Proc. Instn Civ. Engrs, Part 2, 1977, 63, Sept., 757–758

7988 DISCUSSION

Non-linear finite element analysis of concrete slab structures

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The modelling of concrete elements by means of a linear function for in-plane displacements and a cubic function for out of plane displacements would seem to result in incompatibility across inter-element boundaries along the web–flange intersections of box beams. The distortion of the top and bottom flanges and the vertical deflexion are consequently artificially restrained. Would not a higher degree function to describe the vertical in-plane displacement of the webs allow the use of a smaller number of elements?

61. Did the Authors consider updating the stiffness matrix to take into account the changes due to cracking? The use of the initial stiffness matrix in solving non-linear material problems is well established, but what effect does continually applying the release forces to a structure which is essentially different from the original one due to cracking have on the orientation and location of cracks in the new load stage?

62. It is stated that the iterations continued until equilibrium was achieved to a satisfactory degree of accuracy. What criterion was used to determine that the out of balance force vector was negligible? Could the Authors indicate why the program finally terminated in the examples quoted? Were there any excessive steel or concrete strains or was it not possible to achieve equilibrium?

63. The theoretical load–deflexion curve attributed to us in Fig. 21 appears to have been drawn from table 2 of reference 15 and reference 16. Only three load increments were used in this analysis which was intended to establish the ultimate strength of the box beam: the first load increment did not even crack the member. The beam was also analysed at smaller load increments in order to obtain a more accurate estimate of the first cracking load and the load–deflexion curve. The result of this analysis is given in Fig. 6 of reference 15 and the appropriate curve is shown in Fig. 22.

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Professor Trikha and Dr Edwards have raised a number of interesting points concerning application of the approach to concrete box beams. This application is a searching one, because the state of stress is complex and because of the lack of full displacement compatibility in the finite element formulation.

65. Combination of elements with linear in-plane and cubic normal displacement variations is far from ideal. However, elastic solutions obtained from such arrangements show that reasonable predictions of the main stress effects result. Use of a higher degree function for in-plane displacements would probably lead to use of a

Paper published: *Proc. Instn Civ. Engrs*, Part 2, 1977, 63, Mar., 159–179.

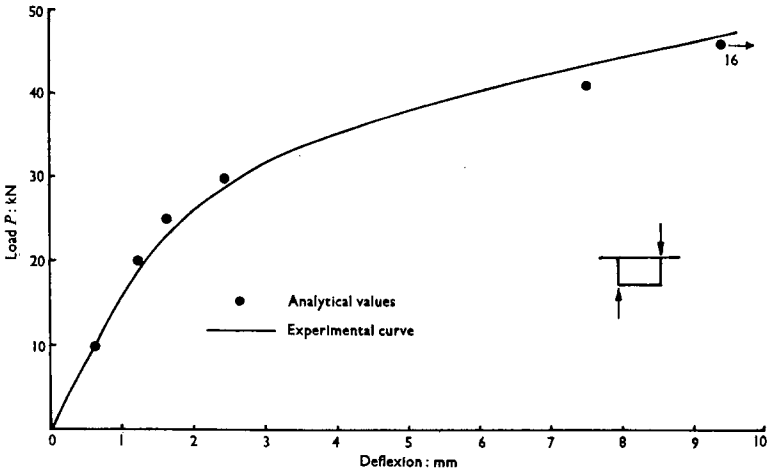

Fig. 22. Load–deflexion at downward web load

smaller number of elements, although not necessarily to a smaller number of degrees of freedom, nor to fewer sampling points. More sophisticated elements are being tried in further studies in an attempt to improve prediction of behaviour and to reduce the cost of solutions.

66. A constant stiffness approach was used for efficiency and because it ensures a well conditioned set of equations. With the approach used to model concrete behaviour, the stiffness matrix is not symmetrical after loading has been applied. This is a consequence of the anisotropic nature of concrete, which is particularly pronounced after cracking.

67. An effect of the pseudo loads is to change the direction of principal strains. Cracks are not considered directly and their directions have to be inferred from the directions of principal tensile strain. Results of computer runs with the different load increments indicated that principal strain directions were not significantly altered.

68. The program was not terminated because of excessive strains; in fact the approach appeared to give an over-stiff prediction of behaviour. Analyses were stopped when it was impossible to obtain equilibrium in a reasonable number of iterations. With the box beams, computer limitations prevented the load increment from being as small as we wished.

Reference

16. TRIKHA D. N. *An analytical and experimental investigation of post-tensioned single cell box girders.* PhD thesis, University of London, 1971.