



July 24, 2020

IN MEMORIAM

Ray W. Clough

Professor of Civil Engineering, Emeritus
UC Berkeley
1920-2016

Professor of Civil Engineering, Emeritus, Ray W. Clough was born on July 23, 1920, in Seattle, Washington and died on October 8, 2016, at the age of 96. His wife of 74 years, Shirley, preceded him in death on April 17, 2016. They are survived by their son Douglas, two daughters Allison and Meredith, five grandchildren, two great-grandchildren, and many nephews and nieces.

Professor Clough was recognized as one of the world's most accomplished engineers and scientists. He and his students at the University of California, Berkeley, created the Finite Element Method (FEM) for solution of problems in continuum mechanics and demonstrated it was a replacement for the Finite Difference Method (FDM) which was the accepted computation mathematical method prior to his fundamental research. In addition, Ray was one of the pioneers in the application of new computer and experimental analysis methods to predict the behavior of many different types of structures subjected to large earthquake motions.

As a teenager, Ray was attracted to the hiking and mountain activities of the Boy Scouts. However, the Boy Scout Group did not attempt to climb high mountain peaks. Therefore, Ray and his teenage friends decided to form their own climbing club, naming it the Ptarmigan Climbing Club after the little mountain birds found in the Pacific Northwest and other mountain regions. The major objective of the club was to develop safe techniques to climb high mountains where the surfaces were a combination of bare rock, snow, or ice. The club had only 20 to 30 members, from which one or more members could form a climbing group using new and safer techniques. Pitons and ropes were used for safety only. In 1938, Ray and three other young friends planned and completed an approximately 10-day, 35-mile mountain climbing trip in the Northern Cascades mountain range. The trip resulted in climbing six mountain peaks that had not been climbed previously. At the present time the Seattle mountaineering community refers to this trip as the Ptarmigan Traverse and it is still considered a challenging trip using modern equipment. Members of Ray's family and his close friends believe the impression made on him as a member of the Ptarmigan Club was profound. After this success as a teenager he developed confidence to attack and solve many complex problems in different fields of engineering.

Ray met his wife Shirley Potter, who was a year younger than he, at Roosevelt High School. Later they both studied at the University of Washington, where they shared their experiences of hiking and skiing in the Cascades and on Mt. Rainier with college friends. In October 1942, Ray and Shirley were married. Ray's professional and family lives were not totally separate. Shirley's talent for interior design and skills in the kitchen always made their homes inviting venues for graduate students, academic colleagues, and professional engineers. They developed a long list of lifetime friends including international leaders in structural engineering.

In 1942, six months after the start of World War II (WWII), Ray graduated from the University of Washington with a bachelor's degree in civil engineering. He attempted to enlist in the Naval Seabee construction program where he could use his engineering education. After he was rejected due to his poor eyesight, Ray went to work at Boeing Aircraft Company in Seattle. This type of job would guarantee a deferment until the end of the war. However, Ray found the job he was given was menial and not a productive way to spend the war years. He then learned that the U.S. Army Air Force had a shortage in meteorology and would accept him because it was considered to be a noncombatant position. After basic training, he obtained a master's degree in meteorology at the California Institute of Technology (Caltech). He then became an instructor at Caltech in meteorology until June 1944. By that time, the Army Air Force had a surplus of meteorologists and Ray was transferred to be in charge of an airfield construction crew.

In July 1945, Ray's construction battalion was on a troop ship traveling from Hawaii to join the war in the Pacific and participate in the invasion of Japan. Not long after they left Hawaii in the convoy departure, the Hiroshima bomb was dropped during the first week of August 1945. They were continuing toward Japan when the Nagasaki bomb was dropped.

Within several days Japan surrendered, ending WWII. Ray continued to Japan and was part of the occupying force on the island of Okinawa. Ironically, having been rejected by the Seabees at the outset of WWII, when his Air Corps construction battalion arrived at Okinawa, he was immediately re-assigned to a Seabee unit that was working on the construction of an airfield runway and the aircraft control tower. In 1946, Ray was discharged from the Seabees in time to enter the graduate program at the Massachusetts Institute of Technology (MIT).

While working for his doctoral degree at MIT Ray took an advanced aerodynamics course from Professor Raymond L. Bisplinghoff, which influenced him for the rest of his life. He completed his thesis on the experimental and theoretical analyses of buckling of arches.

After receiving his Sc.D. degree in 1949, Ray joined the faculty of the Department of Civil Engineering at UC Berkeley. During the next 38 years, 34 students completed their doctoral degrees under his direction. His courses were very popular, attracting students from structural engineering and from multiple other disciplines. According to retrospective reports from several of his students, he was always well prepared and was very effective in presenting a significant amount of practical information in a short period of time.

After arriving in Berkeley, Professor Clough was asked to develop a dynamics course that would enable civil engineers to design earthquake-resistant structures. However, no additional funding was provided for him to conduct earthquake engineering research. Nevertheless, within a few years he published the paper "On the Importance of Higher Modes of Vibration in the Earthquake Response of a Tall Building," *Bulletin, Sociological Society of America*, V. 45, No. 4, October 1955.

In the summers of 1952 and 1953, Professor Clough was employed at a dynamics analysis research group with the Boeing Aircraft Company in Seattle. This work involved modeling the delta wing with three-dimensional strut elements (connected to two joints) and the wing surfaces with triangular or quadrilateral membrane elements (connected to three or four joints). His research involved the development of elements that accurately predicted displacements compared to experimental results. Boeing referred to this work as the Direct Stiffness Method, which was a standard method of structural analysis where the joint displacements were the unknowns.

In 1956, Ray, Shirley, and three small children spent a year in Norway at the Ship Research Institute in Trondheim. The engineers at the institute were calculating stresses due to ship vibrations in order to predict fatigue failures at the stress concentrations. This is when Ray realized his element research should be called the Finite Element Method which could solve many different types of problems in continuum mechanics. Ray realized the FEM was a direct competitor to the Finite Difference Method. At that time FDM was being used to solve many problems in continuum mechanics. His previous work at Boeing, the Direct Stiffness Method, was only used to calculate displacements not stresses.

In the fall semester of 1957, Ray returned from his sabbatical leave in Norway and immediately posted a page on the student bulletin board asking students to contact him if they were interested in conducting finite element research for the analysis of membrane, plate, shell, and solid structures. Although Ray did not have funding for finite element research, a few graduate students who had other sources of funds responded. At that time, the only digital computer in the College of Engineering was an IBM 701 that was produced in 1951 and was based on vacuum tube technology. The maximum number of linear equations that it could solve was 40. Consequently, when Ray presented his first FEM paper in September 1960, “The Finite Element Method in Plane Stress Analysis,” at the ASCE 2nd Conference on Electronic Computation in Pittsburgh, Pennsylvania, the course-mesh stress-distribution obtained was not very accurate. Therefore, most of the attendees at the conference were not impressed.

After the improvement of the speed and capacity of the computers on the Berkeley campus, Professor Clough’s paper was a very fine mesh analysis of an existing concrete dam. The paper was first presented in September 1962 at a NATO conference in Lisbon, Portugal. Within a few months, the paper was republished in an international Bulletin, which had a very large circulation, as “Stress Analysis of a Gravity Dam by the Finite Element Method”, (with E. Wilson), International Bulletin RILEM, No. 10, June 1963.

The Lisbon paper reported on the finite element analysis of the 250-foot-high Norfolk Dam in Arkansas, which had developed a vertical crack during construction in 1942. The FEM analysis correctly predicted the location and size of the crack due to the temperature changes and produced realistic displacements and stresses within the dam and foundation for both gravity and several hydrostatic load conditions. Because of this publication, many international students and visiting scholars came to Berkeley to work with Professor Clough. Also, he freely gave the FORTRAN listing of their finite element analysis computer program to be used to evaluate displacement and stresses in other two-dimensional plane structures with different geometry, materials and loading. Therefore, professional engineers could easily use the powerful new FEM to solve for the stress distributions in their structural engineering problems in continuum mechanics. However, he did not capitalize on his success in the development of the FEM. He returned to the task of building the earthquake engineering program at Berkeley – the task he given when he was first hired in 1949.

In the early 1960s, Professors Joseph Penzien and Clough led a group of faculty at Berkeley in the establishment of the Earthquake Engineering Research Center (EERC) there. The EERC’s first project was the design and construction of a 20-foot by 20-foot shaking table that was capable of testing large structures subjected to realistic earthquake motions. This was the most sophisticated earthquake simulator in the world at the time, and it continues to be an important earthquake simulator today.

A remarkable aspect of Ray's approach to earthquake engineering research was his balanced approach of conducting physical experiments, both in the laboratory and in the field, to verify and improve the development of more accurate analytical methods. Notable among his laboratory studies are several shaking table tests to explore the nonlinear dynamic response of multistory building models (including the first-ever tests on rocking buildings), structure-fluid dynamics, and dynamic responses of dams.

In 1975, Professors Clough and Penzien published the book *Dynamics of Structures*. Being widely adopted, that book had a major impact on the education of generations of structural and earthquake engineers. The second edition of the book is still in demand.

Professor Clough traveled extensively as a pioneer in earthquake engineering, having surveyed the damage caused by the Agadir, Morocco, and Chile earthquakes of 1960, and the Skopje, Yugoslavia, earthquake of 1964. He was a member of the UNESCO Seismology and Earthquake Engineering Mission to the Mediterranean area in 1962, a member of the U.S. delegation to the UNESCO Governmental Meeting on Seismology and Earthquake Engineering at Paris in 1964, and a member of the U.S. delegation to inspect earthquake engineering research and construction in the U.S.S.R. in 1969. In addition, He served on many governmental advisory panels and boards, representing the technical areas of earthquake engineering and structural dynamics. Also, he served as the first editor of the *International Journal of Earthquake Engineering and Structural Dynamics*.

Throughout his professional career, Clough was retained as a consultant on complex structural problems in the design of power stations, ships, dams, multistory buildings, transmission towers, offshore drilling platforms, aerospace projects, and fluid structure interaction problems

Professor Clough's research and professional contributions have been recognized by many organizations in the United States and internationally. Only a partial summary of these awards will be presented here. He was elected to the National Academy of Engineering in 1968 and the National Academy of Science in 1979. In 1994, U.S. President William Clinton awarded him the National Medal of Science. In 2006, he received the Benjamin Franklin Medal in Civil Engineering. At that time, he was the only engineer in each group of Americans to receive the Medal of Science and the Franklin Medal. His international awards include: a Fulbright Fellowship (1956-57); an Overseas Fellowship from Churchill College, Cambridge University, England (1963-64); an Honorary Doctor of Technology at Chalmers University, presented by the King of Sweden (1979); an Honorary Doctor of Technology from the Norwegian Institute of Technology, Trondheim (1982); the International Association of Computational Mechanics Medal (1988); and the Berkeley Citation for distinguished achievement and for notable service to the University (1987).

Edward L. Wilson

Jack P. Moehle

2018 *From* <https://senate.universityofcalifornia.edu/in-memoriam/files/ray-clough.html>

Shirley Potter Clough May 13, 1921 – April 17, 2016

After living a full, rich life, Shirley Potter Clough passed away peacefully at home in Bend, Oregon, on April 17, 2016, less than a month shy of her 95th birthday. At her side were her husband Ray, of 73 years, and their three children, Douglas Potter Clough (Linda Clough), of Kapowsin, WA; Allison Justine Clough (Dan Weber), of Flagstaff, AZ; and Meredith Clough Jacobs (Ken Jacobs), of Bend, OR. Also with her was Doug's wife, Linda, Meredith's husband, Ken, and one of Allison and Dan's twin daughters, Brooke Weber, of Port Townsend, WA.

With her in spirit were Allison's husband, Dan, and her additional grandchildren, Doug and Linda's daughter, Kenna Bonzer (Taylor) of Tacoma, WA; Allison and Dan's daughter, Morgan Weber, of Portland, OR; Meredith's daughter Lauren Ayrey, of Lacey, WA, her son Kyle Ayrey (Missy) of Flagstaff, AZ; and Shirley's two great-grandchildren, Trinity and Eli, children of Kyle and Missy; as well as numerous nieces and nephews all across the country.

Shirley Claire Potter was born on May 13, 1921, to Thora Gronvold Potter and Chester Arthur Potter, of Seattle, Washington. During the Depression years, the family, including Shirley's younger sister, Justine, retreated to their vacation cabin near Fletcher Bay on Bainbridge Island in Puget Sound. Shirley often spoke fondly of her childhood on Bainbridge, where she and her sister spent days on the beach and playing in the woods near their home. When the economy improved, the family returned to Seattle, where Shirley attended Roosevelt High School. It was there she met Ray William Clough, Junior. He impressed her as a ruffian; she had seen him among a group of "bad boys" smoking cigars outside a school dance.

Later they both studied at the University of Washington, where they shared their college experiences, of hiking and skiing in the Cascades and on Mt. Rainier, with schooldays friends. Evidently, Ray wasn't so bad after all. The couple married on October 30, 1942. In 1949, they moved to Berkeley, CA, where Ray was Professor of Structural Engineering at UC Berkeley, for some 40 years until retirement.

Throughout her life, Shirley displayed an exceptional talent for interior design, fine cooking, and the art of gracious entertaining. She was an active member of Berkeley Faculty Wives, collecting and coordinating the distribution of donated housewares for foreign students arriving to study at the campus. She contributed generously of her time and talents as a member of the Berkeley Women's City Club, in particular during the later years when the historic "clubhouse" was renovated and opened to the public as The Berkeley City Club, an acclaimed hotel.

When Ray retired, the couple gravitated to the High Desert of central Oregon, a favorite locale for family vacations, moving to Sunriver, OR, in 1992, and later to Touchmark at Mount Bachelor Village, in Bend, OR.

Shirley and Ray had traveled widely in Europe and the Orient making fond friends, many of whom had come to Berkeley to collaborate in Ray's research. These globe-spanning connections had stimulated Shirley's interest in foreign cultures and cuisines. She and Ray had frequently hosted family, friends, students, and colleagues at their Berkeley house, and at their mountain cabin in the Sierra. Guests always remarked on the delicious meals and the beauty of their home, filled with colorful rugs, paintings, and other objects collected on their world travels and on Shirley's serious forays into California's eclectic shopping venues, which had appealed to her discriminating eye.

These are the facts. But to leave it at that would be to sell her short. Our mother was the quintessential woman behind a successful man. No one would dispute Dad's brilliance, but Mom's orchestration of their social life contributed incalculably to the atmosphere of collegial good will in which his scientific achievements would flourish; she knew how to entertain as few people do. She was brilliant, a good match for Dad, and her expertise was mordant humor.

Who could forget how, as children, having been brought from our rooms to say good night to their guests, we would find Norwegians, Germans, Brits or Chileans - or Russians (while the Cold War was in full swing) or Chinese (very shortly after relations with China were opened) all with smiles and cocktails. When conversation lagged, it was Mom who would fire up the group again with an arch witticism. And we would fall asleep to the convivial sounds of good dining, bright with good fellowship. Without realizing it we had been party to many meaningful moments in the scientific detente that emerged from the Cold War.

These are the ways we want to remember her: In the art she hung on the walls of her homes, in the intricate flavors of a brilliantly prepared meal, in a love for theater and for great cities. In her appreciation for the beauty of nature, the misty blue the fog would sometimes catch over the San Francisco Bay, the delicate colors in a spray of blossoms. Even in the control she exerted over all our lives, as if we too could somehow be made perfect.

Most of all, Shirley had wanted always the best for us, her family, and lavished us with a bounty of gifts from her talented hands, from hand-knit sweaters to the best apple pie this side of heaven. Godspeed, Mom.

Additional information by Ed Wilson



*1994 in Venice, left to right: Ray Clough, Shirley Clough, Diane Wilson, and Ed Wilson
Ray, Shirley and Diane (April 17, 1937 – Feb. 7, 2016) all died during 2016
The sadist year of my life- elw*