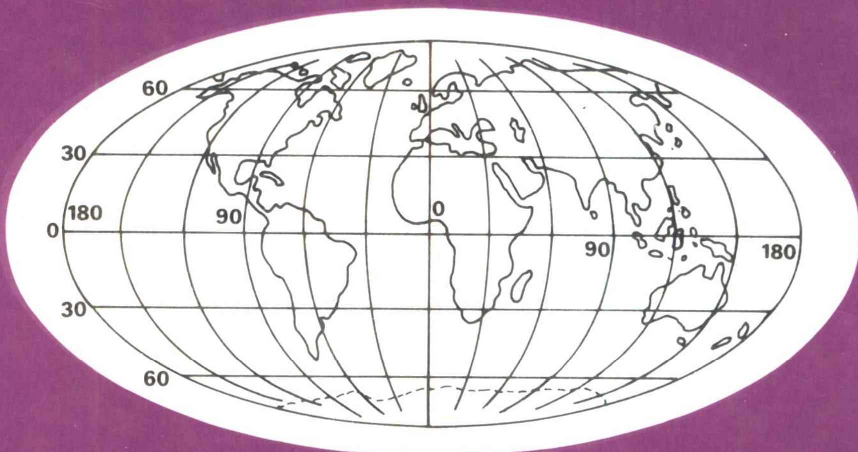
Progress in Fracture Research



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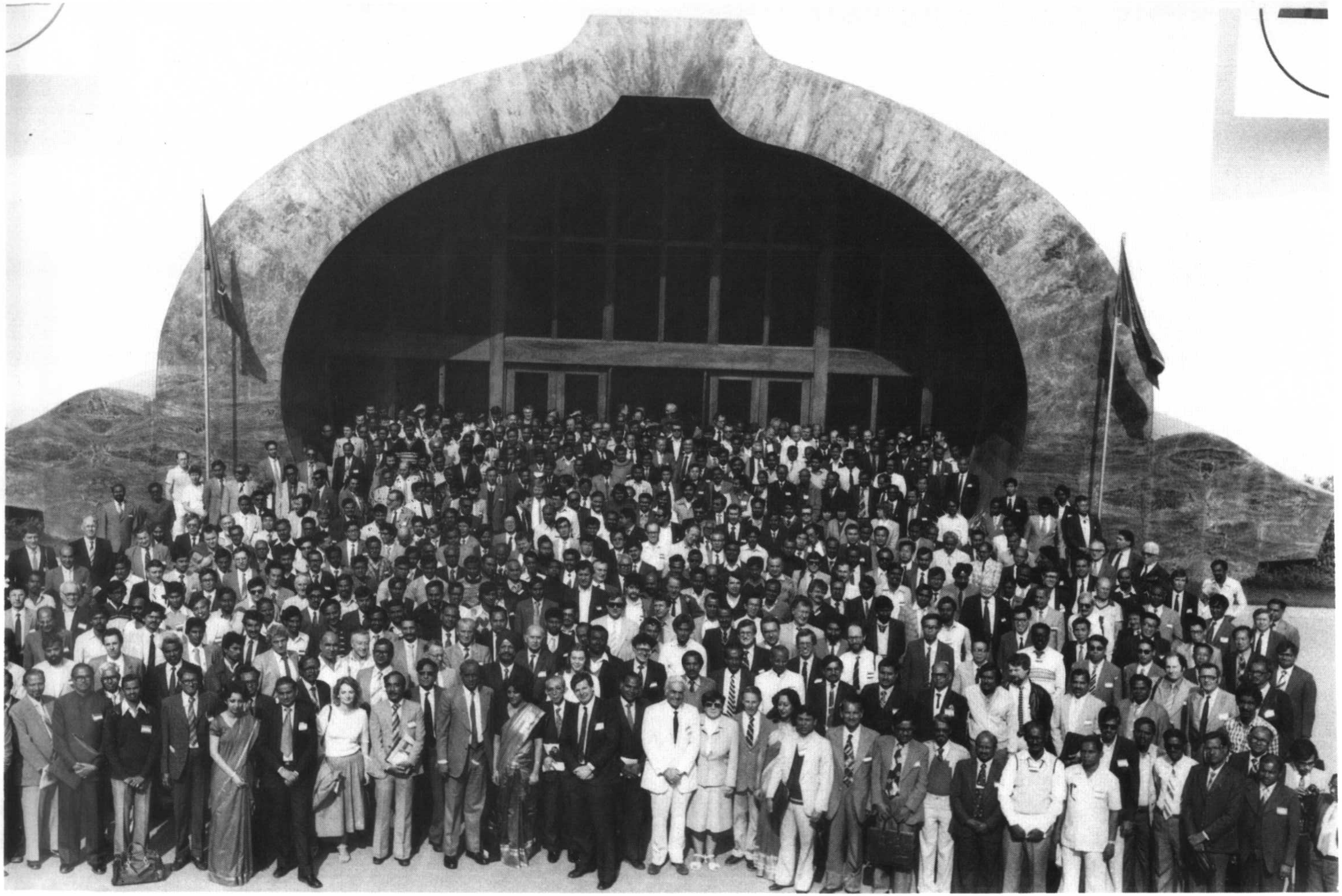

ICF6 participants with Vigyan Bhavan in the background

Foreword

This represents the final volume of the proceedings of ICF6 held at New Delhi during December, 1984. Unlike the first six volumes which were devoted solely to the technical proceedings of the conference, this volume includes a brief description of the inaugural function and closing ceremony, the complete list of ICF6 participants, and reports on the panel discussions on education and progress in fracture research. We are sure that this volume, apart from being informative, will revive the pleasant memories associated with ICF6. Finally, we take this opportunity to thank all the participants of the conference for making ICF6 a successful event.

Editors

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PANEL
DISCUSSIONS

Education in Fracture

The ICF Conferences have aimed at fulfilling the objective of the International Congress on Fracture to promote worldwide cooperation among materials scientists and engineers not only by encouraging presentations in oral and written form of research and development activities but also by focussing their attention on aspects pertaining to basic training and education in the discipline of strength and fracture of materials and structures. Thus at ICF4 as well as at ICF5, besides plenary and workshop paper presentations, panel discussions were organised on Education in Fracture.

The quantum and quality of instruction in fracture related topics has certainly grown over the years. While the importance of fatigue and fracture of materials and structures is increasingly felt in many fields of engineering, these topics are still being taught as part of courses in Civil, Metallurgical, Mechanical Engineering and Applied Mechanics. Between ICF5 and ICF6, a noteworthy development in UK in this context is the constitution of a group by the fracture sub-committee of the Royal Society to take stock of the situation with regard to 'Education in Fracture'. This group headed by Prof. F.M. Burdekin prepared a report giving specific recommendations, the most important of which is reproduced below:

"A recommended curriculum for undergraduate teaching of fracture has been prepared (Appendix A). The lecture time associated with the minimum recommended course is 18 hours, although individual disciplines are recommended to consider additional teaching in specific areas of the order of a further 18 hours. This implies that present fracture teaching is generally very inadequate compared to the recommended curriculum".

In the light of the above and the worldwide interest in issues pertaining to fracture education, a renewed panel discussion on 'Education in Fracture' at ICF6 was felt necessary and hence organised. Dr. A.A. Wells, Director, Welding Institute, Cambridge U.K. kindly agreed to chair the panel discussion at ICF6. He circulated months before the conference copies of the Burdekin Report to serve as a basis to a number of ICF6 participants the world over who had expressed a desire to participate in this panel discussion. Further, the following guidelines were provided by Dr. Wells to the panel members selected to make presentations during the panel discussion:

1. Broadly what facilities are available in your country for teaching of "Fracture"?

2. How do you believe that fracture should be taught to

   (a) technicians
   (b) undergraduates
   (c) postgraduates

3. What recommendations would you wish to make and what questions need to be answered?

Presentations were made by

(1)	U.S.A	- Prof. C.W. Smith, Virginia Polytechnic and Prof. R.E. Stephens, University of Iowa;
(2)	U.K	- Dr. J. Anderson, Derby, Dr. K. Williams, Open University, London and Prof. C.E. Turner, Imperial College, London;
(3)	AUSTRALIA	- Prof. J.R. Griffith, Monash University, and Dr. A.O. Payne, R.M.I.T., Melbourne;
(4)	FRANCE	- Dr. J. Galland, Ecole Centrale des Arts et Manufactures, Chateney, Malabry;
(5)	CANADA	- Prof. Raj Dubey, University of Waterloo;
(6)	CHINA	- Dr. Yao-Wu-Shi, Xian Jiaotong University, Xian Shaanxi;
(7)	ITALY	- Donato Firrao, Dept. of Mat. Science & Chem. Engg. Polytechnic, Torino;
(8)	JAPAN	- Dr. S. Fukuda, Welding Research Institute, Osaka University, Osaka;
(9)	INDIA	- Prof. S. Banerjee, I.I.T., Bombay and Dr. R.N. Singh, B.I.T., Sindhri, Dhanbad.

At the end of the session Prof. J.F. Knott, University of Cambridge, London, summed up the highlights of the various presentations made during the session along with his own views on the topic.

SUMMARY OF PRESENTATIONS

U.S.A. - Prof. Smith discussed the courses offered at undergraduate and graduate levels in Virginia Polytechnic particularly in respect of topics taught and the number of hours of lectures in each topic. It was pointed out that fracture mechanics topics are taught of under-graduate level as part of a course in Engineering Materials with a total of 6 hours of lectures. Attention was drawn by him to the fact that this was more than 2 hours of lectures, which 67% of the undergraduates receive in U.K., as per the Burdekin Report. He pointed out that a separate course on fracture mechanics is offered at graduate level with about 28 hours of lectures. The topics covered at undergraduate level are L E F M, plasticity, F C G and a applications. At the graduate level the topics are stress analysis and L E F M, plasticity effects, F C G and E P F M, dynamic fracture. He mentioned that environmentally assisted crack growth and probabilistic fracture mechanics are covered in special courses at Virginia Polytechnic. He observed that most of the Ph.D. students working on fracture mechanics ended up in academic institutions, while the M.E. students generally found place in industry and Govt. institutions.

He finally recommended that only L E F M and F C G should be taught in a basic course while topics like E P F M, dynamic fracture, microstructural effects, etc. should be taught as extensions or special courses.

Prof. Ralph Stephens pointed out that fracture mechanics topics are taught at University of Iowa for a week in the Fourth year of Bachelors degree in Mechanical Engineering as part of a course on design of machine elements. He referred to the various short term courses on fracture mechanics offered at the national level to engineers with a variety of backgrounds and the discussions he had with the people taking these courses. He felt that at the undergraduate level the students do not go through the course with serious interest, but only from the point of view of getting through the examinations. He observed that students who go out to industry very rarely come back with any specific problem for application of fracture mechanics. He said that he has difficulty in exciting in the students serious interest in fracture mechanics. He felt that there is a need for getting a feed back from students and analysing the feed back to get an idea of how the knowledge of fracture mechanics is being used in practice. He felt that fracture mechanics seems to be rarely applied to practical problems, part of the reason being that practical problems are complex and application of fracture mechanics to them is difficult.

U.K. - Dr. J. Anderson informed that the undergraduates receive about 20 hours of lectures on L E F M and crack growth including environmental and frequency effects in the final year. He referred to the Masters degree course in pressure vessel design which he is involved in and pointed out that L E F M is dealt with in detail in this course and E P F M is not touched upon. He observed that a majority of the fracture problems are not concerned with thin-section fracture which requires E P F M. He therefore felt that there is enough justification to restrict the basic or graduate course to L E F M and F C G, as recommended by Prof. Smith during his presentation. He added that the emphasis in the course on pressure vessel design is on material selection and importance of appropriate design. He recommended numerical type of examinations involving problem solving for fracture mechanics courses at least at the postgraduate level.

Dr. K. Williams of the open university described in some detail the case study approach to teaching fracture mechanics at the Open University. He highlighted the tremendous advantages in using the audio-visual techniques such as video tapes, TV monitors and the use of animation in imparting in depth understanding of the principles of fracture mechanics and their application to practical problems. He also referred to the use of computer terminals in tutorials and in problem solving exercises. He pointed out that fracture mechanics form about 2% of the total content of teaching in engineering degree courses. A detailed paper (Appendix B) on teaching fracture by the case study approach appears at the end of the section. All the eight video tapes mentioned in the detailed open university paper were screened throughout the conference in the lounge of Vigyan Bhavan and proved to be of great interest to ICF6 participants.

Prof. C.E. Turner of the Imperial College stated that at the Imperial College fracture mechanics is taught to engineering students as part of engineering materials course, elasticity as well as plasticity courses. Thus teaching of fracture mechanics to engineering students has diffused into other courses. He was of the opinion that there is nothing special about fracture mechanics to merit a special (or separate) course at the undergraduate level, He felt that there is need, however, for a special course at the post-graduate level to deal with E P F M aspects. He further pointed out that a case study approach needed a properly selected case along with a lot of data and felt that there is a need for putting together at one place design data to supplement conventional textbooks. He suggested that an appropriate organisation should undertake the work of putting together design data, now available in handbooks, E S D U data sheets etc. in a form useful to students for problem solving or for doing exercises which have a bearing on engineering applications.

AUSTRALIA - Prof. J.R. Griffiths discussing the structure of courses offered at the undergraduate and graduate level in Monash University, indicated that all engineering students get exposed in their first year to two hours of lectures in L E F M and also do a couple of experiments, while in the second year students branch out to different departments like Civil, Mechanical, Chemical and Electrical engineering departments and receive an additional 3 lectures in fracture mechanics. He added that the materials engineering students receive 12 lectures in the third year and 6 lectures in the fourth year on fracture mechanics, while the Civil engineering students receive only 3 lectures in the third year. He pointed out that the courses emphasise on fracture mechanics of adhesion, viscoelastic fracture, design of pipelines etc.

Dr. A.O. Payne briefly outlined the courses in fracture mechanics and structural fatigue that are proposed to be introduced at the undergraduate level in the Royal Melbourne Institute of Technology (R M I T). The proposed course on fracture mechanics at R M I T covers about 20 hours of lectures and the course on structural fatigue covers about 3 lectures. According to him the topics covered in these two courses give a basic introduction to L E F M, plasticity effects, J-integral etc. He added that a special course is being offered in the fourth year on fracture mechanics applied to composite materials involving about 25 hours of lectures. The topics covered in this course include studies on crack growth in composite construction at micro level and studies relating to fatigue of notched and unnotched fibre glass specimens and full scale fatigue evaluation of a fibre glass glider wing. Dr. Payne conveyed that facilities have been built up at R M I T over a period of time, which include a 50T M T S machine with digital programmer, data acquisition system, a full scale fatigue testing being set up for testing F R P wings and an instrumented glider for flight load studies.

CANADA - Prof. Raj Dubey emphasised the particular importance attached to studies on brittle fracture in welds of pipe lines, in view of the rather extensive network of pipe lines laid out in Canada carrying natural gas operating at sub-zero temperatures. He pointed out that fracture mechanics is dealt with as part of material science courses given at Civil and Mechanical engineering departments. He added that the lectures are basically on L E F M. He felt that there is a need to include a good set of lectures on theory of plasticity in a fracture mechanics course. He was of the opinion that plasticity theories are being used in fracture mechanics in an inconsistent manner mixing up Lagrangian and Eulerian viewpoints.

CHINA - Dr. Yao Wu Shi traced the progress in engineering education to the rapid developments in agriculture and industry. He described briefly the structure of engineering education in China. He informed that among the large number of universities and institutes about 86 are preuniversities and 9 to 10 among these are universities, out of which 3 are comprehensive science and engineering universities. The engineering students study for a period of four years to get the Bachelor of Engineering degree. Of these four years, they take the first two years to go through basic courses such as physics, chemistry, mechanical drawing, strength of materials, engineering mechanics etc. The third year is devoted to technology courses while in the final year students receive special courses as per their speciality. Engineering fracture mechanics courses are given to Mechanical engineering students who also do a project finally for a period of 12 weeks. Dr. Shi pointed out that over the last four years the postgraduate study programmes have been revised. He added that currently about 100 students study fracture and modern facilities such as closed-loop fatigue testing machines, computers, high voltage electron microscopes have been imported for use in the universities in keeping with the rapidly developing nature of China.

FRANCE - Prof. Galland discussed the pattern of education in fracture in France as given to technicians, undergraduates and postgraduates. He mentioned that nearly 15% of approximately 60,000 technicians per year are exposed to lectures in fracture for a period of 5 to 10 hours along with experimental exercises in the laboratory. He added that 15% of approximately 12,000 undergraduates per year end up as mechanical engineers and receive anywhere between 5 to 50 hours of lectures on fracture including computational and experimental exercises. In his country about 300 postgraduates per year are exposed to fracture mechanics for durations between 20 to 80 hours.

Prof. Galland recommended a pedagogical approach to teaching of fracture under the broad headings of (1) Fracture Mechanics, (2) Fracture Mechanics application to stress corrosion cracking, and (3) Fracture Mechanics applications to fatigue and corrosion-fatigue. In his view knowledge under these headings could be imparted to the students at three different levels, depending on the specialisation opted by the students (mechanical, metallurgical, physics, etc.). These levels are indicated in Appendix 'C'.

JAPAN - Dr. Fukuda mentioned that the undergraduates in the universities in Japan are exposed to fracture mechanics lectures for about 3 hours. He added that although case studies are desirable as part of teaching fracture, it has not been possible to introduce them due to lack of time. He recommended increasing use of computer aided instruction systems involving 5th generation computers (as referred to in Japan) in teaching. He felt that there are difficulties in using computers in teaching.

ITALY - Prof. Donato Firrao, outlining the structure of fracture education in Italy, mentioned that undergraduates were taught fracture mechanics in courses on machine design, metallurgy, material properties and engineering mechanics, while postgraduates are exposed to fracture mechanics in specialised and specific areas. He pointed out that apart from universities, independent bodies such as Centro Sperimentale Metallurgico, I S M E S (Civil engineering), C I S E are also involved in fracture education. He outlined the activities of the Italian fracture group in fracture education.

INDIA - Prof. Banerjee describing the structure of fracture education in India mentioned that annually only 1000 students out of approximately 7000 undergraduate students of Civil, Mechanical, Metallurgical and Aeronautical engineering are exposed to fracture mechanics and only about 50 out of 200 postgraduate students are exposed to fracture. He added that only 15 Ph.D. students per year are involved in research in the area of fracture mechanics. He stressed the need for rapid expansion in fracture education in India and for exposing greater number of students to fracture mechanics. He referred to the lack of widespread availability of experimental facilities such as testing machines, electron microscopes and teaching aids such as educational films on fracture mechanics. He felt that there is a need to develop good course material, specially for the courses of fracture mechanics at undergraduate level. He suggested that there should be an independent fracture mechanics course at the postgraduate level and that periodical workshops in fracture mechanics with emphasis on practical applications should be organised for engineers in industries and students as well. He pointed out the need to include probabilistic aspects and NDT in the fracture mechanics courses.

Dr. Singh indicated the various topics that need to be taught in a fracture mechanics course. He stressed the need for development of suitable syllabus for the course and its periodical revision every five years to keep up with the developments in the field.

Prof. J.F. Knott summed up the discussions in the session and pointed out that fracture mechanics has far wider and complex role to play, ranging from design of structures in quantitative terms for required durability and reliability levels to making decisions about retirement for cause or repair before a crack is found in the structure. He felt that fracture design should become an integral part of computer aided design and that CAD would be pointless if the design has no proper basis. He concluded by saying that there is a need for emphasising the application of fracture mechanics in material design such as defining the material defect content as a function of service life.

APPENDIX A

RECOMMENDED BASIC CURRICULUM

UNDERGRADUATE TEACHING-CORE TOPICS RECOMMENDED FOR STUDENTS IN ENGINEERING

Topic A Fast Fracture (3 Lectures, 1 Practical)

General intro uction to different modes of failure-deflection, buckling, plastic collapse, crack growth, fast fracture.

Distinction between brittle and ductile, stable and unstable fracture. Basic phenomenon of unstable brittle fracture - no macro ductility at fracture surfaces - occurs under tension stresses.

Material resistance not indicated by uniaxial tension tests-effect of notches/cracks on stress concentration and triaxiality.

Mechanisms of fracture-cleavage, microvoid coalescence and shear fracture, inter-granular fracture.

Fracture surface-chevron markings.

Effects of geometric stress concentration and residual stresses.

Transition temperature effects for ferritic steels effects of thickness, strain rate, notch sharpness, welding and local embrittlement on transition behaviour.

Circumstances under which unstable ductile tearing may occur. Materials selection to avoid fracture-initiation philosophy, wide plate tests, linked to Charpy tests-propagation philosophy, crack arrest tests, drop weight tear, stiffness and energy effects, etc.

Practical-Charpy transition curves for two steels.

Topic B Fatigue (3 Lectures, 1 Practical)

Topic B Fatigue (3 Lectures, 1 Practical)

Basic phenomenon-cyclic loading and slow crack growth.

Fracture surface and appearance.

Classical S-N curves for polished specimens-Stage I and Stage II growth-fracture surface at low and high magnification-effects of mean stress frequency and environment (introduction only)-Goodman diagrams etc.

Effect of stress concentration-rotating machinery-combined bending and torsion-fretting and other initiation causes-fillet radii, K_t and K_f analysis approaches and their limitations.

High cycle/low cycle fatigue-stress controlled/strain controlled.

Behaviour of welded joint in fatigue by design S-N curves-effects of scatter.

Treatments for improvement of fatigue performance-metallurgical, mechanical.

Effects of cumulative damage-Miner's law-simple treatments of random loading.

Effects of shear loading, fretting etc.

BS.5400 and BS.5500 treatments.

ESDU data banks.

Practical - Fatigue S-N curves for specimens without and with stress concentrations.

Topic C Basic Fracture Mechanics (7 Lectures, 1 Practical)

Griffith strain energy release rate/crack extension force for central crack in infinite plate - G - compliance effects.

Critical G for fracture-surface energy to create new fracture surfaces-work of fracture. Stability and instability of fractures.

Model I, II, III loading for cracks.

Solutions for stress fields at cracks in elastic materials-stress intensity factor K.

Typical values of K for through crack, surface crack embedded crack, under tension and bending stresses. General form Y-factor curves for different configurations. Relationship K to G.

Critical K for fracture K_c-effects of stress state and thickness-plane strain fracture toughness K_{Ic}-criteria for valid K_{Ic}-specimens used for laboratory toughness tests.