coefficient F_a in Table 1615.1.2(1) are a function of site class mapped spectral response acceleration at short periods (S_S). Use straight-line interpolation for intermediate values of mapped spectral acceleration at short period S_S.

Note: Per section 1615.1.5.1 (IBC, 2003) site-specific geotechnical investigation and dynamic site response analyses shall be performed to determine appropriate values, except that for structures with periods of vibration equal to or less than 0.5 s, values of F_a for liquefaction.

2.3.2. IBC 2003 soil-rock factors

The IBC soil-rock factors are shown in Table 14 (IBC, 2003, Table 1615.1.2(1)). These factors represent the ratios in ground motions for various types of rock and soil, compared to Site Class B (soft rock).

For the present purposes, approximate soil-rock factors for ground motions expressed in terms of PGA may be inferred from short-period (S_s) spectral acceleration values given in Table 14 by dividing the S_s values by 2.5. For example, a value for S_s of 1.00 g corresponds to a PGA of about 0.40 g and so on.

2.3.3. Comparison of RVS and IBC 2003 soil factors

RVS results that illustrate the effects of soil factors are shown in Table 15. RVS results were calculated for two low-rise building types: C1 and URM. As are all RVS results, these results are calculated at the median values of seismic hazard for each seismicity region: 0.104 g and 0.328 g for the moderate and high seismicity regions, respectively.

There is a strong variation in the probability of collapse as a function of soil type. For RVS final scores of 2.0 and soil type B (rock), the probability of collapse is

Table 15. Sample results for the rapid visual screening (RVS) method for building types C1 and URM and soil factors B, C, D, and E.

Seismicity Region	Soil Type	RVS Soil Factors		RVS Final Score[1]		$P_{collapse}$[2]	
		C1	URM	C1	URM	C1	URM
High	B	0.0	0.0	2.0	2.0	1.00%	1.00%
High	C	0.4	0.4	1.6	1.6	2.51%	2.51%
High	D	0.6	0.6	1.4	1.4	3.98%	3.98%
High	E	1.2	0.8	0.8	1.2	15.85%	6.31%
Moderate	B	0.0	0.0	2.0	2.0	1.00%	1.00%
Moderate	C	0.6	0.4	1.4	1.6	3.98%	2.51%
Moderate	D	1.0	0.8	1.0	1.2	10.00%	6.31%
Moderate	E	1.6	1.6	0.4	0.4	39.81%	39.81%

[1] Assuming a final score of 2.0 before score modifier for soil type.

[2] In RVS the level of ground shaking is determined only by the seismicity region and does not vary with local seismic hazard within a given seismicity region.

1% for both the moderate and high seismicity regions (i.e., per the mathematical definition of RVS final score, *S*). The calculated probability of collapse increases markedly with the progression from soil types C, D, and E. For soil type E, probability of collapse values are about 15 times higher and 40 times higher, respectively, for the high and moderate seismicity regions. These substantial increases in probability of collapse arise because of the large score modifiers for soil type E.

We compare IBC-based soil factors with the above RVS soil factors by first obtaining the appropriate IBC soil factors for the 0.104 g and 0.328 g median PGA values for the moderate and high seismicity regions, respectively. As per the guidance in footnote 1 in Table 14, the IBC soil factors were interpolated linearly for accelerations between the tabulated values. Then, the IBC short-period spectral acceleration (S_s) values are converted to PGA values by dividing the S_s spectral accelerations by a factor of 2.5. These values are shown in Table 16.

IBC-based results were obtained by selecting fragility curves to match RVS results exactly for soil type B (a probability of collapse of 1% at the median PGA for each seismicity region. For a C1 (concrete moment frame) building, these values are 0.82 g and 0.26 g, for the high and moderate seismicity regions, respectively. For a URM (unreinforced masonry) building, these values are 0.86 g and 0.27 g, respectively. Both fragility curves use the HAZUS (FEMA, 2006) beta value of 0.64 and the HAZUS relationship between the probability of the complete damage state and the probability of collapse. These results are summarized in Table 17.

Table 16. International Building Code (IBC) soil factors interpolated and converted to peak ground acceleration (PGA).

Ground Motion (g)		IBC (2003) Soil-Rock Factors[1]			
IBC S_S	PGA	Soil B	Soil C	Soil D	Soil E
≤0.25	0.1	1.000	1.200	1.600	2.500
0.260	0.104	1.000	1.200	1.592	2.468
0.50	0.2	1.000	1.200	1.400	1.700
0.75	0.3	1.000	1.100	1.200	1.200
0.820	0.328	1.000	1.072	1.172	1.116
1.00	0.4	1.000	1.000	1.100	0.900
>1.25	0.5	1.000	1.000	1.000	0.900

[1] Values for PGAs of 0.104 and 0.328 soil factors are by linear interpolation per IBC (2003).

Table 17. Calculated probabilities of collapse using fragility curves and International Building Code (IBC) soil factors.

Seismicity Region	Soil	IBC		$P_{collapse}$[1]	
		Factor	PGA	C1	URM
High	B	1.000	0.328	1.00%	1.00%
High	C	1.072	0.352	1.22%	1.23%
High	D	1.172	0.384	1.55%	1.57%
High	E	1.116	0.366	1.36%	1.37%
Moderate	B	1.000	0.104	1.00%	1.00%
Moderate	C	1.200	0.125	1.65%	1.68%
Moderate	D	1.592	0.166	3.15%	3.28%
Moderate	E	2.468	0.257	6.43%	6.96%

[1] Calculations for buildings with median peak ground acceleration (PGA) values for the complete damage state which yield a 1% probability of collapse at the median PGA for each seismicity region, for soil type B. For C1 building, these values are 0.818 g and 0.259 g for the high and moderate seismicity regions, respectively. For the URM building, these values are 0.858 g and 0.272 g, respectively.

Then, probabilities of collapse for soil types C, D, and E are calculated using fragility curves, as shown for example in Figure 2, and the higher PGA values for each soil type, from the IBC soil factors shown in Table 16.

The RVS and IBC-based results are compared directly in Table 18, which shows the ratio of calculated probabilities of collapse (relative to soil type B) between the RVS results (Table 16) and the IBC-based results (Table 17). The RVS results show increases in the probability of collapse, compared to those calculated using the IBC-soil factors directly factors of about 1.5 to 3 for soil types C and D and factors of about 5 to 12 for soil type E.

The results in Table 18 suggest that the existing RVS procedure may significantly overestimate the effects of soil types C, D, and, especially, E. The differences between RVS results and IBC-based results arise because:

1. RVS soil factors are large, and
2. RVS soil factors, unlike the IBC soil factors, are constant and do not vary with level of ground shaking within a seismicity region.

The apparent overcorrection of results for soil types in the RVS procedure may result in incorrect sorting of buildings above or below cut-off final score values and thus may result in less than optimum allocation of mitigation funds and risk reduction actions that are based on RVS results.

Table 18. Comparison of rapid visual screening (RVS) and International Building Code (IBC) based results: Ratio of the probability of collapse calculated using RVS soil score modifiers versus using IBC soil factors.

Seismicity Region	Soil Type	Ratio (RVS/IBC)	
		C1	URM
High	B	1.0	1.0
High	C	2.1	2.1
High	D	2.6	2.5
High	E	11.7	4.6
Moderate	B	1.0	1.0
Moderate	C	2.4	1.5
Moderate	D	3.2	1.9
Moderate	E	6.2	5.7

2.4. Logarithmic scale for RVS

The RVS final score, S, is *logarithmically* related to the probability of collapse at the RVS-defined maximum considered earthquake (MCE) for a given seismicity region as given in section 1.3, equation 3:

$$S = -\log_{10} (P_{\text{collapse}} \text{ given the MCE})$$

OUS requested a scoring system based on RVS scores that was consistent with their existing ranking systems used in their facilities management program in developing budget needs. The existing OUS ranking system includes scores ranging from 0 to 100 that indicate deferred maintenance and energy efficiency needs, with 100 representing the highest need. In response, the E-RVS scoring system was made to be compatible with their existing ranking system. E-RVS scores therefore are provided in a linear rather than logarithmic scale, with complete damage (CODA) scores that range from 1% to 99%.

As an example, OUS creates a needs matrix with scores that range from zero to 100 for both deferred maintenance needs and energy efficiency needs. Linear E-RVS scores that reflect preliminary seismic risk that range from zero to 100 are easier to integrate into the existing OUS needs matrix than traditional RVS scores.

2.5. Conclusions: Technical review of RVS methodology

The preceding technical review of the RVS methodology draws the authors to the following major conclusions:

1. The use of seismicity regions, rather than site-specific seismic hazard data, for the RVS procedure substantially reduces the accuracy of RVS results. This conclusion holds for either of the two RVS seismic hazard methods (using the seismicity region maps by county or determining the seismicity region from site-specific data). The variation in probability of collapse at a site-specific maximum considered earthquake varies by at least a factor of 8 within a single county and by factors of at least 20 to 60 for the moderate and high seismicity regions overall; none of this variation is considered by the existing RVS methodology.
2. In some cases, the combinations of RVS score modifiers result in final scores which are mathematically out of bounds: the final scores correspond to probabilities of reaching the complete damage state or probabilities of collapse which exceed one. These irregularities in score modifiers affect the relative risk assigned to various buildings (i.e., the final score) and also affect which buildings are deemed to be above or below any defined cut-off score and thus directly affect the buildings for which additional study is recommended.
3. The RVS score modifiers for soil types C, D, and E appear to substantially overcorrect for soil effects in comparison to the soil factors in the 2003 IBC (International Code Council, 2002).
4. The logarithmic relationship between final scores and the probability of collapse at the maximum considered earthquake (MCE) makes results somewhat difficult to interpret and apply.

In combination, the above limitations of the existing RVS methodology reduce the accuracy and usefulness of RVS results.

3.0. DOGAMI ENHANCEMENTS TO RVS: E-RVS

The previous section outlined several technical aspects of the current RVS methodology where enhancements would substantially improve the accuracy and usefulness of RVS results::

- Improve the accuracy of seismic hazard data by using site-specific MCEs rather than median MCEs for broad seismicity regions,
- Reduce the effects of out-of-bounds RVS final scores by avoiding interpretation of RVS final scores that are not physically meaningful (i.e., the final score must correspond to the probability of the complete damage state ≤ 1.0),
- Adjust RVS soil-rock score modifiers to yield results consistent with NEHRP/IBC soil factors.
- Make results easier to understand and to apply by using linear rather than logarithmic scales for results.

The above enhancements are incorporated into DOGAMI's enhanced RVS methodology, or E-RVS. Scores for Complete Damage (CODA) and Life Safety Risk Index (LSRI) are produced.

3.1. Oregon Seismic Hazard Calculator

3.1.1. Site-specific seismic hazard data (local MCE)

An important enhancement to the existing RVS methodology is to calculate the final score, *S*, or equivalently the probability of collapse, at the local maximum considered earthquake (MCE), rather than at the median MCE for seismicity regions which encompass a wide range of seismic hazard levels. This enhancement removes the large dispersion in the meaning of identical RVS scores because of the large variation in local MCE within some counties and the even larger variation in local MCE within the RVS-defined seismicity regions.

The existing RVS methodology suggests two methods for determining seismicity region: 1) using the county maps in FEMA 154 (FEMA, 2002a) or 2) using site specific USGS data to determine the appropriate seismicity region. Neither of these two methods corrects the large dispersion of seismic hazard levels within a county or within a RVS-defined seismicity region.

RVS final scores explicitly define the probability of collapse at a defined level of ground shaking (the median value for each seismicity region). The probability of collapse is in turn directly related to the probability of being in the complete damage state via the HAZUS (FEMA, 2006) relationship between the complete damage state and the probability of collapse (see Table 3).

The mathematical steps to calculate the enhanced RVS (E-RVS) adjusted final score, *S*, are:

1. Conduct RVS evaluation and obtain the final score, *S*.
2. Determine the probability of being in the complete damage state at the median MCE level of ground shaking for the appropriate RVS seismicity region from the probability of collapse (final score) and the probability of collapse if the complete damage state is reached (Table 3).
3. Infer a fragility curve (the median ground motion for the complete damage state) from the above probability at the RVS median level of ground shaking, using the HAZUS (FEMA, 2006) beta (lognormal dispersion parameter) value of 0.64.
4. From the fragility curve for the complete damage state, calculate the probability of the complete damage state, the probability of collapse, and the equivalent adjusted final score, *S*, for the *local* MCE.

The above calculations are done automatically in the DOGAMI E-RVS software, which requires only that the user enter the RVS score, building type, seismicity region, soil-rock type — all of which are part of the existing RVS procedure — and the local MCE (two thirds of the 2% in 50-year ground motion value). The E-RVS software uses peak ground acceleration (PGA) for these calculations.

To facilitate users obtaining the correct local seismic hazard data, we have also developed an Oregon Seismic Hazard Calculator, which returns the necessary seismic hazard data (e.g., a full seismic hazard curve) upon entry of a site's latitude and longitude and soil-rock type. The Oregon Seismic Hazard Calculator uses the consensus USGS national seismic hazard data (gridded values) and automatically looks up and interpolates between the four surrounding grid points to obtain the site seismic hazard data necessary for the above calculation. An example printout from the Oregon Seismic Hazard Calculator is shown in Figure 3.

3.1.2. Soil-rock factors

The Oregon Seismic Hazard Calculator starts with the USGS PGA values for rock sites (actually, for the B-C boundary) and then makes adjustments for soil type and adjustments for earthquake magnitude/duration.

The soil factors used in the Oregon Seismic Hazard Calculator are shown in Table 19. These factors are interpolated from the 2003 IBC (International Code Council, 2002) factors shown in Table 14, simplified by using a factor of 1.000 for rock types A and B. This simplification was made because there are essentially no buildings on type A rock in Oregon.

Seismic Hazard Data by Latitude - Longitude

OREGON

Version 1.01 February 20, 2007

Project Name:	Deep Creek Bridge	Date:	February 20, 2007
Address:	Clackamas County	User Name:	A. B. User
City, State, Zip:			

Enter Site Latitude-Longitude in degrees-minutes-seconds OR in decimal degrees

	Degrees	Minutes	Seconds	Decimal Calculated
Latitude:	45	23	27.23	45.390897
Longitude:	122	23	26.09	122.390581

Enter Project Site Soil/Rock Type: D — Soil/Rock entries must match letter codes exactly.

Soil Rock Choices:

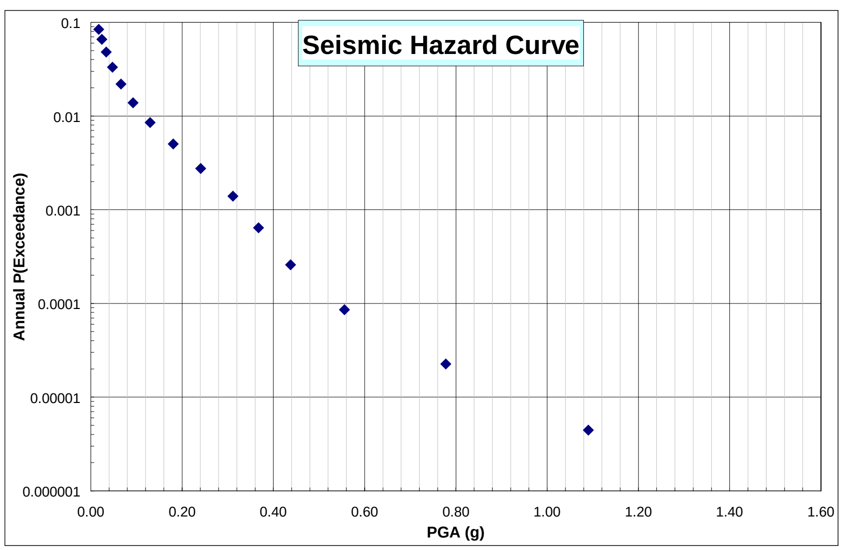
Rock	AB
Very Dense Soil	C
Firm Soil	D
Soft Soil	E
Very Soft Soil	F

Soil/Rock types and definitions as per IBC 2003 (2006).

If soil/rock unknown, use Firm Soil D as default.

Site specific geotechnical analysis encouraged for Soil F

Site Hazard Data	
PGA	Annual P
0.008800	1.145E-01
0.012320	1.005E-01
0.017248	8.391E-02
0.024112	6.587E-02
0.033792	4.825E-02
0.047344	3.322E-02
0.066176	2.188E-02
0.092752	1.387E-02
0.129888	8.514E-03
0.180600	5.028E-03
0.240845	2.750E-03
0.311280	1.399E-03
0.367382	6.426E-04
0.437891	2.583E-04
0.556000	8.588E-05
0.778000	2.260E-05
1.090000	4.449E-06
1.520000	6.103E-07
2.130000	3.300E-08



2/3rds of 2% in 50 year PGA value: **0.269** Enter this value into the E-RVS spreadsheet

Reference PGA values:	g	% g
10% in 50 years:	0.269	26.9%
5% in 50 years:	0.334	33.4%
2% in 50 years:	0.403	40.3%

PGA values are shown as fractions of g, the acceleration of gravity. Thus, for example, 0.500 means 0.5 g or 50% of g.

Figure 3. Example printout from the Oregon Seismic Hazard Calculator.

Table 19. Oregon Seismic Hazard Calculator soil-rock factors.

Soil Type	Peak Ground Acceleration (PGA, g)										
	≤0.074	**0.103**	**0.145**	**0.203**	**0.284**	**0.397**	**0.556**	**0.778**	**1.090**	**1.520**	**2.130**
	Soil-Rock Factors										
AB	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C	1.200	1.200	1.200	1.197	1.116	1.003	1.000	1.000	1.000	1.000	1.000
D	1.600	1.594	1.510	1.394	1.232	1.103	1.000	1.000	1.000	1.000	1.000
E	2.500	2.476	2.140	1.685	1.280	0.909	0.900	0.900	0.900	0.900	0.900

3.1.3. Magnitude-duration adjustments

The DOGAMI E-RVS enhancements to the RVS methodology draw directly on HAZUS (FEMA, 2006) fragility curves and other HAZUS (FEMA, 2006) consensus results such as the relationship between the complete damage state and the probability of collapse for various building types. The HAZUS (FEMA, 2006) fragility curves are derived in substantial part from historical experience with earthquake damage in California, predominantly for earthquakes in the roughly M7± range.

In western Oregon the dominant seismic source is the Cascadia Subduction Zone (CSZ), where the characteristic earthquakes are very large magnitude events (M8+) with correspondingly very long duration ground shaking. For a given level of shaking, the long duration shaking is expected to result in more damage than would be experienced in much shorter duration earthquakes such as crustal M7 earthquakes in California.

To account for the longer-duration shaking expected in western Oregon, the most rigorous approach would be to develop new sets of building fragility curves taking into account not only the duration of shaking but also the spectral content of CSZ earthquakes. Such an effort is beyond the scope of our current enhancements to RVS.

To account approximately for the higher levels of damage expected from long-duration CSZ earthquakes, we adopt the same simplified approach used in FEMA seismic hazard software recently developed for Washington State (FEMA, 2005). Seismic hazard curves are adjusted to increase the expected damage levels as follows:

- For sites with longitudes west of –123°, increase PGA values under 0.30 g by 15% and increase PGA values from 0.30 to 0.40 g by 10%.
- For sites with longitudes east of –123° and west of –122.5°, increase PGA values under 0.30 g by 10 % and increase PGA values from 0.30 to 0.40 g by 5 %.
- For sites with longitudes east of –122.5°, no adjustments.

Making adjustments by longitude reflects the approximately north-south alignment of the CSZ, with correspondingly diminishing contributions from the CSZ with increasing distance eastward from the Oregon coast. We recognize that these empirical adjustments are based largely on professional judgment and that they are only approximate. An alternative approach of using USGS disaggregated ground motions for each USGS seismic hazard data grid point is beyond the scope of our present effort. Accounting approximately for the effects of long-duration shaking is preferable to not considering such effects, and we believe that the method given by FEMA (2005) is acceptable for the present purposes, especially given the intrinsically approximate nature of the RVS methodology. These adjustments reflect the professional judgment of structural engineers highly experienced in estimating earthquake damage, taking into account 1) the expected increase in damage from long duration ground shaking, and 2) the longitude dependence of the fraction of seismic hazard attributable to Cascadia Subduction Zone events.

3.2. Oregon E-RVS Calculator

3.2.1. Out-of-bounds RVS final scores

As noted in section 2.2, many possible combinations of RVS basic structural hazard scores and score modifiers yield final scores lower than the physically meaningful limit that neither the probability of collapse nor the probability of the complete damage state can exceed 1.0 (see Table 9 and Table 10).

In the DOGAMI E-RVS methodology, interpretation of possible out-of-bounds scores is precluded simply by truncating the maximum possible probability of being in the complete damage state at 99%. This truncation is equivalent to limiting RVS final scores to the minimum physically meaningful values shown in Table 10.

3.2.2. RVS score modifiers for soil types C, D, and E

As documented by the calculations summarized in section 2.3, RVS score modifiers for soil types C, D, and E are larger than corresponding soil-rock factors in the IBC (2003). As shown in Table 18, RVS score modifiers correspond to increasing the probability of collapse for example buildings by factors from about 2 to nearly 12 in the high seismicity region and by factors of about 1.5 to 6 in the moderate seismicity region, compared to results using the IBC 2003 soil factors. RVS score modifiers for soil types C, D, and E thus overcorrect for soil effects, especially in the high seismicity region. To avoid overcorrection, the DOGAMI E-RVS methodology removes the score modifier component from the RVS final score, *S*, and, instead, accounts for soil-rock factors in the seismic hazard data by using the IBC 2003 soil factors as documented in section 2.3.3 above.

3.2.3. Linear results scales

As noted in section 2.4, we developed an alternate scoring scheme to better meet the needs of the OUS administrators, as they required results that were easier to understand, i.e, results in a nonlogarithmic format.

The DOGAMI E-RVS methodology shows the linear equivalent of RVS final scores in two ways:

1. CODA, the probability of the complete damage state at the local MCE, and
2. LSRI, Life Safety Risk Index, which is 100 times the probability of collapse at the local MCE (i.e., the probability of collapse expressed as a percentage).

The probability of the complete damage state, CODA, is much greater than the probability of collapse (see Table 3) and is the best RVS measure of potential economic loss. The probability of collapse, LSRI, is the best RVS measure of life safety risk. Experience with the OSU suggests that they have the additional advantage of increasing the public policy driving force for implementation of mitigation actions with scores that are easier to understand.

4.0. APPLICATIONS OF THE DOGAMI E-RVS METHOD

4.1. Example 1: Western Oregon University

The DOGAMI E-RVS methodology was applied in a pilot study for Western Oregon University in Monmouth, Oregon. An example of E-RVS results compared with RVS results is shown on a campus map (Figure 4). An example printout of the E-RVS summary table developed to facilitate the calculations necessary for this enhancement of the RVS procedure is shown in Table 20. This example shows the RVS, E-RVS, CODA, and LSRI scores and illustrates the modifications made to RVS results at a single geographic location. It includes 23 buildings with RVS scores below 2.5 at WOU. These 23 buildings are a subset of the 46 major buildings on campus. The other 23 buildings were not included in this example, as they had RVS scores of 2.5 or higher, indicating a low level of probable risk.

The DOGAMI E-RVS methodology, as outlined above, closely follows the logic and mathematics inherent in RVS, along with the mathematics of the HAZUS (FEMA, 2006) fragility curves. The enhancements, especially the determination of the probability of collapse at the local MCE, substantially improve the accuracy and meaningfulness of RVS results. E-RVS results, including the probability of being in the complete damage state (CODA) and the probability of collapse (i.e., LSRI), are analogous to the RVS final score. The RVS score is an explicit measure of the probability of collapse and an implicit measure of the probability of the complete damage state.

Upon completion of an E-RVS screening of a population of buildings, preliminary prioritization of potentially vulnerable buildings can be determined using the CODA values or the LSRI, which indicates the probability of collapse at the local MCE. As with RVS final scores, users/owners may set whatever cut-off scores they deem appropriate for their specific facilities. In consultation with OUS, we sorted the population into buildings with CODA values over 30%, values from 10% to 30%, and values less than 10%, which, respectively, may be considered as very high, high, and moderate priorities for further study and possible retrofit or replacement. This sorting scheme is illustrated in Figure 4.

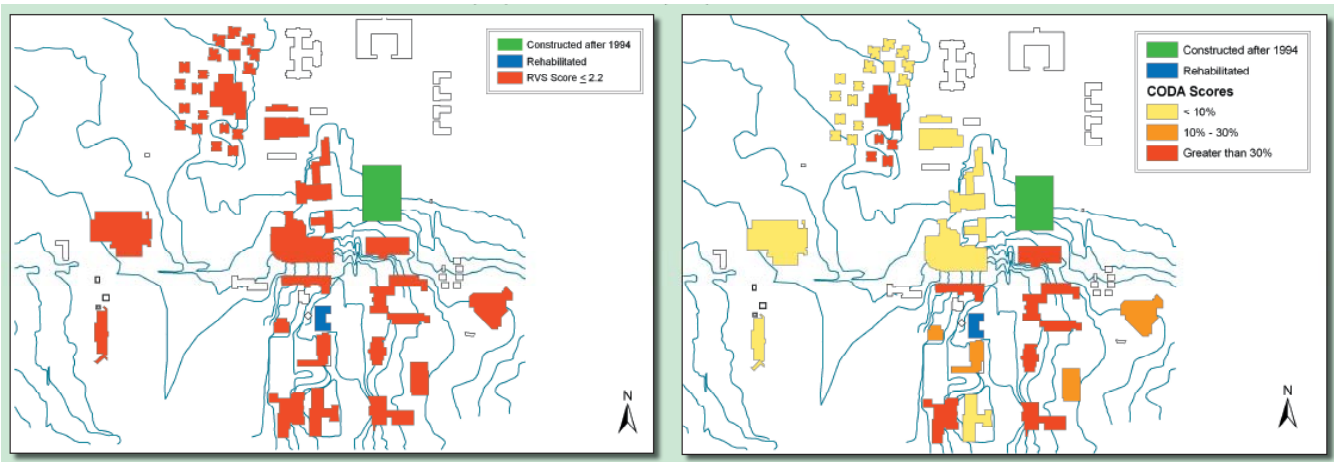


Figure 4. Plan view map of Western Oregon University buildings. (left) Rapid visual screening (RVS) results and (right) probability of complete damage state (CODA) score results. The CODA score, developed using the enhanced RVS (E-RVS) methodology, provides a prioritized risk score that allows for better risk decision making.

Table 20. Enhanced rapid visual screening (E-RVS) results for Western Oregon University buildings.

Enhanced Rapid Visual Screening (E-RVS): DOGAMI Earthquake Life Safety Risk Assessment for Oregon Version 1.01

Organization:	Western Oregon University
City:	Monmouth, Oregon 97361
Contact Person:	
Contact Telephone	
Contact E-mail:	
County:	Polk (Morrow, Multnomah, Polk, Sherman, Tillamook)
Seismicity Region:	HIGH
Date:	2/5/2007

Building Name	Building Location or Address	Building Area (sf)	Year Built	Building Use	Peak Occu-pancy	Other Rehab Plan?	RVS Building Type	Low Rise Mid Rise High Rise	Soil Type	RVS Final Score S	2/3rds of 2% in 50 Years PGA	E-RVS Final Score S	Probability of Complete Damage	Life Safety Risk Index
ITC		42,365	1915		>250		RM2	Mid	D	0.5	0.28	1.2	70%	7.00
Education		34,752	1965		>250		C2	Low	D	0.2	0.28	0.9	99%	13.00
PE and Wolverton Pool		36,600	1936		>250		URM	Low	D	-0.5	0.28	0.8	99%	15.00
Smith Music Hall		14,315	1958		>250		C3	High	D	1.2	0.28	1.8	17%	1.74
Natural Sciences		47,109	1969		>250		C2	Low	D	2.2	0.28	3.1	1%	0.08
Stadium		11,090	1980		>250		C2	Low	D	2.2	0.28	3.1	1%	0.08
Physical Plant		30,108	1960				RM2	Low	D	2.2	0.28	3.1	1%	0.08
Werner University Cntr.		33,045	1960		>250		C2	Low	D	1.7	0.28	2.5	2%	0.28
Arbuthnot Hall		35,182	1961				RM2	Low	D	1.2	0.28	2.0	8%	0.99
Maaske Hall		22,260	1955				C2	Low	D	1.7	0.28	2.5	2%	0.28
Butler Hall Dorm 5		24,641	1964		>250		C3	Mid	D	0.7	0.28	1.2	50%	6.50
Gentle Hall Dorm 6		24,619	1966		>250		C2	Low	D	1.4	0.28	2.2	5%	0.61
Barnum Hall Dorm		24,550	1968		>250		C2	Low	D	1.4	0.28	2.2	5%	0.61
Landers Hall Dorm 8		55,925	1970		>250		C2	Low	D	1.4	0.28	2.2	5%	0.61
Valsetz Dining Hall		48,022	1971		>250		RM2	Low	D	-0.1	0.28	0.9	99%	13.00
PE Building New		62,468	1971		>250		PC1	Low	D	1.9	0.28	2.8	1%	0.17
Rice Auditorium		27,667	1976		>250		RM1	Low	D	0.7	0.28	1.4	29%	3.75
Police Academy		24,712	1988		>250		RM2	Low	D	1.7	0.28	2.5	2%	0.28
Administration Bldg		25,000	1936		>250		URM	Mid	D	-0.5	0.28	0.8	99%	15.00
Maple Hall		4,603	1900				URM	Low	D	1.0	0.28	1.8	11%	1.68
HSS Humanities		36,799	1964		>250		C2	Low	D	0.7	0.28	1.4	29%	3.75
Todd Hall		36,799	1912		>250		URM	Mid	D	0.5	0.28	1.2	42%	6.26
Academic Programs		42,900	1951		>250		C1	Low	D	-0.3	0.28	0.9	99%	13.00

The rightmost three columns contain values calculated using E-RVS methodology. Cell background colors have been revised from the original display to match the colors in Figure 4 representing RVS and CODA scores.

4.2. Example 2: Selected buildings from six Oregon universities

A second example of the application of the E-RVS methodology to buildings at six Oregon university campuses is shown in Table 21. Five of these locations are in the RVS high seismicity region; one is in the moderate seismicity region.

The E-RVS final scores are systematically higher than the RVS scores because the ground motions at all these sites, except EOU, are lower than the median ground motions for the high or moderate seismicity region and because E-RVS adjustments for soil types C and D are smaller than the RVS score modifiers for these soil types.

4.3. Oregon University System RVS applications

In Oregon, RVS and DOGAMI E-RVS methods will continue to be applied to support state funding requests for seismic upgrades to state-owned university buildings. In late 2004, seismic upgrade needs in terms of RVS scores were included in the Oregon University System (OUS) state budget request along with deferred maintenance and energy efficiency scores. In the 2005–2007 legislative session, eight million dollars were appropriated for seismic upgrades. This was the first time state seismic funds were systematically appropriated in the OUS budget.

This E-RVS method was developed in time to be used in the 2007–2009 OUS budget request. It allowed

Table 21. Enhanced rapid visual screening (E-RVS) results for selected buildings at six Oregon universities.

Building Name	Building Type	Low-Rise/ Mid-Rise/ High-Rise	Soil Type	RVS Final Score	Two Thirds of 2% in 50 Years PGA	RVS Seismicity Region	E-RVS Final Score	Probability of Complete Damage	Life Safety Risk Index
SOU Churchill	C2	low	D	–0.3	0.23	high	0.9	99%	13.00
WOU HSS	C2	low	D	0.7	0.28	high	1.4	29%	3.75
WOU PE-Pool	URM	low	D	–0.5	0.28	high	0.8	99%	15.00
PSU Lincoln	S5	low	D	–0.1	0.31	high	1.1	99%	8.00
PSU Stott	C2	low	D	2.2	0.31	high	2.9	1%	0.12
PSU Science II	C2	mid	D	2.6	0.31	high	3.3	<1%	0.05
UO Fenton	URM	mid	C	0.7	0.23	high	1.3	30%	4.54
UO Condon	URM	low	C	0.7	0.23	high	1.3	30%	4.54
UO Straub	C2	mid	C	1.3	0.23	high	2.1	8%	0.78
OSU Nash	S4	mid	D	1.1	0.28	high	1.8	30%	1.51
OSU Dearborn	S1	mid	D	0.9	0.28	high	1.6	52%	2.61
OSU Sackett	S1	low	D	0.7	0.28	high	1.4	52%	4.18
OSU Finley	C2	low	D	1.2	0.28	high	2.0	10%	1.03
OSU Callahan	RM2	low	D	1.2	0.28	high	2.0	10%	1.03
EOU Inlow	C2	low	C	0.4	0.12	moderate	1.1	55%	7.20

SOU: Southern Oregon University
WOU: Western Oregon University; HHS, Humanities and Social Sciences building; PE, Physical Education
PSU: Portland State University
UO: University of Oregon
OSU: Oregon State University
EOU: Eastern Oregon University
Two thirds of 2% in 50 Years PGA is two thirds of the 2% probability of exceedance in 50-year peak ground accelerations. The right-most three columns contain values calculated using the E-RVS methodology.

OUS to improve their budget requests by better prioritizing seismic risk and providing clear seismic deficiency scores so that decision makers could more easily understand the requests.

In November 2006, Governor Ted Kulongoski recommended $26 million to the 2007–2009 Legislature in his budget for seismic upgrades of six high risk university buildings. These buildings were integrated in the OUS 2007–2009 budget request with a needs matrix showing scores developed using the E-RVS method alongside deferred maintenance and energy efficiency scores. Specifically, Governor Kulongoski recommended:

- $4.123 million for Western Oregon University's Humanities and Social Sciences building, of which $0.952 million is for seismic improvements;
- $15.575 million for Oregon State University's Nash Hall, of which $3.834 million is for seismic improvements;
- $29.218 and $26.309 million for Portland State University's Lincoln Hall and Science Building II, of which $9.819 and $4.799 million are for seismic improvements, respectively;
- $8.072 million for the University of Oregon's Fenton Hall, of which $3.691 million is for seismic improvements; and
- $6.242 million for Eastern Oregon University's Inlow Hall, of which $1.195 million is for seismic improvements.

4.4. Future applications of RVS in Oregon

In Oregon other public buildings including kindergartens through high schools, community colleges, fire stations, police stations, hospitals, and emergency operation centers are being screened using the RVS (FEMA, 2002a) method. Screening is being conducted by DOGAMI as part of a statewide needs assessment mandated by 2005 Senate Bill 2. We anticipate that the DOGAMI E-RVS method will be applied to the traditional RVS scores in Spring 2007. The final statewide needs assessment will be issued on July 1, 2007, and will be publicly available.

Pending funding, and as field testing of the methodology progresses, additional comparisons and enhancements may be made by DOGAMI or others.

5.0. SUGGESTED IMPROVEMENTS TO THE RAPID VISUAL SCREENING METHODOLOGY

Enhancements made in the DOGAMI E-RVS methodology to the RVS methodology, especially calculating the probability of collapse at the local MCE instead of by seismicity regions, improve the accuracy of results. We suggest that these enhancements should be incorporated into future versions of the RVS methodology.

Given the large dispersion in the meaning of RVS final scores that arises because of the large variation in seismic hazard level within some counties and the even larger variation in seismic hazard level within RVS-defined seismicity regions, an upgrade of the RVS methodology to base final scores on local MCEs is essential. This refinement would improve the accuracy and meaningfulness of RVS results and is an important refinement for the RVS methodology.

Other possible enhancements to the existing RVS methodology include:

1. Re-evaluating score modifiers for reasonableness, including both the structural characteristics score modifiers and the soil-rock score modifiers,
2. Replacing the present linear combination of score modifiers with a more sophisticated method, including perhaps a simple root mean square combination or sorting the score modifiers by importance and using engineering judgment to weight the score modifiers' contributions to the final score.
3. Incorporating state-specific information on building code history, benchmark years, and local practices.

RVS final scores are, in effect, fragility curves for the complete damage state because they determine the probability of collapse at a defined level of ground shaking. The entire RVS score calculation would be more understandable to both developers and users if the fragility curves were explicit rather than implicit. The basic structural hazard score (BSH) can be expressed directly as a fragility curve for the complete damage state, with score modifiers explicitly included as adjustments to the fragility curve.

This approach would facilitate the re-evaluation of score modifiers and the improvement of the mathematics for combining score modifiers noted above by making it easier to evaluate the reasonableness of final scoring results. In contrast, the meaning and reasonableness of the present logarithmic score modifiers are not evident, even to many experienced structural engineers. For example, a given building with score modifiers of −0.6, −0.8, −0.4, and −1.2 might have a final score of 1.2. Determining whether or not this final score is "reasonable" is more difficult than evaluating the reasonableness of a median PGA of, for example, 0.25 g, for the complete damage state because median PGAs for fragility curves can be compared directly to consensus HAZUS fragility curves for typical buildings.

Expressing RVS results in terms of fragility curves would also facilitate comparison of results with consensus HAZUS (FEMA, 2006) fragility curves for typical buildings.

6.0. CONCLUSIONS AND CAVEATS

DOGAMI E-RVS enhancements to the RVS method improve the accuracy and usability of the RVS method. Nevertheless, it is important to remember that E-RVS and RVS are *preliminary* screening tools based on the limited information available from a sidewalk survey (or brief interior inspection). Thus, the primary use of E-RVS or RVS scores is to sort a population of buildings into those that require further engineering study and those that probably have acceptable seismic performance.

7.0. ACKNOWLEDGMENTS

During the course of this project, the preliminary results were repeatedly reviewed by Robert Simonton of OUS for usefulness and application. The ultimate method recommended in this paper reflects modifications based on Robert Simonton's insights, especially concerning ease of integration in the state budget requests and understanding among decision makers. John Mester, Stanford University, provided technical reviews of the algorithms of the E-RVS methodology, including the calculations for the CODA and LSRI scores and the Oregon seismic hazard calculator. Paul Finke of Western Oregon University reviewed the results of the Western Oregon University pilot study.

Reviews of this paper and/or earlier versions were provided by Charles Scawthorn, Kyoto University; Kent Yu, Degenkolb Engineers; Christine Theodoropoulos, University of Oregon; and Ian Madin, DOGAMI. Each reviewer provided insightful comments that have been addressed. Matthew Mabey, Oregon Department of Transportation; and Ivan Wong, URS Corporation, also provided comments. Constructive verbal comments on the E-RVS methodology were provided by Tom McLane and Christopher Rojahn of the Applied Technology Council, Barry H. Welliver, Structural Engineer, William Holmes of Rutherford & Chekene, and Melvin Green of Melvin Green & Associates Finally, we acknowledge the encouragement from Cathleen Carlisle of FEMA to pursue our suggested enhancements to RVS.

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