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III-3 Prof. A. L. L. BAKER

As I think most of you know, John Newman has done a lot of work at Imperial College on triaxial strength and produced a space envelope and Dr. Sullivan has done a lot of uniaxial testing for creep rates at various temperatures and various stresses. They both regret they were unable to come, they were otherwise seriously occupied, so I have come along to give you an attempt to correlate the work, the uniaxial work of Sullivan with the triaxial work of Newman, which seems to me to be necessary in order to provide adjustements to triaxial strength due to long term effects and also due to temperature effects, so that in the finite element calculations you brought into the calculations the correct characteristics of the finite element.

It is not easy to get a physical model of concrete which gives you everything. As you know the process of making concrete means that you finish up with hard stones packed tightly together and the voids are filled with a much softer mortar. So you definitely have a two-phase material in which the stones are attempting to span as rings or arches around the soft voids. Those characteristics can be represented by a double tetrahedron of rods in which the rods have particular stiffnesses which at any stage of loading will give the same deformation characteristics as the concrete. In other words, at each stage of loading in the stress history of the pressure vessel you need to have the appropriate E value for the time interval, the appropriate Poisson ratio value and the appropriate ultimate strength or ultimate strain value. Concrete as you know does seem to fail in ordinary uniaxial compression tests at a particular or limiting compressive strain. The Poisson's ratio certainly at lower stresses is fairly consistent in value, so that if you multiply your failure compressive strain by the Poisson's ratio you get an extension strain which seems to be a suitable criterion of failure, as distinct from a strain obtained from a direct tensile test in which the rate of loading and the method of application of the load has a very great influence on the ultimate strain. That enables one to derive an expression for triaxial strength in terms of strength obtained from uniaxial tests and the expression includes the confining values of any confining pressures, values for the Poisson's ratio and different values of E , in the three directions. Applying such an expression and using what seems to be reasonable values of E and Poisson's ratio one gets fairly close agreement with Newman's space envelope, but one must admit that the expression is extremely sensitive to small variations in the value of E and in the value of Poisson's ratio.

The result is that one does get a reduction in strength of concrete with time and with temperature and that does agree with the work of Glucklich who found that if you load unbound concrete to 60% of its ultimate strength for a long period of time it will ultimately fail. Of course this effect is not so pronounced at lower stresses, but there again research is needed to show exactly where the limit is. Then that leads us to need for pressure vessels, to do step by step, computer calculations for intervals of time. At each time interval the creep rate will depend onthe temperature and the stress. The strain due to stress will also depend on the E value, which depends on the temperature and again on the stress. In addition to that there is displacement due to direct temperature expansion or contraction, so you have those three displacements coming into the calculation. The resultant displacements of course must be included in the compatibility calculation, for whatever compatibility to boundary conditions applies.

The method I have suggested is simply a proposal to take account of the possible weakining of concrete over a long period of time due to creep, in addition to temperature effects and also due to the temperature effects increasing the extensional strain. There is one thing one must be clear about, and that is that it is possible to get an extensional strain, even though the concrete is in compression. If your confining compression is not sufficient to prevent the strain normal to the main stress due to a high Poisson's ratio the concrete extends laterally, but at the same time it has lateral confining compression and it seems to me reasonable to assume that a limiting value of that extensional strain is the stage at which the bond between the mortar and the stones begins to breakdown sufficiently to cause internal instability.

III-5 Dr. P. ROSSI

Ladies and gentlemen, I would like to add some words and to emphasize some points in the paper presented by Mr. Bellotti and myself for this seminar: "New prospects for evaluating the degree of safety in concrete structures subjected to multiaxial stresses". Also if we are sure we are in a domain which is "far" from a failure condition, namely when stress states are very "internal" to the failure surface, it is very important to know how the material behaves in the actual stress condition and above all the degree of safety associated with such a stress condition, not only as regards the failure, but especially in relation to the loss of efficiency of the structure itself.

To this end knowledge of the failure surface only is no longer sufficient. To arrive at satisfactory practical results, it remains, in our opinion, to emphasize the experimental research in order to investigate and locate those factors which are, as far as possible, characteristic and determinant of the appearance of fundamental phenomena considerably affecting the physical and mechanical properties of a material.

Part of the experimental work carried out at the Niguarda Laboratories of the Hydraulic and Structural Research Centre of ENEL was presented to the RILEM Symposium in October 1972 and part is summarized in the paper presented at this seminar. Because we cannot consider as completely satisfactory for establishing the degree of safety the definitions which lead to the determination of coefficients as "values" which somehow or other "map" or "compare" the actual stress state with a failure stress state (in fact the failure stress state to which it is necessary to refer cannot definitely be determined from among the infinite points of the failure surface) and because it is also not always permissible or possible to fix a priori the stress path along which the failure should be reached, at the present state of research in our opinion it seems advisable that any consideration concerning the degree of reliability and safety should be related to the actual physical conditions of concrete as we have tried to recognize and represent by the four fundamental domains described in our paper.