THE DEVELOPMENT OF ASEISMIC CONSTRUCTION IN THE UNITED STATES

By
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The United States has really been very fortunate as far as earthquakes are concerned as only about two percent of the total area lies within the very definite limits of the world's great belt of frequent violent earthquakes. This belt which extends around the world except for short gaps of freedom from records of violent quakes, runs up the West Coast of North and South America. It becomes prominent in the United States near San Diego, California and continues active northward along the coast to the Columbia River. There is a gap in the region of British Columbia and then it continues along the coast of Alaska thru the Aleutians and on into Asia.

It is within the area of this belt that most of our earthquake activity and history has occurred.

There have, however, been other earthquakes in the United States of considerable violence. In Boston in 1755, there was an earthquake that was noticed from Portsmouth, New Hampshire to New Haven, Connecticut. Considerable damage was done to the buildings of that day.

One of the sharpest earthquakes, or at least one of the most vividly described was the New Madrid earthquake of 1811 in the Missouri Valley. The area was sparsely settled but considerable damage was due to the few structures that were in existence. However, it must be remembered that most of them were built of logs. Probably the eyewitness accounts were grossly exaggerated but there was a considerable shock followed by after-shocks which were said to last for three months.

There was also an earthquake at Charleston, South Carolina in 1886. This was one of the most widely felt in America and was second only to the one in New Madrid.

However, in these areas the incidence of earthquakes has not been so constant and repetitious as it has been in the earthquake belt along the Pacific Coast.

In this earthquake belt there has been a continuous series of seismic shocks. Most of them are minor but at intervals major ones have occurred that have caused us to stop and take stock of our knowledge of design and construction. Among these are the San Francisco quakes of 1865 and 1868; the great Owens Valley quake of 1872; the San Francisco quake of 1906; one in Santa Barbara in 1925; at Long Beach and Compton in 1933; the ones at Tehachapi and Bakersfield in 1952, and others at Helena, Montana, Seattle, Washington and the Imperial Valley of California. Also the one near Fallon, Nevada in 1954 which, although

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the damage was slight because it occurred in a relatively uninhabited area, was probably a far greater earth shock than many of those which have received far greater publicity.

The continuing occurrence of these earth shocks along the Pacific Coast has caused this area to be the leader in the development of an approach to aseismic design and construction in the United States.

The San Francisco Earthquake of 1906 and the wide-spread damage that was caused by the fire that followed accelerated our research in earthquake engineering and our progress has been steady and in the direction of rational and reasonable design criteria. A great deal of work and study was done in San Francisco after the 1906 earthquake.

The first look was quite confusing because the big question mark appeared as to which was earthquake damage and which was fire damage? However, the local people kept saying that it was the fire that did the damage and not the earthquake. A detailed study of the ruins confirmed this belief.

City, State, United States Government commissions, Engineers -- some of whom represented building material firms -- American Society of Civil Engineers' special committee and others, flooded the engineering reading with papers and reports on the damage by the earthquake and fire. Many of these were very well illustrated with pictures. All are of value, in that they furnish historical data and a few made recommendations that structures in seismic regions should be designed to resist a lateral equivalent of 30 to 50 pounds per square foot of exposed area.

A thorough examination of the damage done to buildings in the 1906 earthquake and an equally thorough examination of buildings that were not damaged to any great extent even though many were of inferior construction, led to the conclusion that the most important thing to do to make the buildings safe in a seismic region was to build of good materials, honestly constructed and all to have their component parts thoroughly tied to each other.

Two examples of structures in the ruins which lead to this conclusion might be of interest:

First, the old Palace Hotel. There it stood, seven stories of brick walls with the former interior wood framing completely burned out. The condition of the brick walls gave evidence that the building had not been damaged by the earthquake. The cement mortar reinforced with steel bands and with the anchors still protruding from the walls indicated that the walls had been thoroughly tied to the wood frame floors, which, in turn, had acted as a diaphragm.

Second, the Rialto Building. There was a large diagonal crack in the wall caused by the supporting beam pulling away from the column because of a very weak connection. A good tie to the column could have saved this wall.

Another conclusion that could be drawn from buildings left standing after the 1906 earthquake was that we do not have enough data to warrant differentiating lateral forces for various types of soils. It is possible to name many examples of buildings that escaped earthquake damage although they were built on unstable soil. Two most noteworthy examples of this were, the Appraiser's Building, built of heavy masonry walls and brick arch floor construction on made ground and which suffered only slight damage and the Montgomery Block constructed of brick walls and wood interior framing in the filled area of the city. This latter building survived not only the 1906 earthquake and fire but also the 1868 earthquake and is still standing today.

Another substantiation of this conclusion can be gained by some quotes from the Daily Evening Bulletin of Wednesday, October 21, 1868:

> "At about 8 o'clock this morning, the city was shaken by the heaviest earthquake it has yet experienced. The shock lasted 42 seconds and was both longer and severer than the memorable one of October 8, 1865."

> "Not a single thoroughly good building even in the lower part of the City (filled in area) has been seriously injured. All the superior large brick structures erected since 1865, including the biggest warehouses, show no mark of strain or damage."

Records at the City Hall indicate that San Francisco had no real Building Code until July 5, 1906. Although in 1903 it did have a few written, general requirements which probably never were read or enforced. The 1906 Code required that any building over 100 feet high or a height of over three times its least horizontal dimension that the steel frame should be designed for a wind force of 30 pounds per square foot, acting in any direction upon the entire exposed surface. In 1909 the wind factor was changed to 15 pounds. In 1910, the concrete frame was included with the steel frame and the wind factor was raised to 20 pounds. Then in 1926 the wind factor was again reduced to 15 pounds, where it remained until the complete revision of the building code was made in 1947.

However, in 1934, the Code made reference to the Riley Act, a State Code requirement adopted by the Legislature of California in 1933. The Riley Act was enacted after the Long Beach Earthquake of 1933 and was the first legislation ever enacted in the United States in which the percentage of gravity became the factor in the design for lateral force.

Also, as an aftermath of the 1933 Long Beach earthquake, the Field Act was passed in California setting up the practice of the Division of Architecture checking the plans for all school buildings constructed. in the state. This system is still in use today.

No severe earthquake occurred in the United States from 1906 until the one in Santa Barbara on June 29, 1925.

John G. Little, T. Ronneberg and the writer were engaged by The Research Department of the California Common Brick and Manufacturers' Association to inspect the earthquake damage and prepare a report. We concluded our report as follows:

> "All architects, engineers, contractors, building materials people and building owners should visit Santa Barbara immediately to see and study the effects of the recent earthquake. The destroyed buildings are an indictment against poor structural design, inferior materials and careless workmanship. This is so self-evident even to a layman that it needs no theoretical arguments because it is plainly and practically demonstrated by the fact that in the midst of the ruins there remain standing intact as a monument to skill and integrity, structural steel framing, reinforced concrete construction, brick buildings, terra cotta wall construction, and wood frame buildings.
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> In every building damaged in the earthquake at Santa Barbara, the damage is due not to the kind of material used nor the type of construction attempted but to poor workmanship, inferior quality of materials, improper design or a combination of the three.
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> For a number of years after the destruction of San Francisco in 1906, the phrase "Lest we forget" was the universal slogan and warning. But as time rolled on, the people have forgotten and through ignorance or selfishness, poor construction is creeping in. Let us revive the phrase "Lest we forget" and insist that all buildings be properly designed and carefully inspected and constructed with good materials, honest and careful workmanship."

Some years after the Santa Barbara Earthquake, the State Chamber of Commerce became interested in developing a building Code, particularly as related to earthquake safety, for State-wide use.

A committee of engineers was appointed, joined later by committees from the architects and other interested groups. A great deal of time and energy was put into the work and was particularly stimulated after the Long Beach Earthquake on March 10, 1933. When the Code was finally completed in 1939, there were two codes for lateral forces because of a minority group refusing to compromise. These codes followed the Riley Act in that a percentage of gravity was used as a measurement for the lateral forces. However, they differed from the Riley Act in that they varied the percentage of gravity to be used in different stories of the building. This concept of flexibility had first been introduced in the Los Angeles City Building Code.

On April 2, 1948, the San Francisco (Calif.) Section ASCE, and the Structural Engineers' Association of Northern California appointed a Joint Committee on Lateral Forces to evaluate the current understanding of wind and earthquake forces and to draft a model lateral force provision for the building codes in California.

As part of its study the Joint Committee has:

1. Reviewed the historical record of earthquake damage;
2. Noted the limited accurate recording of ground accelerations in earthquakes;
3. Extended the mathematical response of simplified structures subjected to known earthquake acceleration patterns into a practicable dynamic approach to earthquake design forces on engineering structures;
4. Indicated a number of problems that require further study, acknowledging that there is still much to be learned about earthquakes and earthquake affects on structures; and
5. Prepared the model lateral force provision.

A statement of the function of the lateral force provision is necessary so that it is understood and agreed what is to be accomplished by the provision. It is the province of the building code to specify design and construction requirements which will result in structures safe against major structural damage and the loss of life in the event of precedented winds or earthquakes. The lateral force provision is primarily structural. Panic and fire hazards, for example, are covered in other sections of the building code. The design requirements are considered to be the minimum consistent with the general objective. If unfavorable conditions of a particular site, such as the proximity of known faults, extreme exposure to high winds, or the importance of continued operation of a facility in the event of unprecedented winds or earthquakes, suggest the advisability of using design lateral forces in excess of those specified, this is left to the judgment of the owner on the advice of his engineer. The basis of such judgment is a matter of evaluating the calculated risk and is beyond the scope of the minimum provisions of a building code.

In their studies, the behavior of structures in earthquakes has generally been recognized as a dynamic vibration phenomenon of a transient nature. Although rigorous solutions are possible for particular ground motions applied to particular structures, these solutions are too involved and of too limited significance to be of direct practical value to the structural engineer. The more rigorous methods, however, should be encouraged to guide the thinking toward less rigorous but more practicable methods.

It is the purpose herein to outline an approach to earthquake forces which, although not new in its basic concept, has been extended to a rational dynamic method for establishing the design forces on a structure. The method involves: first, the determination of the total lateral force or the base shear transmitted into the structure from the ground; and, second, the distribution of that shear as equivalent forces applied to the structure.

The Committee concluded its work and reported to the Boards of Directors of their respective Societies. The April 1951 Proceedings of the American Society of Civil Engineers, published the Committee's report in full, as Paper No. 66. In the writer's opinion, the conclusion developed by the Committee for lateral forces of earthquake and wind is the best approach to the problem that has yet been developed. It is a theoretical approach to the practical application and it is the first time that the dimensional properties of a building in its responses to seismic forces has been considered.

The City of San Francisco has just adopted a new building code which is based upon the work of this committee. The recommendations of the committee were not taken entirely but a compromise code was made which includes most of the basic recommendations of this committee. In a problem as abstract as aseismic design we can never expect one hundred percent agreement but can progress only by compromising.

As a few final thoughts, a quotation from John R. Freeman's book on "Earthquake Damage and Earthquake Insurance" in which he has the following notation under a panoramic view of San Francisco after the Earthquake and before the Fire of April 18, 1906:

"A particularly noteworthy fact is that FEW OR NONE OF THE BUILDINGS SHOWN IN THIS PHOTOGRAPH WERE OF THE SUPERIOR QUALITY OF THE GREAT MAJORITY OF THE MODERN OFFICE BUILDING, HOTELS, AND WAREHOUSES, BUILT IN SAN FRANCISCO AND OTHER AMERICAN CITIES DURING THE PAST 10 YEARS. And from Nicholas Hunter Heck's book, entitled "EARTHQUAKES":

"Until recently, too much attention was paid to spectacular destruction and too little to the buildings which came undamaged through the same intensity of earthquake. Such a building, with or without premeditation on the part of its designer, represents in itself a solution of the problem of design to resist earthquake. There may be no desire nor need to duplicate the building, but it should be possible to draw valuable lessons which may be applied to other buildings. Important progress has been based on such procedure."

In conclusion, in over a half century of active participation and observation, the writer has seen a gradual development of a more logical and practical procedure in the method of design for structures in an earthquake region. Accordingly, the design and construction are relatively better today than formerly.