

Text of speech delivered by Dr. P. Rama Rao - Past President, IIM - at the inaugural session of the Interquadrennial Conference of the International Conference on Fracture (IQCICF-2008) held at the Indian Institute of Science, Bangalore on August 4, 2008.

India clearly is registering steady and sure progress in several areas of technology related to transportation, power generation, nuclear and aerospace technology, to name a few of these. Naturally, there is significant awareness of the need to design and build complex engineering systems with enhanced performance capability. And reliability and durability, as you all appreciate, are critical in such systems due to fatigue and fracture.

How and where did it all start?

If I go back in time to the 1960s, that is when, as a young lecturer at BHU, I started to look around to learn what was on in the country not only in fracture research but also generally. NAL was a pioneer in the field of fatigue research because of Dr. S.R. Valluri's leadership. Ably supported by Dr. K.N. Raju, our next speaker this morning, NAL got engaged in the design and fabrication of a multiactuator electrohydraulic computer controlled full scale facility for fatigue testing fighter aircraft. At BARC, structural mechanics research was nascent to be later nurtured and led by Dr. Anil Kakodkar and it is an honour to have him here today with us. Fracture research was shaping up at IITs at Bombay & Delhi, BHEL, SERC of CSIR and SAIL (R&D).

I wish to recall the name of Professor Bob Piercy of Chalk River Nuclear Laboratories, Canada who came to BHU during the early 60s as a Visiting Professor. As he was leaving after a year of brilliant teaching difficult topics such as dislocation theory, he had a piece of advice for me. He asked me to read the then recent papers of George Irwin and suggested that I should initiate fracture mechanics research which he foresaw as a promising field. I only wish I had taken his visionary advice more seriously than what I actually did. I realize I should not offer the excuse of lack of facilities or poor funding. I mentioned Prof. Piercy to underscore the value of inviting distinguished scholars from other countries to our universities to spend extended periods of time. Not long after the departure of Professor Piercy, Professor David Taplin came to us from Australia. He got me and Professor Kutumba Rao interested in creep fracture. David was also responsible for me to be inducted into the Council of ICF and thereby hangs a long tale. A notable event in this story is the largely attended 6th International Conference on Fracture held in New Delhi in 1984 of which Dr. Raju was a tireless organizer. By all accounts, this was a landmark conference and I trust it provided fillip to fracture research in India.

Present research interests in the country encompass the following five broad topics :

1. Analytical aspects of fracture and fatigue, by which I mean determination of stress intensity factors, analytical modeling of fracture and fatigue, numerical simulation techniques to map initiation and propagation of flaws and the like.
2. Microstructural aspects of fracture and fatigue.
3. Testing techniques.
4. Non-destructive evaluation (NDE), and
5. Failure analysis.

We do not have the time to mention individual names and highlights of their research in each of the above five areas. But, allow me to make the following remarks.

Apart from the well-endowed institutions and the well-known individuals, several of whom are at this conference, I wish you to note that we have in the country institutions and researchers in far flung regions.

To give you a feel for what I am saying, there is Panigrahi involved in failure of laminated FRP composites at North East Research Institute of S&T in Arunachal Pradesh, Verkey at Rubber Research Institute, Kottayam, Kerala studying fracture mechanics of natural rubber to metal bond, Kulkarni at BITS Pilani, Goa Campus interested in Experimental and FEM analysis of largescale yielding fracture mechanics. To reinforce the point, let me add Indian Council of

Forestry Research and Education, Dehradun working on fracture mechanics in solid wood composites, a private company, Mesy (India), and NGRI studying fracture mechanics in rocks and Apollo tyres, another private company, researching fracture of tyre structures using J integral.

Let me draw your attention to the topics – Nondestructive evaluation and Failure Analysis.

As you know, NDE is a powerful tool to quantitatively measure flaws prior to, during and after service. India may be regarded as a leading country with comprehensive expertise in the 10 to 12 major methods of NDE and their multiple variants. Much of this capability has developed as a consequence of the first of its kind demands made by the nuclear industry. The 14th World Conference on NDT held in India in 1996 was an important milestone and this event is to the everlasting credit of Dr. Baldev Raj. India has strong groups today in NDE at IGCAR, BARC, IISc, IITs at Madras, Delhi and Kharagpur, NAL and NML of CSIR, VSSC, defence laboratories DMRL and DRDL and several labs of power generation and manufacturing industries.

Analysis of failure of materials, components and structures has understandably grown to be an important multi-disciplinary scientific activity. NAL, DMRL, BARC, HAL and VSSC have established strengths in the use of a range of sophisticated characterization tools and more importantly to derive from

the observations the dependence of performance on the complex interrelationship between composition, processing, structure and mechanical properties. NAL's investigation of the Air India Boeing 747 aircraft Kanishka accident over the Atlantic Ocean and the ASM (International) publication entitled Failure Analysis of Engineering Structures by Ramachandran, Raghuram, Krishnan and Bhaumik are commendable contributions. Let me take this opportunity to emphasise the need to increase several-fold the number of such institutions to meet the obviously growing requirements. To achieve this goal, teaching institutions should use case studies of failures as a pedagogic tool to impart education in fracture phenomena and also to generate a sizeable number of trained failure analysis experts.

It is not for me to mention to this audience that mechanics alone or materials science by itself will be inadequate to develop a more wholesome understanding of fracture and arrive at novel approaches to design of new materials and components. Substantial progress is achievable when we understand not only mechanics and microstructural aspects of fracture, but also the thermodynamic and electronic basis of embrittlement. We have nurtured strengths in our country in a range of fields related to this subject. We have active scientists working in different aspects of fracture such as finite element modeling, experimental characterization of materials fracture behaviour as well as quantum physics so important to understand bonding at the atomic level. While we have nurtured strengths in these individual areas, what we are not

seeing is an integrated approach. Real progress can occur when we address issues of fracture at various scales – from atomic to macroscopic scale in a holistic manner. I hope this forum will serve as a catalyst for building productive interactions among various scientific groups working in the different relevant areas in our own country.

It is also interesting to point out that linear elastic fracture mechanics is useful in addressing failure at an astonishing range of length scales spanning 10^{14} orders of magnitude, that is covering fracture in NEMS which is of the order of 10^{-9} of a meter to tectonic plate movements whose dimensions are of the order of 10^5 meters. With reference to this mind-boggling range, although we have scientists like Bhattacharya at IIT Kharagpur doing good work on fracture in carbon nanotubes and the Snow and Avalanche Studies Establishment at Manali interested in fracture mechanics for avalanche prediction, it will not be untrue to say that a large part of the work in India occupies a fairly narrow space in the middle of the range.

Besides, much of the activities, barring a few notable exceptions, are centered on quasistatic fracture and mode I fracture in traditional materials. Internationally, headway is currently being made in studies of fracture in new materials, in the areas of dynamic fracture, in mixed mode fracture and in multi-axial testing. We have amidst us Professor Ravi Chandar who is a world leader in dynamic fracture. One reason for lack of significant progress in some of these

areas in India so far may be that the experimental facilities for carrying out such studies are complex and expensive. However, in the changed economic and consequently the research funding scenario, finding money should not prove to be a bottleneck. I would strongly urge the younger community to take up challenges in these and the other so-called hot topics like fracture in biological and natural materials as well as not to miss the opportunities for working at the extreme ends of the length range we referred to like fracture at nano scale at the one extreme end and laboratory earthquakes at the other extreme end. We should also encourage our scientists to collaborate with groups in other countries to be able to achieve a jumpstart in some of these emerging topics.

Finally, a word of congratulations to Prof. R. Narasimhan and his colleagues on spearheading the organization of this ICF Interquadrennial Conference. This meeting once again shines light on the field, its variegated and multidisciplinary nature, on its frontier topics and on the potential for application of the science of fatigue and fracture to new materials design and to sustainable, practical design of components and structures.

Let me reiterate in conclusion that the success of meetings of this nature should be gauged in terms of their impact on :

- (a) widening the base of research in our universities,

- (b) enhancing interactions among experts drawn from apparently different disciplines for advancing fracture research and
- (c) seeding international partnerships to accelerate the pace of research in topics new to India.

Thank you.