The Effects of the 1906 Earthquake in California on Research and Education

Robert Reitherman, a) M.EERI

The great earthquake that struck on 18 April 1906 and caused a disaster also forged the first link in a chain of research and education effects that extended over the following decades. Now, with a century of hindsight, we have an advantageous point from which to view that earthquake and the developments it parented. We also face two disadvantages. One is that first-hand accounts and obscure documents are either lost or hard to find. The other is that while the centennial of the earthquake has prompted celebration and promotion activities, however appropriate they may be for advancing seismic safety, a different attitude is required for an objective historical review. The research reported here was conducted within such a critical frame of mind, but the final conclusion is not that the research and education impacts of the 1906 earthquake are overrated. Rather, several unacknowledged developments stemming from the earthquake are brought to light. While the first- and second-generation effects constituted a wave of influence that has largely passed by a century later, the tide today in the earthquake research and education field is still persistently higher than it would be if the 1906 earthquake had not occurred. [DOI: 10.1193/1.2187053]

INTRODUCTION

On the occasion of the 100th anniversary of the 1906 earthquake in Northern California, this paper asks the question: What were the effects of that event on earthquake research, and on researchers and their research organizations, and what were the effects on education, and on educators and their students and universities?

It may seem strange to celebrate, not just commemorate, a disaster, but at present that is sometimes the case in the San Francisco Bay Area as the centennial nears. Sensationalist articles on the 1906 earthquake with exclamation points in their titles (Dalessandro 2005) have appeared in the popular press, and more than a dozen organizations in the earthquake field have mounted public relations campaigns. It is tempting and in many cases justifiable to use history to motivate people now, not just to explain what happened then, but this paper restricts its scope to the latter.

In linking causes and effects, we must consider the period preceding 1906 and be alert to trends that were already developing by the time the 1906 earthquake occurred. We must also consider events in other countries that may have influenced developments

a) Consortium of Universities for Research in Earthquake Engineering (CUREE), 1301 S. 46th Street, Richmond, CA 94804-4600

Earthquake Spectra, Volume 22, No. S2, pages S207–S236, April 2006; © 2006, Earthquake Engineering Research Institute
in the United States after the 1906 earthquake. Finally, throughout this examination of
discrete events, we must maintain a wide-angle view of their social and technological
context.

**INFLUENCES FROM OTHER EARTHQUAKES IN THE UNITED STATES**

Three great New Madrid earthquakes of approximately magnitude 8 occurred in De-
cember 1811 and in January and February 1812. Several New Madrid aftershocks in that
undeveloped Mississippi Valley region were as large as any of the Bay Area’s nineteenth-
century earthquakes that are discussed below (Algermissen 1983, p. 40). But the re-
search and education impact of the New Madrid earthquakes was as small as the energy
release was large. The only research on the earthquakes that could be called comprehen-
sive and scientific—in effect, the reconnaissance report for the earthquake—was pub-
lished a full 100 years later (Fuller 1912). Had any comparable earthquakes occurred at
that time in Europe, where as Davison (1927) points out, the modern science of seis-
mology was already beginning, the effects on the development of knowledge would have
been quite different. The societal context of where and when an earthquake occurs, not
just its size in terms of seismological or destructiveness measures, is central to the un-
derstanding of its long-term effects.

In Charleston in 1886 a damaging earthquake struck, and the report written by an
engineer, Clarence Dutton, was the best account of an earthquake in the United States up
to that time (Dutton 1889). But the year 1886 does not mark the initiation of any major
research or education initiative, other than Dutton’s.

In California we can quickly pass over the period from 1542, when Juan Rodriguez
Cabrillo captained a Spanish exploration voyage along the coast, to the 1800s. Spanish
settlement of California was limited to the planting of three primary institutions: the
military (presidios), church (missions), and towns (pueblos). While other European na-
tions in the 1600s and 1700s had cultures that were hospitable to the development of
scientific societies and investigations of wide-ranging curiosity about the natural world,
both in terms of geography and discipline, Spain was not among them. Of course, native
Americans were also present during the Spanish period in California and for centuries
earlier, when there were a number of instances of surface fault rupture, for example, that
might have been recorded. However, that culture understood and took note of earth-
quakes mythologically and orally rather than scientifically and in writing.

In the 1800s two major earthquakes occurred on the San Andreas Fault (1838 and
1865), as did two on the Hayward Fault (1836 and 1868), that heavily shook the San
Francisco Bay Region (Steinbrugge 1968). The extent of development at the time of
these earthquakes, more than their smaller size, helps explain why none of them had the
major impact on research and education that the 1906 earthquake did. The two earth-
quakes that preceded the 1848–1849 Gold Rush occurred when San Francisco was a
hamlet called Yerba Buena with a population of less than 500. In 1850, San Francisco
had a population of only 57,000, and that accounted for almost all of the Bay Area’s
total, and research and educational institutions were not yet established. By 1906, the
population of San Francisco was 372,000 and that of the Bay Area 789,000 (Kircher
Also by that time, the University of California at Berkeley and Stanford University were well established in the region and were operating seismographic instruments, along with governmental agencies such as the Weather Bureau, and astronomy institutes such as the Chabot and Lick observatories.

The two Bay Area earthquakes of the 1860s, though they only affected a sparsely populated region, had some lasting positive effect. Stephen Tobriner points out that in the nineteenth century some designers and building contractors in San Francisco were already experimenting with earthquake-resistant construction features (Tobriner 1986, 1992, 2006). What is today called reinforced masonry has walls composed of two wythes of brickwork with reinforcing steel embedded in grout in between to form a monolithic structural sandwich. That innovation was added to the construction types in California only after the 1933 Long Beach earthquake, and its advent was simultaneously accompanied by a seismic building code that defined structural analysis procedures. Tobriner has found that after the 1865 and 1868 earthquakes “It became a common practice to lay linked iron bars, called bond iron, in exterior walls all around a building” (Tobriner 1992, vol. 9, p. 5337). The question of the efficacy of these nineteenth-century efforts to devise earthquake-resistant construction rules of thumb is outside this paper’s scope. In terms of impact on research, it seems that the generation of scientists and engineers that was launched into the earthquake field by the 1906 earthquake did not seem especially aware of, or at least was not much interested in, that pre-1906 construction tradition.

The most significant overall development in earthquake studies of the past 100 years has been the introduction of quantitative techniques, both in seismology, as with the example of magnitude measurements based on seismograms, and in engineering, as in the case of calculations of lateral design forces. It is true that qualitative construction features designed without benefit of quantitative engineering techniques can still play a useful role in vulnerability reduction for some kinds of construction. However, it is the quantitative line of inquiry—numbers begetting numbers—that is largely responsible for the evolution of earthquake engineering and seismology in the twentieth century.

After the 1868 earthquake, the next large earthquake in California was the Owens Valley earthquake of 1872, of approximately magnitude 8, which was of no engineering interest because there was almost nothing man-made for the earthquake to affect, other than the tiny town of Lone Pine. The earthquake was just as barren for the geologists, who in retrospect should have literally and figuratively had a field day. Josiah Whitney (1819–1896), the state geologist of California at the time, conducted brief fieldwork after the earthquake in Owens Valley, where the fault offsets were impressively large and well defined, and where the arid climate and lack of vegetation were ideal for preserving the trace. He found little of interest, however, when he observed the scarp:

*The ground fractures, which are so carefully measured now after each earthquake, were of small importance, as they were the result, not the cause of the earthquake. To him, when the earth shakes, the ground breaks; to modern theory, when the earth breaks, the ground shakes*” (Hill 1972, p. 53).

That “modern theory” is the elastic rebound theory put forth by Hugo Fielding Reid
(1859–1944) on the basis of his research on the 1906 earthquake (Reid 1908). The concept that strain builds up at various rates in different geologic regions, is suddenly released by fault rupture, and thereby causes ground shaking, has affected the research and education of virtually all earth scientists since then and is the essential theory underlying seismic hazard analysis. Sharing credit with Reid for this seminal development is Bunjiro Koto of the University of Tokyo, who studied the prominent fault offsets from the 1891 Mino-Owari (or Nobi) earthquake in Japan, a magnitude 8 event. Koto realized that the faulting caused the shaking, not the other way around as Whitney mistakenly thought only a few years before. Another research impact of the 1891 earthquake was the data it provided Fusakichi Omori, leading to Omori’s Law concerning aftershocks. The Mino-Owari earthquake of 1891 also caused the creation of the Imperial Earthquake Investigation Committee, whose significant output is indicated by the fact it published volume number 100 in its report series (some volumes having more than one book-length part) on the 1923 Kanto earthquake. In the United States, perhaps Reid’s contribution and the 1906 earthquake are given undue credit as compared to the advances of Koto and Omori and the 1891 earthquake.

In addition to the Owens Valley earthquake of 1872 in California, there was one other magnitude 8 earthquake in the state in the 1800s: the 1857 Fort Tejon earthquake, which occurred far to the south of the San Francisco Bay Area on the southern segment of the San Andreas Fault. Hill (1972, p. 128) speculates:

Surely strike-slip movement would have been recognized, the long and active fault zone would have been traced for several hundred miles, the elastic-rebound theory might have been formulated (certainly if a G. K. Gilbert had been there), and the fault would have some other name.

That opinion is supported by the fact that there was no significant difference in fault study technologies over that 50-year time span that would have prevented such breakthroughs. History is what happens, not what might have happened, and so it was the 1906 earthquake on the segment of the San Andreas Fault in Northern California, not the 1857 earthquake on the segment in Southern California, that had such great impact.

It will come as a surprise to many readers that Andrew Cowper Lawson (1861–1952), head of the geology department of the University of California at Berkeley, mapped the trace of the San Andreas Fault on the San Francisco Peninsula 15 years prior to the 1906 earthquake (Prentice 1999). Yet it took the 1906 earthquake, along with decades of subsequent earth science research, to produce the modern understanding of the fault. Geologists learned from the earthquake that slip along a long fracture zone released the pent-up strain energy explained by Reid. However, plate tectonic theory would not be revealed until six decades later. Hill (1981) explains how geologists of the era following the 1906 earthquake looked at clear evidence of large-scale cumulative lateral offsets of the landscape along fault lines such as the San Andreas, but at the time had no logical explanation for them. As the geologist’s proverb says, “If I hadn’t have believed it, I wouldn’t have seen it.” Hill documents how the earth science understanding of the immediate 1906 era developed over the following 50–60 years, a post-1906 story in which there is still a thread of 1906 earthquake causality, especially because several
crucial roles were carried out by people who became earthquake investigators because of that earthquake: Lawson and his post-1906 interest in geodetic studies of California; Frederick Vickery (1880–1965), who finished his undergraduate education at U.C. Berkeley the year before the 1906 earthquake and went on to get his Ph.D. at Stanford; and H. O. Wood and John Buwalda, who found it credible that kilometers of offset on the San Andreas in the Carrizo Plain had accumulated, and who were both originally Berkeley geologists much influenced by Lawson and the 1906 earthquake.

The name of the San Andreas Fault comes from Lawson’s fieldwork in the San Andreas Valley of the San Francisco peninsula dating back to 1891. Because of the Lawson Report (Report of the California State Earthquake Investigation Commission on the 1906 earthquake) (Lawson 1908), San Andreas was the name that became firmly attached to the segment approximately 500 km long that ruptured in 1906 and that later was applied to this entire 1,000-km-long geologic feature that extends south to Mexico. The fact that the fault was permanently labeled with Lawson’s preferred name indicates the degree of his influence over the 1906 earthquake investigation. John Casper Branner (1850–1922), the head of the geology department at Stanford University, would have named it the Portola-Tomales Fault based on his own pre-1906 fieldwork (Hill 1981, p. 129). The San Andreas Valley had received its name from Don Fernando de Rivera y Moncada, when his band of 20 Spanish explorers camped there on the Feast Day of St. Andrews (San Andrés, or San Andreas) in 1774. (Hoover et al. 1966, p. 391) Gaspar de Portola had hiked into that same valley with his exploration party five years earlier on 4 November 1769, (Hoover et al., 1966, p. 390) but he declined to name it. Had he done so, he would have honored the saint’s day on that date, and one of the most famous faults in the world would today be called the San Carlos Borroméo Fault.

THE 1933 LONG BEACH, CALIFORNIA, EARTHQUAKE

The prime force behind the introduction of widespread seismic regulations in the building code in the United States, the moderate magnitude- (6.3) Long Beach earthquake in Southern California in 1933, raises an important question: Did the 1906 earthquake plant any seeds of research and education that sprouted in 1933, or were the effects of 1933 independent of the earlier earthquake?

Even though over 25 years had passed, the 1906 earthquake was still having an impact in Southern California through students of Lawson at Berkeley and Branner at Stanford. Ralph Arnold, for example, was a successful Southern California petroleum geologist, a former student of Branner, who gave his former professor access to civic and professional society rostrums in the 1920s to talk openly about earthquake hazards, preparing the ground for a reaction to the 1933 earthquake that accepted scientific findings rather than denial (Geschwind 1996, p. 124).

Another influence from 1906, the 1927 “Palo Alto Code,” was “developed with the advice of Professors Willis and Marx of Stanford University” and was “adopted in Palo Alto, San Bernardino, Sacramento, Santa Barbara, Klamath, and Alhambra” in California, specifying “the use of a horizontal force equivalent to 0.1 g, 0.15 g, and 0.2 g acceleration on hard, intermediate, and soft ground, respectively” (Trifunac 2002, p. 27). The engineering knowledge that was to be embodied in the building code regulations
passed because of the 1933 earthquake was already available and had been influenced at least somewhat by the 1906 earthquake, via the work of these Stanford professors. Bailey Willis (1857–1949) figures prominently in the “seismic genealogy” of Stanford discussed later, being handed the mantle of geology and earthquake studies there by J. C. Branner, as well as taking over Branner’s leadership role in the Seismological Society of America. Charles David Marx (1857–1939) was the professor who established the civil engineering department at Stanford when the university was opened in 1891, and who for several years after the 1906 earthquake was a key member of the engineering committee guiding the reconstruction of the campus. The Palo Alto Code and other earthquake engineering thinking in the United States in the 1920s was in turn influenced by advances from abroad, as will be discussed later.

In the context of 1933, the critical role of the 1906 earthquake was to spark an initial blaze of earthquake research and education in California and keep at least its embers burning until the Long Beach earthquake occurred. The 1933 earthquake, unlike the larger one in 1906, happened when the political climate was receptive to implementing knowledge about the seismic hazard of ground shaking and earthquake-resistant design. The new regulatory climate of the 1930s is indicated by the fact that by 1933, a statewide law regulating construction to protect public safety had been on the books for four years; the 1929 dam safety act passed after the disastrous failure of the St. Francis Dam in 1928. The overall societal and governmental context in March of 1933 was dominated by the Depression and the activist response to it by the new administration of Franklin Roosevelt. In maintaining interest in earthquake studies in the years prior to 1933, the moderate-sized (magnitude 6.3) 1925 Santa Barbara earthquake in California also had a large effect, perhaps as large as that of 1906. A historical attenuation relationship exists between elapsed time since the occurrence of an earthquake and the degree of influence of the earthquake on research and policy. (This is in parallel with the ground motion attenuation relationship whereby a smaller energy release, if much closer than a larger one, causes greater shaking intensity.)

Today the building code and associated seismic design methods are a market force creating a strong demand for research and education. This is so ubiquitous we take it for granted. Without widespread seismic regulations in the building code during the years from the 1906 earthquake to 1933, the pioneers in the earthquake field in the United States survived, but never thrived, on meager sources of support and a reception from the wider world of engineering practice and public policy that was usually indifferent and sometimes even hostile. It was a chicken-and-egg problem in that there was little demand for earthquake research and education when there was no code requiring the application of such knowledge, yet with more research and a better-educated cadre of scientists and engineers, it would have been easier to institute a building code.
INFLUENCES FROM EARTHQUAKES AND DEVELOPMENTS IN OTHER COUNTRIES

Space does not allow a thorough review of seismology and earthquake engineering in Japan and Italy at the time of the 1906 earthquake and through the 1920s and 1930s that influenced developments in the United States. Engineering is emphasized in the following brief summary.

EARTHQUAKES AND RESEARCH AND EDUCATION ADVANCES IN JAPAN

Many who have done the seismic calculations for buildings as specified in many editions of the *Uniform Building Code* will recall the familiar 0.133 figure plugged into the base shear formula. While seemingly accurate to three decimal places, this is merely the round number, 10%, increased by another round number, one-third. The 10% figure came from the 1924 Building Code Enforcement Regulations in Japan (Otani 2004, p. 6). The 10% equivalent static lateral design seismic ratio was based on the ground motion level of the 1923 Tokyo (or Kanto) earthquake, as estimated from seismographic records in Tokyo (Naito 1939, p. 11). The one-third increase was an arbitrary amount thought to be reasonable for California seismicity and construction (Steinbrugge 1977). The same 10% figure had another important aspect in the thinking underlying the historic seismic regulations adopted in Japan after the 1923 earthquake: “a structure built in compliance with specified provisions was not expected to resist an earthquake without damage but would sustain damage which could be repaired for a cost of not more than 10 percent of the original cost of construction” (Otsuki 1956, p. 16-3, Muto, 1954, p. 22). Thus, as of 1924 in Japan, we not only have the first building code regulations in the world that govern a large and sophisticated inventory of construction, we also have a well-documented example of performance-based seismic design: a quantitative ground-motion hazard level connected with a performance level quantified in economic terms.

Toshikata (Toshiki, or Riki) Sano of the University of Tokyo was the originator of the seismic ratio (“shindo”), or seismic coefficient design approach, in Japan. Sano’s student, Tachu Naito (1886–1970) of Waseda University, refined and carried out that quantitative method on the scale of reinforced-concrete multistory buildings up to 30 m in height that performed well in the 1923 earthquake. Meanwhile, some of the other largest buildings in Tokyo, designed and built by an American firm, the George Fuller Company, without benefit of the Sano-Naito seismic design method, were heavily damaged (Waseda University, 1986, p. 69). Frank Lloyd Wright’s Imperial Hotel was also significantly damaged, although that fact is even today commonly misunderstood due to Wright’s self-publicizing skills and well-earned reputation as an innovative architect (Reitherman 1980). Wright made a good impression on the popular press in the United States, but it was Naito who influenced the engineering community. H. M. Engle, one of the most influential American earthquake engineers of the time, noted for example that “the three buildings in Tokyo specifically designed by Dr. Naito to be earthquake-resistant actually fulfilled their function in 1923, while many other large structures designed more along customary American lines were subject to very serious damage in many cases in the shock of 1923” (Engle 1929, p. 89). Engle also stated that Naito “after
1923 made available to engineers in this country the details and design of some of those buildings that he designed before 1923 and which survived the shock so successfully” (Engle 1956, p. 39-5).

Leading engineers in the United States such as John R. Freeman and Romeo Raoul Martel were readied for the application of the seismic ratio method and other earthquake engineering know-how developed abroad once there was a mandatory policy in California that required such techniques. Freeman (1855–1932) was author of the influential *Earthquake Damage and Earthquake Insurance* (1932). Martel (1890-1965) of Caltech was the first structural engineering professor in the United States to develop a career-long specialty in earthquake engineering and who was instrumental in the writing of the optional appendix of seismic regulations in the 1927 *Uniform Building Code*. Martel not only attended the 1929 World Congress on Engineering in Tokyo with Freeman and met with leading Japanese engineers there (Hudson 1997, p. 36), he also attended the 1926 Council on Earthquake Protection at the Third Pan-Pacific Science Congress in Tokyo. For brevity, four individuals in Japan and a key publication of each are cited to represent knowledge in Japan that percolated into the thinking of American civil engineers from the turn of the century up to the 1933 earthquake: Fusakichi Omori (1894), Toshikata Sano (Sano 1915), Kyōji Suyehiro (1926, 1931), and Tachu Naito (Naito 1927).

Otani (2006) documents how Japanese professors Omori and Sano of the University of Tokyo learned from their study of the 1906 earthquake. That earthquake, it should be noted, was only one of many earthquakes studied by faculty there by that time. A strong earth science and engineering research and education program concerning earthquakes there dates back to the 1870s, with notable professors such as James Ewing (1855–1935), Cargill Gilston Knott (1856–1922), Thomas Corwin Mendenhall (1821–1924), John Perry (1850–1920), T. Gray (1850–1908), William Ayrton (1847–1908), Fusakichi Omori (1868–1923), Bunjiro Koto (1856–1935), and John Milne (1850–1913), as summarized in Reitherman (1997). Of further note is that the university appointed its first full-time chair of seismology, Kiyokage Sekiya (1855–1896), exactly 20 years prior to the 1906 earthquake in California (Otani 2004, p. 4).

**EARTHQUAKES AND RESEARCH AND EDUCATION ADVANCES IN ITALY**

The 1908 Messina-Reggio earthquake in Italy had a historic effect on the application of structural engineering to the earthquake problem. Freeman (1932, p. 565) goes so far as to say,

*The beginning of scientific study of the mechanics of earthquake-resisting construction followed immediately after more than 100,000 people had been killed in the Messina-Reggio earthquake of 28 December 1908. It began with the appointment of a remarkable committee, comprising nine practicing engineers of large experience and five eminent college professors of engineering.*

Earthquake code regulations were also legislated for the region of the earthquake. While Freeman obtained and, through his influential book, disseminated a valuable English-language summary of the work by Italian engineers after the 1908 earthquake, that summary does not fully give justice to their advances. Luigi Sorrentino (2005) of
the University of Rome “La Sapienza” has compiled and studied the original research papers and government reports and laws of that time. The thinking of Modesto Panetti (1875–1957), a leading member of the 14-member committee mentioned above by Freeman, is represented in the Comuni Colpiti Dal Terremoto report (Panetti et al. 1909), although a number of related regulations and appendices are also essential documents. What Sano called shindo in his research in Japan, and what Panetti called rapporto sismico were what was later called in English the seismic ratio or seismic coefficient, i.e., the percentage of gravitational acceleration to be applied to a mass to obtain its seismic inertial force. Apparently, these Japanese and Italian developments occurred independently. Sorrentino has also found that Arturo Danusso (1880–1968), who was intensively involved in engineering research following the 1908 earthquake though not a member of the committee, developed an early response spectrum method to compute the response of single- and two-degree-of-freedom systems subjected to harmonic motion, and suggested the design strategy of tuning the building’s dynamic properties to lessen response.

Panetti was aware that estimates of ground accelerations were only approximate but that they provided a rational means of structural analysis. In Japan, Omori (1900) published an intensity scale keyed to estimated accelerations, derived from his shake table experiments conducted with John Milne. In Italy, Adolfo Cancani (1856–1904) and Guido Alfani (1876–1940) were working to quantify the intensity scale of Giuseppe Mercalli (1850–1914) with relationships between observed intensity effects and estimated acceleration levels, bridging between the information collected by seismologists and the information needed by engineers. It is curious that this quantitative aspect of the Mercalli (or Mercalli-Cancani-Sieberg) Intensity Scale was not carried into U.S. practice when the “Modified” version of it was published by Harry Wood and Frank Neumann (1931).

The advanced level of earthquake engineering of Panetti and his colleagues that has recently been revisited by Sorrentino included converting allowable design stresses to actual stresses and then comparing the acceleration levels that corresponded to the structure’s elastic limit to the force level twice as great, and to the force level four to five times greater. The fact that the upper stories of the structure displace more and experience higher accelerations was reflected in a distribution of increasing design force levels up the height of the building, only much later to be incorporated into U.S. practice via the inverted triangular distribution of base shear. Consideration was also made of what we would call the importance factor, with higher design forces for a building with more occupants. Calculations were made of surviving buildings in the 1908 earthquake to estimate their lateral strength in terms of a back-calculated seismic ratio, whereas no such calculations appear to have been done after 1906. Even the need to check foundation elements for uplift due to overturning moments was noted. One reason the Italian engineering advances from the 1908 earthquake were ahead of the Americans in their post-earthquake studies at almost the same time may be that the Italian engineers explicitly included a wide-ranging review of the relevant literature from Japan and America, as well as from Italy and elsewhere in Europe. The Americans investigating the 1906 earthquake seemed much more insular in their research approach. Davison (1927, p. 152)
notes that the seismological content in the Lawson Report, while impressive, was also somewhat exclusive in its lack of reference to "corresponding features in other earthquakes."

Freeman (1932, p. 371, p. 805 ff.) documents the conclusion of influential American engineers who investigated the 1906 earthquake that a design wind load of 30 pounds per square foot in California was an adequate seismic design loading, and that often only half that was actually adopted in the building code, as was the case in San Francisco after 1906. Freeman’s opinion of the adequacy of this approach can be summarized by the index entry for that discussion in his book: "Wind stresses, unsafe guide to earthquake stress analysis." It is not clear why American engineers, even after they were thrust into earthquake engineering by the 1906 earthquake, pursued the evolutionary dead end of using a surrogate wind load for seismic design purposes. They did so at the same time that engineers in Japan and Italy were thinking and calculating in a much more advanced way that opened the door to modern earthquake engineering.

Arguably the most fundamental engineering development in the earthquake field, the seismic ratio method, was invented and refined in Japan and Italy. Perhaps the second major engineering development to come, the response spectrum method, was already conceptualized by Danusso in Italy after the 1908 earthquake, and as of the 1920s in Japan, Kiyogi Suyehiro (1877–1932) had developed his displacement-based mechanical response spectrum instrument for analyzing an earthquake record (Suyehiro 1926). Response spectrum method developments by Biot (Biot 1932) and others at Caltech were to prove to be influential in the United States and elsewhere, but they were to begin only in the 1930s (Trifunac 2002).

THE LAWSON REPORT

Given the context of what had been contributed from elsewhere and other events, what were the effects of the 1906 earthquake in California? The two-volume Lawson Report (Lawson 1908) is clearly a notable and direct effect of it. It assembled an impressive amount of information on the geology and engineering fieldwork that had been conducted by dozens of individuals, though it had very little documentation of societal effects. While reports on the earthquake on the topic of what is now called emergency management and emergency response were published by government agencies (see Cantor, 2006, in this issue), the 1906 earthquake occurred during an era when the social sciences were just beginning to be established in academia, especially in California. Quarantelli (2005) has brought to light a previously obscure and interesting instance of social science research published by Eduard Stierlin on the 1908 Reggio-Messina earthquake, but that appears to be a lone example from that era. The Columbia University Ph.D. thesis published in 1920 by Samuel Prince on the 1917 ship explosion disaster in Halifax, Nova Scotia, is the first well-known social science work on a disaster, and such research was not undertaken on an ongoing basis until the establishment in 1964 of the Disaster Research Center at Ohio State University. The 1906 earthquake offered a rich set of data for social scientists to study, but apparently their field was not yet mature enough to conduct research on the event.

The second volume of the Lawson Report containing seismograms compiled from
all over the world documents that the earthquake was one of the first large-magnitude earthquakes to be so well observed by seismologists (Hough 2005). As of 1903, seismologists already constituted a worldwide community of scientists, had formed the International Association of Seismology, and were holding major conferences. The triumvirate of today’s academic research establishment with regard to earthquakes—earth sciences, engineering, and social sciences and emergency management—developed approximately in that order.

Even 100 years later, researchers still consult the Lawson Report, as is the case in several papers published in this special issue of *Earthquake Spectra*. In the educational arena, it is still an often-used text in university courses on earthquakes in geology and civil engineering departments. Asked by the Geological Society of America to pick the single most important publication of the twentieth century on the San Andreas Fault, Prentice (1999) singled out the Lawson Report. Four of the members of the California State Earthquake Investigation Commission were geologists and four were astronomers. (At that time, scientists who ran astronomical observatories, along with those responsible for meteorological stations, often were also the only scientists who recorded earthquakes, at least until seismology developed into its own specialty.) The members of the commission involved in producing the report included Andrew C. Lawson; J. C. Branner; Grove Karl Gilbert (1843–1918), U.S. Geological Survey; Harry Fielding Reid, Johns Hopkins University and the Carnegie Institution; and George Davidson (1825–1911), U.C. Berkeley geodesy and astronomy professor and formerly of the Coast and Geodetic Survey and first president of the Seismological Society of America. In *Founders of Seismology*, Davison (1927, p. 152) notes that prior to 1906 only Gilbert had any reputation for the study of earthquakes. But because of the earthquake, all of these key individuals along with several other contributing members of the team that produced the Lawson Report stayed in the new field of earthquake studies and played important subsequent roles in the development of the field.

**HARRY WOOD, THE CARNEGIE INSTITUTION, AND THE SEISMOGRAPHIC PROGRAM OF CALTECH**

Most readers know of the Lawson Report via the 1969 reprint by the Carnegie Institution. Readers who own an original 1908 edition should hold on to it: only 1,000 were printed (Prentice 2005). “That there was such strong interest in and demand for what at that time was a 60 yr old scientific publication speaks volumes for its importance and place in the history of the earth sciences” (Prentice 1999, p. 83). The foreword of the 1969 reprint edition, as Prentice points out, provides fascinating information in and of itself: “The reprinting has been made possible by a grant of $15,000 from the Harry Oscar Wood Fund for this purpose.” Wood (1879–1958), left all of his property to the Carnegie Institution, and in a letter to the executor attached to his will said he was primarily interested in his bequest funding research on “strong earthquakes in their central region. I have less interest in conditions in the deep interior of the earth, or in general physical theories or hypotheses relating to global seismology.” Many seismologists have
studied earthquakes merely as a convenient way of “taking an X-ray” of Earth’s interior, while Wood promoted the study of their effects at the surface, that is, the study of earthquakes for their own sake.

At the time of the 1906 earthquake, Wood was an instructor in the geology department at Berkeley, specializing in mineralogy. Without the 1906 earthquake, he probably would have had a career as a mineralogist. After Lawson recruited him into the state earthquake investigation commission’s team and assigned him the important task of studying the intensity of ground shaking in San Francisco, Wood became a seismologist for life, and one of the more influential ones of the twentieth century, even though he had more than his fair share of ill health that hindered his productivity. We shall see that Wood was instrumental, in more ways than one, in the establishment of seismology at Caltech.

Almost as significant as the individuals who wrote the Lawson Report is who published it: the Carnegie Institution of Washington, D.C., one of the nonprofit organizations set up by the philanthropy of Andrew Carnegie, the richest man in the world at the turn of the century. Within a week of the earthquake, both Lawson and Branner, unknownst to each other, sent telegrams to Robert Woodward, president of the Carnegie Institution, asking for financial support for a team to study the earthquake. Branner asked for $1,000 and Lawson for the even more princely sum of $5,000 for the total reconnaissance and publication effort (Geschwind 1996, p. 29), or approximately $20,000 and $100,000 in today’s dollars. Though the report is that of the committee given its charge by Governor Pardee, and in its full title is the Report of the State Earthquake Investigation Commission, California provided no funding for its publication or for the investigators’ travel or other expenses. The Carnegie Institution not only underwrote the publication, but it involved itself in earthquake research prompted by the 1906 earthquake such that it would continue to be a major funder to the young earthquake field over the coming decades. “Major” is used relatively.

Geschwind (1996) notes that Harry O. Wood, the primary continuing contact between the earthquake field and the Carnegie Institution, was funded in 1921 at the Institution with a research associate position that had a salary of $3,500 per year, and there was a further $3,500 annual budget for an Advisory Committee in Seismology (Geschwind 1996, p. 118). Laughably small sums today—even converting $3,500 in 1921 to today’s dollar value of a little over $30,000—but such sources of support at that time stand out in the context of the almost total absence of any other funding. The advisory committee included Lawson and H. F. Reid—direct ties to 1906—and Bailey Willis, the geologist who replaced J. C. Branner at Stanford as the leader of its earthquake studies and who followed Branner as SSA’s president. Presaging the involvement of Caltech into the earthquake field, Robert Millikan, who as of 1921 was president of Caltech (though technically called chair of the executive council), and who would receive the Nobel Prize for physics two years later, was also a member of Wood’s committee.

The recruitment of Millikan by Wood into the still-tiny cadre of scientists and engineers in the United States who were interested in earthquakes was to prove extremely significant with regard to a later earthquake. The Millikan Report issued after the 1933
Long Beach earthquake, produced by a Joint Technical Committee of representatives of various organizations, including Caltech geologist John Buwalda and engineer Romeo Martel, was perhaps the most important report on that earthquake. It had a great effect in making respectable the kinds of seismic safety recommendations that prior to the earthquake were dismissed as mere “academic” speculation in the negative sense of the word. Geschwind (1996, p. 225) credits the Millikan Report, for example, with rotating 180 degrees the pre–Long Beach earthquake viewpoint of the *Los Angeles Times*, which was that there was no significant earthquake hazard in Southern California and that therefore nothing had to be done.

The seismographic instrument that was co-invented by Wood with Mt. Wilson Observatory astronomer John Anderson (1876–1959), the Wood-Anderson Torsion Seismograph, deployed in a small array in Southern California in 1923, was later to produce so much valuable data that it led Charles F. Richter (1900–1985) to devise the magnitude scale (Richter 1935). In other words, the magnitude scale was devised to make sense of the seismograms recorded by the Wood-Anderson instrument. When Richter titled his historic paper “An Instrumental Earthquake Magnitude Scale,” the “instrumental” part of the title referred explicitly to the instrument that Wood had the lead role in developing. Richter’s formula for calculating a Richter or local magnitude is calibrated to the amplitude in micrometers, log base 10, corrected for an epicentral distance of 100 km, that the Wood-Anderson seismograph records. Kiyoo Wadati (1902–1995) had in 1931 plotted ground motion amplitudes versus distance, presaging the breakthrough by Richter, but it was the latter who went on to develop a workable and widely used magnitude scale. By 1923, the Carnegie Institution was funding a seismology research program with an annual budget of $20,000, and earthquakes were one of the small number of topics being funded by the National Research Council, for which Wood worked in World War I and where he began to develop his influential Washington contacts (Geschwind 1996, p. 124). Wood’s seismology data collection effort in Southern California was headquartered in Pasadena, but not on the Caltech campus.

By 1927, the small array of Wood-Anderson seismographs and associated supporting program of the Carnegie Institution in Pasadena were inherited by Caltech (Caltech Archives 2003). Note that Wood’s work in establishing in 1923 the seismographic array that evolved into the Caltech Seismology Laboratory was several years prior to (1) 1926, when John Buwalda established the division of geological sciences at Caltech; (2) 1927, when Charles Richter joined the Caltech Seismological Laboratory; and (3) 1930, when Beno Gutenberg (1889–1960) added the luster of a prominent European geophysicist to Caltech’s seismology faculty (Caltech Seismological Laboratory 2004). Buwalda was a protégé of Lawson, hired away from U.C. Berkeley, and he provided a boost to the initial influence of Wood on seismology at Caltech. “He [Buwalda] set things up here very much in the image of Berkeley, with even greater emphasis on seismology...He brought the idea from Berkeley. Berkeley had seismology, and he thought we ought to have seismology, too, because we’ve got just as many, perhaps even more, earthquakes” (Sharp 1998, p. 23). Whether one emphasizes the role of Wood or of Buwalda in the origination of Caltech’s seismology program of education and research, there are causal links that connect back to the 1906 earthquake.
THE SEISMOLOGICAL SOCIETY OF AMERICA

The principal leaders and supporters from inception onward of the Seismological Society of America (SSA), as well as the majority of the members, have been earth scientists, not engineers. It is interesting to note, however, the observation of one of the principal founders: “The idea of organizing a seismological society may have occurred to many people, but the one whose ideas resulted in concrete action was William R. Eckart, San Francisco engineer” (Townley 1922, p. 1). The first organizing meeting, attended by 13 people, was held at the California Promotion Committee Assembly Hall in San Francisco on 30 August 1906; it was organized with a charter by November and it had the first meeting of its board of directors on 1 December of that year (Byerly 1964). For SSA to be in business only a few months after the earthquake was seemingly a rapid and auspicious beginning. But it was not until 1911 that the society managed to produce its first issue of the Bulletin of the Seismological Society of America (BSSA). That flagship publishing enterprise of SSA might have foundered without the editorial efforts of Sidney Townley, an astronomy professor at Stanford and all-around deputy of Branner in earthquake affairs who served as SSA’s secretary and the Bulletin’s editor for many years, being relieved in the latter duty by Berkeley geology professor George Louderback (1874–1957) only in 1935. Another prerequisite for the success of the journal was the agreement of Stanford University Press to be the publisher. A third essential ingredient was the donation of $5,000 by Robert Sayles, a geologist at Harvard. J. C. Branner, third president of SSA after George Davidson and Andrew Lawson, occasionally contributed his own funds to keep the publication going, and the Carnegie Institution that published the report on the 1906 earthquake also occasionally had to make donations to sustain the society (Byerly 1964).

BSSA provided a forum for all of the disciplines involved in the earthquake field for several decades. It was not until 1948–1949 that the Earthquake Engineering Research Institute was founded, only slowly to build up its membership and eventually begin publication of its journal, Earthquake Spectra, 25 years ago in 1981. In its first seven decades, SSA, largely by itself, “carried the torch” of producing the main multidisciplinary journal in the field in the United States. Thus, if only that one seed had been planted by the earthquake, it would be cause for commemorating the centennial of the 1906 earthquake and its effects on education and research.

THE EFFECTS ON STANFORD UNIVERSITY

At Stanford, the family tree of influential professors involved in earthquake education and research extends in a continuum from 1906 to the present. A summary “seismic genealogy” chart of the transmission of earthquake research and education at Stanford University, from Branner on, is shown in Figure 1. The names of other significant individuals could be hung on this simplified family tree, but nonetheless it provides a convenient multigenerational historical framework.

One of the individuals prominent at the 1956 World Conference was Lydik Jacobsen (1897–1976), EERI’s first president and a mechanical engineering professor at Stanford interested in vibration phenomena. He had a major influence on a student of his, John
Blume (1909–2002), who was to be one of the eminent figures in earthquake engineering of the latter half of the twentieth century. Blume, who had an interest in earthquake engineering as a young man, later recalled why he selected Stanford University:

One reason I chose Stanford was that they had worked on the shaking table down there, and also had a background of earthquake damage in 1906—very severe damage, by the way. And Bailey Willis had attracted my eye. He was the ebullient geology professor who literally bounced when he walked (Blume 1994, p. 8).

After getting his undergraduate degree at Stanford in 1933, Blume then did two years of graduate work to obtain an engineer’s degree, working on his thesis with Jacobsen and taking every course Jacobsen taught, while obtaining other earthquake-
engineering knowledge from courses in geology and aeronautical structures. He recounted that “There was no program in earthquake engineering at Stanford, or anywhere else for that matter, so I more or less had to write my own program” (Blume 1994, p. 8). The engineering side to the study of earthquakes within academia in the United States matured later than in the earth sciences.

Blume did work for the Coast and Geodetic Survey, helping begin its vibration studies of buildings and other structures (Blume 1994, p. 10ff). He later had a major influence on Stanford’s earthquake research and education efforts, not only with regard to the founding of the John A. Blume Earthquake Engineering Center and by providing funding for graduate students working in earthquake engineering, but in the way his advanced thinking left an imprint on the direction Stanford took in its civil engineering department. Blume championed advanced analytical methods to account for inelastic behavior. He also thought probabilistically during somewhat rigidly deterministic times and perhaps influenced Stanford in that regard, though the prime mover in that subject at Stanford was Jack Benjamin (1917–1998), and later, C. Allin Cornell.

A critical person in the pedigree of earthquake engineering at Stanford was Lydik Jacobsen. He had been recruited into the earthquake field with the help of Bailey “Earthquake” Willis, the Stanford geology professor and active earthquake researcher who followed Branner. In 1927, when Jacobsen obtained his Ph.D. from Stanford in physics and joined the faculty, he started a vibration laboratory that included a shaking table suitable for earthquake simulations with models. That type of experimentation was central to the thesis work of Blume. The funding for Jacobsen’s laboratory was obtained by Willis (Blume 1979); this mirrors an earlier gesture of support to the engineering study of earthquakes by a Stanford geology professor: J. C. Branner motivated F. J. Rogers to conduct his shake table testing after the 1906 earthquake (see Figure 2), the first in the United States, to investigate the response of different kinds of soils (Rogers 1908).

Willis joined the Stanford faculty only in 1915, so his own career does not directly
tie back to 1906, but 1915 was a time when the original team of Stanford professors who participated in the Lawson Report and the founding of the Seismological Society of America was still active. Branner, for example, was not only the leader of a dozen Stanford students doing reconnaissance work on the 1906 earthquake, but “during the period from 1911 to 1921, Dr. Branner, at his own expense, sent investigators to study seven different earthquakes which occurred in different parts of California” (Townley 1922, p. 3). Townley also notes that the core of the Stanford geology department’s collection of earthquake-related publications was established when Stanford acquired Branner’s 8,000 personally owned works, and then later acquired from him the seismology library of Compte de Montessus de Ballore.

By a per-professor measure, Stanford had a large engineering and earth science participation rate in the earthquake field as compared to the University of California across San Francisco Bay. As of 1911 when BSSA began publication, the 14 Stanford-affiliated members in the Seismological Society of America added up to twice the comparable Berkeley figure. (SSA 1911) One explanation for why Stanford had a larger presence in the field than its neighboring university across the bay is precisely that fact—Berkeley was across the bay, that is, farther from the San Andreas, and thus was only moderately shaken in 1906; the University of California buildings were only slightly damaged. By contrast, buildings at Stanford were very near to the fault’s emanation of vibrations and were severely damaged, with 37% of them suffering either complete collapse or the fall of at least half their wall area (Smith and Reitherman 1984) (see Figure 3).

The profound effect of the earthquake on Stanford is indicated by the fact that the president of the university, David Starr Jordan (1851–1931), not only supported the efforts of his faculty to study the earthquake, he wrote a book about it (Jordan 1907). Jordan was not by scientific background predisposed to author such a work, as he was an ichthyologist. But the fact that he had such a keen interest in earthquakes and was followed in his post in 1913 by none other than the sire of the Stanford lineage in the earthquake research and education field, J. C. Branner, makes Stanford stand out even more, although as noted earlier, Caltech was to have a president, Robert Millikan, with more than a passing interest in earthquakes as well.

Without the 1906 earthquake, Branner might well have spent most of his career studying things much different than earthquakes (mineral resources, for example), as did many geologists of the time. Prior to arriving at Stanford he worked for the Pennsylvania state geological agency mapping anthracite coal-producing region, then was state geologist of Arkansas mapping bauxite deposits. But if not for the 1906 earthquake, Branner would probably have concentrated on Brazil—one of the least seismic regions on Earth—to the exclusion of most else; he was interested in all things Brazilian. And he would not have dedicated so much of his career to the subject of earthquakes, nor would he have wielded such a strong influence over his contemporaries in developing that field.

**THE EFFECTS ON THE UNIVERSITY OF CALIFORNIA, BERKELEY**

In seismology at U.C. Berkeley, there is continuity from the first generation of geology faculty there who studied the 1906 earthquake onward to today. It is still true that
the personal transmission of knowledge and motivation, from instructor of one generation to student of the following generation, is essential to the sustainability of the field. See Figure 1 for a simplified “seismic genealogy” chart that is helpful in summarizing person-to-person continuity in the field as well as indicating who was a contemporary of whom. Although a generation later than that of Berkeley faculty members A. C. Lawson, George Louderback, or Harry Wood, Perry Byerly (1897–1978) had a keen appreciation for the great 1906 earthquake that occurred on the home turf of the Berkeley seismological laboratory that Byerly established in modern form. Lawson personally recruited Byerly, and Byerly in turn handed the mantle of U.C. Berkeley seismology to Bruce Bolt (1930–2005) when he induced Bolt to join the faculty there in 1963. Bolt’s career brings us to present time.

Lawson’s article on the first page of the first issue of the Bulletin of the Seismological
The Society of America stated both a personal and a broader historical fact: “This awakening interest [in the United States] in the phenomena of earthquakes dates chiefly from the California earthquake of 1906” (Lawson 1911, p. 1). Without the 1906 earthquake and his energetic response to it, Lawson might well have devoted himself to the subject he found dear, and which he pursued for many years even after 1906: mining.

If one stands today at the Hearst Mining Building on the Berkeley campus and gazes eastward, it is along the line of the “Lawson tunnel,” or the Lawson addition (Lawson Adit), the tunnel bored into the hill behind Hearst Mining to give students practical experience in that line of work (Figure 4). George Louderback (1874–1957) appropriated the tunnel for earthquake research beginning in 1939, extending it farther east to explore through the nearby Hayward Fault fracture zone (Berkeleyan 2002). Louderback was one of the three people—along with fellow Berkeley geologist, Joseph Le Conte, and Alexander McAdie, who headed the San Francisco office of the U.S. Weather Bureau—who drew up the incorporation papers of the Seismological Society of America in the fall of 1906. Louderback’s name will frequently be seen on fault maps of the Bay Area today due to the fact he remained dedicated to the geological study of earthquakes throughout his career, beginning soon after the 1906 earthquake when he joined the Berkeley faculty. Like Lawson, Louderback was primarily a mining engineer before the earthquake.

In civil engineering, Berkeley over the past several decades, beginning after World War II and increasingly so after about 1960, has been prominent in the field of earthquake engineering. The primary bearer of the earthquake engineering torch at Berkeley
after 1906, Charles Derleth (1874–1956), apparently did not pass on his youthful passion for the subject to the faculty who extend into our contemporary era, though his career at Berkeley overlapped with that of the first post–World War II faculty hires who developed earthquake engineering careers. Derleth was not the only civil engineering faculty member at Berkeley interested in earthquakes in the first few decades of the twentieth century, but in this brief treatment he can be singled out.

According to Geschwind (1996, p. 63), “Frustrated by his lack of success, Derleth after 1907 ceased to urge greater earthquake preparedness in California. Over the next two decades, California engineers would pay only scant attention to seismic hazards.” A future earthquake engineer, Joe Nicoletti, who was a civil engineering student at U.C. Berkeley beginning in 1941, recalls that there were no earthquake engineering courses or seminars offered at that time (Nicoletti 2005). Derleth became dean of what was called the College of Civil Engineering in 1907 and served in that post until 1930, when the separate civil, mechanical, and electrical colleges were combined, and he then became dean of the College of Engineering until 1942. One suggestion for why Derleth did not contribute more to earthquake engineering research and teaching after his initial enthusiasm in 1906 is that serving as a dean for most of his career was a preoccupying university responsibility (Sitar 2005).

The first of the individuals who were to become renowned for their earthquake engineering contributions on the Berkeley faculty in civil engineering in our contemporary era (roughly speaking, those who joined the faculty by 1960) include the following: Boris Bresler (joined the faculty in 1946), T. Y. Lin (1946), Egor Popov (1946), Robert Wiegel (1946), Ray Clough (1949), Harry B. Seed (1950), Joseph Penzien (1953), Jack Bouwkamp (1957), Hugh McNiven (1957), and V. V. Bertero (1960) (Penzien 2004, p. 24). They all entered the earthquake engineering field afresh as young faculty at Berkeley, rather than being recruited to come to Berkeley to fill defined earthquake engineering faculty positions or arriving with previous earthquake engineering qualifications. Clough and Penzien, for example, developed a structural dynamics course and wrote their famous textbook without drawing on previous earthquake engineering or dynamics courses at Berkeley (Clough and Penzien 1975).

This does not in any way downplay the achievements of faculty at Berkeley in inventing how their civil engineering department would teach students and conduct research concerning earthquakes. To the contrary, it is all the more impressive when professors achieve great competence in a subject that was not even taught when they were in school, and are forced to develop their courses, textbooks, and research methods unmentored.

EFFECTS ON THE DEVELOPMENT OF STRONG-MOTION SEISMOGRAPHS

Charles Derleth reached a pessimistic conclusion after the 1906 earthquake:

> Many engineers with whom the writer has talked appear to have the idea that earthquake stresses in framed structures can be calculated, so that rational designs to resist earthquake destruction can be made, just as one may allow for dead and live loads, or wind and impact stresses. Such calculations could lead to
no practical conclusions of value (Derleth 1907, p. 314).

George Housner has quoted this statement from Derleth to indicate the limitations in the state of knowledge at that time, and how it was necessary for the field to develop further before engineers could rationally calculate seismic loads and effects on structures (Housner 1995). Even as of 1940, Arthur Ruge, professor of engineering seismology at MIT and the first to hold such a position in the United States, noted that “The natural tendency of the average designing engineer is to throw up his hands at the thought of making any dynamical analysis at all....” (Ruge 1940, p. 307). Measurement of the motion of the ground and of structures during earthquakes, and analytical tools such as the response spectrum method were needed for engineers to quantify the seismic forces they should design their structures to resist.

Key advocates of the development and deployment of strong motion instruments, such as John Freeman, achieved an initial success by having Coast and Geodetic Survey accelerographs developed and in the field by 1932 (Stepp et al. 2001, Reitherman 1997). That is, prior to the 1933 Long Beach earthquake, having as motivating disasters only the 1906 earthquake and the more recent but much smaller and less devastating 1925 Santa Barbara earthquake, hard-working advocates such as Freeman were able (just barely) to get a federal strong-motion recording program initiated. Because one person, Freeman, was so influential in advancing the cause of strong motion recording, and the entire earthquake engineering field, any influence of 1906 on him is a significant thread that ties many developments in the field back to that earthquake. There are more index references to the 1906 earthquake than any other in his book that defines the state of knowledge as of 1932, excepting only the 1923 Kanto. If only because of its effect on Freeman, the 1906 event had a far-reaching influence, even if modest and indirect, on the development of strong-motion seismology.

THE INVENTION OF THE MODERN ELECTRIC RESISTANCE STRAIN GAUGE

The 1906 earthquake significantly and directly influenced the invention of one of the twentieth century’s most ubiquitous engineering instruments, the modern strain gauge. The electric resistance strain gauge was co-invented by Edward Simmons at Caltech and Arthur Ruge at MIT, as indicated by the fact that early strain gauge model numbers were preceded by “SR,” the initials of their last names (Reitherman 2003, p. 16). Ruge was an expert in dynamics at MIT at a time when that university was prominent, or perhaps preeminent, in the United States in that subject area, whether with regard to the dynamics of acoustics, aeronautics, blast and impact, or earthquakes. He, along with Jacobsen, was one of the very few people in the United States at this time who was familiar with seismic experimentation with structural models (Ruge 1934).

Ruge hit upon the strain gauge concept in the mid-1930s while conducting small-scale shake-table seismic testing in his vibration laboratory in the basement of Building 1 at MIT, illustrated in Figure 5. He was testing a model of an elevated water tank. “He had received funds from insurance companies because the elevated water tanks had collapsed in the San Francisco earthquake of 1906” (Meier 2002). The specific funding
source was Factory Mutual Insurance Companies, the organization that John R. Freeman was associated with for many years. A thread of influence is tied at one end to the 1906 disaster and then extends through three decades to the invention of the modern strain gauge at the other. Ruge, motivated and funded by the 1906 disaster, worked completely independently from Simmons and would have achieved this momentous invention in the absence of the work done at Caltech that came from nonseismic research. One could also state the converse, that the invention would have come via Simmons without the earthquake-influenced work of Ruge, but nonetheless there is a direct causal connection between 1906-motivated earthquake engineering research and this invention. It is puzzling why this earthquake engineering connection with one of the most important engineering inventions of the twentieth century has been overlooked, and that it is published here in our field’s literature for the first time (other than in a work by the author in 2003).

**Figure 5.** Professor Arthur Ruge (foreground), c. 1936, in his laboratory at MIT conducting earthquake shake table testing of a model of an elevated water tank. During this research project, he independently invented the electric resistance strain gauge. The research was funded by Factory Mutual Insurance Companies out of concern for water tanks that had collapsed in the 1906 earthquake in Northern California. (Photo credit: MIT Museum)
THE EFFECTS OF THE 1906 EARTHQUAKE IN CALIFORNIA ON RESEARCH AND EDUCATION

Figure 6. The cover of the proceedings of the first of the world conferences on earthquake engineering, held in 1956 on the 50th anniversary of the 1906 earthquake in California.

THE WORLD CONFERENCE COMMEMORATING THE 50TH ANNIVERSARY OF THE 1906 EARTHQUAKE

In addition to our view of the 1906 earthquake 100 years later, we should also consult the viewpoints of those who observed its 50th anniversary in a historic event at the University of California at Berkeley. To be precise, it was not the “First” World Conference on Earthquake Engineering that was held in June of 1956, as we refer to it today; it was entitled the “World Conference on Earthquake Engineering” (Figure 6). Dr. Kiyoshi Muto (1903–1989) and others in Japan organized a conference that was held in Tokyo and Kyoto in 1960, which they formally named the “Second World Conference on Earthquake Engineering,” and at that point the 1956 conference commonly became known as the First. Muto and his colleagues deserve the credit for the establishment soon after the 2WCEE of the organization that has overseen and sustained the world conference series to date, the International Association for Earthquake Engineering.
Conference attendance in 1956, which was from more than a dozen countries, was impressive (see Figure 7) and was a significant accomplishment for the conference organizer, the Earthquake Engineering Research Institute, still a small and all-volunteer organization. (Even in the 1970s, EERI shared a tiny office and one-person staff with the Seismological Society of America.) The keynote talk was by Harmer Davis, head of civil engineering at Berkeley, who stated the case for the influence of the 1906 event in the first sentence of his paper: “This is an anniversary of an event which focused not only general attention but scientific attention on the problems that are created by the subject that brings us here” (Davis 1956, p. A-1). That is precisely the topic investigated in this paper—the “scientific attention” focused by the earthquake. Professor George Housner, president of EERI, in his preface to the proceedings listed two purposes of the 1956 conference, the first of which was “Observing by an appropriate technical meeting the fiftieth anniversary year of the destructive San Francisco earthquake of 1906,” and the second was to pool the knowledge from around the world concerning earthquakes and earthquake-resistant construction (Housner 1956).

Reports from other countries at the 1WCEE traced the lineage of earthquake engineering in their regions back to earthquakes other than the one in 1906 in California. New Zealand reported that great strides had been made there since 1931, because that was the year of the Hawke’s Bay earthquake (Murphy 1956). At the beginning his paper, Perry Byerly cited a famous seismologist of a preceding generation, Compte de Mont-
essus de Ballore (Byerly 1956, p. 1-1). In the United States, “1906” in the earthquake field means the earthquake of 18 April in California, but de Ballore, one of the leading seismologists in the world at the turn of the century, moved from France to the Western Hemisphere because of the much larger magnitude Chilean earthquake of 17 August 1906 that devastated Valparaiso, and caused many times more deaths—approximately 20,000. The count became the first director of the new Seismological Service of Chile in 1907, and in 1909 he instituted a university course for engineers on earthquake-resistant construction (Servicio Sismológico 1911). In a striking similarity with the San Francisco disaster, the Valparaiso earthquake of 1906 did not immediately result in seismic building codes—that awaited the 1930s, when engineering and public policy had become more developed (Bertling 1956, p. 20-3).

Standing at the benchmark of knowledge provided by the 1956 conference and viewing the 1906 earthquake from that historical context, we can see that the influence of the 1906 earthquake in California was becoming hard to trace, due to the attenuation effect of the passage of time and also because many other important seismic threads had been spun in that intervening 50-year time span. The 1964 Alaska earthquake and the 1971 San Fernando earthquake in the following two decades were to be the primary motivators behind the 1977 enactment of the National Earthquake Hazards Reduction Program (NEHRP). Because the majority of NEHRP funds, approximately $100 million per year, have been spent on research and education, it has wielded a great influence that has diluted that of the 1906 earthquake in that arena. And because the current era with its NEHRP funding introduces a major subject in its own right, we end our narrative at this point with the 50th anniversary of the event whose centennial we celebrate today.

CONCLUSIONS

In a historical assessment that is conducted in this year of the centennial of the 1906 earthquake in California, it is necessary to avoid overstating or understating an event that has long-term historic significance as well as short-term newsworthiness. The following nine major effects of the 1906 earthquake have been identified, crediting the earthquake for important influences on research and education but doing so only when the historical evidence has been compelling.

1. Preparation and publication of the Lawson Report, along with the recruitment of a small but influential cadre of earthquake researchers who stayed in the field for decades afterward;
2. The work of Harry O. Wood, brought into the seismology field by the 1906 earthquake, and whose subsequent Carnegie Institution research efforts became the origin of the seismology program at the California Institute of Technology;
3. Establishment of the Seismological Society of America, the only association in the United States for decades thereafter that was dedicated to the earthquake subject, and whose publication of BSSA and whose meetings and conferences remain a major resource for research and education today;
4. Motivation of several earth science and engineering professors at Stanford University to devote significant portions of their careers to the earthquake problem;
5. A similar effect on earth science and engineering faculty at the University of California at Berkeley;
6. The facilitation of the development of the strong motion accelerograph;
7. Arthur Ruge’s co-invention of the modern electric-resistance strain gauge while conducting shake table experimentation at MIT that was funded by the insurance industry’s concern over 1906 earthquake-caused fire losses;
8. Initiation of the series of world conferences on earthquake engineering and a related internationalization of the field;
9. Establishment of the credibility of the study of earthquakes in the United States, legitimizing the decisions of a small number of earth scientists and engineers to devote their careers to the field in the first half of the twentieth century when funding was scarce, individuals to whom all of us in the earthquake research or education field today should feel indebted.

The more one looks carefully into the history of the effects on education and research that the earthquake caused, the more significant those effects are seen to be. The initial wave of influence of the 1906 earthquake has passed, but the tide is nonetheless persistently higher today because of that event.

ACKNOWLEDGMENTS

Carol Prentice of the U.S. Geological Survey in Menlo Park, California, provided me with several important documents relating to the evolution of the understanding of the San Andreas Fault, as well as historical background concerning individuals such as Harry Wood and J. C. Branner. Meeting with Luigi Sorrentino and reviewing his collection at the University of Rome of original source material on the 1908 Reggio-Messina earthquake was invaluable in comparing the engineering effect of that earthquake with its contemporary event in California. Tetsuo Kubo, Keiji Doi, and Hitoshi Shiohara similarly gave freely of their time in meeting with me and providing access to original sources at the University of Tokyo that document the state of earthquake engineering and seismology in Japan as of the early years of the twentieth century. Makoto Yamada of Waseda University generously gave me access to the notebooks, papers, and other materials of Tachu Naito in the university’s collection and at the Naito House in Tokyo. While the 2005 EERI-FEMA Professional Fellowship funds my work on the history of earthquake engineering in countries other than the United States, portions of that effort have helped inform the research reported on here. Discussions and advice from my faculty advisor for that project, Vitelmo Bertero, and with my seismological co–faculty advisor, the late Bruce Bolt, are gratefully acknowledged.

REFERENCES


____1956. Synopsis of panel discussions on seismic matters other than structural design, *Proceedings, World Conference on Earthquake Engineering, Berkeley, Calif., June*, Earthquake Engineering Research Institute, Oakland, CA.


___1900. Seismic experiments on the fracturing and overturning of columns, *Report by the Earthquake Investigation Committee*, vol. 4, pp. 69–141.


___2005. Personal communication, September.

Quarantelli, E. L., 2005. The earliest interest in disasters and the earliest social science studies of disasters: A sociology of knowledge approach, draft, Preliminary Paper #349, Disaster Research Center, University of Delaware.


Sitar, N., 2005. Personal communication.

Sorrentino, L., 2005. Personal communication, Universita Degli Studi di Roma “La Sapienza.”


____1977. Personal communication.


____1934. His 1931 lecture series is available in *Kyoji Suyehiro, Scientific and Technical Papers*, Suyehiro Memorial Committee, Tokyo, Japan.


(Received 24 October 2005; accepted 9 January 2006)