Structural performance of steel frames with semi-rigid connections

Autor(en): **Nethercot, David A. / Kirby, Patrick A. / Davison, J. Buick**

Objekttyp: **Article**

Zeitschrift: **IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht**

Band (Jahr): **13 (1988)**

PDF erstellt am: **11.09.2024**

Persistenter Link: https://doi.org/10.5169/seals-13066

Structural Performance of Steel Frames with Semi-Rigid Connections

Comportement de cadres métalliques avec des assemblages semi-rigides

Verhalten von Stahlrahmen mit teilweise steifen Verbindungen

David A. NETHERCOT
Reader in Civil & Struct. Eng.
University of Sheffield
Sheffield, UK

Patrick A. KIRBY
Lecturer in Civil & Struct. Eng.
University of Sheffield
Sheffield, UK

J. Buick DAVISON
Lecturer in Civil & Struct. Eng.
University of Sheffield
Sheffield, UK

David Nethercot has 20 years experience of teaching, research and specialist advisory work, principally in the field of structural steelwork, since graduating from University College Cardiff. He has contributed to national and international standards, is a member of several technical committees and the author of some 100 publications.

Patrick Kirby obtained his degrees from the University of Liverpool where he began his teaching career; moving to the University of Sheffield in 1971. Throughout this period he has been active in the field of structural response in particular in the behaviour of steel structures, has published many papers and participated in numerous short courses for practising engineers.

Buick Davison graduated from Sheffield University in 1980. He worked for a Consultant for four years before returning to the University as a Research Assistant. He was awarded a PhD in 1987 for his work on the performance of beam-columns in flexibly connected steel frames and is now a lecturer at Sheffield University.

SUMMARY
The results of a programme of research into the effects of semirigid joint action on the performance of non-sway steel frames are drawn together to explain behaviour up to collapse. Full-scale testing and numerical analyses of the frames, supported by detailed studies of components and subassemblies, are used. Actual behavior is contrasted with that normally assumed for design purposes.

RÉSUMÉ
Les résultats d'un programme de recherche des effets de l'action d'assemblages semi-rigides sur le comportement de cadres métalliques soint présentés afin d'expliquer leur comportement jusqu'à la rupture. Des essais en vraie grandeur et des analyses numériques de cadres ainsi que des études détaillées d'éléments et d'assemblages ont été réalisés. Le comportement réel contraste avec les prédictions obtenues lors des calculs.

ZUSAMMENFASSUNG
Die Resultate eines Forschungsprogrammes zum Einfluss von teilweise steifen Rahmenknoten auf das Verhalten von seitlich gehaltenen Stahlrahmen werden zusammengefasst, um das Verhalten bis zum Einsturz zu erklären. Versuche in voller Grösse und Rahmenberechnungen, unterstützt durch detaillierte Studien von Komponenten werden dazuverwendet. Das wirkliche Verhalten wird den üblichen Berechnungsannahmen gegenübergestellt.

1. INTRODUCTION

Traditional approaches to the design of steel framed structures assume that the connections either function as pins or provide full continuity. The reality is, of course, that all practical types of steelwork joint operate somewhere between these two idealised extremes. A more realistic approach therefore requires the semi-rigid nature of connection behaviour to be properly recognised. This paper draws together results from a co-ordinated programme of research aimed at providing a full understanding of the influence of connection details on the performance of steel frames. It does this by contrasting the actual response, as observed in full-scale tests and through numerical analyses, with the simplified approach normally taken in design. Only non-sway frames in which out of plane deformations were prevented by bracing are considered.

2. TEST FRAMES

The type of frame under consideration is illustrated in Fig. 1. Beam to column joints were formed using flange cleats one with the beams framed into the column flanges, in which bay ABCD was not present, and a second with the beams framed into the column web. On the assumption that lateral forces will be resisted elsewhere in the structure e.g. by bracing, shear walls etc, it is customary to employ "simple" connections between beams and columns i.e to design them to transmit beam reactions in shear. The design basis is therefore to assume that the beams act as if simply supported, with only nominal moments transferred into the columns [1,2].

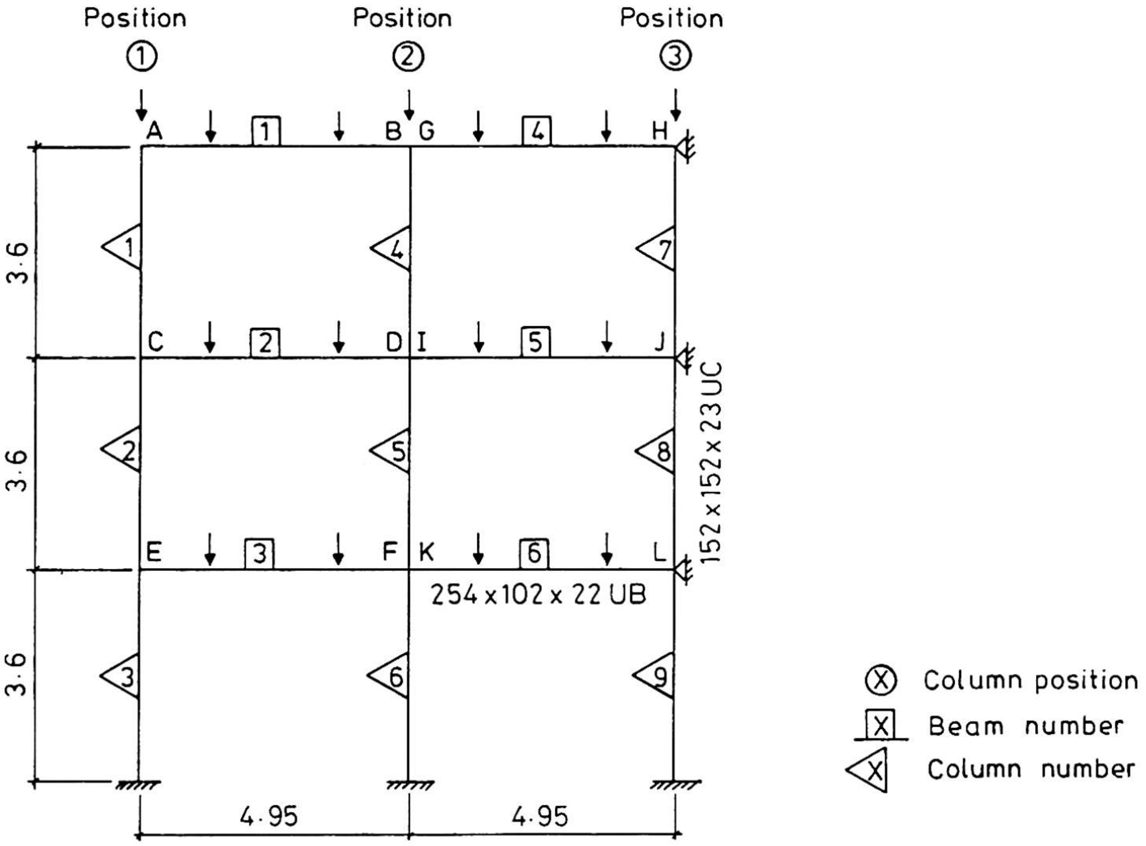

Fig. 1 Details of Frame Considered

Two frames of the type shown in Fig. 1 were tested [3] to collapse under a combination of beam loads and direct column loads and a full record of beam and column deflections, strains at key locations and joint rotations, amounting to some 600 channels of data, taken. Detailed analyses of the frames' behaviour were also undertaken using the SERVAR program developed at the Politechnico di Milano [4]. This program allows for spread of plastic zones, semi-rigid joint action and geometrically non linear effects. Full measured frame properties, including initial geometry, were used in the analyses. Fig. 2 compares bending moment diagrams at an advanced stage of the test for the first frame in which column 1 and beam 1 were absent.

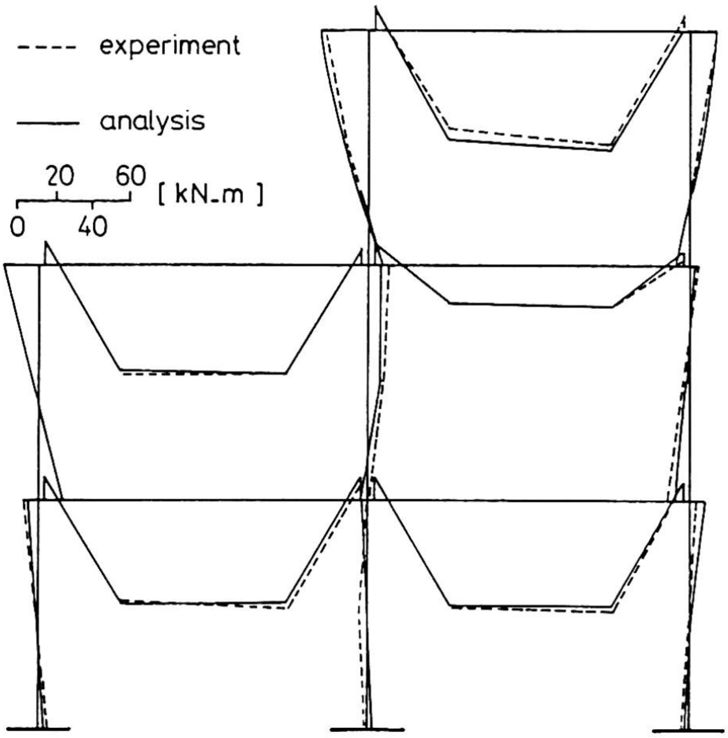

Fig. 2 Comparison of Measured Bending Moments and SERVAR Predictions Under Beam and Column Loading

3. FRAME BEHAVIOUR

3.1 Joints

The joint moment-rotation (M-Φ) characteristics used in the analyses were obtained from a separate series of connection tests [5]. However, a check on the performance of the connections in the frame was also made and Fig. 3 compares M-Φ curves, including that obtained from a further series of tests on column subassemblages [6]. All joints were nominally identical but were, of course, subject to some variability due to inevitable differences in fit-up. The effect of this level of variability on the performance of beams, columns and frames has been assessed through sample calculations, which show only very small differences in the resulting load-deflection behaviour. It therefore seems probable that variations in joint M-Φ characteristics due to "normal" variations in fabrication, location in a frame etc will have negligible effects on the performance of the frame as a whole.

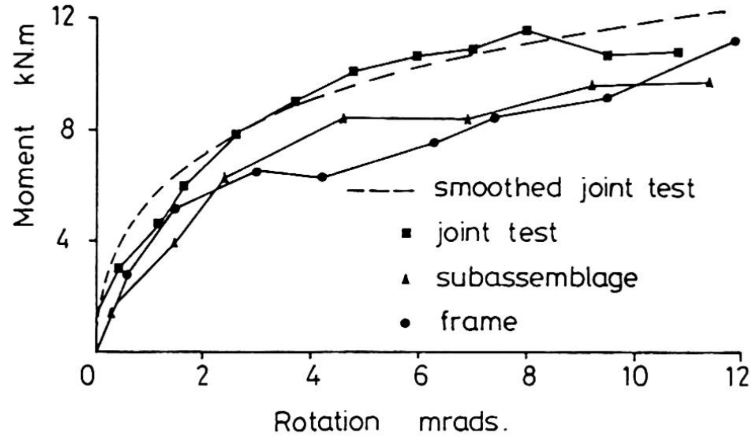

Fig. 3 Comparison of Joint Moment Rotation Characteristics

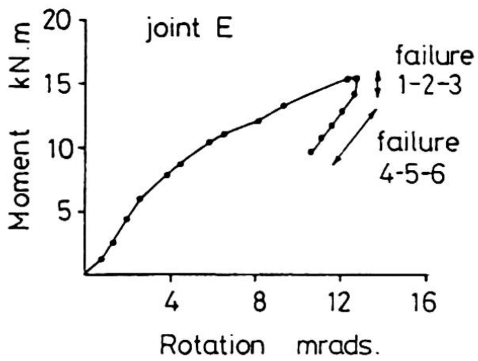

Fig. 4 Behaviour of Joint E Showing Unloading Phase

On the other hand, larger variations of the type produced for example in web cleats or flange cleats by using oversize holes - as might be required in cases of misalignment that were rectified on site - may well have a significant effect. Lack of fit is less important, however, for end plate connections for which quite large plate distortions - as might occur when welding the plate to the beam - have little influence on M-Φ behaviour [7].

One particularly important feature of joint behaviour in frames is their unloading. Fig. 4 shows how, for frame 2, the rotations of a joint to an external column during the three phases of frame loading; beam loads, column 1-2-3 additional direct load to failure, column 4-5-6 additional direct load to failure, reverse as column failure is initiated. Since the operative joint stiffness is then effectively its initial value [5], this is clearly beneficial in terms of stabilising the column. This feature has been explained in more detail both theoretically [8] and in full-scale tests [7] on column subassemblages, where it was found that greatly enhanced column loads were obtained as compared with those given by current design methods.

3.2 Beams

Clearly for beams the presence of end restraint provided by the semi-rigid connections will tend to reduce span deflections and moments as compared with the design assumptions. This is illustrated quantitatively for one beam in the test frame in Fig. 5, where the measured response is compared with that predicted by both the normal design approach and by the analysis in which end restraint has been included.

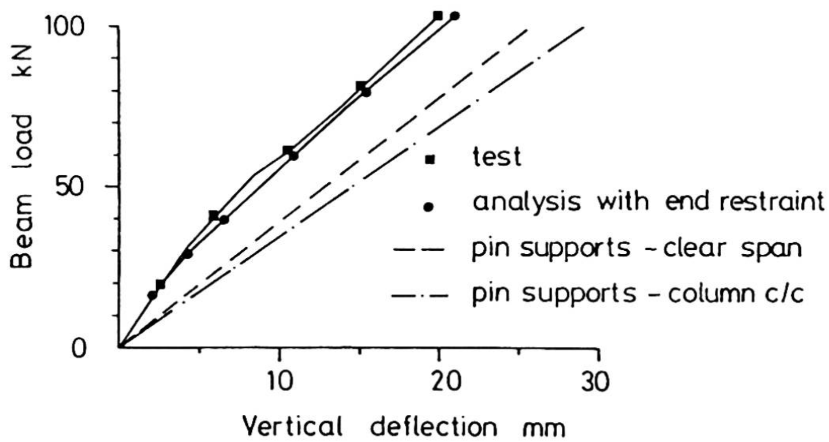

Fig. 5 Load Deflection Response of a Beam in Frame 1

3.3 Columns

The real behaviour of the columns is actually the most complex feature of the frame response. Whilst deflections are reduced as compared with those that would be expected of equivalent pin-ended members, the actual loads in the columns - especially the end moments transferred by the beams - require very careful assessment as collapse is approached. Fig. 6 shows the variation of moment at the column head at each level for column 1-2-3 of frame 2 as loads are increased to produce failure in the column. For both columns 1 and 2 two distinct phases can be observed; an initial linear phase corresponding to the application of beam loads followed by a non linear phase as column load is increased. For column 3, however, this second phase includes a reversal of moment. Similar behaviour has been observed in both tests and analyses of single column subassemblages [6, 8].

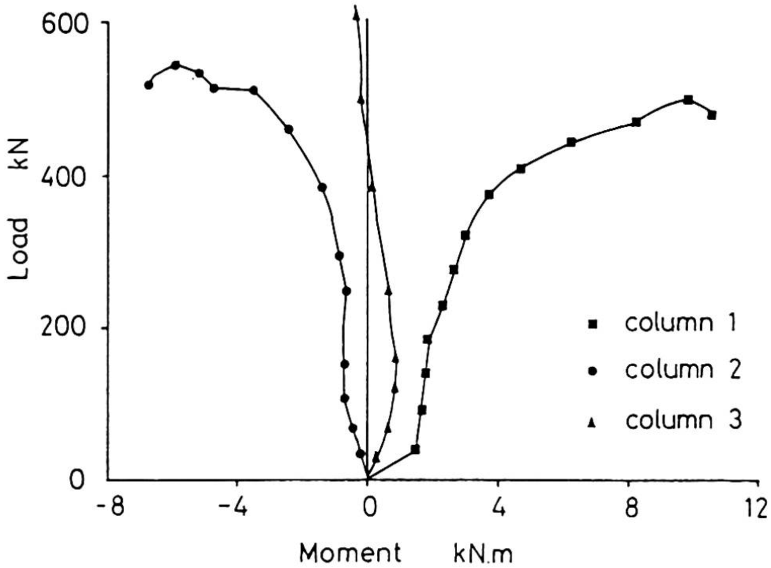

Fig. 6 Development of Column Moments

It is therefore not sufficient merely to regard the effect of the semi-rigid end connections on the column as simply providing some restraint against end rotation. Moments must be transferred from the beam through the connections and the exact form of these moments depends on the balance of stiffness. As frame loading is increased beam stiffnesses will be reduced by plasticity, connection stiffnesses reduce with increasing rotations according to their $M-\Phi$ curve unless a reversal in direction of rotation causes them to provide a higher unloading stiffness, whilst column stiffnesses will be reduced - very rapidly as collapse is approached - by the combination of plasticity and destabilising effects.

4. DESIGN IMPLICATIONS

The principal effect of semi-rigid joint action is to cause the frame to respond as a complete structure rather than as a set of isolated members as is assumed in the simple design approach. If the frame contains beams which are stiff and strong compared with the column clearly the beams will, via the connections, provide support to the columns thus improving their load carrying capacity. If on the other hand the columns are stiff and strong compared with the beams then restraint offered by the column will reduce both the beam midspan moments and also the deflections. These situations represent extreme limits to the real situation in which collapse will be initiated by the weaker components which will nevertheless receive assistance from the remainder of the frame. To convert the knowledge of such behaviour into a design procedure it is necessary to determine the extent to which such interactions occur and to devise rules which exploit the effect at both the ultimate and the serviceability limit states yet are sufficiently simple to be practical.

5. CONCLUSIONS

Connection details have been shown to have a significant influence on the structural performance of steel frames. Using the results of full scale tests and numerical analyses the exact nature of this influence has been described. Although the main features have been identified, it remains for these to be represented by simple design rules.

6. ACKNOWLEDGEMENTS

The work reported herein was supported by a grant from the Science and Engineering Research Council, supplemented by contributions and assistance from the Building Research Establishment, Construction Industry Research and Information Association and Constrado (whose activities have now been subsumed into the Steel Construction Institute) and has benefited from collaboration with the Politechnico di Milano.

7. REFERENCES

1. British Standards Institution, BS 5950 : Part 1 : 1985, Structural Use of Steelwork in Building. BSI, London, 1985.

2. Eurocode 3, Common Unified Rules for Steel Structures. Directorate-General for Internal Market and Industrial Affairs", Commission of the European Communities, 1984.

3. KIRBY, P.A., DAVISON, J.B. and NETHERCOT, D.A., Large Scale Tests on Column Subassemblages and Frames. State-of-the-Art Workshop on Connections, Strength and Design of Steel Structures, Cachan, France, May 1987.

4. POGGI, C., and ZANDONINI, R., Behaviour and Strength of Steel Frames with Semi Rigid Connections, in Connection Flexibility and Steel Frames, ed. W.F. Chen, ASCE, New York, 1985, pp. 57-76.

5. DAVISON, J.B., KIRBY, P.A. and NETHERCOT, D.A., Rotational Stiffness Characteristics of Some Steel Beam to Column Connections. Journal of Constructional Steel Research, Vol. 8, 1987, pp. 17-54.

6. NETHERCOT, D.A., KIRBY, P.A. and DAVISON, J.B., Column Behaviour in PR Construction - Experimental Behaviour. Journal of Structural Engineering, ASCE, Vol. 113, No. 9, September 1987, pp. 2032-2050.

7. DAVISON, J.B., KIRBY, P.A. and NETHERCOT, D.A., Effect of Lack of Fit on Connection Restraint. Journal of Constructional Steel Research, Vol. 8, 1987, pp. 55-69.

8. NETHERCOT, D.A., KIRBY, P.A. and RIFAI, A.M., Column Behaviour in PR Construction - Theoretical Behaviour. Canadian Journal of Civil Engineering (in press).