Discussion on a paper published in

Magazine of Concrete Research

Volume 22, Number 70: March 1970

Destructive tests on rationally designed slabs*

M. A. Muspratt

Contribution by G. I. N. Rozvany, PhD

Civil Engineering Department, Monash University, Clayton, Victoria, Australia

The experiments described in the paper under discussion formed part of the ARGC project No. 65-15897 and were carried out in the Civil Engineering Department, Monash University. For this project I was the Chief Investigator.

Membrane action

In explaining membrane action, Mr Muspratt gives in his Figure 13 a cross-section of the slab showing compressive and tensile zones and lever arm as indicated in Figure 1a of this discussion. This diagram is based on one in a paper by Taylor⁽¹⁾ but Taylor's diagram appears to have been misinterpreted. Such a stress pattern would arise in a homogeneous beam cross-section under flexure and the moment capacity of the beam would be proportional to the lever arm indicated. However, the same does not apply to two-way slabs. The diagram by Taylor⁽¹⁾ (see Figure 1b) considers the stresses along yield lines on a rigid segment T. The resultant of these stresses is a couple that balances the moment about the edge support of the external loads on segment T. The neutral axis can be determined from considerations of plastic potential⁽²⁾ and is not horizontal in general. Instead of the 'centroid of the tensile zone', the centroid of the tensile reinforcement determines the lever arm. Naturally, if more reinforcement is concentrated along the central band of the slab (as in Hillerborg's solution and in the

Figure 1

torsionless solution), the membrane action is more pronounced owing to the greater lever arm. This statement has been verified by the above experiments.

The experimental points shown in Figure 12 of Mr Muspratt's paper do not seem to agree with the measurements recorded during the experiment.

*Pages 25 to 36 of *Magazine* No. 70

'Monte Carlo approach'

In an earlier paper⁽³⁾, Mr. Muspratt concludes that 'pre-yield' behaviour does not depend upon the reinforcement layout and almost any reinforcement pattern 'develops' at yield. On the basis of these conclusions, he recommends⁽³⁾ the 'Monte Carlo approach' and refers to the paper under discussion. The Monte Carlo approach turns out to be a random distribution of reinforcing bars.

In actual fact, a random reinforcement may result in an entirely unserviceable and unsafe structure. If the reinforcement content is low in areas of high elastic moments, local yield and large cracks may occur at service loads. One cannot rely on the tensile strength of the concrete, because in most practical slab design the cracking load is smaller relative to the ultimate load than in the above experiments. Further, shrinkage may decrease the cracking load capacity.

Considering various reinforcement layouts of the same volume, the ultimate load capacity varies considerably and depends on the reinforcement distribution used. Hence a random layout may result in a failure at an unexpectedly low load value*.

Over-all yield

Mr Muspratt in item (3) under the heading 'strains' claims that 'Rozvany's assumption of general yield' is 'inexact'. There appears to be some misunderstanding

*Naturally, a random distribution of a large number of very thin steel fibres is likely to result in an essentially isotropic reinforcement. However, Mr Muspratt proposed a random layout of a few bars.

Reply by the author

Membrane action

Dr Rozvany has misunderstood Figure 13. Section AA was intended—hence the centroid of the tensile zone is correct, rather than that of the tensile reinforcement, in view of the uncracked concrete along this section. This Figure was constructed from experimental data and similarity to Taylor's figure was merely for convenience.

Regarding Figure 12, Kemp's theory assumes rigid plastic behaviour up to yield, i.e. negligible deflections. All experimental deflections after yield were thus taken relative to the deflection just prior to the theoretical yield point. If we take as an example, $W_o/d = 0.5$, for $d_t = 2.25$ in., $W_o = 1.12$ in. From Figure 4, the load corresponding to this deflection measured relative to the deflection at yield is about 300 lb/ft². This figure includes the self-weight of the slab of about 50 lb/ft². Therefore

$$\text{True load} = 250 \text{ lb/ft}^2$$

here, because I have never claimed that simultaneous yield throughout the slab would occur in optimized slabs. In fact, in describing earlier experiments on optimized slabs in 1966⁽⁴⁾ reported quite simple failure mechanisms.

Mr Muspratt's criticism might be a result of some misconception about the usual lower-bound approach, in which the design moment capacities are made either greater than or equal to some statically admissible moment field. Naturally, simultaneous yield throughout the slab would never occur, because of the finite steps in the reinforcement and the unintentional variation of the concrete strength and thickness over the slab.

Deflections at yield

Mr Muspratt lists deflection values corresponding to the formation of the yield-line mechanism. These values are somewhat unreliable and arbitrary, because the deflection/load slope is almost infinite at that stage and the deflection increases rapidly in time. It would be better to compare deflections at a lower load level of a given value.

The listing of these values seems to be a result of misinterpreting a statement by Kemp⁽²⁾. The latter did not suggest that a deflection/depth ratio of 0.6 is 'generally acceptable' for ensuring 'satisfactory service behaviour under working load'. Kemp⁽²⁾ and Taylor⁽¹⁾ correctly note that the load capacity increases monotonically with the deflection after flexural failure and hence it is necessary to define the 'limit load' in terms of a given deflection. This concept is not related to service behaviour.

and so

$$\frac{P}{P_y} = \frac{250}{220} = 1.14$$

Monte Carlo approach

Dr Rozvany is referred to reference 17 for more details of this approach. Concrete strengths and thicknesses vary stochastically, as do load distributions, and so the deterministic system definition is highly idealized. The method for including spatial cross correlations between load and strengths to minimize the probability of any slab section being subject to overload and under-strength will be published elsewhere. This strategy will, except for conditions lying in the very extreme tails of load and strength distributions, give safer designs than the deterministic approach.

Over-all yield

If design moment capacities are made greater than

some statically admissible moment field, the design is no longer optimal. The whole point of optimal design as proposed by Dr Rozvany is simultaneous collapse of all sections of the slab—this discrepancy again highlights the unavoidable practical perturbations existing in levels of variables used for system definition, and reinforces my proposal for stochastic design.

Deflections at yield

This comment seems irrelevant—time dependence

of deflections occurs before as well as after yield. The yield point is a definite transition in the slope of the load-deflection curve and so is an easily reproducible characteristic.

Dr Rozvany's interpretation of "service" is an error in semantics. 'Overload' as well as 'working load' service conditions are acceptable in view of contemporary looseness in the use of this terminology and the tremendous latitude in interpretation.

REFERENCES

1. TAYLOR, R. A note on a possible basis for a new method of ultimate load design of reinforced concrete slabs. *Magazine of Concrete Research*. Vol. 17, No. 53. December 1965. pp. 183–186.
2. KEMP, K. Yield of a square reinforced concrete slab on simple supports allowing for membrane forces. *The Structural Engineer*. Vol. 45, No. 7. July 1967. pp. 235–240.
3. MUSPRATT, M. A. Behaviour of simply supported slabs. *Proceedings of the American Society of Civil Engineers*. Vol. 95, No. ST 12. December 1969. pp. 2703–2721.
4. ROZVANY, G. I. N. The behaviour of optimal reinforced concrete slabs. *Civil Engineering Transactions, Institute of Engineers, Australia*. Vol. CE9, No. 2. October 1967. pp. 283–294.
5. MUSPRATT, M. Behaviour of footing slabs. *Building Science*. Vol. 4, No. 3. December 1969. pp. 109–118.