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Standard Guide for the Estimation of Building Damageability in Earthquakes[1]

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INTRODUCTION

Lenders, insurers and equity owners in real estate are giving more intense scrutiny to earthquake risk than ever before. The 1989 Loma Prieta earthquake, which caused more than $6 billion in damage, accelerated an already established trend for improved loss estimation in California; the 1994 Northridge event with over $20 billion in damage has completed the process—loss analysis is now an integral part of real estate financial decision making. Financial institutions are in need of specific and consistent measures of future damage loss for this decision process. The long used notion of "probable maximum loss" (PML) has become, for many, a catch phrase to encapsulate all earthquake issues into a simple number that can be used to qualify or disquality a potential commitment. Unfortunately, there has been no previous industry or professional consensus on what PML means or how it is computed. This guide presents specific approaches, which the real estate and technical communities can use to characterize the earthquake vulnerability of buildings. It recommends use of new terms, probable loss (PL), and scenario loss (SL) in the future to make specific the type of damageability measures used. Use of the term Probable Maximum Loss (PML) is not encouraged for future use.

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1. Scope

1.1 *Purpose*—This guide defines and establishes good commercial, customary practice, and standard-of-care in the United States for conducting a probabilistic study of expected loss to buildings from damage associated with earthquakes and for the preparation of a narrative report containing the results of the study. As such, this guide permits a user to satisfy, in part, their real estate transactional due-diligence requirements with respect to assessing a property's potential for building losses associated with earthquakes.

1.1.1 *Recognized Earthquake Hazards*—Hazards addressed in this guide include earthquake ground shaking, earthquake caused sit instability, including faulting, land sliding, and densification, and earthquake caused tsunamis and seiches. Earthquake caused fires and toxic materials releases are not considered.

1.1.2 *Other Federal, State, and Local Laws and Regulations*—This guide does not address requirements of any federal, state, or local laws and regulations of building construction or maintenance. Users are cautioned that current federal, state, and local laws and regulations may differ from those in effect at the time of the original construction of the building(s).

1.2 *Objectives*—The objectives for this guide are as follows:

1.2.1 To synthesize and document good commercial, customary practice for the estimation of probable loss to buildings from earthquakes for real estate improvements;

1.2.2 To facilitate standardized estimation of probable losses to buildings from earthquakes;

1.2.3 To ensure that the standard of site observations, document review and research is appropriate, practical, sufficient, and reasonable for such an estimation;

1.2.4 To establish what reasonably can be expected of and delivered by a loss estimator in conducting an estimation of probable loss to buildings from earthquakes;

1.2.5 To establish an industry standard for appropriate observations and analysis in an effort to guide legal interpretation of the standard of care to be exercised for the conducting of an estimation of probable loss to buildings from earthquakes; and,

1.2.6 To establish the requirement that a loss estimator communicates observations, opinions, and conclusions in manner meaningful to the user and not misleading either by content or by omission.

1.3 *Considerations beyond the scope*—The use of this guide is limited strictly to the scope set forth herein. Section 3 of this guide identifies, for information purposes, certain conditions that may exist on a property that are beyond the scope of this guide but may warrant consideration by the parties to a real estate transaction.

1.4 *Organization of this guide*—This guide has several parts (see the Table of Contents).

1.5 *Limitations*—This guide does not purport to provide for the preservation of life safety, or prevention of building damage associated with its use, or both. 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.

1.6 *Commentary*—See Appendix X1 for commentary on Section 1.

2. Terminology

2.1 *Definitions*—This section provides definitions of terms used in this guide. The terms are an integral part of the guide and are critical to an understanding of the guide and its use.

2.1.1 *active earthquake fault*, *n*—an earthquake fault that has exhibited surface displacement within Holocene time (about 11 000 years).

2.1.2 *building code*, *n*—any federal, state, local, recognized design professional, or trade/industry association compilation of systems or rules that govern design or construction practices, or both.

2.1.3 *business interruption*, *n*—a situation when an earthquake causes an interruption to normal business operations; and therefore, potentially or materially causes a loss to the operator of that business. The loss may be partial or total for that period. Business interruption is expressed in days/weeks/months of downtime for the facility as a whole or the equivalent operating value.

2.1.4 *computer assessment tools*, *n*—any of a variety of computer software provided by vendors to identify the seismic hazards of a site, or estimate the earthquake damageability of a building, or both. Some programs may be interactive, using a question/answer format that adjusts the scores based on responses, making default assumptions where specific information is unavailable or not known. Other programs may use spread sheet-type data entry. Such software sometimes may be customizable by the user. These software packages almost always depend on large files of site, earthquake source and building damageability data that usually are updated periodically to reflect new information. The particular method of processing the input data often is proprietary and not available to the user.

2.1.5 *contents*, *n*—contained elements, for example, furniture, fixtures, equipment and contents within the building that are not part of the permanent structure or architectural finishes and equipment of the building.

2.1.6 *correlation*, *n*—the tendency or likelihood of the behavior of one element to be influenced by the known behavior of another element.

2.1.7 *damage distribution*, *n*—the probability function for the possible damage states of a given building type due to a

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given level of earthquake ground motion. Actual damage to a building is random because actual future ground motion, as represented by a given measure and level, is not described completely by that representation, and a particular building has its own resistance, fragility characteristics, and orientation with respect to ground motions that are not completely described by the building structural system type. This probability function allows the evaluation of the conditional probability of the building having a given damage state (a given range of damage ratios, such as 25 % to 50 %) due to a given level of ground motion.**(1-3)**.[2]

2.1.8 *damage cost or repair cost*, *n*—the construction cost, including design and construction observation and management costs, required to restore the building to its original condition.

2.1.9 *damage predictor*, *n*—a relation giving a central or mean damage ratio in terms of a measure of the building class or system damage factor, the level of the measure of ground motion, and possible site-structure vibration effects. This relation should have some measure of the scatter of actual damage ratio about the predicted mean, or preferably, provide the damage distribution function. Examples include Steinbrugge, ATC-13, Thiel-Zsutty. Providers may have their own proprietary relations based on their experience and data sources.

2.1.10 *damage ratio*, *n*—the ratio of the cost to repair a building to its original condition divided by its replacement construction cost.

2.1.11 *damage state*, *n*—a range of damage ratios, (for example, 0 to 5 %, or 75 % to 100 %) or generalized building damage condition, for example, a linguistic term such as "low" or "serious" associated with a defined range of damage ratios, that is treated the same for assessment purposes.

2.1.12 *dangerous or adverse conditions*, *n*—situations, which pose a threat or possible injury hazard to the occupants, and also those situations, which require the use of special protective clothing, safety, or access equipment.

2.1.13 *deficiency*, *n*—patent, conspicuous defect in the building or significant deferred maintenance of a building, components, or equipment. This definition specifically excludes routine maintenance, miscellaneous repairs, operating maintenance, etc.

2.1.14 *describe*, *n*—to represent in words sufficient information to visualize a type of system, component, or potentially hazardous condition.

2.1.15 *due-diligence*, *n*—the act of conducting an assessment of a property's physical condition for the purposes of identifying potentially dangerous conditions. The extent of due-diligence exercised on behalf of a user is proportional to the user's uncertainty tolerance level, purpose of the estimate of probable loss assessment, and the resources and time available to the loss estimator to conduct the site visit and research.

2.1.16 *earthquake*, *n*—the sometimes violent oscillatory motions of the ground caused by the passage of seismic waves radiating from a fault along which sudden movement has taken place.

2.1.17 *earthquake loss (for damage ratio)*, *n*—the property damage loss evaluated as the percentage of the building construction cost to effect restoration to the pre-earthquake condition, including salvage and demolition, to the present-day building cost at the same location, assuming a virgin site condition. Loss includes damage to architectural finishes, partitions, ceilings, and other portions of the permanent building from ground shaking, but not loss of rents or other income, or damage to contents, furnishings, equipment, or other tenant capital assets contained within the building. Loss is expressed in terms of a probability distribution of the damage ratio due to a specific earthquake ground motion affecting the building project or development under consideration.

2.1.18 *estimate of earthquake loss study*, *n*—a study completed in accordance with the requirements of this guide; also sometimes referred to as an Estimate of Earthquake Damageability study.

2.1.19 *expected or mean value*, *n*—of a random variable, such as building damageability, the mathematical centroid of the probability distribution for the random variable; that is, it is determined as the sum (or integral) of all the values, such as damage levels, that can occur times their probability of occurrence. The expected or mean value is not the same as the median value, which is the value that divides the probability function into equal parts, such that the value of the random variable has an equal probability of being above or below the median value.

2.1.20 *fault zone*, *n*—the area within a prescribed distance from any of the surface traces of a fault. The distance depends on the magnitude of earthquakes that could occur on the fault-500 ft (152 m) from major faults, those capable of earthquakes with magnitudes of 6.5 or greater, and 250 ft (761 m) away from other well-defined faults. Within California, use the zones determined by the California Division of Mines and Geology under the Alquist-Priolo Special Studies Zones Act for active and potentially active faults they have identified by the state or other governmental bodies.

2.1.21 *interdependency*, *n*—a condition wherein the function of a facility also is dependent on another facility, utilities, lifelines (example, transportation), which 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.

2.1.22 *interplate areas*, *n*—regions of the United States where there is poor understanding of the sources of local earthquakes. The plate boundaries along the Pacific coast, Hawaii, the Caribbean, the Basin and Range province (Nevada, Utah, Idaho, Montana) are understood fairly well. In the interplate areas, the balance of the country far removed from plate boundaries, the specific sources and mechanics of earthquake are understood less well, and thereby, more uncertain.

2.1.23 *landslide*, *n*—the rapid downslope movement of soil, or rock material, or both, often lubricated by ground water,

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

over a basal shear zone; also, the tongue of stationary material deposited by such an event.

2.1.24 *level*, *n*—the degree of investigation of the particular earthquake damageability attribute. For each type of assessment, four levels are described in the guide: Level 0 is a screening investigation, while Level 3 is an exhaustive technical investigation; Levels 1 and 2 are intermediate between these two. It is emphasized that the lower the level of investigation the higher the uncertainty in results, given that the same loss estimator undertakes the investigations.

2.1.25 *liquefaction*, *n*—the transformation of loose, saturated, sandy materials under sustained strong cyclical shaking into a fluid-like condition. Damage from liquefaction results primarily from horizontal and vertical displacements of the ground. These displacements occur because sand/water mixtures in a liquefied condition virtually have no strength and provide little or no resistance to compaction, lateral spreading, or down slope movement. 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 liquefaction occurs within the building's foundations.

2.1.26 *magnitude of earthquake*, *n*—any of a variety of measures that indicate the "size" of an earthquake. The most commonly used lay term is the Richter magnitude, which is determined by taking the common logarithm (base 10) of the largest ground motion recorded during the arrival of a "P" wave, or seismic surface wave, and applying a standard correction for the distance to the epicenter of the earthquake.

2.1.27 *maximum capable earthquake (MCE)*, *n*—the earthquake that can occur within the region that produces the largest average ground motion at the site of interest. All faults and features for which there is reasonable professional basis within engineering seismology and geology to assign a maximum earthquake to the fault or feature are to be assessed. The ground motion at the site is determined by application of an appropriate attenuation relationship determined from those available that best represent the specific seismic and tectonic setting of the immediate region. This earthquake is sometimes termed the maximum credible earthquake.

2.1.28 *modified mercalli earthquake intensity (MMI)*, *n*—a qualitative description of the local effects of the earthquake at a site. Normally, it is given as a roman numeral for I to XII, to emphasize its qualitative, not quantitative nature. **(3)**

2.1.29 *nonstructural components*, *n*—the broad definition includes all components of a building other than the structural frame. Nonstructural components sometimes may be categorized further, including more conventional elements, such as non-load bearing wall systems (interior and exterior walls that are not part of the primary vertical or lateral load resisting systems), ceilings, and raised access floors. Other categories include mechanical systems (most commonly related to heating, ventilating, and air conditioning), electrical and power systems, building utility equipment, production equipment, and stock and supplies related to operations.

2.1.30 *observe*, *n*—the act of conducting a visual survey of conditions that are readily accessible and easily visible. The loss estimator is not required to use or provide scaffolding, ladders, magnifying lenses, etc.

2.1.31 *observations*, *n*—the results of loss estimator's actual survey.

2.1.32 *obvious*, *n*—that which is readily accessible and can be seen easily by the reviewer without the aid of any instrument or device and understood by the reviewer as a result of a walk-through survey.

2.1.33 *occupant*, *n*—tenant or owner conducting business or residing in property being studied.

2.1.34 *original construction documents*, *n*—documents used in the original construction and subsequent modification(s) of building(s) for which the estimate of probable loss is prepared. If as-built plans are available, they are preferred.

2.1.35 *other earthquake hazards*, *n*—other earthquake hazards include, but are not limited to, soil liquefaction; ground deformation including subsidence, rupture, differential settlement, sliding, slumping, etc; and, flooding from dam or dike failure, tsunami, or seiche. The significance of such hazards is to be evaluated during earthquakes whose ground motions are comparable to the level prescribed for seismic loadings for the site by the Uniform Building Code.

2.1.36 *owner*, *n*—the entity or individual holding the deed to the property subject to an estimate of probably loss, one's agent, or contractor.

2.1.37 *P-delta effect*, *n*—the condition in which a vertical load resisting element is displaced horizontally from its original position so that instability can result from the vertical load without further consideration of any applied lateral loads.

2.1.38 *peak ground acceleration (PGA)*, *n*—the maximum acceleration at a site for the ground motions caused by an earthquake; it may be the actual recording or an estimate. Most often, PGA is given as the maximum of the horizontal components. Usually, it is expressed as a fraction of gravitational acceleration, 32.2 ft/s^2 (9.8 m/s^2).

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

2.1.40 *probabilistic ground motion*, *n*—earthquake ground motions for the building site that are determined from a site-specific evaluation of the seismic exposure over 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.

2.1.41 *probable loss (PL)*, *n*—the earthquake loss to the building(s), not including contents or equipment, that has a specified probability of being exceeded in a given time period from earthquake shaking. PL values are expressed as a percentage of building replacement construction cost (current). The PL estimates are to be evaluated, in a statistically consistent manner, considering the probability distribution functions of the possible ground motion levels at the site and the probability distribution function for the building's damageability due to each possible level of ground motion. Ground motions are determined from a site-specific evaluation of the seismic exposure and are represented by a probability distribution function. Building damageability and seismic performance depends on the level of study and shall recognize the dynamic response characteristics of the building(s). The building damageability distribution is determined from past performance data, expert estimates of performance, detailed analysis at specific ground motion levels, or a combination thereof. PL values are given either as a value(s) with a specified return period(s), PL_N, or as the value that has specified probability of exceedance (from 1 % to 50 %) in a given time period (1 to 50 years). The most common return periods used are 72, 190 and 475 years, that correspond to a 50 % probability of exceedance in 50 years, and a 10 % probability of exceedance in 20 and 50 years, respectively. The most commonly used probability of exceedance is 10 %, and the most common time periods are 20 and 50 years.

2.1.41.1 *PL values for group of buildings*—must be determined in a statistically consistent manner that fully recognizes the probabilistic damage distributions for the individual buildings and the possible correlations between the buildings' damageability. Where the buildings in a group are located at nearby sites with common expected ground motions, the ground motions for each building's damageability determination may be fully correlated such that the damageability distributions are based on the same ground motions. Where the sites are sufficiently separated, or the buildings' site soil conditions are different, then the damageability determination must consider the degree of correlation in ground motions for the separate sites or site conditions as part of the PL determination.

2.1.42 *probable maximum loss (PML)*, *n*—a term used historically to characterize building damageability in earthquakes. It has had a number of significantly different explicit and implicit definitions. It is recommended that the term not be used in the future, and that the terms probable loss (PL) and scenario loss (SL), whose definitions are precise, be used to characterize the earthquake damageability of buildings and groups of buildings.

2.1.43 *property*, *n*—the real property that is the subject of the estimate of earthquake damageability described in this guide. Real property includes buildings and other fixtures and improvements located on the property.

2.1.44 *report*, *n*—the narrative deliverable written product that results from this guide outlining the loss estimator's observations and opinions of the estimation of probable loss. At the request of the user, the report may include order-of-magnitude cost estimates for retrofit construction aimed at mitigating some or all identified deficiencies and/or reduce the estimated PL or SL values.

2.1.45 *retrofit*, *n*—a preliminary suggestion(s) to correct, mitigate, or repair a physical deficiency in the building that will improve its seismic performance so that it is acceptable to the user.

2.1.46 *return period*, *n*—the return period of a particular value of a random variable is the inverse of the annual probability that the value is equaled or exceeded. It 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 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; this is completely wrong. For example, earthquake occurrences usually are considered as Poisson distributed random variables, that is, ones 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 %.

2.1.47 *scenario expected loss (SEL)*, *n*—the expected value loss in the specified ground motion of the scenario selected. Since the damage probability distribution usually is skewed, rather than symmetrical, it should not be inferred that the probability of exceeding the SEL is 50 %; it can be higher or lower than this amount.

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

2.1.49 *scenario loss (SL)*, *n*—the earthquake loss to the building(s), not including contents or equipment, resulting from a specified scenario event on specific faults affecting the building, or specified ground motions. The specific damageability and ground motion characterizations are to be specified. SL values are expressed as a percentage of building construction cost (current replacement cost). The ground motion used for determination of the SL can be specified in a variety of ways, which must be stated clearly in the report, including:

2.1.49.1 —Ground motion in the maximum capable earthquake (MCE) for the building site;

2.1.49.2 —Ground motion specified as the design ground motion in the applicable building code for the building site;

2.1.49.3 —Ground motion from specific earthquake(s) likely to affect the building site with a specified probability of exceedance, using an accepted attenuation relationship for the seismic setting and with the uncertainty of the estimate clearly indicated; such maximum scenario events are prescribed for various faults based on paleoseismic evidence;

2.1.49.4 —Ground motion with a specified return period as determined from a probabilistic ground motion seismic hazard analysis;

2.1.49.5 —A selected maximum Modified Mercalli Intensity (MMI) for the site determined from published maximum value maps; or,

2.1.49.6 —the MMI for the site as estimated from peak ground acceleration values.

2.1.49.7 —The probability of the SL value being exceeded in the scenario must be stated in the report. The term SEL is used when the reported value is the expected value, while SUL is used when the probability of exceedance is 10 %. Other values may be specified by the user.

2.1.49.8 *SL values for groups of buildings*—must be determined in a statistically consistent manner that fully recognizes the probabilistic damage distributions for the individual buildings and the possible correlations between the buildings' damageabilities. Where the buildings in a group are located at nearby sites with common expected ground motions, the ground motions for each building's damageability determination may be correlated fully such that the damageability distributions are based on the same ground motions. Where the sites are separated significantly, or the building site soil conditions are different, then the damageability determinations must consider the degree of correlation in ground motions for the separate site conditions as part of the SL determination.

2.1.50 *seiche*, *n*—a water wave caused in a closed, or partially closed, body of water in response to the passage of seismic waves.

2.1.51 *significant*, *adj*—important and serious.

2.1.52 *site visit*, *n*—a preliminary, visual reconnaissance or scan of the property to observe and gather information for the purposes of conducting an estimate of probable loss. Also sometimes referred to as a walk-through survey or a field visit.

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

2.1.54 *structural component*, *n*—a component, which is a part of a building's lateral and/or vertical load-resisting system.

2.1.55 *survey*, *n*—observations or measurements made by the loss estimator as the result of a walk-through or reconnaissance to obtain information on the property's readily accessible and easily visible components or systems.

2.1.56 *tsunami*, *n*—long water waves that are generated impulsively be tectonic displacements of the sea floor associated with earthquakes; tsunamis also may be caused by eruption of a submarine volcanoes, submerged landslides, rock falls into the ocean, and underwater nuclear explosions. Tectonic displacement having substantial vertical (dip-slip) component are more likely to cause tsunamis than 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. The tsunami run-up can cause loss of life and substantial property damage.

2.1.57 *uncertainty tolerance level*, *n*—the amount of uncertainty in financial exposure that can be incurred by a user resulting from the cost to remedy earthquake damage associated with potentially hazardous conditions not identified by an estimate of probable loss. This is 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.

2.1.58 *user*, *n*—is the individual that retains the loss estimator to prepare an estimate of probable loss.

2.1.59 *uncertainty*, *n*—the degree of random behavior represented by an applicable probability distribution and associated parameters.

2.1.60 *walk-through survey*, *n*—the loss estimator's site visit to the property consisting of a visual reconnaissance of readily accessible and easily visible systems and components. This definition implies that such a survey is preliminary, not in-depth, and without the aid of exploratory probing, removal of materials, or testing. It is literally the loss estimator's walk of the property's improvements and resulting observations.

2.1.61 *weak story*, *n*—a story in a building that has significantly greater deformation than any story above it under a given lateral loading. Such weak stories can occur at any level in a building, except the roof.

2.2 *Abbreviations:*

2.2.1 *MCE*—maximum capable earthquake.

2.2.2 *PL*—probable loss

2.2.3 PL_N—probable loss with a return period of *N* years

2.2.4 *PML*—probable maximum loss

2.2.5 *SL*—scenario loss

2.2.6 *SEL*—scenario expected loss

2.2.7 *SUL*—scenario upper loss

2.3 *Commentary*—See Appendix X1 for commentary on Section 2.

3. Significance and Use

3.1 *Uses*—This guide is intended for use on a voluntary basis by parties who wish to estimate damageability from earthquakes to real estate. This guide outlines procedures for conducting an estimate of earthquake loss study for a specific user considering the user's due-diligence requirements and risk tolerance level. The specific purpose of the estimate of earthquake loss study is to provide the user with an adequate measure of possible earthquake losses that may be expected during the anticipated term for holding either the mortgage or the deed. A study prepared in accordance with this guide may reference or state that it complies with this guide provided that it identifies any extraordinary exceptions to same. No implication is intended that a person must use this guide in order to be deemed to have conducted an inquiry in a commercially prudent or reasonable manner in any particular transaction. Nevertheless, this guide is intended to reflect a commercially prudent and reasonable inquiry.

3.1.1 *Building Owners, Tenants/Purchasers and Others*—This guide is designed to assist the user in developing information about the earthquake-related damage potential of a building, or groups of buildings, and as such has utility for a wide range of persons, including, but not be limited to, building owners, building tenants, lenders, insurers, occupants, and potential investors/owners and mortgages.

3.1.2 *Types of investigations*—This guide provides requirements for the performance of five different types of earthquake loss studies intended to serve different financial and management needs of the user. Several of these types of assessment depend on earthquake ground motion characterization as given in Section 4.

3.1.2.1 *Building Stability*—Assessment of the likelihood that the building will remain stable in earthquakes, see Section 5.

3.1.2.2 *Site Stability*—Assessment of the likelihood that the site will remain stable in earthquakes, that is not be subject to failure through faulting, liquefaction, landsliding or other site response that can threaten the building's stability or cause damage, see Section 6.

3.1.2.3 *Damageability*—For assessment of the damageability of the building to earthquake ground motions and the degree of damage expectable over time, and for performing and completing the damageability assessment as either a probable loss or a scenario loss assessment, or both, see Section 7.

3.1.2.4 *Contents Damageability*—For assessment of the damageability of the building's contents to earthquake ground motions, see Section 8.

3.1.2.5 *Business Interruption*—For assessment of the implications for continued use or partial use of the building for its intended purpose due to earthquake damage to the building, contents, equipment, see Section 9.

3.1.3 *Level of Investigation*—The estimate of earthquake loss may consider any level of investigation from 0 to 3 that serves the particular purposes for which the results are desired. Level 0 is termed a screening level of investigation while Level 3 is an exhaustive investigation.

3.1.4 *Extent of Due-Diligence Exercised and Purpose of the Estimate of Earthquake Loss*—A user can rely only on the estimate of earthquake loss for the specific purpose that such study was commissioned and that point in time that the loss estimator's observations are conducted. This guide recognizes that a loss estimator's opinions and observations often are impacted or contingent on information, or the lack thereof, that is readily available to the loss estimator at the time of conducting an investigation. For instance, a loss estimator's observations may be impacted by building occupancy load or the availability of property management to provide information, including but not limited to, original construction documents at the time of the estimate of earthquake loss study.

3.1.5 *Site-Specific*—The guide is site-specific in that it relates to estimation of earthquake loss to building(s) located at a specific site.

3.2 *Principles*—The following principles are an integral part of this guide and are intended to be referred to in resolving any ambiguity or exercising such discretion as is accorded the user or the loss estimator in estimating loss to buildings from earthquakes. Also, it is to be used in judging whether a user or loss estimator has conducted appropriate inquiry or has otherwise conducted an appropriate estimation of loss from earthquakes to buildings.

3.2.1 *Uncertainty Not Eliminated*—No estimate of earthquake loss from earthquakes to buildings can wholly eliminate uncertainty regarding damage resulting from actual earthquakes. The successive levels of study of this guide are intended to reduce, but not to eliminate, uncertainty regarding the estimation of damage resulting from actual earthquakes in connection with a building, or a group of buildings, and the guide recognizes the reasonable limits of time and cost, related to a selected level of study.

3.2.2 *Not Exhaustive*—There is a point at which the cost of information obtained or the time required to gather it outweighs the usefulness of the information and, in fact, may be a detriment to the orderly completion of transactions. One of the purposes of this guide is to identify a balance between the competing goals of limiting the costs and time demands inherent in performing an estimate of earthquake loss to building(s) and the reduction of uncertainty about unknown conditions that may result from the acquisition of additional information.

3.2.3 *Level of Study*—Not every property will warrant the same level of earthquake loss assessment. Consistent with good commercial or customary practice, the appropriate level of estimate of earthquake loss to buildings from earthquakes will be guided by the type of buildings subject to assessment, the resources and time available, the expertise and risk tolerance of the user, and the information developed in the course of the inquiry.

3.3 *Minimum Reporting Requirements*—An earthquake damageability assessment may be performed for an individual building or a group of buildings. When an earthquake damageability assessment is performed under this guide, at the minimum, it should always include an assessment of building stability (BS, Section 5), and site stability (SS, Section 6). Also, it may include a damageability, contents damageability, or business interruption assessment, or both.

3.3.1 The user may select any level for these investigations (0 through 3), but must perform an assessment for each of the two issues—building stability and site stability.

3.3.2 The selection of the level of the investigation performed should be guided by the level of uncertainty in the result that is acceptable to the user. The matrix of Table 1 is offered as a guide to selection of the levels of investigation to match the acceptable level of uncertainty. The zone references are from the map of seismic zones as it appears in the 1994 edition of the Uniform Building Code **(4)**, which is reproduced in Fig. 1. The acceptance levels are not defined, but are given to reflect the progression of investigation levels with changes in acceptable uncertainty.

3.3.3 The damageability portion of the assessment may report a probably loss (PL), with specified probability of exceedance and time period, or a scenario loss (SL), where the specific scenario and the probability of exceedance are given, or both.

3.3.4 When a new investigation is performed that is consistent with this guide and has a higher level than a prior investigation, then the new investigation supersedes the former one.

3.4 *Qualifications of the Loss Estimator*—The estimation of earthquake loss to building(s) may be conducted by either an agent or employee of the user or wholly by a contractor. No practical standard can be designed to eliminate the role of judgment and the value and need for experience by the party performing the inquiry. The user should retain to conduct estimate of earthquake loss studies only those who have the

TABLE 1 Recommended Minimum Levels of Inquiry Based on Seismic Zone of the Property and the Acceptable Level of Uncertainty of the User

Acceptable Uncertainty Level	Seismic zone/UBC-94[A] Zones 0, 1, 2A, 2B	Zone 3	Zone 4
Very low	BS0, SS0, D1	BS1, SS1 D1	BS2, SS2 D2
Low	NA	BS1, SS1, D1	BS1, SS2, D2
Moderate	NA	BS0, SS0, D0	BS1, SS1, D1
High	NA	NA	BS0, SS0, D0

[A]See Fig 1 for the seismic zones. BS refers to the Building Stability assessment (see Section 6), SS to the Site Stability assessment (Section 7), and D to the Damageability Assessment (Section 8); the number following the abbreviation is the level of investigation; that is, BS0 is a Building Stability Level 0 assessment.

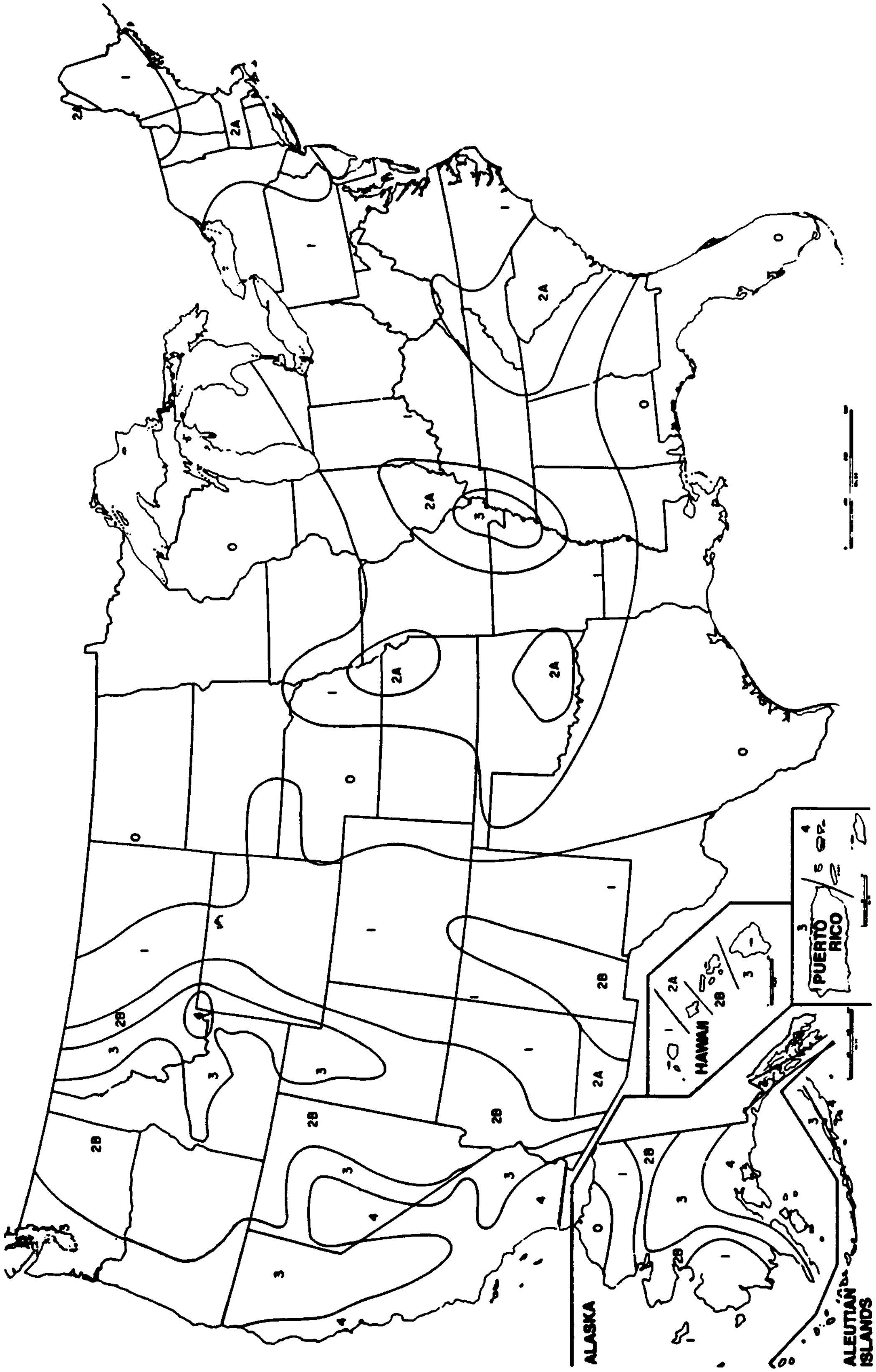

FIG. 1 1 Seismic Zone Map of the United States Taken from the Uniform Building Code requisite knowledge and experience to perform such studies in a reliable manner for the level of investigation specified. There are two main qualifications that bear on the ability of the loss estimator to reliably give professional opinions on the earthquake hazard posed by a site and the damageability of a building:

3.4.1 Knowledge of the current state of knowledge and practice of the underlying professional and scientific disciplines that bear on the particular practice; and

3.4.2 Experience in application of the specific professional skills required for seismic evaluation to the specific buildings and conditions of the subject site or building.

3.4.3 The user shall evaluate the qualifications of the performer (loss estimator) before the performer is retained to complete a study. The following issues are ones for which the user should seek information on qualifications:

3.4.3.1 *Personnel*—Identification of the individuals by task assignment that are to be engaged in the specific study. This should include those professional personnel that will complete the majority of the total effort. Provide evidence of sufficient knowledge of the technical, analytical, and mathematical concepts required for the performance of the level of inquiry undertaken.

3.4.3.2 *Professional Registrations or Licensing*—The state, type, and dates of registration with an inclusion of a statement of whether the registration process included specifically earthquake issues.

3.4.3.3 *Design Experience*—The number of years experience in earthquake related practice with an enumeration of projects and the roles played in these projects that are comparable to the type of conditions that are expected to be encountered. Special note should be made to distinguish the work done by the person with the current employer from that done for another organization, and to distinguish those projects completed by the firm with other personnel than those proposed for the individual project.

3.4.3.4 *Research and Professional Practice Development Experience*—The earthquake hazards related research and professional practice development that bears on the specific professional duties that are to be performed.

3.4.3.5 *Loss Estimation Experience*—The number of years experience in seismic practice with an enumeration of projects and the roles played in these projects that are comparable to the type of conditions that are expected to be encountered. Special note should be made to distinguish the work performed by the person with the current employer from that done for another organization, and to distinguish those projects completed by the firm with other personnel than those proposed for the individual project.

3.4.3.6 *Earthquake Investigation Experience*—A listing of the earthquakes the principal performers of the study have had field experience in investigating, including the citations of reports that they prepared or to which they made contributions.

3.4.4 The following general guidance is given on setting of acceptable qualifications. It should be noted that the qualifications for building stability and damageability assessments are similar, but different from those for ground motion, site stability, contents damageability, and business interruption. It is seldom that one individual will have sufficient expertise and experience to perform all of these types of investigations for Level 2 or Level 3 inquiries.

3.4.4.1 Qualifications should be determined of those individuals performing the majority of the work, as well as the person-in-charge, who reviews and possibly signs the work. The fewer the number of individuals involved, the more important is the experience and qualifications of the person doing the work and making the professional judgments.

3.4.4.2 For a Level 0 investigation there are no specific requirements; however, it is advisable that the individual performing the assessment be a registered professional and that their competence in the related area of the assessment be declared.

3.4.4.3 Level 1 investigations require the highest general experience in professional practice and evaluation, because usually there is little oversight or review of the work product and conclusions. For example, professional experience in the specific professional area of 20 years and in performing loss evaluations of 5 years may be appropriate. Specific experience in the characteristics of the particular site or structural system is not required, but useful. For example, experience in field investigation of earthquake response in four or more damaging level earthquakes is desirable.

3.4.4.4 Level 2 investigations require substantial understanding and experience in the specific technical issues that pertain to the particular type of site or structure. For example, professional experience in the specific professional area of 10 years and in performing loss evaluations of 3 years may be appropriate. Specific experience in the characteristics of the particular site or structural system is not required, but useful. For example, experience in field investigation of earthquake response in two or more damaging level earthquakes is desirable.

3.4.4.5 Level 3 investigations require demonstrated, substantial understanding and experience in the specific technical issues for the specific type of site or structure.

3.5 *Representation of Seismic Risk*—The report shall specify clearly how seismic risk and hazard are evaluated and represented, what assumptions are made in the risk assessment that could substantially influence the results, and what level of overall uncertainties there are in the results.

3.6 *Projects Comprised of Multiple Buildings*—Where projects consist of several buildings or building sections whose damageability is independent of the others, one or more of the following must be presented in the damageability analysis:

3.6.1 Damageability results are given for each individual building only in addition to those of the group; these may be average, mean, range, or statistic, for example, value with 10 % probability of exceedance;

3.6.2 Average and standard deviation of damage given for each building for selected specific events, or for the ground motion probability distribution at the site; and,

3.6.3 Where there is a group of assessed buildings, report how the individual building results are combined statistically to provide the SL or PL values for the group of buildings.

3.7 *Retrofit Scheme Development*—Where the client specifies development and analysis of a retrofit scheme for a building, describe the retrofit scheme with sufficient detail that the projected damageability of the retrofitted structure can be estimated. Identify and describe the principal building characteristics, the nature of the deficiencies, and the approach to their mitigation in sufficient detail, such that an independent technical reviewer can adequately understand the basis for the suggested work and evaluate its efficacy. The description of the retrofit scheme is not a design, and should not be used as such; it is a discussion of the approach to the retrofit that may guide a designer to identify the basic earthquake performance issues of the building that require mitigation or verification of their expected performance.

3.8 *Use of Computer Assessment Tools*—Limit the use of interactive computer programs developed specifically to assess the damageability of buildings and requiring only general information about the building and site to screening level (Level 0) damageability assessments.

3.9 *Additional Services*—Additional services may be contracted for between the user and the loss estimator.

3.10 *Independent Peer Review*—Independent peer review is an objective technical review by a knowledgeable reviewer(s) experienced in the structural design, analysis, and performance issues involved in the specific building(s). The client may desire to utilize independent peer review of the damageability assessment as a means of improving confidence and reducing the uncertainty in the reported results.

3.10.1 *Qualifications and Terms of Employment*—The independent peer reviewer shall be independent from the loss estimator. The independent reviewer shall have technical expertise meeting or exceeding the requirements specified for the performer for the level of inquiry performed. The peer reviewer shall have a declared competence in damageability evaluation, seismic hazard evaluation, and probability and statistics as required for the level of the investigation.

3.10.2 *Selection*—The independent peer reviewer(s) may be selected at any point during the loss estimation process but not later than 10 days before its completion.

3.10.3 *Independence*—The independent peer reviewer shall have no other involvement in the loss estimation process for the specific building before, during, or after the review, except in a review capacity.

3.10.4 *Reports*—The independent peer reviewer shall prepare a written report to the user that covers all aspects of the review performed, including conclusions reached by the reviewer, with identification of any areas, which need improvement or further study, investigation, or clarification.

3.11 *Commentary*—See Appendix X1 for commentary on Section 3.

4. Probabilistic Ground Motion Hazard Assessment

4.1 *Objective*—The objective of ground motion assessment of the site is to characterize the earthquake ground motions at the site having a specified probability of being exceeded in a given time period for the assessment. This ground shaking is required for PL evaluations of damageability, and can have applications in some SL studies, building stability, or site stability assessments, or a combination thereof. The ground motion level of inquiry should always be at least as high as the level of the inquiry its results are used in, except for Level 3, which may use a Level 2 ground motion assessment.

4.2 *Levels of Inquiry in Probabilistic Ground Motion Hazard Assessment*—There are three levels of inquiry in ground motion hazard assessment. They are described as Level G0, Level G1, and Level G2. Level G3 is not used. The ground motion representation whether PGA, spectral ordinants, or time histories, must be consistent with the analysis procedures which utilize them.

4.3 *Level G0 Inquiry (Screening Level)*—This level shall consist of, but not be limited to, the following:

4.3.1 The ground motion values for the site may be estimated from a current edition of ground motion probability maps published by a governmental agency. Where the project site is between contours the value associated with the higher contour shall be used. The values may be determined from commercial software based on the provision of gross project coordinates (zip code or address) may be used. The 1997 edition of the Uniform Building Code (UBC) **(4)** seismic coefficient C_a may be used for the ground motion with a 10 % probability of exceedance in 50 years.

4.4 *Level G1 Inquiry*—This inquiry shall consist of, but not be limited to, the ground motion values for the site may be determined from commercially available software based on the provision of project coordinates (latitude and longitude) and assessed site conditions, provided the software provides probabilistic estimates of ground motion that consider all sources of earthquakes and includes uncertainty in ground motion attenuation relationships.

4.5 *Level G2 Inquiry*—This inquiry shall consist of, but not be limited to, the ground motion values for the site developed as a specific project site probabilistic seismic hazard analysis (PSHA). PSHA provides a framework to identify and characterize the nature of earthquake sources, the seismicity or temporal distribution of earthquakes on those sources, the ground motion produced by those sources, and the uncertainties associated with each, when combined, to obtain the value of ground motion parameters that have a given probability of being exceeded during a particular time period.

4.5.1 *Identification of Hazard Sources*—Hazard sources shall include all possible sources of seismic activity that may affect the building site. Identification of those sources may be conducted by the following methods. If reports, or other reference publications, or both, are used, it should be verified that these methods were used.

4.5.1.1 *Geologic evidence (paleoseismology)*—The geologic records may contain evidence of the occurrence of earthquakes, primarily in the form of offsets, or relative displacements, of various strata. Such offsets may indicate the presence of faults. Tools and techniques to be used may include the review of published literature; interpretation of aerial photographs; remote sensing (infrared photography) imagery; field reconnaissance, including logging of trenches, test pits and borings, and geophysical techniques.

4.5.1.2 *Tectonic Evidence*—Earthquakes occur at tectonic plate boundaries to relieve the strain energy that accumulates on the plates where they move relative to one another. Geologic indicators may indicate the rate of strain energy accumulation from tilting and changes in distances between fixed points on the ground.

4.5.1.3 *Historical Seismicity*—Earthquake sources may be identified from records of historical or preinstrumental seismicity. Historical accounts of associated ground shaking may be used to confirm the occurrence of past earthquakes and aid in the identification of seismic sources.

4.5.1.4 *Instrumental Seismicity*—Instrumental records of earthquakes and aftershocks may be used to identify earthquake sources and aid in delineating the orientation and geometry of the source.

4.5.1.5 *Recurrence of Events*—The activity of the seismic sources shall be established to estimate the recurrence of earthquake events on those sources. Fault activity may be evaluated based on geologic (paleoseismic) evidence, instrumental evidence, or inferences from geologic data. Estimates of the size of past earthquake events may be made from correlations of observed information characteristics with known magnitudes. The activity and size information may be used to estimate the recurrence of events.

4.5.1.6 *Attenuation Relationships*—The approach and method used shall be fully described. Predictive relationships shall account for variables that are significant in estimating ground motion parameters. These variables may include earthquake magnitude, distance from source to site, wave propagation path, local site conditions, type of faulting, directivity effects, and orientation of the component of the ground motion parameter.

4.5.1.7 *Accuracy and Completeness*—The PSHA shall account for those uncertainties that can be identified and quantified which are incorporated in a rational manner to evaluate the seismic hazard. Sources of uncertainty include uncertainty in spectral parameters due to source characteristics, uncertainty in the size of earthquakes, uncertainties in the earthquake recurrence relationship, uncertainty in the ground motion parameter attenuation relationship, and temporal uncertainty due to creep data. Where more than one seismic hazard model is plausible, a logic tree representation may be used that weighs the various models; this usually is reserved for use in high level assessments.

4.6 *Commentary*—See Appendix X1 for commentary on Section 4.

5. Building Stability Assessment

5.1 *Objective*—The purpose of the building stability assessment is to determine if the building is stable under earthquake loadings. A building is deemed stable if it is able to maintain the vertical load-carrying capacity of its structural system under the inelastic deformations due to the earthquake ground motion prescribed for the structure and site by the current edition of the Uniform Building Code. A group of buildings is deemed stable if each of the buildings in the group is deemed stable.

5.2 *Levels of Inquiry in Building Stability Assessment*—There are four levels of inquiry in Building Stability Assessment. They are described as Level BS0, Level BS1, and Level BS3. The level of the assessment shall be the same as that used for the damageability assessment.

5.3 *Conclusions and Findings*—These findings should be commensurate with the level of study being performed on the structure. Observations and any analysis performed may be completed in conjunction with the damageability assessment, if performed. The results of the assessment must state if an instability condition exists or not.

5.4 *Level BS0 Inquiry (Screening Level)*—This inquiry shall consist of, but not be limited to, the following:

5.4.1 Determine the gravity and lateral load-resisting systems for the structure by review of the construction documents or visual review if no documents are available. Where records are not available for review, estimate the era in which the building was designed, as well as the governing building code (based on experience).

5.4.2 Based on the type and era of construction, evaluate the stability of the building under gravity and earthquake loads.

5.4.3 Special note should be made of irregular conditions which may create instabilities, such as weak stories, columns restrained by sloping floors or stiff wall panels, long unbraced elements; and potentially fragile materials and systems, such as unreinforced masonry, precast concrete elements, etc.

5.4.4 This level of inquiry has an inherently high uncertainty in result.

5.5 *Level BS1 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

5.5.1 This level of study may be used when structural drawings are not available.

5.5.2 Perform a walk-through survey of the building to determine its condition, and quality of construction, including significant modifications since original construction, possibly including a limited review of original construction documents, if available, and brief examination of the building.

5.5.3 Determine whether conditions exist that are understood to lead to unacceptable behavior of the building in the code prescribed level of seismic ground motions or interstory displacements. Particular attention should be given to the configuration, compatibility, continuity, redundancy, and condition of structural elements, and whether there are unusual loads applied to the structure.

5.5.4 Where possible, sufficient examples of the structural framing should be observed to reasonably establish the condition and characteristics of both the gravity and lateral load resisting systems.

5.5.5 This added knowledge of the structure will increase the level of confidence of the loss estimator, although there would still be a relatively low degree of confidence without the ability to analytically verify the competence of the structural design.

5.6 *Level BS2 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

5.6.1 Review the existing original construction documents for the building in its current condition or, if they are not available, measured drawings characterizing the structural system, including both original construction and any modifications than may have subsequently occurred, to identify the gravity and lateral load-resisting systems for the structure. Determine the governing building codes.

5.6.2 Identify the existence of known structural problems, such as weak stories, rigid columns at sloping floors, long unbraced elements, discontinuous shear walls, or details and connections that have the potential of poor performance (many potentially hazardous situations may have been considered to be acceptable under the building code to which the structure was originally designed and constructed).

5.6.3 In addition to performing the tests described in Level BS1, nondestructive testing of building elements may be performed to generally establish the type, construction, and condition of materials.

5.6.4 Evaluate building framing system for stability issues such as weak column-strong beam conditions in rigid frames, bracing members and their connections, and ability of gravity load bearing members (structural and nonstructural) that are not part of the lateral load-resisting system to tolerate the effects of the expected interstory drift at maximum earthquake response.

5.6.5 Computations should be performed as required to determine the anticipated structural behavior of elements or systems.

5.7 *Level BS3 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

5.7.1 In addition to the information determined in 5.6, Level BS2, perform at least a two-dimensional analysis (three dimensional analyses may be more beneficial) of the lateral load-resisting system of the building, including all P-delta and torsional effects.

5.7.2 For highly irregular structures, include the effects of a site specific ground motion response spectrum. From this analysis the various stability issues can be more quantitatively evaluated, especially those dealing with the expected drift effects on nonframe elements. Include in the analysis any nonstructural elements which, in the opinion of the loss estimator, may become unstable or cause instability of the structure.

5.7.3 Based on the nature of the structure, a progressive failure (push-over) analysis may be performed.

5.8 *Retrofit Recommendations*—When specifically requested by the user, develop recommendations for modifications of the building's structural system, including members and connections, aimed at correction of any detected instability conditions or reducing damageability.

5.9 *Commentary*—See Appendix X1 for commentary on Section 5.

6. Site Stability Assessment

6.1 *Objective*—The objective of the site stability assessment is to determine if the building is located on a site that may be subjected to site instability due to earthquake-induced hazards that induce surface fault rupture, liquefaction, seismic settlement, land sliding, tsunami, seiche, etc.

6.1.1 *Active Earthquake Fault Zone*—If the building is located within a zone determined for a generally recognized active earthquake fault as identified by any federal, state, or local governmental agency, or other authoritative source.

6.1.2 *Potentially Active Earthquake Fault Zone*—Determine if the building is located within a zone determined for a generally recognized potentially active earthquake fault as identified by any federal, state, or local governmental agency or other authoritative source.

6.1.3 *Other Significant Earthquake Hazards*—Determine if the building is located such that its seismic exposure to other earthquake-related hazards is deemed significant, including, but not be limited to, liquefaction, land sliding, tsunami, and seiche.

6.2 *Levels of Inquiry in Site Stability Assessment*—There are four levels of inquiry in site stability assessment of real estate. They are described as Level SS0, Level SS1, Level SS2, and Level SS3.

6.3 *Level SS0 Inquiry (Screening Level)*—This inquiry shall consist of, but not be limited, to the following:

6.3.1 Determine site conditions from generally available published reports and maps coded to general areas of susceptibility, such as maps identifying general areas of hazard susceptibility, perhaps established by postal zip codes, Alquist-Priolo Zones in California, geographic location, or other defined system.

6.3.2 Determine if the area where the site is located has fault rupture or liquefaction, or landslide susceptibility from generally available studies or from a geotechnical report for the site.

6.3.3 Determine if site is located near ocean shoreline for susceptibility to tsunami or if site is located near an enclosed body of water for susceptibility to seiche, or dam rupture caused water waves, or both.

6.3.4 This level analysis has an inherently high uncertainty in result.

6.4 *Level SS1 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

6.4.1 Determined site conditions for location from generally available published reports and maps.

6.4.2 Review the geotechnical report, if available, for site specific information.

6.4.3 Determine if site is located within a zone where there is susceptibility to faulting, liquefaction, landslide, or other earthquake site hazards.

6.5 *Level SS2 inquiry*—This inquiry shall consist of, but not be limited to, the following:

6.5.1 Review the geotechnical report, if available, and site-specific assessment of the site stability potential based on existing information relative to the site, with the addition of an assessment of the degree of site stability expected and its implications for catastrophic damage to the building (or for other level of damage, depending on the performance level).

6.5.2 If possible site stability is expected, then determine if the structure is at risk of significant damage due to site failure.

6.6 *Level SS3 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

6.6.1 Perform a site-specific response assessment, possibly including field explorations (trenching, borings, cone penetrometer studies, etc.), modeling of the site response, and interaction with the building and its foundation system.

6.6.2 Assess the degree and likelihood of site stability expected and its implications for damage to the building and its foundation system.

6.7 *Commentary*—See Appendix X1 for commentary on Section 6.

7. Damageability Assessment

7.1 *Objective*—The objective of the damageability assessment is to characterize the building(s) expected seismic losses by performing a sufficiently detailed engineering analysis and evaluation of the damageability characteristics of the building at given levels of earthquake ground motions. The analysis includes architectural, nonstructural, and mechanical components of the building other than the building's primary gravity and lateral load resisting systems and foundations that would not be classified as contents and furnishings. Damageability may be expressed as the probable loss (PL) or the scenario loss (SL). The results may be reported as either the mean of the value or the value with a given upper confidence.

7.2 *Levels of Inquiry in Damageability Assessment*—There are four levels of inquiry in damageability assessment of real estate. They are described as Level D0, Level D1, Level D2, and Level D3.

7.3 *Requirements for All Levels of Damageability Assessment D0–D3*—The damageability analysis shall consider all earthquakes that can potentially impact the site that have magnitudes greater than 5.0, and that have PGA values greater than 0.05 g at the site, except where other values specifically are justified by characteristics of the specific building(s) and conditions. Report whether the mean or upper confidence limit value, or both, are given for loss values used in the assessment.

7.4 *Level D0 Inquiry (Screening Level)*—This inquiry shall consist of, but not be limited to, the following:

7.4.1 Determine the general architectural and structural characteristics of the building and its seismic resistance systems.

7.4.2 Evaluate the building's stability by determining the building code to which it was designed, the type, condition and age of the structure, and its gross characteristics (for example, configuration, continuity of load paths, compatibility of system deformation characteristics, redundancy of load paths, strength of elements and systems, toughness of elements and connections, and physical condition).

7.4.3 Determine the PL or SL values from tables or an equivalent procedure for a basic building type representative of the building, possibly completed with the aid of an interactive computer program, see 3.8. Adjustments should be made to accommodate deviations of the specific building's characteristics from that of the standard or tabulated building type.

7.4.4 The impacts on damageability of possible site stability are not included in the assessment.

7.4.5 This level analysis has an inherently high uncertainty in result.

7.5 *Level D1 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

7.5.1 Visit the building to determine its condition, structural characteristics, and quality of construction.

7.5.2 Cursory review the original construction documents, if available.

7.5.3 Evaluate the seismic loads and capacities of selected systems and elements and connections.

7.5.4 Identify potential flaws in the lateral load-resisting systems that contribute to the building's damageability without performing a detailed investigation. Nonstructural conditions are identified that may contribute to the damageability of the building.

7.5.5 Estimate ground motion characteristics by a Level G1 or higher inquiry, see 4.2.

7.5.6 Determine PL or SL values from tables or equivalent procedures for a basic building type, possibly completed with the aid of an interactive computer program, but not solely on such a basis.

7.5.7 The impacts of possible site failures are not included in the assessment.

7.5.8 This analysis has an inherent moderate uncertainty in its result.

7.6 *Level D2 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

7.6.1 In addition to the requirements of the Level D1 (see 7.5), investigation, evaluate the condition of the building, and quality of construction, including significant modification since original construction.

7.6.2 Examine the original construction documents, or conditions deduced from observation if they are not available, and perform selected calculations to verify demand/capacity characteristics of the building's expected seismic response.

7.6.3 Determine the seismic response characteristics of the building by assessing those issues likely to dominate its performance, including configuration, continuity of load paths, compatibility of system deformation characteristics, redundancy of load paths, strength of elements and systems, toughness of elements and connections, and physical condition.

7.6.4 Estimate damage ratio due to representation of each of all possible levels of ground motion at the site, and compute the PL or SL values for corresponding probabilities of occurrence.

7.6.5 PL or SL values shall not be determined from tables or equivalent procedures for a basic building type, nor from use of an interactive computer programs.

7.6.6 Consider the impacts on damageability to the building(s) due to possible site failure.

7.6.7 This analysis has moderately low uncertainty.

7.7 *Level D3 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

7.7.1 In addition to the requirements of the Level D2 investigation, 7.6, perform a full engineering analysis of the building's expected performance, for example, by modeling to determine story accelerations and interstory displacements, including possibly both three-dimensional and nonlinear methods to estimate the expected damage.

7.7.2 Where appropriate, consider the soil-foundation-structure interaction.

7.7.3 The user should consider implementing the peer review process of 3.10 to assure acceptable technical performance.

7.7.4 The building's seismic performance is characterized correctly at the minimum uncertainty level.

7.8 *Commentary*—See Appendix X1 for commentary on Section 7.

8. Contents Damageability Assessment

8.1 *Objective*—The objective of the damageability of contents assessment is to perform an analysis of the earthquake performance of furniture, fixtures, equipment and contents within the building that are not part of the permanent structure, nonstructural components, architectural finishes, or equipment.

8.2 *Type of Damageability Assessment*—Analyses are recommended to be performed only on a scenario loss basis, with the specific scenario fully described. Performance of the contents assessment requires that the same level damageability assessment be completed for the same specified scenario, so that there is a common basis of understanding building and contents damageability.

8.3 *Levels of Inquiry In-Site Stability Assessment*—There are four levels of inquiry in contents damageability assessment of real estate. They are described as Level C0, Level C1, Level C2, and Level C3.

8.4 *Level C0 Inquiry (Screening Level)*—This inquiry shall include no specific evaluation of contents and equipment; instead the overall building damage estimate is based on data (tables or graphs) that include an allowance for contents and equipment damage.

8.5 *Level C1 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

8.5.1 A simplified evaluation of contents and equipment is made.

8.5.2 Contents and equipment damage is determined from a generic damage curve (or other data), and modified based on conditions at the study site.

8.6 *Level C2 Inquiry*—This shall consist of, but not be limited to, the following:

8.6.1 The level of complexity of the evaluation is increased beyond the Level C1 investigation (see 8.5).

8.6.2 The evaluation shall include the major subcategories of contents and equipment damage as discrete items, with an allowance for remaining less significant categories.

8.6.3 The loss estimator also may consult with other specialists, as required, since contents damageability analyses addresses a wide variety of items.

8.7 *Level C3 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

8.7.1 The level of complexity of the evaluation is increased beyond the Level C2 investigation (see 8.6).

8.7.2 Contents damage is determined from a detailed analysis which addresses all significant contents and equipment and recognizes the value and corresponding potential damage of each.

8.7.3 Specially designed computer software typically would be used to incorporate the probabilistic effects of all damage components.

8.8 *Commentary*—See Appendix X1 for commentary on Section 8.

9. Business Interruption Assessment

9.1 *Objective*—The objective of the business interruption assessment is to perform an analysis of the site, building, equipment, inventory systems, infrastructure, interdependent businesses and all other relevant parameters to determine one or more of the following:

9.1.1 If the facility will suffer business interruption from on-site effects, such as direct damage to buildings and equipment, or loss of critical supplies.

9.1.2 If the facility will suffer business interruption from off-site earthquake damage to the infrastructure, such as transit systems, power and telecommunications utilities, and water and waste supply and treatment facilities.

9.1.3 If the facility will suffer business interruption from earthquake damage to the interdependent facilities (not necessarily owned or operated by the owner).

9.2 *Related Investigations*—In addition to its own unique lines of inquiry, the evaluation of business interruption will draw upon other related aspects of the probable loss or scenario loss analyses, including building damageability, site failure, building stability, and secondary impact. A business interruption assessment should not be performed unless a damageability assessment, as in Section 7, has been performed.

9.3 *Type of Business Interruption Assessment*—Analyses are recommended to be performed only on a scenario loss basis with the specific scenario fully described. Performance of the business interruption assessment requires that the same level damageability and contents assessments be completed for the same specified scenario so that there is a common basis of understanding earthquake impacts on the building(s).

9.4 *Business Interruption Assessment*—This assessment is performed on a scenario basis, that is, the assessment is conducted assuming that damage corresponding to that estimated in the PL or SL analysis has occurred.

9.5 *Levels of Inquiry in Business Interruption Assessment*—There are four levels of inquiry in business interruption assessment of real estate. They are described as Level B0, Level B1, Level B2, and Level B3. Damageability evaluations that include Levels B2 or B3 evaluations should clearly state what effects are included and excluded in the evaluation process.

9.6 *Level B0 Inquire (Screening Level)*—This inquiry shall consist of, but not be limited to, the following:

9.6.1 Estimate business interruption losses from a loss estimation curve that is representative of a broad industry category, with no consideration for details of the facility's location and operation. This curve typically uses the overall building damageability value estimate (PL or SL based, including secondary effects) as its sole input parameter.

9.7 *Level B1 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

9.7.1 Perform a simplified evaluation of business interruption. The loss estimator conducts interviews with key facility personnel to ascertain the principal modes of operations.

9.7.2 No off-site facilities are visited or evaluated.

9.7.3 Estimate business interruption losses based on a generic damage curve representative of the industry under investigation. This curve uses the overall building damage equal to the PL or SL estimate (including secondary effects) as its sole input parameter but may be modified based upon conditions at the site.

9.7.4 The evaluation will address the only major causes of damage or loss and no interdependencies with related off-site processes. If there is a possibility of site failure, this potential effect on business interruption is noted but not quantified.

9.8 *Level B2 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

9.8.1 The evaluation will address the more significant causes and interdependencies. The building damage now is only one parameter of the evaluation, and the effects of earthquake damage on equipment systems, supplies, and other variables are not taken into account.

9.8.2 Off-site effects also may be considered.

9.8.3 Separate estimates of downtime may be prepared for the major functions of a facility and then combined into an aggregate for the overall facility.

9.8.4 Business interruption calculations shall consider the values associated with the principal component processes.

9.9 *Level B3 Inquiry*—This inquiry shall consist of, but not be limited to, the following:

9.9.1 Business interruption is determined from a detailed analysis, which addressees all significant interdependencies and all significant contributors to vulnerability.

9.9.2 The use of logic trees would be used to interpret these interdependencies.

9.9.3 Specially developed computer software would be used to incorporate the probabilistic effects of more complex interdependencies in a process that is closely related to reliability analysis.

9.10 *Commentary*—See Appendix X1 for commentary on Section 9.

10. Subsequent Use of Damageability Assessments

10.1 *Objective*—This guide recognizes that earthquake damageability assessments of buildings prepared for specified levels of inquiry and performed in accordance with this guide will include information that subsequent users may want to use to avoid undertaking duplicative estimation procedures. This guide, therefore, describes procedures to be followed to assist them in determining the appropriateness of using these results. The system of usage of prior reports is based on the following principles that should be adhered to in addition to the specific procedures set forth elsewhere in this guide.

10.2 *Comparison With Subsequent Inquiry*—It should not be concluded or assumed that an estimate of probable loss to buildings from earthquakes is not an appropriate estimate of probably loss for specified levels of inquiry merely because the estimate did not identify all potentially vulnerable areas in connection with a building or a group of buildings. Estimates of probable loss to buildings from earthquakes prepared for specified levels of inquiry must be evaluated based on their reasonableness of judgments made at the time and under the circumstances in which they are made. Subsequent estimates of probable loss to buildings from earthquakes prepared for same levels of inquiry should not be considered valid standards to judge the appropriateness of any prior assessment based on hindsight, new information, use of developing technology or analytical techniques, or other factors.

10.3 *Continued Viability of Estimates of Probable Loss to Buildings from Earthquake*—An estimate of probable loss to buildings from earthquakes meeting or exceeding the requirements of this guide and completed less than 180 days previously is presumed to be valid. An estimate of probably loss to buildings from earthquakes meeting or exceeding the requirements may be used to the extent allowed in 10.4-10.7.

10.4 *Use of Prior Information*—Users and loss estimators may use information in prior reports provided such information was generated as a result of procedures that meet or exceed the requirements of this guide for specified levels of inquiry and then only provided that the specific procedures set forth in the guide are met.

10.5 *Prior Assessment Meets or Exceeds*—A prior report prepared for specified levels of inquiry may be used in its entirety, without regard to specific procedures set forth in this guide, if in the reasonable judgment of the loss estimator the prior report was prepared for specified levels of inquiry meeting or exceeding the requirements of this guide and the conditions of the building(s), current data on the earthquake performance of the building types assessed, and the seismic hazards affecting the site are not likely to have changed materially since the prior report was prepared. In making this judgment, the loss estimator should consider the types of building construction assessed and new information related to the behavior of building constructions of the specific type in recent earthquakes, as well as, current understanding of the site conditions.

10.6 *Current Investigation*—Prior reports should not be used without current investigation of conditions likely to affect the estimation as related to current level of knowledge on and experience with building constructions of particular type, as well as, current understanding of the site conditions that differ from those in existence when the prior report was prepared.

10.7 *Actual Knowledge Exception*—If the user or loss estimator has actual knowledge that the information being used in a prior report is not accurate or if it is obvious, based on other information obtained by or known to the loss estimator conducting the earthquake damageability assessment for the building(s), that the information being used is not accurate, such information from a prior report may not be used.

10.8 *Contractual Issues Regarding Prior Estimation Usage*—The contractual and legal obligations between prior and subsequent users of damageability reports or between loss estimators who prepared the report and those who would like to use such prior reports are beyond the scope of this guide.

10.9 *Rules of Engagement*—The contractual and legal obligations between a loss estimator and a user, and other parties, if any, are outside the scope of this guide.

10.10 *Commentary*—See Appendix X1 for commentary on Section 10.

11. User's Responsibilities

11.1 *Scope*—The purpose of this section is to describe tasks that will establish the limitations of estimate of probable loss to buildings from earthquakes.

11.2 *Relevant Records*—These records include acquisition and subsequent transfer to loss estimator drawings, specifications, other relevant documents used in original construction of the building(s) and subsequent modifications, geotechnical site information, post-earthquake building evaluation reports, and any other relevant materials.

11.3 *Access to Property and Records*—It is the user's responsibility to provide the loss estimator with timely access to all reports, plans and specifications for the building, both for the original building and for any modifications, alterations or additions. This includes all geotechnical reports and analyses of the site and any reports of engineering investigation of the building, particularly those following earthquakes.

11.4 *Access to Consultants*—It is the user's responsibility to provide to the extent practical timely access to consultants who have designed the building or supported its design, analysis, and assessment.

11.5 *Investigation Level*—It is the user's responsibility to establish the level(s) of investigation on building stability (BS), site stability (SS), and damageability (D) that is commensurate with the risk tolerance level of the user.

11.6 *Return Period*—It is the user's responsibility to establish the return period(s) for seismic activity to be used in the estimation of probable loss.

11.7 *Commentary*—See Appendix X1 for commentary on Section 11.

12. Evaluation and Report Preparation

12.1 *Report Format*—The report findings arrived at in the process of conducting an earthquake loss estimation assessment should be reported in a written report following the format provided by the user.

12.2 *Documentation*—The report should include documentation (for example, references, key exhibits, photographs) to support the analysis, opinions, and conclusions found in the report. All sources, including those that revealed no findings, should be sufficiently documented to facilitate reconstruction of the research at a later date.

12.3 *Contents of Report*—The report shall include those matters required to be included in the report pursuant to various provisions of the guide.

12.3.1 The report shall present the technical basis for the specific conclusions on damageability reached and provide full technical details of the methods and procedures used to determine the damageability values in sufficient detail that a peer reviewer can validate the appropriateness of the technical decisions and procedures used.

12.3.2 An appendix to the report shall present the technical details of the methods used to determine the PL or SL values.

12.3.3 *Credentials*—The report shall name the loss estimator(s) involved in preparing the report, their qualifications and expertise in earthquake building performance evaluation, and a description of their experience that is specific to the earthquake performance issues addressed for the particular building(s). This includes not just the person in-charge, but the individuals conducting the site visit, if conducted, and all others who participated in the assessment, with an indication of the proportion of the total time they committed to the evaluation.

12.3.4 If a computer software assessment tool is used in the damageability assessment, the report shall specify the software used, the vendor, edition, date of the data files utilized, the criteria used, limitations, and the preparer's qualifications.

12.3.4.1 The specific edition of the software and issuance date of any data files used.

12.3.4.2 The identity and experience of the person providing the input to the program and the reviewer's names and experience, if appropriate.

12.3.4.3 Identification of the primary assumptions made that could significantly change the results. Discussion of the primary contributing factors that caused the result to be high (low).

12.3.4.4 Whether a more detailed analysis recommended and the reasons why.

12.3.5 Any specific limitation or exclusions that limit conclusions presented in the report.

12.4 *Findings and Conclusions*—The report shall have a findings and conclusions section that states the following:

12.4.1 "I (We) have performed an estimate of probable loss to building(s) from earthquakes in conformance with the scope and limitations of ASTM STANDARD GUIDE FOR THE ESTIMATION OF BUILDING DAMAGEABILITY IN EARTHQUAKES E 2026–99, edition dated [date], for the property located at [insert address or legal description]. The assessment was performed at ASTM level [specific types of assessment and levels]. {Any exceptions to, or deletions from, this Guide are described in Section [direct to section] of this report. (Include this statement only if there are exceptions.)} The estimated values of damageability and earthquake impacts to the building (group of buildings) are as follows—[insert results of analysis with reference to the type of result, for example, SUL, or PL_{190}]."

12.4.2 Where the report is expressly for the purposes of evaluating the suitability of the property to act as the security for a loan, then the report shall contain a limitations language statement:

12.4.2.1 "This report is addressed to (client name), such other persons as may be designated by (client name) and their respective successors and assigns."

12.4.3 Any special conditions shall be included, such as:

12.4.3.1 The Report may be distributed to and relied upon by the (client name) in determining whether the make a loan evidenced by a note ("The property Note") secured by the Property,

12.4.3.2 The Report may be relied upon by any purchaser in determining whether to purchase the Property Note from (client name) and any rating agency rating securities issued by or representing an interest in the Mortgage Note.

12.4.3.3 The Report may be referred to and included with materials offered for sale of the Property, Note or any interest in the Property or Note.

12.4.3.4 Persons who acquire the Property Note or an interest in the Property Note may rely on the Report.

12.4.3.5 The Report speaks only as of its date in the absence of a specific written update of the Report signed and delivered by (loss estimator's name).

12.5 *Deviations*—All deletions and deviations from this guide, if any, shall be listed individually and in detail and all additions should be listed.

12.6 *Signature*—The loss estimator(s) responsible for the estimate of probable loss to buildings from earthquakes shall sign the report.

12.7 *Additional Services*—Any additional services contracted between the user and the loss estimator(s), including a broader scope of estimate, more detailed conclusions, liability/risk evaluations, recommendation for materials testing, etc., are beyond the scope of this guide, and should only be included in the report if so specified in the terms of engagement between the user and the loss estimator(s).

12.8 *Commentary*—See Appendix X1 for commentary on Section 12.

APPENDIX

(Nonmandatory Information)

X1. COMMENTARY ON THE GUIDE PROVISIONS

The following commentary it provided to assist the user in understanding and applying this guide. It is organized by the section to which it is referenced; for example, X1.4 is the commentary for Section 4 of this guide. Some sections do not have commentaries.

X1.1 Commentary for Section 1—Scope

X1.1.1 The financial criteria used to evaluate a property should address three distinct issues:

X1.1.1.1 Life-safety threat posed by the building or portions of the building;

X1.1.1.2 Likelihood of failure of the site, for example fault ruptures passing through foundations, significant settlement, or liquefaction of the supporting soils; or secondary hazards affecting the site, for example flood waves from ruptured dams, tsunamis and seiches; or a combination thereof, and,

X1.1.1.3 Financial measures of possible damage due to effects of earthquakes on the building(s) directly or indirectly related to physical damage.

X1.1.2 The first issue is simply one of characterizing circumstances where the possibility of life endangering damage or failure of the building is sufficiently high that it poses an unacceptable liability to the owner and his debt holders. Such cases generally entail local or global failure of the structural system that supports gravity loads. The second is to identify circumstances where there are preventive measures in building design and construction that can be or have been taken to avoid a major loss when there is site failure or inundation. The third is to assess the possible damage and loss of use that characterize the financial risks, for example, upper bound losses, expected annualized loss, maximum insurance loss, from earthquakes.

X1.1.3 The term, "probable maximum loss" (PML), has been in use for some time and has a variety of meanings. The purpose of this guide is to present standard definitions to be used in assessing the seismic vulnerability of buildings and to present a series of technical specifications for their estimation. The term PML explicitly recognizes that there is uncertainty in the value given. Current understanding of earthquakes and the response of structures is not yet sufficient to make absolute statements on damageability. The notion of a probable maximum loss originated in the insurance industry. A key question in managing an insurance pool is how large the reserve must be to ensure being able to pay the loss in a timely manner. The occurrence of the event that triggers payments and the amount of the payment are seen as uncertain or random events, leading immediately to these problems being characterized as probabilistic ones.

X1.1.4 For example, suppose that a triggering earthquake event has occurred, and the problem is to determine the payment required. This is a straightforward problem in expectations. If there are a large number of policies, then no matter what the underlying probability distribution function is for the individual losses, the statistics of the sum of the losses approach a normal distribution whose mean is the sum of the mean expected loss for each individual policy. For insurance purposes, where very large numbers of policies are considered, the mean is a very good measure of the probable loss with whatever probability of exceedance is assigned. Then the problem of determining the largest loss that could occur to the insurer becomes a question of determining the most serious event that could affect (within the physical constraint of being realistic) the portfolio of policies and of assessing the average loss for each policy in this event, and summing them. Thus, for insurance purposes, the average damage in the largest earthquake likely to affect an area is a good measure of the risk for portfolio risk management where the properties are geographically distributed. By this reasoning it is not surprising that probable maximum loss determinations for insurance applications may not require consideration of the underlying statistics of individual losses nor of the likelihood of the causative seismic event, given only that it has some reasonable likelihood of occurrence.

X1.1.5 This notion of PML as the mean loss due to a large but possible event was and is a good one for the insurance purposes to which it is intended, that is, the management of insurance risk by insurance coverage writers. It is, however, not particularly useful for individual policies and most assuredly is much less useful for financial analysis of individual investments.

X1.1.6 This guide has considered the problem of characterizing the damageability and financial risk posed to building(s) by earthquakes, and recommends two practical measures for this expression, specifically, the probable loss (PL) and the scenario loss (SL). These terms replace probable maximum loss since maintenance of use of PML where there is such wide diversity in prior meanings of the PML term only can lead to future confusion; therefore, totally new terms, PL and SL, have been adopted so that there is absolute clarity in the future of what information is being provided. PL and SL values for the same building(s) are fundamentally different measures for damageability. SL considers the building's damageability due to a specific scenario earthquake ground motion. PL values simultaneously consider the uncertainties in both ground motion due to all possible earthquakes and building damageability in these ground motions in a statistically consistent manner. PL and SL values are intended to serve different risk management or fiduciary purposes and are not strictly comparable. PL values are expected by be most useful when the financial decisions are to be made for the individual building or group of buildings under consideration. SL values (with varying definitions of the specific consideration. SL values (with varying definitions of the specific scenario(s) considered) are expected to be most useful when it is desired to compare the expected performance of a particular building with the performance of other buildings in a portfolio.

X1.1.7 This guide is organized to address each of the typical earthquake impacts likely to represent a threat to the financial integrity of the property. These are:

a) Building stability assessment.

b) Site stability assessment.

c) Damageability assessment.

d) Non-structural components damageability assessment.

e) Business interruption assessment.

X1.1.8 The text for each element presents a nested series of guidelines that are intended to respond to a range of the needs for accuracy and associated degrees of effort, that is, from a screening level, termed Level 0, to an intensive technical effort, termed Level 3. By their nature, the uncertainty in the result of a Level 0 effort is very high while the uncertainty in the result of a Level 3 effort is considerably less uncertain, but still not certain, since earthquake occurrences and structural response have residual uncertainties that cannot be eliminated in the current state of the art or knowledge. Generally, the quality of the results and their associated reliability will be determined largely by the experience and quality of effort of the loss estimator.

X1.1.9 At a minimum it is recommended that every earthquake vulnerability assessment include the building stability assessment, the site stability assessment, and the damageability assessment elements. Site and building stability are deemed to be of overriding potential for financial impact to properties, whether owned or used as securities for other financial instruments. It is expected that individual organizations will select from among these this guide's different elements and performance levels and select those that are appropriate to their particular circumstances.

X1.1.10 In order to understand the different measures related to estimates of how a building may behave due to selected levels of earthquake ground motions, it is helpful to consider the stated performance objectives and design concepts of the governing design code for regions of moderate to strong seismicity; specifically the Uniform Building Code (UBC) seismic provisions are based on the technical provisions of the SEAOC Blue Book **(5)**. It states as the objective for buildings that meet its minimum requirements to:

X1.1.10.1 Resist a minor level of earthquake ground motion without damage.

X1.1.10.2 Resist a moderate level of earthquake ground motion without structural damage, but possibly experience some nonstructural damage;

X1.1.10.3 Resist a major level of seismic ground motion, such as the intensity equal to the strongest earthquake, either experienced or forecast, for the building site, without collapse, but possibly with some structural, as well as, nonstructural damage.

X1.1.11 It is clear that a building designed and constructed to comply with the most recent code can suffer damage. If the structure has been designed to older versions of the code (recognizing the significant changes such as the 1976 UBC), or there are errors in the design and construction process, then there also is the possibility of local or general collapse, or both.

X1.1.12 Buildings subjected to the major level of seismic ground motion may undergo both load and deformation effects that exceed the corresponding calculated values resulting from the seismic loading specified by the applicable design code. The transition factor between allowable stress design and strength design, other than seismic load combinations, final selected element sizes, significant nonstructural elements, along with multiple element redundancy or backup systems can result in a total lateral load yield level resistance for the structure equal to about three to four times the specified allowable stress design load. As a result, elements such as columns that support shear walls, collectors or tie elements between horizontal diaphragms and shear walls or frames, and horizontal diaphragm anchors to walls positioned normal to loading all need either the strength or toughness to sustain these actual response loads.

X1.1.13 Similarly, the actual response deformations in the inelastic yielding structure can be about six to twelve times the calculated drifts due to the specified design load. All gravity load bearing elements that may or may not be designated as part of the seismic force resisting system, together with their support conditions and details, must be able to sustain these maximum response deformations without a local or general collapse that could cause a serious life safety hazard. Also, the elements and connections of the designated lateral force resisting system must have the details and connections necessary to provide the toughness or ductility to maintain their yield level strength up to and reasonably beyond the maximum deformation demands.

X1.1.14 For the evaluation of an existing building for seismic damage potential and stability against collapse, there are seven basic characteristics that should be considered to assess the expected performance: compatibility, condition, configuration, continuity, redundancy, strength, and toughness. These characteristics are identified as follows:

X1.1.14.1 *Compatibility*—All building elements and their material properties should be able to sustain the maximum deformation without destructive interference. For example, stiff and brittle in-fill wall elements should not interfere with the deformation of the more flexible framing elements and columns.

X1.1.14.2 *Condition*—How the building has been maintained. Whether or not there is evidence of deterioration, decay, damage, settlement, or unauthorized modifications to the structure.

X1.1.14.3 *Configuration*—Determination of any irregularities in the building elevation or plan that could lead to concentration of excessive deformation or stress, such as soft or weak stories, or torsion due to eccentric location of resisting elements. These conditions may be caused by the noncompatible installation of rigid nonstructural elements, such as panels or in-fill walls.

X1.1.14.4 *Continuity*—There must be a continuous load path of structural elements and connections to carry gravity loads to the foundation and to carry seismic inertial loads from the diaphragms to the lateral load resisting shear elements, for example, shear walls, braced frames, or moment frames, or a combination thereof, and then to an adequate foundation.

X1.1.14.5 *Redundancy*—The presence of a series of resisting elements or an additional backup system can provide extra assurance against collapse where the possible failure of a single element can occur due to design error, condition or construction weakness; the load initially taken by the failed element can be redistributed to the other elements in the lateral load-resisting system.

X1.1.14.6 *Strength*—The existing lateral load-resisting capacity should be high enough to prevent brittle failure or excessive inelastic yield distortion.

X1.1.14.7 *Toughness*—Detailing should be provided to prevent excessive strength degradation of structural elements and connections due to the actual cyclic loading that leads to the maximum seismic deformation response.

X1.1.15 It is important that any building for which an estimation of earthquake damageability is made be reviewed for all aspects of its characteristics that can impact its seismic performance, including at a minimum the seven listed above.

X1.2 Commentary for Section 2—Terminology

X1.2.1 None.

X1.3 Commentary for Section 3—Significance and Use

X1.3.1 Earthquake Damageability Assessments:

X1.3.1.1 Earthquake damageability assessment involves the interaction among four major elements: hazard type, local conditions, exposure, and vulnerability. For a given hazard type and set of local conditions, a seismic damageability assessment of a highly vulnerable property with a low exposure may be exactly the same as that of a highly exposed property that exhibits low vulnerability characteristics. A brief discussion of these four major elements follows after a description of the types of hazards posed by earthquakes.

X1.3.1.2 Ground motion, site failure, and indirect effects are the three basic classes of earthquake hazards. While faulting and site failure are the most dramatic direct earthquake effects, ground shaking accounts for over 90 % of all direct damage effects of earthquakes. Site failure includes surface faulting and rupturing, soil liquefaction and lateral spreading, ground subsidence, settlement and slumping, differential settlement, land sliding, and avalanches. Indirect effects include both those circumstances where the hazard comes from off-site, for example, flooding from dam failure, tsunami and seiche, and those from indirect causes, for example, fire following earthquake and toxic releases. Indirect causes are not considered in this guide.

X1.3.1.3 Exposure is a measure of the frequency and intensity with which the hazard occurs. It is evaluated recognizing region geologic and seismologic patterns and history, together with local geologic and site conditions. Understanding of where earthquakes occur is markedly different by area. Seismic activity in the far west is characterized by geological fault movement. In some cases, federal, state, or local authorities, or a combination thereof, have established special earthquake study zones that envelop many active fault segments, as well as, requirements that may place severe restrictions upon future real estate development in these zones. In other seismic regions, future seismic activity generally is estimated on the basis of historical data coupled with tectonic plate models.

X1.3.1.4 Local site conditions substantially can affect the impacts of earthquakes on supported structures. The underlying soil profile and the surface topography can be capable to modify bedrock accelerations as they propagate to the surface. Surface ground motions may be amplified or reduced and accompanied by a shift in the predominant frequencies, all of which merit site-specified evaluation, if of significance and merited for the level of investigation.

X1.3.1.5 The fourth element in the earthquake damageability assessment process involves both vulnerability of the site itself and the property improvements. Vulnerability to the ground shaking hazard is largely manifested by damage to improvements and business interruption. Evaluation of the future seismic performance of buildings can be accomplished with varying levels of sophistication. It is customary to express property damage loss as a percent of replacement construction cost. Business interruption loss may be so expressed as "down-time" estimate.

X1.3.1.6 Seismic damageability assessment is the consideration of the interaction between the four components of earthquake damageability results in the assessment of the seismic damageability for either an individual property or a portfolio. For any specific hazard that incorporates the effects of local site conditions, the relationship between exposure and vulnerability represents the earthquake damageability. It should be noted that for a given seismic hazard, for instance, ground shaking and favorable local site conditions, an earthquake damageability assessment may be of the same order for a highly vulnerable, nonseismically designed building and having a low seismic exposure, as that of a highly exposed building that exhibits low vulnerability characteristics.

X1.3.1.7 Modified mercalli intensity scale (MMI) is sometimes used to evaluate seismic exposure. MMI is a subjective characterization of earthquake impacts and is qualitative, not quantitative in nature. An MMI value for a specific earthquake at a particular location is assigned based on an observers sensation and the physical effects incurred. Once established, MMIs then are used to predict property damage, thus reflecting the circular definition problem. At no stage does an MMI define the nature and characteristics of a seismic disturbance, unlike the probabilistic and multiple scenario approaches discussed heretofore. In order to overcome such a deficiency, efforts are sometimes made mathematically to translate MMI's into surface ground accelerations. This is difficult to achieve in a consistent manner, largely because the subjective nature of MMI's severely erodes the confidence level of the earthquake damageability assessment process.

X1.3.2 Computer Program Usage in Damageability Assessment:

X1.3.2.1 For many years, earthquake insurance engineers utilized a method of categorizing expected loss due to seismic events as a class PML. This deterministic system, based upon the Insurance Services Office building classifications was developed **(1)** in the 1940s for the insurance industry. Rather than estimating site and/or building-specific loss, this approach estimated the probable maximum loss for six building classes of risks (16 subclasses) in underwriting zones with similar expected maximum seismic events. Modifiers were used to adjust the PML for certain building-specific factors. In the terms of this guide the damageability would be characterized as a scenario loss (SL).

X1.3.2.2 This method was utilized exclusively until the mid-1980s when a more site-specific system was developed. The advent of desktop computers allowed engineers and academicians to compile databases of site-specific soil information, such as landslide, soil liquefaction, and fault rupture potential. In addition, the ATC-13 building classification system **(1)** expanded and clarified building construction types and used an expert opinion mechanism to assign damage rates and ranges. This allowed development of computer models for somewhat more statistically accurate estimating of building loss due to earthquakes. Most models have concentrated on the California area where more extensive data were available.

X1.3.3 *Types of Models*—There are currently two principal types of interactive computer software methodologies available to evaluate damage or loss to buildings:

X1.3.3.1 *Deterministic*—The traditional method of analyzing earthquake damageability by producing a small set of earthquake scenarios on major fault systems. This type of SL approach is generally quite conservative and does not take into account the probability of a given earthquake.

X1.3.3.2 *Probabilistic*—The method of analyzing earthquake damageability utilizing the statistical probability of a specific seismic events and can include a SL study where the scenario is the event with a selected probability of exceedance or a PL study for the total seismic hazard. Advantages of probabilistic risk assessment methods include:

(a) Ability to simulate the complete range of seismicity

(b) Development of a loss distribution for individual sites or portfolios of sites; and

(c) Ability to calculate the average annual risk or the probability of exceeding some threshold risk level.

X1.3.3.3 Utilizing probabilistic techniques, there are several ways to evaluate potential loss and portray the level of uncertainty of the analysis:

(a) mean or median loss

(b) average loss

(c) a user-defined upper bound confidence level (for example 10 % probability of exceedance in 50 years).

X1.3.4 The accuracy of the output from computer models is limited by several factors:

X1.3.4.1 *Quality of User Input*—Earthquake risk analysis models have been designed to general loss information regardless of the quality or extent of input. For instance, if the input is limited to a street address without building specific data, the output would be exceptionally conservative but would not have a high level of accuracy. This approach may be useful in analysis of large portfolios where risk is spread over many properties but is not recommended for analysis of individual buildings, except for screening level investigations. (Level 0).

X1.3.4.2 *Quality of Database Information*—The quality of seismological data in the models' database may be limited by the quality of available soils information, or the frequency of updates, or both. In addition, the quality of data may be limited in locations that are outside the perceived higher-risk areas of costal California.

X1.3.4.3 *The Extent of the Damageability Data Base*—Those that are based on specific building damageability observations are preferred to those that are based principally on professional judgment or consensus processes. The credibility of the results are limited by the credibility of the data base on which the damageability models are based. Disclosure of the data bases, how they are collected, and how they are assigned to different building classifications is key to evaluating the reliability that should be placed on the program's results. This is particularly important when the programs use a rating scheme or scoring approach to determining relative damageability.

X1.3.5 The end user of damageability values generated by computer modeling should be careful to understand the basis for the results. Such results are numbers, not to be used blindly but with full knowledge of their basis and limitations. At a minimum, the following determinations must be made by the provider:

X1.3.5.1 The relative experience of the individual providing input. The input information provided by the user limit the accuracy of the result.

X1.3.5.2 The source of site-specific soil data.

X1.3.5.3 Any assumptions that could drastically affect the result, including the effect be on an alternative assumption.

X1.3.5.4 The primary contributing factor to a high (low) result.

X1.3.5.5 The possible structural building modifications that would significantly improve the result. The cost estimate for such work.

X1.3.5.6 Recommendations for a more detailed seismic analysis be performed by a structural engineer.

X1.3.5.7 Whether or not the software provider maintains networks of technical alliances with leading experts and research institutions.

X1.3.5.8 How often is the software upgraded and the revision dates for all software and data files used. When the seismic hazard data are not regularly revised, say at least annually, important changes in understanding of seismic hazard may not be included that could have significant impact on the results.

X1.3.5.9 The definition of the value provided (SL, PL, mean value, or confidence limit, time period for PL).

X1.4 Commentary for Section 4—Probabilistic Ground Motion Hazard Assessment

X1.4.1 Several of the damageability assessments require the determination of the probabilistic ground motion at the project site to complete the analysis. These include all of the probable loss (PL) assessments and may include the scenario loss (SL) where the ground motion is specified as the result of a probabilistic analysis. This section provides guidelines for the performance of such investigations.

X1.5 Commentary for Section 5—Building Stability Assessment

X1.5.1 The higher the level of the study selected, the more in-depth will be the required analysis. It is assumed that most complex, multistory structures will be assess at Level BS2 or higher level, with most one-story buildings assessed at levels BS0 and BS1.

X1.6 Commentary for Section 6—Site Stability Assessment

X1.6.1 *Tsunami*—Simple methodologies do not exist to predict tsunami occurrence and run-up heights, as the source of the tsunamis could be from earthquakes on very distant faults across oceans, as well as local faults, Obviously structures sited near ocean bodies and bays at lower elevations would have exposures to tsunamis. It is known that the elevation reached by a tsunami (and rising water) depends upon many factors, including the offshore hydrography, on the orientation, slope, and configuration of the shoreline, and on resonance. Resonance of waves can occur in harbors. There have been observations that the heights of the tsunamis at the heads of triangular bays generally are higher than at the mouths of the bays. It has been observed that coastal regions facing the area in which a tsunami originated usually suffered a high run-up of the water. When tsunamis are generated locally, the wave heights along the coast usually are higher along the portion of the coast nearest the epicenter if the tsunami originated from a roughly circular source, and near the intersection of the coast and the line drawn perpendicular from a line through the epicenters for aftershocks in the case of an elongated elliptical source. The evaluation of tsunami damage potential is complex and difficult. Careful consideration of a structure's site near the shoreline may, at best, provide a relative comparison of vulnerability to tsunami exposure.

X1.7 Commentary for Section 7—Damageability Assessment

X1.7.1 The damageability measure of a building is a representation of its damageability to earthquake ground motions and the degree of ground motion hazard at the building's site. There are two fundamental approaches to characterizing the damageability of the building, the first is to focus on the likelihood that a damage level occurs from all possible earthquakes that can affect the site. It will be termed a probable loss (PL). The second is to characterize the building's damageability in a prescribed ground motion, that is, a scenario loss (SL). PL and SL values for the same building(s) are fundamentally different measures of damageability **(7)**. SL values characterize the building's damageability uncertainty in a specified ground motion. PL values simultaneously consider the uncertainties in a statistically consistent manner of both ground motions due to all possible earthquakes and building damageability. PL and SL values are intended to serve different risk management or fiduciary purposes and are not strictly comparable. PL values are expected to be most useful when the financial decisions are to be made for the individual building or group of buildings under consideration. SL values (with varying definitions of the specific scenario(s) considered) are expected to be most useful if it is desired to compare the expected performance of a particular building or group of buildings with the performance of other buildings in a portfolio that are not specifically assessed in the subject damageability assessment.

X1.7.2 The main difference between the level D3 analysis from those of the lower levels is that it evaluates damage to the major individual components (structural system, exterior shell, facade elements, interior finishes, tenant improvements, mechanical/electrical systems) of the building rather than treating the building as a whole having a particular system type. The major components are identified and their values are established, such that their sum equals the total replacement cost of the building. Costs usually are determined by consultation with a cost estimation professional, or for simple cases, by using publicly available cost estimating procedures or aids. Each component is divided into categories that have damage that is best predicted in terms of the response characteristics of, such as, floor acceleration, interstory drift, local element deformation demands, etc.; and damage ratios are established either from available data or published tables, or from judgment coupled with specific detailed cost estimates, that is, the result is a damageability relation or curve that provides the component damage ratio and corresponding cost of repairs for the possible range of response values. The structure is modeled appropriately and dynamic analyses are performed at selected successive discrete levels of ground motion having known probabilities of occurrence. Response spectrum analyses of the elastic structure model may be used with assumed relations between the elastic and inelastic response. Inelastic time history analyses may be performed to more reliably establish particular demand characteristics. When the response values at each floor and story are determined for a given level of ground motion, the damage ratio and corresponding damage cost is found for each component at each floor and story level and the total damage cost for the building is then evaluated as the sum of costs at each floor, then summed over all floor levels. Since the individual component damageability relations often are judgmental with large uncertainties, or, at best, based on sparse amounts of data, the actual individual component damage cost and resulting total cost for the building are random for a given ground motion. Feasible representation of this randomness may be expressed by use of low, best, and high damage ratios for each component along with a subjective probability or likelihood, such as 25 %, 50 %, 25 % for low, best, and high. Alternatively, the best or mean value could be selected along with standard deviation (sigma) of scatter for component damage. Then, by the central limit theorem, the sum or total cost would have a normal probability distribution with mean equal to sum of the component mean costs, and with sigma (assuming independence between components) equal to the RMS (square root of the sum of the squares) of the component sigmas; alternatively more appropriate specific distribution functions may be used that for the particular case are better statistical predictors. The assignment of a specific damage state probability distribution for each component would result in an analysis that is more complex than the degree of accuracy concerning the assigned distribution would justify.

X1.7.3 The evaluation of damage to the nonstructural elements can be complex if done in detail. PL analyses typically treat major equipment systems as separate parts of a PL evaluation, and not as part of the structure. This is also true of stock (finished goods) and supplies (materials to be consumed or processed). Separate vulnerability damage functions would thus be utilized for estimating damage to these categories.

X1.7.4 Since secondary structural damage commonly occurs in wall systems (both curtain walls and interior partitions), the evaluation should consider the expected inter-story drift magnitude, brittleness of the wall or glazing system materials, and the ability of their support details, that is, their flexibility to accommodate interstory drift. These considerations would begin to be included for Level SS1 evaluations, and should be included for levels SS2 and SS3 evaluations.

X1.7.5 Another major area of secondary structural damage occurs in ceiling systems, more typically in ceilings with lay-in tiles. This is due to lack of bracing in older ceiling systems and is greatly increased if unbraced ducting and piping is located above the ceiling systems. Ceiling vulnerability assessments, therefore, must include the inherent fragility of the ceiling system, and indirect ceiling vulnerabilities such as sprinkler piping penetrating the ceiling, and unbraced mechanical equipment above the ceiling. Also relevant is bracing of the ceiling system and isolation detailing at its perimeter. The latter may allow the ceiling to avoid shearing forces induced by wall restraint.

X1.7.6 If equipment systems are included in the scope, the relevant parameters would include, at a minimum, inherent fragility, anchorage, or bracing, or both, and flexibility at interfaces with attachments (piping etc.).

X1.7.7 If stock and supplies are included in the scope, relevant parameters for evaluation should include inherent fragility, mitigating factors, such as bulk packaging, that is, palletizing, and repackaging costs associated with recovering unspoiled good in spoiled packaging. The client also may be interested in indirect damage, such as water damage to stock following leakage from damaged fire protection systems. Note that in some industries (for example, biotechnology, pharmaceuticals) the slightest suspicion of damage or contamination of stock may lead to 100 % loss of that stock.

X1.7.8 For all categories within the nonstructural elements evaluation effort, the relative percentage of each vulnerable subsystem must be considered in determining their associated PL or SL components for evaluation levels other than SS0.

X1.8 Commentary for Section 8—Contents Damageability Assessment

X1.8.1 The evaluation of business interruption can be extremely complex if done in detail. In practice, for PL analyses, simplified evaluations business evaluations typically are not performed. If requested as additional work scope, Levels B0 or B1 typically are used. Levels B2 and B3, or variations thereof typically are used only when specifically requested by a user for a detailed seismic risk evaluation.

X1.8.2 *Business Interruption Component Values*—Computation of the value of business interruption may include variables, such as fixed costs, variable costs (personnel that may or may not be retained during the post-earthquake period, supplies etc.) and profit. The evaluation should be consistent with the user's accounting practice when computing business interruption.

X1.8.3 The following lines in inquiry (investigation) are given as examples of determining business interruption. The actual number of different lines of inquiry is very wide and specific to the facility under evaluation. The items below are for guidance in methodology for the higher levels (B2 and B3, and to a much lesser extent, B1), and are not intended to represent a sufficient scope.

X1.8.3.1 *Resumption of Occupancy*—This term refers to the time after an earthquake at which a facility can be reoccupied in whole or in part. Note that re-occupancy may occur before any, or possibly all, damage is permanently repaired, if satisfactory shoring or interim repairs can be made that provide a life-safe environment.

X1.8.3.2 *Materials*—At its simplest this refers to raw materials, delivered by truck, tanker, sack, tin, bottle, box, carton, etc.

X1.8.3.3 *Parts*—This term refers to components made off-site or on-site required for manufacture at the facility under evaluation. This could include a metal casting, an injection-molded plastic part, a circuit board (loaded or empty), a case, a bottle (for filling), a cardboard case (for packaging).

X1.8.3.4 *Production Machinery*—This term refers to machinery and equipment directly involved in product manufacture or packaging; some equipment may be unique, critical, and have a long lead time for its repair parts. Examples of manufacturing equipment related to computers (as an example) include steppers (which expose the circuits on silicon wafers), semiconductor wafer testers, and (circuit) board stuffers (put components on the circuit boards).

X1.8.3.5 *Support Machinery*—This refers to machinery in a supporting role, such as boilers, water treatment units (filers, deionizers), air compressors and vacuum pumps, emergency generators (including cogeneration plants on-site), air conditioning and filtration (that is, HEPA filters at wafer-fabrication ["Fab"] plants), refrigeration equipment (for example, for cooling beer or wine), etc.

X1.8.3.6 *Distribution*—This term refers to all facets of delivering the finished product to the buyer. It includes warehousing (on-site or off-site), distribution and shipping via road, rail, sea, or air carrier. Note that it is becoming common for manufacturers to have several manufacturing facilities that deliver goods to one central site for warehousing and distribution, using highly computerized stock tracking and ordering systems.

X1.8.3.7 *Process Sensitivity*—Some manufacturing processes are more sensitive than others, either by their nature (semiconductor), or by legislation (for the control of toxins). If a manufacturing process follows a lengthy proscribed restart or recertification procedure, it may adversely impact the business operation.

X1.8.3.8 *Redundancy*—Large facilities often have excess capacity designed for peak demand and have multiple lines making the same product. Some redundancy also may be available by diverting production to other facilities, if they have excess capacity. Redundancy also refers to having multiple sources of materials and parts.

X1.8.3.9 *Infrastructure*—This refers to all transit, communications, and utility systems. Effects may be estimated from generic curves; the level of investigation should be increased as necessary, for example, considering actual routing of electrical transmission lines, location of substations, number of electrical power supply routes that are possible, availability of staff after a major earthquake.

X1.8.3.10 *End-User*—Business interruption does need to consider the source of revenue.

X1.8.3.11 *Inter-Dependency*—Internal components of a facility usually have significant interdependencies, but interdependencies also may exist with related off-site facilities, for example, plants in the same town make different parts for the same product.

X1.8.4 This issued above are important because:

X1.8.4.1 Business operations are assumed to be suspended when an owner or tenant vacates a building due to earthquake damage.

X1.8.4.2 The quantity of parts or materials on hand after an earthquake and the ability of suppliers to maintain supply directly affect business interruption.

X1.8.4.3 The time required to repair or replace damaged production machinery.

X1.8.4.4 The time required to restore support systems (including machinery). Portable or rented equipment may be considered.

X1.8.4.5 The time required to restore a manufacturing process.

X1.8.4.6 Damage to various parts of the infrastructure supporting the facility may affect the transport of materials, parts and finished goods, and necessary utilities, such as water and power.

X1.8.4.7 If the end-user cannot accept the product (or service), a facility may have to suspend part or all of its business operations.

X1.8.4.8 Interdependencies increase the vulnerability of a facility's operation.

X1.9 Commentary for Section 9—Subsequent Use of Business Interruption

X1.9.1 None.

X1.10 Commentary for Section 10—Subsequent Use of Damageability Assessments

X1.10.1 None.

X1.11 Commentary for Section 11—User's Responsibilities

X1.11.1 None.

X1.12 Commentary for Section 12—Evaluation and Report Preparation

X1.12.1 None.

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(**4**) *Uniform Building Code*, various editions, International Conference of Building Officials, Whittier, California.

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