STRUGGLE AND THRILL IN A QUEST TO PREVENT FRACTURE AND COLLAPSE OF STRUCTURES

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The first critical moment of my career came in Prague in 1951 when, at the age of 13, I was expelled from the Pioneer. Labeled a bourgeois child and slated for coal miner apprenticeship, it looked as if my beginning love affair with mathematics and sciences could not continue. Although mobilization of all my family's connections got me admitted to high school eventually, I secretly resolved to escape to the West once I would grow up and, accordingly, became a zealous student of French, German and English even though I was not particularly gifted linguistically. My resolution somewhat wavered when, at the age of 25, my career in Prague started looking satisfactory; at that time, after being an external student employed full time as a civil engineer, I managed to attain a doctorate and get hired as a researcher at the Technical University.

In 1966, I nevertheless seized an opportunity. That year, an offer of postdoctoral fellowships was accepted in Prague from de Gaulle's government (regarded friendly because of its antagonism to the U.S.). By agreement, a long list of ranked candidates was submitted to the French, but the French were entitled to choose. Luckily, my proficiency in French, improved during my compulsory military service as an interpreter at a guerrilla training base in Trencin, helped, and the French interviewer rejected all those ahead of me on the list. I vividly recall the heartbreaking moment of departure at which I had no anticipation of being welcome back with the highest honors a quarter century later. From France, I arranged a Ford Foundation Postdoctoral Fellowship at the University of Toronto where my wife, who had just finished medicine at Charles University, managed to join me. During Prague Spring, we planned to return but the Soviet invasion changed our mind instantly. After a visiting appointment at UC Berkeley, a very pleasant experience spoiled by seeing hordes of communist sympathizers, I joined Northwestern University in 1969 as an associate professor. Four years later, it was a tremendous feeling to become the youngest full professor in the engineering school. America has treated me well.

The greatest reward of my immigration has been the opportunity to get a hand on some of the most interesting and important problems of solid and structural mechanics, concerned with the safety of structures against fracture and collapse and their long-time performance. It has been a struggle, but a rewarding and exciting struggle, a thrilling experience throughout all these years. I was lucky to obtain large and continuous funding for my research, mainly from National Science Foundation, Office of Naval Research, Air Force Office of Scientific Research, Army Corps of Engineers, and Department of Energy, as well as some additional funding from various firms.

In the 1970's, a major problem was the safety of design of nuclear power plants. Various scenarios of hypothetical large-energy nuclear reactor accidents in standard water-cooled reactors as well as experimental sodium-cooled breeder reactors were supplied to us, and with my research group, we analyzed the dynamic fracturing of these structures as well as long-term cracking and other deterioration due to non-uniform creep and pore water diffusion.

The scaling-up from small-scale laboratory experiments to much larger real structures emerged as a major problem. This made me think hard about the laws of size effect, conduct some experiments, and come with perhaps the luckiest idea in my career -- formulation of the size effect law for quasi-brittle fracture, which has been bringing me increasing fruits to this day. The study of scaling of structural failure and the change of their response with increasing size, has occupied me and my numerous able collaborators until today, and resulted in two books.

Another lucky idea that paid off much later was the formulation of the non-local damage concept for mathematical treatment of failures caused by cracking that does not localize into distinct fracture but remains distributed. An interesting theoretical aspect of this problem is the stability of propagating damage zones and fractures, which provided me considerable food for thought and led to my first large book in English, dealing with the stability of structures, elastic as well as inelastic, or fracturing.

During the 1970s and up to the mid 1980s, there was an increasing concern about hypothetical accidents involving the heating of protective structures to very high temperature. This provided me a fertile ground for conducting some interesting experiments, led me to develop some mathematical models for the behavior and disintegration of thick protective reinforced concrete walls in such postulated extreme situations, and summarize the results obtained in another book, dealing with concrete at high temperatures.

During the last two decades, deterioration of the civil engineering infrastructure raised alarm and led to some intriguing problems. I found it very interesting to cope with long-term creep and shrinkage of concrete, the frequent cause of cracking seen in older structures. The basic physical mechanism of the coupling of creep with moisture diffusion needed elucidation, which has been one rewarding effort with a complex materials science side to it, and since the phenomena of creep and moisture effects exhibit a large statistical scatter, probabilistic material models occupied much of my time. The resulting mathematical models make possible more realistic long-term performance of bridges as well as buildings. Some of the results of my group at Northwestern found their way into the building codes and standard recommendations (as did a new fracture test method based on the size effect law mentioned earlier).

In the 1980's, exciting research problems were presented by various defense needs. I got occupied with the fracture of hardened concrete structures and rock under missile impact or blast (whose understanding happens to be also helpful for earthquake resistant design of concrete structures in general), with fracture and scale effects in fiber composites for new navy ships and aircraft, and with fracture of floating sea ice plates, whose improved understanding was needed at that time for answering various practical questions regarding the surfacing and detectability of submarines, aside from being also of use to oil companies operating in the Arctic. Unlike brittle materials, fracture of concrete does not localize but remains distributed, and instead of the standard energetic models for propagation of a sharp crack tip one needs a model for the relationship between the stresses and the deformations in the fracturing zone. In our group we have had some success and develop a material subroutine which was then used in large computer codes in various laboratories, as well as some commercial computer codes.

My participation in the 1980s on a Navy submarine review panel opened my eyes to the intriguing effects of ice thickness and led me to propose some mathematical models for this effect. The culmination of my endeavors in ice fracture and scaling came in 1993 and 1994, when a team in which I took part (organized by John Dempsey) transported computers and various heavy equipment onto the frozen Arctic Ocean and conducted novel experiments in which floating ice plates (almost 2 m thick, and up to a record-breaking size of 80 m) were cut out and fractured under precisely controlled conditions (as documented by a slide show at the SVU Congress). Aside from the thrill of feeling the Arctic air and seeing with my own eyes the serene Arctic environment, I was delighted that the results, among other things, agreed closely with the general size effect law that I had proposed ten years earlier.

At present I am focusing mainly on further problems of the scaling of failure and size effect on structural strength, which have been researched in solid mechanics much less than in fluid mechanics. Aside from my continuing interest in fracture of quasi-brittle materials, which is now mainly oriented toward fiber composites, sandwich plates and cellular materials (rigid polymeric foams) for ships, one new current effort (which ties nicely with my long-standing passion for skiing) is the size effect on snow avalanches and mountain slides, both very destructive phenomena, hard to predict. Another project deals with using microwave heat shock to decontaminate concrete containing radionuclides by spalling off the surface layer. With a smart Italian visiting scholar, we are looking for an explanation why ancient towers in Italy are collapsing after about a thousand years of standing intact (our tentative explanation is an unfortunate constellation of the half-times of drying and carbonation with creep, fracture and size effect).

I must also admit that I succumbed to the currently fashionable trend toward nanotechnology and have amused myself lately with figuring out the size effects in plasticity of metals on sub-micrometer scale, at which dislocations in crystal structure play a different role than on the normal scales and the surface tension of a solid cannot be neglected. Doubtless much struggle and thrill can be found in that research direction.

My presentation at the SVU Congress, accompanied by an abundance of transparencies, focused on explaining in detailed but layman terms only three of the subjects on which I worked: The fracture studies of sea ice and composites for the Navy, and the missile impact studies for the Army. In conclusion of my talk, I briefly shared with the audience some of my personal views on how to make the system of public funding of research effective, which I published in some detail elsewhere and cannot include in this synopsis.