Jan D. Achenbach

1935–2020

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
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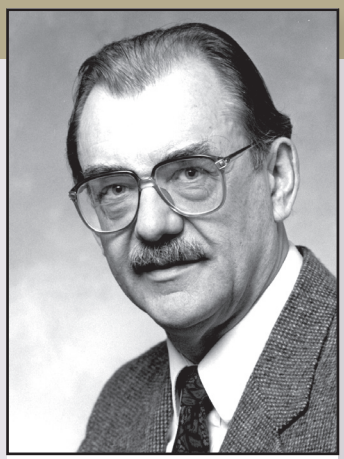
NATIONAL ACADEMY OF SCIENCES

JAN DREWES **ACHENBACH**

August 19, 1935–August 22, 2020

Elected to the NAS, 1992



By Jianmin Qu and Zdeněk P. Bažant

Jan Drewes Achenbach was the Walter P. Murphy Professor and Distinguished McCormick School Professor Emeritus-in-Service at the McCormick School of Engineering and Applied Science at Northwestern University. Throughout his career, a distinctive feature of Jan's research was the elegant use of rigorous mathematical methods in engineering applications. For example, traditional ultrasonic nondestructive methods are based on empirical measurements and heuristic analysis based on signal processing. It was Jan who introduced quantitative analysis of scattering of ultrasonic waves by defects to nondestructive evaluation. Later in his career, when Jan was asked what work of his that he was most proud of, he answered "I added the letter Q to NDE." In fact, the research field is now called quantitative nondestructive evaluation (QNDE). In 2008, Jan delivered the plenary lecture at the 27th Annual Review of Progress in Quantitative Nondestructive Evaluation, the prime annual gathering of the QNDE community around the world. Jan's lecture was entitled, "NDE with a Q." It was a brilliant blend of science with a retrospective on progress in engineering.

A renowned educator, a celebrated researcher, and a respected leader of the scientific community, Jan had an illustrious career. He dedicated his entire professional life to science and engineering education. He never stopped working until the last days of his life. His last paper was published posthumously four months after his death. Our memorial of Jan, our dear colleague and friend, celebrates his life and his contributions to the scientific literature and to engineering education and practices.

Life and Family

Jan was born on August 19, 1935, in Leeuwarden, a provincial town in the northern part of the Netherlands. It was occupied by Germany from May 1940 until April 15, 1945, when the Canadian Army liberated this part of the country. Leeuwarden was in the path

of British and American bombers flying from England to Germany. A German air base for fighter planes was established on the outskirts of the town and, towards the end of the war, Jan and his friends, mostly about nine years old, would get as close to the air base as the barbed wire and the minefields would allow to see the German fighter planes take off to engage the Allied planes that were flying overhead. The excitement of watching fighter planes in action generated his lifelong interest in aviation. Jan attended high school in Leeuwarden, where he excelled at soccer. Jan became so accomplished that he would have become a professional soccer player if his father, a barber, had not counseled him to pursue an academic career. So, Jan went to study aeronautical engineering at the Delft University of Technology (TU Delft). The launch of Sputnik in 1957 and the ensuing space race, which stimulated rapid growth in both fundamental and applied research in U.S. universities, inspired Jan. He applied and was awarded a scholarship to attend Stanford University for graduate studies in 1959, before he was able to officially graduate from TU Delft. Jan thus became a member of the Sputnik generation of scientists and engineers.

After receiving a Ph.D. in aeronautics and astronautics from Stanford University in 1962, Jan spent a year as a postdoctoral fellow at Columbia University. In 1963, he was appointed assistant professor in the Department of Civil and Environmental Engineering at Northwestern University, where he remained for the rest of his career except for sabbatical leaves at the University of California at San Diego and the TU Delft. In 1981, he became the Walter P. Murphy Professor in the Departments of Civil and Environmental Engineering and Mechanical Engineering, and in 1992 he was named Distinguished McCormick School Professor.

In June 1999, the night before a planned flight to Korea, Jan suffered serious cardiac arrhythmia with a loss of consciousness. He was brought by ambulance within a few minutes to the nearby Evanston Hospital, then transferred to Northwestern Memorial Hospital and kept for two weeks in an induced hypothermic coma. Upon waking up, his first phone call was to his secretary to check on his project funding. It took him a year, but his recovery was remarkable. It is a testimony to Jan's will, determination and perseverance that he restarted his research programs, and successfully so, which his colleagues doubted at first.

In 2009, he was awarded emeritus status, which he sought in part to give his departments more positions for hiring younger faculty. He remained a voting member of the faculty by taking the position of Walter P. Murphy and Distinguished McCormick

School Professor Emeritus-in-Service in the McCormick School of Engineering and Applied Science. He kept this position until his death. During all his years as an emeritus-in-service faculty member, he continued his research, supervised a number of Ph.D. students, and published numerous papers.

It was on a blind tennis date at Stanford that Jan met his future wife Marcia Fee. They were married in 1961. The following year, Jan earned his Ph.D. in aeronautics and astronautics and Marcia her bachelor of arts in history. During their year in New York when Jan was a postdoctoral fellow at Columbia, Marcia worked for Oxford University Press as a copywriter. When the couple settled in Evanston, Marcia returned to school and earned a master's degree in English from Northwestern in 1965 and then taught at Kendall College and Oak Therapeutic School, both in Evanston. These experiences led her to pursue a master of social work degree at the University of Chicago in 1975. Marcia worked for three years at Cook County Hospital's Department of Psychiatry and then for 23 years at the Jewish Child & Family Services. After her retirement, Marcia continued helping others through her Evanston community activities. She was appointed to the Evanston Mental Health Board and Commission on Aging by the mayor and served as a Master Gardener plant information officer at the Chicago Botanic Garden. Jan and Marcia found especially enriching their time with family and Jan's students, many of whom were from China, Japan, and Korea. They also enjoyed traveling, the Chicago Symphony, Chicago's Lyric Opera, and live theater. Marcia passed away on July 25, 2019, after 58 years of happy marriage. Marcia was extremely close to her two sisters, Judy and Wendy, and her godson Paul. She was a devoted and deeply loved aunt and great aunt to four nephews, one niece, and seven great nieces and nephews. Judy now lives in Stamford, Connecticut, and Wendy lives in the Washington, D.C., area. Both of them have fond memories of the Achenbachs.

Marcia was born in Cebu Province in the Philippines, where her American parents were living for her father's work with Standard Oil. She was one year old when the Japanese seized Manila on January 2, 1942, rounding up and interning 5,000 Americans at Santo Tomas Internment Camp. As a result, Marcia was separated from her parents until she was two. Her parents had gone to Manila on business, and Marcia was left at the family home on the island of Cebu under the care of her Amah and the company's assistant manager. It is this moment that set Marcia on a path to appreciate the kindness of strangers and to seek to help others. A British couple with an 11-year-old son cared for Marcia from hideouts in the hills of Cebu during internments at multiple detention centers until finally she was reunited with her parents and baby sister Judy at Santo

Tomas with the help of the Red Cross. They were liberated when Marcia was four years old. After the war, Marcia's father resumed his career with Standard Oil in Singapore and Bangkok, and Marcia attended boarding schools in Australia, Switzerland, and the United States. She enrolled at Stanford University in 1958.

Both Marcia and Jan were very active within the Northwestern community. The couple once said, "We have spent most of our lives at Northwestern and have always been happy here. Northwestern has given us lifelong education, culture, music, travel, and other benefits." Their lifelong association with Northwestern inspired the couple to give their entire estate to the university. The planned gift will establish two endowed professorships in mechanics of materials and solids in the Department of Mechanical Engineering and the Department of Civil and Environmental Engineering.

Career

In 1963, Jan started his long career at Northwestern University. As an early member of the solid mechanics group, Jan was instrumental in building a team of top scholars that established Northwestern's leadership position in solid mechanics in the United States and around the world. Established in the early 1960s by George Herrmann, the Theoretical and Applied Mechanics (TAM) Program at Northwestern has been a hub of research activities even since its inception. In addition to Jan, the early members of the group in the civil engineering department in the 1970s included excellent young researchers such as John Dundurs, Leon Keer, Toshio Mura, Zdeněk Bažant, Sia Nemat-Nasser, and Ted Belytschko, and from the Materials Science Department, Johannes (Hans) Weertmann, all of whom later attained fame and six became National Academy of Engineering (NAE) members. The group in the 1960s also included George Herrmann (later inducted to the NAE, too) until he left to become department chair at Stanford, and Seng-Lip Lee until he left to become department chair at the Asian Institute of Technology in Thailand. The largest, multimillion-dollar effort in this group, conducted jointly with Los Alamos National Laboratory (LANL), took place from 1974 to 1979 and was a project funded by the National Science Foundation's Research Applied to National Needs (RANN) program. Led by Weertmann, it also involved Jan and several others from the Northwestern faculty. The goal was to analyze a proposed hot-dry-rock geothermal energy scheme and drill in the Jemez caldera in New Mexico. The findings showed the heat output to decay too fast. Nevertheless, this skeptical conclusion had a major influence on policy and further research in the United States and Japan.

For two decades beginning in the mid-1960s, the young solid mechanics group in the Civil Engineering Department, with Jan at its helm, was very collaborative and social. Every Friday at 4 p.m., there was a mechanics seminar, led mostly by a guest speaker. Long discussions often followed in a group standing at a three-leaf blackboard filled with equations and sketches in chalk (such a mode of presentation, from which one could actually understand the speaker's argument, unfortunately disappeared with the arrival of transparencies and PowerPoint). John Dundurs made sure that after each seminar there was a party with the speaker at someone's home. One memorable party in 1972, at Toshio's home, lasted until 4 a.m., as Ronald Rivlin, the speaker and one of the famous mechanics gurus of that time, entertained all with anecdotal stories about other mechanicians.

With support from the Federal Aviation Administration, Jan founded the Center for Quality Engineering and Failure Prevention (QEFP) at Northwestern in 1985. The center initially focused on developing nondestructive evaluation (NDE) technologies for the aerospace industry, then gradually expanded its scope to many areas of engineering applications, including structural health monitoring of civil infrastructures and nuclear power facilities. The center quickly became a magnet that attracted many young and promising students, postdoctoral fellows, and visiting professors from all over the world. Within the NDE community, it was well known that there were two centers of excellence—one was at Iowa State University and focused on applied research, and the other was the QEFP at Northwestern and focused on fundamental research.

Throughout his career, Jan supervised more than forty Ph.D. students and numerous postdocs. Some of Jan's former students, such as Ben Freund and C. T. Sun, the former a member of both the National Academy of Engineering and the National Academy of Sciences, have become distinguished researchers themselves. As many of Jan's students can testify, Jan was a strict mentor with very high standards. Jan's high expectations of his students inspired many of them to make achievements beyond their potentials. For his teaching and mentoring, Jan was elected to the *Chicago Tribune* All-Professor Team in 1993. In 2004, he received the Tutorial Citation Award from the American Society of Nondestructive Testing. In 2014, Sigma Xi recognized Jan with the Monie A. Ferst Award for his "notable contributions to the motivation and encouragement of research through education."

Jan was also very active in serving the professional societies. He was a leader in our mechanics research community. As a member of the Executive Committee of the

Applied Mechanics Division of the American Society of Mechanical Engineers (ASME) and of the U.S. National Committee on Theoretical and Applied Mechanics, as editor and founder of the *Journal of Wave Motion*, as QEFP director, and as holder of other important offices, he provided strong leadership to our research community.

Jan was elected a member of the National Academy of Engineering in 1982 and the National Academy of Sciences in 1992 and a Fellow of the American Academy of Arts and Sciences in 1994. He became a Corresponding Member of the Royal Dutch Academy of Arts and Sciences in 1999 and an Honorary Foreign Member of the National Academy of Sciences, Republic of Korea, in 2010. He was awarded the ASME Timoshenko Medal in 1992, the SES William Prager Medal in 2001, ASME Honorary Membership in 2002, the ASCE Raymond D. Mindlin Medal in 2009, the ASCE Theodore Van Karman Medal in 2010, and the ASME Medal in 2012, as well as a number of other awards. He became a Fellow of the American Association for the Advancement of Science, the Japan Society for the Promotion of Science, the Acoustical Society of America, and the American Academy of Mechanics. He received honorary doctorates from Zhejiang University in China in 2011 and from Clarkson University in Potsdam, New York, in 2017, and was awarded the position of Honorary Professor at the Beijing Institute of Technology in 2012.

In 2003, Jan was awarded the U.S. National Medal of Technology for engineering research and education in the use of ultrasonic methods. In 2005, he received the U.S. National Medal of Science for pioneering the field of quantitative nondestructive evaluation. He received both from President George W. Bush in ceremonies at the White House.

Major Contributions to Scientific Literature and Engineering Practice

Jan was a preeminent researcher in solid mechanics for more than half a century. He made major contributions in the field of propagation of mechanical disturbances in solids. He achieved important results in quantitative nondestructive evaluation of materials, damage mechanisms in composites, and vibrations of complex structures. He developed methods for flaw detection and characterization by ultrasonic scattering methods. His work was both analytical and experimental in nature. Early in his career, Jan made important advances in dynamic fracture mechanics. He also achieved valuable results on earthquake mechanisms, on the mechanical behavior of composite materials under dynamic loading conditions, and on the vibrations of solid propellant rockets.

In addition to numerous journal and conference papers, Jan published four books that consolidated and synthesized many of the advances that he had made in these areas.[1,2,3,4]

Jan's doctoral dissertation at Stanford in 1962 dealt with waves and vibrations in viscoelastic solids, a problem of considerable interest for the dynamic response of solid rocket propellants. He solved the three-dimensional problem by means of a viscoelastic correspondence principle for transient waves and presented simplified solutions based on a novel viscoelastic constitutive model.[5]

From 1964–75, Jan's work focused on dynamic behavior of composite materials. In the mid-1960s, these inhomogeneous materials were represented by a homogeneous anisotropic material via the "effective modulus" theory. This representation, however, was often unacceptable at higher frequencies.

Jan developed a better model for laminated media and fiber-reinforced composites based on a generalized continuum theory and formulated a method to calculate the material constants from the elastic constants of the constituents and geometrical parameters. His new theory properly represented dispersion of wave motion at high frequencies. He published numerous papers on this subject and eventually summarized them in an influential monograph of lasting value.[2]

From 1968 to 1980, Jan was one of the main investigators advancing the understanding of the dynamic effects on fracture caused either by high crack propagation speeds or by dynamic external excitation. He derived expressions for elastodynamic stress intensity factors and combined them with energy conditions for the propagation of a crack. His first paper on this subject set a new direction,[6] and many others developed his approach further, notably Lambert B. Freund, one of his former students. He has also obtained important results on diffraction coefficients. Working with his postdoctoral assistant Arthur K. Gautesen and student Harry McMaken, he generalized the geometrical theory of diffraction to elastodynamics by solving two canonical problems, both concerned with the diffraction by a semi-infinite crack of a plane wave incident under an arbitrary angle with the edge of the crack.[7,8] Along with applications to scattering by cracks of finite dimensions, he later consolidated this work in a book.[3]

Jan's book on elastic waves, written during his sabbatical at TU Delft, was published in 1973.[1] It was the first to appear since the much earlier work by Kolsky. This book, which covered the then state of the art, was extremely well received and is still in print in a

paperback form. Numerous other books on elastic waves have been published, but Jan's book is still the most frequently referenced book in the general area of waves in elastic solids.

Jan became widely known for his groundbreaking contributions to acoustic microscopy. Around 1985, he started a laboratory in quantitative ultrasonics. Among the advanced instrumentation that he used and further developed was a line-focus acoustic microscope. He supplemented the experimental work on measurement of the V(z) curve with a theoretical analysis based on measurement models. His theoretical and experimental research, particularly on the determination of the elastic constants of thin films, resulted in a number of significant papers (written jointly with graduate students). A novel feature was Jan's use of an accurate measurement model with all the systemic features of the actual measurement process, but based on rigorous analysis. Jan's model made it possible to obtain the material parameters with great accuracy by systematically minimizing the difference between the measured and calculated V(z) curves. Jan eventually summarized his results in an influential review paper.[9]

Beginning in 1985, the emphasis of his work shifted to the theory and applications of ultrasonic methods to quantitative nondestructive evaluation, particularly on the measurement of elastic properties of thin films by acoustic microscopy and the detection of cracks and corrosion in safety-critical structures. He also began to work on the development of probabilistic methods for structural health monitoring of fatigue damage in structural components for the purposes of diagnostics and prognostics. His pioneering ideas have often defined new directions of research.

In the early 2000s, Jan returned to classical elastodynamics. He derived a new formulation to express Lamb waves in terms of a carrier wave propagating in the mid-plane of the layer. The carrier wave, which is the solution of a simple reduced wave equation, carries the thickness motion of the layer.[10] This information, in conjunction with a novel application of elastodynamic reciprocity, was extremely useful in deriving expressions for wave motion in an elastic layer (generated by a time-harmonic point load of arbitrary direction) in terms of superposition of wave nodes.

Jan was also very successful in practical applications of his results on quantitative ultrasonic nondestructive evaluation. With his co-workers, he made major contributions to practical applications of ultrasonics to detection and sizing of cracks and corrosion damage in metal structures. An example is the detection of corrosion and stress-corrosion cracks in the wing box of the DC-9. In the mid-1990s, Northwest Airlines had in

operation more than 125 DC-9 aircrafts older than twenty years. These aircraft needed periodic inspections for corrosion in the inner layers of the wing box, which is a fuel compartment. The old way was to enter the wing box for visual inspections or to disassemble the wing from the fuselage. This procedure took about 800 hours.

Jan was the leader of a team that developed an ultrasonic technique for nondestructive testing of the wing box from the outside of the wing, thus eliminating the need for wing box entry or disassembly. This reduced the inspection time to 50 hours and saved Northwest Airlines millions of dollars. The technique is now being used by other airlines and by the U.S. Air Force. Vital details of this technology were published in a 1995 paper,[11] and Jan's team was awarded the 1995 Medal of Excellence Award from the McDonnell-Douglas Company.

In his later years, Jan focused his research on applying the elastodynamic reciprocity[4] to obtain closed-form solutions for the scattering of elastic waves by surface cracks in plates and pipes.[12,13]

He never stopped doing research till his last days. Jan passed away peacefully in Evanston, Illinois, on August 22, 2020, three days after his 85th birthday. Some of his work was published posthumously.[14]

ACKNOWLEDGEMENTS

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