AN HISTORICAL VIEW OF EARTHQUAKE ENGINEERING

G. W. Housner*

Earthquake engineering is a 20th Century development, so recent that it is yet premature to attempt to write its history. Many persons in many countries have been involved in the development of earthquake engineering and it is difficult, if not impossible to identify the contributions of each. Many advances in the subject are not well-documented in the literature, and some of the documentation is misleading, or even incorrect. For example, in some instances, earthquake requirements were adopted in building codes but were not used by architects and engineers, and in other instances earthquake design was done by some engineers before seismic requirements were put in the code. A history of earthquake engineering written now could not present a satisfactory account because of poorly documented facts and, in addition, there are still many people that remember relevant information and would be severe critics of a history. To write an acceptable history, it is necessary to wait till most of the poorly known facts have disappeared from memory and literature, then, with a coherent blend of fact and fiction, history can be written.

Although 1984 is too soon to write a definitive history, it is an appropriate time for an historical view of earthquake engineering development to see where we were, where we now are, and where we are going. In this regard, it is interesting to compare the Eighth World Conference with the First World Conference on Earthquake Engineering. In 1956, the 50th anniversary of the San Francisco earthquake, the First World Conference was held in the city of Berkeley, California. It is indicative of the very recent development of earthquake engineering that many

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* Department of Civil Engineering, Caltech, Pasadena, California, USA

of those pioneers who attended the First Conference are also present, 28 years later, at the Eighth Conference. It is gratifying to see that the attendance at 8WCEE is more than 10 times as large as the number attending 1WCEE. In the Preface to the Proceedings of the First Conference, the President of EERI said "The world conference on earthquake engineering was originated and planned by EERI for the purpose of 1)Observing by an appropriate technical meeting the 50 th anniversary year of the destructive San Francisco earthquake of 1906. and, 2)Bringing together the scientists and engineers from major seismic areas of the world in order that their knowledge of earthquakes and developments in the science and art of earthquake-resistant design and construction might be pooled for the benefit of all mankind." And this still represents the purpose of the Eighth Conference. However, a big change has occurred in the number of papers presented. The Proceedings of the First Conference had 40 papers and the Proceedings of the Eighth Conference contain 844 papers. This 20 times increase in the number of persons seriously studying earthquake engineering is indicative of the increased importance of the subject in the seismic countries of the world. The authors in the First Conference came from 11 countries and the authors in the Eighth Conference came from 42 countries. Very few seismic countries are not represented at the 1984 Conference and this indicates that there are few seismic countries that are not actively trying to protect against destructive earthquakes, and this is a great change from the situation in 1956.

EARLY DAYS OF EARTHQUAKE ENGINEERING

In viewing the early days of earthquake engineering, it is not appropriate to consider developments in pure seismology but, rather, restrict consideration to developments which were made by engineers or which have a special relevance to earthquake engineering. It is surprising to learn that in the early days the most prominent men in earthquake engineering were almost all natives of England, a country of low seismicity. This can be attributed to the Industrial Revolution, in which England was a pioneering country. The intellectual excitment associated with rapid developments in all of engineering between the years 1700-1900 attracted the attention of many able men and some developed an interest in earthquakes. Robert Hooke (1635-1703), the discoveror of Hooke's Law, which is well-known in engineering, gave a series of lectures at the Royal Society in 1667-68 which were published in book form in 1705 with the title "Lectures and Discourses of Earthquakes and Subterranean Eruptions". This was before the days of earthquake engineering and Hooke was actually considering geological matters when he argued that the raising of sub-acqueous land into mountains was caused by earthquakes, so it might be said that Hooke took the first step along the path that led to the theory of plate tectonics. Also, Thomas Young (1773-1829), of Young's Modulus, in his book "Lectures on Natural Philosophy", vol. 2. 1807, gave what appears to be the first European bibliography of earthquake publications. It is interesting that both Hooke and Young, who are so well known by engineers, should have studied earthquakes, though in those early days it was premature to think about earthquake engineering.

In the 19th Century, a number of English engineers developed a keen interest in earthquakes, including Robert Mallet (1810-81), a civil engineer, John Milne (1850-1913), a mining engineer, James Ewing (1855-?) and Thomas Gray (1850-1908), both mechanical engineers. In the last century no distinction was made between seismology and earthquake engineering. In fact, the word "seismology" derived from the Greek word "seismos=shaking", was invented by the engineer Robert Mallet and covered all the various interests in earthquakes: earthquake occurrence, ground shaking, earthquake damage, etc. It seems that the name "seismology" (=shake-knowledge) originally designated what we would call earthquake engineering, and it was only during later developments that the name came to designate the studies of the nonengineering aspects of the subject. Robert Mallet also coined the terms "epicenter", "seismic focus", "isoseismal line", and "meizoseismal area".

Robert Mallet published his first paper, "On the Dynamics of Earthquakes" in the Transactions of the Irish Academy, vol.2, 1848. In this paper he discusses earthquake effects and considers seismic waves and tsunamis, and he also describes his invention of the electro-magnetic seismograph (see Figure 1). This instrument sat at rest till it sensed the arrival of the seismic waves which activated it and the response of the instrument was recorded on a rotating drum. Mallet did not build such an instrument but a modified seismograph along these lines was built in 1855 by Luigi Palmieri (1867-96) in Naples, Italy which actually made some earthquake records. Mallet also invented the "rocking blocks" (or falling pins) intensity meter, a form which for many years was used by the construction industry to measure the intensity of ground motion generated by blasting; and he also compiled a seismic map of the world which was in use for many years. Mallet also studied the destructive Naples earthquake of 16 December 1857 and wrote a detailed report which include carefully drawn isoseismal lines. He also compiled a 600-page catalog of earthquakes which he said was the "first attempt to complete a catalog that shall embrace all recorded earthquakes". Robert Mallet, I believe, can be called the Primeval Earthquake Engineer.

Milne, Ewing and Gray* developed an interest in earthquakes while teaching at Imperial College of Engineering in Tokyo (later merged into Tokyo University). In addition to studying earthquake damage and other phenomena, they were pioneers in the design and construction of sensitive seismographs and the study

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* Thomas Gray later emigrated to the United States and from 1888 to 1908 was professor of engineering mechanics at Rose Polytechnic Institute in Indiana.

of the seismograms. The work of these men, together with Japanese seismologists such as Seikei Sekiya (1855-96), the world's first officially appointed professor of seismology, and Fusakichi Omori (1868-?) led to modern seismology. The Seismological Society of Japan was organised by these men in 1880 and this first earthquake society was the forerunner of the many National Societies of Earthquake Engineering that make up the International Association for Earthquake Engineering.

In the latter part of 19th century and the early part of the 20th century, some large and important earthquakes occurred that aroused the interests of engineers and seismologists and marked an important phase of earthquake engineering. These were the 1891 Mino-Awari, Japan; the 1906 San Francisco, California; and the 1908 Messina, Italy earthquakes. The Mino-Awari earthquake left a prominent fault scarp which is still shown in books on seismology and the San Francisco earthquake focused attention on the San Andreas fault and its displacement. Although these two large earthquakes received worldwide attention, the time was not yet ready for earthquake engineering. In this 1907 ASCE paper "The Effects of the San Francisco Earthquake of April 18, 1906 on Engineering Construction", Professor Charles Derleth said: "An attempt to calculate earthquake stress is futile. Such calculations could lead to no practical conclusions of value". Engineering thinking was still based in a static world and dynamics seemed yet to be unthinkable. Despite the fact that in 1906 California had a small population with no great cities, the damage caused by the earthquake was $10 $20 billion (1980 dollars) though the number of deaths was only about 1,000. This did not shock engineers into developing earthquake engineering. In 1908, however, a large earthquake devastated the city of Messina, Italy and surrounding area with a loss of life of 83,000 and this disaster was responsible for the birth of practical earthquake design of structures.

It appears that prior to December 28, 1908 engineering thinking was not ready for grappling with the engineering design of structures to resist earthquakes. In most seismic regions, the common type of construction was masonry buildings, low in height. At that date, the use of reinforced concrete, and the use of structural steel, was still in its infancy, and the education of engineers was not of a type to encourage thinking about earthquake forces and stresses.

MESSINA, ITALY EARTHQUAKE OF DECEMBER 28, 1908

As the population of the world increases, the number of structures at risk also increases, and the number of people exposed to earthquake hazards increases. This leads to the possibility of great disasters. The 83,000 death toll of the Messina earthquake was the greatest number ever from a European earthquake. Even the famous 1755 Lisbon, Portugal earthquake had fewer deaths (60,000). The government of Italy responded to the Messina earthquake by appointing a special committee composed of nine practicing engineers and five professors of engineering to study the earthquake and to make recommendations. The report of this committee appears to be the first engineering recommendation that earthquake-resistant structures be designed by means of the equivalent static method (%g method). This portion of the report appears to have been the contribution of M. Panetti, Professor of Applied Mechanics in Turin, and he recommended that the first story be designed for a horizontal force equal to 1/12 the weight above and the second and third stories to be designed for 1/8 of the building weight above. He stated that the problem is really one dynamics which, however, is so complicated that it is necessary to have recourse to a static method. Also, in 1909 A. Danusso, Professor of Structural Engineering at Milan, won a prize with his paper, "Statics of Anti-Seismic Construction". The method recommended by Panetti and explained by Danusso, gradually spread to seismic countries around the world. First it was used by progressive engineers and later was adopted by building codes. In Japan, the method was applied successfully to reinforced concrete buildings by Professor Tachu Naito prior to the 1923 Tokyo earthquake and, in the late 1920's, it was applied by Professor R. R. Martel in the design of a 12-story steel-frame building in Los Angeles. Following the Tokyo earthquake the static method of design with seismic coefficient of 10% was adopted by the Japanese building ordinance and, following the 1933 Long Beach earthquake, the city of Los Angeles adopted the method with a coefficient of 8%. On January 1, 1943, the city of Los Angeles changed its earthquake requirements so that the seismic coefficient varied over the height of the building and was also a function of the total height (i.e. the period of vibration). This was the first time that the seismic requirements of a building code took into account the flexibility of a building as well as its mass; and these requirements were based on dynamic analyses of structures, carried out by R. R. Martel and his students, under research grants made by the Los Angeles County Department of Building and Safety.

The 1923 Tokyo earthquake was also responsible for the establishment of the Earthquake Research Institute at Tokyo University with an eminent engineer, Professor Kyoji Suyehiro, as the first director. This was the first research group formed to study earthquake engineering and seismology.

RECORDING AND ANALYSIS STRONG EARTHQUAKE SHAKING

The recording of earthquake ground accelerations was often recommended by engineers who studied the problem of designing for earthquakes, including John Milne, Kyoji Suyehiro, R. R. Martel and others. However, it seems that prior to 1925 the technology of seismic instruments was not adequate to building strong-motion accelerographs and even in the latter 1920's the mental and financial inertia was too great for an accelerograph to be developed. We owe the first accelerographs to the eminent engineer John R. Freeman (1855-1932) who became interested in earthquakes in 1925 at the age of 70, and who attended the 1929 World Engineering Conference in Tokyo where he met and became friends with Martel and Suyehiro. He immediately understood the need for a strong-motion accelerograph and strongly recommended to the Secretary of Commerce that such an instrument should be designed and constructed. On March 11, 1930, Secretary Lamont, an engineer, stated in a letter to Freeman that it would be done. The first accelerographs were installed by the Seismological Field Survey of the U.S. Coast and Geodetic Survey in late 1932, just in time to record the strong ground shaking of the destructive March 10, 1933 Long Beach earthquake. This was a most important step in the development of earthquake engineering. For the first time engineers could see the nature of strong ground shaking: the amplitude of motion, the frequency characteristics, and the duration of shaking. These were items of great interest and they cleared up much confusion, as the literature prior to 1933 contained many erroneous estimates of these quantities. We, who live in 1984, can hardly conceive of the difficulty of estimating these quantities 100 years ago when the world had not yet moved into the modern age. For example, in the Transactions of the Seismological Society of Japan a paper by J. MacGowan on "Earthquakes in China" describes the earthquake of June 12, 1878 which occurred near Suchow, and he said that it was reported that in Suchow the "shaking was felt for the space of time taken in swallowing 1/2 bowl of rice". At the time of the First World Conference in 1956, fewer than 70 strong-motion accelerographs were installed in the world, and at that time, few destructive earthquakes occurred close to an accelerograph. It is significant that now most seismic countries have installed networks of accelerographs and that important records are being obtained in many countries. We now have a much better understanding of earthquake ground motions and their effects. In addition, many accelerographs are now installed on structures to record their motions during earthquakes, and these have demonstrated the dynamic responses of multistory buildings, bridges, dams, etc.

The development of computers, first the analog type and then the digital type, was very important for earthquake engineering. These made possible the practical analysis of accelerograms, for without computers the analysis was exceeding slow and laborious. Computers made possible the development of the response spectrum of earthquake motions and the design spectrum which have played important roles in earthquake engineering and have been adopted in other branches of engineering also. Computers have also made possible the calculation of the dynamic response of structures to earthquake ground shaking and this has greatly clarified our understanding of structural dynamics. We are now able to make dynamic analysis of complex structures. The finite element method of analysis has also been an important development for earthquake engineering. The widespread installation of strong-motion accelerographs, together with the development of powerful computers, has provided large amounts of data and this poses problems of data acquisition, data analysis, data storage, data retrieval and also data understanding.

In retrospect, it can be seen that in the last twenty years earthquake engineering has been strongly influenced by the implementation of major projects, such as: nuclear power plants, highrise buildings, major dams, offshore oil drilling platforms, longspan bridges, LNG storage tanks, etc. The large cost of these projects and the need for a high degree of safety required a level of earthquake analysis and design much higher than for ordinary structures. As a consequence, the development of earthquake engineering was accelerated by the needs of these special projects.

DEVELOPMENT OF BUILDING CODES

Special structures such as high-rise buildings, major dams, LNG storage tanks, etc., because of their critical importance are usually analysed and designed by making use of the latest research developments. On the other hand, ordinary structures which compose the bulk of modern construction are usually designed according to the requirements of a building code. Because the code is a legal document that specifies a minimum level of design that must be attained by structures, and because it has a large socio-economic impact, substantial changes in code requirements are made slowly and cautiously. In addition, because the building code affects so many agencies, groups, individuals, etc., there is a great inertia against change and developments in the building code tend to lag behind developments in research. In many instances, needed changes in the code are deferred until the occurrence of a destructive earthquake; for example, 1908 Messina, Italy; 1923 Tokyo, Japan; 1933 Long Beach, California; 1971 San Fernando, California; 1976 Tangshan, China. The development of the building code thus illustrates the development of applied earthquake engineering for ordinary construction. The development of earthquake requirements in the Los Angeles city building code is a good example. Until 1933, earthquake design was not required; then the deaths and damage caused by the M6.3 March 10, 1933 Long Beach earthquake produced the requirement that every building must be designed for a minimum horizontal force of 8% of the weight, without consideration of height, shape, rigidity, material of construction, use, foundation condition, or degree of seismic hazard . The code was changed at intervals and the requirements of the present code do take into account the foregoing items. In addition, following the 1971 San Fernando earthquake a requirement was added that every structure over 160 feet in height shall have strength sufficient to resist the effects of earthquakes as determined by a dynamic analysis, and that this analysis shall be based on the ground shaking prescribed by a soil-geology-seismology report. The 1984 Los Angeles code is a great improvement over the 1934 code. The past fifty years, which is a short time in the life of a building code, have seen great improvements in building codes worldwide; and these improvements will certainly reduce loss of life and property damage in future earthquakes. During the past 100 years, over one million persons have been killed by earthquakes and it is the responsibility of earthquake engineers to ensure that this does not happen again during the coming 100 years. Earthquake engineers should examine the building codes in their countries to make sure that the requirements are indeed appropriate to the seismic risk.

NON-TECHNICAL EARTHQUAKE ENGINEERING

A history of earthquake engineering should also examine the development of thinking in governmental agencies, and the thinking of the public. Relatively recent developments in some cities, such as Tokyo and Los Angeles, include improved thinking in city government agencies. National and state government agencies are also giving earthquake hazards increasing consideration. In some regions, earthquake preparedness measures are being taken to reduce the risk to life and property, to prepare to handle the emergency when the coming earthquake occurs, and to mitigate the effects of coming earthquake disaster upon the functioning of the city and the impact on the public. These are noteworthy developments in non-technical earthquake engineering, if we define earthquake engineering broadly to encompass all non-technical as well as technical efforts, directed toward minimizing the harmful effects of earthquakes.

Public understanding of earthquake risk is also important. A great advance in earthquake knowledge possessed by the average citizen has occurred over the past thirty years, and this has resulted in greater support for earthquake preparedness measures. However, even today, the average citizen has a relatively poor understanding of earthquake risks and earthquake engineering benefits. Because of the way the news media handle the topic of earthquakes, the public tends to oscillate between excessive alarm and excessive complacency. Improvements need to be made in public education about earthquake risks and earthquake preparedness, beginning with children in the public schools.

SUMMARY

Over the past fifty years, there has been remarkable progress in earthquake engineering research. Knowledge of earthquake ground shaking and earthquake vibrations of structures has undergone a great expansion. Advances in method of dynamic analysis enable the earthquake response of planned structures to be calculated. Experimental research is providing valuable data on the physical properties of structures and structural elements. The increase in number of research papers published each year is indicative of the progress being made. We have now attained a good understanding of the elastic earthquake response of typical buildings. However, there are many special structures, industrial equipment, etc. whose earthquake survival is important and which need special earthquake engineering research. Also, the question of "maximum credible" or"maximum probable" earthquake needs to be better defined by research, as well as the question of appropriate level of design of structures for such events of low likelihood. And more research needs to be done on designing for controlled damage in the event of large, infrequent earthquakes.

Building codes have also undergone a big development over the past fifty years. The 1984 building codes now handle the earthquake design of structures in a much improved way over the 1934 building codes. However the real test of a building code comes when a city experiences strong ground shaking. Actual structures, as distinguished from ideal structures, are so complex that their behaviour must be tested by strong shaking to establish their adequacy or to reveal inadequacies. In 1984, conclusive tests of modern building codes have not yet been made. It is important that in the future destructive earthquakes be studied with a view to assessing the adequacy of the building code. Many earthquakes have been inspected in the past, and many reports have been written, but too few valuable conclusions have been deduced. Earthquake engineers should prepare ahead of time to learn from coming destructive earthquakes. Thought must be given ahead of time to what can be learned, and preparations should be made ahead of time for the learning process.

When the earthquake comes, everything connected to the earth either directly, or indirectly, will be shaken. All those items whose survival is very important must be given special attention in design and construction to insure against unacceptable damage, and structures must also be designed to protect against injury and loss of life. An earthquake disaster requires three things: 1) the occurrence of an earthquake sufficiently large to produce strong ground shaking; 2) the earthquake must be sufficiently close so that a city experiences strong shaking; and 3) the city must be unprepared for an earthquake, with numerous weak buildings. When these three coincide there is a disaster. Such coincidences were not uncommon in the past, for example,

Earthquake Location	Date	Magnitude	Approx. Nº of Deaths
Hokaido, Japan	Dec 30, 1730	?	137,000
Calcutta, India	1737	?	300,000
Lisbon, Portugal	Nov 1, 1755	8+	60,000
Syria	Oct 30, 1759	?	30,000

Earthquake Location	Date	Magnitude	Approx. Nº of Deaths
Calabria, Italy	Feb 5, 1783	?	30,000
Peru-Ecuador	Feb 4, 1797	?	40,000
Kangr, India	Apr 4, 1905	?	19,000
San Francisco	Apr 18, 1906	8.3	1,000
Santiago, Chile	Aug 17, 1906	8.6	20,000
Messina, Italy	Dec 28, 1908	7.5	83,000
Avezzano, Italy	Jan 13, 1915	7	30,000
Kansu, China	Dec 16, 1920	8.6	100,000
Tokyo, Japan	Sep 1, 1923	8.3	100,000
Bihar, India	Jan 15, 1934	8.4	11,000
Taiwan	Apr 20, 1935	7.1	3,000
Quetta, Pakistan	May 30, 1935	7.5	30,000
Chile	Jan 25, 1939	8.3	28,000
Erzincan, Turkey	Dec 26, 1939	7.9	30,000
Ambato, Ecuador	Aug 5, 1949	6.8	6,000
Agadir, Morocco	Feb 29, 1960	5.8	10,000
Quazin, Iran	Sep 1, 1962	7.0	12,000
Tangshan, China	Jul 28, 1976	7.8	250,000+

The foregoing list is incomplete; many other destructive earthquakes occurred with death tolls numbered in the thousands. Disastrous earthquakes can be expected also in future years, for many existing cities are poorly prepared to resist earthquakes. In addition, in as much as the world's population is increasing by 80 million persons per year and cities are correspondingly expanding, the earthquake risk is increasing. In coming years large earthquakes can be expected to occur close to large cities more frequently than in the past. It is the responsibility of earthquake engineers to insure that the new construction in these cities is earthquake resistant, and that the greatest hazards from old weak buildings are eliminated. The discipline of earthquake engineering is now entering its golden age with greatly expanded knowledge and capabilities, but it is also facing important new problems, for the coming years will construction of large, complex, and costly structures, industrial facilities, and socioeconomic projects which the earthquake engineer must make safe against destructive ground shaking.

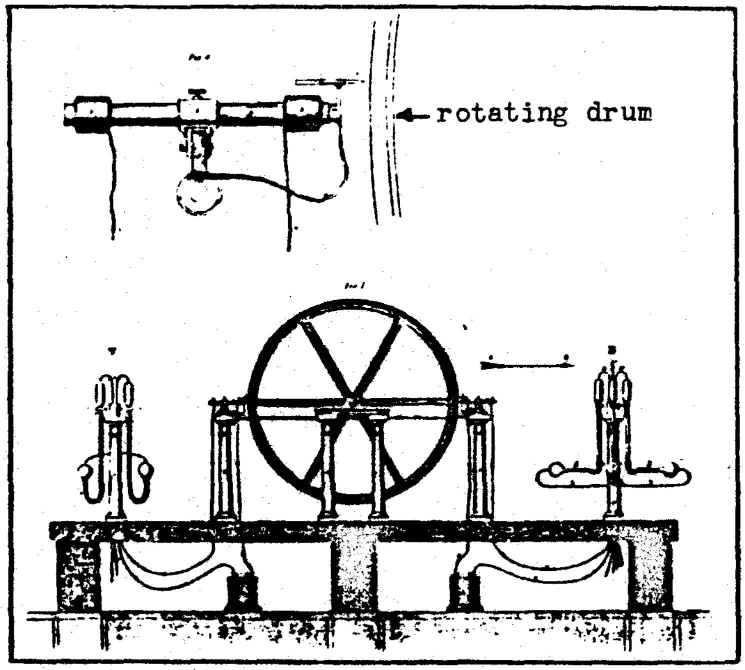

Figure 1. Drawing of Robert Mallet's proposed seismograph (1848). The seismic elements, two horizontal and one vertical, are tubes of mercury which are excited into oscillation by the earthquake. The oscillation of the mercury makes and breaks an electric circuit and this activates a spring-loaded solenoid to press a pencil against a rotating drum thus recording the time of making or breaking the circuit. This would give some information about the oscillations of the mercury.

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