

Elastic-plastic column stability and the design of no-sway frames

by

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Dr A. C. Cassell (Department of Civil Engineering, Imperial College) wrote that economy was most easily found when the engineer had a choice of different structural forms. The Author offered an alternative to the heavy column/light beam design method which was a welcome step towards freedom of choice.

70. The type of collapse must always be considered and the Author's method introduced a new probable mode. If a tall building was subjected to local overloading on either an exterior bay beam or on an interior beam (if this was longer and stronger than the adjacent spans), the load envisaged was less than the local beam collapse load but large enough to cause some plastic hinges. A plastic moment at the beam/column joint would then have to be supported by the exterior column alone, whilst a plastic moment from the long, strong beam would need to be supported by the interior column as well as the weaker short beam of the adjacent span. Both load cases envisaged might be more critical than the pinned end column case envisaged in the Author's method. Did the Author agree that a designer using his method should keep this possibility in mind, particularly as local overload of a beam was a reasonable possibility? This type of overload did not merit attention in the heavy column/light beam design, and a designer coming from this method to the Author's method might overlook the case of local beam overload.

71. It would be interesting to know what economy resulted from the light column/heavy beam design; could the Author give any examples?

Professor J. A. Yura (Department of Civil Engineering, The University of Texas) wrote that Dr Gent had restricted his design method to frames in which the beams remained elastic, presumably so that beam end-moments could be relaxed as the columns deformed. However, even if the loaded beams were plastic at the ends, relaxation would still occur.

73. Two tests conducted on full-size, braced steel frames at Lehigh University might be of interest. The test set-up and specimen were shown in Fig. 14. The detailed test results were given elsewhere,⁹ and only a brief resumé would therefore be given. The loads P were applied to all the 12 in. beams until the plastic bending capacity, M_p , was reached in the beams at the face of the interior column. The beam loads were about 92% of the beam mechanism load, and were held constant as load P_1 at the top of the interior column was applied. The maximum axial load in the interior column was approximately 60% of the squash load. The tests showed that moments were redistributed in the interior column until the maximum capacity of all three portions of the interior column was reached under the applied beam end moments. Further loading produced joint relaxation. When the beam end-moments relaxed to the point where the loads P could not be maintained, failure of the beams occurred and the test was concluded. From a structural standpoint, it was gratifying to note that failure was localized in beams and not the columns.

The Author, in reply, thanked Dr Cassell who had raised the question of the effect of local beam overload on a frame designed on the weak column/strong beam

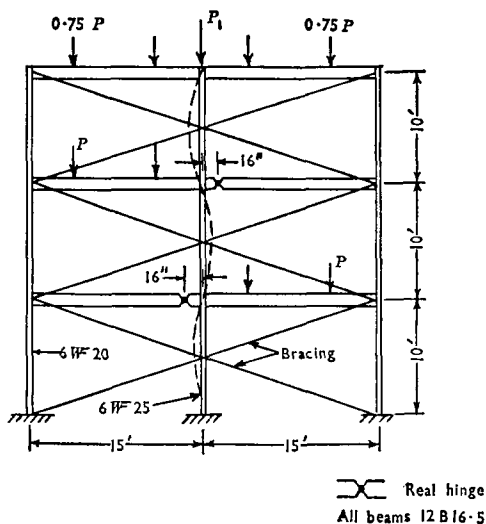


FIG. 14: FRAME-SPECIMEN AND TEST SET-UP

approach suggested in the Paper and the possibility of its causing column failure. The Author did not feel that this was a more serious consideration for the proposed design approach than for any other reasonably economic method of design.

75. Firstly, although the method was based on plastic performance, it would not achieve the ultimate ideal of a true limit design and therefore there would still be some unknown reserve of strength against complete collapse. Also designers should be wary of assuming that a rigid jointed frame designed on a strong column/weak beam basis had any more reserve of strength against column failure due to beam overload than a strong beam/weak column one. The effect of beam overload in a weak beam design would be unlikely to be confined to one span. A single beam, if overloaded, would not in fact collapse immediately, but would sustain its load by developing membrane forces and, due to strain hardening, higher end moments. The adjacent columns would thus be subjected to excessive end moments, combined with sway forces due to the beam membrane action, and these could under adverse circumstances cause column collapse.

76. Another point was that the strong beam/weak column design was not new. The Author's approach had now been fully developed for the case of frames spanning in one direction with simple joints, and trial designs confirmed the suggestion in the Paper that *Simple Design* B.S. 449 really designed plastic columns. Almost identical column sizes were given in most cases by applying the provisions of B.S. 449 as with the Author's method of fully plastic column design. It followed therefore that most simple jointed frames currently in use were weak column/strong beam designs.

77. On the other hand, Dr Cassell's assertion that there was a reasonable probability of occurrence of beam overload, if true, should not be accepted with complacency. As progress was made towards the ideal of assessing and designing on the true ultimate load capacity of the structure, it was essential that the design loads must be realistically assessed and an adequate load factor assumed.

78. Professor Yura's contribution was of particular interest in that it quoted independent full-scale experimental confirmation of the ability of columns deforming plastically to relax beam moments. With regard to the question of elastic beams,

the Author restricted attention to elastic beams in the Paper primarily to clarify the presentation of the concepts involved. It was true that relaxation of beam moments could still be relied upon with some plasticity in the beams and further beam economy could be achieved on this basis. Care must, however, be taken to ensure against shake-down effects under repeated loading cycles of the type recently mentioned elsewhere by the Author.¹⁰

REFERENCES

9. YURA J. A. *The strength of braced multi-storey steel frames*. Lehigh Univ. Fritz Engng Lab. Rep. No. 273. 28 September, 1965.
10. GENT A. R. Discussion on Levi *et al.* *Proc. Am. Instn civ. Engrs*, 1966, **92** (Jun.) 268-270.