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Determining the Reliability of A Seismically Assessed Building Conclusion Using A Modified FEMA P-154 Procedure

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Abstract

The quality of seismic risk management decisions depends on professional judgements. Such require an assessment of the reliability of the thought process and information used to give them credibility. The goal is to develop a process that assesses the reliability of a traditional FEMA P-154 assessment to determine whether it is sufficiently reliable to warrant action. P-154 is a triage approach meant to determine whether a detailed engineering assessment is required or not. Modifications to the P-154 procedures are proposed to warrant such actions without additional engineering assessment. This involves requiring highly experienced evaluators, specification of building document review, and technically independent supervision. Based on the nature of the conclusions, whether using the modifications or not, the reliability of the assessment can be evaluated, and a decision made whether it warrants action. It was validated by application to 56 likely hazardous buildings on three CSU campuses. The result of application of P-154 was that 52 of the 54 buildings need further engineering evaluation to reach a decision: two needed immediate attention, 12 requiring work overtime, where the reliability of all the evaluations indicated a good reliability for the conclusions, when the companion paper's procedures for portfolio management were implemented. The application of the recommended approach was about $2,500 per building, including assessor time, travel, and expenses, more than the conventional P-154 cost but far less than the engineering P-154 assessment. A companion paper, Setting the Priority for Seismic Retrofit of Buildings Using a Modified FEMA P-154 Procedure develops the seismic management program using this reliability determination as a key ingredient. The principal impact of the Modified P-154 process is that the retrofit decisions it recommended had acceptable reliability 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 [1] since that time. 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-P154 [2] 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 objective of this paper is to develop a modified P-154 assessment procedure and provide a means of assessing the reliability of its conclusions for a given building. The companion paper, Setting the Priority for Seismic Retrofit of Buildings Using a Modified FEMA P-154 Procedure, proposes how to use the P-154 conclusions for one or a series of buildings and to set priorities based on assessment S_{L2} values that measure the risk of collapse of the building without adopting a risk adverse priority given in P-154 of immediately assessing the hazard posed by the building with a $S_{L2} \leq 2.0$, and the reliability of the assessment. 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(s) is to appoint a Consulting Board (CB) of seismic experts who do not perform the subject building evaluation assessment(s), 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 to assess a proportion of the group of 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) 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 and 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 Assessment Procedure

The goal of this procedure is to distinguish Good buildings from Bad buildings quickly with limited information and great uncertainty and 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. Heuristics and biases perspective, as conceptualized by Kahneman [3] 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 (URM) 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 in lower magnitude and site ground motions, even more of the URMs performed acceptably as providing good life and property safety [8,9]. So concluding that no additional investigation is warranted may exhibit that the decision was not based on facts, but on a heuristic, which should be subject to verification to be accepted in many cases. Cioff [4] 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.

In the experience of the authors, all of these biases, and many more, can cause real problems in structural engineering, particularly where decisions are not challenged on their bases and conclusions. And doing triage of a building's performance is a prime candidate for these and other biases to reap havoc.

Keeping these biases in mind, and others not discussed, was a goal of the developed procedure. This was approached by:

a Having highly skilled and experienced structural engineers do the evaluations.

b. Having the ability to change the conclusions from the right formulaic approach where the evidence and so indicate, and the case can be made.

c. Having the individual conclusions discussed in the working group with the goal of finding weakness in the reasoning that led to the conclusion.

d. Having a second level review by the Seismic Review Board to act as a second screen validation of the conclusions.

The P-154 method of seismic assessment has been selected because it is an accepted FEMA standard, and its resulting S_{L2} score allows the evaluation of the relative probability or risk of collapse due to all possible levels of seismic ground motion at the building site over a given time period. Knowledge of this Risk Measure for a particular deficient building allows a rational basis for decisions concerning prioritization of the related retrofit work. In contrast, the seismic provisions of ASCE 7 [5] for new buildings provide only the conditional risk taken as equal to 10% of a compliant building not meeting the ASCE 7 performance objectives (collapse avoidance) due to the Maximum Considered Earthquake (MCER) level of site ground motion. This is a scenario ground motion-

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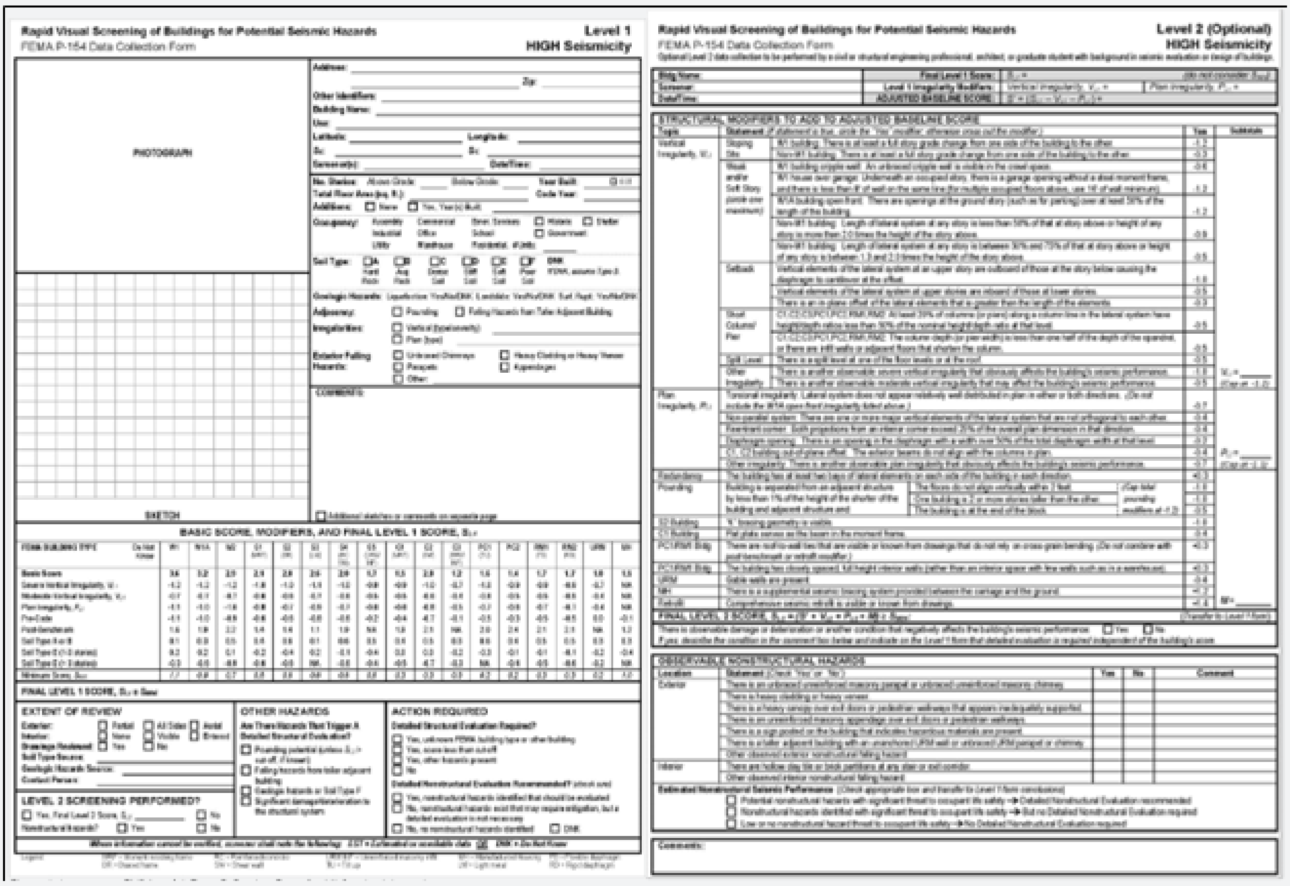
based representation of performance and does not reflect the probabilities that collapse could and will occur at lower ground motions than the MCER. The actual risk must include the hazard due to both lower and possibly higher levels of ground motions, and all the likelihoods of the building's response to any ground motions to which it is exposed. For existing buildings, the ASCE 41 Tiers also depend on scenario ground motions for evaluation. Similarly, the Californian Existing Buildings Code (CEBC) provisions for existing state-owned buildings treat building performance at two scenario ground motion Levels I and II, and thereby do not provide the total risk for rational decisions. None of these design standards use the ASTM E2026-16a concept of Probable Loss that considers all possible ground motions to which a building could be subjected over a given time period, as well as the statistics of how the building could respond to a given ground motion level. For the purpose of retrofit priority assignment, it is necessary to determine the Probable Loss corresponding to a fixed time period.

Fortunately, the detailed analytical bases for P-154, given in FEMA P-155 [6], provides the required Probable Loss measure approach. This is obtained by the evaluation of the Risk Score $S_R = S_{L2} + 1$, which represents the degree of hazard per unit time for a specific location. For the specific application to the CSU Assessment Procedure, it is necessary to correct the downside aspect of P-154 as originally intended to be a Rapid Visual Screening (RVS) of buildings that could potentially pose a collapse risk. Per P-154 Section 1.6, it is intended that RVS results are to be reviewed by an expert structural engineer in order to provide the need for a more detailed analysis and possible retrofit. For the 2021 CSU Assessment, the screening process has the following improvements to the RVS process: the necessity for review of available construction documents, the use of expert assessors, the necessity of a building site visit, the assignment of quality of information, and a required peer review process. CSU has undertaken to change the terms and conditions of how the P-154 assessments are done. Its objective is to allow the determination of the risk category for a building having potential deficiencies in seismic resistance. The proposed changes in the RVS process are outlined in Proposed Changes to the RVS Process discussion.


Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form
Level 1
HIGH Seismicity

PHOTOGRAPH

SKETCH

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form
Level 2 (Optional)
HIGH Seismicity

STRUCTURAL MODIFIERS TO ADD TO ADJUSTED BASELINE SCORE

OBSERVABLE NONSTRUCTURAL HAZARDS

Figure 1: Reproduction of P-154 Forms 1 and 2 for a site at high exposure seismic hazard. Different forms are available for each of the Hazard Exposure zones of (Table 1). The principal differences are the numerical values for different seismic exposure levels, which is in the table of adjustment values.

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The P-154 Level 1 and 2 Forms for the High Exposure region, as reproduced in Figure 1 [2] provide initial scores for each structural performance-related item of a building, and as discussed previously, the assessor may modify the initial score based on the structural characteristics of the building and corresponding expertise of the assessor. The forms vary by seismicity region; Very High, High, Moderately High, Moderate, and Low seismicity forms each have a unique set of basic scores for the basic building types considered but are otherwise identical. (Table 1) gives the distinctions among these zones. See P-154 for these forms.

Proposed Changes to the RVS Process

For setting the priority process for Seismic Risk Assessment, the authors have elected to use a modified version of the P-154 Rapid Visual Screening (RVS) Method discussed below. The RVS procedure was developed to identify, inventory, and screen buildings that are potentially seismically hazardous and intended for use by a wide range of screeners including: civil engineers, structural engineers, architects, design professionals, building officials, construction contractors, firefighters, architectural or engineering students, or other individuals with general familiarity or background in building design or construction. The P-154 requires a supervising structural engineer to review all scores. This backup requirement for an expert review of the data collection allows the use of a broad range of individual qualifications for the assessors. Once identified as potentially hazardous, the subject building should be further evaluated by a design professional experienced in seismic design to determine if, in fact, the building is seismically hazardous. The RVS procedure uses a methodology based on a sidewalk survey of a building and use of Data Collection Forms. These forms are completed by the person conducting the survey, and the resulting scores are based on information obtained from visual observation of the building from the exterior and, if possible, the interior. It is important to recognize that the reliability and confidence in the determination of a building's attributes would be increased if the type and condition of the structural system were to be evaluated by a highly qualified assessor performing the exterior and interior screening, along with a review of available construction documents (as will be the case for the CSU Assessment). The P-154 Data Collection Forms 1 and 2 (Figure 1) include limited space for documenting building identification information, including its use and size, a photograph of the building, and sketches. Further, Forms 1 and 2 provide a list of critical items and corresponding scores related to the seismic resistance of the building. The score S_{L2} is used as a measure of the seismic vulnerability of the building. Also, most importantly, there is a Comments section on Form 2 to describe and justify specific attributes or conditions that could alter the reliability of the initial S_{L2} score as an indicator of collapse vulnerability. This allows CB interpretations and score adjustments to the general structural items as listed on Forms 1 and 2.

The original RVS method identifies building attributes that may contribute to poor seismic performance, and conservative assumptions concerning the score values for these attributes have been made to minimize calling a Bad building Good. However, because RVS is intended to be performed from the sidewalk, where interior inspection is not always possible, and because there is no requirement for review of construction documents, hazardous details will not always be detected, and seismically hazardous buildings may not be detected as such. Conversely, buildings initially identified as potentially hazardous by RVS may prove to be adequate. Therefore, recognition of the reliability of the P-154 RVS assessment becomes an important issue.

Clearly, there can be a wide range of reliability in the determination of a P-154 score. The P-154 scores are based on a representative level of damaging ground shaking levels for the prescribed seismicity region, and they are intended to reflect the seismic design and construction practices for this region. Consequently, a building in a HIGH seismicity region will have generally been constructed with more seismic resistant systems and details than a similar building in a LOW seismicity region. Also, seismic design and construction practices vary and are not necessarily uniform across regions of the State having similar seismic risk. The appropriately evaluated P-154 score has the advantage that it is intended to yield consistent measures of collapse probability across different building systems and seismic exposures. For the user agency, CSU, it is therefore important for decisions concerning assignment of resources that the reliability of the methodology leading to an assessed score be evaluated. For example, the reliability of a score developed by an experienced seismic structural engineer should not be the same as that by an inexperienced architect; or a score developed from information obtained from complete construction documents along with a thorough visual inspection of the building should be superior to that where neither of these actions took place. In the CSU modified RVS procedure, SUPERIOR quality is assigned when complete construction documents are available and reviewed and a thorough site visit has been performed by the expert assessor. In contrast, with the initial RVS process, FAIR to POOR quality can result from a building walk-around by a person of limited capability. CSU needs this extra reliability or quality evaluation for prudent allocation of funds and use of time for seismically deficient buildings.

The recommended screening process is intended to place each building on lists that reflect its degree of seismic hazard without further evaluation. In order to achieve this objective, the CSU has chosen not to implement the initial P-154 RVS procedure as presented. The modified RVS is intended to be a self-contained process, not a preliminary process, that provides definite identification of seismically deficient buildings along their hazard of collapse during a specified time period. As a result, prudent decisions for retrofit can be implemented as a part of the ongoing

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seismic Risk Management program. Therefore, with this goal in mind, the initial P-154 RVS process has been modified to:

a. Restrict the assessors to be highly skilled and knowledgeable earthquake engineers who are members of the CB.

b. Require a review of all available structural plans, even if these may be partial, for the construction and for any modifications of the building, together with an on-site review by the assessor of the physical condition of the building and its lateral load resisting system. While past assessment reports may be available and shall be reviewed, no additional structural analysis is required.

c. Require both Level 1 and Level II P-154 score sheets to be completed to provide the more comprehensive initial S_{L2} score. When the assessor finds that the P-154 Form item sub-score does not represent the actual conditions described by the listed items on the Level 1 or 2 Forms, then scoring adjustments are to be noted and entered as Comments with an explanation of the basis for observations. In addition, the assessor must use the Component Matrices of (Table 2) to assign the Quality of the available information and the Quality of implementation used by the assessor for each component in the evaluation process for review by the CB.

d. The results of an individual assessment will be reviewed first by the other assigned assessors for consistency, and then by the CB. The CB review will approve or change the initial S_{L2} score based on their review and augmentation of the Comments sheet. The CB will review the assessor's Quality assignments in (Table 2) and finalize it in order to evaluate the reliability of the final score assignments (the root mean square (RMS) procedure will be used). Quality represents the reliability of how the P-154 score represents the seismic risk (collapse potential) of the building. A specific Quality level is required for assignment of a building to one of the priority lists for seismic retrofit. For the case where the Quality level is not sufficient, the building is assigned to a list for further study.

e. The initial S_{L2} score may be adjusted by the CB where the expert assessor and Board conclude that issues covered and related score contributions in the P-154 Level 1 and 2 Forms do not adequately consider related positive or negative characteristics that are important to the representation of the expected seismic performance of the building. The assessor's reasons for these adjustments are to be documented on the Comments form, and they shall be considered for an appropriate adjustment of the score at the discretion of the CB after their peer review and documented acceptance.

f. For a given building, the CB will employ the approved Risk Score, $S_R = S_{L2} + 1$, as a consideration for the assignment of the building to the appropriate Priority List. The Risk Score S_R has a direct relation to the collapse hazard of the building over a given time period (see Procedures for Modification of Itemized Scores discussion). Based on the Risk Score, the Risk category of the building, along with acceptable QUALITY of the assessment, the CB is to make an appropriate assignment to one of the Priority Lists.

While the above listed modifications may require more effort than the original P-154 RVS process, they will result in a documented method of determining, with acceptable reliability, which buildings are at highest risk for purposes of List assignment. The extra effort is feasible and does not require a very costly ASCE 41 [7] Tier 3 assessment for its application, which can easily reach multiples of $10,000 in effort to complete. It also allows the successful CSU seismic risk management program to continue on the same basis, with a more consistent, justifiable, transparent, and documented priority setting process.

P-154 S_{L2} Score Modification

A building seismic assessment S_{L2} score can lead to one of at least four dispositions discussed below:

A. There is inconclusive and/or insufficient information concerning the building such that no conclusion of collapse susceptibility can be made. For example, there may not be any existing drawings to review, and physical observation does not indicate a definitive lateral force resisting system. The required information may be obtained in the next assessment of the campus building or in the next annual seismic assessment review as a special purpose review. It is expected that very few buildings will be assigned this classification.

B. The building is assigned to List 1 as a building posing significant hazard and warranting detailed seismic assessment and retrofit as required under the Organization's policy triggers. This detailed assessment and retrofit should be implemented as soon as practical.

C. The building is assigned to List 2 as a building posing sufficient hazard to warrant detailed seismic assessment and potential retrofit when any work is proposed that requires a permit. The assessment and retrofit are not subject to any of the triggers of the CEBC that could allow delay in the full assessment.

D. The building has a seismic vulnerability that does not warrant assignment to Lists 1 or 2; that is, it will be assessed and retrofitted if the triggers of the applicable Building Code regulations require for the issuance of a permit for proposed work.

The latest CSU Seismic Review Boards (SRB) and Assessment Group discussions have yielded the following proposed processes for Assessment Submittals and their review and recommendations:

a. The assessor will prepare a P-154 Forms 1 and 2 report, as well as a supplementary discussion of the factors that were important to the assessment of the S_{L2} score. The supplementary discussion concerns items and conditions that the assessor

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considers as important in understanding the hazard of the building but where these are not adequately reflected in the items and scoring procedure of P-154. The report may include additional materials germane to the evaluation. These materials may include available backup text or previous reports describing conditions that would justify changes of altering the interpretation of the assigned S_{L2} score and corresponding reliability.

b. The CB shall receive all individual building assessments and review the recommended determination of the disposition of each building.

c. Each assessment report will be reviewed by each CB member who shall consider whether there is cause for review by the full CB. If there is cause, the CB member shall provide a basis for why this was concluded in order to guide the full CB discussion.

d. The CB shall consider any building that is either: recommended by the Assessment Group to be reviewed by the CB, or for which any CB member has recommended a full CB review. The discussion will proceed to consider the basis of the recommendation of the Assessment Group and, if applicable, the cause for additional review as recommended by the individual CB member.

e. The CB will reach a conclusion concerning the disposition of the subject building by recommending an assignment to the appropriate priority list, along with the Quality of the related information

f. The CB shall forward its recommended assignments for each assessed building to the Client.

The procedures of Procedures for Modification of Itemized Scores discussion are proposed to determine the modified S_{L2} score for the case where there is specific information concerning building performance that is either not included or not adequately represented in the P-154 Form Levels 1 and 2 item descriptions and related scores. This added information can occur because the assessor judges that the value for the specific Form item sub-score is either over or under the appropriate contribution that the added information has on the collapse hazard of the building. A modification of the initial Risk Score $S_R = (S_{L2} + 1)$ is required to evaluate the appropriate hazard. The modification is based on the assessor's evaluation and experience, and justification as given in the Comments section of P-154 Form 2. Any change in initial Risk Score must have the approval of the CB during the peer review process. In any case of an adjusted score, it is necessary to consider the corresponding effect on the Probability of Collapse of the structure (see discussion in Procedures for Modification of Itemized Scores discussion) and whether the corresponding hazard level is consistent with judgement of the CB.

The initial P-154 Rapid Visual Screening Process is predicated on the assessor having limited information on the building being evaluated and limited expertise in evaluation. Therefore, a review by a knowledgeable professional is required for the building's disposition. In contrast, the revised CSU application of P-154 requires that the assessor is highly qualified, has access to the design drawings, has completed an interior and exterior visual assessment, and the evaluator's recommendation is subject to vigorous technical peer review, first by the assessment team, and then by the CB. The assessor may find that an elemental score either over- or underestimates the contribution to the collapse potential and, therefore, may choose to modify that score. Procedures for Modification of Itemized Scores discussion presents examples of ways that can be used for this purpose, subject to peer review acceptance of the basis for the modification. When a modification is proposed to the S_{L2} score elements or total, the CB shall consider its basis. After discussion, each member will be asked to provide the best assessment of the score modification, and the average of these shall be considered as the value. P-154 and P-155 discuss the items or characteristics that affect collapse hazard and how it was decided on the corresponding score deductions or additions. It is useful to study these discussions in order to understand their basis and assumptions, so that their limitations can be understood and how appropriate changes can be made for given circumstances or conditions.

Procedures for Modification of Itemized Scores

In some cases, the P-154 element scores may be deemed to not adequately represent the expert assessor's evaluation of the condition's impact on damageability and ultimate collapse likelihood. Each modification must be justified by documented comments on why it was warranted. It is useful to consider the following examples of how the modifications to the initial S_{L2} score may be made in practice.

Example 1: A wood-framed building at a High Seismicity, Soil Class D Site, with a tuck-under configuration, is initially rated by P-154 Form 2 as having a Weak or Soft Story, from item 3 (ASCE 41 building designation W1A, wood frame with open front). By observation, the opening is over 50% of the building length. By P-154 this requires an addition of -1.2 to the S_{L2} score.

a. This scoring would be appropriate if there were no structural elements that mitigated this condition, and alternatively, that there are no other contributing factors that would cause worse than typical expected performance.

b. If the structure is observed to have wood rot or otherwise damaged structural elements that could impact the gravitational stability of the first-story structural system, then it would be rational to consider that the threshold at which extreme behavior would initiate is at substantially lower ground motions, and that it is more hazardous than the S_{L2} assigned value of -1.2 would imply, justifying an additional subtraction of $\Delta = -0.6$ or more.

c. If there were transverse wood end walls over the full width of the building and the supported diaphragm sections have

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aspect ratios less than 3:1 when the interior transverse shear walls are considered, then it could be argued, using professional judgement, that the penalty is too great, and the positive increment should be of the order of ½ credit of the deduction if they were plywood shear walls, $\Delta = +0.6$, or $\Delta = +0.3$ if they were straight board sheathing.

d. If the building has full longitudinal plywood shear walls supporting the upper occupied residential story(s) on each side of the center of mass of the building, then a credit of the order of 1/3 might be professionally justified depending on the characteristics of the supported diaphragm, for a credit of $\Delta = +0.40$.

e. If the building has both transverse and longitudinal shear walls at the first story, as discussed in the prior two bullets, then the open front may be of no consequence to the collapse potential of the building, and $\Delta = +1.2$ is appropriate. If there were one or more frames or wall sections along the open side, then the adjustment might be more than 1.2, based on the decrease of the torsional response.

Example 2: A three-story reinforced concrete (r/c) rectangular classroom building at a High Seismic Soil Class E Site constructed about 1962 with no isolated columns, and r/c diaphragm without ductile detailing of the walls. It has transverse r/c walls between every pair of classrooms, r/c corridor walls on each side, and r/c with strip windows on the exterior lateral walls with short columns/piers between windows. The walls have detailing typical of the era of construction. For Form 1, the pre-code ASCE 41 C2 value score modifier is -0.70 (note that the closely spaced shear wall allowance for P2 and RM1 do not apply to a C2 building), and the Form 2 Short Column modifier is -0.4, for a $\Delta = +1.2$ total score of $S_{L2} = 0.90$.

a) A simple calculation indicates that for each foot of shear wall at grade, there are 20 sf of floor area. This suggests that the shear walls are likely to crack in the Maximum capable earthquake but not lead to a likelihood of collapse, and that the deduction for the short columns is unwarranted. Also, the penalty for pre-code detailing is not warranted because Science Buildings with similar construction had limited damage in the 1994 Northridge earthquake at California State University at Northridge (CSUN).

Example 3: A long span roof truss in a pre-code C2(SW) auditorium has non-conventional connections to a reinforced concrete wall pilaster. By simple calculation, can this connection, in this stiff structure, support lateral load without tear-out? If a review of the connection detail on the plans shows that the bearing plate anchor bolts have, by current standards, sufficient embedment with transverse tie reinforcement and concrete cover to support the estimated load, then the Pre-Code modifier of (-0.8) is not warranted. Cases such as good detailing, while not called for in the initial code requirements, were employed by some California design offices specializing in earthquake resistant structures-by reputation. If this non-conventional connection item were to be the only potential deficiency, then the final S_{L2} score should be adjusted to be equal or greater than SMIN.

Example 4: Total Score Adjustments based on Assessed Damage or Base Shear Capacities: If the assessor evaluates the resulting S_{L2} score with or without adjustments to the sub-scores as above, then the assessor may also consider making an adjustment of the S_{L2} based upon an aggregate estimate of the likely performance of the total building based on all its characteristics, including elements not considered as a part of the lateral load resisting system, e.g. floor to floor wood framed walls in residential buildings. A first approach could be to consider the ratio of the damage values for the P-154 S_{L2} score and its associated equivalent damage ratio value of μ_r to the modified value μ_n that reflects the reassessed damageability, including considerations in addition to those that lead to the P-154 assignment. Since the S_{L2} value is a measure of the damageability of the building used by the P-154 process to determine acceptability of the resulting vulnerability estimate, then the authors can consider the inverse ratio of the P-154 determined score S_{L2r} to the modified score S_{L2n} , which considers additional information not included in the base scoring, as:

$$\frac{\mu_n}{\mu_r} = 1 + \Delta = \frac{S_{L2n}}{S_{L2r}} \text{ or } S_{L2n} = (1+\Delta) S_{L2r}$$

Where Δ is the proportional increase (+) or decrease (-) in the S_{L2r} value based on the information that was not adequately represented in the P-154 assessment form. Obviously, a positive value for Δ indicates lesser damageability, while a negative value indicates greater damageability than the base P-154 score suggests. Note that the score modification is expressed as the estimated increase or decrease in the ratio of damageability value, not absolute values. The authors assume that most experienced structural engineers think in terms of impact percentage, not calculated values, to make judgements on seismic performance as expressed in terms of damage.

A second approach would be to assess the modified value changes if the engineer has an opinion on how the alternative information may impact the base shear capacity of the building, V; then, by use of the TZY model results, the damageability ratio can be estimated by use of [8, 9, Part 2, Equation 2)]:

$$1 + \Delta = \left(\frac{V_n}{V_Y}\right)^{0.606}$$

where V is the base shear capacity of the design, the right side of the equation is for where conditions of the original design are in doubt in the equivalence shear capacity by the design base shear of ASCE 7-10 [5] for a linear procedure application, if the differences in weight, importance, incorrect soil designations, or R value for the design were used. Again, the users are using the estimated ratios, not the absolute values of the base shear before and after consideration of the additional information. The formula has a power constant that has been determined from

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empirical damage data collected from earthquakes in several countries, with a total of 44 data sets including 31,049 buildings. Key to this development was damage data for 825 concrete shear wall buildings of the same configuration, similar design and construction in the 1976 Tangshan, China earthquake for distances from the epicenter ranging from 1 to 100 kilometers, located in a variety of known soil types, see [8, 9] for the appropriate damage data demonstrating this point.

In many cases there can be several observed conditions that could be important to the collapse hazard of the building and yet not be adequately considered in the P-154 scoring procedure. In such cases, they can be considered separately or in aggregate. When considered separately, the aggregate adjustment Δ should be determined as a product of the $(1+\Delta_i)$ terms for each item considered important.

Therefore, for the case where the assessment engineer has a sense for the increased or decreased damageability, or base shear capacities, when considering the additional information that was not accommodated in the P-154 S_{L2} value determination, then the impact on the damageability parameter score S_{L2} from these noted points can be directly determined, as discussed in this section. The impact on the likelihood of collapse can be determined in exactly the same way as P-155 suggests, only using the modified performance S_{L2} score reflecting the additional information available to the assessor. In summary, when the assessor prefers to use judgement in terms of base shear, use $\frac{V_n}{V_\gamma}$, and when the preference is in terms of stability damage ratio, use μ_n/μ_γ.

When a modification is proposed to the S_{L2} score, the CB shall consider its basis. After discussion, each member will be asked to provide her/his best assessment of the score modification, and the average of these shall be considered as the value. P-154 and P-155 suggest how to assess these characteristics and how the team decided on the deduction and addition to the scores. It is useful to study these in order to understand their basis and assumptions so that their limitations can be understood.

Determination of Assessment Components for Quality or Reliability

Why is it necessary that the user 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 is for 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 large uncertainties in our understanding and resulting models of earthquake processes and response of complex structures, along with the lack of empirical actual performance data 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 of the issues, herein termed as components, which can contribute to this uncertainty. For the evaluation of the uncertainty measure for each component in the assessment process, the users 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, and then combining these uncertainties to quantify the total uncertainty and corresponding reliability of the resulting assessment by the method proposed below. This effort, in essence, is a measure of the epistemic (degree of knowledge or validity of assumed behavior) uncertainty of the assessment result.

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 Standard proposed in Procedures for Modification of Itemized Scores discussion is based both on the score and a representation of the combined Quality or Reliability of the assessment process (P-154 S_{L2} Score Modification discussion).

a. Basis of Evaluation - Plans and Reports: Were the original design and/or any modification retrofit documents available for review (likely provided by the campus)? Were these documents sufficient to describe the structural system? If a retrofit was completed, was it consistent with the then currently applicable requirements? Was this retrofit partial or complete? Were there other seismic assessment reports available (also likely provided by campus)? (If so, include copy(s) appended to the P-154 form.) Were all structural modification drawings provided (i.e., do the reviewers know if the entities providing existing drawings know of all of the changes/modifications made to the building since it was constructed)? Otherwise, might there have been changes/ modifications that are not known? See (Table 4), Matrix 1. (See Table 4A.).

b. Basis of Evaluation - Site Visit Inspection: Was the building accessible for the visit? Was it possible to observe a representative number of important structural elements (and potentially hazardous non-structural elements, such as cladding, ceilings, partitions, and heavy equipment, where failure could affect life-safety) in order to verify the as-constructed condition? See Table 4B.

c. Basis of Evaluation - Personal Qualifications: The qualifications of the assessor performing the assessment is of key importance to the reliability of the conclusions of the evaluation. In

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addition to the licensing and expertise of the assessor, the degree of experience in seismic performance evaluation is important; ASTM E2026-16a provides a good standard for such qualification requirements (see Table 4). For the CSU process, the assigned CB Peer Review Engineer qualifies as a Senior Assessor under this standard. See Table 4C.

d. Design Basis: What were the seismic design criteria under which the building was designed and/or retrofitted or otherwise altered since construction? This includes the specific seismic requirements as well as the regional standard of practice used (i.e., choice of structural system, extra detailing, evidence of construction quality control, or lack thereof). See (Table 4D).

e. Configuration and Load Path: What are the vertical and horizontal irregularities of the structure using the ASCE 7 designations? Does the detailing of lateral load-resisting system elements accommodate the response effects of these irregularities? Is there an effective load path complete to the supporting foundation material? Does the detailing of the lateral load resisting system provide adequate ductility to accommodate expected demands? What is the potential collapse mechanism? If over-turning tension resistance is required, are there sufficient foundation details to ensure transfer to the supporting foundation material or to tolerate limited rocking? See Table 4E.

f. Compatibility of Deformation Characteristics: Are the deformational characteristics of the building's structural and nonstructural elements compatible with the expected seismic drifts? Is there any unintended interference from other stiff elements that could cause failure of critical support elements (e.g., short columns or partial masonry infill in a moment frame system)? See Table 4F.

g. Condition: Are the structural elements in good condition, damaged, or deteriorated? Are any deteriorated elements important to the seismic resistance and stability? Is there any damage due to past earthquakes, accidents, or fires, and is this damage important to the seismic resistance? Are there any un-authorized modifications (e.g., openings, infills, installed equipment, etc.) that decrease structural resistance or create life-safety hazards? See Table 4G.

The Table 4 matrices describe the conditions that result in a Quality Assignment for the component under discussion based on the Quality Measure Characteristics and the Implementation Characteristics (how the information was evaluated by the assessor). These considerations are intended to assess both the principal and secondary influences that impact the resulting risk of collapse of the building as represented by the score SL_2 (see Procedures for Modification of Itemized Scores discussion). With this pair of Quality Assignments for Description and Implementation, Table 2 provides the value for β_i corresponding to the Quality Measure and Implementation Characteristic values. Example: for Component Description Quality of High and Implementation Quality of Medium, Table 2 gives a GOOD assignment, with a $\beta_i = 0.20$. NOTE: For some Components, there is only a single column for Quality Assignment. In this case, the assigned Quality is entered directly into Table 3 for the β_i value. NOTE: Particularly applicable conditions may not be appropriately described and scored by the Topics listed on the Level 2 Form. The assessor shall use the supplemental Comments Form of the P-154 Level 1 and 2 tables (Figure 1): describe these conditions, recommend an appropriate Topic change and score modification, and provide a Quality assignment for the related additional information.

The quality of this assessment depends on degree of accessibility to inspect critical structural elements and potential falling hazards. In most cases, this inspection may not be complete because architectural finishes normally conceal important structural elements, which may require access to the design documents if they are to be reliably evaluated.

Representation of Quality, Related Uncertainty, and Reliability of an Assessment

The analysis of the reliability of the P-154 assessed S_{L2} score utilizes the methods developed in the peer reviewed paper Reliability of Seismic Performance Assessments for Individual Buildings and Portfolios ([10]; termed as TZL below). These methods have been adapted to the task at hand. In the TZL paper, a procedure was developed for the evaluation of the quality of the seismic damageability of an individual building. They were developed based in part as an adaptation of the procedure introduced in FEMA P-695 for the evaluation of the reliability of Building Seismic Performance Factors [11]. In this FEMA publication, the specific problem addressed was the evaluation of the reliability of a predicted building collapse displacement under seismic loading. In order to represent the amount of relevant information and how this information was implemented in the process of analysis, the following procedure was proposed.

For a given factor of the seven-component (a-g) used in the Determination of Assessment Components for Quality or Reliability discussion 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). FEMA P-695 Section 3.4 [12] presents a simple matrix, shown here in Table 2, that 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 of the Quality of Component Description Measure (High, Medium, Low). Implementation refers to how well the assessor was able to apply the available information corresponding to the specific description. The lower the β value, the greater the certainty

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(reliability) of the result; conversely, the higher the β value, the lower the certainty (reliability). For application to the CSU Assessment process, the means of assigning the required quality measures are prescribed in Table 4, which provides matrices 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 4 or Table 3. A statistically valid approach to combining the uncertainties of the seven components is by the Root Mean Squared (RMS) value of their related β values (Table 5.). This resulting numerical value of β (the RMS of the component values) can be expressed as a qualitative linguistic term by the use of Table 3 following the numerical upper and lower bounds. The β values of Table 3 are essentially the same as those used in P-695, but with the exception that P-695 did not provide an assignment of a (Low, Low) entry, which was added in TZL, and is termed as BAD with a corresponding assignment of $\beta = 1.0$.

A most 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 method to provide the total uncertainty of the result of the evaluation. 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 the proposed method of evaluating the uncertainty of an assessed score of the building hazard, the approach described above for the assignment of qualitative uncertainty expressions by the matrices of Table 4, finding the corresponding quantitative β_i factors by Tables 2 and 3, and their RMS combination in Equation 1 below is necessary because building hazard assessments are based on varying degrees of available information, professional knowledge, and related judgements. The expression of the likelihood for building collapse response due to a given ground motion, or for all possible site ground motions, and the corresponding degree of uncertainty is based primarily on the experience and qualifications of the assessor and the availability of information concerning the specific characteristics of the building and related seismic hazard. For a particular building, detailed engineering analyses and on-site materials testing, and investigation (such as ASTM E2026 Level 3 investigations) are usually not feasible within available resources. Also, actual seismic performance data, or damage statistics, for most existing building types are not sufficient to provide accurate empirical prediction. Consequently, it is necessary to utilize expert judgmental qualitative values as a major basis for performance assessments. At best, these judgmental values are based on the assessor's experience and the information obtained from building construction documents, where available, and/or a building visit when possible. (Note that for the specific CSU Assessment process, construction documents are usually available, the assessor is highly qualified, and a building visit is required.) (Table 3) gives a simple qualitative ranking based on qualitative terms SUPERIOR, GOOD, FAIR, POOR, and BAD and their corresponding (judgmentally assigned) qualitative uncertainty measures (β values). The number (five) of the qualitative terms of (Table 3) has the benefit of being odd such that there is a subjective middle or neutral representation for judgement heuristics. (Table 4) shows how the β_i values can be assigned where two descriptors, Component Description and Implementation Characteristics are used (refer to the two column matrices of (Table 4)). (Table 3) is to be used where only one judgmental Quality choice (refer to the one column matrices of (Table 4)) is made concerning a particular component involved in the assessment process.

In order to make justifiable, prudent decisions concerning priorities for allocation of resources related to the seismic retrofit of deficient buildings in the CSU system, it is necessary to provide a means of evaluating the Quality of the assessed S_{L2} score. If the Quality is insufficient for a given building, then decisions must be delayed until improved information can be obtained. Note again, that for the specific CSU Assessment process: construction documents are usually available, the assessor is highly qualified, and the building visit is required, such that Quality will be GOOD or better. For the CSU Assessment process, it may be asked, "Why then is it necessary to evaluate Quality if it is usually GOOD or better? The answer is that a record of a technically independent Quality Assignment is necessary for future decisions or performance problems related to the building.

It is important to recognize that the particular wording of the structural modifiers in the FEMA P-154 Level 2 Form is intended for use by "Civil and Structural Engineers, Architects, and Graduate Students with a background in seismic evaluation or design of buildings." Clearly, even with the P-154 required final review of the Form submittals by an experienced assessor, the Quality of the resulting assessed Score could vary greatly due to this wide range of assessor qualifications. With the condition that the CSU assessments are to be performed by Senior Assessors defined by ASTM E2026-16a, Section 6.2.3.2, see Table 1 (e.g., the CB Peer Review Engineer for the campus), certain modifications are needed to the wording of the Level 2 Form. It is necessary to represent the obvious changes of description and related scoring that would be possible if it were given that the assessor was of a Senior Level. These modifications relate to levels of assigned Quality of Description and Implementation. For example, a Plan Irregularity Reentrant Corner condition may exist, but the designer has provided sufficient details to prevent concentrated damage; or a Soft Story may be observed, but the columns have sufficient over-strength to resist failure. These special conditions may not be evident to some of the generally lower qualified assessors allowed by P-154. The P-154 Rapid Visual Screening (RVS) process needs to be adapted to represent the CSU requirements for a Senior Assessor, Construction Document Review, and a detailed exterior

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and interior site visit for the building. The following component matrices in Table 4 are to further extend the conditions beyond the wording of the Level 1 and 2 Forms and allow assignment of Quality in terms of the description of the availability of information and how this information was obtained and implemented. These Quality assignments, and resulting combined RMS value, are not intended to influence how the P-154 forms are to be filled out but to reveal to the CSU, as the client, what the uncertainties may be in the information and methods used for a particular building assessment.

Table 1: Reproduction of Tables 2-3 from P-154 indicating the designations for different seismic regions based upon MCER Spectral Acceleration response values for the building site under consideration (P-154).

Seismicity Region	Spectral Acceleration Response, (short period 0.2 seconds)	Spectral Acceleration Response, (long period 1.0 second)
Low	less than 0.250g	less than 0.100g
Moderate	greater than or equal to 0.250g but less than 0.500g	greater than or equal to 0.100g but less than 0.200g
Moderately High	greater than or equal to 0.500g but less than 1.000g	greater than or equal to 0.200g but less than 0.400g
High	greater than or equal to 1.000g but less than 1.500g	greater than or equal to 0.400g but less than 0.600g
Very High	greater than or equal to 1.500g	greater than or equal to 0.600g

Notes: g = acceleration of gravity in horizontal direction

For the specific objective of evaluating the Quality or Reliability of a building assessment, the following procedure will be used. For each of the seven components of an assessment, Table 4 provides descriptive matrices for corresponding qualitative terms either as a pair of component Quality Measure and Implementation Characteristics description, or a single descriptor used for the component evaluation. For a component having a pair of Quality Measures, the uncertainty measure β_i is found by direct application of the pair of Quality Assignments in Table 4 (a-g). For the case where there is a single Quality Measure that combines the Quality of Implementation within its description, then Table 3 is used directly to assign the β_i value. Essentially, in these matrices, the assessor can express the Quality of the available information concerning a building, and how this information was implemented for the purpose of determining the applicable items on Forms 1 and 2 and related scores, or reasons for justifying changes in these scores due to particular conditions.

A. Plans and Reports

B. Site Visit Inspection

C. Basis of Evaluation-Personal Qualifications

D. Design Basis

E. Configuration and Load Path

F. Compatibility of deformation characteristics

G. Condition

Representation of uncertainty in Quality assignment: In some cases, it may not be clear that definitive choices can be made in the (Table 2) Measure and Implementation assignments. For example, the assignment is mid-way between High and Medium, or the probability of High and Low are each 25% and the probability of medium is 50%. In other words, there is legitimate doubt in which assignment is appropriate. If the user designates the probability of the Quality Measure as P_j for the three Measures $j = H, M$ and L, and as probability Q_K for the Implementation Characteristics, and β_{jk} be the corresponding β value in (Table 2) for row j and column k, then the appropriate combined value is determined as:

$$\beta_i = \sum_{j=1}^{3} \sum_{k=1}^{3} P_j Q_K \beta_{jk} \quad (1)$$

where β_{jk} is the value entry in (Table 2) for the appropriate matrix location. This weighting approach is used to determine the assigned value since the users are, in essence, interpolating between the b values of the component matrix. (Table 4) shows what these values look like for several different assumptions on the probabilities of both Quality Measure and Implementation Characteristics. These numerical values should be used in the subsequent analysis, not the linguistic equivalents of (Table 5).

It is also important to recognize that (Table 2) provides the means of expressing a quantitative measures expression of a quantitative value of a numerical β value. There may be cases where decision makers may prefer to express their judgements to their peers in qualitative terms. Similarly, users, particularly for non-technical audiences, may feel more comfortable or effective in using these qualitative terms for the justification of an economic decision rather than quantitative values, which would require more explanation and possibly result in confusion. Our goal is to use these sets of quantitative and qualitative terms to describe the Quality, reliability/uncertainty of the assessment results. (Table 3) provides guidance on how to assign quantitative β values according to the pairs of qualitative expressions for

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component Description and Implementation Characteristics as obtained from the (Table 2) component matrix evaluations. The β values are considered as measures of uncertainty (in terms of the standard deviation for error ranging from zero to unity) and serve to indicate higher reliability as the lower the β value, and the converse, the lower the reliability as the higher the β value.

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

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

Table 4a Plans and Reports

Assignment	Quality Measure Characteristics	Assignment	Implementation Characteristics
High	Building Construction Plans were available for the original construction and for subsequent modifications that may have impacted the seismic performance of the building. A previous seismic evaluation report may be available that informs this decision.	High	The assessor determined that the structural plans were sufficient to describe the lateral load resisting system and related specific detailing to evaluate reliability of the conclusion.
Medium	The structural design drawings were partially available and are evaluated as sufficient to make an informed decision on the seismic performance of the building. A previous seismic evaluation report may be available that informs this decision.	Medium	The assessor determined that the drawings were sufficient to reach an informed decision on the nature of the lateral load resisting system, although specific essential details are not available.
Low	Otherwise	Low	Otherwise

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Table 4b Site Visit Inspection

Assignment	Quality Measure Characteristics	Assignment	Implementation Characteristics
High	There is access to all areas of the building deemed important to observing the as-built elements of the vertical and lateral load-resisting systems and their condition. Structural drawings were available to confirm this conclusion.	High	The structural drawings of the building and its latest modifications were reviewed before the site visit, and therefore the assessor had a good knowledge of the vertical and lateral load resisting systems and related details before visiting the building. Any rigid non-structural elements that could interfere with displacement of the lateral load resisting system are identified. Support conditions of heavy non-structural elements, ceilings, partitions, and cladding were observed. For observed conditions that were not anticipated, additional information was found that confirmed that these conditions have a significant effect on the vertical and/or lateral load resisting system. It was possible to verify the type and condition of diaphragm to wall connections.
Medium	Assessor had access to the highest priority portions of the building structure; however, some important elements that could be important were not accessible.	Medium	Structural drawings were sufficient to define a valid structural system.
Low	Otherwise	Low	Assessor observed that the as-constructed connections were not according to plans. There were significant unauthorized or non-documented alterations or changes to the building. These changes were not indicated on the reviewed documents. Further evaluation is required.

Table 4c Basis of Evaluation-Personal Qualifications

Assignment	Implementation Characteristics
Superior	Review completed by an ASTM E2026 Section 6.2.3 qualified Senior Assessor for Level 1 or higher assessments, and who has a working knowledge of P-154, ASCE 41 and ASCE 7. The assigned CB Campus Peer Review Engineer meets the Senior Assessor Requirements.
Good	Review completed by an ASTM E2026 qualified Assessor, or higher, for ASTM Level 1 or higher assessments, see ASTM E2026, Section 6.2.3. Alternatively, if the report has been completed and the FEMA P-154 score is less than 2.0.
Fair	Review completed by a licensed structural engineer.
Poor	Review completed by a licensed civil engineer or architect.
Bad	All others

Table 4d Design Basis

Assignment	Quality Measure Characteristics	Assignment	Implementation Characteristics
High	Original design regulations applicable are 1997 or later editions of the UBC or CBC building codes. Otherwise, the design and implementation of a full seismic retrofit was completed after the appropriate ASCE 41 threshold date for the building type. Refers to Post Benchmark item on P-154 Level 1 Form and Redundancy item on P-154 Level 2 Form.	High	The executed design is evaluated as addressing the relevant characteristics needed to produce a reliable level of performance based on experience from past events (e.g., Benchmark Requirements). The assessed design and its execution are evaluated as showing a high level of practice in seismic performance issues, especially in the load path and detailing of elements and connections. This is a professional judgment by the assessor based upon their knowledge of both the current state of professional practice, along with historic practices that have been shown to provide a high level of performance in past events, and did not use practices that resulted in unsatisfactory performance in past seismic events.
Medium	The design was completed before the applicable ASCE 41 threshold date or the original design regulations were by the 1976-88 UBC or equivalent seismic design code. Refers to Post Benchmark item on P-154 Level 1 Form.	Medium	The design basis is evaluated as identifying relevant performance characteristics needed to prevent building collapse based on experience from past events. Design appears to meet minimum applicable building code requirements at the time of design with no particular evidence shown for contemporary good state-of-the-practice special detailing at the time of design beyond direct code compliance. This design is assessed as having a low to moderate margin of over-strength and ductility of the critical seismic elements necessary to assure stability.

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Low	Otherwise	Low	The design basis is evaluated as not addressing seismic issues or has failed to address relevant performance characteristics needed to prevent building collapse based on past events. It was not possible to verify if the key details of construction of the building, upon which the seismic response principally depends, were of the type(s) that have been shown to be deficient in earthquakes since the building was constructed, such as: brittle welds in steel moment frames, K-braces, thin-walled tube steel braces, gusset plates subject to buckling, inadequate ties in grade beams, 3/8-inch plywood shear walls with overdriven nails, notched let-in timber bracing, among many other items of common knowledge to experienced structural engineers. For the case where these non-verifiable deficiencies would dominate considerations in the expected seismic collapse performance of the building at moderate or higher ground motions, the Low-quality assignment should be considered, even though the High or Moderate assignment might be applicable.

Table 4e Configuration and Load Path

Assignment	Quality Measure Characteristics	Assignment	Implementation Characteristics
High	There are no ASCE 7 irregularities in the lateral load-resisting system, or these are specifically addressed in the building design and analysis so as to comply with current ASCE 7 requirements.	High	Structural drawings reviewed and/or a site visit led the assessor to determine that the design appears to accommodate the specified load, resistance, drift, and detailing requirements described in the CEBC for ASCE 41 S-3 performance (Life Safety) in BSE-C seismic loading. The design is evaluated as accommodating the applied loads for the configuration and/or irregularities.
Medium	There are none of the following current ASCE 7 irregularities: Horizontal Types 1b and 4 or Vertical Types 1, 4, and 5.	Medium	The design appears to accommodate the specified load, resistance, drift, and detailing requirements described in CEBC for ASCE 41 S-5 performance (Collapse Prevention) in BSE-R seismic loading.
Low	Otherwise	Low	The building investigation process did not consider concentrations of cyclic inelastic deformations capable of causing global or partial collapse (High S-5 or exceeding S-5) in the CEBC ground motion BSE-R. Provision for over-turning effects, where applicable, were not considered.

Table 4f Compatibility of Deformation Characteristics

Assignment	Compatibility Quality Implementation Characteristics
Superior	The stiffness and deformational characteristics of all elements of the lateral load-resisting system appear in the opinion of the assessor to be compatible in all directions and were considered and documented in the assessment. The assessor was able to identify structural elements that could pose a stiffness incompatibility with the orthogonal lateral load-resisting system. These include elements posing stiffness incompatibilities occurring in both horizontal directions, say with steel braced frames in the transverse direction and moment frames in the longitudinal direction.
Good	Less than Superior but better than Fair.
Fair	The assessor's evaluation considered structural elements that may pose a stiffness incompatibility with the orthogonal lateral load-resisting system. These include elements posing stiffness incompatibilities occurring in both horizontal directions, say with steel braced frames in the transverse direction and moment frames in the longitudinal direction.
Poor	Less than Fair but better than Poor.
Bad	The assessor's evaluation did not consider whether any structural elements with or without stiffness incompatibilities occur in both horizontal directions.

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Table 4g Condition

Table 4: The following matrices describe the conditions that result in a Quality Assignment for the component under discussion based on the Quality Measure Characteristics and the Implementation Characteristics (how the information was evaluated by the assessor). These considerations are intended to assess both the principal and secondary influences that impact the resulting risk of collapse of the building as represented by the score SL_2 (see Procedures for Modification of Itemized Scores discussion). With this pair of Quality Assignments for Description and Implementation, Table 4 provides the value for β_i. Example: for Component Description Quality of High and Implementation Quality of Medium, Table 4 gives a GOOD assignment, with a $\beta_i = 0.20$. NOTE: For some Components, there is only a single column for Quality Assignment. In this case, the assigned Quality is entered directly into Table 3 for the β_i value ((Tables (4a,4b,4c,4d,4e,4f,4g)).

Assignment	Quality Implementation Characteristics
Superior	It was possible to observe that the building's non-structural (e.g., cladding, stairways) and structural elements were to be either in acceptable condition with no visually observable deterioration, or damaged in a way that significantly weakens the seismic performance. This also includes observation of any modifications in ways that have not been permitted and that could reduce the reliability of the lateral load-resisting system.
Good	Less than Superior but better than Fair.
Fair	Some (but definitely not all) structural elements of the vertical and/or lateral-load resisting systems were observed and/or reported to have suffered some localized deterioration, damage, or alteration that may have diminished the capacity of a few elements, but these do not generally reduce the reliability of the seismic load-resistance system.
Poor	Less than Fair but better than Poor.
Bad	Observation of the building's condition suggests that there are damaged or degraded structural system elements, but it was not possible to observe the extent to which building materials and elements may be degraded, damaged, or have non-permitted modifications, at locations impacting the seismic resistance of the building.

NOTE: Particularly applicable conditions may not be appropriately described and scored by the Topics listed on the Level 2 Form. The assessor shall use the supplemental Comments Form to: describe these conditions, recommend an appropriate Topic change and score modification, and provide a Quality assignment for the related additional information.

Table 5: Interpolation for β values where the horizonal (Implementation Characteristics) probabilities are given as (PH, PM, PL), and the vertical probabilities are used as weights of the horizontal b value of Table 4.

Horizontal Probabilities	Vertical Probabilities			
	Same as H	0.1	0.25	0.35
(3/4, 1/4, 0)	0.15	0.13	0.24	0.39
(2/3, 1/3, 0)	0.17	0.13	0.25	0.4
(1/2, 1/2,0)	0.21	0.15	0.28	0.43
(1/3, 2/3, 0)	0.26	0.17	0.3	0.45
(1/4, 3/4, 0)	0.28	0.18	0.31	0.46
(1/2, 1/3, 1/6)	0.27	0.18	0.3	0.51
(1/4, 1/2, 1/4)	0.38	0.21	0.35	0.59

An important advantage of the quantitative β_i values for each component is that the total uncertainty β value assignment may be evaluated in a statistically consistent procedure as discussed below. Rationally, it would not be possible to express the Total Uncertainty as a combined effect of a set of different qualitative terms, except perhaps by assigning the most prevalent value, which is not very compelling.

It may be instructive to see how different arrays of β_i values contribute to the total uncertainty of the β value assignment. (Table 6) shows the impact on β of having all the β_i values the same except one, two or three (denoted by $nX\beta$) that have assigned the same value, possibly different from the fixed value. Note that achieving a GOOD rating does require most, but not all, of the ratings to be GOOD or better. If one is POOR, then all the rest have to be GOOD or better, and if three are FAIR, then the rest have to be GOOD or better. In the Decision Rule developed in the companion paper, CSU and the SRB concluded that the reliability of the assessment would have to be $\beta \le 0.30$ to be actionable It is instructive to note that the elements for a conventional P-154 assessment as shown in (Table 2) indicates that items 1, 2 and 6 are highly likely to be POOR or higher without the review of documents and performance by a highly skilled assessor, which yields $\beta = 0.34$ if the balance are all Superior, which is highly unlikely.

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Table 6: Impact of the results of Equation 1 where the various β_i values from the qualitative value set have probabilities of applying to the determination of the value, with one, two or three (1x, 2×, 3x) values set at a different value impact of the aggregate uncertainty β value. The Green values qualify for SUPERIOR assignments by Table 3, the blue for GOOD, and the yellow for FAIR.

Fixed	Variable				
	1X0.10	1X0.20	1X0.35	1X0.50	1X1.0
0.1 0.2 0.35	0.1 0.19 0.33	0.12 0.2 0.33	0.16 0.23 0.35	0.21 0.26 0.38	0.39 0.42 0.5
	2X0.1	2X0.2	2X0.35	2X0.50	2X1.0
0.1 0.2 0.35	0.1 0.18 0.3	0.14 0.2 0.31	0.21 0.25 0.35	0.28 0.32 0.4	0.54 0.56 0.61
	3X0.1	3X0.2	3X0.35	3X0.5	3X1.0
0.1 0.2 0.35	0.1 0.16 0.27	0.15 0.2 0.3	0.24 0.27 0.35	0.34 0.36 0.42	0.66 0.57 0.71

Determination of Reliability/Uncertainty Value β for an Individual Building Assessment: The determination of the reliability for a specific building's assessed score S_{L2} requires a statistically consistent manner of combining the individual component uncertainties, β_j, in order to reach an aggregated value, β, as a measure of uncertainty for the building assessment process.

The users are dealing with the subjective assignment, by the designated assessor, of the quality and corresponding quantitative β_j value for each component of the assessment process. The information obtained from each component is represented as score modifiers in the P-154 Level 1 and 2 Forms and associated Comments. Since the final assessed score S_{L2} is the result of an additive process, the most appropriate method of combining the associated subjective uncertainties, β_j, is to consider them as the "standard deviations" of error such that β_j^2 is the variance of error. If the users tacitly assume that the assigned qualities are independent for each component, then the combined variance is the "sum of the component variances" (essentially, independence may not be completely valid: for example, the Quality of some components depend on the Quality of the completeness of the design documents; however, the effect of the neglect of any covariance contributions are minor when compared to the variability of the judgmental assignments of Quality). Also, in order to ensure that the combined β value, shown below, remains between 0 and 1 such that (Table 3) can be used for the qualitative description of this mathematical (quantitative) result, it is necessary to divide the combined variance by the number (7) of components. In some cases, not all the seven components of this document will be important to the evaluation, and there are likely to be others that are not in the group that are vital; therefore, assume that there are n items. The resulting aggregated value, β, is the Root Mean Squared (RMS) value

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

This method of uncertainty combination is consistent with the accuracy of the assigned uncertainty values in (Tables 1 and 3). It is assumed that each of the uncertainty components, β_j, have equal importance such that no weighting factor is required for components. Note that the division by the number n of components achieves the desired result that if all the β_j values are the same, then the aggregated β is the same as each of the individually equal values. The value of β determined from Equation 2 is the assessed reliability parameter for the assessed building which will be at the core of the companion paper procedure for determining whether the assessment performed value of S_{L2} is actionable.

CSU Application Experience

CSU assessed the seismic vulnerability of 56 buildings and one building-like structure (providing vertical access among buildings, Building A17) on three 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 7) 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.

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Table 7: 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 of 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, 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
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

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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, without illustrations and copies of details of construction, with many having limited added comments because the case was so clearly evident that the building was either not highly hazardous on its face or not in doubt for its hazard. 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 (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 Standard 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 3 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 7, 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 not be viewed as an absolute rule for decision making. As

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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.

It is interesting that of the 56 buildings assessed in Table 7, all but four had S_{L2} values lesser than 2.00. In other words, P-154 would require detailed seismic evaluation to decide how to proceed. The modifications of the RVS procedure developed for CSU reduced this to two buildings put on List 1 requiring near term seismic evaluation, and 12 buildings on List 2 requiring evaluation when any permitted work was proposed, and the balance awaiting proposal of permitted work that the CEBC would trigger seismic evaluation. The assessors noted that the individual assessors made no adjustments to the P-154 S_{L2} scores. Instead, the scores were recorded as consistently as possible with the P-154 instructions, even if a particular score did not necessarily reflect the significance of a particular issue. The assessors summarized instances as additions to the P-154 Forms where they believed certain scores incorrectly underestimated or overestimated the significance of a given issue. These summaries, in addition to the scoresheet, formed the basis for the review committees' deliberations as to whether a building belonged on one of the seismic priority lists or on no list. In a few cases, P-154 S_{L2} score interpretations were changed, but this was reflecting a different interpretation of the scoring statements by the review committee from that taken by the original assessor. These recommended changes were ultimately accepted by the original assessor.

Although the decision rule had not been formalized at the time the assessments were performed and discussed, enough was known about the proposed rule to generally guide discussions and recommendation by the review committee. List assignments did not follow the Decision Rule in all instances, but these deviations were limited and substantiated by the professional judgment of the original assessor and the review committee. The SRB did not alter any recommendations presented.

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. This suggests that the basic structure of the P-154 process is sound, and that when modified as recommended in this paper, yields good decisions that are reliably based when they are reviewed in a consistent manner. However, if the client is interested to the P-154 determination of identifying which buildings warrant an ASCE 41 [3], Level 3 (or lower) assessment, then it can be used to advantage unchanged. We would recommend that for such applications the $S_{L2} \leq 2.0$ triggering remains, since there is high uncertainty in the reliability for the resulting assessment as reflected by poorer reliability of the assessment using the methods of this paper.

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 is the advanced planning stages 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.

CSU has also used a method from time to time to estimate the period of time that a known hazardous building can be occupied (whether owned or leased) and not exceed the life-safety during this period probability that a new building would expect in a 50-year time period. Those desiring to make such a decision are advised to consider using the methods of Thiel and Zsutty [13] supplemented by the reliability evaluation procedures of this paper.

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 as a scenario-based event, often the MCER, 475- or 2,475-year return period events. For owners of individual or large portfolios of buildings, the cost implications of these binary outcomes are likely to demand significant resources to resolve. A key issue in seismic management is to determine whether the reliability of the seismic assessment is sufficient to warrant action. This paper has focused on this issue so that there is a procedure that can be easily applied to determining whether the conclusions were found based upon adequate information and technical skills of the assessor. It is no longer necessary to have blind, untested faith in the reliability of an assessment.

A great advantage to the proposed method of reliability assessment presented is that is can be easily modified to any series of uncertainties in (Tables 2 and 3) that properly reflect a given client's requirements. The procedures then will reflect the client's needs for differentiation among actions required.

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I am sorry to report that my coauthor, Theodore C. Zsutty,

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died in the last week of April after a long and productive life to his end at age 92, before this paper's submission, but after it was in essence completed. 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 participants in their resolution of technical problems. He and I have 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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