ADVANCES IN THE ANALYSIS OF PRESTRESSED CONCRETE PRESSURE VESSELS

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The paper describes recent developments in the structural analysis of prestressed concrete pressure vessels with particular reference to work carried out by the Central Electricity Generating Board's Berkeley Nuclear Laboratories.

The first concrete pressure vessels were designed largely to an "ultimate" failure criterion, a full analysis not being feasible at that time. Since then considerable advances have been made in the fields of elastic and thermal analysis by finite element methods. The paper shows the application of three dimensional isoparametric elements to a podded boiler type vessel and the correlation obtained with experimental measurements. (Experimental results subject to permission of B.N.D.C.)

Creep in concrete has been shown to be of prime importance due to the stress reversals which can occur on cooling. Correlations are shown between strain predictions and site measurements over the first five years of the life of the Oldbury vessels. Iterative type creep analyses are shown to be valuable in the examination of detail problems. For example, the effect of standpipe reinforcement on the creep behaviour of a top cap has been assessed. Such methods are however, very expensive in computer time for the examination of a full non-symmetrical vessel geometry. The paper shows how viscoelastic collocation techniques can be used to study the creep behaviour of such vessels with a minimum of computation.

Finally, a criterion is required, for acceptance of the multiaxial stress states calculated by these advanced computer methods. A simple graphical method is shown, based on experimental results, which allows the rapid assessment of the acceptability of a multiaxial compressive stress state in concrete.

DISCUSSION

G. L. ENGLAND, U. K.

Q

With regard to the collocation theory, have the authors applied their analysis to more complex structures than the simple disc for which good results were obtained, and if so, how successful was the method in predicting stresses and strains in these structures ? Secondly, if it were found necessary to include more than 4 distributions of stress in the analysis by the collocation method how much difficulty would be experienced ?

D. J. LEWIS, U. K.

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We have applied the collocation method to more complex structures than that shown in the paper. In particular, a flat circular plate containing an array of holes and subjected to a non-uniform temperature distribution has been analysed. The results, which were extremely good, are given in a paper which is to be published (Goodall and Irving (1)). This analysis was based on a maximum of eight separate elastic solutions and no great difficulty was experienced in obtaining the results. It may be interesting, in this context, to compare our experience with that of Dr. England with the variational method.

Reference:

- (1) J. Irving and I. W. Goodall, "Approximate visco-elastic analysis of Maxwellian materials by collocation of terminal values" (to be published).

Z. P. BAŽANT, U. S. A.

Q

In your lecture I did not hear any mention of the delayed thermal dilatations, appearing after temperature of the material is changed. Experimental data already available point out that such effects are important. Considerable change in the stress estimates also is to be expected, when the variable properties of material, especially as affected by variable temperature, are accurately accounted for. Finally, it seems to me questionable whether the collocation method using the Dirichlet series could lead to an acceptable prediction of stresses in such cases.

J. IRVING, U. K.

A

We are not certain what Dr. Bažant means by delayed thermal dilatations. We assume, however, that this refers to the creep phenomenon which is analogous to "delayed elastic strains", and occurs when the temperature of the concrete is changed. If this is the case we would be interested to know the source of the experimental data to which he refers. We are aware of the method of analysis suggested by Neville (1) based on Bresler's data (2), but from our own attempts at correlation of actual with theoretical behaviour we are not convinced that this is a completely satisfactory solution to the problem. The second part of Dr. Bažant's question deals with the collocation method which was described

briefly in the paper. This method of creep analysis is based upon a linear viscoelastic representation of concrete stress-strain behaviour. It is also restricted to cases of time independent temperature distributions so that the effects of temperature changes are not considered. Within these quite reasonable limits the collocation method gives extremely good results. We believe that the best way of analysing variable temperature effects would be in a time increment type of solution and would be most interested to hear of any progress Dr. Bažant has made in this direction.

References:

- (1) A. M. Neville, "Creep of concrete : plain, reinforced and prestressed", North-Holland Publishing Co. , Amsterdam, p. 622 (1970).
- (2) B. Bresler, "Some factors in the investigation of long term behaviour of reinforced concrete structures", Road Research Laboratory, Note No. LN/150/BB, (1962).

Q

J. H. ARGYRIS, Germany/U. K.

It is important when modelling a structure under thermal effects to select elements which reflect the true physical situation. For example, the element type should be such that no residual stresses result from a linear distribution of temperature. The TRIM 6 element with 3 vertex and 3 mid-side nodes fulfills this condition in two dimensions, the TET 10 with 4 vertex and 6 mid-side nodes and the hexahedronal LUMINA (or HEXE 27) element based on Lagrangian interpolation and internal nodes fulfills this condition in three dimensions. The hexahedronal iso-parametric elements, which have nodes only at the corners and on the sides, are incomplete in this respect and their use can give rise to considerable residual thermal stresses which are strictly non-existent. The same applies to the corresponding elements in two dimensions.

A

D. J. LEWIS, U. K.

This is an interesting observation which we shall certainly examine. We have used the isoparametric elements in a number of thermal applications where comparisons have been possible with practical measurements. The results have always shown good correlation and we believe the elements to be quite satisfactory for calculations of practical accuracy. We would be pleased to see any results Prof. Argyris may have published which shows the extent of these discrepancies.

Q

Y. R. RASHID, U. S. A.

The interaction of cracking and creep can be quite significant. Are you planning to further your work to include cracking in the presence of creep ?

D. J. LEWIS, U. K., J. IRVING, U. K., G. D. T. CARMICHAEL, U. K.

A

We agree with Dr. Rashid that the interaction of concrete cracking and creep could be significant. To-date, however, we have considered cracking as a time-independent phenomenon; indeed the lack of suitable data could severely restrict the study of the interaction of cracking and creep. Cracks in a number of concrete structures have been investigated by means of the decoupling mechanism incorporated in BERSAFE (O'Connell and Hellen (1)). These investigations have shown that there are limitations in using a concrete failure surface, and consequently a fracture mechanics solution has been considered based on the crack closure work approach (Jerram (2)).

References:

- (1) O. M. O'Connell and T. K. Hellen, "Shear slip and its influence on the behaviour of a sleeve reinforced circular penetration in a concrete slab", C. E. G. B. Report RD/B/N1615.
- (2) K. Jerram, "The use of a finite element stress analysis computer program for the calculation of stress intensity factors", C. E. G. B. Report RD/B/N1521.