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# A SHORT HISTORY OF THE INVOLVEMENT OF UNIVERSITIES IN THE USA IN EARTHQUAKE ENGINEERING

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## ABSTRACT

The history of the involvement of universities in the United States in earthquake engineering research and education is briefly recounted. In the period following the 1906 San Francisco Earthquake, Stanford University and the University of California at Berkeley stand out (although from an international context, both the seismology and engineering disciplines in Japan and Italy were more advanced in that era.) The 1933 Long Beach Earthquake was a boost to university programs, leading to the first significant seismic regulations in building codes and other seismic criteria in the USA. Codes are a separate topic, but they have been the major source of demand for seismically educated civil engineers. Stanford continued its seismic engineering work through the 1930s, while the subject waned in importance at U.C. Berkeley. In the 1920s, the recently founded California Institute of Technology began its engineering and earth science activities concerning earthquakes, twin lines of work that continue there as interrelated disciplines to this day. Some seismic engineering research was also underway at the Massachusetts Institute of Technology in the 1930s. By the late 1940s and in the 1950s, several individuals who would soon join the Berkeley faculty and cause its ascendancy in earthquake engineering were educated in civil engineering at MIT, often taking dynamics courses in aeronautical and mechanical engineering: the era was just beginning when structural dynamics was taught by civil engineering professors, and there were no courses yet on earthquake engineering. Also in the 1950s, the dynamic and inelastic behavior of structures, especially concrete ones, became a specialty at the University of Illinois, while the University of Michigan developed early structural engineering and soil dynamics programs to study earthquakes. From the 1960s onward, the number of American universities active in the field became much greater. Come the 1980s, after the passage of the 1977 National Earthquake Hazards Reduction Act, the field became recognizably the same as it is today: funding was steadily provided for earthquake engineering, chiefly by the National Science Foundation; numerous graduate students specialized in earthquake engineering; and NSF-established centers recruited a wider array of US universities into the field.

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## Introduction

The emphasis of this paper is on the early years of American university activities in earthquake engineering. That emphasis is opposite to the variation with time of the size of the underlying subject matter: In recent years, the number of universities, faculty, students, and research facilities has grown rapidly; in the early years, only a few people and institutions were involved. My focus on the early years has been chosen for three reasons. First, today's milieu is all around us, and like fish in the sea, we know those waters relatively well simply by being immersed in our environment. It is more difficult to gain an accurate idea of the work done by those who are several generations removed from us and who lived in very different times. Second, it is also difficult to add up or evaluate the earthquake engineering field today, partly because it is so large and partly because any present day individual in the field brings his or her background and biases to the subject. Third, the field of earthquake engineering today is a mature one. Advances are still being made, but they are more incremental than the breakthroughs of its formative years. There can be only one first, and the historic firsts in many areas in the field have already been made. The field is relatively comfortably funded today to an extent unheard of when it was a novel idea to introduce civil engineering studies of earthquakes into the university curriculum. Earthquake engineering in American academia is built on the accomplishments of the early years, and those are the years selected for examination here.

## Up through the 1930s

Prior to 1900, the history of the involvement of American universities in engineering education and research concerning earthquakes was almost non-existent. It was not until the mid-1800s that colleges or universities in the United States even started civil engineering departments. The first such program was at the US Military Academy in West Point, New York in 1802. In 1835, the first civil engineering degree was conferred by Rensselaer Polytechnic Institute in Troy, New York. One of RPI's more famous graduates, Washington Roebling, assisted his father, John Roebling, in carrying out the design and construction work on the Brooklyn Bridge in the 1860s. Slowly, the pattern emerged that an academic education in civil engineering was a prerequisite for practice in the field, and by 1900, a civil engineering department was a common feature of a US university's structure. First must come established programs in civil engineering, in particular the structural engineering discipline, before earthquake engineering can develop, and there must also be a demand for civil engineering graduates, most of whom then as now go into careers as practicing engineers. Soil mechanics in the 1920s, soil dynamics in the 1950s and 1960s, and still later the broader field of geotechnical engineering, were to form the second civil engineering sub-discipline related to earthquakes. In the 1970s and later, risk and probability analysis formed the third major earthquake-related civil engineering sub-discipline. Until several decades into the twentieth century, many civil engineering departments featured irrigation, water supply, and sanitary engineering programs but had only relatively minor structural or soils/geotechnical programs of study.

### Comparative Levels of Advancement of Earth Science and Engineering

Before practicing engineers expressed the need for seismically educated engineering graduates, and before civil engineering faculty became interested in the subject, the earth science academics studying earthquakes were already relatively advanced and organized. On an international scale, compare the following pair of dates. In 1901, the First International Conference on Seismology was held in Strasbourg, Germany (now part of France); half a century later, in 1956, the World Conference on Earthquake Engineering was held in Berkeley in the USA. Or consider another comparison: The International Seismological Association was founded in 1904; the International Association of Earthquake Engineering was established more than half a century later in 1963. By 1921, to cite one American example, James B. Macelwane (1883-1956) received a PhD in seismology from the University of California at Berkeley and proceeded to the faculty of St. Louis University, where he quickly set up a program in seismology that regularly turned out seismologist PhDs, and he linked together Jesuit universities into an actively maintained seismological network. Compare that 1920s data point with the fact that George Housner received the first civil engineering doctoral degree in the United States with specific reference to "earthquake forces on structures" twenty years later, in 1941, and that such PhDs were to remain a rarity for another twenty years after that.

**The 1906 Earthquake, Stanford University, and University of California at Berkeley**

The first significant boost to university involvement in earthquake engineering came with the April 18, 1906 earthquake that affected northern coastal California and caused the widespread building damage, and especially the ensuing disastrous fire, in San Francisco, then the largest city on the west coast of the USA or Canada. Details on the effect of the earthquake on research and education are provided in Reitherman (2006) and only briefly touched upon here. There were two universities in the San Francisco Bay Region at the time, the University of California on the eastern side of the Bay in Berkeley (the only UC campus as of then) and Stanford University located quite near to the causative San Andreas Fault on the western side. The campus of U.C. Berkeley received slight, but at Stanford, almost 40% of the buildings either collapsed or had at least half their walls destroyed.

Berkeley's engineering response was primarily a single-handed affair, with a young assistant civil engineering professor, Charles Derleth (1874-1956), taking the lead. He was to go on to be an influential dean at the university and consultant on some large design projects, but Berkeley did not establish and maintain an engineering program of courses and research on the earthquake subject. At Stanford, however, several engineering faculty were involved in a committee to guide campus reconstruction and the key cadre of individuals who made the Seismological Society of America and its *Bulletin* a reality kept up their interest from 1906 onwards, maintaining a continuous Stanford lineage of involvement in earthquake engineering to this day. The first shaking table in the USA was built by an engineering professor, F.J. Rogers, with the encouragement of geology professor J.C. Branner to study the shaking response of different kinds of soil placed in a large box subjected to uniaxial motion, Another example of inter-departmental cooperation at Stanford is the way Bailey Willis (1857-1949), head of the geology department, was instrumental in the hiring of Lydik Jacobsen (1896-1976) in the mechanical engineering department and raising funds to develop a vibration laboratory. By the 1930s, a civil engineering student who was to be prominent in the earthquake engineering field for several decades, John Blume, decided to attend Stanford because it already had professors and research resources devoted to that subject (though the term "earthquake engineering" was not come into use for another two decades).

> 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 bounded when he walked. (Blume 1994, p.8)

Blume's master's work on structural dynamic aspects of earthquake engineering, completed in 1935, was very unusual for the era, and even when he returned to Stanford to finish his education with a PhD in 1967, it was still unusual to receive a graduate degree in that subject. Largely through his efforts, the John A. Blume Earthquake Engineering Center was established at Stanford in 1974.

**California Institute of Technology**

California Institute of Technology in the city of Pasadena adjacent to Los Angeles had evolved from the former Throop College of Technology into a major research university only as of the early 1920s, with a new focus on high-level science and engineering education and research, dispensing with the high school and vocational missions it previously had. It soon was home to the first civil engineering professor in the United States to have a career-long specialization in earthquake engineering, Romeo Raoul Martel (1890-1965). By the mid twenties Martel had attended the Third Pan-Pacific Science Congress in Tokyo in 1926, as a delegate to the Council on Earthquake Protection, and also attended the World Engineering Congress in Tokyo in 1929. As of the 1920s, Japan was the world leader in earthquake engineering. Martel advised on the optional seismic design appendix that was included in the 1927 Uniform Building Code. He was also the advisor of George Housner in his graduate studies in earthquake engineering in the 1930s, and in turn Housner was long one of the few steady forces in American academia to keeping the subject growing until an increase in funding arrived in the 1960s and 1970s. The mechanical and aeronautical engineers at Caltech, as elsewhere in universities at the time, were generally much more advanced in their work on dynamics than the civil engineers. Only as of the 1970s and 1980s did civil engineers typically take a course in structural dynamics, whereas mechanical and aeronautical engineering students had been taught this subject in the context of their own disciplines for some time. Theodore von Kármán (1881-1963) was the Caltech professor who was the doctoral advisor of Maurice Biot (1905-1985), whose 1932 thesis in the aeronautics department was on the general topic of *Oscillations in Elastic Systems,* but in one chapter he took up the problem of "Vibrations of Buildings During Earthquake" and developed the concept of the earthquake response spectrum, a concept that is still current today (Trifunac and Todorovska 2008). Biot left the earthquake field by the 1940s, but Housner remained a central earthquake engineering figure beyond the 1980s.

Caltech was also home to a cadre of influential seismologists, beginning in the 1920s, a program that strengthened the civil engineering seismic program there. The first head of the Caltech geology department was John Buwalda (1886-1954), hired away from Berkeley in 1926, and he was Caltech's head of that department for slightly over two decades, until 1947. Charles Richter (1900-1985) joined the seismology faculty group in 1927 just as its Seismological Laboratory was founded, and in 1930 Caltech, less than a decade old, recruited Beno Gutenberg

– one of the first seismologists in academia in the USA who had a heavyweight European academic and research institution pedigree. Although not on the faculty, another strong influence on earthquake studies at Caltech was Harry Wood (1879-1958). Wood got into the earthquake field in 1906 as a young mineralogy professor at Berkeley. His department head and leader of the state's earthquake report committee, Andrew C. Lawson (1861-1952), assigned him the task of studying intensities in San Francisco after that earthquake, and he remained in the field from then on. He was the "Wood" of Wood-Anderson Seismograph fame, and the growing array that he started in Southern California with Carnegie Institution funding was later bequeathed to Caltech and started its seismological observatory. That instrument proved so useful in providing standardized records of Southern California earthquakes that it led Richter in 1935 to publish what he called his "instrumental" magnitude scale (he did not call it the "Richter scale"), because it was based on the records from those Wood-Anderson instruments.

From its early days to today, seismologists at Caltech have tended to share interests with their civil engineering colleagues there. Richter, for example, in his famous textbook, *Elementary Seismology* (Richter 1958), included several sections on construction, insurance, and earthquake-resistant design, even though his book was primarily intended for earth science students. Wood's interest was in studying earthquakes as the agents of destruction at Earth's surface, not as most seismologists did as convenient ways to "X-ray" the planet to see what its interior was made of. Today, a seismologist by training with research interests in strong motion effects on structures, Thomas Heaton, holds a faculty position at the university with joint appointments in Geophysics and Civil Engineering, continuing that inter-disciplinary tradition.

**Massachusetts Institute of Technology and Harvard University**

Two more universities can be singled out in this early era that ends with the decade of the 1930s, both far to the east of the more seismic Western United States. At the Massachusetts Institute of Technology, Professor Arthur Ruge (1905-2000) was a faculty member interested in acoustics and other vibratory phenomenon. He created a small shake table for seismic research in his lab, and was funded by the insurance industry to study the behavior of elevated water tanks. During this research in 1936, he independently invented the electric resistance strain gage, which was co-invented with slight precedence by Edward Simmons at Caltech. While Caltech was already a center of earthquake studies, the Caltech work had nothing to do with that subject, whereas Ruge's research was specifically an earthquake engineering research project. His breakthrough came as he visualized how to attach a thin membrane to the sides of his model of a water tank on his shake table to measure how the tank strained when it was shaken. The joint invention of the device, which became one of the most ubiquitous instruments in all of engineering, was commemorated by naming the early models SR (Simmons-Ruge). Ruge also consulted on the design of strong motion instruments and means to calibrate them with shake table tests, but did not stay in the earthquake engineering field in his later career.

Either at MIT or across town in Cambridge, Massachusetts at Harvard University, two major pioneers in what was then called soils engineering were on the faculty of one or the other of those schools at various times. Karl von Terzaghi (1883-1963) was educated and practiced in Europe as a structural engineer before specializing in soils. In 1925 he was hired by MIT, then moved back to Austria, then emigrated again to the USA just prior to the outbreak of World War

II, where he joined the faculty of Harvard University till his retirement, consulting on a number of large dams and other projects. Arthur Casagrande (1902-1981) joined the MIT faculty in the 1926-1927 academic year, one year after Terzaghi did, and like Terzaghi also taught later at Harvard. Neither one was centrally interested in seismic topics, but their formation of strong geotechnical engineering programs at these schools poised both Harvard and MIT in the 1960s, especially after the 1964 Alaska and Niigata Earthquakes, to study important seismic topics such as earthquake-induced liquefaction.

## 1940s through 1960s

At the beginning of this period, strong motion earthquake records were accumulating, beginning with the national government's deployment of the first instruments in 1932. Those records provided the potential to do advanced research on how to analyze them, and universities thrive on advanced research. Had no strong motion instruments been invented and accelerograms collected, there could have been structural engineering research on different systems and details. However, with only a judgmentally set equivalent lateral force coefficient to determine seismic loading, professors and students would have had no raw material with which to develop their earthquake engineering skills in dynamics and statistics.

In World War II, the United States was a victor, unlike Japan, Italy, and Germany, who not only lost the war but suffered great losses and took years to rebuild their infrastructure, including university infrastructure, to what it was prior that global-scale conflict. Absent the Second World War, it is plausible that today German would be the international language of science and engineering, rather than English. The USA also had tremendous pent-up demand for things that required the services of civil engineers. As recalled by one American civil engineer:

> There was a great surge of private work, as compared with the previous defense and war-related work….The main effort was on schools and municipal public buildings, whose construction had been curtailed during the war. Then, of course, there was the general private sector, such as buildings for the telephone company and gas company….Refineries were beginning a big building program about that time. (Crandall 2008, p. 20)

Earthquake engineering in academia cannot be analyzed apart from earthquake engineering in practice. Civil engineers design and analyze what society wants to have constructed, and university civil engineering departments respond to that employment demand.

While the Second World War ended in 1945, the Cold War of conflict between the Union of Soviet Socialist Republics and the United States of America heated up shortly thereafter. During the 1940s and 1950s, most of the research funding for US faculty on subjects that were later to be applicable to earthquake engineering were funded by military agencies, such as how to design blast-resistant structures or advanced airplanes. Ray Clough co-developed the Finite Element Method while working for the Boeing Aircraft Company on the dynamics of jet airplane wings during the summer of 1952 (Clough 1980). Prior to entering the earthquake engineering field, Robert Whitman did his most advanced experimentation and analysis of geotechnical phenomena at MIT studying how nuclear bomb blast waves transmitted through the air could “slap” the ground and affect underground structures (Whitman 2009). Vitelmo Bertero was also investigating dynamics and inelasticity for blast-resistance rather than earthquake-resistance at MIT in the 1950s. Bertero was later to build on that background in introducing the first regularly given university course in the USA devoted to earthquake engineering in 1968 (Bertero 2009). Nathan Newmark and William Hall at the University of Illinois were funded in the 1950s to investigate topics of military importance to the country that gave them the expertise to later develop earthquake engineering innovations, such as inelastic spectra and seismic design criteria for nuclear power plants.

The first edition of the series of updated Structural Engineers Association of California seismic guidelines that formed the basis for the frequently updated seismic provisions of the Uniform Building Code, the model code in California and most western (more highly seismic) states, was published in 1959 (SEAOC 1959). There were seismic regulations in the USA prior to that, at least in California, but as of the 1960s, the seismic code became more complex each time it was revised, approximately at three-year intervals, creating a demand for the education of graduate engineers who knew the latest methods of earthquake engineering.

On March 27, 1964, the great (magnitude 9.2) Alaska Earthquake occurred. It was a major science and engineering event, and it had an effect in inducing the National Science Foundation to allocate grant funding for earthquake engineering research. The University of California at Berkeley in particular had been developing earthquake engineering as a line of research around this time, and by 1968, a research unit on the theme had been approved by the University, called the Earthquake Engineering Research Center, with Professor Joseph Penzien as its first Director. A number of key faculty there who were to become prominent in the field had been hired by the end of the 1960s, including Boris Bresler (1946), Egor Popov (1946), Robert Wiegel (1946), Ray Clough (1949), Alexander Scordelis (1949), Harry B. Seed (1950), Joseph Penzien (1953), Jack Bouwkamp (1957), Vitelmo Bertero (1960), Bruce Bolt (in the earth sciences department, 1963), James Kelly (1965), Edward Wilson (1965), Graham Powell (1966), and Anil Chopra (1967). See Penzien (2004) and Popov (2002) for details. Egor Popov was perhaps the most significant in terms of the growth of the civil engineering department’s seismic specialty and the hiring of key faculty, as well as in creating a doctoral program. The first PhD in structural engineering granted by the university was to Mihran Agbabian in 1950. As of the 1950s, the doctoral programs in structural engineering at MIT and the University of Illinois were already prominent, so Berkeley was a latecomer in that regard, and then quickly accelerated into prominence. MIT in particular was the training ground from which several of the above-named Berkeley faculty were obtained: Popov, Clough, Scordelis, Penzien, and Bertero. Jack R. Benjamin became a faculty member at Stanford in 1948, when there was little interest in funding earthquake engineering research, but at MIT when he did his PhD under Professor Robert Hansen in the 1940s, he had learned much about inelasticity and probability in the process of doing research on blast effects on reinforced concrete. In the 1960s and later Benjamin was to shift his research and practice to earthquake engineering.

Note that the first large “crop” of US civil engineering faculty researching and teaching earthquakes were self-taught. Other than George Housner and his 1930s graduate work on the subject and tutoring from R. R. Martel, the others who were leaders in the 1950s and 1960s had not taken a course in earthquake engineering, and yet they developed the curricula to teach it.

That is a great distinction between then and now. Today, professors who teach earthquake engineering usually have had some exposure to it as undergraduates, probably took at least one course on it as a master's student, and then have done their PhD thesis work in that subject area under the guidance of a professor who has already studied the subject in his or her education.

The centerpiece of experimental research in the 1960s was the shake table, with one established at the University of Illinois at Champaign-Urbana in 1967 and a 20 ft by 20 ft one at U.C. Berkeley at its Richmond Field Station facility near the Berkeley campus in 1972. At that time, the Japanese were just starting work in that area but were soon to construct considerably more extensive shake table research facilities than existed in the USA. The 1964 Alaska and 1964 Niigata Earthquakes motivated geotechnical engineers to focus on liquefaction, including in-situ measurements, for example concerning shear wave velocities and Standard Penetration Test data; laboratory investigations of field-collected samples; and centrifuge simulation of seismic shaking of soils subjected to surrogate gravity overburden pressure. On the "wet" side of civil engineering departments, the significant tsunami waves accompanying the 1964 Alaska earthquake increased the importance of that research area.

In the annual report of the Universities Council for Earthquake Engineering Research (1969), Michael Gaus of the National Science Foundation reported that NSF support for earthquake engineering research in 1967 totaled $1,045,600 ($6.8 million in year 2009 dollars as adjusted by the US Bureau of Labor Statistics Consumer Price Index). While small as compared to the earthquake engineering budget at NSF after passage of the 1977 National Earthquake Hazards Reduction Act, which pushed the figure, depending on the year, to about $20 million, the late 1960s research funds for earthquake engineering were significant enough to fuel programs at a number of universities. NSF research grants, throughout the Foundation, have gone almost exclusively to academics. At the 1969 UCEER conference, there were reports from 23 US universities on their research programs. Admittedly, at some places that research was limited to the work of one or two key faculty, and probably the strongest programs as of then were at this half-dozen: Berkeley, Caltech, Stanford, Illinois, Michigan, and MIT.

## 1970s and 1980s

By the end of the 1960s, computers had supplemented but not replaced the slide rule and mechanical adding machine. Electronic computers as of 1970 were cumbersome, inefficient, expensive, huge, and access to them was limited. In the 1970s and especially the 1980s, computer products in the private sector developed rapidly, changing many things in the world, including earthquake engineering. When computers allowed practicing engineers to conduct more advanced analyses, it created a market for engineering graduates who understood more advanced seismic analysis methods, and professors and students could conduct more advanced research. Along with a continuing upward trend in economic development and construction, and the increasing sophistication of seismic regulations in the building code, the demand for civil engineering graduates with seismic know-how pushed the field from below, while NSF funding pulled it from above.

The February 9, 1971 San Fernando Earthquake showed how much progress earthquake engineering still needed to accomplish. Although the Los Angeles area had enforced seismic regulations for the longest period of time of any region in the country, engineered construction suffered some alarming damage, in particular with regard to hospitals, reinforced concrete frames, highway bridges, dams, and low-rise industrial (tilt-up) buildings. California funding then began to augment federal funding, in particular from the state's highway department for research on the design of new freeway bridges and retrofit measures for existing ones.

By the end of the 1980s, the National Earthquake Hazards Reduction Program was firmly in place, with a protected niche of funding at NSF for earthquake engineering studies, mostly in structural and geotechnical engineering, with about 10% allocated to social science research on disasters. US Geological Survey had a budget three or more times that of NSF and devoted its research funding to earth science topics. In 1986, as a result of a nationwide competition, NSF funded the University at Buffalo, part of the state university of New York system, to establish the National Center for Earthquake Engineering Research, and ten years later, $46 million in NSF funds had been complemented by $26 million in state contributions and $14 million from the Federal Highway Administration. A key effect of the establishment of NCEER was to provide the incentives and opportunities for faculty at Eastern universities to enter the field or greatly enlarge their programs. Following another NSF competition after the ten-year award to NCEER was complete, three regionally-centered programs were funded in 1997 for another decade-long timespan: one again headquartered in the East at Buffalo; another in the Midwest at the University of Illinois; and the third in the West at U.C. Berkeley. This continued the trend set with NCEER of extending the academic span of earthquake engineering from coast to coast. The rapidly developing field continued to expand, and in this brief paper it is impossible to survey that broad landscape after the 1980s, except to summarize that later changes were incremental, rather than pioneering. The trend established by the 1980s of widespread study and research on earthquakes at civil engineering faculties across the country, even in regions where the local earthquake ground shaking hazard was low, continued to be the pattern. The opportunity of undertaking doctoral work with a seismically-expert faculty advisor became too widespread to allow for counting the number of instances; it became routine for major research universities to offer a master's course devoted earthquake engineering on structures and another on geotechnical aspects; and some inclusion of earthquake engineering typically was included in undergraduate courses such as steel or concrete design, risk engineering, and geotechnical engineering. Given the need for breadth in undergraduate education, it is still rare for an undergraduate course to be devoted to earthquake engineering, although San Jose State University and the University of California at San Diego have done so.

## Conclusions

Earthquake engineering at American universities is a twentieth century phenomenon, beginning with the effects of the 1906 San Francisco Earthquake on Stanford University and the University of California at Berkeley. By the end of the 1960s there were at least two dozen US universities conducting research and educating graduate students in earthquake engineering. National Science Foundation funding began on a significant scale in the 1960s and grew in the 1970s with the passage of the National Earthquake Hazards Reduction Act. By the end of the 1980s, with the NSF establishment of the National Center for Earthquake Engineering Research at the University of Buffalo, the pattern of nationwide education and research in this area was set. Subsequent academic trends may be considered incremental, rather than pioneering.

The practice of earthquake engineering has created a demand for university graduates with earthquake engineering knowledge, a demand that grew from the 1960s onward and in the last two or three decades has become more nationwide in extent. Today the building code in the USA essentially consists of the International Building Code and the American Society of Civil Engineers standard ASCE 7 loading provisions, which have extended earthquake design requirements to some moderately seismic areas of the eastern two-thirds of the nation where previously there were none.

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