**Subcommittee WK55885 – Seismic Risk Assessment of Real Estate Portfolios**

***A new standard for real estate owners, lenders and insurers, and the Providers who serve them.***

**11/19/19**

**INTRODUCTION**

Real estate owners and mortgage lenders with sets of properties (“portfolios”) distributed in active earthquake regions need to know and manage their seismic risks. They may need to report the risks to company management, shareholders, investors, regulators and rating agencies, and they may choose to purchase earthquake insurance. This standard establishes methods and procedures for this set of Users so that risk Providers (engineers, seismologists, geologists and others), may adequately assess financial and other exposures, site hazards and property seismic vulnerabilities and, using sound risk approaches, accurately estimate financial and other relevant risks to portfolios from future earthquakes, and properly disclose the uncertainty in the estimates. This standard is related to, but distinct from ASTM E2026 — “Standard Guide for Seismic Risk Assessment of Buildings,” and E2557 – “Standard Practice for Probable Maximum Loss Evaluations for Earthquake Due-Diligence Assessments,” as Users and Providers are distinct, the technology for seismic risk assessment is more complex, and stakeholder concerns are largely financial.  Nevertheless, findings from PML evaluations can provide valuable input for portfolio risk assessments, and the terminology and other technical approaches have many shared elements. The standard describes the elements of portfolio seismic risk models, and recommends methods and procedures to prepare the input and evaluate and interpret model results.

**1. Scope**

1.1 This document provides guidance on conducting seismic risk assessments for building portfolios. As such, this guide assists a User to assess aggregate losses from earthquakes.

1.1.1 Hazards addressed in this guide include earthquake ground shaking, and differential settlements induced by soil liquefaction on flat sites caused by earthquakes;

1.1.2 Hazards not addressed in this guide include losses caused by site instability, including fault rupture, landslides, lateral spreading and settlement from liquefaction, and earthquake-caused off-site response impacting the property, including loss of power, water or other utilities, loss of access, or earthquake-induced flooding from dam or dike failure, tsunamis and seiches;

1.1.3 Losses not addressed include those resulting from the collapse of structures not a part of the portfolio under consideration;

1.1.4 It is the responsibility of the User of this guide to establish appropriate life safety and damage prevention practices and determine the applicability of current regulatory limitations prior to use.

1.2 The objectives of this guide are:

1.2.1 To synthesize and document guidelines for seismic risk assessment of building portfolios from earthquakes;

1.2.2 To encourage standardized seismic risk assessment and reporting of risks;

1.2.3 To establish guidelines for assessment of site conditions and building damageability, and the investigation considered appropriate, practical, sufficient, and reasonable for the seismic risk assessment of portfolios;

1.2.4 To establish guidelines on what reasonably can be expected of and delivered by a Provider in conducting the seismic risk assessment of building portfolios;

1.2.5 To provide guidelines on the effective use of software for portfolio seismic risk assessment;

1.2.6 To establish guidelines by which a Provider can communicate to the User risk results and the uncertainty of those results in a manner that is meaningful and not misleading either by content or by omission.

1.3  This guide does not describe how to conduct single-site investigations for seismic hazards, site stability, building damageability, building stability, contents damageability, or the susceptibility to business interruption (B.I.) — the reader is referred to ASTM E2026 and E2557 for such investigations.  However, for business interruption, portfolio seismic risk assessment can provide a framework for evaluation of systems or network impacts on functionality or revenue.

**2.  Reference Documents**

*2.1 ASTM Standards:*

E631 Terminology of Building Constructions

E2026 Standard Guide for Seismic Risk Assessment of Buildings

E2557 Standard Practice for Probable Maximum Loss (PML) Evaluations for Earthquake Due-Diligence Assessments

*2.2 Building Standards:*The following resource documents provide technical guidance for the seismic evaluation and retrofit of existing buildings.

ASCE 7 Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers, current edition

ASCE 41 Seismic Evaluation and Retrofit of Existing Buildings, American Society of Civil Engineers, current edition

*2.3  Seismic Hazards in the United States:*The following resource document serves as a basis for earthquake hazard models, for seismic building codes for new buildings, and for seismic evaluation and retrofit of existing buildings.

Petersen, M.D., Moschetti, M.P., Powers, P.M., Mueller, C.S., Haller, K.M., Frankel, A.D., Zeng, Yuehua, Rezaeian, Sanaz, Harmsen, S.C., Boyd, O.S., Field, Ned, Chen, Rui, Rukstales, K.S., Luco, Nico, Wheeler, R.L., Williams, R.A., and Olsen, A.H., 2014, Documentation for the 2014 update of the United States national seismic hazard maps: U.S. Geological Survey Open-File Report 2014–1091, 243 p., http://dx.doi.org/10.3133/ofr20141091.

*2.4 Catastrophe Modeling Standards:*The following resource document relates to the use of models.

Actuarial Standard of Practice No. 38, ASOP No. 38, “Using Models Outside the Actuary’s Area of Expertise (Property and Casualty),” Actuarial Standards Board, 2011.

**3.  Terminology**

3.1 *Definitions*:

3.1.1 See Terminology E631.

3.1.2 For definition of terms related to the seismic risks of individual properties, see ASTM E2026 and E2557.  Selected terms are included in this standard.

3.1.3 For definition of terms related to building construction, ASCE 7 and ASCE 41 provide additional resources for understanding terminology and language related to seismic performance of buildings.

3.1.4 For definition of other terms and additional detailed information related to seismic events and structural design, see the reference documents (Section 2) as well as the references at the end of this document.

3.2 *Definitions of Terms Specific to This Standard—*This section provides definitions of concepts and terms specific to this guide. The concepts and terms are an integral part of this guide and are critical to an understanding of this guide and its use.

3.2.1 *acceleration, n–*the rate of change of velocity as a function of time.  Acceleration may change the speed or direction of an object.  Commonly expressed as a fraction or percentage of the acceleration due to gravity (g), wherein g = 32.2 feet per second per second.

3.2.2 *active earthquake fault, n–*an earthquake fault with evidence of displacement during the Holocene epoch, typically about the last 11,000 years. Faults with evidence of displacement during the Pleistocene may be considered potentially active.

3.2.3 *adjacency risk, n–*risk posed by adjacent structures to the subject building, from pounding, from collapse of the neighboring structure or falling debris

3.2.4 *aggregate loss curve, n–*see risk curve or exceedance probability curve

3.2.5 *allocation models, n–*financial models to distribute consequences among stakeholders

3.2.6 *average annual(ized) loss (AAL), n–*the loss per annum due to hazards, calculated from a probabilistic loss contribution of all events.  The expected annual loss is the expectation of the probability distribution of loss per annum, and under certain assumptions may be calculated as the probability-weighted average-of loss due to all possible hazard events.

3.2.6.1   *Discussion–*The expected annual loss is the expectation of the probability distribution of loss per annum and under certain assumptions may be calculated as the probability weighted average of loss due to all possible hazard events.

3.2.7 *building code, n–*a collection of laws (regulations, ordinances, or statutory requirements) applicable to buildings, adopted by governmental (legislative) authority and administered with the primary intent of protecting public health, safety, and welfare.

3.2.8 *building contents, n–*elements contained within the building that are not defined as building systems.

3.2.8.1 *Discussion–*Examples include tenant-installed equipment, storage racks, material handling systems, shelving, stored inventories, furniture, fixtures, office machines, computer equipment, filing cabinets, and personal property.

3.2.9 *building systems, n–*all physical systems that comprise a building and its services.

3.2.9.1 *Discussion–*This includes architectural, structural, mechanical, plumbing, electrical, fire life-safety, vertical transportation and security systems. Not included in building systems are those contained within a building and defined as building contents.

3.2.10 *business interruption, n–*a period of interruption to normal business operations that can potentially or materially cause a loss to the owner/operator of that business.

3.2.10.1  *Discussion–*The loss may be partial or total for the period under consideration. Business interruption is expressed in days/weeks/months of downtime for a building as a whole and the loss estimated using the cost per unit time for the interruption.

3.2.11 *catastrophe model, n–*a computer-based model that assesses the impact of natural catastrophes, estimates physical damage to property, contents and occupants, and assigns probabilities to the range of possible outcomes, to estimate financial loss and other consequences from such perils as earthquakes, hurricanes, or floods.

3.2.12 *catastrophe model provider, n–*a vendor or consultant who creates and maintains a software system for the analysis of earthquake risks, and provides the software, or access to the software to the engineering service provider for seismic risk analysis of the user’s real estate portfolio.

3.2.13 *correlation, n–*the tendency or likelihood of the behavior of one element to be influenced by the known behavior of another element, e.g., geographic correlation of risks; spatial correlation of ground motion.

3.2.14 *damage or repair cost, n–*cost required to restore the building to its pre-earthquake condition, allowing for salvage and demolition.

3.2.14.1  *Discussion–*The value includes hard costs of construction as well as soft costs for design, site supervision, management, etc. (See also replacement cost.)

3.2.15 *damage ratio, n–*ratio of the damage or repair cost divided by the replacement cost.

3.2.15.1  *Discussion–*sometimes called 'damage factor'

3.2.16 *deductible, n–*(Insurance) The amount of loss above which an insurance payment is due to the insured.

3.2.17 *deficiency, n–*conspicuous defect(s) in the building or significant deferred maintenance items of a building and its components or equipment.

3.2.17.1  *Discussion–*Conditions resulting from the lack of routine maintenance, miscellaneous repairs, operating maintenance, etc. are not considered a deficiency.

3.2.18 *demand surge, n–*a sudden and usually temporary increase in the cost of materials, services, and labor due to the increased demand for them following a catastrophe. [ASB, Actuarial Standard of Practice 39, 2000].

3.2.19 *design basis earthquake (DBE), n–*the site ground motion intensity (e.g., PGA, SA) with a 10% probability of exceedance in 50 years, equivalent to a 475-year return period for exceedance, or a 0.2103% annual probability of occurrence.

3.2.19.1  *Discussion–*The design basis earthquake ground motions are associated with any earthquake that has the specified site ground motion value; often there are several earthquakes with different magnitudes and causative faults that yield equivalent site peak ground motions.

3.2.20 *deterministic, adj–*a method of engineering and decision-making evaluation based solely on the selection of one or at most a few hazards events used as scenarios.  For instance, an historical earthquake may be taken as a scenario to see what would happen if that earthquake recurred.  Deterministic methods are typically based on source models and intensity propagation methods that exclude random effects.

3.2.20.1  *Discussion–*This contrasts with probabilistic approaches, which attempt to consider the full range of hazards or scenarios, and include random (aleatory) effects.

3.2.21 *direct loss, n–*(Insurance) The portions of the ground-up loss retained by the insurer are losses above the deductible and below the limit of liability. Also called the gross loss (to the insurer).

3.2.22 *distribution function, n–*the probability distribution for a random variable.

3.2.22.1  *Discussion–*The random variable may include such things as loss, ground motion, or other consequence of earthquake occurrence.

3.2.23 *diversification, n–*a strategy to reduce the volatility of risk by limiting the exposure to correlated events producing a loss.

3.2.23.1  *Discussion–*In portfolio seismic risk, diversification may aim to geographically distribute the property exposure to avoid multiple high losses in a single earthquake.  Other forms of diversification may seek to avoid common seismic vulnerabilities or defects, such as nonductile concrete moment frames or unreinforced masonry.

3.2.24 *due diligence, n–*the assessment of the condition of a property for the purposes of identifying conditions or characteristics of the property, including potentially dangerous conditions, that may be important to determining the appropriateness of the property for financial or real estate transactions.

3.2.24.1  *Discussion–*The extent of due diligence exercised on behalf of a User is usually proportional to the User’s tolerance for uncertainty, the purpose of seismic risk assessment, the resources and time available to the Provider to conduct the site visit and research.

3.2.25 *duration, n–*The time interval in earthquake ground shaking during which motion exceeds a given threshold.

3.2.26 *earthquake, n–*a sudden motion or trembling in the earth caused by the abrupt release of gradually accumulated strain in the earth's crust.

3.2.27 *earthquake sprinkler leakage loss (EQSL), n–*damage, typically to contents and nonstructural items, resulting from leakage from charged fire-water sprinklers due to damage in earthquakes.

3.2.28 *empirical model, n–*a predictive model, relating a number of relevant, quantifiable input parameters to a measurable outcome parameter.  Such models may be based on judgement (heuristic) or may be tested against data (statistical).  Examples include ground motion models (GMM) such as those used in the U.S. Geological Survey’s National Seismic Hazard Mapping Project, and building damage models (e.g., HAZUS®™).

3.2.29 *event set, n–*a set of (earthquake) simulations, each with a spatial distribution of ground shaking and annual frequency of occurrence, intended to represent the complete ensemble of future earthquakes for the defined region(s), used for the evaluation of earthquake damage to spatially-distributed real estate properties.

3.2.30 *exceedance probability curve, n–*a plot of the severity of loss or other consequence as a function of annual exceedance probability.  See also risk curve

3.2.31 *expected loss, n–*the mean value of loss [$] from a statistical distribution of loss

3.2.32 *expected value, n–*of a random variable, the average or mean of the distribution function.\_

3.2.32.1  *Discussion–*The expected value is determined as the sum (or integral) of all the values that can occur multiplied by the probability of their occurrence. (Compare: median value.)

3.2.33*exposure, n–*the quantity and value of the properties or infrastructure, and the number of occupants at risk from earthquake hazards.

3.2.34 *exposure period, n–*the period of time over which a facility or population at risk is subjected to a hazard.

3.2.35 *fault zone, n–*area within a prescribed distance from any of the surface traces of an active fault.

3.2.35.1  *Discussion–*Within California, the fault zones are determined by the California Geological Survey under the Earthquake Special Studies Zones Act for active and potentially active earthquake faults that have been identified by the state or other governmental bodies.

3.2.36 *fire-following earthquake, n–*(Insurance) a collateral hazard from earthquake, adding to damage from shaking and soil failures

3.2.37 *fragility, n–*the relationship to estimate damage from an engineering demand parameter such a ground acceleration, floor acceleration or interstory drift

3.2.38*frequency, n–*in the context of risk analysis, this refers to how often an event or outcome will occur, given a specified exposure period. For example, annual frequency is the number of events per year.

3.2.39 *geographic correlation index (GCI), n–*an index intended to indicate the relative severity of the risk contribution from a particular building or site on the aggregate losses of a geographically distributed portfolio of buildings or other values at risk from earthquake hazards.

3.2.39.1  *Discussion–*See [Graf & Lee, Proceedings of 7NCEE, 2002].  This is useful in identifying the buildings or sites contributing most to catastrophic portfolio risks, so those sites or buildings can be targeted for further investigation or risk mitigation.

3.2.40 *gross loss, n–*(Insurance) The portions of the ground-up loss retained by the insurer are losses above the deductible and below the limit of liability. Also called the gross loss (to the insurer).

3.2.40.1  *Discussion–*Gross loss may refer to  (1) gross of policy terms (i.e. before deductibles and limits) or (2) gross of reinsurance (but after deductibles and limits).

3.2.41*ground failure, n–*a general reference to fault rupture, liquefaction, landsliding, and lateral spreading that can occur during an earthquake or other land movement causes.

3.2.42 *ground motion model (GMM), n–*an empirical model relating the intensity of ground shaking to earthquake magnitude, distance from causative fault to site, and other factors

3.2.43 *ground-up loss (GU), n–*(Insurance) the total financial loss considered by an earthquake insurance policy, prior to allocation through the application of deductibles and limit of liability.

3.2.43.1  *Discussion–*The portions of the ground-up loss retained by the insured are losses below deductible and loss in excess of the limit of liability.  The portion paid by the insurer (also called direct loss or gross insurer loss) is the loss above the deductible, but below the limit of liability.

3.2.44 *hazard, n–*a natural physical manifestation of the earthquake peril, such as ground shaking, soil liquefaction, surface fault rupture, landslide or other ground failures, tsunami, seiche.  These hazards can cause damage to man-made structures.

3.2.44.1  *Discussion–*This is an event or physical condition that has the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, damage to the environment, interruption of business, or other types of harm or loss.

3.2.45*independent reviewer, n–*technically qualified individual or organization that has not been engaged in the design or modifications of the building(s), and is not in any way affiliated with the Provider.

3.2.45.1  *Discussion–*The concept may also be represented by the phrases “independent technical reviewer,” or “independent peer reviewer”.

3.2.46 *insured loss, n–*losses to be paid by an insurer under an insurance policy.  Typical earthquake policies for buildings specify a deductible, given as a fraction of the building's insured value, and a limit of liability.  See also: Ground-up Loss; Gross or Direct Insurer Loss

3.2.47*intensity measure (IM), n–*a measure of ground motion severity, such as peak ground acceleration, peak ground velocity, or spectral response acceleration at a particular period, etc.

3.2.47.1  *Discussion–*Intensity measures that can be directly recorded by instruments (acceleration) or derived from instrumental recordings (spectral acceleration) are generally more useful in engineering applications than those based on human observations (e.g., MMI).

3.2.48*interdependency, n–*a condition wherein the function of the building is dependent on another building, on utilities, or on other critical elements in a supply chain.

3.2.48.1  *Discussion–*Other critical elements include transportation and may include a customer, vendor (for example, supplier of materials), contractor (supplier of services), staff (for example, supplier of staff), information (for example, data processing for accounting or distribution), etc.

3.2.49 *landslide, n–*(1) ground motion; the rapid downslope movement of soil or rock material, or both, often lubricated by ground water, over a basal shear zone; and (2) geological, stationary material deposited in the past by the rapid downslope movement of soil or rock material, or both.

3.2.50 *lateral load-resisting system, n–*the elements of the building system that resist the seismic forces applied to the building. This includes vertical, horizontal, and torsional response of elements and systems.

3.2.51 *lender loss, n–*the financial risk to a lender from damage to a property or properties that secure a mortgage in an earthquake, should the owner choose to default.

3.2.51.1  *Discussion–*This may occur when the cost to make earthquake repairs exceeds the owner's equity in the property or properties (owner equity is found as the market value minus mortgage balance for the property). Owner-retained earthquake insurance may reduce repair costs paid by the owner, reducing the probability of default or guaranteeing the repayment of the loan.  An owner may choose to continue to pay on a damaged property in order to preserve reputation or credit rating, or in anticipation of future property value growth.  Additionally, a lender may forbear on a foreclosure for various reasons, such as a decline in market values.

3.2.52*limit of liability, n–*(Insurance) The maximum payment amount which an insured may receive for a covered loss.

3.2.53 *logic tree, n–*a method to evaluate the outcomes from multiple admissible scientific models.  Each branch of the logic tree considers mutually exclusive, scientifically admissible method, and the branches are intended to represent the full span of admissible solutions.  A numerical weight may be assigned to each branch, with the weights summing to 1.0.  Also called solution trees.

3.2.54 *magnitude of earthquake (M, Mw), n–*a measure of the size of an earthquake.

3.2.54.1  *Discussion–*Various magnitude scales have been developed and applied (e.g., local magnitude, body wave magnitude, surface wave magnitude).  Currently, the moment magnitude scale (M or Mw) provides the best quantification of the size of the event in terms of energy released, and is the preferred term used by the U.S. Geological Survey for large earthquakes.

3.2.55 *maximum capable earthquake (MCE), n–*earthquake that can occur within the region that produces the largest average ground motion at the site of interest.

3.2.55.1  *Discussion–*This is NOT the same as the ASCE 7 definition of MCE, which is a ground motion with a 2,475-year return period or 150% of the median ground motion in a design basis earthquake, which ever is the lesser. The concept of MCE for purposes of the guide does not include a return period value.

3.2.56 *median value, n–*value that divides the distribution function into equal parts, such that the value of the random variable has an equal probability of being above or below the reference value. (Compare expected value.)

3.2.57 *mitigation, n–*sustained action taken to reduce or eliminate long-term costs and risks to people and property from hazards and their effects.  Mitigation distinguishes actions that have a long-term impact from those that are more closely associated with preparedness for, immediate response to, and short-term recovery from a specific event.

3.2.58 *model, n–*a representation of a physical system or process intended to enhance our ability to understand, predict, or control its behavior

3.2.59 *Modified Mercalli Intensity (MMI), n–*qualitative description of the local effects of the earthquake at a site.

3.2.59.1  *Discussion–*Normally, it is given as a Roman numeral, from I to XII, to emphasize its qualitative, not quantitative, nature. A single earthquake can have many different MMI intensities assigned over the region in which the earthquake is felt. MMI does not specify a specific ground motions, but a range of peak horizontal ground motion are assigned to a given MMI value. Use of MMI to characterize ground motions for use in the seismic risk assessment of buildings should be done with caution because the damage level predicted is associated with a very wide range of earthquake ground motions, not a specific earthquake ground motion.

3.2.60 *Monte-Carlo simulation, n–*a statistical method that relies on repeated random sampling of the statistical distributions of input variables to obtain a numerical estimate of the probability distribution of the output variable. Monte Carlo methods avoid errors produced by closed-form solutions that assume the shape of the output variable.

3.2.61 *mortgage-backed securities, n–*a type of asset-backed security or collateralized investment vehicle that is secured by a mortgage or collection of mortgages. The loans are packaged together and sold in the financial markets, with the proceeds from mortgage payments used to repay the security.

3.2.61.1  *Discussion–*Examples include commercial mortgage-back securities (CMBS) and residential mortgage-back securities (RMBS)

3.2.62 *non-structural components, n–*components of a building system that are not part of the vertical or lateral-load resisting structural systems nor are defined as building con- tents.

3.2.63*observations, n–*the relevant information or measurements, or combination thereof, documented during the site visit survey.

3.2.64 *obvious, adj–*readily accessible and can be seen easily by the independent reviewer without the aid of any instrument or device and understood by the Provider as a result of a walk-through survey.

3.2.65 *occupant, n–*of a building, a group or organization, or a part thereof, or an individual or individuals, that is or will be occupying space in a particular facility.

3.2.65.1  *Discussion–*Persons who are authorized to be present only temporarily, or in special circumstances such as those permitted to pass through during an emergency, are visitors.

3.2.66 *offsite factor, n–*a source of loss or business interruption resulting from damage or system failure outside of the property boundaries of the real estate properties in the portfolio, such as from disruption to the utilities and lifelines serving the sites in the portfolio.

3.2.67 *original construction documents, n–*documents used in the initial construction phase and any subsequent modification(s) of building(s) for which the seismic risk assessment is prepared.

3.2.67.1  *Discussion–*Generally as-built plans are the preferred form of construction documents.

3.2.68 *other earthquake hazards, n–*i.e., other than strong ground shaking.  Other earthquake hazards include, but are not limited to, soil liquefaction; ground deformation including subsidence, rupture, differential settlement, landsliding, slumping, etc; and, hazards from off-site response to the earthquake including flooding from dam or dike failure, tsunami, or seiche.

3.2.69 *owner, n–*the entity or individual holding the deed to the building, or their designated representative. An agent or contractor may be considered an owner in some circumstances.

3.2.70 *P-delta effect, n–*the secondary effect of column axial loads and lateral deflections on the shears and moments in various components of a building.

3.2.71 *peak ground acceleration (PGA), n–*the maximum acceleration at a site caused by an earthquake ground motion. PGA is most often given as the maximum of the two orthogonal horizontal components and is usually expressed as a fraction of gravitational acceleration, g, 32.17 ft/s2 (9.81 m/s2).

3.2.72 *portfolio, n–*within the context of typical building seismic risk studies, this refers to a geographically-distributed set of facilities or other values-at-risk.

3.2.73 *potentially active earthquake fault, n–*an earthquake fault that shows evidence of surface displacement during the Quaternary period (approximately the last two million years).

3.2.74 *probabilistic ground motion, n–*earthquake ground motions for the building site that are determined from an evaluation of the seismic exposure for the site for a given time period and are represented by a probability distribution function. Where appropriate, the ground motion assessment process should reflect conditional probabilities of the temporal dependence of earthquakes on specific seismic features, where they are known.

3.2.75 *probable loss (PL), n–*earthquake loss to the building systems that has a specified probability of being exceeded in a given time period, or an earthquake loss that has a specified return period for exceedance.

3.2.75.1  *Discussion–*This value is meant to reflect in a statistically consistent computational manner all of the uncertainties that can impact damage, including when and where earthquakes occur and with what magnitude, attenuations of ground motion to the site, local site effects and performance of the building systems in this ground motion. The PL is expressed in terms of the damage ratio and is generally limited to earthquake loss associated with the earthquake ground-shaking hazard, but may include losses from other earthquake hazards as prescribed by a User. Dollar values can be determined by multiplying the damage ratio by the replacement cost estimate for the building. Where seismic analysis of discounted present value is to be performed then annual PL, mean and standard deviation are appropriate damageability measures for use in such application.

3.2.76 *probable maximum loss (PML), n–*term historically used to characterize building damageability in earthquakes.  See ASTM E 2026.

3.2.76.1  *Discussion–*PML has had a number of very different explicit and implicit definitions. The concepts of probable loss (PL) and scenario loss (SL) are used in this guide to characterize the earthquake losses of buildings or groups of buildings. When a Provider uses the term PML, it should be defined in terms of SL or PL as defined herein.

3.2.77 *provider, n–*person or organization that conducts the site visit and prepares a report on the seismic risk of a building or group of buildings.

3.2.78 *replacement cost, n–*cost required to construct an entirely new building of the same size, envelope, configuration and character as the referenced building, assuming a virgin site.

3.2.78.1  *Discussion–*Replacement cost includes costs for construction, including building materials and labor; design; site supervision; management; etc.

3.2.79 *retrofit scheme, n–*preliminary suggestion(s) of modifications or additions to the building intended to correct, mitigate, or repair a physical deficiency that will improve the seismic performance of the building so that it is acceptable to the User.

3.2.80 *return period, n–*(of a random variable) this is the average period of time between recurrence of consequences equalling or exceeding a given level.  It is the inverse of the annual probability that the value is equaled or exceeded.

3.2.80.1  *Discussion–*Return period is not the time period between occurrences of the value, but is the long-term average of the random times between occurrences. Often, return period is incorrectly interpreted to mean that if the value was realized in 1994, and the return period is 100 years, then the next occurrence will be in 2094. For example, earthquake occurrences usually are considered as Poisson-distributed random variables, that is, variables where the probability is near constant from year to year, and the probability of an occurrence this year is independent of what happened last year. For a Poisson random variable, the probability that the value will be equaled or exceeded in its return period term is 63%.

3.2.81 *risk curve, n–*a plot of the severity of loss or other consequence as a function of annual exceedance probability or average return period

3.2.82 *robust simulation, n–*a method to evaluate the outcomes and the dispersion of outcomes from multiple admissible scientific models, preserving the coherency of the model chains (e.g., as depicted in a logic tree).  Robust simulation adapts Monte Carlo simulation using equiprobable events in diachronic simulations, and is applicable to numerous mega-risks resulting from natural and human-generated hazards.

3.2.82.1  *Discussion–*See Taylor, C.E., Robust Simulation for Mega Risks, Springer, 2015

3.2.83 *scenario expected loss (SEL), n–*expected value of the scenario loss for the specified ground motion of the earthquake scenario selected.

3.2.84 *scenario loss (SL), n–*earthquake damage loss expectation to building systems and site improvements and where User-prescribed, building contents and/or related business interruption loss, associated with specified earthquake events on specific fault(s) affecting the building.

3.2.84.1  *Discussion–*SL values are expressed in terms of the damage ratio or damage cost/repair cost in present day dollars. The SL is generally limited to earthquake loss associated with the earthquake ground-shaking hazard, but may include losses from other earthquake hazards, as prescribed by a User.

3.2.85 *scenario upper loss (SUL), n–*scenario loss that has a 10% percent probability of exceedance due to the specified ground motion of the scenario considered.

3.2.86 *secondary modifiers, n–*building-specific structural characteristics considered in commercial seismic risk models to account for structural condition, vertical and plan irregularities, pounding with adjacent structures, etc. and their impacts and improve prediction of building damage, life-safety and loss-of-use.

3.2.87 *site class, n–*a classification of the propensity of a site to amplify ground shaking, based on soil profile or Vs30.  Site Class A = hard rock, B = rock, C = soft rock or very firm soil, D = firm soil, E = soft soil and F = soils susceptible to failure in earthquake.  ref: ASCE 7; ASCE 41

3.2.88 *site visit, n–*visual reconnaissance of the site and physical property by the Provider to gather information on the physical property for the purposes of preparing seismic risk assessment.

3.2.87.1  *Discussion–*The Provider is not expected to use or provide scaffolding, ladders, magnifying lenses, etc. in undertaking the visual reconnaissance of the building systems and components during the site visit. This definition implies that such a visit is preliminary, not in-depth, and typically done without the aid of exploratory probing, removal of materials, or testing. It is literally the Provider’s visual survey of the building(s) and site improvements.

3.2.89 *soil liquefaction, n–*the transformation of loose, saturated, sandy soil materials into a fluid-like state.

3.2.89.1  *Discussion–*Damage from soil liquefaction results primarily from horizontal and vertical displacements of the ground. This movement of the land surface can damage buildings and buried utility lines such as gas mains, water lines and sewers, particularly at their connection to the building. Extreme tilting or settlement of the building can occur if soil liquefaction occurs underneath the building foundations.

3.2.90 *soil profile, n–*the vertical arrangement of soil horizons down to the parent material or to bedrock.  Under current building codes (e.g., International Building Code) and FEMA NEHRP guidelines, the soil profile may be categorized by average shear wave velocity in the upper 30m of sediments for the purpose of estimating amplification of ground motions with respect to those occurring on rock.

3.2.91 *spectral acceleration (SA or Sa), n–*the maximum acceleration of an elastic spring-mass system with 5% critical damping to a specified (ground) shaking time history, typically given in units of [g]

3.2.92 *stakeholder, n–*one of the parties who may suffer damage, loss or injury from an earthquake event

3.2.93 *statistically consistent manner, n–*following the mathematical rules and concepts of probability and statistics.

3.2.94 *structural component, n–*component that is a part of a building’s lateral and/or vertical load-resisting system.

3.2.95 *system model, n–*a mathematical model intended to represent the behavior of a system. System models may be depicted by nodes and links.   In portfolio seismic risk analysis, nodes may represent geographically distributed real estate properties and links may represent product, data or revenue flows between the properties.

3.2.96 *tsunami, n–*long water waves that are generated impulsively by tectonic displacements of the sea floor associated with earthquakes.

3.2.96.1  *Discussion–*Tsunamis also may be caused by eruption of a submarine volcano, submerged landslides, rock falls into the ocean, and underwater nuclear explosions. Tectonic displacements with a substantial vertical (dip-slip) component are more likely to cause tsunamis than are strike-slip displacements. Wave heights associated with tsunamis in deep water generally are small; however, as the wave fronts approach coastlines where there is shallow water, the wave heights increase and will run up onto the land. Tsunami run-up can cause loss of life and substantial property damage.

3.2.97 *uncertainty, n–*degree of random behavior represented by an applicable probability distribution and associated parameters.

3.2.98*uncertainty tolerance level, n–*amount of uncertainty in financial exposure that a User is willing to accept resulting from the cost to remedy earthquake damage not identified by an seismic risk assessment.

3.2.98.1  *Discussion–*This can be influenced by such factors as initial acquisition cost or equity contribution, mortgage underwriting considerations, specific terms of the equity position, projected term of the hold, etc.

3.2.99 *user, n–*individual or organization that retains the Provider to prepare a seismic risk assessment.

3.2.100 *valuation, n–*the process of assessing or assigning financial value to an asset or process

3.2.101 *vulnerability, n–*the susceptibility of a building, equipment item or component to damage or loss from a specific hazard.  See also fragility.

3.2.102 *weak story, n–*story in a building that is expected to deform significantly more than any story above it under a given lateral loading. Such weak stories can occur at any level in a building, except the top story.

**4. Significance and Use**

4.1 *Uses—*This guide is intended for use on a voluntary basis by parties such as lenders, loan servicers, insurers and equity investors in real estate (Users) who wish to estimate possible earthquake losses to groups of buildings (real estate portfolios). This guide outlines procedures for Providers (Professional Engineers or other risk analysts) to prepare an assessment for a specific User considering the User’s requirements for portfolio seismic risk.  User needs may include portfolio acquisition, seismic risk management, earthquake insurance purchase, financial risk rating or reporting requirements (i.e., to shareholders, investors, etc.).

A seismic risk assessment prepared in accordance with this guide should reference or state that the guidance in this document was used as a basis for the investigation and the report, and should also identify any deviations from the guidelines. This guide is intended to reflect a commercially prudent and reasonable investigation for performance of seismic risk assessments.  Building damageability assessments and terminology are intended to be generally consistent and compatible with ASTM E2026, Standard Guide for Seismic Risk Assessment of Buildings and ASTM E2557, Standard Practice for Probable Maximum Loss (PML) Evaluations for Earthquake Due-Diligence Assessments.  Lenders and owners may use standards such as E2026 and E2557 to screen properties at acquisition for site stability and building stability, with estimates of damage levels to compare with their screening standards, and then perform portfolio studies periodically to monitor and manage risk accumulations, and to provide feedback to the acquisition due-diligence process.  For large portfolios, the number of properties and their geographic distribution, as well as constraints on budget and schedule, may make it impractical to conduct new engineering investigations for all properties in the portfolio.  Lenders or owners may utilize previous PML assessments to help characterize site conditions and building damageability, with engineering investigations limited to selected high-value buildings deemed likely to drive high-consequence portfolio-wide losses.

Further discussion of the individuals involved in portfolio seismic risk studies and their responsibilities is presented in Chapter 6.

4.1.1 *Users—*This guide is designed to assist the User to obtain assessments for the earthquake-related damage potential of geographically dispersed groups of buildings (portfolios). Potential Users include, but are not limited to, building owners, building tenants, lenders, loan servicers, insurers and insurance brokers, rating agencies, potential investors/owners and mortgagors.  For these Users, the principal objective may be the assessment of financial risks from damage to buildings, and (as applicable) contents as well as losses from business interruption resulting from the inability to occupy damaged or non-functional buildings or systems.

4.1.2 *Types of Investigations—*This guide provides suggested approaches for the performance of two different levels of seismic risk assessments – Desktop and Engineered. A Desktop study is typically provided by an insurance broker or other consultants, but is not conducted by a Professional Engineer.   An Engineered study is conducted under the direction of a Professional Engineer (Civil or Structural), with the intent to improve the quality of site hazards and damage modeling.  Assessment subtypes arise from the stakeholder position of the User and the intended use of the results (e.g., for the selection of earthquake insurance coverage amounts).  Each is intended to address the differing financial and management needs of the User. Types of investigations depend upon the needs and objectives of the User, the information available, the seismic risk assessment software employed, whether engineering professionals are engaged, and the budget and schedule allotted.  Portfolio seismic risk assessments are typically probabilistic (relating consequence to annual probability of exceedance, or to average return period), although specific earthquake scenarios may be extracted from an earthquake catalog and presented separately, or a deterministic scenario earthquake may be the specific subject of the study.  This standard is limited to the subtypes defined below.

4.1.2.1 *Basic Portfolio Seismic Risk Assessment (Ground-up Losses).*

This is the most straightforward type of study, computing portfolio-wide loss resulting from damage to buildings, and (where applicable) contents and basic business interruption losses caused by building closure for repairs.  This type of study computes "ground-up" losses, without allocation of the losses to the affected stakeholder(s), unlike studies for insured loss or lender loss.  Portfolio studies for deterministic earthquake scenario(s) are typically limited to ground-up losses and other direct impacts.

4.1.2.2 *Insurance Portfolio Seismic Risk Assessment (Direct or Gross Insurer Losses)*

These studies are done to inform decisions involving the purchase of earthquake insurance.  The studies typically involve the computation of both ground-up and gross or direct (insurer) loss for a large synthetic earthquake catalog or “event-set,” and the results presented in risk tables and risk curves with losses as a function of annual exceedance probability or average return period.   Additionally, average annual loss rates are presented, as these represent (unloaded) pure premiums.  The insurer's loss is reduced with respect to the ground-up (or unallocated) loss by the effect of the insurance deductible for each building and each line of coverage (building, contents, and business interruption).  Gross losses are those that are paid by the insurer, so estimates of gross losses can be used to inform decisions on limits of pooled insurance coverage for the portfolio.  The allocation of losses between stakeholder parties shall be done using statistically sound methods, accounting for the uncertainties in hazards, and the variability in damage and loss given the hazards.

4.1.2.3 *Lender Portfolio Seismic Risk Assessment (Lender Loss)*

These studies are done to inform risk management decisions by lenders, including requirements for borrowers (i.e., owners) to purchase of earthquake insurance.  Real estate loans typically are limited to some fraction of the market value of the real estate property, with the owner retaining a significant financial stake.  Portfolio risk studies for lenders typically involve the computation of losses that may accrue to lenders when owner equity and owner-retained earthquake insurance are considered as risk buffers.  In simple terms, the owner’s equity is found as the current market value minus current mortgage balance.  This equity creates a financial stake for the owner.  The owner’s equity varies over time as real estate market values change and as the loan principal balance diminishes.  The lender’s loss is reduced with respect to the ground-up (or unallocated) loss by the effect of the owner’s equity, as well as any owner-retained earthquake insurance.  The estimation of losses to lenders shall be done using statistically sound methods, accounting for the uncertainties in hazards, and the variability in damage and loss given the hazards.

4.1.3 *Application and Temporal Relevance of Report*—A User should only rely on the portfolio seismic risk assessment report for the specific purpose that such assessment was commissioned, for that time when the report was completed, for the state of the buildings in their respective condition (known or assumed) and values in place at the time of assessment as documented in the report.

4.1.4 *Availability of Information*—This guide recognizes that a Provider’s findings and risk estimates may be affected or contingent on information that is readily available to the Provider during the conduct of an investigation, as well as the budget and schedule. For instance, a Provider’s loss estimates may be affected by the availability of previous seismic risk assessments or other engineering information for high-value buildings.

4.2 *Principles*—The following principles are an integral part of this guide and should be referred to in resolving any ambiguity or exercising such discretion as is accorded the Provider in estimating loss to portfolios of buildings from earthquakes. The principles should also be used in judging whether a Provider has conducted an appropriate assessment and estimation of earthquake loss to a group of buildings, and has adequately described the quality of the study and its limitations.

4.2.1 *Uncertainty Not Eliminated*—No estimate can wholly eliminate uncertainty regarding risks to a portfolio of buildings resulting from actual earthquakes. The successive levels of assessment described in this guide are intended to reduce, but not eliminate, uncertainty regarding the estimation of financial loss. This guide describes a method to communicate the quality of the study, and acknowledges that practical limits of time and cost impact the quality of the assessment.

4.2.2 *Not Exhaustive*—There is a point at which the time and cost to gather information outweighs the usefulness of the information and, in fact, may be detrimental to the orderly and timely completion of transactions. This guide identifies and suggests that a balance be sought between the competing goals of limiting the costs and schedule versus limiting the uncertainty regarding unknown conditions by acquiring as much information as possible.

4.2.3 *Level of Investigation*—Not every site or property warrants the same level of investigation in seismic risk assessment. Consistent with good commercial or customary practice, choosing the appropriate assessment for each property level is guided by the type of buildings subject to assessment and their relative values, the resources and time available, the expertise of the Provider and risk tolerance of the User, information available from previous studies and the information developed during the investigation.  Further discussion of the level of investigation for each property and the impact on the quality of the portfolio seismic risk results is provided in Chapter 8.

4.3  *Use of Existing Reports and Data*—This guide recognizes that prior reports or other data sources can be utilized in a portfolio risk assessment, to economize on the required field work and drawing review or other investigations.  These resources may include previous single site Seismic Risk Assessments prepared under ASTM E2026 and E2557, geotechnical investigation reports, or prior portfolio Seismic Risk Assessments.  Other site-specific documents may be available that, while not necessarily prepared for the purpose of seismic risk assessment, contain useful information on the buildings or hazards.  Such documents may include Property Condition Assessment reports, and property risk reports prepared by insurers or third parties.   Restrictions on use and reliance that are noted in existing reports or documents should be respected.  Prior reports and data that are used should be listed in the report for the portfolio seismic risk assessment (see 9. Report Requirements).  Usage of prior reports or other sources of data should be based on the following principles in addition to the specific procedures set forth in this guide.

4.3.1 *Use of Reports or Data Provided by User*—The User may furnish prior reports or other data sources to the Provider prior to commencing the study, in order for the User and Provider to agree upon appropriate use of such and the scope of any additional investigation.

4.3.2 *Existing Information Meets or Exceeds*—Information from prior reports or other data sources may be used if, in the reasonable judgment of the Provider, the information in the prior report meets or exceeds the requirements of this guide, and the conditions affecting the buildings or site are not likely to have changed materially since the prior report was prepared. In making this judgment, the Provider should consider the types of building construction assessed in the report, readily available information such as exterior photos, published maps, and any new information related to the behavior of building constructions of that specific type in recent earthquakes, as well as current understanding of the site conditions.

4.3.3 *Actual Knowledge Exception*—If the User or Provider has actual knowledge that the information being used from a prior report or data source is not accurate or is suspected of being inaccurate, then such information should not be used.

4.4  *Superceding Investigation*—When a new portfolio seismic risk assessment is performed for the same User, and that new investigation is consistent with this guide and has more complete and current information than a prior investigation, then the new investigation should supersede the former one.

**5. Assessment Methodology, Approaches and Tools**

5.1  *Overview of Methodology*

5.1.1  *Objective –*The objective of portfolio seismic risk assessment is to quantify the aggregate risks from future earthquakes to a geographically dispersed group of properties.

5.1.2  *Roles and responsibilities –* Users (e.g., real estate lenders or owners) request portfolio seismic risk studies to inform risk management decisions regarding acquisition, disposition, earthquake insurance and risk mitigation.  Risk Providers work with catastrophe modeling software or catastrophe modeling consulting firms to assess the risks, identify the factors driving the risks and opportunities for risk reduction.  Others such as insurers and insurance brokers may use the results from portfolio seismic risk assessments in insurance placements, and rating agencies may use the reports from portfolio seismic risk studies in rating financial instruments collateralized by a real estate portfolio.

5.1.2.1  *Exposure –* the locations of the real estate properties to be evaluated and their exposure values (e.g., replacement costs) are generally determined by the User (owner or lender) and transmitted to the risk Provider.  It is important to note that inaccurate values directly impact the accuracy of the financial risk estimates resulting from portfolio studies.  The provider should review the exposure data and request clarification or correction from the User where locations or values are missing or appear to be in error.  The User may wish to engage the services of valuation professionals or automated systems to ensure accurate and consistent values for the buildings, contents and business activities at risk, to avoid systematic underestimation or over-estimation of the exposure values.

5.1.2.2  *Seismic Hazards –* Catalogues of earthquake simulations (“event sets”) with event probabilities and estimates of the resulting ground motion are included in the catastrophe models.  These may be derived from the National Seismic Hazard Mapping Project by the United States Geological Survey [e.g., Peterson et al., 2008, 2014] or from other accepted standard.

Typical software for portfolio seismic risk assessment includes digital maps for geologic conditions such as Site Class and liquefaction susceptibility.  With geocoding of the site locations, the software can identify sites with adverse geologic conditions such as soft soils or susceptibility to liquefaction, to allow further investigation by the seismic risk Provider.  The software may allow over-ride of the mapped condition, to accommodate site-specific information from geotechnical investigation reports or other sources (e.g., past PML reports).   In many cases, foundation systems are specifically engineered to mitigate adverse geologic conditions, and the Provider may specify modeling parameters to account for these design features.

Note that the risks resulting from certain seismic hazards are normally excluded from existing catastrophe software and require site-specific engineering investigation, such as surface fault rupture.  Risks associated with special hazards such as slope instability, liquefaction effects such as lateral spreading, or tsunami effects may be addressed some catastrophe software in approximate ways.  Within the context of a large, geographically distributed portfolio, the impact of losses from such hazards may be small compared to the aggregate losses to the portfolio from ground shaking.  However, surface fault rupture or other special hazards may affect a critical facility functioning as a critical hub within a non-redundant system, resulting in large business interruption losses.  Note that where active risk management routinely requires the screening of all significant acquisitions, the resulting real estate portfolios may systematically exclude properties with significant risks from surface fault rupture, slope instability or liquefaction effects, as these would be deemed “unstable sites."

5.1.2.3  *Seismic Vulnerability of Buildings –* the basic structure of a building is composed of a frame with gravity load carrying elements (slabs or framed floors, columns and/or bearing walls, and foundations), and a lateral force-resisting system (e.g., moment frames, braced frames, shear walls, etc.).  In addition, there are architectural elements (e.g., cladding, partitions, and ceilings) and building service equipment. Some damage models do not segregate these elements, but estimate damage to the building as a whole (e.g., ATC-13).  Other models (e.g., HAZUS™®, FEMA P-58) distinguish the structural frame from the nonstructural elements (architectural elements and building service equipment).

Building damage models utilized in catastrophe modeling software developed for property insurance applications typically rely on building height (or number of stories), year built and building type or class.  Structural classification systems vary, as does the ability of insurance models to accommodate the findings from engineering reviews.  The models can be used with building classification systems based on occupancy (i.e., residential, office, commercial, industrial, etc.).  Weighted average damage relationships may be derived from logic trees from candidate structural classes (i.e., steel moment frame, steel braced frame, masonry shear wall, etc.) with an associated high uncertainty. In seismic risk assessments involving engineers (civil or structural), determinations of the materials of construction and the gravity and lateral systems allow for direct assignment of the structural class, with improved accuracy and reduced uncertainty.  Where catastrophe modeling software offers damage relationships based on engineering building classification systems, “secondary modifiers” may be input to modify the models to make them more building-specific.  Users and Providers are referred to the catastrophe modeling vendors for the specific details of the modeling and the opportunity each tool affords for engineering input.

Damage models that follow engineering methods (e.g., HAZUS™®, FEMA P-58) typically distinguish the structural frame from the nonstructural elements.  A structural response model is used to estimate building peak responses (i.e., displacements and accelerations) from ground motions, and these responses are converted to engineering demand parameters (EDPs).  Damage to the structural system is usually caused by the inter-story drifts that occur under lateral earthquake loads, so drift is the engineering demand parameter used to predict the damage states for structural drift-sensitive elements.  Architectural elements may be drift-sensitive (e.g. full-height partitions) so drift is the EDP used to predict damage states.  Nonstructural elements such as roof-mounted equipment, or suspended ceilings are acceleration sensitive, so the engineering demand parameters used to predict damage to nonstructural elements are floor accelerations for above-grade items, and ground accelerations for items at or below-grade.  The amount of damage is found using a fragility model, relating damage states (with associated repair costs) to median values of the relevant engineering demand parameter.  For example, in HAZUS, the damage states are described as ‘none,’ ‘slight,’ ‘moderate,’ ‘extensive’ and ‘complete.’  Each damage state is associated with a repair cost and an expected time to complete repairs, and may be tied to life-safety consequences (injury rates and fatality rates).  The fragility models include a dispersion parameter (β) to account for the variability of damage state as a function of the relevant engineering demand parameter.

5.1.2.4  *Seismic Vulnerability of Contents –* Some damage models (e.g., ATC-13) relate ground motions to contents damage without consideration of the building in which they are contained.  Damage models that follow engineering methods (e.g., FEMA P-58) use ground accelerations or floor accelerations as the EDP, so that the building response is considered when estimating damage to contents located above grade.  Engineering methods use the EDP with fragility models to predict the damage state, and the damage state is associated with a repair cost.

5.1.2.5  *Business Interruption Loss Assessment –*Damage models derived from ATC-13 use Social Function Classes and building damage factor to predict restoration time for facility function.  Damage models that follow engineering methods use structural (or in some cases nonstructural) damage states to predict restoration time for facility function.

5.1.2.6  *Use of Findings from Previous PML Investigations –* The major catastrophe models currently used in insurance risk assessment (see Section 5.2) are capable of producing a damage estimate for individual buildings, as well as listing the corresponding hazard levels.  This allows for the provider to check results, or for some degree of calibration, e.g. adjusting “secondary modifiers” to achieve better agreement with previous seismic risk assessment estimates.  The user should be careful to utilize similar outputs (e.g., Probable Loss) with similar uncertainty levels, and to disable secondary loss features (e.g., fire-following earthquake, or demand surge) when comparing results to the results of PML studies.  Other models may be able to re-use the vulnerability relationships developed in detailed single-site studies directly in portfolio seismic risk assessments, maintaining calibration.

5.1.2.7  *Risk Assessment for Financial Stakeholders –*When earthquake damage occurs, there may be a number of parties with a financial stake in the loss: apart from the owner, there may be a lender and/or an insurer.  Other stakeholders may include tenants, owners or occupants of neighboring buildings, etc.  The models that apportion the losses to the various parties at risk are commonly called stakeholder models or loss allocation models.  Since damage estimates from earthquake models are uncertain, the predicted losses have a statistical distribution that must be considered in allocating the financial consequences.  For example, in the case of a mortgage lender, the owner is unlikely to default on the mortgage if the loss amount is less than the owner’s equity in the building (where equity is found as market value minus mortgage balance).  If the statistical distribution of losses includes loss levels above the owner’s equity, then a lender’s loss is predicted.  Expected losses to the parties are found by examining all potential loss levels and their probabilities.  A similar approach is used for earthquake insurance, where the statistical distribution of losses is used with the specified deductibles and limits of liability to allocate losses between the owner and insurer.  The user should identify the key stakeholders and the outputs required to meet their needs, as well as the insurance coverage details or information (e.g., owner equity) to allow appropriate stakeholder risk analysis.

5.1.2.8  *Management of Uncertainty –*Major contributors to uncertainty in portfolio seismic risk assessments include the uncertainties in exposures (i.e., the locations and values of the properties), earthquake hazards (e.g., ground shaking and the attendant geotechnical effects such as liquefaction), the vulnerability of buildings and equipment, and business interruption with its financial impacts.  The available catastrophe models (see Section 5.2 below) all attempt to consider these uncertainties in a comprehensive way.  Since portfolio-wide or aggregate losses are strongly affected by effects that are correlated portfolio-wide, care is needed where the effects of uncertainty are correlated, for instance in accounting for interevent uncertainty in ground motion prediction equations.

5.2  *Available Catastrophe Risk Models (Tools) for Portfolio Seismic Risk Assessment*

5.2.1  *Catastrophe Models Used for Earthquake Insurance*

Commercial earthquake insurance catastrophe modelers offer catastrophe models for use in assessing risks to real estate portfolios for earthquakes and other perils.  The models all utilize large inventories of earthquake simulations (“event sets”) to represent the ground shaking and other hazards at each site within a portfolio, and then use damage relationships and the values of the building and contents, and the costs of business interruption, to predict the resultant losses at each site, and total portfolio-wide losses.  Uncertainties are tracked and managed, and financial loss-allocation models are used to distribute the losses to each stakeholder (e.g., owner, insurer, or lender).  These models are specifically developed for insurance risk assessment, rather than for engineering applications, but they establish a baseline for the state-of-the-art and practice of portfolio seismic risk assessment.  The models offer various ways to include and consider site-specific geologic conditions that may differ from values obtained from their digital maps of local hazards, and building-specific features that affect damageability, and Providers who use these models must adapt the scope of their investigations to suit the specific capabilities of the model they choose.

5.2.2  *Damage Models Controlled by Engineers*

Some earthquake damage models allow full control of the damageability of each building by an engineering service Provider.  Such models may be used to calibrate damageability of some or all of the buildings to previous results from engineering seismic risk assessments.  Several of the publicly-available models are described below.  Other models may be proprietary, offered by particular engineering service Providers.  Additionally, commercial earthquake insurance catastrophe modelers may allow users to specify a customized vulnerability relationship.

*5.2.2.1 HAZUS®MH AEBM*

The seismic damage model for buildings in HAZUS®MH was originally developed for use by emergency planners and government decision-makers, looking at large, regional building portfolios subjected to individual earthquake scenarios.  There is also an "engineer's" version of HAZUS, called the Advanced Engineering Building Module or AEBM, suitable to model the expected performance of particular buildings.  The HAZUS model building types correspond roughly to the common engineering building types defined in ASCE 41-13 (e.g., W1, W2, S1, S2, etc.), with subtypes defined by height (Low-rise, Mid-rise, and High-rise) and usage as defined by an Occupancy Class.  HAZUS models are further discussed in the Technical Appendix.  HAZUS outputs include probabilities of different damage states (“none”, “slight”, “moderate”, “extensive”, or “complete”), duration of downtime, and casualties (injuries and deaths).

As provided by FEMA, HAZUS can produce estimates of expected loss for one or more specified earthquake scenarios, which the user can define by specifying the location of the causative fault rupture segment and event magnitude, and by selecting an attenuation relationship, or through use of a map depicting the distribution of ground shaking.  HAZUS can also provide estimates of average annual loss based on the probabilistic ground motions such as those provided by the U.S. Geological Survey’s National Seismic Hazard Mapping Project. Some Providers also offer versions of HAZUS that extend these capabilities, to allow probabilistic portfolio analysis and insurance risk analysis.

*5.2.2.2  Code-Oriented Damage Assessment (CODA)*

CODA, for Code-Oriented Damage Assessment [Graf & Lee, Earthquake Spectra, EERI, 2009] is an adaptation of ATC-13, estimating expected building damage as a function of a demand-to-capacity ratio *(DCR).* The CODA model uses ground motion response spectra at the fundamental building structural period as the “demand,” while “capacity" is defined as *Cs x R*, where *Cs* is the base shear coefficient and *R* is the response modification factor as defined in current codes.  The uncertainty in building damage for a given demand-to-capacity ratio is a function of the evel of investigation, similar to the “Levels” defined in ASTM E2026 e.g., BD0, BD1, etc.).  A scaling factor may be used to achieve calibration of the damage relationship for a specific building with past seismic risk assessment results at a relevant pre-defined hazard level.

*5.2.2.3  FEMA P-58, Seismic Performance Assessment of Buildings*

FEMA P-58 [FEMA, 2012] is the state-of-the-art methodology developed to be used in performance-based seismic design.  “The procedures are probabilistic, uncertainties are explicitly considered, and performance is expressed as the probable consequences, in terms of human losses (deaths and serious injuries), direct economic losses (building repair or replacement costs), and indirect losses (repair time and unsafe placarding) resulting from building damage due to earthquake shaking. The methodology is general enough to be applied to any building type, regardless of age, construction or occupancy; however, basic data on structural and nonstructural damageability and consequence are necessary for its implementation.”  *(from the Preface of FEMA P-58-1, 2012)*

5.3  *Financial Stakeholder Considerations*

5.3.1 *Financial models and consideration of uncertainties.*  Portfolio seismic risk assessment generally includes consideration of stakeholder financial positions.  For example, studies performed to assist in decisions for the purchase of earthquake insurance will typically allocate losses between the property owner and the insurer(s), and studies for lenders may allocate earthquake losses between the lender and the property owner.  The allocation models must follow statistically sound methods, addressing the statistical distribution of losses subject to uncertainty.

5.3.2  *Owner risks*– these are the losses retained by an owner. Where earthquake insurance applies, the policy will specify coverage with a deductible and limit of liability.  The owner’s (retained) loss is that portion of the loss below deductible and above the limit, with the balance paid by the insurer.  Deductibles typically apply per event, per building and per unit of coverage.  Limits may apply portfolio-wide, and site-by-site limits may also apply.  In order to account for this in allocation of losses, an event-by-event approach is typically used, with an “event set” or a stochastic catalog of earthquake simulations.

5.3.3  *Lender risks*– these are the losses that accrue to a lender when owner(s) default on a loan.  Loans are typically made for an amount less than the market value of the property, so that the owner’s equity (market value minus loan balance) provides an incentive for the owner to meet mortgage payment obligations and avoid default.   After an earthquake, an owner may be faced with repair costs and loss of revenue that prevent them from meeting mortgage payments, or which result in “negative equity” for the owner, where repair and sale of the property would not provide the funds to pay off the mortgage.  In such cases, the owner may elect to default on the mortgage.  When a lender chooses to foreclose on a loan that is in default, the lender takes possession of the property and may then sell the property to pay off some or all of the loan balance.  In effect, owner equity serves as a buffer to limit lender risks.  In portfolio seismic risk analysis, where the cost of damage and loss of property revenue exceed the owner’s equity, the lender is exposed to a loss equal to the mortgage balance and the cost to repair and sell the property, net of the price of the sale of the property.  The model to estimate lender loss must follow well-defined logic to predict defaults and address the statistical distribution of losses subject to uncertainty.

5.3.4 *Insurer risks*– these are the losses retained by an earthquake insurer, as specified under a policy in place at the time of an earthquake.  These are less than the “ground-up” losses, as reduced by the application of policy deductibles and limits of liability.  The insurer allocation model must implement the logic of the earthquake insurance policy, while following statistically sound methods, addressing the statistical distribution of losses subject to uncertainty.

**6. Individuals Involved and Their Responsibilities**

6.1  Overview

The User identifies their objectives for the seismic risk assessment of a real estate portfolio and then selects and engages the Provider to perform the portfolio seismic risk assessment (Portfolio SRA), to meet the User’s needs.    It is expected that to perform the Portfolio SRA, the Provider will utilize seismic risk analysis software (a “model”), which may be supplied by a third party (“Catastrophe Risk Model Provider”).

The User may be the property owner or their representative, a real estate lender, or some other entity.

The User may request Portfolio SRAs either periodically or as needed for seismic risk management and reporting —  to report the level of risk to a purchaser or lender, to inform earthquake insurance purchase decisions, to help manage risk, or to guide recovery planning and enhance corporate resilience.  Alternatively, the User may request a Portfolio SRA in support of a specific transaction.

Providers of Portfolio SRAs may be risk consultants or insurance brokers, performing Portfolio SRAs using readily observable characteristics of the buildings, such as age, height, location and occupancy.  Such Portfolio SRAs make efficient use of available data and may be sufficient for certain purposes, but generally are not under the direction of engineering professionals (civil and structural engineers, geotechnical engineers, etc.).   The vulnerability data on which they are based but is often limited or unverified and the results therefore may have high uncertainty, although it may include past reports from engineers.   In this standard, these are referred to as “Desktop” Portfolio SRAs.

One purpose of this standard is to indicate where and how additional information and investigation can improve the Portfolio SRA results, by improving accuracy and reducing uncertainty, and to describe the role of the Professional Engineer in such studies.  Seismic risk assessments for which the vulnerability modeling is under the responsible charge of a Professional Engineer (Civil or Structural) are referred to as “Engineered” Portfolio SRAs in this standard, can provide an improved basis for making earthquake risk decisions and may also indicate other risk mitigation options.  An “Engineered” Portfolio SRA need not involve detailed investigation and improved modeling for all locations – the focus of efforts should be high-value properties and locations with high impact on the overall portfolio.

6.2  User’s Role and Responsibilities

It is the User’s responsibility to furnish the Provider with:

1.     Initial specification of the desired scope of work and deliverables, schedule and other terms.

2.     A list of the buildings to be included in the Portfolio SRA, their locations and replacement values.  If risks to Contents and/or Business Interruption (BI) are to be included, replacement values for Contents and the annual cost of BI should be provided.  The asset replacement values to be used in the Portfolio SRA shall be current and accurate.

3.     Available information on the buildings including year built, number of stories, occupancy (usage), framing system or materials of construction.  In the insurance industry this data is often referred to as COPE for Construction, Occupancy, Protection, Exposure.

4.     Other existing information regarding the buildings and site seismic hazards, including reports from previous single site or portfolio seismic risk assessments, and any past earthquake damage and losses.

5.    Where relevant based on the finalized scope of services, provide assistance with access to sites, design documents and other information needed for new investigations or for updates of previous investigations for any of the included properties.

Prior to commencement of the Portfolio SRA, the User and Provider should discuss and agree on the final scope of work, the deliverables, schedule and other terms. During the Portfolio SRA project, the User should then interact with the Provider and provide feedback to ensure that the completed Portfolio SRA meets the User’s needs.

6.3   Provider’s Role and Responsibilities

The Provider reviews the documents and data furnished by the User and discusses and agrees on the final scope of work, deliverables, schedule and other terms.  For Engineered Portfolio SRAs, the Provider and the User should concur on any additional drawings reviews, site visits or other investigations to be included in the study.

The Provider then performs the Portfolio SRA for the User in accordance with the agreed scope and terms as well as the minimum requirements identified in this standard.   The Provider’s organization may perform all components of the assessment, or they may engage other individuals or entities for some components.  However the Provider’s organization remains responsible for all components of the services.

There are normally three main components to the Provider’s services:

i.     Collect/review/supplement data on the seismic hazards and vulnerabilities

ii.    Analyze the potential losses using a suitable model

iii.   Provide a report with Portfolio SRA results

These are further elaborated on:

i. Collect/Review/Supplement Data

Data sources may include:

• Property data and reports furnished by the User, as noted above.

• Any single-site seismic risk assessment reports or other reports relevant to the buildings that were previously prepared by the Provider.

• Other public data sources regarding the site hazards or building vulnerabilities.  For example, public websites may contain geotechnical reports or data, or information on building year of construction or past earthquake damage.  Street-view or other images may also be available online.

The Provider is responsible for organizing the existing data in a form that is suitable for the model to be used, but may request that the User provide the data in a particular format.

*Additional Requirements For Engineered Portfolio SRAs:*

*The Provider should also review the data for completeness, and identify additional field investigations and/or drawing reviews that may be warranted.    These should be discussed and agreed with the User as noted above, and then carried out.  Items that warrant further investigation may include:*

• *Buildings where the primary lateral force-resisting system or other key seismic features are unknown or unclear, particularly if these buildings are high value and/or in high hazard locations*

• *Locations with large Contents or BI values*

• *High value locations where secondary hazards such as liquefaction may be a significant contributor to the potential losses*

• *Buildings whose insured values appear either unreasonably high or low, based on their attributes (e.g., size)*

ii. Analyze the Expected Losses Using a Suitable Model

The Provider should have sufficient knowledge of the model being used to understand how the model works, what input is required, what adjustments can be made, and how to review the results.  The Provider should understand how the model addresses:

• Shaking hazard – what are the data sources?

• Secondary hazards such as liquefaction, landslide, fault rupture

• Vulnerability of the buildings, and (where applicable) the contents, as well as downtime for restoration and the resulting Business Interruption

• ‘Demand Surge’ or ‘Loss Amplification’ (if included)

• Aggregation of losses and treatment of uncertainty

The typical steps in analyzing the losses are:

a.     Prepare data for use in loss model

b.     Run the model

c.     Review results

*Additional Requirements For Engineered Portfolio SRAs:*

*The focus of the Provider should be on properties which contribute significantly to high aggregate losses, or which have potential to contribute significantly to such losses.  When reviewing the results, the Provider should check the assumptions the model has made about ground conditions (i.e., Site Class), liquefaction and other secondary hazards for each significant site.  The Provider should also review loss analysis results on a building-by-building basis for important properties and compare these to single-site SRA results where available.   If warranted, further adjustments should then be made to input data and the losses should be re-analyzed.*

iii.  Provide a report with final results and supporting information (see Chapter 9).

6.4  Minimum Qualifications of the Provider

Providers of Desktop Portfolio SRAs should have a good general understanding of earthquake hazards and building structures and experience with the model selected.  They should also have general knowledge of typical building costs and earthquake insurance coverage provisions.

The experience and judgment of the Provider of an Engineered Portfolio SRA are key to improving building data and vulnerability modeling, reducing the uncertainties in results compared to Desktop studies.  In addition to the foregoing requirements, Providers of Engineered Portfolio SRAs must be licensed Professional Engineers — Civil or Structural — experienced in single-site seismic risk assessments.  They should meet the minimum requirements for Level 1 Field Assessor in ASTM E2026, and be knowledgeable of the model to be used and its hazard data sources and structural and nonstructural vulnerability models.

6.5  Other Parties and Their Roles and Responsibilities

6.5.1  *Catastrophe Risk Model Provider*

A Catastrophe Risk Model provider develops and maintains a software system (model) for the analysis of earthquake risks to real estate properties, and provides the software, or access to the software, to the Provider for seismic risk analysis of the User’s real estate portfolio.

In some cases, the company which provides the model may also fulfill the entire role of the Provider (per Sections 6.3 and 6.4).

The model Provider should provide technical documentation describing the geologic hazards, seismological basis and ground motion models, building vulnerability models and uncertainty management to allow the service provider to understand and select a model and make effective use of its capabilities to the benefit of the User.  Where the seismic ground-shaking hazards are based upon the USGS’ National Seismic Hazard Mapping Project, the model Provider should provide comparison of the shaking hazards from the model to results published by the USGS for the intensity measures considered by the catastrophe model and relevant to the buildings in the portfolio (e.g., PGA or Ss for low-rise construction, or S1 for mid- or high-rise construction).  The model Provider should describe methods used to account for the effects of local site conditions (e.g., Site Class) on ground shaking intensity, and (if considered) liquefaction effects.  The documentation should describe the features and options of the software, and the limitations of the software.

6.5.2  *Insurance Broker* – An insurance broker often works with the owner to develop a Statement of Values listing all of the properties in the portfolio (or alternatively the subset of properties in seismically-active areas), assists in estimating the values-at-risk (e.g., replacement values for buildings and/or contents, monthly rents, etc.).  The insurance broker may function as User’s representative in the Portfolio SRA.   In some cases, the insurance broker may function as the Service Provider or collaborate with the Service Provider in the use of the model.  However the Insurance Broker should not serve as both User’s representative and Provider on an Engineered Portfolio SRA.

6.5.3  *Valuation Consultant* – if needed, a valuation consultant can provide improved exposure data, i.e., replacement values for buildings and (where relevant) for contents.  See also the Technical Appendix.

6.5.4  *Rating Agency* – may provide a rating of a transaction for stock in a real estate investment trust (REIT), or a security issued by a real estate mortgage investment conduit (REMIC), or other financial instrument.  The rating may be based in part on the results of the Portfolio SRA and the owner’s earthquake insurance coverage.

**7. Assignment of Damage Relationships**

7.1  *Damageability Models for Buildings, Contents and Business Interruption*

7.1.1  *Types of Damageability in Seismic Risk Assessments*

Users are referred to ASTM E2026 and E2557 for the recommended scope of seismic due-diligence studies for individual properties at the time of acquisition.   The following types of investigation are defined in ASTM E2026 and E2557 (see Chapter 2), for seismic risk assessment for individual properties, and are relevant to portfolio seismic risk assessments.

*Building Damageability (BD)*—Assessment of the economic consequences associated with damage to the building(s) resulting from earthquake ground shaking and other seismic hazards.  Where liquefaction hazards exist at a specific site within a portfolio, additional information (e.g., type of foundation) may be needed to define incremental damage resulting from liquefaction hazards.

*Contents Damageability (CD)*—Assessment of the economic consequences associated with damage to building contents resulting from earthquake ground motions and other seismic hazards.

*Business Interruption (BI)*—Assessment of the economic consequences associated with partial or full loss of use of the building due to earthquake damage to the building, or to contents, or from offsite factors (e.g., loss of power or other utilities, or loss of access).

Other types of investigation that are not typically conducted in portfolio seismic risk assessment include:

*Building Stability (BS)*—Assessment of whether the building will maintain vertical load-carrying capacity in whole or in part during considered earthquake ground motions.

*Site Stability (SS)*—Assessment of the likelihood that the site will remain stable in earthquakes and is not subject to failure through faulting, soil liquefaction, landslide, or other site response that can threaten the building’s stability or cause damage.

Portfolio risk managers typically engage consultants for seismic risk assessments for individual properties  (i.e., "PML studies") at the time of acquisition, and such studies include assessment of building stability and site stability (BS, SS) when they conform to ASTM E2026 Level 1 or higher.  Hence, where recommended seismic due-diligence has been exercised in acquisition, the portfolio may have identified and excluded unstable sites and buildings with significant potential for collapse, for the earthquake hazard levels defined in the PML studies.

7.2  *Building Damageability*

Costs for repair to damage to the buildings are normally considered, unless otherwise specified by the User.  Each catastrophe software system has its own methods and categories for modeling building damage, and these may differ from methods used in seismic risk assessment for individual buildings (i.e., ASTM E2026), requiring judgment and interpretation on the part of the Service Provider.  The User and Service Provider are referred to the specific catastrophe software system and Catastrophe Risk Model Provider for more details.

7.3  *Contents Damageability*

Where requested by the User, costs from damage to contents within the buildings may be considered.  Each catastrophe software system has its own methods and categories for modeling contents damage.  The User and Service Provider are referred to the specific catastrophe software system and Catastrophe Risk Model Provider for more details.

7.4  *Business Interruption*

Business Interruption (BI) losses or costs from loss of use due to earthquake damage typically include costs from lost rents and other consequences from the period of vacancy required for repair, restoration of access and function.  BI losses are generally related to the duration of the interruption or vacancy, and exposure values must specify the time period assumed (e.g., cost per month or cost per year).  Loss of use due to site access restrictions or other off-site factors may or may not be considered, depending on User needs and the capabilities of the catastrophe model.  Higher-order disruption costs (e.g., costs from disruption of supply chains for manufacturers) may require system or network models.  Each catastrophe software system has its own methods and categories for modeling business interruption and its economic consequences.  The User and Provider are referred to the specific catastrophe software system and Catastrophe Risk Model Provider for more details.

7.5  *Service Provider Efforts to Improve Damage Modeling*

Proprietary damage models provided as a part of commercial catastrophe models may be statistical, empirical, or engineering-based.  Catastrophe risk model Providers may have access to loss experience data from their insurance clients, and this data may provide validation and calibration for their models.  Service Providers and Users are encouraged to work with their selected catastrophe risk model Provider to gain thorough understanding of the details of the selected model, and the procedures to utilize detailed information on significant buildings (i.e., “secondary modifiers”), and site hazards that the Service Providers and Users may possess.  Similarly, Service Providers are encouraged to understand the catastrophe models and options available for modeling contents and business interruption impacts, where these are relevant.

In scoping efforts to improve the quality of portfolio modeling, an important consideration is portfolio size.  Most portfolios have an assortment of properties with varying values-at-risk (i.e. building replacement values + contents values + business interruption cost over a stated time-span).  As portfolio size increases (i.e., as the number of properties increases), it becomes increasingly costly to improve the modeling for each property, so efforts are generally limited and prioritized.  For large portfolios (i.e., with more than 50 properties having significant value), the scope of Provider efforts may be limited to a general review of the damage models for suitability to the properties in the portfolio.  For portfolios of high value, but with a smaller number of properties, the importance for data enhancement through engineering review increases.

An effective way to prioritize Provider efforts to improve modeling is to perform preliminary analysis based on available information, and then to focus on the high-risk sites identified (e.g., sorting in order of decreasing Average Annual Losses, in dollars).  For the purpose of scoping efforts to improve modeling, each seismically active region with significant exposures may be examined separately.  Portfolio properties may be geographically dispersed, or there may be clusters, i.e., local concentrations of exposure.   High-value clusters near large active faults tend to have significant impact on portfolio-wide loss, and on the uncertainty of loss estimates, and may warrant greater scrutiny.

Provider efforts to improve the quality of the portfolio risk assessment for properties that signficantly to portfolio-wide risks may include the following steps:

* Review of geologic conditions assigned by the geologic maps embedded within the selected catastrophe model at sites that contribute significantly to aggregate losses, or at sites indicated as important by the User.  Where needed, over-ride can be made to ensure appropriate assignment of Site Class, liquefaction susceptibility and other local conditions affecting losses.
* Assignment of damage relationships based on structural engineering characteristics (materials, framing system, height, year built), where possible, rather than building usage or occupancy.
* Specification of ‘secondary modifiers,’ to the extent known.
* Specification of foundation type (e.g., spread footings, structural mats, or piles), where a potential for ground failure may be present.

Such efforts are not required but may be included within Desktop portfolio SRAs.  Such efforts shall be included in Engineered portfolio SRAs for a set of properties to be decided by the User in discussion with the Provider, subject to limitations of available information, and within the budget and schedule available.

*Use of Past Seismic Risk Reports —*The Provider may make use of past PML reports that they deem to be credible – that is where the original design documents or other engineering design details were determined by qualified individuals.  The Provider may also conduct new investigations as needed, in concurrence with the User.  See Chapter 5 (e.g., Section 5.1.2.6).

Commentary:  Most single-site seismic risk assessment reports (“PML reports”) are based on 475-year ground shaking hazards from the U.S. Geological Survey (or other authoritative source), adjusted for Site Class.  Most PML reports describe site conditions (e.g., Site Class and liquefaction susceptibility) and describe the structural systems of the building(s), but may not address contents or business interruption.  For properties deemed signficant to portfolio-wide risks, to facilitate comparison with past PML reports, the User needs the ability to run the catastrophe model for each such property and extract a  475-year Probable Loss (PL) for the property, for comparison with the risks given in the PML report, typically Scenario Expected Loss (SEL) or Scenario Upper Loss (SUL) for the 475-year shaking hazards. Such comparisons may be limited to specific hazards (e.g., shaking only), and without the effects of “loss amplification” or “demand surge,” or fire-following earthquake, to match the scope of typical PML reports.  Often SEL ≤ PL ≤ SUL for single-site assessments, so the PL from the Cat model may be compared accordingly.  Such comparisons afford an important opportunity to “ground truth” the modeling for significant real estate properties, and may indicate the need for adjustment of the parameters of the catastrophe model, or for further investigation to explain the observed differences.

Commentary:  *Custom Modeling of Critical and High-Value Properties –*At the most advanced level, the Engineer Provider may be able to specify relationships between Intensity Measure(s) available in the catastrophe model and the modeled consequences (damage state, repair cost, downtime and other effects).   Each catastrophe model handles custom modeling in different ways, and to varying degrees.  Service Providers are referred to catastrophe model Providers for more details.  Such custom modeling may be cost-justified under special circumstances for critical, high-value properties.

**8.  Level of Investigation and Impact on Uncertainty in Risks**

This section describes two levels of portfolio seismic risk assessment (SRA): Desktop Portfolio Seismic Risk Assessment and Engineered Seismic Risk Assessment, where more extensive levels of investigation are intended to reduce the degree of uncertainty in the portfolio aggregate risks.  We note that a portfolio may first be analyzed at the “Desktop” level, without engineering input, to indicate key risk drivers and help decide on the level of effort to be devoted to the engineering investigation.  With these two levels defined, Section 8.3 outlines how to describe the quality of a portfolio seismic risk investigation that allows for non-uniform level of investigation at the sites that make up the portfolio.

8.1  *Desktop Portfolio SRAs*

Typical portfolio seismic risk studies for insurance placements are performed as “desktop” analyses, based on approximate values for the buildings and contents, and business interruption cost rates (dollars per unit time, e.g., for lost rents).  Values may be estimated by the insurance broker, often in discussion with the owner.  These studies typically use owner-provided information for the location (i.e., address), building height or number of stories, year built and occupancy (i.e., commercial, residential, warehouse, etc.).  Site geological hazards are assigned by the catastrophe modeling software from digital mapping using geo-coded locations, and risks are evaluated for an exhaustive set of possible future earthquakes.  The vulnerability models are approximate, based on year built, height and occupancy, but with minimal information about materials and structural system, generally with no input from structural engineering professionals (Civil or Structural Engineers), although single-site seismic risk assessment reports (“PML reports”) may be consulted.

The estimates of damage and loss that are produced for any individual site are highly uncertain.  Owing to the Central Limit Theorem and the “law of large numbers," the accuracy of portfolio-wide losses tend to improve, depending upon the geographic distribution of the exposure, so that portfolios with hundreds or thousands of structures widely distributed across seismic regions should produce more accurate estimates of aggregate loss, if no net bias exists in the values and vulnerability.  The catastrophe models used in earthquake insurance applications typically account for the high uncertainties involved in ways that produce aggregate loss estimates with high uncertainty, reflecting the approximate input data. Such evaluations, typical of risk studies produced by insurance brokers for earthquake insurance placements, are referred to herein as “Desktop Portfolio Seismic Risk Assessments."

8.2  *Engineered Portfolio SRAs*

Under the direction of a Professional Engineer, improved portfolio seismic risk results may be achieved based on more accurate values, geologic information and vulnerability modeling.  Improved, current values for the buildings, contents and time-element exposures, may be found by appraisal specialists, or by using valuation software.  A Professional Engineer (Civil or Structural) can assign damage models based on the structural systems found from engineering site visits and/or review of Structural design drawings, with adjustment of vulnerability parameters or assignment of “secondary modifiers." The engineer can also consult geotechnical investigation reports or published maps to improve the assignment of Site Class and local site hazards (i.e., liquefaction, landslide), and to assign foundation type (e.g., piles) for sites with potential soil failures.  This engineering information may be recovered from acquisition due-diligence studies (PML reports), produced through new engineering studies, or a combination of sources.

The accuracy of the estimates of damage that are produced for any individual site will vary, depending on the quality of the information and level of investigation for that site.  The accuracy of portfolio-wide losses also depends upon the geographic distribution of exposure and vulnerability.   A  single high-value, vulnerable property may dominate loss and uncertainty for a small portfolio, whereas portfolios with many structures (i.e., hundreds or more) in multiple seismic regions will be less sensitive to losses at any single property.

For large portfolios, uncertainties in estimates of aggregate loss are proportionally lower, especially if higher levels of investigation are completed for the concentrations of exposure that can produce high levels of portfolio-wide risk. Ranking sites using single-site risk parameters (e.g., AAL, or SEL) in dollars may provide a way to prioritize efforts to improve the input data and scope engineering investigations.

Catastrophe models used in insurance applications generally account for the increased precision of structural vulnerability models (rather than occupancy-based models) by assigning reduced uncertainties. Such evaluations, typical of risk estimates produced by engineering firms for earthquake insurance placements, are referred to herein as “Engineered Portfolio Seismic Risk Assessments."

8.3 *Describing the Quality of Investigation for Portfolio Seismic Risk Assessment*

The quality of the investigation underlying a portfolio seismic risk investigation shall be reported to Users along with the other findings of the study.  With reference to 8.1 and 8.2, if the quality of data and the level of investigation are uniform throughout the portfolio, the overall quality of a portfolio evaluation may be described directly as "Desktop Portfolio Seismic Risk Assessment,” or “Engineered Portfolio Seismic Risk Assessment” as appropriate.

More generally, the levels of investigation (as described in E2026) will vary for each site and for each building. Furthermore, the qualifications and experience of the investigators will vary, and the capabilities of seismic risk models may differ.  The Providers and Users may not have access to a catastrophe model before establishing the scope of study and identifying the sites to be examined in greater detail, and conventional models are not set up to produce an estimate of the precision of risk estimates as a function of input data quality, so an approximate way to describe the quality of investigation is needed.

The simplest way to describe the quality of investigation is to tabulate the quality of investigation at each site, using terminology derived from ASTM E2026.  The information for each site may include:

* Building name or other identifier
* Building address
* Location information quality: was the address successfully geocoded? (Y/N)
* Exposure values (replacement value, contents replacement value, business interruption loss rate, etc.)
* Source and date for exposure values (owner, broker, etc.)
* Occupancy / Usage (e.g., residential, industrial, office, etc.)
* Source of site geologic information (Site Class, liquefaction susceptibility): from GIS data or geotechnical report
* Building damageability system: **Structural** (e.g., ATC, NEHRP, ASCE 7) or **Occupancy-based**, and
* Basis for damageability class (description by others, photos, visual survey by P.E., design drawing review by P.E., etc.)
* Basis for secondary modifiers (if included)

Where investigation quality varies, the quality of investigation for the overall portfolio (or for any independent seismic region) can be described as the fraction of the total exposure value meeting that quality, such as “50% of the southern California exposure was investigated to Level BD1 or better.”  Such communication regarding the quality of the input data will allow the User to assess the adequacy of Provider efforts and the expected quality of the risk results.

**9. Report Requirements**

9.1  *General Requirements*

The results of the portfolio seismic risk assessment investigation shall be documented in a written report following a format acceptable to the User.   The report shall contain a statement indicating who may rely upon the report’s findings and conclusions. The report shall contain a statement describing omissions and deviations from this guide, if any.

The report shall specify clearly how seismic risks and hazards were evaluated and represented, and any special assumptions made in the seismic risk assessment that could substantially influence the results.  The report shall describe the level of overall uncertainty (e.g., high, moderate, low) of the risk results.  See also Chapter 8.

The report shall identify  the individual(s) responsible for preparation of the data, vulnerability modeling and risk analysis and describe their technical qualifications.

The report shall include documentation (e.g., references) to support the analysis, opinions, and conclusions found in the report.  All sources of information should be sufficiently documented to facilitate retrieval or re-use at a later date. The report shall state any specific limitation or exclusions that impact the technical reliability of the conclusions.   The report shall list any previous seismic risk assessment reports (“PML reports”) that have been used, their author and dates, and the Level of Investigation conducted at the time, using terminology suggested in ASTM E2026.  The report shall describe any new investigations performed, identify the assessor(s), and the Level of Investigation conducted.

The report shall present the overall portfolio risks (Probable Loss or PL) for a range of return periods.  Risks shall be presented as loss estimates, in dollars, from a ground-up position, as well as for any specific stakeholder position(s) and return period(s) requested by the User.  For example, the User may request risks for both ground-up and net of earthquake limits and deductibles.  The report may present the results in tables and/or risk curves.  The report shall identify the hazards considered in addition to ground shaking for each set of results presented (i.e., liquefaction, landslide, fire-following, fire sprinkler leakage, etc.), and whether the losses have been inflated to consider post-earthquake loss amplification or “demand surge."  Probable losses shall be described as annual exceedance probability or occurrence exceedance probability.

9.1.1  *Options.*At the option of the User, the report may:

• Present details of risks from seismic hazards and identify the principal contributors to the seismic risks, using regional risk curves, location risk details, scenario risk details or other useful de-aggregations

• Identify risk reduction opportunities

• Recommend further investigation where warranted, to reduce critical uncertainties

The Provider may also:

• Return the modeling data for archiving and re-use in future studies

• Participate in presentations and discussions

• Perform other follow-up actions

9.2  *Matters of Interest and Technical Details*

9.2.1  The report shall describe the basis for the analysis.  Specifically, it shall:

• Identify and describe the catastrophe risk model used for the analysis, including the vendor and the version of the software used.

• Identify the basis of the earthquake ground-shaking modeling (e.g., U.S. Geological Survey National Seismic Hazard Mapping Project, citing the year and version, or other authoritative model) and describe its adaptation for use in portfolio seismic risk assessment.

• Define the exposure – including the replacement values for buildings, and (if applicable) for contents and equipment and business interruption loss rates, and identify the source of the exposure data.  Summary totals should be presented from the exposure to ensure agreement on values.  Optionally, exposure summaries may include breakdowns by: line of business, division or zonal totals; along with totals for construction and occupancy types.   In addition, exposures may be mapped in relation to active earthquake faults, to provide feedback on local accumulations.

• Where insured losses are presented, earthquake limits and deductibles shall be documented. Where other stakeholder risk allocation mechanisms are used, the logic for allocation of loss shall be explained.

• Describe ground conditions (Site Class) at each site and list any special seismic hazards considered in the risk estimates (e.g., liquefaction).  List any sites where site coordinates were not successfully geo-coded, address errors, etc.

• Define the sources and quality of the vulnerability data used in the study (e.g., past PML reports), including steps to improve data and reduce uncertainty.

9.2.2  The report shall state whether the vulnerability modeling for each building is derived from a classification system based on building usage or occupancy, or from a classification system based on the structural system.  For buildings modeled based on the structural system, the report shall detail the level of structural investigation for each building using terminology derived from ASTM E2026, specifically, whether a Civil or Structural Engineer conducted a visual inspection of the building and/or reviewed the design documents (especially Structural design drawings), and whether such review provided the basis for any Secondary characteristics (i.e., structural condition, load path discontinuity, irregularities in plan or height, etc.) specified.  See also Section 8.3.

9.2.3  The report should clearly describe limitations of the information provided, of the investigations conducted, and of the analytical model(s) used so that the User may draw appropriate conclusions regarding the quality of the results.

**10.  References (check where cited)**

ASCE 41-17, Seismic Evaluation and Retrofit of Existing Buildings, American Society of Civil Engineers, Reston, Virginia, 2017.

ASCE 7-16, Minimum Design Loads and Associated Criteria for Buildings and Other Structures, American Society of Civil Engineers, Reston, Virginia, 2016.

ATC 13. Earthquake Damage Evaluation Data for California, ATC-13, Applied Technology Council, Redwood City, California, 1985.

ATC 13-1. Commentary on the use of ATC 13 earthquake damage evaluation data for probable maximum loss studies of California buildings, ATC-13-1, Applied Technology Council, Redwood City, California, 2002.

Baker, J.W. and Jayaram, N., Correlation of Spectral Acceleration Values from NGA Ground Motion Models. Earthquake Spectra: Vol. 24, No. 1, February 2008.

Detweiler, S.T., and Wein, A.M., eds., 2017, The HayWired earthquake scenario—Earthquake hazards (ver. 1.1, March 2018): U.S. Geological Survey Scientific Investigations Report 2017–5013–A–H, 126 p., https://doi.org/10.3133/sir20175013v1.

Goda, K. and Hong, H. P., Spatial Correlation of Peak Ground Motions and Response Spectra, Bulletin of the Seismological Society of America, Vol. 98, No. 1, pp. 354–365, February 2008.

Graf, W.P., and Y. Lee, “Code-Oriented Damage Assessment for Buildings,” EERI Spectra Journal, Vol. 25, No. 1, February, 2009.

Graf, W. and Lee, Y., “A Geographic Correlation Index For Portfolio Seismic Risk Analysis,” 7th U.S. National Conference on Earthquake Engineering, Boston, July, 2002.

Grossi, P. and Kunreuther, H. (editors), “Catastrophe Modeling: A New Approach to Managing Risk,” Springer, 2005.

HAZUS MH MR1, 2003. "Advanced Engineering Building Module, Technical and User's Manual.”

Hudnut, K.W., Wein, A.M., Cox, D.A., Porter, K.A., Johnson, L.A., Perry, S.C., Bruce, J.L., and LaPointe, D., 2018, The HayWired earthquake scenario—We can outsmart disaster: U.S. Geological Survey Fact Sheet 2018–3016, 6 p., https://doi.org/10.3133/fs20183016.

Jones, Lucile M., Bernknopf, Richard, Cox, Dale, Goltz, James, Hudnut, Kenneth, Mileti, Dennis, Perry, Suzanne, Ponti, Daniel, Porter, Keith, Reichle, Michael, Seligson, Hope, Shoaf, Kimberley, Treiman, Jerry, and Wein, Anne, 2008, The ShakeOut Scenario: U.S. Geological Survey Open- File Report 2008-1150 and California Geological Survey Preliminary Report 25 [http://pubs.usgs.gov/of/2008/1150/].

Kircher, C.A., Nassar, A.A., Kustu, O. and Holmes, W.T., “Development of Building Damage Functions for Earthquake Loss Estimation,” Earthquake Spectra, Vol. 13, No. 4, November 1997.

Lemaire, J., Taylor, C.E., and Tillman, C., “Models for Earthquake Insurance and Reinsurance Evaluation,” Proceedings of the Second International Symposium on Uncertainty Modeling and Analysis, 1993.

Olsen, A. H. and K. A. Porter. (2011). What we know about demand surge: Brief summary. *Natural Hazards Review*. **12: 2**, 62–71.

Taylor C.E, “Robust Simulation For Mega-Risks - The Path from Single Solutions to Competitive, Multi-Solution Methods for Mega-Risk Management,” Springer International Publishing, ISBN 978-3-319-19413-4, October, 2015.

Thiel, C. C., and Zsutty, T. C., 1987. Earthquake characteristics and damage statistics, Earthquake Spectra, Volume 3, No. 4, pp. 747–792.

Wesson, R.L., Perkins, D.M., Leyendecker, E.V., Roth, Jr., R.R., and Petersen, M.D., “Losses to Single-Family Housing from Ground Motions in the 1994 Northridge, California, Earthquake” Spectra, August, 2004.

Wesson, R.L., Perkins, D.M., Luco, N., and Karaca, E., Direct Calculation of the Probability Distribution for Earthquake Losses to a Portfolio, Earthquake Spectra, Volume 25, No. 3, pages 687–706, EERI, August 2009.

Woo, Gordon, “Calculating Catastrophe,” Imperial College Press, 2011

**Technical Appendix**

This Appendix provides background to enable users of the standard (building owners, lenders, insurance brokers, etc.) and service providers (engineers and risk consultants) to make effective use of the standard.

**A1. Event Sets**

**A2. Building Damage Models**

**A3. Value Estimation**

**A4. Other Risks**

**A5. Risk Aggregation Methods**

**A6. Stakeholder Allocation Models**

**A7. Limitations to the State of the Art**

**A1. Event Sets**

The objective of portfolio seismic risk assessment is to find the losses to a geographically distributed group of real estate properties in future earthquakes.  Some researchers have attempted to develop ways to combine the risks from geographically separated sites based on correlation of risks found using single-site methods, e.g., [Wesson et al., 2009].  Such methods can provide estimates for the “ground-up” losses for a portfolio in a particular region, but they have greater difficulty addressing losses to stakeholders such as insurers, where insurance deductibles apply event-by-event.  They also typically do not address the effects of spatial correlation of ground shaking and loss in large-to-great earthquakes, where the source fault rupture may be tens to hundreds of kilometers long.  A more common approach is to simulate individual potential earthquakes one at a time, each one with its spatial distribution of ground shaking and other hazards.  In the past, some real estate lenders tracked portfolio-wide losses for a few selected maximal scenarios, such as magnitude 8 events on the San Andreas in northern or southern California, but focusing on any individual scenario may lead to poor decisions on particular properties, and will not provide adequate guidance on earthquake insurance needs.  Over the past several decades, as led by insurance catastrophe modelers, losses are now evaluated for comprehensive sets of earthquake simulations in a balanced, probabilistic approach.

In the most common probabilistic approach to multi-site seismic risk assessment, portfolio losses are computed for a comprehensive set of earthquake simulations (or scenarios), sometimes referred to as an ‘event set.’ Each event or earthquake simulation attempts to accurately reproduce the geographic distribution of ground shaking and other hazards from a possible future earthquake. The ground motion simulations estimate ground motion intensity parameters (i.e., peak ground acceleration, or spectral acceleration) at each property site in the portfolio for each potential future earthquake with the associated event probabilities or annual frequency.

Since geographic correlation of damage is of primary concern in the seismic risk assessment of a geographically distributed system, the physical size of the source rupture must be properly modeled. The affected area is modeled with an appropriate ground motion attenuation relationships. Each event is associated with an annual frequency of occurrence (a number of events per year, typically << 1), where the annual frequencies are derived from fault activity, magnitude and fault rupture location “sampling.” The ‘event set’ systematically exercises the full range of earthquake magnitudes and rupture locations for each seismic sources, including known faults and background seismicity. The set of scenarios is carefully constructed so that the ensemble accurately reproduces the severity and frequency of earthquake hazards for the region of interest. These simulations usually involve thousands or even millions of scenarios in each complex tectonic region, such as southern California, where numerous known and unknown faults exist and produce frequent earthquakes.

Ground motion models for portfolio risk assessment are typically derived from, and attempt to conform to, the National Seismic Hazard Mapping Project by the United States Geological Survey [e.g., Frankel et al, 1996, 2002; or Peterson et al., 2008, 2014].    The National Seismic Hazard Mapping Project is an ongoing national program that utilizes the seismologists, geotechnical engineers and other experts of the USGS as well regional experts to assess earthquake hazards based upon the best available science. This sustained scientific effort (1996, 2002, 2008, 2014…) has produced substantial improvements in the knowledge of and prediction of earthquake activities and ground shaking hazards in the U.S., and is widely emulated around the world.  As the National Seismic Hazard Mapping Project is the source for the maps used in all design codes for new buildings to resist seismic loads, as well as for the standards (e.g., ASCE 41) used in the evaluation of existing buildings, the USGS seismic hazard model represents the *de facto* national standard.

In selecting and appropriate catastrophe model for use in portfolio analysis, the Service Provider may wish to request documentation that compares or demonstrates the conformance of ground shaking hazards produced by the ensemble of simulations in the event set to the current USGS National Seismic Hazard Mapping Project model. See Section 2.3.  The comparison should address the Intensity Measures (IMs) used by the damage models to be used (i.e., spectral acceleration, or Sa), spanning the range of structural periods of interest (0s to 5s or more) and the return periods of interest (e.g., 100 years to 1,000 years).

Ground motion models such as the NGA West 2 models [PEER, 2013] segregate the aleatory uncertainty in ground shaking estimates into inter-event and intra-event terms.  Inter-event (or “between event”) uncertainty in ground shaking manifests in systematically higher or lower ground shaking throughout the affected area that occurs from earthquake to earthquake, whereas intra-event (or “within event”) variability in ground shaking that occurs from site-to-site within the same earthquake.  The inter-event uncertainty of ground shaking causes correlated changes in ground shaking and hence loss throughout the portfolio, producing significant changes in aggregate loss, whereas intra-event uncertainty of ground shaking causes locally correlated changes in ground shaking [Baker and Jayaram; Goda & Hong], with more limited impacts on portfolio-wide loss.  Such distinctions are not relevant in single-site seismic risk assessments, but are important in portfolio analysis.  The hazard model “event set” and the component vulnerability models for buildings and contents must carefully manage the uncertainties, capture their effects but avoid double-counting.

**A1.1  Uncertainties in Ground Motions and Relevance to Portfolio Risk**

***A1.1.1  Types of Uncertainty***

One common way to classify uncertainty in mathematical models of physical process is to distinguish between *aleatory* and *epistemic* uncertainties.  Aleatory uncertainties are associated with the inherent randomness of a physical process, and this randomness is often quantified by a statistical distribution.  For example, the uncertainty in ground motion models (attenuation relationships) are assumed to have a lognormal distribution.  In contrast, epistemic uncertainty – also called scientific uncertainty – is more concerned with the adequacy of our understanding of the physics underlying the process and the adequacy of existing models of the process.

***A1.1.2  Aleatory Uncertainty***

Re-write to address uncertainty in each major part: exposure ($$, time, people), hazards, vulnerability and repair cost (adjustment or construction).

In estimating the statistical distribution of financial losses from each ground motion simulation, all of the uncertainties must be carefully tracked and accounted for.  Some earthquake damage models (e.g., HAZUS) may include consideration of ground motion uncertainties in computing damage state probabilities or repair costs.  Catastrophe modelers must be careful not to neglect, nor to double-count the uncertainties.

***A1.1.3  Epistemic Uncertainty***

The development of an earthquake risk catastrophe model requires selection from among multiple admissible component models – for asset valuation, for ground shaking and other hazards, for damageability, and for the aggregation and allocation of losses or other consequences. No component model is perfect, and comprehensive approaches may incorporate logic trees or other methods to manage the uncertainty arising from the use of multiple component models.  Differences arising from multiple admissible scientific models is referred to as epistemic uncertainty.

Methods such as Robust Simulation [Taylor, C.E., 2015] preserve and present this epistemic uncertainty, which can be substantial.  This is important to recognize, so that results from such complex models are not viewed as precise.  Furthermore, it is clear that as new findings emerge, new models will be formulated, so any current model must be regarded as incomplete.

**A2. Building Damage Models**

Given any ground shaking simulation for the portfolio, the hazards at each of the individual sites are estimated, and vulnerability or fragility models are then used to estimate the damage and other consequences to the individual properties at those sites.  Portfolio-wide risks may then be found, using aggregation techniques that consider the uncertainties in the building-by-building and site-by-site losses.

**A2.1  Damage Inception and Damage Saturation**

It is important to note that, unlike seismic risk assessment for individual buildings where risks are reported for a defined scenario such as the 475-year probabilistic ground shaking, damage relationships used for portfolio seismic risk assessment must accurately predict damage for the the full range of hazard levels. During the evaluation of losses for a comprehensive set of earthquake simulations (the “event set”), the damage relationship will be interrogated at all hazard levels, and aggregations of loss may include many locations with low levels of damage, some with moderate or high levels of damage, and (typically) a few locations with complete or near-complete loss.  Hence the damage relationships used for portfolio seismic risk assessment should have appropriate behavior throughout the range of damage, from damage inception to saturation.

**A2.2  Overview of Building Damage Models**

Depending on the damage model to be used, different data must be collected for portfolio seismic risk studies.

Available models may be classified as expert-based, statistical, empirical, or engineering-based (either lumped-parameter or explicit).

An example of a published statistical model is [Wesson, 2004].  ATC-13 [Applied Technology Council, 1985] is drawn from expert opinion sampled at Modified Mercalli Intensities, using defined Facility Classes.  The Code-Oriented Damage Assessment model (or CODA) [Graf & Lee, 2009] is an example of empirical damage model, but where damage is a function of a demand-to-capacity ratio in terms of engineering parameters.   HAZUS [Kircher, 1997] is another example of an engineering-based model, although model parameters are often expert-based.

Commercial catastrophe modelers have developed their own proprietary damage models. Some are based upon building usage (termed ‘occupancy’) for use when structural characteristics are not known. Other damage models are based upon the structural systems and materials used. These structurally-based models can be made more building specific using attributes often referred to as secondary modifiers, such as *soft-story* or *torsional irregularity.*

**A2.3  Insurance Taxonomies**

Taxonomies in insurance earthquake damage models generally rely on attributes and externally observable features (age, height, occupancy), that are readily available or may be determined without the involvement of engineers, with the result that they do not achieve maximum correlation with damage, nor minimize the prediction variance. An example of earthquake insurance inventory reporting categories is the system published by the Insurance Services Office (ISO), and still used by the California Department of Insurance (CDI).

**A2.4  Structural Building Classification Systems (Structural Taxonomies)**

Structural building classification systems or structural taxonomies are used to group buildings with similar earthquake damage characteristics, for the purpose of loss estimation. Such groupings are needed when examining loss experience data, and should be based on relevant observable or readily-determined building characteristics. Because they consider the building systems designed to resist earthquake loading, structural taxonomies are assumed to achieve higher correlation with damage, and to minimize the prediction variance, compared to taxonomies that are not based on the lateral force-resisting system.

Location and age may be used to determine the code under which a building was designed and constructed, and can be used to account for local design and construction, inspection and enforcement practice.  Other relevant and effective information includes height or height class, materials of construction of floors and roof (wood, steel, concrete), and earthquake resisting system (braced frame, moment frame, shear wall) and materials of construction (wood, steel, concrete, masonry).

**A3. Value Estimation**

Building replacement values, contents values and costs per unit time resulting from functional interruption are generally supplied by the property owner or broker.  Damage models for individual buildings usually predict damage or loss as a fraction of replacement value.  To obtain dollars losses, the loss rates are multiplied by replacement values, so any errors in value translate directly to errors in risk results.  Care must be exercised in estimating the values, to be consistent with stakeholder position.  For instance, a commercial building owner may own only the building shell and may not own or be responsible for damage to tenant contents or tenant improvements.  Therefore the building and other values used for estimating losses must focus on the exposure of the particular stakeholders whose risks are to be examined.

Commercial systems may be used for value estimation.  Valuation consultants may also be useful.  Costs for business interruption may be estimated by individual business units for the enterprise in question.  Insurance brokers may also be able to offer guidance.

**A4. Other Risks**

Additional loss or damage may occur due to the temporary increase in repair costs that occurs following large regional earthquakes (“demand surge” or “loss amplification”), damage to contents and architectural building elements caused by earthquake-induced leakage of fire sprinkler piping (or “EQSL” for earthquake sprinkler leakage), or earthquake-initiated fires (“fire-following” damage).  Each catastrophe model offers a different approach to modeling these additional loss or damage elements.

**A5. Risk Aggregation Methods**

Models that assume that aggregate losses conform to a particular statistical distribution (e.g., a normal, lognormal, or Pareto distribution) may be subject to significant errors where insurance deductibles and limits (or other risk “buffers” related to stakeholder position) affect the shape of losses for individual properties, and these errors may compound for higher stakeholder positions (as encountered in reinsurance). Aggregation methods based on statistical sampling strategies, similar to Monte Carlo methods, when properly applied, produce more reliable estimates of aggregate loss distributions.

**A6. Stakeholder Allocation Models**

For each earthquake simulation in an “event set”, a hazard model predicts the ground shaking intensity (i.e., PGA, spectral acceleration) at each site, and damage models then estimate the damage level for each building, given the earthquake hazard intensity predicted.  There is significant uncertainty in the prediction of the ground-shaking intensity. Ground motion uncertainties may be modeled using a lognormal distribution as published for attenuation relationships (e.g., NGA West2, [PEER]), for instance by binning the intensity into a large number of hazard states, each with a specified probability.  Furthermore, for each hazard state, the actual loss for any type of building may vary from a predicted mean loss.  Building damage models generally predict repair cost as a fraction of the building replacement value, so the uncertainty in the repair cost, in dollars, is a function of the uncertainty in the damage model and (as appropriate) the uncertainty in estimated replacement values.

Given these uncertainties, for any earthquake “event,” the loss for any property can be represented using statistical distributions.  The cost to repair a building may vary from zero to a repair cost equal to the full replacement value of the building. The statistical distribution of the loss can be subdivided into bins, and the loss in each bin allocated to the stakeholders according to stakeholder logic as described below.

**A6.1  Insurance Loss Model**

Insurance may cover costs to repair buildings, costs to replace damaged contents, costs related to downtime or business interruption, or costs related to temporary relocation while repairs are effected. For insured properties, losses are allocated between the insured party (typically the owner) and the insurer. The insurer may in turn cede a portion of their risks to one or more reinsurers.

A typical insurance policy uses stated deductibles and limits to determine the portion of the loss retained by the insured and the portion paid by the insurer. A minimum deductible may be specified, as well as a per unit deductible, usually stated as a percentage of the property replacement value. For costs related to business interruption, the deductible may be specified as a period of time. Limits of coverage are generally specified for portfolio-wide losses to buildings, to contents and/or time-element (downtime) losses.

Insurance loss allocation models operate on the statistical loss distributions for building damage, for contents damage and for losses from downtime or business interruption to allocate the losses between the insured party and the insurer. Deductibles and limits apply typically per event (that is, per earthquake) with the “event” defined by a period of time. If an aftershock occurs after the main shock and outside the time window used to define the event, an addition deductible would apply.

**A6.2  Lender Loss Model**

The lender for a property will not be affected by earthquake losses unless the borrower (owner) defaults on the mortgage.  The lender is protected by the owner’s equity (and any owner-retained earthquake insurance).

A stakeholder loss allocation diagram for the lender loss depicted in the figure below.  The vertical axis (in dollars) denotes building value at the left and a statistical distribution of loss at the right. The market value of the property is composed of the replacement value building(s) and the value of the land.

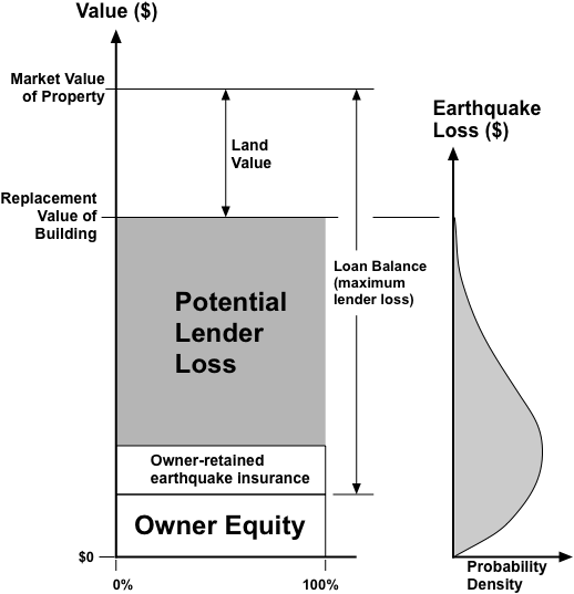
The figure illustrates the normal mortgage case, with positive equity (i.e., market value exceeds mortgage balance).  That is, the loan-to-value ratio (LTV) is less than one.  For low levels of loss (just above the zero dollars axis), repair costs are below owner equity.  For such losses, the owner may repair the damage, and continue to make mortgage payments.  Alternatively, the owner may sell the property, pay off the mortgage and recoup the equity remaining after the cost of repairs.  When losses exceed owner equity, the owner may choose to default on the mortgage. In this case, the lender may repair the structure and sell the property at market value, with a loss equal to:

*Lender Loss = Mortgage Balance + Earthquake Repair Cost – Market Value (Salvage)*

Note that when market value falls below the mortgage balance, the owner has no equity.  In lender terms, the loan-to-value ratio exceeds 100%, and (presumably) default becomes much more likely.

The lender model accounts for the variability of the damage prediction using statistical distributions and easily accommodates declines in the real estate market.  The model can be run at full current market value and at any specified fraction of the market value (representing an assumed level of market value decline).

If the owner has earthquake insurance, the earthquake insurance coverage amount acts like additional owner equity.  The earthquake insurance payments offset repair costs, with any earthquake deductible coming out of the owner’s equity.

  *Lender Loss Model*

**A7. Limitations to the State of the Art**

Conventional risk models may not adequately consider cumulative earthquake effects on urban regions, for instance due to impacts from lifeline disruption, and due to collateral impact from the collapses of tall buildings in urban areas.

**References for the Technical Appendix**

ATC 13. Earthquake Damage Evaluation Data for California, ATC-13, Applied Technology Council, Redwood City, California, 1985.

Baker, J.W. and Jayaram, N., Correlation of Spectral Acceleration Values from NGA Ground Motion Models. Earthquake Spectra: Vol. 24, No. 1, February 2008.

Goda, K. and Hong, H. P., Spatial Correlation of Peak Ground Motions and Response Spectra, Bulletin of the Seismological Society of America, Vol. 98, No. 1, pp. 354–365, February 2008.

Graf, W.P., and Y. Lee, “Code-Oriented Damage Assessment for Buildings,” EERI Spectra Journal, Vol. 25, No. 1, February, 2009.

Kircher, C.A., Nassar, A.A., Kustu, O. and Holmes, W.T., “Development of Building Damage Functions for Earthquake Loss Estimation,” Earthquake Spectra, Vol. 13, No. 4, November 1997.

PEER 2013/04, 05, 06, 07, 08, Pacific Earthquake Engineering Research Center, available at: https://peer.berkeley.edu/peer-reports

Taylor C.E, “Robust Simulation For Mega-Risks - The Path from Single Solutions to Competitive, Multi-Solution Methods for Mega-Risk Management,” Springer International Publishing, ISBN 978-3-319-19413-4, October, 2015.

Wesson, R.L., Perkins, D.M., Leyendecker, E.V., Roth, Jr., R.R., and Petersen, M.D., “Losses to Single-Family Housing from Ground Motions in the 1994 Northridge, California, Earthquake” Spectra, August, 2004.

Wesson, R.L., Perkins, D.M., Luco, N. and Karaca, E., Direct Calculation of the Probability Distribution for Earthquake Losses to a Portfolio, Earthquake Spectra, Earthquake Engineering Research Institute, 2009.