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Deflection control by span/depth ratio*

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In their paper, Professor Neville et al. have suggested a modified design procedure for deflection control based on the West German Code. The advantages of this modified design procedure mentioned are (a) that it provides the inexperienced designer with reliable criteria which are independent of post-hoc considerations and (b) the results obtained by using the procedure are very close to the satisfactory values (as defined in the paper). From the computer study carried out, it appears that the span/depth ratios obtained by using CP 110:1972 are considerably higher than the satisfactory values. In addition, it is stated that the CP 110:1972 ratios cannot be used as a initial design aid, because they are functions of parameters ascertained in the design.

The consistently higher values of span/depth ratios obtained from CP 110:1972 can be easily explained. The computer study uses a deflection limit of $L/350$ or 20 mm. The deflection limits suggested in CP 110:1972 are that (i) the final deflection should not, in general, exceed span/250 and (ii) the deflection after construction of partitions or the application of finishes should not exceed span/350 or 20 mm, which ever is the lesser. There is thus a difference between the deflection limits used and the ones suggested in CP 110:1972.

In the paper, a satisfactory section was defined as one that meets the Code's requirements for reinforced concrete flexural members in respect of the three limit states: ultimate, serviceability and local damage. Such a section is not unique. It is possible to find a large number of satisfactory sections within the feasible region defined by the three limit states. In fact, from the sample calculation given in Appendix 2, it is clear that the beam section has been over-designed. The depth of beam and area of tension steel are greatly in excess of what is required for the ultimate limit state. This is due to the constraints built into the computer program on depth/breadth ratios and steel percentages. From the sample calculation it can be seen that, though the steel area required is 2420 mm^2, owing to the constraints placed on steel percentage and bar sizes, the area used is 3218 mm^2. Thus the section used has an ultimate strength 50% in excess of what is required. If the program had been more flexible, it would have selected five 25 mm dia. bars to provide the 2420 mm^2 of steel area required. It is clear from the sample calculation that the modified design procedure will lead to a very conservative design.

If the objective of the designer is to find a satisfactory section which lies within the feasible region defined by the three limit states, the procedure suggested in the paper can be adopted. If the objective is to select a section which not only lies within the feasible region, but is also optimum in terms of cost, the procedure suggested is not satisfactory. It has been shown[1] that, in the design of slabs, the optimum depth is determined by the deflection limits, for most values of cost-strength index. In such cases, a more accurate assessment of deflection becomes important. In all other cases, where the deflection is only a requirement to be satisfied and does not control the optimum design parameters, a procedure based on span/depth ratio can be adopted. Even here, the procedure suggested in CP 110:1972 is satisfactory. In the initial design stage, Tables 8 and 9 together with the assumed steel percentage for Table 10 can be used to obtain the span/effective depth ratio. Once the optimum design parameters are obtained, a final check can be carried out for deflections. Design charts[2] can be devised to make the calculation of deflection by the method given in Appendix A of CP 110:1972 much easier.

There are some minor errors in the sample calculation given in the Appendix 2, and these are listed below.

(a) The nominal cover when using 32 mm dia. bars

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should be 32 mm. This will modify the effective depth from 709 mm to 702 mm.
(b) The maximum shear stress the section can take without shear reinforcement should be 0·627 N/mm^2, if only two 32 mm dia. bars are used at the support. Even if all four 32 mm dia. bars are used at the support, the maximum shear stress for the section will be 0·802 N/mm^2. Both values are less than the ultimate shear stress and shear reinforcement is required.
(c) Cracking is a serviceability condition, and lever arm is not $d - x/2$.
(d) The distance from centre to centre of bars should be 72 mm and not 56 mm as indicated and used in the calculation.
(e) a_{cr} is the distance from the point considered to the surface of the nearest longitudinal bar.

Reply by the authors

Mr Gunaratnam's contribution arises largely from a misunderstanding: he assumes that our paper was recommending a design procedure based on the computer analysis, which is not so. In fact, the point was that a procedure based on an approach different from that now adopted in the U.K. would allow an inexperienced designer to arrive more quickly at an acceptable solution.

As things are, the span/depth ratios of CP110:1972 cannot be used directly at the outset of the design, and even if design charts are available they do not 'guarantee' an acceptable deflection. The limitation of long-term deflection to $L/350$ or 20 mm is applied by the computer program initially as a guide to keep the subsequent calculation within reasonable bounds. This initial long-term deflection evaluation is based on a simple multiplier method of short-term deflection (ACI 318-63) before creep and shrinkage are taken into account explicitly. The final long-term constraint is indeed $L/250$ together with the constraint of $L/350$ or 20 mm for that deflection arising from permanent load. The consistently higher span/depth ratios of CP110:1972 are then explained as mentioned in the paper by the fact that, in their formulation, account has been taken of restraint at the supports, allowing span/deflection ratios of $L/183$[3].

It is not new to observe, as Mr Gunaratnam does, that for the three limit states mentioned, there is no unique solution. In our study, so as to produce meaningful results which could be compared one with another, certain over-all constraints such as depth/breadth ratio, fixed percentages of compression and tension steel, and recommended bar sizes had to be adopted; otherwise an impossible situation would have arisen. The design procedure outlined in the Appendix was evaluated some 37 440 times. At each calculation of deflection, the values were checked by four different methods (CP110 – methods A and B, ACI 318-63, Draft Unified Code 1969, ACI 318-71), in each case using three ratios of permanent/total load, three creep coefficients, three shrinkage strains, and examining the effect of increasing the compression reinforcement. In some cases, these constraints may have produced over-design, whereas other cases may have resulted in cost-effective design. To keep the results tractable and comparable, fixed percentages of reinforcement had to be imposed; it is unfortunate that in the example in the paper, the required steel area of 2420 mm^2, which does not correspond to the percentages, could be satisfied so effectively by 5 × 25 mm dia. bars at 2455 mm^2. The program is flexible in that it distributes the required area with the maximum number of the smallest bars and it adjusts various combinations of bars to come within a tolerance of 10% of the 'required area' (modified by percentage considerations). The problem here is not a program fault but a consequence of the size of the problem tackled.

The type of modification suggested is seen very much as a 'first step'; it is pointed out that the expression may be further modified to bring it more into line with Beeby's ideas on end restraints[3].

It is unfair to judge the whole study by examining a sample calculation which has been produced as an illustration only, and appears out of context. Because of the vast number of calculations, the results were produced in a shorthand fashion with few or no intermediate results; the errors that have been identified have arisen as a consequence of working back by hand from the computer results.

In discussing cost, Mr Gunaratnam implies that this is determined by the *quantity* of material used, which is naïve. Fabrication and other factors may be at least as significant. His reference to internal reports of the University of Sri Lanka is unhelpful: if these are worthy of note, they should be published.

To consider some of the detailed points:

(1) *Nominal cover.* According to CP110, this depends upon concrete grade, exposure and bar diameter. Because the bar diameters were kept as small as possible, it was decided, rather than make a complicated situation even worse, not to introduce a variable cover but to use a nominal cover of 25 mm throughout.

(2) *Shear reinforcement.* Shear reinforcement was not designed explicitly – all the program did was to

check that the ultimate shear stress was below the maximum permissible value, which in this case is 4·10 N/mm^2, and to check whether reinforcement is required. According to CP110:Part 1:1972, clause 3.3.6.1, as long as 'anchorage and curtailment' are satisfied, the full area of the tensile steel may be used. In the example in the paper, it is unfortunate that two typing errors occurred together – for ultimate shear stress, 0·9 should read 0·7 (the value for 30 N/mm^2 concrete at 1% A_{st} – not 1·36 as this is a check only) and the line beneath should read "Links to clause 3.11.4.3 required".

(3) *Lever arm.* This is a mistake. As this is a serviceability condition, this should read $d - x/3 = 604{\cdot}43$. This only affects the steel strain, which is acceptable at its current high value.

(4) *Bar spacing (centres).* The distance between bar centres was incorrectly taken as spacing $+D/2$ and not spacing $+D$. Errors 3 and 4 have passed unchecked because the resultant value is so small. In checking a machine which works to 22 places of decimals with a desk-top calculator which only works to 5 places, when one arrives at an answer similar to that given by the computer, one tends to think the approach is correct. The crack limit is 0·3 mm or 0·004 × nominal cover = 0·128 mm, so here there is little significant difference.

(5) a_{cr}. According to the Code Handbook (reference 6 of the paper), page 152, larger flexural cracks occur between bars rather than under them because of the restraint to cracking afforded by the steel, so that the case considered in the paper is the most severe; the code does not specify the location of the point considered on the surface.

REFERENCES

1. GUNARATNAM, D. J. and SIVARKUMARAN, N. S. *Optimum design of reinforced concrete slabs.* Peradeniya, Faculty of Engineering, University of Sri Lanka, 1977. Internal Report.
2. GUNARATHAM, D. J. *Assessment of deflection in reinforced concrete flexural members.* Peradeniya, Faculty of Engineering, University of Sri Lanka, 1977. Internal Report.
3. BEEBY, A. W. *Modified proposals for controlling deflections by means of ratios of span to effective depth.* London, Cement and Concrete Association, 1971. pp. 19. Technical Report 42.456.