Discussion - Session 3, part 1

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Session 3, part 1: Applications and Experimental Verifications

Introduction by A.C. Scordelis, Chairman.

On Tuesday and Wednesday our speakers told us about the basic problems involved in material modelling and structural modelling, and perhaps they raised more questions than we have answered for the present time.

However, the ultimate aim of our work is its application to real structures that must be designed to have sufficient strength, stiffness and stability to meet the design requirements with respect to deflection and cracking under service load and time-dependent effects, and as well they must have a specified ultimate strength under design loads.

Those are our objectives.

If I may I would like to make a few historical comments about the finite element method; some of you may have heard some of these remarks from me before, but I am sure many have not.

Being from Berkeley, which has sometimes been referred to as the "birthplace of the finite-element method", my interest in the finite-element method goes back some 27 years, when my colleague, prof. Clough, returned to Berkeley after a summer working with the Boeing Airplane Company in Seattle, and set out talking about a new method for analyzing complex structures.

The method was ideally suited to the then newly available digital computers and to the matrix methods of analysis which were being developed.

In 1960, in a paper by Clough, he first gave the method the name "the finite element method" (f.e.m.)

The peal of the method to many of us at Berkeley, involved in structural analysis and design, was that the f.e.m. could be thought of in terms of a physical model, familiar to a structural engineer.

Of course, since that time tremendous developments have taken place in the application of the method to all kinds of problems, as well as to the establishment of a firm mathematical basis for the method.

It might be of interest to you, historically, that some of the earliest important applications of the method by the Berkeley group in the late fifties and early sixties was an analysis of cracking in many of the large, mass concrete dams, which were being built in the U.S. at the time. These were unreinforced, plain concrete structures.

On the other hand, while some of us thought that it could be applied to modelling a reinforced concrete structure, including cracking, it was not till about 1967 that the first paper, to my knowledge, was published on this type of application.

Since that time there has been a tremendous interest in the development in the field culminating in our colloquium here in Delft this week.

As I listened to the papers here during the last two days, I thought back to the first general conference on this subject, held in Montreal in 1972, almost ten years ago.

At that time I gave a state-of-the-art report and showed a table of problems to be solved. These problems are still with us: the composite material, cracking of the concrete, non-linear constitutive relationship, failure

We recognized these problems ten years ago and at that time I indicated that I thought that what was really needed was experimental research, so that we could get the necessary input to put into this computer program.

That was ten years ago. Well, much progress has been made in this area since the Montreal conference in 1972, as evidenced by the papers presented at this Colloquium.

Finally, I like to emphasize again, if I may, that our objective is really to be able to make these methods to design complex structures, such as the following example.
This happened to be a project I was a consultant on by 1968; it is a large hyperbolic shell in Portorico, spans 82 m, it is 4 in. thick and has edge beams.

At the time we used f.e.m. to design this structure and to analyse it, and we used linear-elastic solutions, and I was concerned about what happens if it cracks, if it creeps and what can go on in ten years later. Will we have the tools then?

And I think that I am still interested in the total structure. I think also that I hope very shortly I will be able to trace the total response of such a structure through its elastic and cracking, its inealastic and ultimate ranges, including material and geometric non-linearities, as well as the timedependent effects.

I think we are getting there. And this conference has taken us in that direction and I think we will continue to go.

DISCUSSION

Session 3, part 1: Applications and Experimental Verifications

Introductory Report by White/Gergeley, U.S.A.

Scordelis (U.S.A.): Professor White has shown to us the wide range of topics he covers and given us his impression as to what the future should hold for us. I should like to hear comments from the audience as to what should be the future direction of our efforts in the field of finite elements and concrete mechanics.

Gerstle (U.S.A.): I wonder how to incorporate micro-effects such as bond-slip and crack behaviour in a global analysis. As an example he refers to the approach of Prof. Collins and to the approach of Prof. Sarja which seems to be appropriate in a global model.

Hsu (U.S.A.): As the chairman, Prof. Scordelis, suggested to discuss about the development and use of the finite element method in the future, Prof. Hsu states that, rather than using the finite element method to predict experiments in advance (see also Collin's suggestion in the discussion of Session 2, part 2), the finite element method should be used to explain and understand the behaviour of the experimental results.

Blaauwendraad (The Netherlands): comments on the future use of the non-linear finite element method. He states that it is to be expected that the use of it will develop in the same way as the use of the linear (elastic) finite element method. That will be in two directions:
On one side, structures can be better understood which enables later on to develop simple design rules.
On the other side, the engineer becomes more familar with this type of analysis and so we will see an increased use of it. Moreover, because of better and cheaper hardware, the accessibility will increase and the use of more advanced methods will be stimulated.

Paper by Van den Beukel/Blaauwendraad/Merks/Monnier, The Netherlands

Braestrup (Denmark): Do you expect that the results from the beam specimens (plane stress) are representative for what is going on in a tunnel (plane strain)?

Monnier: We started with a simple approach and we realize that the behaviour of a beam is not the same as the behaviour of a slab.

Marti (Switzerland): I would like to suggest to give some additional information about the experimental details in the final report of this colloquium.

Monnier: I will do my best to fulfill your wishes.

Paper by Niwa/Maekawa/Okamura, Japan

Bazant (U.S.A.): If the concrete is uncracked, you have an isotropic stiffness matrix, yet your relationship between equivalent stress and strain corresponds to the total stress-strain relationship. If that is differentiated fully, you get a completely anisotropic form. Equations 17 and 6 do not seem to be compatible.

Maekawa: The reported stiffness matrix of uncracked concrete is not derived from this total strain formulation directly. It is difficult to differentiate the reported stress-strain relationship by analytical form. Therefore we defined the stiffness matrix so as to agree with the results which were calculated from the reported stress-strain relationship by numerical differentiation with reasonable accuracy. However, there exists the difference between the real stiffness and the assumed one. This difference is corrected by iterative calculation with rapid convergence.

Blaauwendraad (The Netherlands): Could Prof. Okamura explain what is meant by NAPRA (Non-linear Analysis Program Research Association)?

Okamura: NAPRA is a small group dealing with non-linear finite element method and concrete. It started about two years ago.

Abdel Rahman (U.K.): Is it not better to use a finer mesh instead of 5 by 5 Gauss points?

Niwa: Using 5 by 5 Gauss points, an underestimation of stress is avoided; also less computer time is needed.

Paper by Plauk/Hees, F.R.G.

Mehlhorn (F.R.G.): Did you compare your bond-slip test results to the test results of Doerr as presented in 1978 in Darmstadt?

Plauk: No, I did not. The bond investigations were done by Mr. Eifler who had compared the results of his bond slip tests with experimental observations obtained from 50 cm long excentrically reinforced tension members with the steel bar extending through the concrete without interruption. The agreement was excellent.

Macchi (Italy): Can you get with your approach plastic rotation in one section of the beam in the case of a constant moment?

Plauk: For this particular case I have no analytical results up to now, but if between single loads a constant moment area exists, you will get with the finite element approach a concentration of tensile stresses under the single loads, which causes cracks and plastic deformations in these cross sections. This is the reason why the proposed method will also work here.

Bergan (Norway): How can you model the S-shaped shear transfer with only one element between the cracks?

Plauk: Only if ultimate load is reached, it is possible to have one concrete element between two cracks, but also in this case our super-element, which actually consists of 4 single elements, continues to work properly.

Paper by Minami/Wakabayashi, Japan:

Braestrup (Denmark): A question to the paper of Minami and Wakabayashi. With a normal amount of shear reinforcement, the maximum strut angle is not 45°, it is lower. What are your comments?

Minami: Our paper mainly deals with a method for design and we intended to make simple equations. The problem of the angle of the compression strut is treated in detail in the paper of Shohara and Kato.

General discussion

Comments on future developments, as suggested by the chairman, Prof. Scordelis.

Elfgren (Sweden): Multinational structural design companies will quickly incorporate international codes, e.g. the CEB-FIP Model Code for concrete, in their programs for computer aided design. Furtheron they will design standard structures at prices that are very competitive at the expense of medium size national companies. To prevent such a development we must take care that the engineering society becomes familiar with the new methods. All companies and countries should have a possibility to take advantage of advanced computerized methods for design and analysis of reinforced concrete.

Saouma (U.S.A.): Structures where a few cracks are descisive, must be analysed with the discrete crack approach. If more cracks govern the behaviour, the smeared crack approach should be recommended.

Kotsovos (U.K.): Concrete is very sensitive to constraints. This results in higher strengths of the concrete in the constrained regions. Nobody has mentioned the contribution that these regions make to the overall strength of the structural member. If one is considering this contribution it would be found that probably e.g. aggregate interlock and dowel forces are not as important as is believed at the moment.

Meyer (U.S.A.): Referring to earlier remarks of Profs. White and Blaauwendraad, I am also looking forward to the moment when design engineers have their own personal computers, but at the same time I am aware of the danger of misuse of general analysis and design programs. Those familiar with computation know how often ordinary linear analysis programs are misused. Now imagine, releasing fully non-linear dynamic finite element programs for common use! We should use this kind of sophisticated technology only for very unusual structures, but mostly as a tool to educate ourselves, to learn how concrete behaves in order to develop simple methods suitable for design offices. These complicated programs that we have been discussing here will never be used in ordinary design offices.

Braestrup (Denmark): Cracks can occur even under pure compressive stresses. However in the finite element methods, as discussed in this colloquium, cracks are assumed to occur when the principal stress reaches a certain positive value, which is then interpreted as the tensile strength. How can that be?