Evolution of Building Code Seismic Performance Standards for New and Existing Buildings

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Background of Building Codes

• 1666 London fire resulted in first comprehensive building code and set precedent for government enforced codes

• Each country has its own somewhat unique history of how authority for building codes evolved.

• Important principal of U.S. Constitution is delegation of police power to states:
  – Police power is the authority to regulate for the health, safety, and general welfare of its citizens.
  – Typical Building Code Purpose statement:
    • The purpose of this code is to provide minimum standards to safeguard life or limb, health, property, and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of all buildings and structures…
Background of Seismic Codes

- 1755 Lisbon devastating earthquake resulted in prescriptive rules for building certain kinds of buildings common in the area.
- Events in Messina, Italy (1911), and Kanto (Tokyo) Japan (1923) led to guidelines for engineers to design buildings for horizontal forces of about 10% of the weight of the building.
- 1906 San Francisco, interestingly, produced little or no code development in the US.
- 1925 San Barbara convinces critical mass in California on the need for seismic requirements.
- 1933 Long Beach results in CA legislature passing the Field Act (for schools) and the Riley Act (for all buildings).
- Code under constant evolution since 1927, with changes often instigated by earthquakes in California.
Charleston, 1886
San Francisco, 1906
Santa Barbara, 1925
Long Beach, 1933
Purpose of First Codes Clear

• Prevent collapse
• Prevent heavy materials falling to street
• Size or rareness of earthquake not specified—and probably not understood. References are to “earthquake loading”
Introduction to 1927 UBC
Lateral Bracing Appendix

“The design of buildings for earthquake shocks is a moot question but the following provisions will provide adequate additional strength when applied in the design of buildings or structures.”
Riley Act Rationale

The facts constituting the necessity are as follows: The series of earthquakes occurring in the southern portion of the State has caused great loss of life and damage to property. Much of this loss and damage could have been avoided if the buildings and other structures had been properly constructed. The buildings which will be constructed and reconstructed to replace the buildings damaged or destroyed by earthquake should be so constructed as to resist, in so far as is possible, future earthquakes. These buildings will be constructed and reconstructed at once and accordingly it is necessary that this act go into immediate effect in order that these buildings be so constructed that the lives and property of the people will be safeguarded.
Enduring Performance Intent by Structural Engineers Association of California
Recommended Lateral Force Requirements and Commentary, SEAOC, 1968

The SEAOC Code is intended to provide criteria to fulfill the purposes of building codes generally. More specifically with regard to earthquakes, structures designed in conformance with the provisions and principles set forth therein should be able to:

1. Resist minor earthquakes without damage;
2. Resist moderate earthquakes without structural damage, but with some nonstructural damage;
3. Resist major earthquakes, of the intensity of severity of the strongest experienced in California, without collapse, but with some structural as well as nonstructural damage.

In most structures, it is expected that structural damage, even in a major earthquake, could be limited to repairable damage. This, however, depends on a number of factors…
SEAOC Performance Objectives subsequently clarified (and hedged)

• Earthquake changed to ground motion:
• Item 3 word-smithed: Resist a major level of earthquake ground motion—of an 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.
• …damage limited to repairable level for most structures… In some instances, damage may not be economically repairable.
• “No Guarantee” paragraph added:
  …While damage to the primary structural system may be either negligible or significant, repairable or virtually irrepairable, it is reasonable to expect that a well planned and constructed structure will not collapse in a major earthquake. The protection of life is reasonable provided, but not with complete assurance.
Introduction of *Risk* into Building Code Seismic Performance

First explicit discussion of actual risks for building construction by a code writing group appeared in commentary of ATC 3, which was intended to develop more rational and scientific seismic design provisions. (Tentative Provisions for the Development of Seismic Regulations for Buildings, ATC, 1978)

*It is not possible by means of a building code to provide a guarantee that buildings will not fail in some way that will endanger people as a result of an earthquake. While a code cannot ensure the absolute safety of buildings, it may be desirable that it should not do so as the resources to construct buildings are limited. Society must decide how it will allocate the available resources among the various ways in which it desires to protect life safety. One way or another, the anticipated benefits of various life protecting programs must be weighed against the cost of implementing such programs.*

ATC 3 suggested that this risk is primarily due to uncertainty in the characteristics of the ground motion…
Technical Definition of Ground Motions Important for Determination of Effective Safety Levels

- Initially: *earthquake shaking*
- SEAOC: *minor, moderate, major earthquake*; later *ground motion*
- SEAOC/UBC: Design Basis Event (DBE) defined as motions with 10% chance of exceedance in 50 years or 475 year return period
  - Did not necessarily clarify the performance objective because most think that the 475 year shaking level was between the traditional descriptions of “Moderate” and “Major” Ground Motion.
Refinements in Basic Goal through definition of ground motions: 1997 NEHRP Provisions

- Concern about protecting the country from larger infrequent events to prevent “regional disasters.”
- Use 2500 year return (except near active faults)
  - Called the Maximum Considered Event
  - Primary goal became *No Collapse in MCE* (rather than life safety for something smaller)
  - Accomplish by designing for 2/3 MCE with traditional code formulas (1.5 “safety factor” against collapse assumed).
- Resulted in increased design loads in regions threatened by very rare, large events (e.g. Memphis, Charleston, etc.)—Many think these increases were too large.
ATC 63/FEMA 695

• Current research (ATC 63-FEMA 695) based on studies of a few structural types concluded that for ground motions 1.5 times as great as our design ground motions (the MCE), about 10% of code designed buildings may fail. (FEMA 695, in progress).

• FEMA 695 has tentatively set the performance goal for new systems applying for code acceptance as \( \leq 10\% \) chance of collapse in the MCE.

• Risk Targeted Seismic Mapping in regions governed by probabilistic mapping
  – Rather than design for no collapse for 2500 year return motions,
  – Determine mapped motions that will result in a uniform risk of collapse of 1% in 50 years (considers variation in hazard curve)
HAZARD CURVES FOR SELECTED CITIES

Graph from Peterson and Leyendecker

• Risk Targeted Seismic Mapping in regions governed by probabilistic mapping
  – Rather than design for no collapse for 2500 year return motions
  – Determine mapped motions that will result in a uniform risk of collapse of 1% in 50 years (considers variation in hazard curve)
    • Determined by integrating representative code fragility and the hazard curve at any location
    • Requires trial-and-error determination of mapped values

• Change in “intent” statement at beginning of seismic regulations,

  ...The intent of these Provisions is to provide reasonable assurance of seismic performance that will:

  • avoid serious injury and life loss;
  • avoid loss of function in critical facilities;
  • minimize nonstructural repair costs when practical to do so.

The Provisions seek to avoid such losses by allowing only a small risk of collapse for every building and structure covered, even in very rare extreme shaking at the site. For smaller, more frequent shaking levels, the Provisions covering design and installation of both structural and nonstructural systems seek to reasonably control damage that would lead to risks to life safety, economic losses, and loss of function...
Seismic Performance of Existing Buildings
Different Standard for Existing Buildings?

• Not much activity in seismic evaluation and retrofit of existing buildings before 1976 but engineers had used “double standard” prior to that time.

• The concept was institutionalized in 1976
  – Code spectra was increased in 1976 (as a result of San Fernando earthquake) and San Francisco adopted a $\frac{3}{4}$ factor for existing buildings—essentially keeping the 1973 demand values.

• A similar concept was adopted for evaluation in ATC 14 (forerunner to FEMA 178, FEMA 310 and ASCE 31).

• FEMA 310 and ASCE 31 implement the “break” for existing buildings by liberalizing acceptance criteria compared to ASCE 41.
ASCE 41

• Theoretically, ASCE 41 (FEMA 356, FEMA 273, ATC 33) already built a “break” into performance definitions and acceptance criteria—intended to be more liberal than criteria for new buildings.
ASCE 41 Performance *Intention*

- Operational Level
- Immediate Occupancy Level
- Life Safety Level
- Collapse Prevention Level
- Limited Safety Range

Code for new buildings

higher performance

Damage Control Range

lower performance
ASCE 41

- Theoretically, ASCE 41 (FEMA 356, FEMA 273, ATC 33) already built a “break” into performance definitions and acceptance criteria—intended to be more liberal than criteria for new buildings.
  - In practice, other than allowing use of archiac materials, ASCE 41 probably not more liberal than codes for new buildings
- A minimum performance, the Basic Safety Objective was suggested but not mandated in ATC 33.
  - Life Safety for the Design Basis Motion
  - Collapse Prevention for the Maximum Considered Motion
Different Performance Standards Implied for Evaluation and Retrofit

- ASCE 31 (Evaluation) uses more liberal acceptance criteria than ASCE 41 (Retrofit).
  - Tier 3 (most advanced) of ASCE 31 calls for use of ASCE 41 with 75% of demand.
- Both Standards suggest “Life Safety” is achieved when requirements are met
  - similar to, but possibly slightly lower than, expectations from code for new buildings
Risk Reduction Standards

• Many reasonably successful seismic risk mitigation programs have had no identified performance expectation other than “risk reduction.”
  – Most have been devised by technical groups or individuals to judgmentally maximize risk reduction while minimizing cost and disruption.
  – The cost and disruption have often been considered by policy makers to determine political acceptability but the risk reduction side not seriously weighed.

• The costs are the owner’s, but the benefits are generally improved life safety for the community.
Conclusions

• A review of the previously described milestones clearly indicates that engineers have consistently set standards that determine levels of seismic safety, probably due to lack of methodologies to estimate and communicate risks to policy makers.
  – Initially standards were based on observed performance
  – When a “goal” was finally set, code writers had little capability of testing new provisions against the goal.
  – Code goals are gradually becoming more and more numerically defined.

• We are also getting closer to developing practical procedures to estimate building performance with a stated reliability.
  – ATC 63 (procedures to qualify new systems);
  – ATC 58 (performance-based design)

• These methods will enable communication with policy makers and fine tuning of the code
  – We may be soon be in for interesting discussions!