Seismic Design: Past, Present and Future

An Online Continuing Education Course for Engineers

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Introduction

Design of any building is a challenge for architects and engineers, and the challenge is made more complex when there is a need to provide for earthquake resistance. During the past 100 years, seismic design philosophy and details have progressed from simply considering earthquakes to be the same as wind loads, to a sophisticated understanding of the phenomenon of the earthshaking that induces a building response.

This course covers the 100-year history of seismic structural systems, ranging from simple to sophisticated solutions. Basic structural behavior is outlined; guidance for selecting a good structural system is suggested, and the following issues are discussed:

- Scale and size of buildings and structural components
- The impact of building configuration
- Force verses energy
- Drift or movement
- Structural mechanisms (passive to active)
- Costs and post-earthquake repair costs

A Brief Summary of 100 Years of Structural Seismic Design

Seismic exposure has extended over many centuries, but systematic seismic design has occurred only over the past 100 years, especially in California since the 1906 San Francisco earthquake.

A group of thoughtful and creative engineers, responding to the observed damage in the 1906 earthquake, started to study, conceive, and design a progression of structural solutions to solve the earthquake response problem. This creative work has extended over a 100-year period, and continues today. A brief progression of key milestones in this seismic design history follows:

- Initial seismic designs for buildings were based on wind loads, using static force concepts. This approach started in the late 1800s and lasted to the mid-1900s.
- After the 1906 San Francisco earthquake, concepts of building dynamic response gained interest, and in the early 1930s, initial studies of structural dynamics with analysis and models were initiated at Stanford University. This approach ultimately

led to a design approach that acknowledged the importance of building periods and dynamic rather than static design concepts.

- Dynamic design concepts were enhanced by the acceleration spectra method used for design as developed by Professor Housner at the California Institute of Technology.

- While analysis methods were being developed, engineers needed additional knowledge about nonlinear behavior of structural components. Substantial testing of materials and connection assemblies to justify actual behavior were undertaken from 1950 through 1990 at numerous universities (University of California, Berkeley; University of Illinois; University of Michigan; University of Texas; etc.).

- Since 1980 to the present, sophisticated computer analysis programs have been and continue to be developed to facilitate design of complex structural systems and the study of nonlinear behavior.

In the past 70 years substantial change and progress have taken place, not only in California but also over the entire United States, so that concepts and systems can now be utilized that previously could only be dreamt about.

Historic and Current Structural Seismic Systems

Early Structural Systems-Pre-1906 San Francisco Earthquake

San Francisco in 1906 had a varied building stock with a few basic structural systems widely represented. Almost all common residential buildings were of light-frame wood construction, and most performed well in the earthquake, except for those on poor, weak soils or those with unbraced lower story walls. Most small to medium-sized buildings (about five to six stories in height) were constructed with brick masonry-bearing walls, using wood-framed floors and roofs. These buildings had a variable performance, with upper stories experiencing partial collapse and masonry walls typically showing shear cracks to varying degrees. Tall buildings, constructed during the previous 10 to 15 years (prior to 1906), utilized a steel frame to support gravity loads and provided unreinforced brick/stone perimeter walls which served to provide lateral load resistance. These buildings generally performed well during the earthquake. Most buildings, when subjected to the firestorm after the earthquake, did not do well.

The general conclusion following the 1906 earthquake was that a steel-framed building designed to support gravity loads and surrounded with well-proportioned and anchored brick walls to resist earthquake forces was a superior structural system, and it was commonly adopted by the design profession.

The Early Years (1906 - 1940)

Immediately after the 1906 earthquake, when reconstruction and new buildings became essential, a variety of new structural concepts were adopted. Brick masonry infill walls with some reinforcing were used, and steel frames were designed to carry lateral loads using one of the following ideas: knee bracing, belt trusses at floors to limit drift, rigid-frame moment connections using column wind-gussets, or top and bottom girder flange connections to columns.

As concrete construction became popular after 1910, concrete moment frame buildings together with shear walls, emerged for industrial and lower height commercial buildings. Concrete slowly replaced brick as a structural cladding after 1930, and buildings commonly used a light steel frame for floor support with a complete perimeter concrete wall system for lateral loads.

The Middle Years (1945 - 1960)

Immediately after World War II, construction of large projects started again. New ideas were common, and some refinement of framing systems for tall buildings was proposed and adopted.

Expressive structural systems were studied and used, but they were usually covered from view with conventional exterior finishes.

The transition from riveted connections to high-strength bolted joints occurred in the 1950s. By 1960, another steel connection change was starting to occur; girder flanges welded directly to columns to create moment frame connections. Because engineers initially did not trust the limited use of moment frames, structural designs were conservative, with substantial redundancy created by utilizing complete moment-frame action on each framing grid, in each direction.

The Mature Years (1960 - 1985)

The 25-year period from 1960 to 1985 represents the "mature years", in that substantial projects were completed using the concepts of either ductile moment frames or concrete shear walls.

The structural engineering profession accepted the validity of 1) ductile concrete-moment frames, 2) ductile shear walls, or 3) ductile welded steel-moment frames as the primary structural system for resisting lateral loads. The primary design activity became optimization of the system or, in other words, how few structural elements would satisfy the minimum requirements of the building codes. Substantial connection tests were carried out at university laboratories to justify this design approach.

The Creative Years (1985 - 2000)

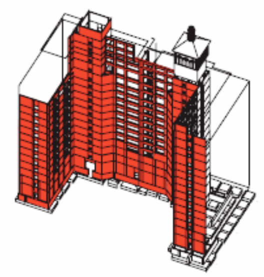
After the damage caused by the 1989 Loma Prieta earthquake (San Francisco Bay Area) and the 1994 Northridge earthquake (Los Angeles), the structural engineering profession began to ask itself about actual earthquake performance. Would real performance differ from the solution obtained by simple compliance with the building code? This investigative process defined many issues, and one of the most important was the dissipation of seismic energy by the building structure. The pursuit of this issue led engineers to the consideration of dual systems and seismic isolation to limit lateral displacement.

Several significant solutions have been developed using the dual-system concept with stable cyclic seismic behavior:

1. Dual-system of steel moment frames and eccentric braced frames. The more rigid eccentric brace provides primary stable cyclic behavior, while the moment frame provides good flexural behavior as a back-up system.

2. The dual-system steel-moment frame and passive seismic dampers provide high damping, which significantly reduces the seismic loads imparted to the moment frame.

3. Unbonded steel braces with the brace providing stable tension-compression behavior, a significant improvement over the conventional braced frame.



4. Coupled 3-part systems with moment frames, links, and shear walls to provide a progressive resistance system in which the resistance progresses from the most rigid system to the more ductile-flexible system.

5. Seismic isolation, developed in the early 1980s, is a completely different and reliable concept, in which the building structure is supported on isolation bearings and is effectively separated from the ground, significantly reducing seismic response.

Each of these systems is part of an overall framing concept. These dual and stable mechanisms represent the current search for reliable seismic performance.

Background and Progression of Structural-Seismic Concepts

The progression of seismic systems selected by structural engineers has resulted from three factors:

1. Study of Past Earthquakes

   Learning from past earthquake performance: Successful seismic structural systems continue to be used; unsuccessful systems are eventually abandoned. New and better ideas frequently flow from observed earthq…

2. Research Da…

   New ideas fo… …tly by design engineers and universit… …lly tested and analytically s…

3. Building Code…

   Finally, structu… …ally are used by many engineers… …n these times of rapidly changin… …ears after new ideas are developed, s… …ing edge of new thinking; overly… …as.

Development of Seismi…

Over a 100-year period, … …substantially. The use of San Francisco buildings … …evolution provides a good summary of the past and present, and … …ication of the future.

A summary of individual buildings gives a clue as to thinking. The plot of systems (Figure 1) connects the concepts and indicates the progression of ideas.