Seismic Risk Assessments
Probable Maximum Loss Analysis

Jeff Coronado, S.E.
Structural Engineers Association of Southern California
Existing Buildings Committee
Earthquake Damage Assessment Subcommittee

Abstract

As a result of the January 17, 1994 Northridge earthquake and other earthquakes, structural engineers (also referred to as earthquake engineers) are being called on ever more frequently by insurers, owners, risk managers, etc., to evaluate the loss potential of structures due to future earthquake actions. Probable Maximum Loss (PML) evaluations involve a larger degree of knowledge and background than a structural engineer usually possesses. This discussion illustrates one of the elements that must be considered in properly evaluating loss potential to a structure, it's occupants, contents, and business. Of the major elements that comprise probable loss analysis (Hazard, Collateral Hazards, Exposure, Vulnerability of the Exposure, Location of the exposure relative to the hazard, and Risk), the structural engineer usually is knowledgeable only about the vulnerability of the structure. However, he is now being asked to address a number of factors outside of his immediate professional scope.

The purpose of this committee effort is to make all of the elements of the problem clear and to identify those areas that the structural engineer can contribute to the Probable Maximum Loss (PML) evaluation process. Also, to establish which tasks the structural engineer can do easily and those which involve collaboration with others or use of the products of others in order to develop a professional and qualified report.

Documentation

The committee effort is intended to present a uniform background and approach to the process of estimating the potential for damage and loss to individual structures or suites of structures. Not only is the loss to the structure(s) itself to be estimated, but also the losses from nonstructural elements, contents, and business interruption to be included.

References

The available reference include the 1985 ATC-13 prepared by the Applied Technology Council which is a compilation of statistical data regarding specific types of buildings or structures, and the associated earthquake risk. Other materials available that are insurance based in origin by Karl Steinbrugge in 1982, EARTHQUAKE, VOLCANOES AND TSUNAMIS - AN ANATOMY OF HAZARD.

Recent earthquake experiences have resulted in large quantities of data in various states and content. Insurance and governmental data does not always describe damage, buildings types, and ground shaking in formats useful to the Structural Engineer and other professional involve in a loss estimation.

Overview of Elements

An overview of the major elements that comprise the evaluation begin with the Assessments, including the building vulnerability, seismic hazard and the business vulnerability. With the assessments, a risk analysis is included for the building and business. The loss evaluation includes the combination of the vulnerability, hazard and the risk analysis. The evaluation can examine the building and business losses, allocation of the loss include the losses to be considered or not.

Professionals

Seismologists and engineering geologists usually address and are knowledgeable of the *Hazard*. Geotechnical engineers, fire protection engineers, and others usually develop information about *Collateral Hazards*. Strong motion seismologists and others mostly know about Attenuation, Site Amplification, etc., which relate the *Location of the exposure relative to the hazard*. Behavior of contents, likelihood of occupant death or injury, the potential for business interruption due to on-site or off-site losses are usually not within the scope of any one scientific or engineering professional including the structural engineer.

General Scope of Inquiry and Assessment

Risk (chance of loss) can be defined as Primary, Secondary, and Higher Order. See Table associated with Figure 1 for a description of some of these loss types. It is envisioned that the structural engineer is responsible primarily for establishing primary losses. An effort can be developed towards establishing business interruption likelihood and extent incorporating the products of others given certain loss states. Further, non-structural elements, possibly contents, possibly death or injury to occupants and third parties, and possibly the release of hazardous materials would be within the structural engineer's scope. Fire following earthquake would be considered to be as outside the scope of the structural engineer from a primary loss perspective. Another purpose is to provide an authoritative document upon which the structural engineer can rely to support his reports.

Elements of a Probable Maximum Loss Assessment

Figure 2 identifies a probabilistic approach to loss estimation. In order to develop the likelihood/ intensity curve shown in Figure 2, one can use probabilistic earthquake maps, earthquake catalogues of past events, seismic source zones developed by others, etc.. One also needs to select the appropriate attenuation curve from a series of 60 or 70 candidate curves that have been produced over the years by various investigators. Site amplification characteristics and the many choices that have been presented by a number of investigators over the years must be selected. ASCE standard 7-95 has five (5) categories of site amplification factors. Finally, modification of intensity caused by structural design such as the effect of piles, or raft foundation, basements, local site conditions, etc., all must by considered in developing the intensity and therefore the inertial loads that can be expected at a site for a given return period of hazard expectation.

Collateral hazards such as faulting, liquefaction, lurching, etc. are factors that must be evaluated as to their likelihood of occurrence over and above that which would affect loss by shaking activity only. Finally, particular structural response, identification of structural capacity for resisting various intensities, evaluating the damage capacity of contents, business, etc., (given a level of intensity and associated structural loss) all must be evaluated, tested in some way or pointedly omitted in a report.

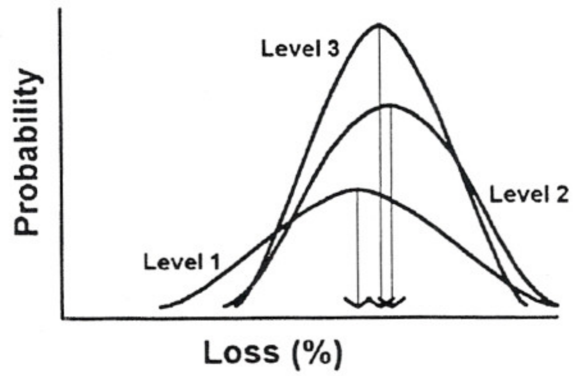
Levels of Effort

Three or four levels of effort reflecting quality of results are being considered as appropriate for use by a structural engineer. The level used for a particular assessment will depend upon such factors as "availability of information", user requirements, client's budget, time available for the study, etc.. Costs cited below are examples only and vary widely. They also relate to one or two structure, single site complexes only. Multisite and multi-structure portfolios will be bid on a project basis.

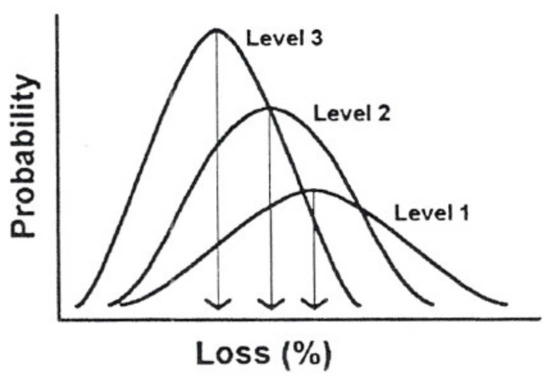
Level One (1): Represents the simplest level of analysis, based on minimal site and building information. Clients need to be warned before hand about the limitations and high degree of uncertainty associated with this level of effort.

Level Two (2): Will be an intermediate level of analysis using available published earthquake data, maps, etc., and brief engineering reviews of the buildings under consideration. A detailed listing of limitations must be established. This may be the most commonly used level of investigation from a client perspective.

Level Three (3): Will go beyond Level Two by using site specific earthquake data and analysis of the actual structures including the interaction of neighboring buildings, etc.. Other professionals such as geologists, seismologists, engineering risk analysts, etc. may be engaged in this level of effort.



"Good" Building



"Bad" Building

An important result of any analysis methodology is that for a "Good" building the increased levels of effort should result in a lower estimated loss. This methodology should also result in increased loss estimates for "Bad" buildings as the level of investigation effort is increased.

Methodology

Damage may be computed by the following generic equation:

F(Earthquake) x F(Building Vulnerability) = Average Damage
where:
F(Earthquake)≡ those factors generating the earthquake hazard and location
F(Building Vulnerability)≡ Those factors influencing exposure and vulnerability

The minimum for any investigation shall include the following:

- Assessment of potential for ground breakage based on recognized faulting.
- Determination of proximity of site to known faults or "special studies zones" as defined by Alquist-Priolo Special Studies Zones Act maps, Seismic Safety Element maps of the authority having jurisdiction, or published fault maps published by an authoritative body.
- Assessment of potential for liquefaction using authoritatively published information.
- Determination of Uniform Building Code (UBC) Seismic Zone.

Hazard for the evaluation should include:

Ground Breakage: Assessment of potential for Ground Breakage at the site.
Basis: Alquist-Priolo Special Studies Zones Act maps. Seismic Safety Elements of city/county general plans Fault Maps.
Professional: Engineer or geologist.
Effort Required for All Levels of investigation.
Comment: This is the first item to check. If an on-site possibility exists, it cannot be ignored. This may be all that is required for the investigation if the client requires that such a possibility be remote. A significant probability of Ground Breakage at the site leads to Very High F(Earthquake)

Ground Shaking: May be defined by the UBC Seismic Zone. (Effective Ground Acceleration)
Basis: UBC Seismic Zone Map.
Professional: Engineer or geologist.
Effort Suitable for a Level 1 or Level 2 type investigation.
Comment: This represents the most simple method of defining the earthquake ground motion. It automatically sets the return period to that tacitly assumed in the code (475 yr.) It is to be expected that the code will be revised from time to time to reflect current opinion. The F(Earthquake) could be the Zone number.

Ground Shaking: Effective Peak Ground Acceleration.

Basis:	UBC Seismic Zone. Interpretation using published information, fault maps and attenuation nomographs USGS or NEHRP maps..
Professional:	Engineer or geologist.
Effort	Suitable for a Level 2 or Level 3 type investigation.
Comment:	This represents the first level of site specific assessment. It may be probability based using earthquake history data, deterministic using known or suspected fault information or a combination of the two.

Additional information could include site specific earthquake response spectra or earthquake time histories. These would be suitable for higher levels of investigation effort.

Losses from ground shaking is not always due to structural damage due to structural response. Local effects to the ground shaking can include Landslide, Settlement, Tsunami, Seiches and Flood.

BUILDING VULNERABILITY

Intended as outline methodology for generating Building Vulnerability input to the "mix" box. Must be coordinated with the earthquake input for a given overall methodology.

F(Earthquake) x **F(Building Vulnerability)** = Average Damage

The following data is required to make an assessment of Building Vulnerability

- Date constructed.
- Code
  - Code under which constructed.
  - Code under which upgrades made (if applicable).
- Structure
  - Definition of materials.
  - Definition of seismic resisting system.
  - Structural Layout.
- Non structural building systems.
- Overall condition (maintenance, previous damage, modifications).
- Special considerations.

The building code under which the building was designed and constructed can be of assistance in an evaluation. Using the building code as justification in a low estimation of loss due to apparent compliance is severely misleading. As the building code process is an evolutionary one, this would lead one to believe that changes in code requirements over the last twenty years has not contributed to a lowering of loss due to ground shaking.

Investigation should consider:

- General compliance with Code.
- Good compliance with code.

- General compliance with code.
- Poor compliance with code.

A vulnerability investigation should also consider the seismic resisting system and the layout of that system that include irregularities and redundancy.

Resisting System	**Irregularities**	**Redundancy**
Bearing Wall System.	No Structural Irregularities	No Redundancy
Building Frame System.	Torsional Irregularities	Average Redundancy
Moment Frame System.	Re-entrant Corners	Good Redundancy
Dual System.	Diaphragm Discontinuity	
Undefined System.	Out-of-plane Offsets	
	Nonparallel Systems	
	Discontinuous Lateral Load Resisting Elements	

Many of the significant losses experienced in the Northridge earthquake resulted from non-structural responses to the ground shaking. Buildings are a structural system to resist vertical and lateral loads, but it also is a collection of architectural, mechanical, electrical and plumbing systems.

- Architectural:
  - Curtain Walls (material, configuration, % glass, set-backs, etc.)
  - Finishes (attached to structure)
  - Non-bearing partitions
  - Ceilings
- Mechanical:
  - Building
  - Contents (eg. Manufacturing Systems, Storage Systems, etc.)
- Electrical:
  - Building
  - Contents (eg. Switching, Electronic, Manufacturing, etc.)
- Plumbing and Fire Protection
  - Flooding