SEISMIC ISSUES THAT DE-RAIL CLOSINGS

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INTRODUCTION

The purpose of this handout is to help people involved in the process of closing commercial real estate loans or acquisitions identify seismic issues that can de-rail the closing. By identifying problematic seismic issues early in the process, actions can be taken to avoid or minimize the financial risks that can result from surprises in the final days of closing.

WHAT IS A PML?

Most lending institutions require a seismic assessment report for commercial buildings. Part of the seismic assessment normally includes an estimation of loss (estimate of damage) for the building when subjected to earthquake ground shaking. Lenders typically want loss estimation results stated in terms of a “Probable Maximum Loss” (PML).

A PML is usually defined as a percentage of the replacement cost of the building for the damage caused by ground shaking during a representative earthquake event, or scenario. PMLs are usually expressed as a percentage of the building replacement cost, but can also be expressed as a dollar value. PMLs usually exclude the contents (items used by the occupants such as equipment, systems and furnishings), relocation costs and costs related to business interruption or market share loss. Unfortunately, the term PML has been defined differently by different people. As a result, it has become a generic term referring to the seismic damage repair costs. This, of course, has led to a great deal of confusion within the industry. The historic, we believe correct, definition of a PML is “the percentage monetary loss (damage/replacement cost x 100) that has a 10 percent chance of being exceeded for a 475-year ground motion”. (See DEFINITONS at the end of this paper.)

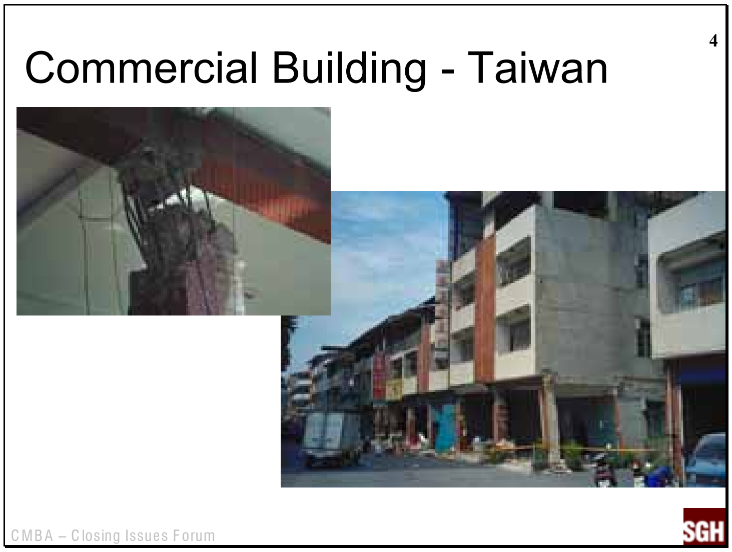
Since no one can predict the exact earthquake damage repair costs a building may incur, engineers rely on probabilistic methodologies to state their expectations. The public is accustomed to similar approaches (though, not exactly the same) for weather predictions (rain predicted with a confidence level), or the high water elevation for the “hundred year flood”.

Post-earthquake reconnaissance reports of building damage show that the degree of damage varies greatly within similar groups of buildings subjected to the same intensity of ground motion (shaking). Figure 1 shows twin apartment buildings in Taiwan. Construction for both was completed just a few months before the 1999 Chi-Chi earthquake which caused wide spread damage in that country. The building on the left side of the photo suffered total collapse of the first story, while the building on the right remained in use after the earthquake.

Figure 2 illustrates the same phenomenon for twin commercial buildings subjected to ground motion during the Chi-Chi earthquake. The building on the left had severe damage in the first story columns and was in a state of “near collapse”. The columns in the building on the right had no observable damage.

Apartments – Taiwan Chi-Chi EQ

Figure 1



Commercial Building - Taiwan

Figure 2

This distribution of damage within similar building groups is illustrated graphically in Figure 3. The horizontal axis indicates the degree of damage, ranging from none to complete. These are called damage states – None, Minor, Moderate, Severe, Complete. The vertical axis indicates the number of buildings within each damage state. The graph represents 100 nearly identical buildings. For a given earthquake, the graph indicates the number of buildings that are expected to be in each of the different damage states. Remember, these are buildings of similar construction, all located in the same vicinity and all subjected to the same earthquake. The variation of building damage is attributable to localized variations in the ground motions, orientation, random variation (material strengths inherently vary, structural member sizes vary within acceptable tolerances, etc.) and expected variation from uncertainty of knowledge about the building (actual construction conditions, accurate values of building weights and occupancies, etc.)

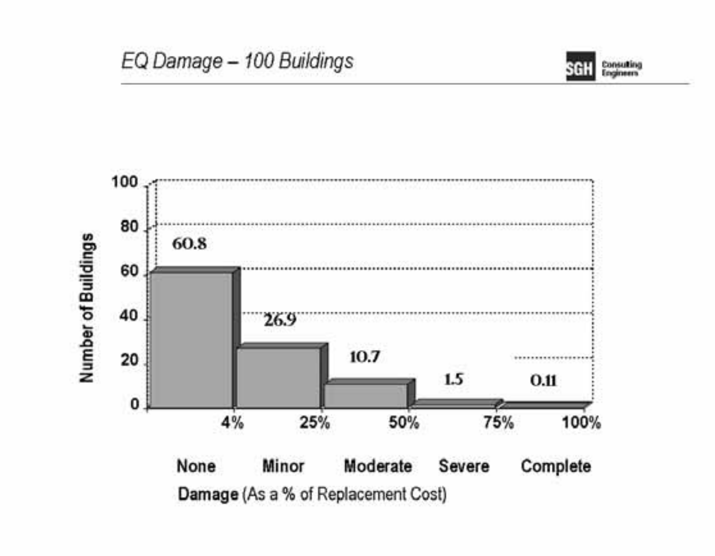


Figure 3

Rather than the vertical axis representing a specific number of buildings, it could be the percentage of the buildings in each damage state, or it could be the probability of the occurrence of each of the damage states for a particular building.

In Figure 4, the vertical axis of the same graph represents the probability of the occurrence of each of the damage states. Figure 4 has a curve drawn through the peak of the vertical bars. This is a “probability curve”. In this case, the vertical line near the middle of the probability curve indicates the expected (mean) damage is 10% of the replacement cost for this building for the assumed seismic event. There is a chance the building will have more or less damage than this amount.

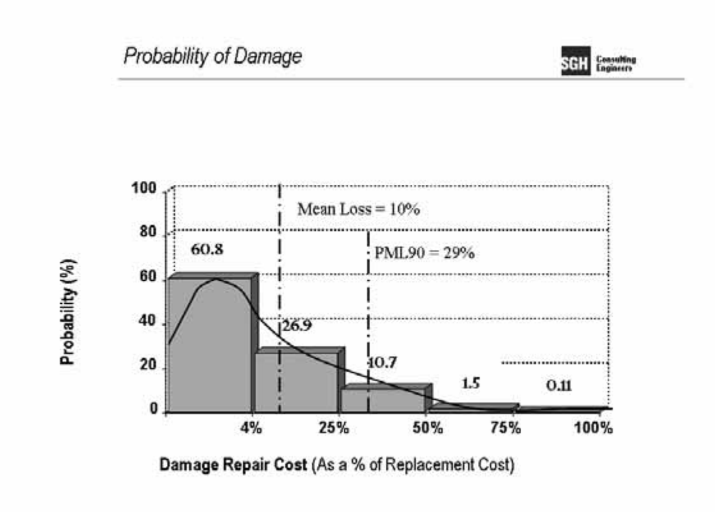


Figure 4

The vertical line at the right side of the probability curve indicates a 90% probability that the damage will not exceed 29% of the replacement cost. (This means for 10 similar structures, on average 9 out of 10 will experience 29% damage or less.) Sometimes the 90% value is referred to as a Probability Not to Exceed (PNE).

Most lenders use loss estimates based on a PNE of 90% that is, the 29% value in Figure 4. Some engineers refer to this value as PML90. Some lenders use loss estimates based on the mean value which is the 10% value in Figure 4.

Lenders also vary which type (or magnitude) of earthquake events are to be used for computing loss estimates. The earthquake event is usually defined as ground shaking intensity that has a certain probability of being exceeded (i.e. 10%) in a specified window of time (i.e. 50 years). The equivalent level of ground shaking intensity can also be specified as a return period (i.e. 475 years).

Commonly used probabilities of exceedance and corresponding return periods are:

Probability of Exceedance	**Return Period**
50% in 50 years	72 years
10% in 50 years	475 years
2% in 50 years	2,475 years

Historically, PML was defined as this 90% value (Ref. 7) computed for ground motions having 10% probability of exceedance in 50 years.

As discussed below in the section on ASTM Standard E2026, all of these variations have resulted in considerable confusion as to what a lender really wants when they ask for a “PML”.

ASTM STANDARD E2026

ASTM E2026, “Standard Guide for the Estimation of Building Damageability in Earthquakes” (Ref. 2) is an attempt to standardize the terminology related to loss estimation and PMLs. As stated in the introduction to ASTM Standard E2026, “there has been no previous industry or professional consensus on what PML means or how it is computed.” The standard discourages the use of the term PML and provides new terms with more explicit definitions. Some of the definitions from the standard are included in the definitions section at the end of this handout.

In addition to defining terms, the standard defines four levels of inquiry, or effort that can be used to estimate earthquake losses. These are referred to as Level 0, 1, 2, and 3, with Level 0 requiring the least effort and Level 3 the most.

Seven pages in the standard are devoted to a discussion of these levels of effort. A brief synopsis of the intent of that discussion is given below.

- Level 0: This is the minimum level of effort and may be performed by someone who is not a structural engineer. The Level 0 evaluation is a screening level of assessment. Generally, the required information is limited to the type of structure (steel frame, concrete shear wall, wood frame, etc.), occupancy, year built, year retrofit, number of stories and address. Ground motions can be obtained from commercially available software or sources published by government agencies.

- Level 1: This is the level used for most PML or due diligence reports. A Level 1 assessment requires the above information plus a drawing review (if available), a site visit and determination of specific structural characteristics. Selected members are evaluated, at least qualitatively, for seismic load capacity and irregular conditions such as soft stories are noted. Ground motions can be obtained from commercially available software or sources published by government agencies. The ASTM standard states that Level 1 assessments require the most experienced structural engineer because most of the assessment is based on judgment, not calculations or detailed plan review and site investigation.

- Level 2: A Level 2 assessment requires the above information plus structural calculations of selected members and determination of the seismic response characteristics of the building. Loss estimation (PML) computations are more sophisticated and involved than for Levels 0 and 1.

- Level 3: A Level 3 assessment requires a full engineering analysis including the use of site-specific geotechnical information. The structural behavior used to determine loss estimates is based on computed dynamic properties of the structure such as roof displacement, floor accelerations and inter-story displacements.

While standardization for computing and reporting loss estimates and PMLs would be greatly beneficial to the industry, widespread adoption of the ASTM Standard has not yet occurred.

METHODS FOR COMPUTING PMLs

Practically all methods for estimating seismic damage costs for buildings are based on, or evolved from, a procedure published by Karl Steinbrugge for the insurance industry in Earthquakes, Volcanoes, and Tsunamis: An Anatomy of Hazards in 1982.(Ref. 7) and ATC 13 “Earthquake Damage Evaluation for California” in 1985 (Ref. 1) by the Applied Technology Council.

With careful judgment used to modify expected building performance and damage considering improvements in construction and knowledge of building behavior developed in the last 20 years, these original documents could be used to perform structural damage estimates. Several loss estimation methodologies have been developed into computer software. Most loss estimation software is proprietary. Some of the software programs available for use are:

- *PropertyRisk* by ABS Consulting (formerly EQE International). This is specialty screening level software available on-line.

- *USQUAKE* by ABS Consulting. This is general-purpose software for estimating property losses for various hazards, including earthquakes. ABS Consulting uses this program for calculating loss estimates in the real estate and insurance industry. Use of the program by others requires an annual licensing fee and trained users.

- *RiskLink* by Risk Management Solutions (RMS). This is general-purpose software for estimating property losses for various hazards, including earthquakes, usually applied to large portfolios of properties. RMS uses this program for calculating loss estimates in the real estate and insurance industry. Use of the program by others requires an annual licensing fee and trained users. In the past, this software has been known as IRAS.

- *ST-RISK* by Risk Engineering Incorporated (REI) and Degenkolb Engineers. This is specialty software for estimating property losses from earthquakes for individual buildings. Engineers use this program for calculating loss estimates in the real estate and insurance industry. The software is available on-line and requires a modest usage fee, negotiated based on the quantity of uses.

- *ALLRISK* by Risk Engineering Incorporated (REI). This is general-purpose software for estimating property losses for various hazards, including earthquakes, usually applied to large portfolios of properties. REI uses this program for calculating loss estimates in the real estate and insurance industry. Use of the program by others requires an annual licensing fee and trained users.

- *HAZUS.* This is general-purpose software for estimating property losses, life losses and infrastructure disruption for specific hazard scenarios, including specific earthquakes. The program is developed and supported by the US government through FEMA and is a public-domain program that is available free from FEMA.

A method published in 1986 by Charles Thiel and Theodore Zsutty (Ref. 8) is available for use without charge. The method requires considerable expertise and modification on the part of the user. The methodology was published nearly 20 years ago and significant advances have been made in the understanding of the behavior of buildings and construction practices following some of the major earthquakes that have occurred worldwide since 1986. The earthquake hazard (ground motions) used as part of the methodology must be obtained from commercially available software, seismology consultants or sources published by governmental agencies. The method is commonly referred to as the Thiel-Zsutty method.

LENDER'S REQUIREMENTS

When a lender requires a loss estimate (usually reported as a PML), many factors apply to that loss estimate. The typical scenario envisioned by the lender is most closely represented by the following example. If an uninsured borrower with an 80% mortgage incurs earthquake losses of 40% of the building's value, the borrower may walk away from the property, leaving the lender with only a 20% down payment to pay for repairs. Strikingly, this is why a PML of 20% is often set by lenders as a threshold for requiring insurance as a loan condition. In particular, the lenders typically specify the PML limit to not exceed 20% for ground motions having a 10% probability of being exceeded in 50 years. This threshold is established as representative of a probabilistic estimate appropriately applied to typical buildings designed and built in accordance with the Uniform Building Code (UBC) (Ref. 9). The UBC design requirements are based on the same ground motions. These ground motions are sometimes referred to as ground motions with a 475-year return period. Variations to the 20% threshold for a PML depend on factors related to the transaction, such as the presence of earthquake insurance, equity and the loan-to-value ratio.

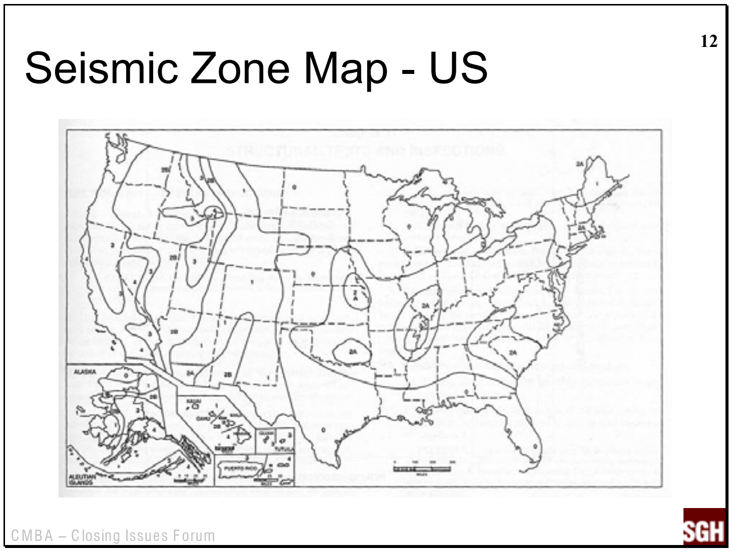
Some lenders use other return periods in addition to 475 years, and some lenders require probabilistic analyses considering hazard contributions from all faults simultaneously. The latter becomes more rational in areas where fault systems are less well defined, or where thrust faults exist (Los Angeles Basin). See the definition for Probable Loss (PL) at the end of this handout.

Most lenders want the PML value that has 90% probability of not being exceeded (PNE = 90% or the 90% confidence level). Others will accept the mean loss. Many do not know the difference. This misunderstanding is disconcerting since, as demonstrated above, the difference in the mean value and the 90% value can be very large (in excess of 200%).

GEOLOGIC HAZARDS

Geologic hazards are those hazards that affect the ground on which the building is sited. Geologic hazards include fault rupture (the slip of the ground at the fault location), consolidation, landslide and liquefaction. To some extent, tsunamis (also historically referred to as tidal waves) are considered geologic hazards as they are the result of landsides and fault ruptures occurring under a body of water. The following definitions are provided to more clearly identify these hazards.

Ground Shaking: Areas, or zones, prone to high levels of ground shaking are shown on various government maps. Figure 5 is a seismic zonation map of the United States taken from Reference 9. Zone 4 is the highest zone identified on this map system. PMLs of more than 20% are common in Zone 4 and lenders usually require a PML assessment in Zone 3 as well as in Zone 4. Typically, lenders do not require loss estimates for individual buildings in zones less than 3. Detailed shaking intensity maps are available on the web. Figure 6 is a shaking intensity map for San Francisco.



12

Seismic Zone Map - US

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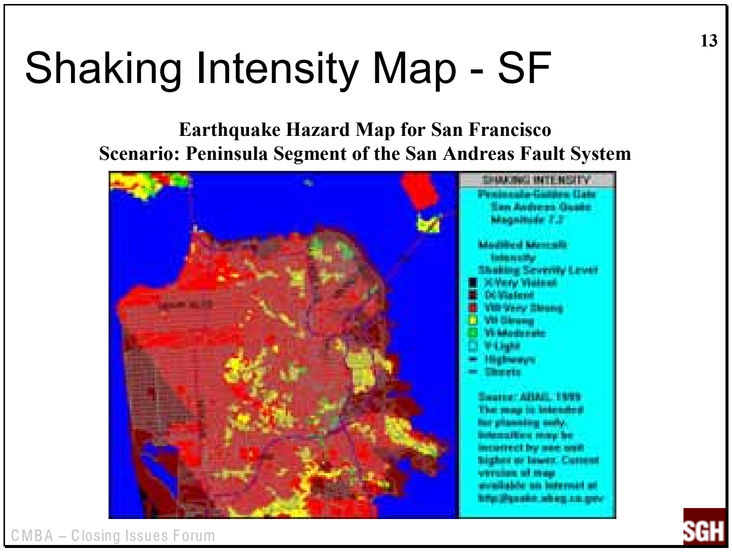
Figure 5



13

Shaking Intensity Map - SF

Earthquake Hazard Map for San Francisco
Scenario: Peninsula Segment of the San Andreas Fault System

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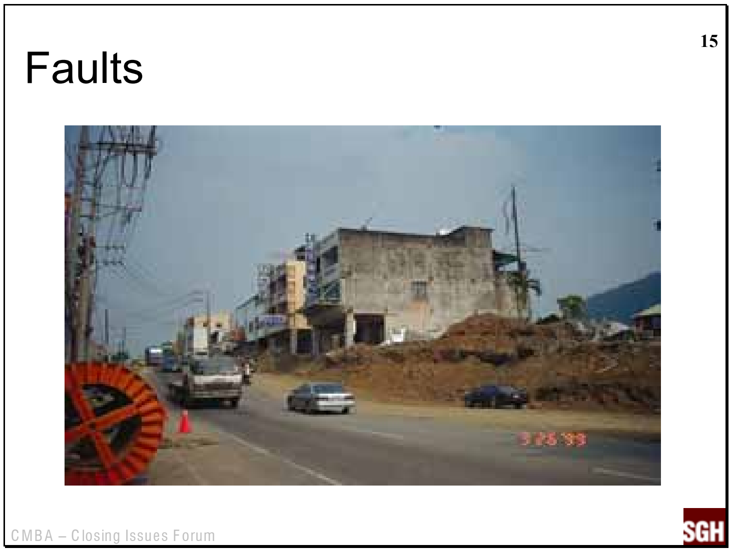
Figure 6

Faults: Earthquakes occur along faults. Fault displacement under a building can cause severe damage. Figures 7 and 8 show thrust fault displacement that occurred in the 1999 Chi-Chi earthquake. Maps showing the locations of known faults are typically available from Government agencies. In California, active faults are shown on Alquist Priolo maps, which are available from the California Geologic Survey (CGS), formerly known as the California Department of Mines and Geology (CDMG). County geologists and the planning department in the local jurisdiction usually have these maps.



Faults

Figure 7

Faults

Figure 8

Consolidation: Ground shaking consolidates loose soils which in turn cause settlement.

Landslides: Ground shaking causes loose soil and rock on slopes to slide.

Liquefaction: Ground shaking causes loose, saturated sands and gravels to lose their bearing strength. The previously stable sands become unstable and the soil mass acts like “quicksand”. Figure 9 shows damage to pavement during the 1994 Northridge earthquake. Figure 9 also shows catastrophic damage to buildings in Japan that occurred when liquefaction occurred in the ground beneath them.

19

Liquefaction

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Figure 9

Lateral Spreading: Lateral spreading occurs in soils that suffer liquefaction that flows laterally towards lower ground. This phenomenon occurs along shorelines, riverbeds and hillsides.

Tsunamis: Tsunamis are high velocity waves that are created by sudden ground displacement (e.g., fault displacement or a landslide) under a body of water. Tsunami waves can cause severe damage to structures along a shoreline and flooding damage to structures inland from the coastline, but at low elevations.

Maps identifying certain geotechnical hazards are available from various public agencies. Many of these maps are available on-line at some of the web sites that are listed at the end of this handout.

Not all loss estimates include damage associated with the occurrence of geologic hazards at the site under consideration. Some analyses methods and loss estimation software identify the existence of some geologic hazards that can cause substantial structural damage. These hazards (e.g. landslide and liquefaction) may cause damage in excess of 50% of the replacement cost of the building and are important to consider when estimating losses for individual structures.

STRUCTURAL VULNERABILITY

The majority of earthquake damage to structures is caused by ground shaking. Most buildings constructed in high seismic zones along the Pacific Coast within the last five years are expected to perform well in large earthquakes. The PML90 for these buildings will generally be below 20%. This expectation is based on a building stock that is built in accordance with the provisions of the UBC. However, building codes are not intended to provide built structures with minimal damage following major earthquakes, but rather codes are intended to provide life safety in structures during and after a major earthquake. A heavily damaged structure that does not collapse or create large falling hazards will meet the code intent but may incur damage costing well in excess of 50% of the building replacement cost. Buildings prone to significant damage, and, therefore to high PMLs, can usually be identified by their age, construction type and configuration. In certain cases, a detailed structural evaluation is required to accurately estimate losses, even in buildings built within the last five years.

Age is typically indicative of performance since codes and construction practice have significantly improved after three major earthquakes in California – The 1971 San Fernando, 1989 Loma Prieta and 1994 Northridge. The UBC has historically been published on a three-year cycle. Accordingly, significant revisions to the seismic provisions in the UBC occurred in 1973 (also 1976, because revising the code can be a lengthy process), 1991 and 1997, as a result of the earthquakes listed above. While the UBC revisions are intended to provide safer structures, some of the code revisions will also tend to provide structures that perform better in earthquakes (i.e. less damage).

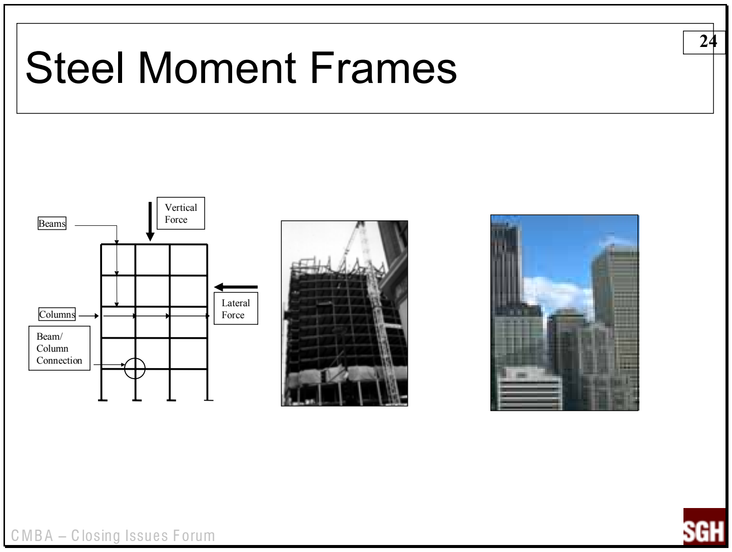
Building types that are prone to damage (resulting in high PMLs) are discussed below:

Steel Moment Frame, pre-1995:

Steel moment frame construction has been popular in California since the late 1950's. It has been used extensively for 100,000+ sq, ft office buildings from three stories to high-rise. Smaller office buildings also are frequently constructed using steel moment frames.

Prior to the 1994 Northridge earthquake, steel moment frames were generally considered by many in the structural engineering profession to be among the most reliable seismic force resisting systems. They were also cost competitive and provided substantial versatility for architectural design.

Steel moment frames resist seismic forces through "frame action" as illustrated in Figure 10. The beams are rigidly connected to columns with strong welded connections.



Steel Moment Frames

24

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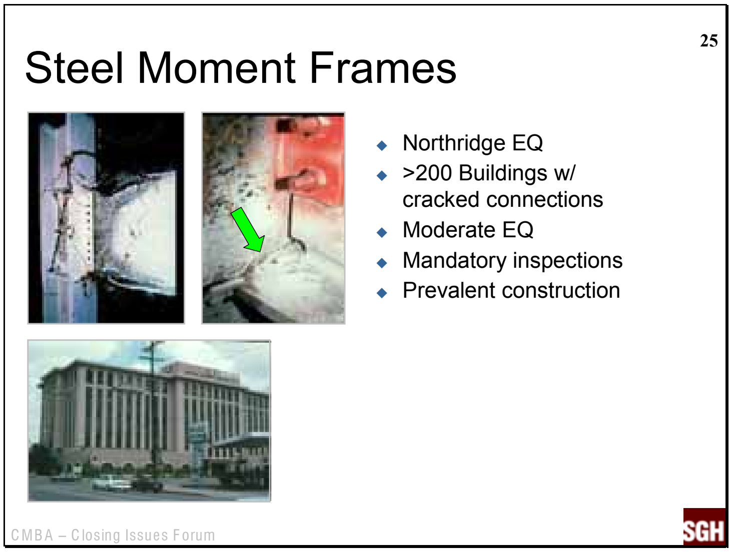
Figure 10

During the Northridge earthquake, over 200 of these structures sustained unexpected brittle fracture of their critical beam-to-column welded connections. None of the damaged steel moment frame buildings collapsed or caused serious injuries or death. However, at least two buildings were subsequently demolished, and the repairs for the other identified structures were expensive. Some structural engineers believe a larger earthquake with longer duration would have resulted in at least partial collapse of some of these structures.

Following the earthquake, the industry quickly issued interim guidelines for the design of new moment frame structures. A $12 million research program funded by FEMA resulted in issuance of comprehensive design recommendations in 2000 (Refs 4 through 6).

Figure 11 shows a steel moment frame connection tested in a laboratory demonstrating the intended behavior of the connections. The beam bends and yields, but does not fracture. This is referred to as “ductile” behavior. Figure 11 also shows the type of brittle behavior that occurred during the Northridge earthquake.



25

Steel Moment Frames

- Northridge EQ
- >200 Buildings w/ cracked connections
- Moderate EQ
- Mandatory inspections
- Prevalent construction

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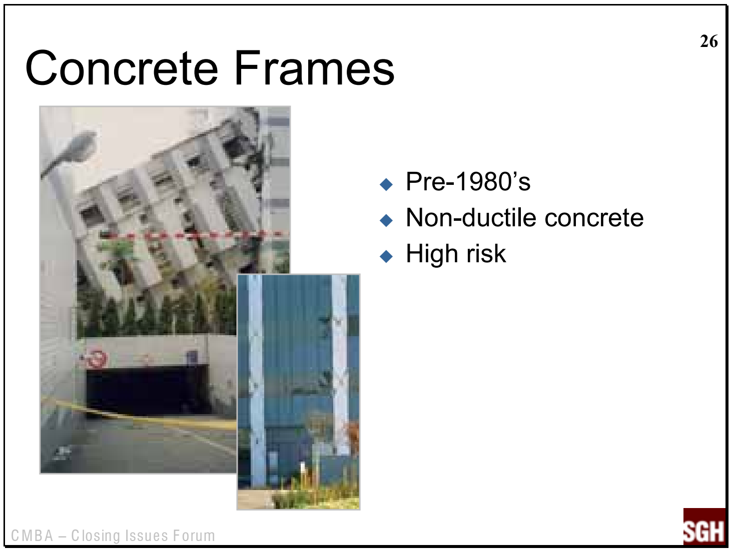
Figure 11

Due to the steel moment frame experience in the Northridge earthquake, and based on the subsequent research, steel moment frames designed prior to the development of the interim guidelines published following the Northridge earthquake are considered to be prone to damage when subjected to moderate and strong earthquake ground shaking. Accordingly, steel moment frames constructed prior to 1995 are expected to have high PMLs.

Concrete Frames:

Concrete frames resist seismic forces by frame action, similar to steel moment frames. Buildings have been constructed with concrete frames since 1900. Few considerations of seismic forces were incorporated into the design of these structures until the early 1970’s. Good engineering practice became more widespread around 1980. Most concrete frame buildings constructed before 1980 are expected to have poor seismic performance. A small portion of these structures are reasonably well designed, but as a class, concrete frame buildings constructed prior to 1980 are considered to be among the most hazardous buildings in California. During the 1980’s, the design practice was greatly improved. Well-designed concrete buildings constructed since 1980 are expected to have markedly better seismic performance than their predecessors. In general, concrete frame buildings constructed prior to 1976 will have PMLs that are unacceptably high for many lenders. Figure 12 shows a collapsed concrete frame building in Taiwan and a building damaged in the Northridge earthquake with diagonal cracks in its concrete columns.



Concrete Frames

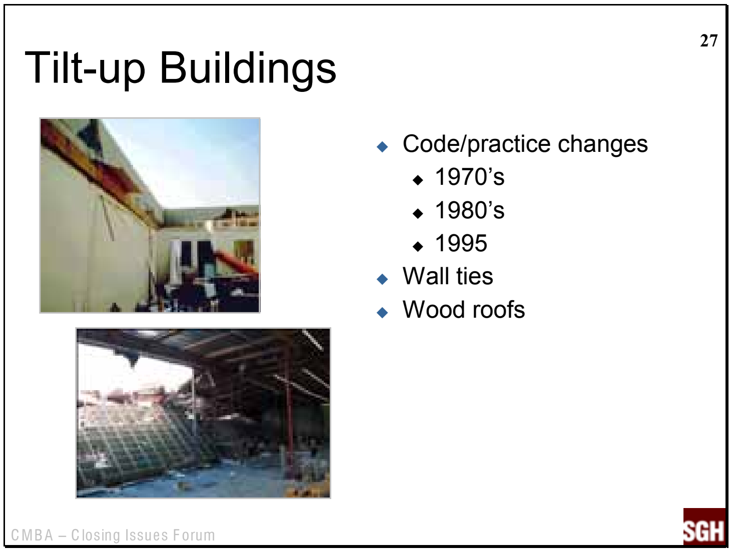
- Pre-1980's
- Non-ductile concrete
- High risk

Figure 12

Concrete Tilt-up Buildings:

Concrete tilt-up construction has had wide spread use in California since the 1950's. These buildings are constructed with large, site-cast concrete panels that are "tilted-up" to form the exterior walls. They have historically had wood roofs on the west coast and metal roofs elsewhere, but metal roofs are becoming more prevalent on the west coast in the last 5 years. Tilt-up buildings are commonly used for warehouses and one or two story office, R&D and manufacturing buildings.

The heavy concrete walls tend to separate from the roof framing when subjected to seismic ground shaking perpendicular to the plane of the walls unless engineered connections (referred to as wall anchors) are provided to tie them together. Many tilt-up buildings suffered partial collapse when their walls tore loose from the roof framing during the 1971 San Fernando earthquake. Figure 13 shows a partial collapse of a tilt-up building that occurred due to earthquake ground shaking.



Tilt-up Buildings

- Code/practice changes
  - 1970's
  - 1980's
  - 1995
- Wall ties
- Wood roofs

Figure 13

Starting with the 1973 UBC, code provisions required engineered anchorage of the tilt-up walls to the roof framing. The 1987 Whittier, 1989 Loma Prieta and 1994 Northridge earthquakes demonstrated that the anchorages needed to be further strengthened and code design forces and detailing requirements were increased

Pre-1973 tilt-up buildings that have not been retrofit will have high PMLs. Retrofit is often mandated by lenders and in some cases local jurisdictions. Tilt-ups constructed or retrofit from 1973 through 1994 may have PMLs high enough to give pause to some lenders, especially if the structure is located near a major fault or supported on poor soils that amplify ground motions.

One and two story reinforced masonry buildings have the same wall anchorage concerns and should result in similar PMLs giving rise to similar problems with lenders as tilt-up buildings.

Wood Frame Apartments with Tuck-Under Parking:

During the 1950's, 60's and 70's, a significant number of wood frame apartment buildings were constructed with parking located at the first level, "tucked under" one to three stories of apartment units above.

A number of wood frame, tuck-under apartment buildings suffered catastrophic collapse of the first story during the 1994 Northridge earthquake. Some were left leaning precariously. See Figure 14.

28

Tuck-Under Parking

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Figure 14

Wood frame apartments with tuck-under parking built prior to 1995 are likely to have high PMLs due to their configuration and lack of engineering for the specific structural deficiency created by the tuck-under parking.

Wood frame apartments constructed on top of concrete parking structures are not considered "tuck-under" structures and should not typically result in excessively high PML values.

Unreinforced Masonry:

Unreinforced masonry buildings were phased out as a construction type in California between 1940 and the mid-1950's. This type of construction has a history of poor performance during earthquakes. Most unreinforced masonry buildings have been retrofitted as mandated by state regulations. However, retrofit criteria vary from jurisdiction to jurisdiction so that expected performance in even moderate earthquakes may be different for similar structures. Unreinforced masonry buildings located in areas of high seismicity (i.e. Zone 4) will probably have high PMLs whether they have been retrofitted or not. Figure 15 shows characteristic earthquake damage of unreinforced masonry buildings.

Unreinforced Masonry, URM

Figure 15

SOLUTIONS

If a seismic loss value is unacceptably high, the first question to ask is whether additional study may result in a lower value. This is not an exercise in “playing games with numbers”. As indicated below under CASE HISTORIES, loss values have a wide range depending on the quality of the design and construction. Some older buildings have seismic resisting systems that are comparable to much newer buildings. We have used advanced structural analysis techniques to demonstrate acceptable seismic performance of buildings constructed in the 1920’s. The additional analysis allowed the owner to proceed with the preferred lender and/or to avoid an expensive seismic retrofit.

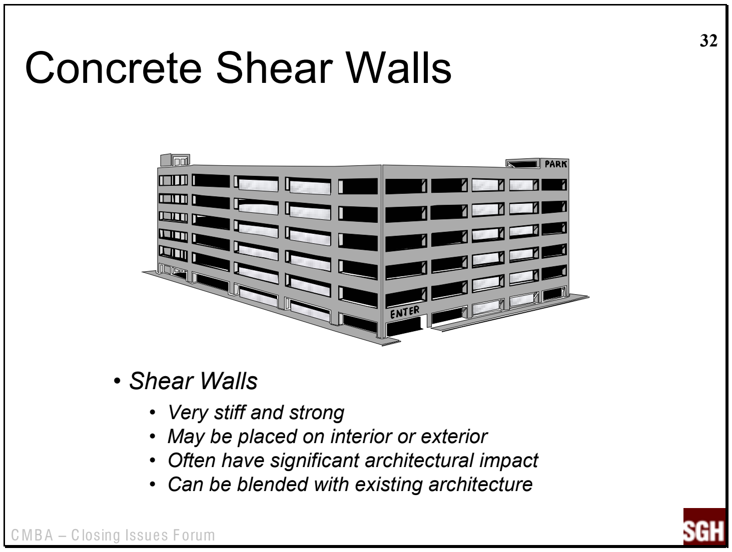
Alternatives available to those obtaining capital for buildings with high PMLs include seismic retrofit of the structural deficiencies, insurance and locating lenders that may not object to the higher risk associated with a high PML. The latter two alternatives should be discussed with an experienced commercial mortgage expert.

If the first alternative (seismic retrofit) is to be considered, a structural engineer can provide conceptual retrofit solutions as well as detailed construction documents for the final retrofit solution. Retrofit concepts are used to estimate order-of-magnitude construction costs, provide an idea of the impact the construction will have on tenants (whether they will be inconvenienced, temporarily displaced, etc) and the permanent impact on the aesthetics and program within the building. As part of the conceptual retrofit solution, the engineer should compute a revised loss estimate for the building considering the effect of the proposed retrofit to assure that the PML will be sufficiently lowered to meet the lender’s requirements.

Recent advances in seismic analysis methodologies provide tools that can help engineers to accurately estimate the required retrofit to reduce damage in these structures. These procedures can help the building owner and engineer select a solution that will reduce the cost of the seismic retrofit for these structures as compared to retrofit solutions presented five or more years ago.

Steel moment frame connections can be strengthened using methods based on the research conducted after the Northridge earthquake. However, such strengthening is often relatively expensive and does not alter the behavior of the building. Steel moment frame buildings are relatively flexible and may have elements (e.g. exterior wall systems) incapable of withstanding the displacements generated in the building during an earthquake. In these cases, the structure will remain in tact but the level of damage may be high, resulting in expensive repair costs following the earthquake.

Both steel frame and concrete frame buildings can be retrofit by adding concrete shear walls, steel braced frames or energy dissipation systems such as base isolation or elements generally referred to as "dampers". The addition of shear walls is illustrated in Figure 16. This retrofit can be costly and often disruptive to the tenants.

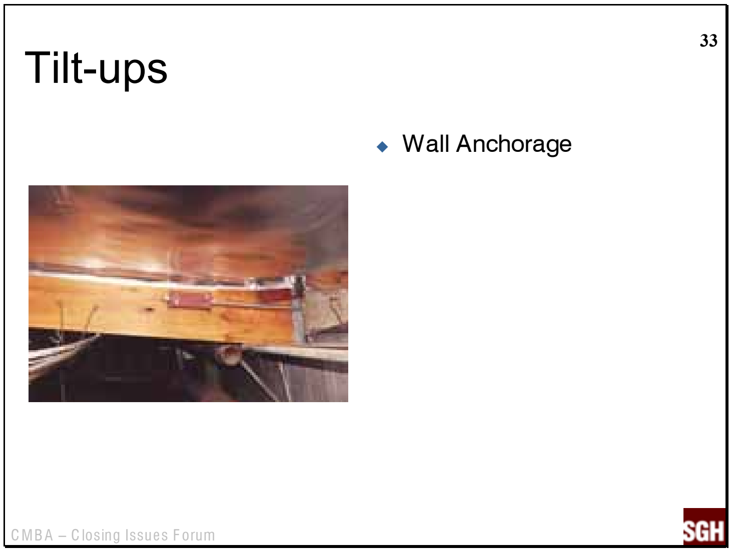


Concrete Shear Walls

- *Shear Walls*
  - *Very stiff and strong*
  - *May be placed on interior or exterior*
  - *Often have significant architectural impact*
  - *Can be blended with existing architecture*

Figure 16

Wall anchorage retrofit for tilt-up buildings is relatively inexpensive and usually can be performed with minimal impact on the tenants. See Figure 17.



Tilt-ups

- ◆ Wall Anchorage

Figure 17

Tuck-under apartment buildings can be retrofitted with the addition of steel moment frames and plywood shear walls. These retrofits are often limited to the parking areas of the building, so they may have a minimal impact on the tenants.

Methods for retrofitting unreinforced masonry buildings are codified and well understood by engineers and contractors. They are primarily intended to reduce life-safety risks, not damage and the associated financial risks. Life safety retrofit will reduce some of the expected damage and indirectly the PML, but a codified retrofit will typically not lower the PML of an unreinforced masonry building sufficiently to be acceptable to many lenders.

If the borrower suspects the building is a type that is prone to earthquake damage, the borrower may want to pay for a screening level PML (Level 0) before entering into agreements with a lender. Since screening level PMLs are based on minimal information, the PML values have a high degree of uncertainty. A Level 1 PML may produce a lower or higher value than the screening level PML. A screening level PML value that approaches the acceptance limit established by lenders should be considered a problem because the Level 1 PML may be higher.

When considering the retrofit solution for a building prone to earthquake damage, a question may arise as to which engineer should be retained to prepare design documents for the retrofit. Some points to consider are:

- Some lenders and engineers may consider it a conflict of interest if the engineer that provided the PML estimate is also the engineer-of-record for the retrofit design.
- If the engineer that provided the PML does the retrofit design, differences in opinions may be avoided between engineers, but not always. An independent loss estimate by a second engineer may be required during or after the retrofit. The second engineer may identify issues not considered by the single/primary engineer, resulting in a PML that differs significantly from the "retrofit" PMLs provided by the engineer responsible for the retrofit. This can be simply stated that in most cases where a building owner is considering retrofit, a "second opinion" is part of a well developed retrofit plan.
- The decision may rest on the comfort level of the owner and lender with the engineer(s) involved.

CASE HISTORIES

To highlight some of the pitfalls in working with "PML's", several case histories are presented.

2 Story Precast Concrete Office Building:

Several years ago the owner of a 2 story precast concrete office building had a seismic loss estimate performed. The consultant used the Thiel Zsutty method and reported a mean value for the "PML". The value was 20%. Later the owner wanted to re-finance the building and assumed he would not have a problem because he had a report indicating a 20% "PML". We computed the PML (PML_{90}, loss having a 10% chance of being exceeded for a 475-year ground motion) as required by many lenders. Our results are shown in the table below.

CASE HISTORY –
LEVEL 1 PML COMPARISON 2 STORY PRE-CAST CONCRETE OFFICE BUILDING

	STRISK		T-Z
Liquefaction Susceptibility	Moderate	Low	N/A
Expected Loss	59	19	20
PML$_{90}$	59	31	46

As shown in the table, the PML$_{90}$ is substantially more with both the Thiel-Zsutty and STRISK methods. These high values are unacceptable to most lenders and resulted in considerable disappointment for the owner. Also of note is the effect of liquefaction susceptibility as computed by the STRISK software.

<u>PML Comparison on a Specific Site:</u>

To indicate the sensitivity of PML's to age and to Level 0 versus Level 1 assessments, we used STRISK to compute seismic losses in terms of PML$_{90}$'s for typical tilt-up and steel moment frame buildings of different ages, all on the same site. For the tilt-up building, we also computed PML$_{90}$'s for worst case and best case seismic resisting design and construction practices in order give an appreciation of the wide range of seismic performance that is possible for buildings constructed or retrofitted as recently as 1997.

PML COMPARISON

Type of Building	Year Constructed	Year Retrofit	PML$_{90}$ Level 0	PML$_{90}$ Level 1 (SGH)	PML$_{90}$ Level 1 (Range)
Tilt-up	1970	None	50	35	-
Tilt-up	1970	1997	30	14	8 to 29
Tilt-up	1997	None	30	14	8 to 29
Steel MF	1985	None	33	22	-
Steel MF	1997	None	22	11	-

Inspection of the table indicates the greater certainty of the Level 1 assessment versus the Level 0 results in a substantially reduced loss value. While screening with a low cost Level 0 method is often prudent, a loss value of over 20% should not be considered a deal killer until the Level 1 assessment has been performed. The table also supports the expectation that newer buildings are expected to have less damage than older buildings. The wide range in Level 1 PML_{90} values for a tilt-up constructed in 1997 supports the expectation that design and construction quality highly influence performance. Similar spreads in loss values are true for other construction types (steel frame, concrete frame, wood, etc.) and for buildings of all ages. Therefore, generalizations about structural issues such as age and construction type should be weighed against these potential ranges in values.

SUMMARY OF STRUCTURAL ISSUES		
Construction Type	**Characteristic Failure**	**Era of Construction**
Steel Moment Frame	Brittle fracture of welded connections of beams to columns	Pre-1995
Concrete Moment Frame	Weak, brittle concrete columns	Pre-1976 UBC Effectively Pre-1980
Concrete Tilt-up	Wall anchorage failure leads to partial collapse of roof	Pre-1995
Tuck-Under Apartments	Weak first story leads to collapse of first story or permanent lean	All
Unreinforced Masonry	Brick walls fall outward and may cause localized roof and floor collapse.	All, but not constructed since mid-1950's

REFERENCES

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

2. ASTM E 2026-99 – Standard Guide for the Estimation of Building Damageability in Earthquakes, ASTM, West Conshohocken, Pennsylvania, United States

3. FEMA-99, A Nontechnical Explanation of the 1994 NEHRP Recommended Provisions, Federal Emergency Management Agency, Washington D.C., September 1995.

4. FEMA-350, Recommended Seismic Design Criteria For New Steel Moment-Frame Buildings, Federal Emergency Management Agency, Washington D.C., July 2000.

5. FEMA-351, Recommended Post-earthquake Evaluation and Repair Criteria for Welded Steel Moment-Frame Buildings, Federal Emergency Management Agency, Washington D.C., July 2000.

6. FEMA-352, Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment-Frame Buildings, Federal Emergency Management Agency, Washington D.C., July 2000.

7. Steinbrugge, K.V., Earthquakes, Volcanoes and Tsunamis; An Anatomy of Hazards, Scandia America, New York, 1982

8. Thiel, C.C., Zsutty, T.C., “Earthquake Characteristics and Damage Statistics,” Earthquake Spectra, Vol3, NO. 4, November 1987

9. Uniform Building Code (UBC), Various editions, International Conference of Building Officials, Whittier, California

DEFINITIONS

Damage Cost or Repair Cost – The construction cost, including design and construction observation and management costs, required to restore the building to its original condition. (Per ASTM E 2026-99)

Damage Distribution – The probability function for the possible damage states of a given building type due to a 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. (Per ASTM E 2026-99)

Damage Ratio – The ratio of the cost to repair a building to its original condition divided by its replacement construction cost. (Per ASTM E 2026-99)

Due-Diligence – 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. (Per ASTM E 2026-99)

Earthquake Loss (for Damage Ratio) – 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. (Per ASTM E 2026-99)

Epicenter – A point on the earth's surface that is directly above the focus of an earthquake. (Per FEMA 99)

Exceedance Probability – The probability that a specified level of ground motion or specified social or economic consequences of earthquakes will be exceeded at a site or in a region during a specified exposure time. (Per FEMA 99)

Expected or Mean Value – 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. (Per ASTM E 2026-99)

DEFINITIONS (cont'd)

Fault – A fracture in the earth's crust accompanied by displacement of one side of the fracture with respect to the other in a direction parallel to the fracture. (Per FEMA 99)

Fault Zone – 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 (76 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. (Per ASTM E 2026)

Frame, Braced – Diagonal members connecting together components of a structural frame in such a way as to resist lateral forces. (Per FEMA 99)

Frame System, Building – A structural system with an essentially complete space frame providing support for vertical loads; seismic forces are resisted by shear walls or braced frames. (Per FEMA 99)

Frame System, Moment - A space frame in which members and joints are capable of resisting lateral forces by bending as well as along the axis of the members; varying levels of resistance are provided by ordinary, intermediate and special moment frames as defined in the Provisions with special frames providing the most resistance. (Per FEMA 99)

Frame, Space – A structural system composed of interconnected members, other than bearing walls, that is capable of supporting vertical loads and that also may provide resistance to seismic forces. (Per FEMA 99)

"g" – The acceleration due to gravity or 32 feet per second. (Per FEMA 99)

Irregular – Deviation of a building configuration from a simple symmetrical shape. (Per FEMA 99)

Liquefaction – 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. (Per ASTM E 2026-99)

Magnitude of Earthquake – 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. (Per ASTM E 2026-99)

Mean Loss – The expected average percentage monetary loss for similarly constructed buildings at a given MMI level. (Per STRISK)

DEFINITIONS (cont'd)

Median Loss – The expected maximum percentage monetary loss which will not be exceeded for 5 out of 10 similarly constructed buildings at a given MMI level. (Per STRISK)

Mercalli Scale (or Index) – A measure of earthquake Intensity named after Giuseppe Mercalli, an Italian priest and geologist. (Per FEMA 99)

Modified Mercalli Earthquake Intensity (MMI) – 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. (Per ASTM E 2026-99)

Peak Ground Acceleration (PGA) – 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). (Per ASTM E 2026-99)

Probable Loss (PL) – 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 motions 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. (Per ASTM E 2026)

Probable Maximum Loss (PML) – 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. (Per ASTM E 2026)

The percentage monetary loss (damage/replacement cost x 100) that has a 10% chance of being exceeded for a 475-year ground motion. (Per STRISK)

Return Period – The time period in years in which the probability is 63 percent that an earthquake of a certain magnitude will recur. (Per FEMA 99)

Scenario Expected Loss (SEL) – The expected value loss for 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. (Per ASTM E 2026)

DEFINITIONS (cont'd)

Scenario Loss (SL) – 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:

- Ground Motion in the maximum capable earthquake (MCE) for the building site;
- Ground motion specified as the design ground motion in the applicable building code for the building site;
- 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;
- Ground motion with specified return period as determined from a probabilistic ground motion seismic hazard analysis;
- A selected maximum Modified Mercalli Intensity (MMI) for the site determined from published maximum value maps; or,
- The MMI for the site as estimated from peak ground acceleration values.
- 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 expected value, while SUL is used when the probability of exceedance is 10%. Other values may be specified by the user. (Per ASTM E 2026)

Scenario Upper Loss (SUL) – The scenario loss that has a 10% probability of exceedance due to the specified ground motion of the scenario considered. (Per ASTM E 2026)

Seismic – Of, subject to, or caused by an earthquake or an earth vibration. (Per FEMA 99)

General Earthquake Website for Maps
http://www.scec.org/earthquakes/index.html

http://www.consrv.ca.gov/index/index.htm

Liquefaction Maps

Los Angeles
http://gmw.consrv.ca.gov/shmp/html/pdf_maps_so.html

San Francisco Bay Area
http://gmw.consrv.ca.gov/shmp/html/pdf_maps_no.html

http://www.abag.ca.gov/bayarea/eqmaps/mapsba.html

Historic Earthquakes for California
http://www.consrv.ca.gov/CGS/geologic_hazards/earthquakes/index.htm

Shake Maps
http://www.trinet.org/shake

Fault Maps
Los Angeles

http://quake.wr.usgs.gov/info/faultmaps/Los_Angeles.html

http://pasadena.wr.usgs.gov/info/hist-geo.html

http://gmw.consrv.ca.gov/shmp/html/pdf_maps_no.html

http://pasadena.wr.usgs.gov/info/images/LA%20Faults.pdf

http://www.data.scec.org/faults/faultmap.html

Northeastern California area (fault by fault maps)

http://quake.usgs.gov/prepare/ncep/northeastern.html
(go to end of the page and flip page by fault name)