Designation: E2557 – 16a

An American National Standard

Standard Practice for Probable Maximum Loss (PML) Evaluations for Earthquake Due-Diligence Assessments[1,2]

This standard is issued under the fixed designation E2557; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice establishes standard-of-care for evaluation and classification of the financial risks from earthquake damage to real estate improvements for use in financial mortgage transactions and capital investment evaluation. As such, this practice permits a user to satisfy, in part, their real estate transaction due-diligence requirements with respect to assessing and characterizing a property's potential losses from earthquakes. This practice is intended to address only physical damage to the property from site and building response.

1.1.1 Hazards addressed in this practice include earthquake ground shaking, earthquake-caused site instability, including faulting, subsidence, settlement landslides and soil liquefaction, earthquake-caused tsunamis and seiches, and earthquake-caused flooding from dam or dike failures.

1.1.2 Earthquake-caused fires and toxic materials releases are not hazards considered in this practice.

1.1.3 This practice does not purport to provide for the preservation of life safety, or prevention of building damage associated with its use, or both.

1.1.3.1 This practice does not address requirements of any federal, state, or local laws and regulations of building construction or maintenance. Users are cautioned that current federal, state, and local laws and regulations may differ from those in effect at the times of construction or modification of the building(s), or both.

1.1.3.2 This practice does not address the contractual and legal obligations between prior and subsequent Users of seismic risk assessment reports or between providers who prepared the report and those who would like to use such prior reports.

1.1.3.3 This practice does not address the contractual and legal obligations between a provider and a user, and other parties, if any.

1.1.4 It is the responsibility of the owner of the building(s) to establish appropriate life-safety and damage prevention practices and determine the applicability of current regulatory limitations prior to use.

1.2 Considerations not included in the scope: the impacts of damage to contents, loss of income(s), rents, or other economic benefits of use of the property, or from legal judgments, fire sprinkler water-induced damage or fire.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E2026 Guide for Seismic Risk Assessment of Buildings

2.2 *Other Standards:*[4]

UBC-97 Uniform Building Code, 1997 Edition

IBC International Building Code, current edition

2.3 *ASCE Standards:*[5]

ASCE 7 Minimum Design Loads for Buildings and Other Structures, current edition

ASCE 41 Seismic Evaluation and Retrofit of Existing Buildings, current edition

3. Terminology

3.1 See also definitions in Guide E2026.

3.2 *475-year site ground motions, n*—seismic induced ground motions at a site with approximately: a return period of 475 years, a 10 % probability of exceedance in 50 years, and an annual frequency of 0.21 %. Also referred to as the DBE.

3.3 *field assessor, n*—field assessor, as defined in Guide E2026.

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[1] This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.25 on Whole Buildings and Facilities.

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[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Available from International Code Council (ICC), 500 New Jersey Ave., NW, 6th Floor, Washington, DC 20001, http://www.iccsafe.org.

[5] Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, http://www.asce.org.

3.4 *independent reviewer, n*—independent reviewer, as defined in Guide E2026.

3.5 *lateral load-resisting system, n*—lateral load-resisting system, as defined in Guide E2026.

3.6 *MCE, n*—Maximum Capable Earthquake, as defined in Guide E2026.

3.7 *probable loss (PL), n*—probable loss, as defined in Guide E2026.

3.7.1 *Discussion*—When there are multiple buildings in the seismic risk assessment, then the damageability values for the group of buildings is to be determined as specified in Guide E2026.

3.8 *probable maximum loss (PML), n*—probable maximum loss, as defined in Guide E2026.

3.9 *provider, n*—provider, as defined in Guide E2026.

3.10 *scenario expected loss (SEL), n*—scenario expected loss, as defined in Guide E2026.

3.10.1 *Discussion*—When there are multiple buildings in the assessment then the SEL for the group of buildings is to be determined as specified in Guide E2026, Section 5.3.

3.11 *scenario loss (SL), n*—scenario loss, as defined in Guide E2026.

3.11.1 *Discussion*—When multiple buildings are in the seismic risk assessment, then the SL for the group of buildings is to be determined as specified in Guide E2026, Section 5.3.

3.12 *scenario upper loss (SUL), n*—scenario upper loss, as defined in Guide E2026.

3.12.1 *Discussion*—When there are multiple buildings in the assessment then the SUL for the group of buildings is to be determined as specified in Guide E2026, Section 5.3.

3.13 *SEL475, n*—the scenario expected loss due to the occurrence of 10 %/50-year site ground motions.

3.14 SEL_{MCE}, *n*—the scenario expected loss due to the occurrence of MCE site ground motions.

3.15 *senior assessor, n*—senior assessor, as defined in Guide E2026.

3.16 *significant damage, n*—significant damage, as defined in Guide E2026

3.17 *SUL475, n*—the scenario upper loss due to the occurrence of 10 %/50-year site ground motions.

3.18 SUL_{MCE}, *n*—the scenario upper loss due to the occurrence of MCE site ground motions.

4. Summary of Practice

4.1 The objectives of this practice are as follows:

4.1.1 To synthesize and document good commercial practice for the determination and rating of seismic risk for buildings.

4.1.2 To facilitate standardization of earthquake risk evaluation terminology for financial transactions.

4.1.3 To establish an industry standard for the requirements to evaluate the financial risk for real estate.

5. Significance and Use

5.1 This practice is intended for use as a voluntary standard by parties who wish to undertake the seismic risk assessment of properties. The goal is for users to objectively and reliably compare the financial risks of earthquake damage to buildings, or groups of buildings, on a consistent basis.

5.2 This practice is designed to provide requirements for the evaluation of earthquake damage risk so that technical reports prepared for the evaluation and rating of seismic risk of a building(s) will be adequate for use by other entities. Potential users including, but are not be limited to, those making equity investments, lending, and financial transactions, including securitized mortgage lending by mortgage originators, loan servicers, underwriters, rating agencies, and purchasers of bonds secured by the real estate.

5.3 The use of this practice may permit a user to satisfy, in part, their requirements for due diligence in assessing a property's potential for losses associated with earthquakes for real estate transactions.

6. Due-Diligence Investigation

6.1 The site stability, building stability and building damageability of the property shall be assessed.

6.2 The user shall specify the condition of the property to be evaluated. The seismic performance can be evaluated for the property in its current condition, or as changed by proposed modification of the seismic response of the soils supporting the building or a proposed seismically retrofitted condition of the building(s) or its sections, or any combination of these conditions.

6.2.1 The proposed seismic modifications of the site must be sufficiently described to allow evaluation of the modifications by an Independent Reviewer.

6.2.2 The proposed seismic modifications of the building systems must be sufficiently described to allow evaluation of the modifications by an Independent Reviewer.

6.3 The Guide E2026 level of investigation shall be specified by the user. The same level of investigation should be performed for each type of the seismic risk assessment. Appendix X2 gives guidance on the setting of the level of investigation.

6.4 The qualifications of the Provider shall be specified as required for the level of investigation specified in 6.3 of Guide E2026. The qualifications level must be equal to or higher than the corresponding level specified in 6.2 and 6.3. Appendix X1 gives further guidance on the setting of minimum qualifications.

6.4.1 For an assessment of Level 1 or higher, the qualifications of Senior Assessor and the Field Assessor of the property and its buildings shall be those of Guide E2026 Sections 6.2.3.2 and 6.2.3.3.

6.4.2 Notwithstanding the asserted level of investigation of a report, if the Senior Assessor or the Field Assessor, or both, do not demonstrate the qualifications of Guide E2026 Section 6.2.3.2 and 6.2.3.3, then the report shall be designated a Level 0 report.

6.5 *Seismic Risk Assessment Report*—The findings shall be reported in conformance to the requirements of Guide E2026 for the level of investigation specified by the user in 6.3 and by a provider qualified in accordance with the requirements of 6.4, with the following sections:

6.5.1 A summary that contains the conclusions of the seismic risk assessment:

6.5.1.1 Location of the building(s), characterization of the site and site soils, and gravity and lateral load-resisting systems.

6.5.1.2 Stability determination of each building site under consideration when subjected to the seismic loadings for the building site location and building characteristics as set forth in Section 9 of Guide E2026. Site stability determination need only be qualitative in nature for an SS0 investigation. For SS1 investigations the site stability is a qualitative assessment that includes the implications on damage to the building structural elements. For SS2 and SS3 investigations the site should be considered unstable if significant damage is caused to the building by the site instability.

6.5.1.3 Stability determination of each building under consideration in the seismic loadings for the building site location and building characteristics and for the level of investigation specified, as set forth in Section 8 of Guide E2026.

6.5.1.4 The building damageability values for the building or group of buildings as a whole for the level of investigation specified as set forth in Section 10 of Guide E2026.

(1) PML shall be user-defined. At a minimum, the SEL_{DBE} and SUL_{DBE} shall be reported.

NOTE 1—CMBS industry is currently defining PML as SEL_{DBE}. It is advisable that SEL and SUL values also be reported for MCE events in areas of low and moderate seismicity areas where MCE poses significantly higher risk than the DBE.

6.5.1.5 A specification of the level of investigation for each assessment and a review of the methods used and the personnel engaged.

6.5.1.6 Results for each of the conditions described in 6.2 that apply.

6.5.1.7 Appropriate reliance language for the report and signature. For Level 1 or higher investigations, the professional seal of the provider.

6.5.1.8 All deletions and deviations from this practice (if any) shall be listed individually and in detail.

6.5.1.9 The report conclusion shall include the following statement: "We have performed a probable maximum loss (PML) evaluation for earthquake due diligence assessment in conformance with the scope and limitations of Guide E2026 and Practice E2557 for a Level XX (specify) assessment of [insert address or legal description], the property. Any exceptions to, or deletions from, this practice are described in Section [ ] of this report. This probable maximum loss (PML) evaluation for earthquake due diligence assessment has determined the PML to be [ ]%." PML is defined as [fill in the definition used]. The project [meets/does not meet] the building stability and [meets/does not meet] the site stability requirements.

6.5.1.10 Each report should include a completed Appendix X4.

6.5.1.11 Each report should include a completed Appendix X5.

6.5.2 A body of the report that provides:

6.5.2.1 All detailed reporting information required by Guide E2026, Section 13, including the basis and background for the work performed in support of the conclusions presented in the report.

6.5.2.2 PML values for each building, and, if appropriate, for the group of buildings.

(1) Report of any other information required by the user, which may include business interruption, and contents damageability.

(2) The organization that commissioned the report and the professional liability limitations of the report provider shall be disclosed in the report.

6.5.3 Attachments and appendices to the report as appropriate including detailed resumes of the Senior Assessor and the Field Assessor that demonstrate their qualifications to perform this work as stated in this Practice.

APPENDIXES

(Nonmandatory Information)

X1. GUIDANCE FOR USE OF E2557

INTRODUCTION

This Appendix provides guidance to decision makers for sorting their way through the intricacies of seismic risk assessment. Usually a due-diligence financial decision is posed as *should the transaction be considered further or not*? A PML assessment is commissioned to understand if there is a seismic hazard at the property and the extent of the risk it poses. The process used to complete PML assessments should consider the various sources of uncertainty as well as the financial and other consequences that may arise when a good building is called 'bad' (Type I error), or when a bad building is called 'good' (Type II error). An error of the first type precludes a possibly profitable investment but otherwise is benign in that it does not lead to a loss, whereas the latter error has a higher risk than is nominally acceptable and may lead to large loss. Type II errors lead to unexpectedly higher risks and should be minimized consistent with other objectives of the User. Experience of the ASTM Committee members suggests that the likelihood of Type II errors is highest in (*1*) Level 0 reports, (*2*) reports issued by individuals that are not sufficiently knowledgeable and experienced at any level, and (*3*) reports where the structural documents were not reviewed. If the result of the assessment is unacceptable to the risk profile of the User and the economics of the deal are still attractive, then the determination can only be made to pursue more, better quality and more reliable information and assurance of qualified performers for the specific property. The goal should be to reach conclusions that give reasonable control of Type II errors, but are not so risk adverse as to reject investments that would be prudent and profitable that otherwise have acceptable seismic risk profiles, incorrectly judged to represent a higher risk (Type I errors). Limiting Type I errors to an acceptable level should be a goal as long as the resulting greater Type II errors are not burdensome. Much of the following discussion addresses how to limit the likelihood of an assessment reaching a technically indefensible conclusion.

This discussion is intended to be considered for application to Building Stability, Site Stability and Building Damageability, Building Contents Damageability and Business Interruption Assessments. While much of the discussion focuses on building damage, it applies to all the assessment disciplines by extension.

Practice E2557 in conjunction with Guide E2026, specify minimum requirements to achieve the purpose of evaluating the seismic risk of a proposed real estate commitment. It requires determination of the:

(A) Likelihood of site failure, that is whether faulting, landslides, or liquefaction can occur within the site that can damage the building;
Discussion: One purpose is to limit investments to sites that will not fail, because often the local jurisdictions may not allow reconstruction of buildings at failed site or the market value of the site may be severely impaired in the future because of the site's past failure. The second purpose is to assure that if site failure occurs the damage is within acceptable bounds.

(B) Stability of the building at the Building Code specified levels;
Discussion: While damage repair can be a formidable cost, it is limited by the value of the property. The settlements for death and injury of occupants caused by instability are bounded by net TOTAL worth of the owner, not just the owner's equity and particularly if the owner had prior reason to suspect instability.

(C) Financial risk in the selected scenario; PML (probable maximum loss) of the building or group of buildings, where PML may be defined as the SEL (scenario expected loss) or SUL (scenario upper loss) in the Design Basis Earthquake ground motion, or in other terms that are specific, such as Probable Loss in the Maximum Capable Earthquake.

Discussion: The level of risk must be specified (for example, mean value, or 10 % chance in 50 years), because if absolute certainty is desired, then every building can suffer a 100 % loss, even if highly improbable. The science and technology of building construction and evaluation is not so well-developed that absolute statements can be made.

X1.1 Site Failure

X1.1.1 It is taken as intuitive that investments in structures that are astride faults should warrant special consideration of the acceptability of the building's seismic performance. Similarly, investments in properties with expected site failure due to liquefaction, landsliding, or faulting warrant careful consideration of the implications of such failure. The issue of significance becomes important, when it is noted that seismically-induced liquefaction within a layer of supporting soils could occur, and yet the differential settlement over the building footprint does not result in significant loss to the building and which may be repaired. In other cases the design may have adequately considered liquefaction and provided a foundation that is bearing below the level of site failure. Practice E2557 defines significant damage as damage exceeding 5 %, but this may be set according to the client's needs. This leaves damageability as the essential open discriminant in distinguishing an acceptable transaction from one that is not.

X1.1.2 There are several available tools to evaluate faulting hazard. Since 1972, California has regulations for the investigation of surface fault rupture hazards, with formal zones established around faults deemed active and geologically well defined [Special Publication 42] (**1**).[6] Most other states have implemented at the state or local level, identification of active faults and fault-zones. And the geological literature has identified and mapped most significant faults in all regions. User guidelines may vary, but sites found within such zones in California need not be deemed unstable if the requisite geotechnical investigations have been done and the reports are available, and acceptable set-backs of the foundation from the nearest identified surface fault traces have been established. Other states have somewhat less well-defined programs, and the surface traces of faults may be undefined or undated. Where surface faulting hazards are known or suspected, the involvement of a qualified geotechnical engineer or engineering geologist is recommended.

X1.1.3 There are several available tools to evaluate soil liquefaction. Soil liquefaction may result in loss of bearing strength of soils supporting shallow foundations, differential settlement on flat sites, tilting of buildings, lateral spread and lurching, disruption of utility connections (causing loss of power, water, gas, signal, or sewer), slope failures, flotation of tanks and upheaval of basement slabs. The best source of information is a site-specific geotechnical investigation report, or foundation report. Such reports, typically done as a part of the original design, often characterize the potential for liquefaction at the site and the severity its effects, and recommend steps to mitigate such effects. In the absence of a site-specific geotechnical report, more approximate means may be used. In the State of Washington, the Dept. of Natural Resources provides statewide maps for liquefaction susceptibility [Palmer 2004] (**2**). Since the 1990s, most urban areas in California have been zoned to identify areas that require geotechnical investigation for liquefaction in new construction, and new designs are required to consider liquefaction by ASCE 7, but such zones indicate only the possible presence, but not the degree, of a liquefaction hazard. Other sources (USGS, ABAG, etc.) produce maps presenting approximate degrees of susceptibility (for example, very low, low, moderate, high and very high) based on surface geology, depth to ground water and limited soil borings. Where liquefaction is expected for the scenario ground motions in question, special care is needed in seismic risk assessment, and the involvement of a qualified geotechnical engineer or engineering geologist should be considered.

X1.1.4 There are several available tools to evaluate landsliding hazard. Most state and regional geological surveys have mapped landslide hazards, including past slides, where the natural slope and/or soil materials are prone to sliding, where related to seismic triggering or other causes. These provide a means of identifying slopes whose debris slides could extend into the property under consideration, as well as conditions that warrant design consideration for the building. Slope instability caused by liquefaction of the toe of an embankment, say at a creek or river, is termed lateral spreading and is normally part of the liquefaction assessment. Where landsliding is expected for the scenario ground motions in question, special care is needed in seismic risk assessment, including involvement of knowledgeable professions in this discipline.

X1.2 Practice E2557 Application

X1.2.1 Application of Practice E2557 requires that the User make a number of decisions on: setting the specific definition of the statistical measures of damageability, requirements for the assessor, the Level of Investigation, and selecting the person or institution to do the assessment. The basic premise is to select the criteria to make investment or lending decisions in such a way as to make distinctions between seismically good and bad buildings, and to do this in a manner that is reasoned, measurably reliable, and sufficiently economical such that decisions can be made within the available resources, knowledge and time for them to be made. The requirements for site and buildings stability are well described and have few discretionary variables except the choice of the Level of

[6] The boldface numbers in parentheses refer to a list of references at the end of this standard.

Investigation, which by Guide E2026 should be the same for site and building stability and damageability assessment.

X1.2.2 The two critical decisions for the User are: (*1*) what damageability measure(s) is to be used to estimate the risk and, (*2*) what level of uncertainty in the risk assessment can be tolerated. From these the Level of the Investigation and the selection of the assessor's necessary qualifications follow. After the assessment is presented, the Users must determine if the report meets their requirements for decision making along with the ASTM requirements. This latter issue is addressed in the validation discussion below. With the understanding of how to make decisions on these three issues, Practice E2557 reports can be used with some confidence in making financial decisions and commitments.

X1.3 Selecting the Damage Measure

X1.3.1 While Practice E2557 requires, at a minimum, reporting the SEL, it may be prudent to consider more than a single measure of the risk of a specified property damageability value. This was a central point of the Black Swan, where Taleb (**3**) argued that to do otherwise is to court disaster when the unexpected occurs that was not considered. The Guide E2026 defined damage measures are:

(1) Scenario Loss (SL), which requires a decision about what statistic to use, the SEL or SUL, or some other statistic, as well as the scenario event to be used, and

(2) Probable Loss (PL) requires the return period for exceedance (PL_N) for a given damage level, or the damage level with a stated probability of exceedance in a given time period.

X1.3.2 The SL and PL damageability measures are fundamentally different. SL presents the damage statistics for a given scenario, say the 475-year return period acceleration, or the average ground motion in a specified earthquake of given magnitude on a specified fault. SL values have no explicit return period, (although the scenario earthquake may be associated with a return period for the ground motions). PL values correspond to a specified return period for ground motions, but have no specific earthquake scenario event with which the damage is associated. While the SL gives the damage associated with the defined scenario event alone, the PL gives a damage level associated with a likelihood of exceedance from all earthquakes that may occur in a given time period. SL has the advantage of being easy to understand, while PL gives a better measure of the risk of damage over time.

X1.3.3 The most common SL measures are SEL and SUL. Caution is suggested when using SUL as a sole reported value, since for a single building the ratio of the SUL/SEL may be large, often in excess of 2.0, [Thiel, Kosonen, Stivers, 2012] (**4**) and as noted in Fig. X1.1. For SL the commonly used scenarios are:

(1) A ground motion at the site with a 475-year return period at the site from a probabilistic ground motion hazard analysis. This in the past was designated the design basis earthquake (DBE).

(2) The Maximum Capable Earthquake (MCE) on any nearby fault.

(3) The maximum of the SL for the DBE or other measures of damageability appropriate to the user.

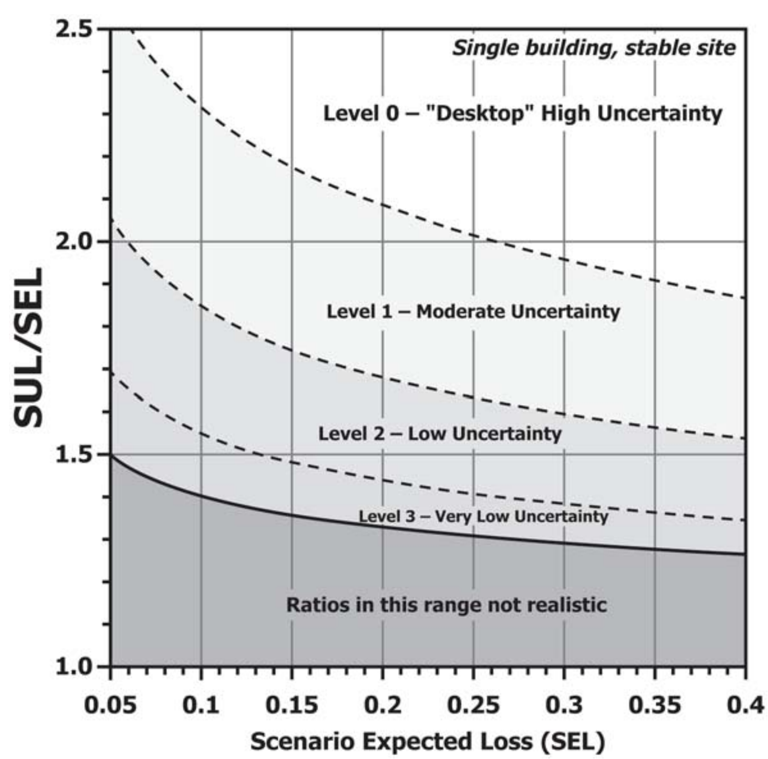

FIG. X1.1 Suggestions of Ranges for SUL/SEL Ratio for Single Building as a Function of Level of Investigation and SEL. The User should inquire of the Provider the basis for damage values not within these ranges to verify that the methods were technically appropriate.

(4) Ground motion referenced in the design building code (for example, ASCE 7) or evaluation standard (for example, ASCE 41).

(5) Ground motions in specified earthquakes on specified faults within the region.

X1.3.4 The MCE used by ASTM is defined differently than it is in ASCE 7 for application in structural design applications. Here the MCE is characterized as the earthquake from among all those likely to impact the site that has the highest mean ground acceleration. In ASCE 7 it is defined based upon performance levels for structural design applications, which may be a probabilistic or deterministic value, and is substantially different.

X1.3.5 The most common characteristics of the PL assessment are to define PL as:

(1) The damage level with a 475-year return period for exceedance (PL475), equivalent to a 10 % probability of exceedance in 50 years, or other stated time period

(2) The damage level with a 10 % probability of exceedance in the nominal term [WG1] of the commitment, or other term required by the User.

X1.3.6 Note that for regular application, Practice E2557 6.5.2.2 suggests reporting of several of these damage measures, not just one. The setting of due diligence criteria, including the damage measure, the Levels of Investigation, and setting criteria for acceptance of a building as an acceptable seismic risk, are discussed in [Thiel, 2001] (**5**).

X1.3.7 Both the SUL and PL are expressed in terms of probability statements. These values need to be supported by calculations based on the mathematical concepts of probability and statistics. For example, to find the SUL as the 90 % upper confidence level of the damage ratio requires that a reasonably applicable probability distribution function be employed for the damage ratio. Also, for a group of buildings at one site, while the replacement value weighted SEL values for the buildings may be added, based on the rule that the mean value of a sum is equal to the sum of the means of the individual components, this addition cannot be done for the SUL or PL values since the standard deviation of a sum of random variables is the square root of the sum of the squares of the individual standard deviations along with any covariance effects due possible non-independent response behavior of the buildings. Many Providers incorrectly assert that the SUL for a group of buildings is the average of the SUL values for the individual buildings. This is not mathematically correct. Determining other statistics on damageability for groups of buildings, whether SL or PL values, have to be performed correctly; only for SEL is the adding approach correct.

X1.4 Selecting the Acceptable Uncertainty Level

X1.4.1 Guide E2026 specifies four Levels of Investigation, ranging from Level 0, which has only reporting requirements, to Level 3, which is an extensive investigation and analysis of the building. The higher the Level, the more expense and effort required to complete such a study. A Level 0 report has the highest uncertainty in its results for both stability and damageability, and noting the lack of requirement for the performer, these uncertainties are likely to be very large. Level 3 should have the lowest uncertainty, with the intermediate levels progressively more certain in their results, with damageability uncertainly decreasing less rapidly than does stability uncertainty. Guide E2026 for Levels 1 and higher provides for minimum levels of expertise and experience for Assessors and defines two levels, Senior and Field Assessors, see 3.2.

X1.4.2 Generally, for a portfolio seismic risk manager that is evaluating the incremental seismic vulnerability of a group of investments, the seismic risk screening process should lead to a more seismically robust set of investment properties. The seismic risk screening process is not foolproof (Type I and II errors will occur), and unanticipated earthquake losses will still occur, even with a good seismic risk screening process. But a good process will reduce their occurrence compared to a no screening process or a poorly executed process. A portfolio seismic risk manager should also seek to avoid localized accumulations of risk, where multiple buildings may be highly damaged in a single large earthquake.

X1.5 Uncertainty Reflected in Risk Estimates

X1.5.1 Seismic risk for a building is reported is commonly presented as scenario loss (SL), with scenario expected loss (SEL) representing the mean or expected value of loss, and scenario upper loss (SUL) representing the loss that has a 10 % percent probability of exceedance due to the specified ground motion of the scenario considered. Earthquake loss estimates should reflect the Level of Investigation in the Building Damageability (BD) assessment as affected by the site hazard characterization, construction documents reviewed, field survey and engineering investigation conducted. Fig. X1.1 provides rough guidance to allow the User to gauge whether the ratio SUL/SEL for an individual building adequately reflects the level of uncertainty from the information considered and the investigation accomplished, for a scenario with a specified hazard level on a stable site. Note that site instability will increase the level of uncertainty relative to those shown. It can be used as an evaluative tool for examining the reliability of a draft or final PML report by comparing the ratio SUL/SEL to the graphed ratios. If an SUL is not reported, then the report has not met the requirements of Practice E2557. When doing this evaluation, be careful to review whether the Level of the report was consistent with work required by the standard. If the ratio is less than the lower threshold of Fig. X1.1, then the User should request a justification for the conclusion. Similarly, if it is higher than the upper bound of the range, then the User should request justification. If the reasoning for these conclusions is not clear, then it may be prudent to request a peer review of the report by a knowledgeable engineer. For groups of buildings, the problems are more complex. See, for example, Thiel [2001] (**5**) for some of the issues posed in computations for multiple buildings.

X1.6 Management of Uncertainties

X1.6.1 There are several ways to control uncertainty of the assessments conclusions in the Practice E2557 process:

(1) The User should set clear criteria for conducting seismic risk assessments, and then screen and select Providers

(engineering consultants) to meet the qualifications set in Practice E2557 and Guide E2026, as well as the User's own requirements.

(2) The User should set the Level of Investigation high enough to assure that the assessment is competently and completely done consistent with the User's needs. It is cautioned that a Level 0 assessment in Guide E2026 has almost no requirements except for reporting, and thereby is has the highest risk of both Type II and Type I errors. Level 0 may be a good starting point for a decision process that can accommodate the possibility of further investigation at a higher level, say for property acquisition that will be held for the long term. Appendix X2 provides some additional guidance on setting levels based on risk tolerance levels or property values.

(3) The User should retain individuals that have reliable qualifications and experience to perform the study. Practice E2557 states that Level 1 or higher assessments should be completed by Level 1 qualified Providers, with no requirements for Level 0. Level 0 Investigations are considered to provide the highest uncertainty of results of any investigation. Some moderation of the uncertainty in Level 0 Investigations can be achieved by requiring the person(s) performing the assessment to be a licensed professional with qualifications for an Guide E2026 Level 1 investigation, rather than the minimal requirements for a Level 0 investigation. This is to assure that the person making the judgments based on minimal information on the building have the experience to make such. The less time and energy expended the more demand for expertise.

(4) The User or Provider should make a strong effort to locate structural drawings. If the assessor does not have access to the structural design and/or structural modification drawings of the existing building or other records of the original construction and how it has been structurally modified, and has not visited the building, then it is unlikely that reliable conclusions can be made of the building's expected seismic performance, even if the assessor is highly qualified and knowledgeable. A site visit alone is sometimes insufficient to draw reliable conclusions even by very well-qualified reviewers. Generally the architectural elements mask the structural system and its character and quality are hard to reliably determine by just visual observation. If the building is particularly simple structurally and its structural elements can be viewed from the interior and exterior reliable conclusions may be possible. In concrete and masonry elements, even when structural elements are exposed, important detailing of reinforcement is not visible. The result is that for most structural types where the connection and construction details cannot be viewed, lack of access to design drawings can limit the conclusions of an assessment to high uncertainty.

(5) Guide E2026 defines the qualifications of Senior and Field Assessors in 3.2 and 6.2.3, and recommends that the investigators for Level 1 and higher meet these requirements. It may be prudent for a User to consider such as a minimum qualification for all investigations where the User has a concern to have a high confidence in the results of an assessment.

(6) If the report includes a recommendation for seismic retrofit to meet the Users requirements, the report should provide enough detail of the proposed modifications and the likely seismic performance of the retrofit such that a technical reviewer or design professional can understand the work to be done, its basis, and the reasons that the retrofit will mitigate the defects identified and yield adequate performance.

X1.7 Other General Guidance

X1.7.1 The ASTM Committee has the following additional specific observations that warrant consideration:

(1) The value of having accurate and current structural documents available for the review cannot be understated; also of value are architectural drawings, soil and foundation investigation reports, and if possible structural calculations, along with field inspection and testing reports. The absence of these documents requires significantly more effort on the part of the assessor to reach a comparable certainty in the results compared to when they are available. The drawings should include both the building as constructed, and as structurally modified to the present, whether by repair, extension or modifications. Geotechnical investigation reports ("soils reports") are also important, particular where community hazard maps call attention to potential site failure hazards for the site. Often when an owner does not have the structural design information or a geotechnical report, the local building jurisdiction has such records; when they do not, they may have other records (for example, the original building permit) with the names of the architect, and structural and geotechnical engineers, who may have these records.

(2) Some buildings have been seismically retrofitted. Caution is necessary when the basis for a retrofit was limited in scope, rather than comprehensive. Some retrofits may be undertaken as "prudent owner" actions, to address a deficiency identified in a structural review. In such cases, the retrofit may be permitted by the building jurisdiction so long as the retrofit is deemed to reduce the seismic vulnerability of the building. Other retrofits may be required by local ordinance. In each case, the requirements for which the retrofit was designed and the areas of work are critical to ascertain. The applicability of the requirement may be limited, for example, many unreinforced masonry bearing wall buildings are reported as retrofitted based on meeting community requirements for bracing parapets, with no other work done to correct floor and roof diaphragm connections to the heavy masonry walls, or other major vulnerabilities. The basis for such community requirements was not to protect the occupants, but to protect the people near the building on walkways. In other cases the community or client requirements of the retrofit could be limited to achieving stability improvements, but may not meet ASCE 41 performance standards, and they may be limited in scope. If an assessment report does not indicate that the retrofit design basis and permitted design documents have not been reviewed, and there is no conformation in the field that the work was completed, then it is advisable to consider the report to be highly uncertain. Many buildings have retrofit work that was permitted and with plans that were approved, but for whatever reason the retrofit was not implemented.

(3) Where the assessor has not visited the building, and relies on photographs taken by others, the uncertainty in the results should be assessed as very high, even if the reviewer is qualified at the Senior or Field Assessor level. Even when the

assessor has the structural design drawings and a geotechnical report, the uncertainly may still be significant, although lower, since the structure may have been altered since construction.

(4) A reasonable (but not sufficient) qualification for the assessor is to be a professional engineer licensed to perform structural work, or a licensed architect. Subsection 6.3 of the reference Guide E2026 provides a number of qualification issues that are not limited just to a license. An assessor having done many assessments may or may not have adequate knowledge of the science and engineering issues necessary to understand to do seismic assessments. Note that there are several branches of Civil Engineering (all of which use the term Professional Engineer), such as environmental, geotechnical and transportation that would not themselves give the assessor proper qualifications to perform a structural reviews consistent with those given in 6.3 of Guide E2026. The User should confirm that the person doing the assessment has the knowledge and experience to complete the assignment for that particular building type consistent with Guide E2026. It is often useful to review several reports the assessor has prepared to discover how thorough the assessment is, the degree to which they provide evidence of technical understanding of the building(s) reviewed, and to assess whether they have met the stated requirements of ASTM and the client's needs for reliability and uncertainty control. Seismic evaluation is a highly technical and demanding application of structural engineering that requires experience and expertise not shared by all structural engineers or architects.

(5) Conformance with the applicable building code at the time of construction should reduce, but will not eliminate, damage in an earthquake. The historic purpose of the building code is to provide a reasonable likelihood of life safety for the occupants of the buildings when various natural events, including earthquakes, occur. It is not generally intended to limit damage to any particular level, except for some special purposes like acute-care hospital regulation, but helps achieve this purpose by limiting catastrophic failure of building elements and systems, and requiring seismic bracing and anchorage of nonstructural elements. Conformance with building codes that are evaluated as providing acceptable performance for the specific building type is an effective, but not absolutely reliable, measure to limiting damage. Benchmark years for different building types and regions are contained within ASCE 41. The benchmark code and years vary based on the building type and building region. A building constructed after its benchmark year is expected to have better performance than one constructed before, and may be comparable for stability to those designed to the current applicable code.

(6) When a seismic resisting system is or was novel or unique at the time of construction, care should be taken to assure that the assessor is adequately experienced to understand its expected performance. This is not to say that they are more dangerous, but early in the development of any new structural system there is more uncertainty in the quality and effectiveness of the system, warranting higher qualifications for the assessor, and sometimes requiring structural engineering analysis, to limit the uncertainty in the resulting estimates to levels that are accepted for other well-established systems.

(7) Until recently, the separation of buildings to avoid collision during earthquakes was not a building code requirement. While referenced as an issue in prior editions, it was not until 1985 edition of the Uniform Building Code (UBC) that a method to calculate the separation was provided. As a consequence, seismic separations for buildings designed prior to about 1990 are often inadequate to prevent contact and pounding under the ground motions commonly considered for studies under Guide E2026. The separation that is adequate depends in part on the structural system and geometry of the adjacent building. Structural stability and damageability assessments should be considered deficient if they do not address the adequacy of building separations and their consequences. Similarly, the possibility of falling parapets, or closure walls, such as from adjacent unreinforced masonry structures, should be considered, unless specifically disclaimed as an external to the building concern and noted.

X1.7.2 These recommendations are intended to provide guidance and perspective on how to use Practice E2557 and what to expect from different levels of investigation and quality of information. The decision maker must be well enough informed to participate in the setting of the criteria appropriate to the risk position of their institution and the specific circumstances of each property to avoid technical pitfalls and achieve the desired level of quality in seismic risk assessment.

X2. LEVEL OF INVESTIGATION

X2.1 The selection of the level of the investigation performed should be guided by the level of uncertainty in the result that is acceptable to the User as discussed in Appendix X1. In addition, two guidance tables are provided: *1)* based upon the level of uncertainty in the results and *2)* based upon the building replacement cost.

X2.1.1 If the degree of uncertainty is the guiding consideration in selecting the level of investigation, then Table X2.1 is offered as a guide to selection of the levels of investigation to match the acceptable level of uncertainty. The zone references are from the map of seismic zones as it appears in UBC-97, which is reproduced in Fig. X2.1. The acceptance uncertainty levels are not defined, but are given to reflect the progression of investigation levels with changes in acceptable uncertainty.

X2.1.2 If the cost of replacement of the building is the guiding consideration in selecting the level of investigation, then Table X2.2 is offered as a guide to selection of the levels of investigation.

X2.1.2.1 The rationale for changing requirements for different property values is as follows. It is expected that the

TABLE X2.1 Seismic Zone of the Site and the Level of Uncertainty Acceptable to the User

Acceptable Uncertainty Level	Zones 0, 1	Zones 2A, 2B	Seismic Zone/UBC-97 Zone 3	Zone 4
Low	none	BS0, SS0, BD0	BS1, SS1, BD1	BS2, SS2, BD2
Moderate	none	none	BS0, SS0, BD0	BS1, SS1, BD1
High	none	none	none	BS0, SS0, BD0

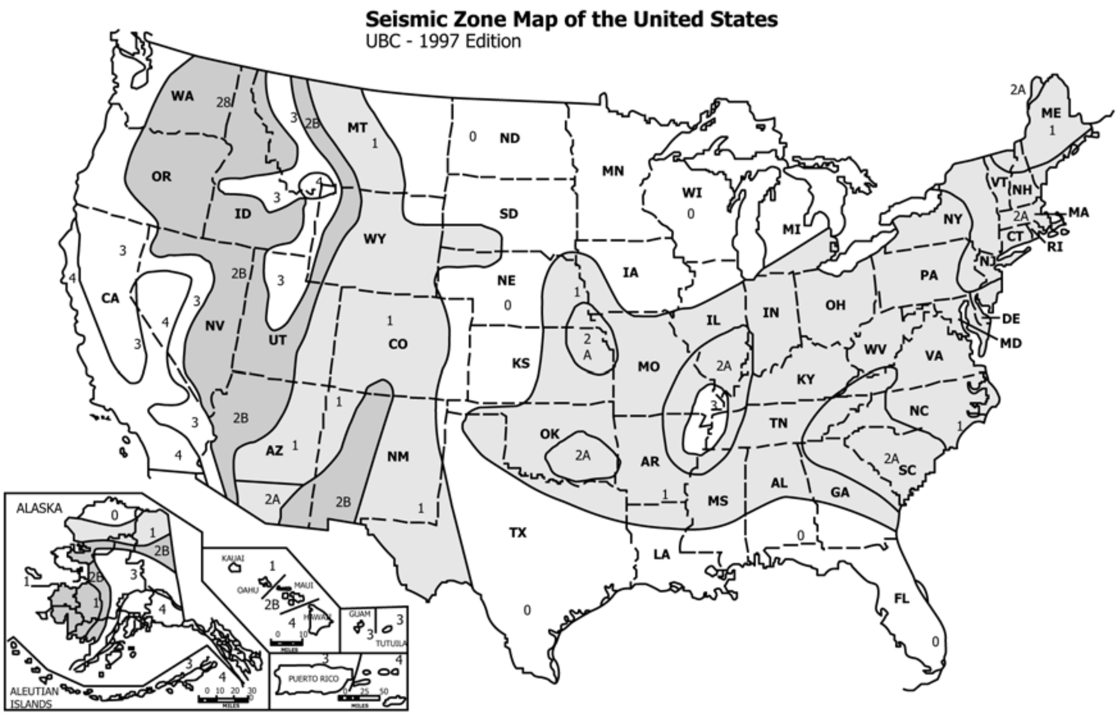

FIG. X2.1 Seismic Zone Map of the United States
Reproduced from the 1997 Edition of the Uniform Building Code with Permission.

TABLE X2.2 Seismic Zone of the Site and the Building Replacement Cost

X, Building Replacement Cost	Seismic Zone/UBC-97 Zones 0, 1	Zones 2A, 2B	Zone 3	Zone 4
$0M < X = $5M	none	none	BS0, SS0, BD0	BS0, SS0, BD0
$5M < X = $15M	none	none	BS0, SS0, BD0	BS1, SS1, BD1
$15M < X = $50M	none	none	BS1, SS1, BD1	BS1, SS1, BD1
$50M < X = $100M	none	BS0, SS0, BD0	BS1, SS1, BD1	BS2, SS2, BD2
$100M < X	none	BS1, SS1, BD1	BS2, SS2, BD2	BS2, SS2, BD2

uncertainty in seismic loss for a given property will decrease significantly with increasing level of investigation. Since most loans will be part of a limited group of financial commitments, the larger an individual loan, the greater is its participation as a fraction of the total risk of the group. A method to reduce the level of uncertainty is to require a higher level investigation for the greater value property. When the pool gets larger, say for a security, then the impact is the same. Therefore, it was assumed in preparing the table threshold values that some parity was needed to keep the uncertainties of the same order for groups of lower property values compared to one larger property.

X2.1.2.2 It should be noted that the costs of doing higher-level investigations are higher and they do not go up linearly, so there is an administrative cost of the decisions made based on this table.

X2.2 The seismic zone references in Tables X2.1 and X2.2 are from the map of seismic zones as it appears in the UBC-97 which is reproduced in Fig. X2.1. These maps were developed so that each zone corresponded with a range of peak ground accelerations associated with the DBE. While there are more recent seismic risk maps, these generally require specific information on the seismic response characteristics of the site and structure that are seldom available before the seismic risk assessment has begun. Therefore, for ease and consistency of use, the 1997 map is used.

X2.2.1 Where a digital ground motion tool (such as the USGS website) is used to determine PGA the DBE for use of these Tables, then the Zone can be determined from the PGA assessed for the specific site assumed to be ASCE-7 Soil Class D, and as follows: if the PGA $\geq$ 0.35 g, then use Zone 4, if 0.25 g $\leq$ PGA $<$ 0.35 g, then use Zone 3, and if 0.175 g $\leq$ PGA $<$ 0.25 g, then use Zone 2, and for all others use Zone 1. While these are not exact, they will lead to more precise site values than use of the maps, particularly near the zone boundaries. It must be noted that the UBC maps were not developed to reflect the exact boundaries of ground motions, but to reflect professional judgment on the part of the UBC for the appropriate relative seismic hazard for design of the sites. The digital procedure may not yield identical Zone assignment for the site as estimated from the UBC map, but are expected to be on average consistent zone determination of the UBC map, and sufficiently accurate for this purpose of determining what level of investigation should be made. When a map is used to determine the need for a seismic assessment, it is prudent to include in a Provider's scope-of-work confirmation of whether the criteria of the User are met to complete a seismic assessment before significant effort is undertaken to complete the assessment.

X2.3 Use of either the Map tool or a web-based DBE determination as suggested always has some uncertainty in whether these tools yield a reliable result. If the User has a low tolerance for making mistakes in determining whether a PML assessment is required, then it is advised that the DBE be determined numerically, and the threshold ground motions of X2.1.1 for requiring a PML assessment be decreased by 0.05 g from those given.

X3. DAMAGE ASSESSMENT APPROACHES

X3.1 Damageability assessments may be completed using: proprietary methods, disclosed or undisclosed, software either on the Internet or custom developed, or methods published in the peer-reviewed literature. In each case the assessment should be thoughtfully applied to the specific characteristics of the building assessed and its specific exposure to earthquake hazards. Among those from the literature are:

(1) ATC 13, 1985 and ATC 13-1, 2002 [Applied Technology Council] (**6**),(**7**),

(2) Karl Steinbrugge, Earthquake, Volcanoes and Tsunami, 1982 (**8**),

(3) Thiel-Zsutty Model, Earthquake Spectra, 1987; Journal of the Structural Design of Tall Buildings, 1997, 2001, 2012 (**9**),

(4) Code-Oriented Damage Assessment, or CODA, Earthquake Spectra, 2009, and

(5) HAZUS and AEBM, Kircher et al., Earthquake Spectra, 1997 (**10**).

X3.2 Some of these models have available software to implement their application. A number of different software tools are available to assist in estimating seismic damage to buildings, some public and some proprietary.

X3.3 Where the analysis for building stability or damageability become significant, a wide range of engineering analysis software typically used for design and analysis can be very useful, including ETABS, SAP, RISA, PERFORM-3D, These programs are expensive to use and require significant structural sophistication to apply. Also their use is seldom within normal due diligences budgets except for Level 2 or higher assessments.

X3.4 Where analysis is not intensive, publicly available software models include:

(1) ST-Risk,[7]

(2) SeismiCat,[8]

(3) HAZUS,[9]

(4) The "Advanced Engineering Building Module" or AEBM — a version of the HAZUS[10] earthquake model from the Federal Emergency Management Agency (FEMA), and

(5) The Performance Assessment Calculation Tool (PACT) as described in FEMA P-58-1.[11]

X3.5 When selecting Users that propose use of any of these tools it is prudent to consider the following issues:

(1) Ability to provide SEL, SUL and PL damage estimates;

(2) Use of engineering measures of ground motion, such as peak ground acceleration (PGA) and spectral acceleration (Sa), rather than Modified Mercalli Intensity (MMI);

(3) Ability to accommodate engineering findings (for example, from ASCE 41 Tier 1 or Tier 2 evaluations) to improve seismic risk estimates, through engineering parameters (for example, ASCE 7 structural parameters, such as structural period, T, and design base shear coefficient, Cs);

(4) Adjustment of uncertainty (for example, the ratio of SUL to SEL) in accordance with concepts of probability and statistics to reflect Level of Investigation and the quality of information available; and,

(5) Ability to estimate risks from ground shaking and settlements induced by soil liquefaction on flat sites.

(6) The procedures should be sufficiently transparent to permit peer review concurrence with assigned judgmental values and procedures.

X3.6 The results of PML software or published methods should not be used without critical evaluation by experienced engineers. Available PML methods and software do not necessarily directly account for important building characteristics such as plan irregularity or impact with adjacent buildings (pounding), nor will it provide risk estimates for seismic hazards such as surface fault rupture, liquefaction-related lateral spreading, tsunami inundation or earthquake-induced slope instability, which require detailed engineering investigation. The available damage models and PML software provide damage estimates for simple building types conforming to a

[7] See http://www.st-risk.com.

[8] See http://www.seismicat.com.

[9] See http://www.fema.gov.

[10] HAZUS is a registered trademark of the Federal Emergency Management Agency.

[11] See http://www.atcouncil.org.

single structural system, and may not accommodate buildings with mixed structural systems. Some engineering-based models (for example, HAZUS) may be able to model seismic retrofit, by modifying engineering parameters relating to capacity and fragility.

X3.7 Whatever method or software is used, Guide E2026 13.2.3 and 13.2.4 require that the methods used and their basis be fully disclosed, including both references to literature used, and editions and dates of software that may have been used, 13.2.6. The report should the input parameters used by the model and, if software, the output should be included in the PML report. These will allow reviewers to verify results.

X4. ASTM SUMMARY FINDINGS FORM

[This page is to be completed and attached to all reports conducted under the above guidelines and serves to specify the scope of services, qualifications of reviewer, and engineers' liability for conducting a seismic review of a property.]

Property Name:

Property Address:

Report Title and Date:

Site Visit Performed By/Date: [Name(s), Company, and License No(s) if different from below]

Evaluation Performed By: [Name(s), Company, and License No(s), if different from below]

Specific Design Documents Reviewed:

Methods to Determine Site Ground Motions and Site Stability:

PML Defined As:

Analysis Methods/Procedures Used to Determine PML:

Analysis Methods/Procedures Used to Determine Building Stability:

ASTM E2026 and E2557 Level of Review: [#] with scope as defined by BS[#], G[#], SS[#], D[#]

The Report Includes the Following Exceptions to ASTM Requirements: [List below]

ASTM Required Statement:
[Company/Individual Name] have performed a probable maximum loss (PML) evaluation for earthquake due diligence assessment in conformance with the scope and limitations of ASTM Guide E2026 and Practice E2557 for a Level [XX] assessment of *[insert address or legal description]*. Any exceptions to, or deletions from, ASTM requirements are described in *[Section]* of this report and are listed above. This PML evaluation for earthquake due diligence assessment has determined the PML to be *[fill in percentage] %*, where PML is defined as *[fill in the definition used]*. The building *[meets/does not meet]* the building stability requirements as determined by [insert assessment method used] and [meets/does not meet] the site stability requirements.

The undersigned hereby acknowledges that the above referenced report is considered an engineering work product, and as such, confirms that he/she is qualified by licensing and experience to conduct such review. Furthermore, the report was prepared by or under the direct supervision of the undersigned as specified by state laws or codes including, but not limited to, the site visit, determination of building stability, and estimation of probable maximum loss. The information and opinions in the report are subject to the limitations and qualifications contained therein.

Name: ________________________________
Company: _____________________________
License No. ________________ State: _______ Affix Seal Here
Registration Title: _________________________

X5. IMPORTANT INFORMATION ABOUT YOUR SEISMIC RISK ASSESSMENT REPORT

[Name] – Project [Project Number] [Date]

Seismic Reports are Performed for Specific Purposes, Clients, and Projects

Seismic risk assessment reports are intended to meet the specific needs of their clients. A seismic report prepared for a particular client may not fulfill the needs of a different client such as a lender, an insurance company, or the owner. Because each seismic report is unique, no one should rely on your seismic report without first conferring with the engineer who prepared it. No one, not even the intended client, should apply the report for any purpose or project except the one for which it was originally prepared.

ASTM Standards

Seismic risk assessment reports should be based on the following ASTM Standards:
- ASTM E2026 Standard Guide for Seismic Risk Assessments of Buildings
- ASTM E2557 Standard Practice for Probable Maximum Loss (PML) Evaluations for Earthquake Due-Diligence Assessments

Reference of the standards in a report does not constitute an adequate report. The report should follow the scope and requirements for qualifications of the preparer.

Basic Report Requirements

As a minimum, each report should contain the following:
- Property information and description of buildings,
- Review of seismic hazards at the site,
- A list of documents reviewed, such as design drawings,
- Level of Review provided by the report,
- Estimation of building loss, the definition of the loss, and the analysis and methods used to determine loss,
- Determination of building stability (collapse potential) and methods used to reach opinion, and
- Qualifications of the reviewer and those conducting the site visit (if different).

Know the Level of Investigation

The ASTM Standards provide for four levels of investigation, each with decreasing uncertainty:

- Level 0 is often referred to as a screening level or desktop review and is based on general information about the building type, characteristics and site information. It is considered to have a high uncertainty level. It is generally provided by in-house PCA or Environmental firms, insurance brokers, or through data entry in seismic risk programs.
- Level 1 is generally considered an engineering cursory review, including a review of construction documents and site visit by a practicing structural engineer. It is considered to have a moderate uncertainty level.
- Level 2 is considered a detailed evaluation with a moderately low uncertainty level. It is generally conducted by a practicing professional engineer with specific knowledge of the particular building systems.
- Level 3 is considered an exhaustive engineering review with minimum uncertainty. It is performed by engineering firms with demonstrated, substantial understanding and experience in the specific technical issues for the specific type of structure.

Qualifications of the Reviewer Can Vary

Each Level of ASTM review allows for different qualifications of the reviewer and those conducting site visits. Simply having professional license does not qualify an individual, as those individuals may be experienced or licensed in an unrelated field such as mechanical, electrical or environmental engineering. For Levels 1 and higher, both the person preparing the report (Senior Assessor) AND the person performing the site visit (Field Assessor) should be a registered Professional Engineer (PE) with primary experience in the design and analysis of building structural systems, and preferably a registered Structural Engineer (SE) in a State with that designation.

Read the Entire Report

Serious problems have occurred because those relying on a seismic report did not read the entire report. Do not rely on an executive summary. Do not read selected elements only. In many cases, clients look for an acceptable "PML" value without reading the definition of the loss, or understanding that there may be building or site stability issues which may result in high risk to life-safety.

Conditions Can Change

A seismic report is based on the conditions of the property and knowledge of seismic hazards at the time the report was prepared. Do not rely on a seismic report whose adequacy may have been affected by: the passage of time wherein damage such as settlement or the deterioration of the structural systems may have occurred; natural disasters such as earthquakes, wind or floods; or man-made changes such as the modification to the building or lateral force resisting systems. Always contact the engineer before relying on the report.

Most Findings are Professional Opinions

Professional Engineers review drawings, conduct site observations, perform analyses of buildings, then apply their professional judgment to render an opinion regarding the potential seismic loss and building stability. Hiring a qualified professional with a complete scope of services will result in seismic risk assessment reports that are comprehensive, reliable, and have lower uncertainty.

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(3) Wikipedia, 2015: Using your web browser in Wikipedia, look up "Type I and Type II errors" for a discussion, or consult any modern statistics textbook under Hypothesis Testing.