

INTERNATIONAL ASSOCIATION OF FRACTURE MECHANICS FOR CONCRETE AND CONCRETE STRUCTURES

FOUNDED IN 1991. INCORPORATED IN THE STATE OF ILLINOIS, USA

LETTER FROM THE PRESIDENT

It is my greatest pleasure to initiate the first newsletter of our newly formed International Association of Fracture Mechanics for Concrete and Concrete Structures, in short, FraMCoS. Ours is a rapidly developing new field, which will most likely have profound consequences for the way concrete structures are designed and analyzed.

The research activity in this field surged dramatically during the last decade and may be expected to continue increasing for many years until, hopefully, the subject of concrete fracture mechanics in particular and the design of concrete structures in general will become as clear and rational as, for example, the analysis of elastic frames. That field, close to the heart of civil engineering, had slow beginnings marred by disagreements and was the object of major research efforts for about 100 years until a satisfactory status was reached shortly after the middle of this century. In our field, likewise, we may anticipate a lengthy period of fruition, which needs to be aided by regular convening of conferences to critically appraise the advances and chart the further course. Our new Association, whose main practical objective is the organizing of major periodic international conferences on the subject, is trying to foster this development.

The design of concrete structures to prevent their failure is a complex scientific problem which, at the beginning, had to be addressed purely empirically. As the theoretical knowledge of the behavior of concrete and concrete structures advanced and a wealth of experimental results was being accumulated, drastic changes in the way concrete structures are designed and analyzed took place. There have already been two revolutions in the field. The first one, which in fact made first larger structures possible, was the development of the no-tension design at the beginning of this century. The second revolution, representing a major advance, was the introduction of limit analysis based on the theory of plasticity. That has been an arduous process, which took about 40 years. It began roughly in 1930 and was completed by 1970 (the ACI Code introduced the limit analysis principles in 1971). From the theoretical viewpoint, the case for limit analysis based on the theory of plasticity was essentially clear already about 1935. The reason that the introduction of plastic limit analysis took such a long time was the need to accumulate detailed and systematic experimental evidence, work out the detailed applications to many different types of failure and, last but not least, educate young engineers in the new theoretical principles. At the moment, we are probably standing at the onset of a third revolution in concrete design practice. The process of introducing the principles of fracture mechanics to the analysis and design of concrete structures will not be easy, but let us hope it would take less than 40 years.

The impetus for the recent rapid development of fracture mechanics applications to concrete structures came basically from four directions:

1. The realization that without some type of fracture mechanics or equivalent concepts such as nonlocal damage, the seemingly all-powerful finite element codes cannot correctly describe damage localization phenomena and cannot provide objective, mesh-independent predictions of brittle failures of concrete structures;
2. the recognition that the existing design codes cannot correctly predict the effect of structure size on the maximum load, ductility and energy absorption capability in these types of failures;
3. the realization that fracture phenomena are particularly important for modern high performance concretes and various new cement based materials; and
4. the recognition that development of better cement-based composites is impossible without understanding the micromechanics of fracture.

Realization of these facts led to an explosion of research activity beginning about 1980. A number of committees of various societies were formed with the objective to advance the subject, for example the influential RILEM committee chaired by F.H. Wittmann, which sponsored the first large international conference devoted to the subject in Lausanne in 1985. After that, conferences proliferated, but unfortunately in an uncoordinated fashion. During the last several years the situation became confusing, several conferences conflicting with each other. An active researcher was unable to attend all of them, while at the same time he did not know which would be the principal conference to choose.

Recognizing this state of affairs firsthand with my initial difficulties at scheduling of what became our Breckenridge conference, I decided to talk about the situation with various leading researchers around the world. In summer 1990 I circulated a letter to the members of the freshly organized International Scientific Advisory Committee of the Breckenridge Conference, suggesting that the disorderly spectrum of conferences could be remedied by founding an international association. The response was overwhelmingly positive. Therefore, I have held detailed discussions with a number of leading researchers, including F.H. Wittmann, S.P. Shah, M. Elices, H. Reinhardt, A. Carpinteri, H. Mihashi, J. van Mier, J. Mazars, L. Cedolin, J. Planas, K. Willam, B.I.G. Barr, V.E. Saouma, and others. We met at several charming locations -- at the International Workshop on concrete dam fracture held in Locarno, Switzerland, September 1990 (organized by Wittmann and Dungan) and at the International Workshop on Concrete Fracture held in Torino in October 1990 (organized by A. Carpinteri).

As a result of these discussions, I called an organizing meeting at Hotel Oranje in Noordwijk, Netherlands, for June 19, 1991, as part of the conference organized by J. van Mier. Our Association was created there by an unanimous consensus of the members of the International Scientific Committee of the Breckenridge Conference who were present in Noordwijk. They became the FraMCoS Founding Members. The first President, secretary and steering committee members were elected on that day. The steering committee, with F.H. Wittmann as chairman and B.I.G. Barr as secretary, has subsequently worked on the by-laws of our new Association which were eventually adopted in Breckenridge. It was decided to incorporate our Association in the state of Illinois and have the headquarters in

Evanston. Mr. Clement J. Carroll, Jr., a Chicago attorney, was hired to take care of the legalities of the incorporation as a non-profit organization, with an initial Board of Directors consisting of F.H. Wittmann, H. Mihashi, and myself, as representatives of three continents. The incorporation was obtained from the State of Illinois on December 16, 1991, which lent our Association legal status. A meeting of the general assembly of FraMCoS, consisting of all the members of the Association, was then called to Breckenridge. It took place on June 4, 1992 in the Beaver Run Resort. With the adoption of by-laws at that assembly, our Association has acquired a definitive form.

Our Association will be run by its Board of Directors, supported by the Advisory Board. The Board of Directors consists of the president, past-president (however, for the initial one-year transitional period, president-elect), secretary and treasurer. The Advisory Board consists of four elected and four appointed members. The finances will be overseen by two auditors, and the secretary will at the same time serve as the newsletter editor and archivist.

The principal goal of our Association, run democratically by its members, is to organize at regular intervals (three years, as decided in Breckenridge) FraMCoS International Conferences, dealing with all aspects of the application of fracture mechanics to concrete and concrete structures. The sites will alternate among various continents and countries, with no geographic or other bias, however, favouring the leading centers of research. Our Association also desires to sponsor or co-sponsor FraMCoS Research Workshops or other symposia focused on more specialized subjects.

The success of FraMCoS-1, our first conference in Breckenridge, depended on the quality of papers and the quality of discussions. In my opinion, as an overall judgment, they were outstanding. I wish to thank all the authors and participants for their efforts which guaranteed the success of our first conference.

Finally, in this first newsletter, I wish to thank all those leading researchers who lent me support in organizing this Association. In FraMCoS, we have a chance of making a significant contribution to the advancement of an important field of science and engineering.

Zdeněk P. Bažant



FOUNDING MEMBERS OF IA-FraMCoS

FraMCoS 2 - 1995

INITIAL THOUGHTS BY THE PRESIDENT-ELECT

The first International Conference on Fracture Mechanics of Concrete Structures (FraMCoS 1), organised by Professor Zdeněk P. Bažant, took place at Beaver Run Resort, Breckenridge, Colorado, USA, from June 1 to June 5, 1992. FraMCoS 1 was initiated at a preparatory meeting which was held at Hotel Oranje in Noordwijk, The Netherlands, on June 19, 1991, during the Fracture Mechanics Conference (Fracture Processes in Concrete, Rock and Ceramics) organised by Dr. Jan van Mier from Delft University of Technology. At that meeting a steering committee headed by Professor F.H. Wittman and Dr. B.I.G. Barr was charged to prepare statutes for the new International Association of Fracture Mechanics of Concrete Structures (IAFraMCoS). During FraMCoS 1 in Breckenridge, June 1992, the statutes were accepted by the first General Assembly by unanimous vote.

The General Assembly of IAFraMCoS also decided that FraMCoS conferences shall be organised regularly after intervals of three years. In-between, regional conferences and workshops can be held. It is one aim of each FraMCoS conference to document the state-of-the-art reached after three years in a quickly developing branch of science.

At Breckenridge, I had the honour of being elected chairman for FraMCoS 2. The second FraMCoS Conference will be organised in Zurich, Switzerland, in the summer of 1995. The Scientific Advisory Committee and a local organising committee is now being set up. The first announcement will be distributed before the end of this year.

Among other topics, particular attention will be given to the following topics:

- 1) Material models for concrete fracture
- 2) Experimental methods to determine fracture characteristics
- 3) Numerical analysis of concrete fracture
- 4) Significance and experimental/numerical determination of parameters used in numerical models
- 5) Mixed mode and dynamic fracture
- 6) Fracture of unreinforced and reinforced concrete structures
- 7) Environmental effects

Special emphasis will be placed on validation of numerical models and on the application of fracture mechanics in structural engineering. Further details regarding FraMCoS 2 will be provided in Newsletter 2.

Folker H. Wittmann



FOUNDING BOARD OF DIRECTORS AND STEERING COMMITTEE

FIRST BOLOMEY-WORKSHOP/FIRST FraMCoS WORKSHOP

Numerical Models and Material Parameters for Concrete Cracking - July 1992

A two day workshop was organised by the Institute for Building Materials, Swiss Federal Institute of Technology, Zürich in July 1992. The organising committee was chaired by Professor F.H. Wittmann. The workshop was initially planned to be the First Bolomey Workshop commemorating Professor Bolomey (1879 - 1952), a renowned Swiss concrete scientist. However, after IAFraMCoS was officially set up at Breckenridge in June 1992, it was decided to designate this workshop, at the same time, as the First FraMCoS Workshop. All contributions and summary reports of the discussions will be published in a proceedings volume by A.A. Balkema in the Spring of 1993.

The main objective of this workshop was to bring together a small group of invited experts to discuss different numerical models which have been developed recently to describe crack formation and failure of concrete. Special emphasis was placed on the significance of the different parameters used in these models and on the possibility of determining the material parameters experimentally.

The theme of the Workshop was covered in five sessions:

- (i) Fictitious crack model: fracture energy and strain-softening,
- (ii) Smeared crack model,
- (iii) Continuous fracture models,
- (iv) Probabilistic aspects, and
- (v) A special session on Applications.

The fictitious crack model has been developed in parallel with appropriate test methods to determine fracture energy and strain-softening, but further work is needed on this and other models. In some cases it might be difficult to determine all the necessary parameters experimentally. It became evident that a joint effort of scientists specialised in numerical methods on one side and in advanced experimental techniques on the other side will be needed to overcome these difficulties.

FraMCoS SPONSORED WORKSHOP

Sendai, Japan - November 1993

Dr. H. Mihashi is organising an International Workshop on Size Effects in Concrete Structures at Sendai on 1-2 November 1993. The Workshop is co-sponsored by FraMCoS as well as the Japan Concrete Institute, CEB and RILEM. The Workshop will address research areas arising from current developments in concrete structures.

Recently concrete structures have become larger and the strength of members is also increasing. Many concrete structures have been constructed, whose size or strength, or both, exceed the testing capacity of even well-equipped experimental laboratories. Thus there is a need to develop design methods for such large or high strength structures without carrying out tests or testing full scale specimens. Rational analytical techniques need to be developed in order to confirm the safety of structures on the basis of test results from small scale specimens. For this purpose, the fracture mechanics approach may be of potential use.

The aim of this Workshop is to discuss the mechanisms that cause size effects in concrete structures and to encourage exchange of ideas among all the parties involved in this research field, to promote development of rational methods for predicting the size effect in concrete structures, and hence designing such structures safely.

REPORT ON THE FIRST INTERNATIONAL CONFERENCE ON FRACTURE MECHANICS OF CONCRETE STRUCTURES (FraMCoS 1)

The first conference of the International Association of Fracture Mechanics for Concrete and Concrete Structures was held at Beaver Run Resort in Breckenridge, Colorado, during June 1-5, 1992. The conference, organized and chaired by Zdeněk P. Bažant of Northwestern University, was financially supported by the U.S. National Science Foundation. The conference was organized in collaboration with the NSF Science and Technology Center for Advanced Cement-Based Materials (ACBM) at Northwestern and with ACI Committee 446 on Fracture Mechanics. It was co-sponsored by the American Concrete Institute and the International Association for Bridge and Structural Engineering.

The conference came at a time in which the applications of fracture mechanics to concrete and concrete structures are undergoing an explosive development and are likely to have a major impact on the design of concrete structures and code specifications, as well as the practice of finite element analysis. It appears that this impact will probably be as far reaching as that of the introduction of plastic limit analysis which took place between 1930 and 1970.

The conference programme consisted of eight sessions. Each of them except the seventh started with a general session featuring principal and invited lectures and a one-hour general discussion, and continued with two parallel sessions featuring the contributing papers. The conference opened with a principal lecture by Z.P. Bažant which described the state-of-the-art and presented an overview of the freshly completed state-of-art report by ACI Committee 446, Fracture Mechanics, chaired by Bažant. S. Reid presented B. Karihaloo's invited lecture, devoted to material models for concrete fracture and discussing the mathematical formulations for strain-softening, including viscoelastic and stability aspects. The subsequent sections focused on propagation criteria and material models for fracture, smeared-crack concepts, and random process modeling. The problem of size effect theory and of an unambiguous determination of material characteristics were prominent in the discussions.

The second session dealing with experimental study, material characterization and size effect opened by the principal lecture of F.H. Wittmann, followed by invited lectures by R. Eligehausen, V. Saouma and V.C. Li. Wittmann presented a sophisticated mathematical analysis of the fracture process zone, including not only the effect of its length but also its width, and covering the effect of thickness of the specimen. He used the recutting method to compare the theoretical analysis to experiment. The invited lectures addressed the size effect in the failure of anchors, fracture of concrete dams and problems of ductility in fracture, including fibre-reinforced cementitious composites. The subsequent sections dealt with experimental study and material characterization, X-ray strain measurements, dowel action, aggregate-paste bond, wedge splitting specimens and lateral flexing of direct tension specimens.

Session three, dealing with numerical methods and structural analysis, featured invited lectures by A.R. Ingraffea, A. Carpinteri and J.G. Rots. The pros and cons of the discrete and smeared cracking models were discussed and numerical problems associated with various models (smeared crack model, orthotropic damage model, rotating crack models, etc.) received considerable attention during the discussion.

In session four, on damaged modeling, a principal lecture by H. Mihashi reviewed recent results on tensile strain-softening properties of concrete, and a principal lecture by K. Willam addressed the fundamental aspects of strain-softening description. In a subsequent invited lecture, de Borst presented a gradient continuum model for the treatment of concrete and rock fracture. There were extensive discussions on the problems of mesh-sensitivity, localization and the related size effect, as well as the problems of identification of damage characteristics from experiments, stemming from the impossibility to achieve uniform damage states. The parallel sections dealt with damage modeling and fracture of reinforced concrete. The papers addressed damage modeling by discrete and smeared crack concepts, micromechanics based continuum theory, microplane-type constitutive models for distributed damage, experimental results on strain-localization in compression fracture, finite element analysis of reinforced concrete panels, crack spacing and width in reinforced concrete, fibre reinforced concrete, and problems of steel bond modeling.

The fifth session, on mixed-mode fracture and interfaces, opened with the principal lecture by J.G.M. van Mier which was focused on the modeling of shear fracture. J-K. Kim substituted for the invited lecturer Y.-W. Mai to present their joint work on interfacial properties of steel fibre cement mortar composites. There has been a particularly lively discussion on interpretation of the various types of shear fracture tests and the existence of shear fracture on the microscale. The parallel sections which followed dealt with mixed-mode fracture, experimental studies, applications to punching failure of waffle flat slabs, analysis of biaxial loading and wedge-splitting tests, torsional damage tests, measurement of fracture energy in early age concrete, and tensile fracture characteristics of high strength concrete.

Session six, devoted to fracture analysis of bond failure, included principal lectures by S.P. Shah and H.W. Reinhardt, and an invited lecture by H.J. Hilsdorf. The lecturers discussed bond properties in fibre reinforced cement and aggregate-cement paste interfaces, role of bond in strain softening at various rates, and applications to concrete repair and protection overlays. The modeling of bond failure, its various influencing factors and appropriate experimentation, received considerable interest in the discussions. The subsequent sections dealt with interfaces, mixed mode fracture, and the practical aspects of shear, bond and anchors in reinforced concrete. The practical applications included fracture design of concrete piles, shear strength of longitudinally reinforced beams, fracture of lightly reinforced beams, dynamic behavior of concrete slabs, comparisons of code and fracture mechanics predictions, analysis of headed anchors, and an evaluation of the results of the recent round-robin testing of anchor bolts.

To avoid conflict with the general assembly of Association members, session seven was shorter and consisted only of parallel sections dealing with the size effect and environmental influences. The presentations addressed the influence of size on the measured fracture energy, the size effect on the nominal strength of short and slender reinforced concrete columns, the size effect on plastic rotational capacity of R.C. beams, crack formation under hygral gradients, thermal fracture, fracture analysis of shrinkage cracks, and fracture in concrete pavements.

The last, eighth session devoted to time-dependence, dynamics and fatigue, opened with a principal lecture by J. Planas and M. Elices, which dealt with fracture caused by drying shrinkage stresses and the consequent structural size effect. In the subsequent invited papers, J. Isenberg presented a review of dynamic fracture of concrete, based on a freshly concluded state-of-art report of ACI Committee 446, Fracture Mechanics, and S.E. Swartz discussed fatigue damage in concrete beams. There have been extensive discussions on the degree of influence of shrinkage cracking on the size effect under applied loads and on the mechanism of the rate effect in dynamic fracture, particularly the difference between fractures under dynamic rates and under slow rates corresponding to loading up to several days duration. The parallel sections that followed dealt with dynamic fracture, fatigue

and rate effect. The particular topics discussed were impact analysis, effect of water on dynamic response, torsional impact, blast-loading, experimental results on fatigue loading and cyclic bond slip behavior, generalization of R-curve modelling for rate effect and size effect, effect of cyclic loading on high strength concrete, and probabilistic aspects.

An unfortunate car accident in Colorado just before the conference forced cancellation of the invited lectures by J. Mazars and G. Pijaudier-Cabot. Despite severe injuries, both invited speakers have fortunately recovered by the time of this publication.

A large number of excellent papers, as well as lively and interesting discussions, have made FraMCoS-1 a great success. There were 139 registered participants at the conference, representing 20 countries. In total, they presented 125 papers.

All the presented papers were published before the conference in a proceedings volume entitled "Fracture Mechanics of Concrete Structures", edited by Z.P. Bažant (Elsevier Applied Science, London and New York, 1992, 1021 pp.) dedicated to the memory of Maurice F. Kaplan, a pioneering researcher in concrete fracture. Aside from the presented papers, the proceedings include the full text of the State-of-Art Report on Fracture Mechanics of Concrete: Concepts, Models and Determination of Materials Properties" by ACI 446, which has just been published as ACI Special Publication and has been reprinted in this volume with ACI permission.

On the social side, there was a conference luncheon on the first day hosted by MTS Corporation (represented by C. Fairhurst and K. Falkenburg). The banquet, held on Thursday night, was enlivened by a capturing speech on the history of mining in Colorado by Kurt Gerstle, and by presentations of awards for a skiing race and tennis tournament held during the free afternoons of the conference. The conference format, with free afternoons and a second session of each day held in the evening after dinner, allowed an extensive program of recreational pursuits during which the participants could come know each other better. The recreational program included a slalom skiing race at Arapaho Basin, a group hike under Mt. Lincoln, a wild white-water rafting trip on the Arkansas river, and a tennis tourney. The only obstacle to these physically demanding activities, fortunately overcome by most participants, was the altitude of Beaver Run Resort (9700 ft. or 3000 m).

An important event was the General Assembly of the founding members of IA-FraMCoS, held on Thursday afternoon. At that assembly, the by-laws of the new Association, previously prepared by the Steering Committee under the chairmanship of F.H. Wittman and with B.I.G. Barr as secretary, were approved and the officers of the new Association were elected. The General Assembly elected the following Board of Directors: Z.P. Bažant (President), F.H. Wittmann (President-Elect, to become President one year after his election), B.I.G. Barr (Secretary), and S.P. Shah (Treasurer). Also elected was the following advisory board: M. Elices, H. Horri, A.S. Kobayashi, J. Mazars, H. Mihashi, H.W. Reinhardt, V.E. Saouma, and J.G.M. van Mier, and auditors K. Gerstle and P. Gambarova. The Secretary will also serve as newsletter editor and archivist. Membership in the Association is open to any interested person active in the subject.

As decided in Breckenridge, FraMCoS-2 will be held at ETH, Zürich, Switzerland, in 1995, under the chairmanship of F.H. Wittmann who will become the second president of the Association. I have no doubt that this will be an outstanding conference rivaling our first one in Breckenridge in most respects except one—the altitude. I extend to Folker Wittmann my best wishes.

Zdeněk P. Bažant
Chairman, FraMCoS 1

FraMCoS 1

NONTECHNICAL ACTIVITIES

A good research conference or workshop is remembered as much for its social and nontechnical events as for its scientific contributions. It is the social events which allow personal acquaintances to be developed and provide the basis for friendship among participants. Indeed, one of the objectives of the by-laws of FraMCoS is to arrange social functions to promote contact amongst the members. In this respect FraMCoS 1 was a resounding success since considerable attention had been given by the organisers to ensure that participants could meet socially in one of the most attractive conference locations. Those fortunate enough to attend FraMCoS 1 will remember the conference setting and activities long after the finer points made during the discussions are forgotten.

The first social event was the ski outing and slalom race on the morning of 1 June, prior to the start of the conference in the afternoon. Ignacio Carol, the winner of the slalom ski race at an earlier conference held at Zell-Man-Zee, Austria (1990), organised the ski outing, in an excellent manner. Twenty-two participants travelled to the nearby Arahapoe ski resort, the highest elevation resort in the US. The mountains, under rapidly moving clouds and occasional glimpses of sun, offered a dramatic view. Thanks to stormy weather which deposited a few inches of powder snow on a hard base, the skiing conditions in the upper part were good.



LINE UP OF SKI PARTICIPANTS

A giant slalom race (a short course of ten gates, run twice) was organised by the professionals from the local ski resort. Eighteen conference participants entered the race. Ignacio Carol was the overall winner, but history does not record the other names nor the names of the four who did not take part! The race, which featured some impressive performances as well as hilarious events, was recorded on a video and shown after the conference banquet amid further hilarity. The slalom was taken more seriously by some since prizes were at stake for the best performance.

Another organised event - a conference hike - was held during the Tuesday afternoon. About sixty conference participants went by cars over Hoosier Pass and hiked the valley under Mt. Lincoln from Montgomery Reservoir towards Wheeler Lake. After earlier rains, thunderstorms and even snowstorms prior to the start of the conference, the weather cleared for the Tuesday afternoon hike. The valley was placid and the views spectacular which encouraged every hiker to make it past the abandoned old mine. Many reached the upper portions of the valley and a few even reached the high altitude lake (3700m), despite having to cross many snow fields and swollen creeks.



CONFERENCE HIKE PARTICIPANTS

The second free afternoon, on Wednesday, featured a white-water rafting trip through the nearby canyon of the Arkansas River. Kurt Gerstle who organised this event managed to entice some 25 participants to take part. A bus was chartered to carry the volunteers to the river where they boarded the rafts provided by the local white-water outfitters. The event may also be described as the white-knuckle event and there were no free hands to provide the publisher of this newsletter with a photographic record of the rafting trip.

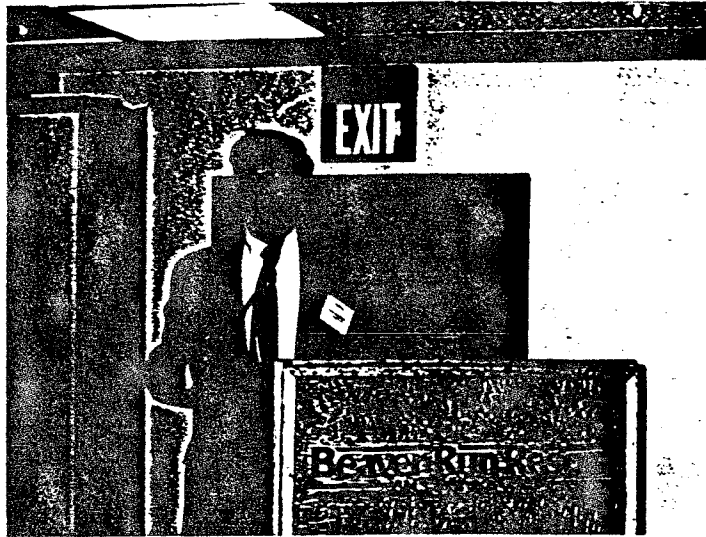
Wednesday afternoon was also set aside for the round-robin tennis tournament. There were nine participants and they did manage to record their efforts for posterity (see below).



TENNIS PARTICIPANTS

The tennis tournament was well organised - it was decided to play in three groups of three. The winners of each group ascended to the final group of three, in which the winner was Jeremy Isenberg, second was Zdeněk P. Bažant and third was Alberto Castro-Montero. Although everybody suffered in various degrees by exhaustion from altitude, it was a memorable meet. We discovered that our professional colleagues are more than just engineers and researchers.

Another highlight of the Breckenridge conference was the banquet held on the Thursday night. A most appropriate and interesting after-dinner speech was made by Kurt Gerstle who enthralled us with a fascinating account of the history of mining in Colorado. His speech was followed by the presentations of awards for the skiing race and tennis tournament.



**KURT GERSTLE SPEAKING
AT CONFERENCE BANQUET**

A number of FraMCoS business meetings were also held during the conference. A meeting of the FraMCoS Steering Committee was held on Wednesday afternoon, 3 June 1992. The Inaugural Meeting of the General Assembly of IA-FraMCoS Members was held on Thursday, 4th June - this meeting was attended by 29 Founding Members and 13 Non-Founding Members. The first meeting of the General Assembly was followed immediately by the first meeting of the Board of Directors of IA-FraMCoS. One of the items discussed by the Board was the need for a document giving "FraMCoS Conference Guidelines". This is an activity being pursued by the Board and the comments or suggestions of members are most welcome.