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Acceptable earthquake damage or desired performance

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ABSTRACT: Acceptable earthquake damage (AED) has different meanings depending on the individual or organization involved. The definition of AED is relative to the characteristics of the seismic hazard, and the economics, social costs and benefits of mitigating measures. The initial goal of seismic design and code requirements was to protect life safety. This was understood to mean protection against building collapse. Thus AED was implicitly defined as anything short of collapse. The life safety goal is still basic to seismic code requirements. However, codes over the past decade or more have added provisions to restrict damage and have been extended to areas of low and moderate seismicity. A clearer understanding of what type and extent of damage is acceptable for various levels of earthquake motions is needed to develop acceptable performance criteria for the different seismic zones. The issue of acceptable damage is examined for high, moderate and low seismic zones. Performance criteria for various levels of performance are presented.

INTRODUCTION

The early editions of the Structural Engineers Association of California Seismic Design Recommendations (1960 SEAOC Bluebook)[1] and the 1961 *Uniform Building Code* (UBC)[2] seismic design provisions were based on the protection of life safety. Basically life safety meant no collapse of a structure. The intent of the building code provisions was to provide a safe building but not to guarantee life safety.

The 1989 Loma Prieta Earthquake caused extensive damage in many types of facilities. Questions were raised by many Northern California owners and users about how much damage they should expect in their facilities in future earthquakes. Similar questions have also been raised in areas outside California. Efforts are underway to develop design requirements for seismic strengthening of hazardous buildings and structures. Thus the issue of what is acceptable earthquake damage is a current and pertinent topic for examination.

PUBLIC'S EXPECTATIONS

The level of damage incurred during the Loma Prieta Earthquake surprised many owners ranging from single family home owners to corporations with many buildings to governmental agencies. Most of the damage was sustained by older buildings and structures designed to earlier codes. However, a number of fairly new structures were damaged; some were completed only a few months to a year or slightly more before the earthquake.

The author talked to many people after the Earthquake about the damage or lack of damage to their building or facilities. A frequent question was "My building was supposed to be constructed in accordance with the building code so why is there so much damage?". Table I was developed based on discussions with owners, engineers and regulatory officials and review of new reports.

Table II is based on data developed during a meeting of U.S. and Japanese engineers and researchers at Kona, Hawaii in August 1990 (ATC 15-3). The expectations are similar to those in Table I.

These two tables illustrate at least two issues; 1) the public needs to be better informed as to what can happen to buildings and structures during an earthquake, and 2) the seismic codes needs to be examined and modified so as to reflect desired or expected performance. Currently a small ad hoc group of U.S. and Japanese engineers and researchers are addressing these issues (U.S.-Japanese New Design Methodology).

CODE USE IN DESIGN

Codes are not design manuals and do not cover every condition or situation that may arise during design

Table I

OWNER OR AGENCY	EXPECTED DAMAGE	NEEDS (ACCEPTABLE LEVEL OF DAMAGE)
Residence or Small Business	None if building met current code, repairable if did not meet code. Few expected collapse or near collapse.	Repairable with no collapse if major earthquake.
Corporate Facilities	Varied from none to minor if building met current code, repairable (but with minor impact on function) if did not meet code. No collapse expected.	Essential facilities - minor damage or interruption of function, Some manufacturing and administrative facilities - repairable damage with short term (2 - 3 days) shutdown. Less important facilities-repairable damage, but few days to one to two weeks shut down.
Institutional	Moderate damage in older buildings minor in newer buildings, minor damage not causing shutdowns for essential facilities.	Essential facilities - minor damage or interruption of function. Facilities necessary for operations - repairable damage with few days to two weeks shutdown. Less important facilities - repairable damage - no collapse. Few weeks to few months shutdown.
Public Infrastructure (Includes bridges, elevated freeways, electrical power transmission systems, water supply, etc.)	No collapse or long term shutdown. Repairable damage,	No collapse and maintain function for main transportation system. Short-term shutdown (few hours at most) for power and main water distribution systems.

and construction of a building. Each provision is intended to help meet or attain the code intent, i.e.., a safe building. It should be kept in mind that code provisions are "minimum" requirements. However in practice they are often treated as the "maximum" and exceeding them is thought to be overly conservative and a waste of money.

Many constructed buildings have seismic weaknesses or "hotspots" not covered by the design, although the design literally meets each code provision. Missing ingredients undoubtedly are 1) engineering judgement and 2) a good understanding of how a structure will perform when subjected to strong seismic ground motions. When an earthquake occurs the weak points show up as serious damage and in some cases collapse. For these and other reasons, the codes can not guarantee a safe structure or "no collapse".

In the U.S. in recent years there have been legal cases where "the design meets the code" (literally conformed to the technical provisions) is not an adequate defense because the design did not meet the "intent" of the code - to provide a safe building.

Society has become much more complex over the past few decades and damage control or serviceability, or continuation of function (functionality) may be of vital importance. For example, during the Loma Prieta Earthquake a number of buildings survived with little structural damage and no loss of life, but they were evacuated because there was loss of function due to extensive nonstructural damage. As a result a large number of people had no place to work for varying periods of time and of course the companies suffered monetary losses. Often management personnel were involved, corporate communications and operations were

Table II

PUBLIC EXPECTATIONS - PERFORMANCE

FACILITY	PERFORMANCE WESTERN U.S.	EASTERN U.S.
RESIDENCE	III	III-IV
STANDARD BUILDING	III	III
OWNER IMPORTANT BUILDING	I-II	I-II
HIGH OCCUPANCY BUILDING	II	II
HAZARDOUS CONTENTS	I-II	I-II
ESSENTIAL BUILDING	I	I
INFRASTRUCTURE	I-II	I-II

I - SLIGHT DAMAGE
II - MINOR
III - MODERATE (REPAIRABLE)
IV - MAJOR (NON-REPAIRABLE)
V - COLLAPSE

disrupted, and hundreds (in some cases thousands) of employees were adversely impacted for a few days to a few weeks.

In San Francisco and Oakland the "enhanced 911" system (computerized response tied to phone number of caller) failed and did not function for several days. The building housing the switch gear and computers exhibited limited structural damage, but the building response during the event damaged the equipment sufficiently so it could not function. (The 911 system permits anyone to dial 911 on a phone to report an emergency and request urgent assistance). The building was a safe structure, but lost its functionality. It is apparent that code provisions need to be examined and changes made so that when appropriate the total building or facility can be properly designed.

Another important issue is how or should design requirements differ from high seismicity to low seismicity areas, other than force level?

HIGH VERSUS LOW SEISMICITY AREAS

The basis seismic force levels used in "code" seismic design practice in the U.S. are based on either of two maps; force coefficient for four seismic zones (1991 UBC and SEAOC) or effective peak acceleration coefficients (1991 NEHRP Provisions). Both sets of maps were derived from the ATC-3 maps prepared in 1974-76. More recently the USGS has developed response spectra maps. These maps are now being assessed by the design profession for possible code use. The intent of each of the maps is that the seismic risk be approximately equal in all parts of the U.S. However, there is considerable disagreement that equal risk is attained.

The seismic design provisions in each of the codes are based on the assumption that buildings properly designed for the specified ground motion will provide protection for occupants during a major earthquake although extensive damage may occur. Studies by the US Geological Survey (NCEER-89-0038) indicate that there may be a wide disparity between the code design ground motions and the maximum motions that could occur. A comparison of peak ground accelerations indicates that maximum accelerations may vary from 110 to 150 percent of design accelerations for California and the Western United States. Because of this relatively small difference, it is reasonable to expect that buildings designed for code forces in the west will provide protection for occupants during a major earthquake.

For other parts of the U.S., mostly areas of lower seismicity, the maximum accelerations may vary from 180 to 270 percent of the code accelerations. This wide disparity raises a serious question of whether, in a low seismicity area, one should pay a relatively small amount to accommodate code design forces and accept the risk that a major earthquake could cause serious life-threatening damage or collapse, or should the design be strengthened?

There are two possible scenarios to be considered when deciding the path to follow for low seismicity areas:

1. Design structures to provide a consistent safety level and provide adequate ductility considering the possible ratio of design accelerations to those for a maximum earthquake, or
2. Focus on designing for life safety and educate the public to accept very infrequent major and possibly life-threatening damage.

A major factor in the process is the very large

Table III

PERFORMANCE CRITERIA

- DEFINE PERFORMANCE LEVELS FOR TYPES OF OCCUPANCY AND TWO OR THREE LEVELS OF INPUT MOTIONS
- MUST CONSIDER TOTAL STRUCTURE INCLUDING STRUCTURAL, NONSTRUCTURAL AND CONTENTS

PERFORMANCE	SEISMIC INPUT	DESIGN METHOD	STRUCTURAL SYSTEM
LEVEL A LIFE SAFETY STRUCT. STABILITY	CODE SPECTRA	STATIC ELF ELASTIC	RECOGNIZED SYSTEMS
LEVEL B LIMITED DAMAGE	DUAL LEVEL SITE SPECIFIC SPECTRA	DYNAMIC SPECT. PSEUDO NON LIN SPECTRA	SMRSF EBF DUCTILE SW DUAL SYSTEM
LEVEL C CONTINUED FUNCTION	DUAL LEVEL SITE SPECIFIC TIME HISTORY	DYNAMIC SPECT TIME HISTORY NON LINEAR ANAL	SMRSF DUAL SYSTEM ISOLATED, PASSIVE

LEVEL "A" PROBABLY 90 PERCENT OF STRUCTURES.

LEVEL "B" OWNER DESIRES OR NEEDS.

LEVEL "C" APPLY TO ESSENTIAL FACILITIES, HAZARDOUS CONTENTS, AND OWNER NEED.

uncertainties associated with determining the maximum earthquakes that might occur, for example a return period of 2,500 years, in the eastern part of the U.S.

CONCLUSIONS AND SUGGESTIONS

The following are offered:

1. Clear definitions of acceptable damage levels or conversely, performance criteria, are needed.
2. Owner and user needs must be considered.
3. Performance criteria must include the structural framing, nonstructural elements, building systems, and contents.
4. Table III lists suggestions for an approach to providing desired performance. The listing is based on suggestions presented at the U.S.-Japan ad hoc study group meeting.[3]
5. Development of the concepts in Table III will require extensive effort and should involve structural and geotechnical engineers, earth scientists, architects, regulators, owners, insurers and lending institutions.

The above issues are being considered by two SEAOC Committees charged with developing resource documents for a future version of the SEAOC Bluebook. U.S. The Japan ad hoc Committee on New Design Methodology is also studying this type of approach.

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