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Setting the Priority for Seismic Retrofit of Buildings using A Modified FEMA P-154 Procedure

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Abstract

The quality of seismic risk management decisions depends on professional judgements of the assessors. Without an assessment of the reliability of the thought process and information used to give them credibility, the decision made based on this information is doubtful. The approach developed here to managing seismic hazards posed to an organization does not require all possibly dangerous buildings to be brought into acceptable performance immediately. It depends on the application of a modified P-154 assessment score, S_{L2}, and an evaluation of the reliability of the assessment process. Typically, a conventional P-154 assessment is reliable enough to determine those buildings that require significant engineering assessment, say a Level 3 ASCE 41, but not sufficient to determine whether retrofit is appropriate. It identifies those that should be retrofitted in the near term without incurring significant costs for engineering assessment of all buildings and massive construction and function disruption in the short term. The goal of this process is to be concerned about buildings that have above a 2% probability of collapse in 50 years for priority, or a value chosen by the organization. It is based on a modification of the FEMA P-154 assessment procedure supplemented by procedure to determine the reliability of the methods and procedures used in the companion paper. It was validated by application to 56 previously identified hazardous buildings on three CSU campuses, all of which FEMA P-154 would require immediate retrofit. The result of the application was that two needed immediate attention, 12 requiring work overtime, and the balance were not scheduled for seismic work except when the CSU Policy required such to meet CEBC requirements. It is interesting to note that the individual assessors made very few adjustments to the P-154 S_{L2} scores, nor did the assessment committee or Seismic Review Board reviews. Where assignment decisions were made, the S_{L2} were not changed, but the List assignment decision did not follow the Decision Rule in a few cases. In summary, the principal impact of the Modified P-154 process is that the decisions it yielded conformed with a level of reliability that was acceptable to CSU management and their advisors.

Keywords: Retrofit; Earthquake; Damageability; Structural evaluation; Safety; Financial risk; Seismic evaluation

Introduction

Seismic risk management decisions depend on risk assessments based upon professional judgements. Some judgements are predictive and can be verified when the outcome becomes known in a short to medium time period. However, many judgements are unverifiable in part because of the time period over which they apply. Determining acceptable seismic performance of a building falls in this latter category. The quality of such judgments can be assessed only by the quality of the thought process and information that produced them. The seismic risk management program for the California State University's building stock has been underway since 1993, and the authors have participated in this process for CSU since that time [1]. For a given potentially hazardous building, this document presents how the current seismic risk evaluation is performed for the purpose of setting a priority for retrofit. For the objective of providing prudent, legally defensible decisions, the risk evaluation and retrofit priority assignment will be by a continuing, consistent, transparent, and documented assessment process. Procedures developed for FEMA will be employed.

While the following procedures were initially intended for application to CSU buildings, they can be used by any individual or public or private organization desiring to evaluate the reliability of a seismic safety assessment of a building or group of buildings and their need for seismic retrofit. This is part of a two-paper set. The first paper, "Determining the Reliability of a Modified FEMA P-154 Conclusion for an Assessed Building," provides the means for incorporating the assessment of reliability into a decision fabric for making decisions on what buildings warrant action.

The objective of this paper is to develop the modified P-154 [2] assessment procedures, and then provide a means of assessing the reliability of its conclusions for a group of buildings.

The objective is to focus available resources on the right building(s). Sound seismic risk management requires a knowledge of both the level of the risk of a building and the reliability of its assessments. The authors suggest that the first action of an organization wanting to make such an assessment is to appoint a Consulting Board (CB) of seismic experts, not less than two and ideally four to seven, depending on the portfolio under consideration and how many assessments are to be performed per year to technically supervise this process. Depending on available resources, selected individual assessors should be assigned for four to five potentially hazardous buildings.

The authors have selected to approach these assessments using a modified FEMA P-154 procedure. The original P-154 Rapid Visual Screening (RVS) [2] process was intended for a wide-spread regional seismic risk assessment without the significant cost of detailed engineering inspections or analyses. Its purpose was to identify buildings that warrant significant engineering evaluation before assessing its relative risk. The RVS assessment procedures permit use by assessors that may have a wide range of qualifications to help identify buildings that should be assessed in detail. The purpose herein is to identify the priority for such assessments and not require further assessment until a time when it is appropriate.

The proposed method will employ the procedures of FEMA P-154 using the risk evaluation metrics of its companion document FEMA-155 in conjunction with the methodologies proposed in the companion paper Determining the Reliability of a Modified FEMA P-154 Conclusion for a Seismically Assessed Building. It was based on work from a recently developed procedure to evaluate the reliability of seismic performance assessments for individual buildings and portfolios by Thiel, Zsutty and Lee in the Risks Journal paper Reliability of Seismic Performance Assessments for Individual Buildings and Portfolios [3]. The central core of this procedure is that the ratings of buildings' risks are independently technically reviewed by the CB to assure that the methods used are sufficiently reliable to warrant taking the conclusions of the study seriously. The details of this reliability evaluation procedure are developed in the companion paper.

The overall organization of the proposed approach to prioritizing retrofit is based on one used for about the last 30 years, during which the California State University (CSU) system has been managing its buildings' seismic risk using methods recommended by the CSU Seismic Review Board (SRB) [1]. For about the last 20 years, these methods have included the assignment of deficient buildings to risk categories or lists that depend on the specific conditions of when the retrofit requirements of the California Existing Building Code (CEBC) as specified in whether the building is on List 1, 2 or No List, as discussed below, must be considered.

The CEBC [4] Section 317 regulates all CSU existing buildings. It requires seismic evaluation of the building only if certain triggers are pulled (see Table 1) that are not very restrictive, when permitted work is proposed. It is unusual compared to other building codes, in that it is performance based for retrofit and can cause a state building to be evaluated even though the base building code does not do so for other owners. CSU found that the CEBC requirements were not sufficient to meet its seismic safety goals to reduce its population of hazardous buildings quickly enough; therefore, an assessment program (on which this paper is based) was implemented to accelerate consideration of the retrofit of buildings that pose excessive risk. The previous purely judgmental priority assignment procedure was used for assignment of buildings to List 1 and List 2, as discussed below. The procedure proposed herein provides a method to identify those buildings that are too seismically risky to allow delay until permitted work by a more transparent method. The CSU Policy recognizes that all non-code conforming existing buildings that are not on Lists 1 or 2 will be required to be retrofitted when the CEBC so requires but accelerates List 1 and 2 cited buildings to be addressed in a timely manner, not just when a permit requiring modification is proposed. The priority system proposed for seismic assignment of buildings is intended to identify those that are the most pressing life-safety issues for early attention, and it allows the normal renewal and building modification trigger process of the CEBC to take care of all those buildings that are not assessed as posing pressing concerns. This was the rationale for the SRB, when they were charged by the Division of the State Architect and the State Building Standards Commission to prescribe the evaluation and related retrofit triggers for the CEBC in the mid-1990s, which are now the basis for the recommended assignment protocol. With the procedure proposed in this paper, the only thing CSU revised was the method of how buildings were assigned to List 1, 2 or to No List at all.

The following priority setting system is proposed as the core management element of the seismic hazard of a building by its assessed level of seismic risk posed by assigning it to:

a. List 1: A building posing significant risk that warrants detailed seismic assessment and retrofit to be implemented as soon as funds are available to do so.

b. List 2: A building posing sufficient risk to warrant detailed seismic assessment when any work requiring a permit is undertaken at the owner's initiative, whether the applicable Building Code requires it or not. Virtually every US Building Code allows an owner to propose work that is not required by the code to be done, as long as the building's hazard is not increased, and all work conforms to the Code's other requirements; that is, the Code is a minimum not a maximum requirement.

c. No List assignment for a building that has a seismic vulnerability that does not warrant assignment to Lists 1 or 2. When any work requires a permit where a trigger limit applies for evaluation and retrofit.

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Table 1: Reproduction of Sections 317.3.1 of the 2019 CEBC setting the conditions under which a seismic evaluation is required for a building. For List 1 or List 2 buildings, these allowances to avoid seismic assessment cannot be used, and such an assessment is required by CSU Policy.

S. No	Existing State-Owned Buildings For Existing State-Owned Structures, including All Buildings Owned by the University of California and the California State University, the Requirements of Section 317 Apply Whenever the Structure is to be Retrofitted, Repaired, or Modified and any of the following Apply
1	Total construction cost, not including cost of furnishings, fixtures and equipment, or normal maintenance, for the building exceeds 25 percent of the construction cost for the replacement of the existing building. The changes are cumulative for past modifications to the building that occurred after adoption of the 1995 California Building Code and did not require seismic retrofit.
2	There are changes in risk category.
3	The modification to the structural components increases the seismic forces in, or strength requirements of, any structural component of the existing structure by more than 10 percent cumulative since the original construction, unless the component has the capacity to resist the increased forces determined in accordance with Section 319. If the building's seismic base shear capacity has been increased since the original construction, the percent change in base shear may be calculated relative to the increased value.
4	Structural elements need repair where the damage has reduced the lateral-load-resisting capacity of the structural system by more than 10 percent.
5	Changes in live or dead load increase story shear by more than 10 percent.

The actions triggering seismic assessment and possible retrofit for California State agencies are those of the CEBC, Section 317, and for others either the requirements of the local building agency or of criteria set by the organization owning the buildings. Notwithstanding, any private owner not subject to these regulations can choose to follow their requirement on their own to guide the scope of what they seek in a permit application whatever the jurisdiction requirements are, as long as its base requirements are met.

In 2021, CSU's Seismic Review Board (SRB) decided to revise its risk assessment to include a modified version of the FEMA P-154 procedure where a low S_{L2}, score value indicates a potentially high-risk level and will guide list assignments as the SRB so recommends. CSU chose to implement a modified FEMA P-154 procedure as a basis for making the list assignment decisions; this is described herein. These modifications allow identification of hazardous building categories as given above. Their objective is to provide prudent and documented decisions for retrofit as required by the ongoing CSU seismic risk management program. While the initial P-154 RVS process is intended to identify potentially hazardous buildings that require further detailed structural evaluation, CSU has modified the process to include the priority for structural evaluation and corresponding retrofit. This was prompted by the fact that the initial assessment was a triage procedure whose limited requirements, and the desire not to call a Bad building Good, leads to many Good buildings being called Bad. This is also true for applications of ASCE 41 [5] Tier 1 assessments, which are a triage approach and cause more error in identifying Bad buildings as Good than vice versa for Level 1, but fewer for the significantly more expensive Tier 2 or 3 applications. Recently the University of California in its systemwide seismic evaluation indicated that using current ASCE 41 Tier 1 procedures yielded a very large likelihood that an assessed building would be identified as requiring detailed inspection at a Tier 2 or 3 evaluation (M. Phipps, Member, UC Seismic Advisory Committee, email April 3, 2022).

It is proposed that the organization or group perform such an assessment for all the buildings in its inventory so that consistency can be achieved, and that the effort is a continuing one to oversee its building safety program over time, to assure that the policy is implemented as policy for the organization. If the inventory of buildings to be reviewed is too large to be completed in one effort because of fiscal constraint, then the CB should decide on the types of buildings and hazard locations and select the first group to be assessed. The CSU, with 24 campuses and many thousands of buildings, has determined that it may take several years to have portions of all campuses assessed. CSU chose not to have its SRB select the individual buildings from the system-wide inventory but to identify the campuses to be assessed and let the assessors (the SRB assigned peer reviewer for all construction undertaken on a given campus) choose the highest in its judgement the hazard buildings for assessment. CSU has an advantage of having had its seismic assessment approach in place for almost 30 years, so there was a well-informed structural engineer familiar with the campus inventory of buildings. Where there are knowledgeable seismic expert structural engineers familiar with the organization's building population, it would be prudent to engage them in this process.

A summary of the annual procedure for a given cohort of buildings considered is as follows:

a. If less than all buildings are to be reviewed, then the CB will assess by professional means to identify these buildings by location, age, condition, or other building type assessment,

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to represent the highest risk. Those buildings not included are proposed to be assessed in a future survey that will be made by the CB to identify. All buildings will be evaluated using this modified P-154 standard.

b. The individual assessments will be completed using the modified FEMA P-154 [2] Level 1 and Level 2 Forms. Each assessment will be accompanied by the P-154 Level 1 and 2 evaluation Forms. The assessor will use the Comments box with supplemental pages to express any specific conditions that could alter the Level 2 score, S_{L2}, and/or Priority List assignment. The assessor shall assign the Level 2 score, S_{L2}, that reflects the assessor's best professional judgment guided by the P-154 score.

c. The CB will consider the building assessment, assign it to one of the risk categories of The Assessment Procedure discussion, and recommend it to the client for action.

Seismic risk management decisions depend on risk assessments based upon professional judgements. The quality of such judgments can be expressed only by the quality of the thought process and information that produced them. This will be assessed in Building Priority Assignment Based on S_{L2} Score and the Decision Rule proposed therein.

The Assessment Procedure

The goal of this procedure is to distinguish a Good from Bad building quickly with limited information and great uncertainty and to then determine how limited resources should be used to the greatest advantage by distinguishing really Bad buildings from those that are so-so Bad. There have been many studies of the psychology of how such processes operate and what can be done to improve them [6]. Heuristics and biases perspective, as conceptualized by Kahneman and others, was viewed by the authors as the underlying theoretical foundation for the development of this assessment procedure. Heuristics are mental shortcuts that individuals use when making complex decisions. They are generally helpful but can lead to systematic errors, which are called biases. One heuristic that applies here is Anchoring, the ease with which a recent decision comes to mind and then influences subsequent decisions. For instance, a structural engineer who has just triaged an unreinforced masonry building that has not been retrofitted to adequate standards assigns it to the really Bad status and does not consider it further for occupation because she/he knows that very few URM buildings can meet the stability requirements of the current building code. This is accepted notwithstanding the fact that in the 1933 Long Beach earthquake, 42% of the three-story URM load bearing wall buildings had less than 20% damage, and only 19% had over 50% damage, and so it was concluded that no additional investigation was warranted. Cioff [7] reported that experienced nurses used more heuristics than inexperienced nurses, and that in conditions of uncertainty both experienced and inexperienced nurses used more probability judgments. The authors have no doubt that the same is true for structural engineers working with the same type of resource and time limitations for evaluations. A second bias is termed Theory-Induced Blindness: Once you have used a theory as a tool in your thinking, it becomes extraordinarily difficult to notice its flaws; your brain wants to do what it knows will ensure its survival. A third is Confirmation Bias: The tendency to notice, accept, and remember information that appears to support an existing belief and to ignore, explain away, or forget information that seems to contradict the existing belief. This is not a conscious act, and thereby much more unlikely to be realized, except where there is external challenge. The reader is urged to carefully consider the contents of the companion paper, particularly the modifications of the P-154 RVS Procedure, for it will not be further discussed here.

Organizational Policy and Triggers for Application

The authors distinguish between the policy triggers that are appropriate for California State Agencies, which have Code triggers for required seismic assessment and retrofit of buildings as discussed below. Many locally enforced building codes have triggers that require seismic assessment and retrofit, but usually it does not except where the jurisdiction has enacted building type specific requirements, such as unreinforced masonry or soft-story buildings. These differences are too varied to address each one, but the authors believe that the approach to identifying those building requires the user to acknowledge the requirements of the local jurisdiction in their decision process.

California State Agency Seismic Required Performance Characteristics

The California Existing Building Code (CEBC) identifies buildings warranting retrofit. When, as a result of the assessment process, a building has been evaluated as posing an unacceptable potentially hazardous condition, then the CEBC requires that retrofit be performed as soon as practical. In order to proceed with the most efficient use of resources as they become available, a priority is assigned according to the particular risk of a building. Here, risk is the probability of seismic ground motion at the site that will result in a life-endangering collapse condition of the building during a specified time period. Note that this policy is more stringent than the CEBC 317.5 allowance of letting triggers (Table 1) determine whether a seismic assessment and implementation are required or can be bypassed. When the procedures recommended here are used and a building is on List 1, then the Owner is on record as wanting to complete this retrofit in a prudent and timely manner, specifically as soon as resources can be made available. If any modification requiring a building permit is proposed to a List 2 building, then the building must be seismically assessed and be retrofitted if it does not meet the seismic performance requirements of the CEBC. For all other buildings, when work requiring a building permit is proposed and the extent of this work exceeds the trigger conditions of

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CEBC Table 317.3.1 (Table 1), then a seismic assessment must be completed. If the results of the assessment do not meet the seismic performance requirements of CEBC Table 317.5, the building must either: be retrofitted as a part of the proposed work, or the proposed work is to be denied and the building placed on the appropriate Priority List based on the CB evaluation of the structural engineering assessment.

Recent developments of the ASCE 7 [8] building standard for new buildings have designated that the prevention of structural collapse and corresponding life loss is the principal performance goal of seismic resistant design. This goal corresponds to that of the FEMA P-154 seismic performance classification system. The authors have made the decision that the scoring system of P-154 has distinct advantages over one that is based on judgement rather than any analysis, or on fractional conformance with the CEBC using ASCE 41 S-3 and S-5 performance levels with BSE-R and BSE-C ground motions from the CEBC for CSU buildings. P-154 leads to scores that are numerical and thereby allows ordering the relative seismic risk among buildings by the likelihood of collapse occurrence during a specified time period (see P-155 [9] Chapter 8). The CB has determined that the expression of a measure of the collapse likelihood is the appropriate criterion for making retrofit classification decisions. For the cases where ASCE 41 and other seismic performance assessments or evaluations are available, they can (when valid) serve to supplement the information needed for the assignment of the P-154 assessment score. The final Comment item of the P-154 Level 2 Form allows the assessor the ability to provide essential additional information and professional opinions concerning the building hazard and resulting score. This is most important to take full advantage of a highly qualified assessor, specifically for the case where the listed items do not allow representation of critical structural condition(s) or assets.

Other Organizations' Performance Assessment Characteristics

It is recommended that non-California State institutions adopt the same List 1 and List 2 priority system that is discussed above, but that they do so as a matter of their adopted Policy rather than building law. It is also proposed that the Organization consider the following additional policy decisions:

A. When a building is assigned to List 1, then the organization should sponsor a detailed engineering evaluation of the building's expected performance when funds become available.

Discussion: In essence, this proposal is to assure that the high hazard of the building was correctly determined. It also can develop, where appropriate, a provisional approach to retrofit to give the organization a clear understanding of the amount of work necessary to make the building seismically safe. Such a study should be conducted under the review of the CB and be completed within no more than two years of the date the building is assigned to List 1.

B. When a building has been on List 2 for 20 years since its assignment and the building was not retrofitted to meet CEBC requirements, then it shall be moved to List 1.

Discussion: As will be seen when the standard for evaluation is developed in CSU Application Experience that the probability of collapse is less than or equal to 2% and more that 0.8% in the prior 20 years, and in 20 years if nothing is done less than or equal to 4.9% and more than 2%, a probability over 2% is deemed unacceptable since collapse prevention requires 1.0% in 50 years. In the intervening time, there may have been a CEBC evaluation completed as CEBC requires, then one of two conclusions could have been reached: the building is not hazardous, in which the CB would have it removed from List 2, or the campus has chosen not to implement the planned permit modifications. Promotion of the building to List 1 does not require assessment and retrofit; it means that a permit is required for a modification if the Policy requires it. By placement on List 1, the building has been identified as one that needs seismic performance attention as a priority action.

Determination of the Quality or Reliability of the Assessment

Why is it necessary that the authors examine the reliability of a seismic assessment, or for that matter, any technically determined decision on an assigned conclusion of the condition of a civil structure? The principal objective here is life safety; however, for the possible case where future earthquakes may result in unanticipated consequences based on these evaluations, this reliability is required to establish that CSU acted in a prudent manner for the determination of these assessments and the resulting actions. Due to the large epistemic uncertainties in our understanding and resulting models of earthquake processes and response of complex structures, along with the lack of empirical actual performance data, aleatory uncertainty, to reduce this uncertainty, expert judgments will always be required in seismic hazard analyses.

The evaluation of the quality or reliability (measure of uncertainty) of a seismic assessment for an individual building requires a careful identification and consideration of all the issues, herein termed as components, that can contribute to this uncertainty. For the evaluation of the uncertainty measure for each component in the assessment process, the authors are interested not only in the amount and quality of information concerning the technical descriptive characteristics of the component, but also how this information was implemented as represented by the skill, expertise, and experience of the assessor. It is proposed that the most efficient method of characterizing the reliability of the results of an assessment report is by the evaluation of the uncertainty of the individual components of the building assessment (see companion paper Closing discussion, (Table 4)) and then combining these uncertainties given in

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Equation 2 repeated below, to quantify the total uncertainty and corresponding reliability of the resulting assessment.

$$\beta = \sqrt{\frac{\sum_{j=1}^{n} \beta_j^2}{n}} \quad (1)$$

This effort, in essence, provides a measure of the reliability or quality and is a measure of the epistemic (degree of knowledge) uncertainty of the reliability assessment result. A low quality (less than FAIR) indicates the need for further information in order to make a prudent decision in all likelihood.

The following components are important in the assessment of an individual building. Some parts of the components are addressed in the P-154 Forms, but it is desirable for the CB to assess the reliability of the conclusions rather than focus on the scored items themselves. The Decision Rule proposed in Section 5 is based both on the modified P-154 S_{L2} score and a representation of the combined Quality or Reliability of the assessment process (see companion paper Determining the Reliability of a Seismically Assessed Building Conclusion Using a Modified FEMA P-154 Procedure) that includes considerations of the following items and the reliability of their characterization:

a. Basis of Evaluation - Review of Plans, other Construction Documents, and previous technical report on expected seismic performance

b. Basis of Evaluation - Site Visit Inspection

c. Basis of Evaluation - Personal Qualifications of Assessor

d. Design Basis

e. Configuration and Load Path

f. Compatibility of Deformation Characteristics

g. Condition

The analysis of the reliability of the P-154 assessed score S_{L2} utilizes the methods developed in the paper Reliability of Seismic Performance Assessments for Individual Buildings and Portfolios [10]. These methods have been adapted to the task at hand. In this paper, a procedure was developed for the evaluation of the quality of the seismic damageability of an individual building. For a given factor (or component) used in the collapse estimation process, a quantitative measure of uncertainty termed as β value $(0 < \beta < 1)$ was assigned corresponding to one of three qualitative levels of Quality of Description of the factor (High, Medium, and Low) and one of three levels of its assessed Quality of Implementation Characteristics (High, Medium, and Low). Implementation refers to how well the assessor was able to apply the available information corresponding to the specific description. (Table 2) provides a single quantitative evaluation of β based on the paired qualitative assessments of Quality of Implementation (High, Medium, Low) corresponding to a specific description Quality of Component Description Measure (High, Medium, Low). The lower the β value, the greater the certainty (reliability) of the result; conversely, the higher the β value, the lower the certainty (reliability).

Table 2: Assessment matrix for the implementation application of a quality measure for a considered issue or component. Each of the assignments of High, Medium, and Low is described by text specific to the component under discussion. A value of 0.10 is taken as very reliable (little uncertainty), and 1 is not reliable (complete uncertainty). This Table is applicable for all Quality Measures. It may be helpful to the reader to be aware that there are three distinctly different uses of the β symbol in FEMA Publications. In FEMA P-155, β_{EF} is the effective damping of the structure, and $\beta_{C,P}$ is the seismic demand uncertainty. In FEMA P-695, and in this paper, β_j is the quantitative equivalent $(0 < \beta_j < 1)$ of an assigned quality of information (SUPERIOR to BAD) of a component "j" of structural behavior.

Quality Measure	Implementation Characteristics		
	High	Medium	Low
High	Superior	Good	Fair
	β= 0.10	β= 0.20	β= 0.35
Medium	Good	Fair	Poor
	β= 0.20	β= 0.35	β= 0.50
Low	Fair	Poor	Bad
	β= 0.35	β= 0.50	β= 1.00

For application to the CSU Assessment process, the means of assigning the required quality measures are described in detail in the companion paper, which provides matrices in (Table 4) of Section 7 for how the pairs or single expressions of quality for each of the seven components are to be assigned. Having the pair or the single quality assignments for a component, the corresponding β value can be found by the respective use of (Table 2 or Table 3). An important advantage of being able to assign a quantitative uncertainty factor, β_i, for each of the seven components, i, used in an assessment process is that these quantitative β_i values $(0 \le \beta_i \le 1)$ can be combined in a statistically valid root-mean-square (RMS) method to provide the total uncertainty of the result of the evaluation. The combination method is given in Section 7 of the companion paper and repeated in Equation 1 here. It is important to note that the combinatory process would be quite subjective if the levels of uncertainties were to be expressed solely in Qualitative terms. For example, how would one be able to combine a set of seven assigned component qualities (SUPERIOR, GOOD, FAIR, POOR and BAD) if they are linguistic expressions, possibly paragraphs long?

Table 3: Reliability qualitative terminology and their associated uncertainty quantitative values. When a β value has been determined quantitively, the authors propose to use the numeric bounds for assignment of a qualitative linguistic term for the value.

Qualitative Reliability term	Quantitative β value		
	Assigned Value	Lower Bound	Upper Bound
SUPERIOR	0.1	0	0.15
GOOD	0.2	0.15	0.275
FAIR	0.35	0.275	0.425
POOR	0.5	0.425	0.75
BAD	1	0.75	1

This resulting numerical value of the reliability value of the assessment, β (from Equation 1), can be expressed as a qualitative linguistic term using (Table 3), following the numerical upper and lower bounds for the terms, following the procedure of the companion paper. The β values of (Table 2) are essentially the same as those used in FEMA P-695 [7], with the exception that P-695 [7]does not provide an assignment of a (Low, Low) entry, which was added by Thiel and Zsutty [13], and is termed as BAD with a corresponding assignment of $\beta = 1.0$.

Building Priority Assignment Based on S_{L2} Score

FEMA P-155 [3] gives an extended discussion that provides information on how the P-154 scoring recommendations were developed. It is demonstrated in P-155, Chapter 8, that the Final Score, S_{L2}, when employed as an exponent, allows the evaluation of the Conditional Probability of Building Collapse given that the ASCE 7 [8] MCE_R ground shaking has occurred. ASCE 7 [8] is the governing building code for new construction, and MCE_R is the Maximum Credible Level of Earthquake Ground Motion at the building site. However, this probability is conditional and does not consider the hazard of shaking less than or greater than the MCE_R level, nor the likelihood of collapse given these other levels and their respective frequencies (hazard) of site ground motion. Chapter 8 further develops a new measure of performance called the Risk Score, denoted by $S_R = S_{L2} + 1$. As a result of an extensive empirical analysis given in P-155 of seismic hazard zones, S_R was found to provide an estimate of the negative base-10 logarithm of the number of earthquakes that could cause building collapse during the design life of the building, which is commonly taken to be 50 years. Another way to state the same thing is that the expected number of collapse-causing earthquakes expected to occur during the design life of the building is 1 per 10^{S_R} lifetimes. The S_R leads to a better representation of collapse risk than the score value S_{L2} as determined by the P-154 Level 2 Form. The value of S_{L2} has nothing to do with the design life of the building nor the number of collapse-causing earthquakes other than the MCE_R, while the simple conversion to $S_R = S_{L2} + 1$ allows the representation of this information. The Risk Score, S_R, was derived by summing the probability of collapse given of any level of shaking multiplied by the number of times in 50 years that that level of shaking will occur, summing overall levels of shaking, and taking the negative base-10 logarithm of that value. The process involves a straightforward application of the procedures used to develop the ASCE 7 [8] risk-targeted design ground motion MCE_R. Applications will be discussed below. The interested reader should examine the development of S_R in FEMA P-155 [3], Chapter 8.

While it may be surprising that the addition is a simple 1, the results of the extensive empirical analyses shows that this is a correct, meaningful approximation across a wide range of S_{L2} scores and is consistently applicable for different building types and seismic hazard zones. The Risk Score can be used to estimate the probability that at least one earthquake that would cause collapse would occur during any given time period under consideration. Let t denote a particular number of years at interest for evaluation of the building's risk; let τ denote the design life of the building, that is the nominal code-assumed life for design regulation (usually 50 years per ASCE 7 [3] Table 1.3-1 and the CEBC); and let $R(t,\ \tau, S_{L2})$ denote the probability that at least one earthquake will occur during t years that is strong enough to cause collapse. This probability of collapse risk is given by:

$$R(t,\ \tau, S_{L2}) = 1 - e^{\left(-\frac{t_{10} - (1+S_{L2})}{\tau}\right)} \qquad (2)$$

This is FEMA P-155 [3] Equation (8-15). It provides a distinct meaning to collapse hazard due to all possible levels of site ground motion and all possible responses of the building to the ground motions. This is how S_{L2} relates to this hazard: an assessed S_{L2} value is not just a comparative score but a distinct parameter that relates to life safety performance. This relationship should always be kept in mind when scoring changes are proposed. Also, recall that the hazard is due to all possible damaging ground motions at the site and not just the single scenario conditional earthquake, MCE_R.

The understanding of the link between the performance objectives of ASCE 7 [8] for new buildings and ASCE 41 for existing buildings is an integral part of this discussion. The characterization of the goals of both these Standards is Collapse Prevention with similar descriptions (Figure 1). The risk goal of ASCE 7 (2010 and subsequent editions) is a collapse risk target (CRT) not greater than 1% in 50 years due to the maximum considered earthquake (MCE_R). ASCE 41 uses similar terms to define the target collapse prevention performance level (S-5) of the structural system [11]. ASCE 7 focuses on the performance level at the structural system level, while ASCE 41 focuses on the performance at the

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structural component level in order to accommodate the greater complexity posed by the wide variety of existing building designs and construction methods for in-place buildings. At the collapse prevention level, the California Existing Building Code (CEBC) for Level 2 ground motions requires achieving S-5 performance for the structural system but does not require assessment of non-structural systems; these vulnerabilities are addressed in conjunction with an S-3 performance level assessment. Notwithstanding the unreconciled differences in the performance definitions (see footnote 2) between the two standards, ASCE 7 has addressed the objective of expected seismic collapse-prevention performance and provided a standard of not more than 1% in 50 years as the risk goal, while ASCE 41 has not addressed this risk goal.

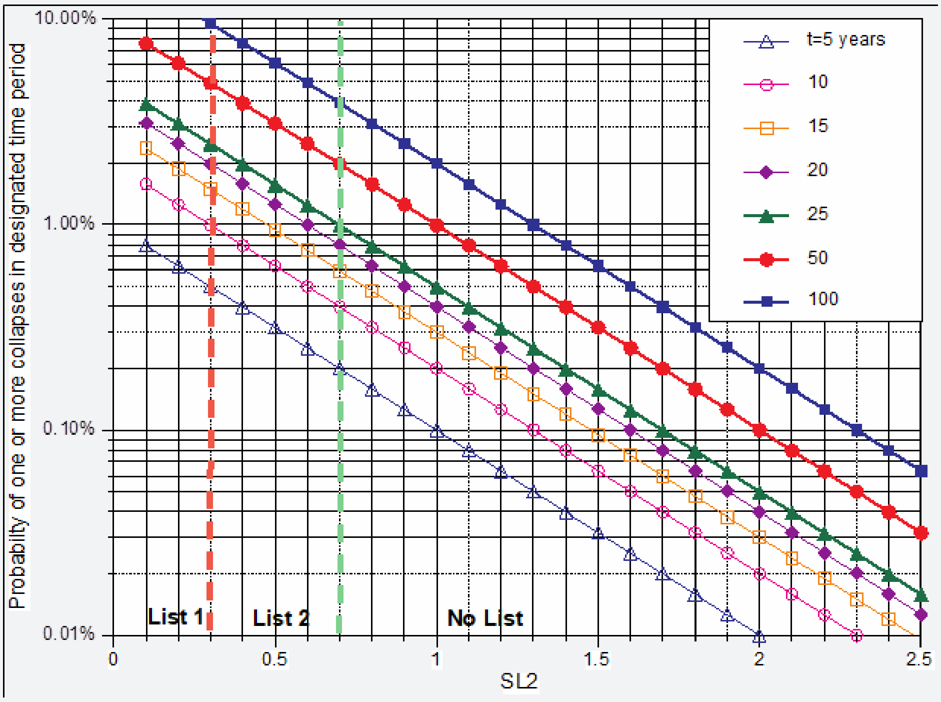

Figure 2: Determination of probability of one or more collapse potential earthquakes in the time period t for a building with τ =50 years for different S_{L2} values. The vertical red and green lines indicate the recommended boundary for S_{L2} critical values for List 1, 2, and No List designations. Note that the vertical axis is logarithmic.

It is proposed that the ASCE 7 goal provides the appropriate risk probabilities of collapse behavior that can serve to guide the CSU procedure for retrofit priority list assignment. (Table 4) indicates the conditional probability (given MCRR) of collapse expectations for a new building that meets the ASCE 7-16 standards; that is, the probability that the construction will not achieve the standard's goal of seismic stability in the MCE_R ground motion. (Table 4) here aggregates performance expectations for new buildings that are designed and constructed to be compliant with ASCE 7-16 requirements for Risk Categories I through IV for ASCE 41 seismic performance categories S-3 and S-5. It should be noted that in the California Existing Building Code, the seismic design requirements for a state-owned, existing building are the same for Risk Class I, II and III, and that the ground motions are different from ASCE 41 in that they are 20% and 5%, respectively, in 50 years, and are not capped by the ASCE 7 new building values as ASCE 41 provides. Since the ASCE 7 reliability results are for new building designs that are code compliant, it is prudent to not change the basis, and use ASCE 7 and ASCE 41 as written in this analysis.

For general applications, the authors propose to use the exceedance probability values of ASCE 41 performance level S-5 from (Table 2) as a measure of the collapse likelihood of the building having an assessed P-154 S_{L2} score. ASCE 41-16 Collapse Prevention Structural Performance Level (S-5) is defined as the post-earthquake damage state in which the structure has damaged components and continues to support gravity loads but retains no margin against collapse. A structure in compliance with the acceptance criteria specified in this standard for the Structural Performance Level is expected to achieve the S-5 performance level. The total probability, or risk, determination must consider all possible earthquake events, including the MCE_R, together with the resulting building performance weighted by the respective likelihoods of all possible impacts upon the building ground motions. This is assumed to be provided by the P-155 Equation (3). The Standard Guide for Seismic Risk Assessment of Buildings, ASTM E2026-16a, [9] defines Probable Loss (PL) as earthquake loss to the building systems that has a specified probability of being exceeded in a specified time period, or an earthquake loss that has a specified return period for exceedance. ASTM

E2557-16a [10] defines Probable Loss (PL) as the earthquake loss to the building(s) that has a specified probability of being exceeded in a given time period, or an earthquake loss that has a specified return period for exceedance. A PL value is meant to reflect, in a statistically consistent computational manner, all of the uncertainties that can impact damage estimates, including when and where earthquakes occur and with what magnitude, attenuations of ground motions at the site, local site effects, and performance of the building systems in these ground motions. The computations are usually based on a site hazard curve for ground motion levels corresponding to the hazard of being exceeded in a 1-year period of exposure. The determination of hazard for longer than 1-year time periods depend on the following assumption: the occurrence of earthquakes is a Poisson random process; that is, the probability density function for an event in a future year is not influenced by an event having occurred in the previous year. By its definition, the exceedance of an S-5 score is equivalent to a collapse performance. It should be noted that P-155 has used the same S-5 performance level in order to evaluate its risk in terms of the $S_R = S_{L2} + 1$ score (P-155, Section 5). This implies that the established ASCE 7 hazard limits can be used for the P-154 evaluation of the collapse risk as determined by the S_{L2} score. With the assessed S_{L2} score, the authors now have an accepted standard basis for classifying seismically deficient CSU buildings into risk categories or lists, according to collapse risk, for management of their retrofit.

Table 4: Anticipated probability of failure conditioned on the occurrence of the Maximum Considered Earthquake MCER (BSE-2E). Reproduced from ASCE 7-16 Tables 1.3-3 and 1.3-4. Roman Numerals indicate the Occupancy Category of the building following ASCE 7 or applicable Code requirements. The equivalent ASCE 41 performance goals were assigned as the authors' interpretation of the ASCE 41 performance levels of the ASCE 7 target performance goals; the senior author has served on the ASCE 41 Committee preparing these provisions. The probabilities are the likelihood of performance worse than the indicated ASCE 41 levels. See ASCE 41-16 for discussions of the basis of seismic reliabilities, Thiel and Zsutty, [13].

ASCE 41 Interpretation	Description	Probability for Risk Category		
		I-II	III	IV
S-3	Target reliability for ordinary noncritical structural members caused by earthquakes	25%	15%	9%
S-5	Target reliability for structural stability caused by earthquakes	10%	5%	2.50%

In order to justify the Risk levels of ASCE 41, it is appropriate to note that there is a long history of treating the building regulations for seismic performance of existing buildings differently from those applicable for new buildings. This began in the City of Long Beach, where reconstruction regulations following the 1933 Earthquake were allowed the use of 3/4 of new building seismic loading for existing building repair and/or retrofit. This concept has been generally adopted by other jurisdictions and serves to encourage the retrofit objective. The rationale, in part, is because a portion of the building's useful life has been used up, and when it is modified to suit a purpose, the Building Code will control how it is done. This reduced load approach has been adopted by many jurisdictions and, in essence, into the CEBC for regulation of state-owned existing buildings. Specifically, in 1997, this was done by allowing the two hazard levels, for design, BSE-R and BSE-C, to be 20% and 5%, respectively, in 50 years for existing buildings. This is to be compared to the last version of the California Building Code (CBC) in the 1990s for new buildings of 10% and 2% in 50 years. CSU is more conservative in its desire for seismic safety than the CEBC, since it requires independent seismic peer review of all existing building modifications to confirm that good practice is followed, rather than at the choice of the permit applicant. This may be appropriate for other owners to consider adopting.

There is, however, another aspect that must be considered related to the use of the P-154 scoring process. When performing a P-154-based seismic performance evaluation, the authors are reluctant to consider the assignments of all the ASCE 7 collapse hazard allowances according to the S_{L2} results of a limited P-154 assessment (RVS) procedure. While the authors have a high confidence in the technical skill, knowledge, and experience of the CB assessors, the authors were concerned because the RVS level of assessment and examination is much less detailed than would be required to reach a reliable understanding of the seismic performance and vulnerability of a building. The authors of P-154 recognized this condition, and they set a likelihood of collapse somewhat more restrictive than that of not meeting S-5 seismic performance requirements. They set the screening goal as the identification of buildings that warranted detailed examination from those that did not. The procedure was intended for the assessment of a large group of candidate buildings. The purpose of the original P-154 approach was to provide a RVS process to limit the requirement for a detailed engineering seismic assessment to only those buildings that were of high enough damageability to warrant such an expenditure; the intent is a screening process and not an evaluation process. CSU chose to modify the RVS process so that no subsequent assessment was necessary unless the hazard posed by the building leads to an excessive risk.

Specifically, the use of the Risk of Collapse value corresponds to the assessed score, S_{L2}, determined by Equation 2 as an aid for assignment of a building to one of the three categories for risk management as described in Section 2: List 1, List 2, and No List. (Figure 2) shows the risk associated with different exposure time periods and P-154 S_{L2} values. CSU has determined that a 2%

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likelihood of collapse in 50 years is an upper bound for the risk of a building that is acceptable and warrants action. Therefore, by policy CSU does not allow the use of the CEBC threshold values to dictate when the required seismic assessment and related retrofit work must be done. (Figure 2) and (Table 5) show that this risk happens when S_{L2} is less than 0.70. Therefore, any building that has an assigned value of 0.7 or less by the CB will be assigned to either List 1 or List 2. (Table 5) provides the probability values for different S_{L2} values for thresholds to aid in the decision for the break point between List 1 and 2. The decision to be made is the score value below which retrofit must be made as soon as possible, and above which a retrofit can be delayed until a project is proposed for the building that requires a building permit. It is proposed that this score be 0.3. If it were to be 20 years before the permitted project took place, then the likelihood of a collapse during this time period would be 2%; if it took the full 50-year period, then the risk would be 5%. This score limit is considered within a reasonable range since the users are prepared to accept a newly constructed ASCE 7 compliant building to have a 10% likelihood of failing due to the MCE_R in 50 years. As an added note, these probability values are the source of the reluctance to use the P-154 recommendation for action for all buildings with an $S_{L2} \le 2.0$.

Table 5: Summary table of probability values for collapse one or more times in 5, 10, and 50 years for buildings assigned to Lists 1 and 2. These are for Risk Class I, II and III, except for as noted for III with hazardous materials content exceeding Risk Class II level, and for Class IV. Note that there is a 10% likelihood that a new permitted building does not meet the ASCE 7 stability performance criteria.

If S_{L2} Value	Assignment	Probability of One or More Collapse Events in			
		50 Years	20 Years	10 Years	5 Years
$S_{L2} \le 0.3$	List 1	>4.9%	>2.0%	>1.0%	>0.5%
$0.3 \le S_{L2} \le 0.7$	List 2	4.9%>p>2.0%	2.0%>p>0.8%	1.0%>p>0.4%	0.5%>p>0.2%
$S_{L2} = 1.0$	No list	1.00%	0.40%	0.20%	0.10%
$S_{L2} = 2.0$	—	0.10%	0.04%	0.02%	0.01%

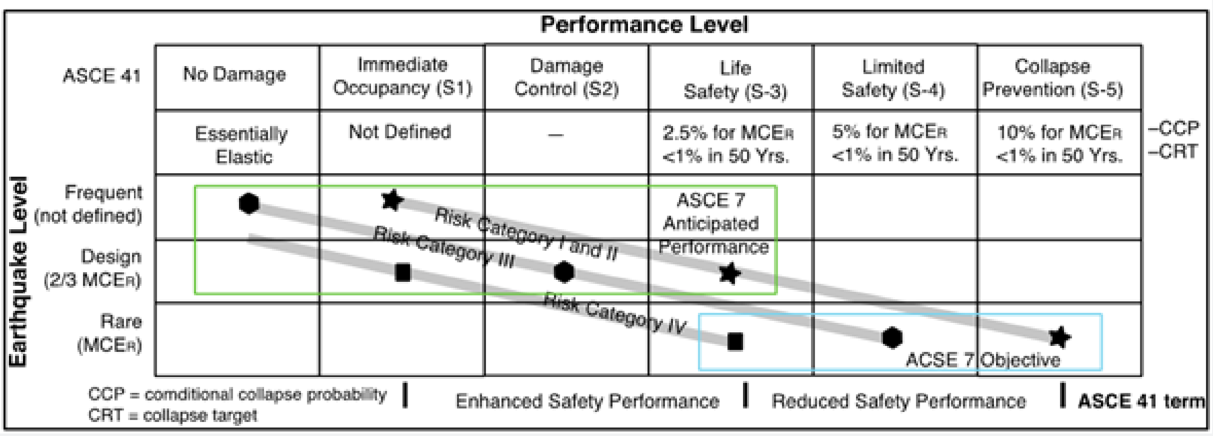

Figure 1: Comparison of ASCE 7 and ASCE 41 seismic performance levels. The ASCE 41 structural performance S- abbreviations have been added to the descriptions (based on [11].

With respect to the Risk Category, the California Existing Building Code (CEBC) assigns the same seismic design threshold values for CBC Risk Category I, II and III, but with the exception that if the Risk Class is not assigned as III because of hazardous materials contents, a III class will be assigned with higher load requirements. Therefore, the authors choose to treat seismic retrofit of these three risk category classes the same in the Decision Rule below. For a CBC Risk Class of IV building, it is appropriate to use the same reasoning as the other Risk Categories and basing them on the comparative probabilities of (Figure 2).

The authors now have the necessary criteria to make building assignments to List 1 and List 2. Based on the results of calculations, as illustrated in (Figure 1), the authors propose to determine the List assignment for the assessed building based on the Quality or Reliability determination (Determination of the Quality or Reliability of the Assessment discussion) of the assessment and the assessor's peer reviewed, recommended value of $S_R = S_{L2} + 1$, with $R(t,\ \tau,\ S_{L2})$ being the decision variable.

The following Decision Rule is proposed for determining the disposition of all assessed buildings:

Decision Rule: The decision on List assignment for an assessed building is to be made based on allowing an $R(t,\ \tau, S_{L2})$ acceptable upper bound limit as follows:

1. If the reliability of the building's quality assessment is less than 0.30, then the S_{L2} assessment is provisionally not prudent for decisions, and a more reliable assessment needs to be performed. This can be done by improving the methods or information available to the assessor to achieve at least a 0.30 rating and/or by performing a more reliable engineering assessment procedure (e.g., detailed building investigation and engineering analyses).

2. If the building's Risk Class is I, II, or III (if not housing CEBC-restricted quantities of hazardous materials) and the quality assessment is 0.30 or better, then provisionally:

a. Assign to List 1 if $S_{L2} \leq 0.3$. This is equivalent to establishing a priority that the building be seismically assessed and retrofitted to meet CEBC Section 3.17 requirements as soon as practical, notwithstanding whether any other work is to be done.

b. Assign building to List 2 if $0.3 \leq S_{L2} < 0.7$. This means that the CEBC Section 3.17 trigger limits do not apply. If work requiring a permit is proposed, then it is required to seismically assess and retrofit the building to meet CEBC requirements.

c. Do not assign to a list if $S_{L2} \geq 0.7$; This is equivalent to letting CEBC Section 3.17 control seismic improvement based on permit applications and whether any of the threshold triggers requiring seismic assessment and related retrofit have been exceeded.

3. If the building's Risk Class is III and the building's quality assessment is 0.30 or better, then the following score limits apply only for those buildings having Risk Category III hazardous materials storage:

a. Assign to List 1 if $S_{L2} \leq 0.7$. This is equivalent to establishing a priority that the building be seismically assessed and retrofitted to meet CEBC Section 3.17 requirements as soon as practical, notwithstanding whether any other work is to be done.

b. Assign building to List 2 if $0.7 \leq S_{L2} < 1.0$. This means that CEBC Section 3.17 does not allow any option other than to seismically assess and retrofit the building to meet CEBC requirements.

c. Do not assign to a list if $S_{L2} \geq 1.0$; This is equivalent to letting CEBC Section 3.17 control seismic improvement based on permit applications and whether any of the threshold triggers have been exceeded, which requires assessment.

4. If the building's Risk Class is IV and $S_{L2} \leq 2.0$ and quality assessment is 0.30 or better, then provisionally assign the building to List 1, unless $1.5 < S_{L2} < 2.0$, then assign it to List 2.

5. The CB will consider the results of this assessment process and its basis and consider whether the provisional dispositions are appropriate or not. According to its professional judgement, the CB will assign the final score and recommend the appropriate Priority List to the Chancellor's Office.

It was proposed that the values for the S_{L2} threshold values originally stated would be considered provisional and that they be reconsidered when the first-year P-154 assessments have been completed. Then these values can be revised, if necessary, to meet the Organization's seismic risk management goals. Decisions will be based on whether the CB determines that the assignments are sufficiently representative of the acceptable hazard for buildings that were assessed for the Organization's purposes. Such was implemented as discussed in Section 7, and the Decision Rule includes the proposed changes. Interestingly, the only value changed was the minimum acceptable reliability value for GOOD to 0.30.

The authors note that the (Figure 2) nomograph provides an immediate way for other users to select the acceptable risk levels for some or all buildings at different thresholds to meet their purposes where the probability of the threshold not being exceeded is set at a specified value. It also allows setting values other than Rick Category II in a logical manner. For example, it could be that for a Risk Category IV building, an acceptable risk of 0.1% over a 100-year time period could be the threshold for List 1 that would yield a lower bound S_{L2} acceptable value of 2.3 or higher as the acceptable performance not to require a full assessment. If other values are desired, Equation 2 provides the means for it to be directly calculated if (Figure 2) does not suit the purpose.

CSU Application Experience

CSU assessed the seismic vulnerability of 56 buildings and one building-like structure (providing vertical access among buildings, Building A17) on the three assessed campuses in 2021 using the procedures recommended in this paper. The Vice-Chair of the SRB served as the chair of the assessors committee, and the SRB served as the equivalent of the CB as recommended here. (Table 6) presents the results of these assessments and their reliability assessment components. As can be seen, the persons doing the assessments were highly qualified structural engineers. All had 30 years or more experience in designing and assessing California building construction and were assigned as campus independent technical peer reviewers for all construction on their respective campuses by University Policy.

Table 6: Reliability results of the 56 seismic performance assessments completed in 2020 following the CSU assessments, consistent with the methods presented in this paper. M is an abbreviation for Quality Measurement, P is for Performance Implementation of Table C1 for the indicated element, and T is the beta value assignment based upon the M and P values by Equation 2. The identification of the building has been excluded; the Letter indicates the campus and the date its construction: A is Humboldt, B is East Bay (Hayward), and C is San Bernardino. In some cases, buildings have two sections of different structural types integrated.

#	ASCE 41 Type and Construction	P-154 S_{L2} Score	CSU List		1. Plans + Reports Available			2. Site Visit Performed			3. Assessor Qualifications			4. Design Basis			5. Configuration + Load Path			6. Com-patibility	7. Con-dition	Reliability Value	V ≤ 0.30?
			L1	L2	M	P	T	M	P	T	M	P	T	M	P	T	M	P	T	T	T		
A1	W1A/69	1.9			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	H	H	0.1	0.1	0.1	0.21	Y
A2	W2/59	1.6			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	H	H	0.1	0.1	0.1	0.21	Y
A3	W2, C2/69	1			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	H	0.2	0.1	0.1	0.22	Y
A4	W2/62	3			H	H	0.1	H	H	0.1	H	H	0.1	L	H	0.35	M	H	0.2	0.1	0.1	0.174	Y
A5	W2/69	1.4			H	H	0.1	H	H	0.1	H	H	0.1	L	H	0.35	M*	H	0.2	0.1	0.1	0.174	Y
A6	W2/62	1.2			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.35	M*	H	0.2	0.1	0.1	0.174	Y
A7	C2/1922	2.2			H	H	0.1	H	H	0.1	H	H	0.1	M	H	0.2	M	H	0.2	0.1	0.1	0.136	Y
A8	C2/33	0.4		X	H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	L	M	0.5	0.2	0.1	0.288	Y
A9	C2/62	2			H	H	0.1	H	H	0.1	H	H	0.1	H	H	0.1	H	H	0.1	0.1	0.1	0.1	Y
A10	S1, C2/72	1			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	M	0.35	0.1	0.1	0.246	Y
A11	C2/40	0.6		X	H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	M	0.35	0.1	0.1	0.246	Y
A12	A1, C2/74	1.2			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	M	0.35	0.1	0.1	0.246	Y
A13	C2, R M2/59	1.1			H	H	0.1	H	H	0.1	H	H	0.1	L	H	0.35	M	H	0.2	0.1	0.1	0.174	Y
A14	C2/60	0.5			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	M	0.35	0.1	0.1	0.246	Y
A15	C2/51	0.8			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.35	M	M	0.35	0.1	0.1	0.205	Y
A16	C2/51	0.8			H	H	0.1	H	H	0.1	H	H	0.1	L	H	0.35	H	H	0.5	0.1	0.1	0.246	Y
A17	C2/71	0.4	X		H	H	0.1	H	H	0.1	H	H	0.1	L	M/L	0.7	M	L	0.5	0.35	0.1	0.359	N
A18	S2/80	0.5		X	M	H	0.2	H	H	0.1	H	H	0.1	M	M	0.35	H	M	0.2	0.2	0.1	0.197	Y
A19	C2/80	1			M	H	0.2	H	H	0.1	H	H	0.1	M	M	0.35	H	M	0.2	0.2	0.1	0.197	Y
A20	C2/59	1.8			H	H	0.1	H	H	0.1	H	H	0.1	H	H	0.1	H	H	0.5	0.1	0.1	0.21	Y
A21	W2, C2/59	1			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	H	H	0.5	0.1	0.1	0.28	Y
A22	C1/70	0.8			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	H	H	0.5	0.1	0.1	0.28	Y
A23	W2/60	2			H	H	0.1	H	H	0.1	H	H	0.1	H	H	0.1	H	H	0.5	0.1	0.1	0.21	Y
A24	W2/59	2			H	H	0.1	H	H	0.1	H	H	0.1	H	H	0.1	H	H	0.5	0.1	0.1	0.21	Y
A25	C2, RM2/59	1.1			H	H	0.1	H	H	0.1	H	H	0.1	L	H	0.35	M	H	0.2	0.1	0.1	0.174	Y
A26	C2/51	1.4			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	H	H	0.5	0.2	0.1	0.288	Y
A27	W2/55	2			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	H	H	0.5	0.1	0.1	0.28	Y
B1	PC1/64	1.3	X		H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	H	M	0.2	0.1	0.1	0.22	Y
B2	C2/56	0.4		X	H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	L	M	0.5	0.1	0.1	0.28	Y
B3	C2/56	0.4			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	H	0.2	0.1	0.1	0.22	Y
B4	C2/62	1			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	H	0.2	0.1	0.1	0.22	Y
B5	C2/62	0.6			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	H	0.2	0.1	0.1	0.22	Y
B6	C2/62	1.6			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	H	0.2	0.1	0.1	0.22	Y
B7	RM1/62	1.3			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	H	H	0.1	0.1	0.1	0.21	Y
B8	C2/63	1			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	H	0.2	0.1	0.1	0.22	Y
B9	PC1/65	0.9			H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	H	0.2	0.1	0.1	0.22	Y
B10	PC2/67	1.5			M	H	0.2	H	H	0.2	H	H	0.1	M	H	0.2	M	H	0.2	0.1	0.1	0.165	Y
B11	C2/67	0.3		X	H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	M	0.35	0.1	0.1	0.246	Y

B12	PC1/69	0.2		X	H	H	0.1	H	H	0.1	H	H	0.1	L	M	0.5	M	M	0.35	0.2	0.1	0.254	Y
B13	RM1/71	1.1			H	H	0.1	H	H	0.1	H	H	0.1	L	H	0.35	H	H	0.1	0.1	0.1	0.161	Y
B14	W1A/87	1.7			M	H	0.2	H	H	0.1	H	H	0.1	L	H	0.35	M	H	0.2	0.1	0.1	0.186	Y
B15	S2/91	1.6			H	H	0.1	H	H	0.1	H	H	0.1	M	H	0.2	H	H	0.1	0.1	0.1	0.12	Y
B16	S1/90	1.3			H	H	0.1	H	H	0.1	H	H	0.1	M	H	0.2	M	H	0.2	0.1	0.1	0.136	Y
B17	S2/91	1.6			H	H	0.1	H	H	0.1	H	H	0.1	M	H	0.2	H	H	0.1	0.1	0.1	0.12	Y
C1	RM1/98	1.1			H	H	0.1	H	H	0.1	H	H	0.1	H	H	0.1	M	H	0.2	0.1	0.1	0.12	Y
C2	C2/68	2.6			H	H	0.1	H	H	0.1	H	H	0.1	L	H	0.35	H	H	0.1	0.1	0.1	0.161	Y
C3	C2/67	2.4			H	H	0.1	H	H	0.1	H	H	0.1	L	H	0.35	H	H	0.1	0.1	0.1	0.161	Y
C4	C2/68	1.4			H	H	0.1	H	H	0.1	H	H	0.1	L	H	0.35	H	H	0.1	0.1	0.1	0.161	Y
C5	C2/69	0.3		X	H	H	0.1	H	H	0.1	H	H	0.1	L	H	0.35	H	H	0.1	0.1	0.1	0.161	Y
C6	PC1/75	0.3		X	H	H	0.1	H	H	0.1	H	H	0.1	L	H	0.35	H	H	0.1	0.1	0.1	0.161	Y
C7	RM1/86	0.3		X	H	H	0.1	H	H	0.1	H	H	0.1	H	H	0.1	H	H	0.1	0.1	0.1	0.1	Y
C8	S2/90	1.2			H	H	0.1	H	H	0.1	H	H	0.1	M	H	0.2	H	H	0.1	0.1	0.1	0.12	Y
C9	S1/93	0.7		X	H	H	0.1	H	H	0.1	H	H	0.1	M	H	0.2	M	H	0.2	0.1	0.1	0.136	Y
C10	S1/93	0.9			H	H	0.1	H	H	0.1	H	H	0.1	M	H	0.2	H	H	0.1	0.1	0.1	0.12	Y
C11	S2/94	1		X	H	H	0.1	H	H	0.1	H	H	0.1	M	H	0.2	M	H	0.2	0.1	0.1	0.136	Y
C12	S1/94	0.8		X	H	H	0.1	H	H	0.1	H	H	0.1	M	H	0.2	M	H	0.2	0.1	0.1	0.136	Y

The 56 structures assessed were constructed from 1922 to 1994, with an average date of 1968. The SRB was given authority for independent building plan technical review for modifications of existing buildings in 1993; this authority was not extended to new buildings until 1994 but did not apply to construction already in progress. Since all new construction initiated after this date and all new purchase of buildings since that date have been reviewed for acceptable seismic safety before purchase and was independently peer reviewed by the SRB, there are likely to be no buildings of more recent age evaluated under this program. The typical report of the P-154 assessment consisted of the two form pages, added discussion of the assessor's observations, and often a few images from the design drawings. The average length of the report was 3.75 pages, with many having limited added comments because the case was so clearly evident that the building was not hazardous on its face. When these were assessed, the full team had access to the design structural drawings for reference and discussion.

The assessors chose not to adjust the S_{L2} values but to discuss their observations with the group and assign each structure to a List based on this discussion. The group's S_{L2} average value was 1.18, and it ranged from 0.20 to 3.0; 50 were less than 2.0, which was the P-154 original method required detailed seismic analysis. Only two were placed on List 1 and 12 on List 2. As can be seen by the values, the quality rating for Elements 1, 2, and 3 were all superior in average (average 0.107, 0.102, and 0.100), reflecting the high qualifications of the assessors. The values for element 4 (Design Basis) and 5 (Configuration and Load Path) were 0.364 $(\sigma = 0.143)$ and 2.51 $(\sigma = 0.143)$ and indicative that many of the buildings were pre-modern seismic design practices and that modern load-path requirements were irregularly followed when they were designed. The compatibility of all the buildings was SUPERIOR (0.10). The resulting Reliability value average was 0.198 (GOOD) with a standard deviation of 0.055 and a range of 0.100 to 0.359, with only one exceeding the acceptable limit of 0.300, which was the non-building that was assessed. Of the 56 buildings assessed, the Decision Rule yielded the same result in all but 6 cases, for an 89% validity rate. The SRB originally recommended an acceptability reliability rate of at least GOOD, with maximum value by (Table 4) of 0.275. The SRB made this assignment before it had experience with the procedure. When they had the results discussed above and given in (Table 6), they had the basis for adjusting the upper bound acceptable score value. There were seven cases where the reliability value was above 0.275, with six values between 0.280 and 0.288. When the sources of the uncertainty were examined, it was decided that the likely performance was adequate, and the SRB changed the upper bound for acceptability from Good to 0.30. There was one value of 0.359 for the non-building structure, which was recommended for action by CSU to assess immediately at a higher level of investigation. It is advisable that the decisions made under this, the Decision Rule, be examined for consistency with good practice, and it is not viewed as an absolute rule for decision making. As a final observation, the application of the proposed approach is evaluated by CSU management costing about $2,500 per building, including assessor time, travel, and expenses, as well as the assessors' discussion of their results prior to the SRB assessment. The SRB time was minimal and attributed to their regular meeting efforts, which covered this as well as other subjects. The decision to use a one-step modified P-154 procedure to assess the thousands of CSU building made it possible to make reliable decisions under its Seismic Policy without the massive investment required to do an ASCE Level assessment.

This process was evaluated by the CSU, SRB, and Administration as appropriate to succeed the prior procedures and to yield a consistent, transparent, and documented assessment process. CSU has recently begun its second and in advanced planning for the third annual evaluation efforts and has committed to its continuing use as its evaluation metric, with annual reassessments by the SRB to refine the effectiveness and reliability of the process.

Conclusion

One of the difficulties with most seismic hazard assessment procedures is that the results of an assessment are binary; that is, they either meet the evaluation standard or they do not. The evaluation is usually approached based as a scenario-based event, often 475- or 2,475-year return period events. For owners of large portfolios of buildings, the cost implications of these binary outcomes are likely to demand significant resources to resolve. If the issue is approached as how much the risk is in a given time frame for each building, one has a better measured consequence that is likely to be far less onerous than if the ASTM E2026 probable loss approach is used for the evaluation, which is what the P-155 assessment does. Thiel and Zsutty developed an approach to evaluating the safe interim use period for a known high hazard building to determine the time period that it could potentially be used before the risk becomes too high, as measured by the likelihood of the performance uncertainty a newly constructed building would pose Thiel and Zsutty [12]. But it can be expensive to apply and should be used principally for high to moderate risk buildings to determine when retrofit becomes, from a risk management standpoint, a prime concern for leased buildings [12,13]. The approach developed herein is to determine those buildings whose risk of collapse exceeds a given rate in a time period, say 50-years, using a P-154 modified S_{L2} score as the measure of the probable loss risk. The selection of 50 years is consistent with most building code requirements for new buildings. The result then is to classify the building depending on whether it should be retrofitted where also the risk in shortened time periods are given on the same risk basis:

a. For a List 1 building - It needs to be modified as soon as practical (S_{L2} <0.3: risk is <5% in 50 years, >2% in 20 years, >1% in 10 years), or

b. For a List 2 building - It needs to be modified when a non-seismic project is needed that requires a building permit (risk is $0.3 \le S_{L2} \le 0.7$: 4.9%>p>2.0% in 50 years, 2.0%>p>0.8% in 20 years, 1.0%>p>0.4% in 10 years),

c. For a NO LIST building - It corresponds to a 1% probability of collapse in 50 years.

For reference, the base P-154 recommended an immediate, significant cost assessment of performance for any building having a modified S_{L2} score ≤ 2.00 (a risk is 0.1% of collapse or lower in 50 years, and 0.02% probability in 10 years).

A great advantage to the proposed method is that it can be easily changed to any series of threshold probabilities of occurrence that are needed for a given client's action using the relationships provided in (Figure 2) or Equation 2. The actions can be adjusted to meet the client's needs for differentiation among actions required. For instance, allow critical manufacturing in the building, unless retrofit is completed in a specified time-period after which the building cannot be used for this purpose, and the use must be moved to another seismically compliant building. Such an approach could also be applied for limiting hazardous building storage, or any of a variety of decisions that need to be made about the use of a building that can be expressed as a numerical risk value. Those desiring to make such a decision are advised to consider using the methods of Thiel and Zsutty [13] that provides a method to estimate the period of time that a known hazardous building can be occupied and not exceed a given probability damage and/or life-safety probability value. It uses the Thiel-Zsutty damage prediction model, [14]. CSU has used this method from time-to-time to estimate the period of time that a known hazardous building can be occupied and not exceed the life-safety during this period probability that a new building would expect in a 50-year time period.

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I am sorry to report that my coauthor, Theodore C. Zsutty, died in the last week of April after a long and productive life to his end at age 92, before this paper's submission. He was an active member of the structural engineering community as a professional engineer, professor, researcher, code and practice developer, peer reviewer, and advisor to many designers and participant in their resolution of technical problems. He and I authored many papers together since the 1980s. He was a respected, energetic and highly competent engineer and thinker. He will be missed by all with whom he worked.

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