IN MEMORIAM

RAYMOND D. MINDLIN

Raymond D. Mindlin, Finch Professor Emeritus of Applied Science at Columbia University died on November 22, 1987 at the Dartmouth-Hitchcock Medical Center in Hanover, NH after a prolonged illness. He was 81 years old and resided in Grantham, NH at the time of his death. Professor Mindlin's active and prolific scientific career spanned more than half a century, during which he made significant contributions in solid mechanics and the peripheral fields of acoustics and optics. As a consequence of this work he was a world renowned authority in both engineering and scientific fields and a consultant to government and industry. In particular, his very important work on the mathematical theory of the vibration of elastic plates and its impact on the field of frequency control is the reason for the inclusion of this remembrance in these proceedings.

Raymond David Mindlin was born in New York City on September 17, 1906. He received four degrees from Columbia University, culminating in the Ph.D. degree in 1936. In the thesis Mindlin addressed and solved the problem of a force at a point in the interior of a semi-infinite solid, which is now and was shortly thereafter regarded as a classic. Mindlin began teaching at Columbia while still a graduate student and started graduate education in mechanics at Columbia in the thirties. Since his mentors were elsewhere, i.e., at Michigan and Harvard, he was in a very real sense the father of the graduate program in mechanics at Columbia. After receiving his degree he continued on at Columbia until the war when he left to serve the government at the Applied Physics Laboratory of Johns Hopkins University. It is of interest to know that during that period Professor Mindlin was instrumental in getting an Italian Jewish scientist out of Italy and that subsequently this scientist was instrumental in getting others in the same boat out.

At the Applied Physics Laboratory Mindlin led a team which designed the firing element of the first proximity fuse, a very important device in World War II. For this he was awarded the Presidential Medal of Merit in 1946. After the work on the proximity fuse Mindlin consulted for Bell Telephone Laboratories, where he worked on the design of spring systems to reinforce containers used for packaging electronic tubes so that they would not break when the packages were dropped from a certain height. This formed the basis of a publication entitled "Dynamics of Package Cushioning," which spawned an entire field.

After the war Mindlin returned to Columbia and became a full professor in 1947. However, he still consulted regularly at Bell Labs. During this period he was made aware of some of the problems associated with the proper functioning of the carbon microphone. This led to his pioneering work on the response of bodies in contact when subject to pressure and shear as a result of elasticity and friction. The results of this work have been applied by others in the design of relay contacts and ball bearings. Mindlin himself used the results in his work on the description of the behavior of granular media.

During this same period Mindlin was introduced to the field of frequency control by being asked some questions by people at Bell Labs about the loss of activity in AT-cut quartz thickness-shear resonators for certain ranges of aspect ratio of the plates. Mindlin was asked these questions even though he knew nothing about thickness-shear because he was an expert in the theory of elasticity and the flexure of thin plates. Although Mindlin had some difficulty communicating with most of the people, he found one, namely Irv Fair, who was able to educate him on what he did not know. This led to his work on the vibrations of crystal plates, in which he included the coupling of thickness-shear to flexure, which quantitatively described the behavior of the activity with aspect ratio and enabled AT and T to relax its tolerances in the fabrication of the plates. But, more importantly, this work led, in one way or another, to all work on the accurate analytical description of the three-dimensional modal behavior of quartz plates to this day.

Once having entered the field of crystal plate vibrations, Mindlin never left it. To be sure, he digressed into other fields at times but he always returned. For example, in the fall of 1960 Rudolph Bechmann asked Professor Mindlin whether a new theory of elasticity with an asymmetric stress tensor and forty-five independent elastic constants that was proposed by two independent groups of scientists should be included in a revision of the IEEE Standards that was currently underway. After a brief investigation Mindlin recommended that the committee ignore the forty-five constant theory. His recommendation was based on the fact that both groups had neglected to satisfy the law of the conservation of angular momentum. This investigation motivated Professor Mindlin to think of generalizing the theory of elasticity by including a couple-traction in addition to the usual force-traction. This led to the work on couple-stress

theory, which led further to work on even more general elastic continua, including microstructure theory. However, even though Mindlin worked avidly on these generalized descriptions during this period, he continued his work on crystal plate vibrations, to which his many publications in this field during the same period testify.

After originating and working in the area of microstructure theory for a number of years, Mindlin investigated ionic lattice theory in order to compare the long wavelength limit with microstructure theory. When he found that the systems of equations differed in certain respects, Mindlin halted his effort on microstructure theory and devoted his time to other productive research. From this it seems clear that just as specific physical considerations led Mindlin to investigate both couple-stress theory and microstructure theory, they caused him to abandon his effort on microstructure theory. This thread of intense concern with the description of physical reality in mathematical terms seems to pervade all of Mindlin's research.

Mindlin had remarkable physical insight and an uncanny ability to get to the heart of a problem, extract the essentials and construct a simple useful model that could relatively quickly yield the desired information. Partly for this reason he was extremely helpful to students he was advising when difficulties arose in their research. He was an excellent, clear and inspiring teacher who was sincerely appreciated by the students. This kind, mild-mannered, gentle man was admired by students and colleagues alike. All held him in great esteem and valued his counsel highly. In fact, a book dedicated to Professor Mindlin encompassing eight distinct subject areas to which Mindlin had made significant contributions was written by a group of his former students and published in 1974.

Mindlin was a member of the National Academy of Sciences and the National Academy of Engineering. He was a fellow of the American Academy of Arts and Sciences, the American Society of Mechanical Engineers and the Acoustical Society of America. Honors and awards that are too numerous to mention were showered on him by such organizations as the American Society of Mechanical Engineers, the American Society of Civil Engineers, the Acoustical Society of America, the Society for Experimental Stress Analysis and, of course, his alma mater and the school where he spent his career, Columbia University. Among these was the C. B. Sawyer memorial award, which was presented to him at the 21st Annual Symposium on Frequency Control in 1967. The citation stated "For fundamental contributions to the theory of vibration in piezoelectric resonators leading directly to advancements in the art." In recognition of his life's work, Mindlin received the National Medal of Science in 1979. Among the industrial organizations he served as a consultant to were Bell Telephone Laboratories, General Electric, General Motors and IBM. He served as an adviser to several government agencies, including the National Defense Research Committee.

Mindlin's first wife, the former Elizabeth Roth, died in 1950; his second wife, the former Patricia Kaveney, died in 1976. A memorial service for Professor Mindlin was held on March 23, 1988 in St. Paul's Chapel on the Columbia campus.

During the long illness prior to his death, Professor Mindlin was struggling to complete the third section of a three section book on the vibrations of crystal plates, but he was very weak and could not find the energy to get the work done. Fortunately, Peter Lee is working to complete the third section of the book, which, thankfully, will now be finished.