Effective slab stiffness in flat plate structures

Y. C. WONG & A. COULL

Professor A. E. Long, Queen's University, Belfast

The procedure described in the Paper produces results comparable with those obtained using elastic plate bending finite elements. Thus tables of slab stiffness values, such as the typical example in Table 3, which take account of different column sizes and a variety of aspect ratios can readily be produced.

40. However, in common with other elastic methods of analysis the loss of fixity which occurs at an actual slab column junction is not adequately taken into consideration. The Authors appreciate that the actual stiffness might be less than predicted (§ 38). However, they do not give any indication as to the likely reduction in effective width as a result of slab cracking and associated bond-slip effects. Indeed designers might even assume that the effect is small as the effective widths are presented to three significant figures.

41. Of direct relevance are tests which were carried out in 1976 on one third scale models at the Royal Military College, Kingston, Canada. Full details of the three test specimens (Fig. 8) are presented in reference 11 and an analysis of the performance of these representative frameworks under lateral loading is given in reference 12. The main findings of the lateral loading tests were as follows.

- (a) The use of an effective width of approximately 0.3 was found to yield realistic estimates of the lateral stiffness of slab-column systems with U/A values of 0.08 and 0.12. In contrast the Authors suggest that effective widths of 0.49 and 0.55 would be appropriate.
- (b) The lateral load stiffness was found to be reduced significantly by the development of cracks induced by design levels of gravity loading. As a consequence elastic plate bending finite element analyses of the type used to calibrate the Authors' method will yield optimistic estimates of effective widths. The influence of cracking is clearly seen from Fig. 9.
- (c) Cracking associated with gravity overloading markedly reduces the lateral stiffness of a framework, as can be seen from Table 4.

42. As a consequence of these findings it is clear that computational procedures need to be calibrated against reinforced concrete models with carefully controlled boundary conditions. At present there is a lack of test results in this area. However, the marked discrepancies indicated by the test results reported in reference 12 would suggest that further tests of this nature are

Fig. 8. Boundary conditions and overall dimensions of slab/column model

Fig. 9. Experimental and analytical distribution of slab rotation from model 1

Table 4. Influence of level of gravity loading on lateral stiffness

Model	Estimated effective width	Gravity loading applied before lateral load test
3A ¹³	0.13	2.7 (DL + LL)
4A ¹³	0.17	1.8 (DL + LL)
RMC ¹²	0.30	1.0 (DL + LL)

essential before the production of satisfactory design tables. Otherwise optimistic estimates of the lateral stiffness of flat plate structures will be obtained. Although these are unlikely to result in unsafe structures, because of the presence of shear walls, these elastic methods of analysis^{3, 4, 6, 10} are clearly unsatisfactory at present.

43. In spite of these limitations the tables in the Paper could be useful to designers in assessing the relative importance of different aspect ratios.

Professor Coull and Dr Wong

Professor Long's comments serve as a timely reminder of the need to exercise care when using an elastic analysis for reinforced concrete structures where stress concentrations occur.

45. The main object of the Paper was to demonstrate the validity of the influence coefficient technique for the elastic analysis of the interaction between laterally loaded columns and floor slabs in flat plate structures. Most of the Paper was thus devoted to an assessment of the convergence and accuracy of the technique, and the tables of effective width (in which results were quoted to three significant figures solely to expedite interpolation) served to emphasize the saving in computational effort in comparison with that required for a finite element solution. The work is essentially a special case of the more general problem of floor slab-shear wall interaction.⁹ Being an elastic analysis, it would not have been appropriate to discuss in detail the non-linear structural behaviour caused by cracking. The results obtained from such an analysis must always be viewed in the limited context of the linear elastic behaviour of concrete.

46. The considerable influence of cracking on the behaviour of the slab-column junction has been shown clearly in Professor Long's tests; similar effects are experienced with shear wall-slab structures.¹⁴ However, there are as yet inadequate test data available to enable a comprehensive set of design curves, giving reliable and realistic effective widths for flat slab structures, covering the entire range of parameters involved, to be produced. The data in the Paper should be regarded as giving upper bounds on the actual stiffnesses which may be mobilized, as well as indicating general trends of behaviour.

47. Although any elastic analysis might be regarded as being more relevant to the transient effects of short-term wind loading, with maximum loads based on a very long return period, the problem is complicated by the lateral stiffness being influenced by the development of cracks induced by long-term gravity loads, as demonstrated by Professor Long. In that case, it might be possible to make a revised estimate of the lateral stiffness by using a reduced flexural rigidity to take account of the cracking of the slab.

References

11. LONG A. E. *et al.* Moment transfer and the ultimate capacity of slab column structures. *Struct. Engrg*, 1978, **56A**, Apr., 95-102.
12. LONG A. E. and KIRK D. W. Lateral load stiffness of slab-column structures. *Symposium on reinforced concrete structures subjected to wind and earthquake forces*. American Concrete Institute, Detroit, 1980, SP 63, 197-220.
13. LONG A. E. *Punching failure of reinforced concrete slabs*. PhD thesis, Queen's University, Belfast, 1967.
14. SCHWAIGHOFER J. and COLLINS M. P. Experimental study of the behaviour of reinforced concrete coupling slabs. *J. Am. Concr. Inst.*, 1977, **74**, Mar., 123-127.