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Behaviour and Design of Composite Connections

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Summary

Previous experimental and numerical investigations of the use of composite action in beam to column joints in multi-storey frames are used as the basis for establishing a set of design procedures covering the key performance requirements of strength, stiffness and rotation capacity. The link between achievable levels of connection performance and the use of moment redistribution based design methods for non-sway composite frames has also been studied so that supply and demand may be balanced in achieving appropriate overall frame solutions.

1 Introduction

A major innovation in recently published structural design codes is the deliberate drawing together of the approach to be used when assessing the distribution of internal forces within a structure and the performance requirements of the connections. As an example, both EC3 and EC4 recognise the semi rigid and/or partial strength nature of many practical types of joint through the concept of the semi-continuous approach to frame design. This requires that explicit consideration be given to actual joint properties. Recognising the best description of joint behaviour to be its moment-rotation or M-ϕ curve, the key descriptions of this are defined as:

- Moment capacity M_c
- Initial rotational stiffness K_I
- Rotation capacity ϕ_u

The recent progress at Nottingham in first identifying the main governing influences on these properties and then in deriving methods for their prediction for a range of connection types forms the core of this paper. The presentation is restricted to non-sway frames since almost no data currently exists on the behaviour of composite connections subject to loading that places the slab in compression.

2 Investigations

Four interlinking techniques have been used to study the overall and detailed behaviour of composite connections:

- Examination of available test data
- Laboratory tests
- Numerical modelling
- Application of basic mechanics

All available composite connection test results have been collected together, carefully reviewed and placed in a computerised database. Specific tests, initially designed to simply investigate the inherent levels of composite action typically provided but normally neglected in design, and later aimed at both developing a better understanding of the complex force transfer mechanism and providing detailed load histories against which to validate numerical approaches have been conducted.

The development of a validated ABAQUS based model (1) for composite connections has permitted several of the more detailed and initially puzzling aspects of behaviour e.g. moment / shear (2) and moment / column axial load interaction (3), to be investigated. Interpreting the findings with the aid of some basic concepts in mechanics has led to the establishment of a unified design approach that provides good predictions for M_c, K_i and ϕ_u.

3 Moment Capacity M_c

Before attempting to devise a comprehensive design basis it is necessary to identify all the possible failure modes. Fig. 1, which shows these for a cleated arrangement, illustrates the importance of recognising the role of each of the components and the possibilities that when acting in combination forms of failure that might not be possible for the non-composite equivalent may occur. The next, and most important, step consists of deciding upon the mechanism of force transfer through the various components. Fig. 2 shows how this is accomplished for a finplate or web cleat arrangement (4). It should, however, be noted that several variants of this are possible, depending on the precise geometry, number of bolts, degree of reinforcement etc. The governing shear resistance may then be determined as the least of all potential shear resistances e.g. for a finplate six conditions must be considered:

i Shear resistance of the bolt group.
ii Bearing of the bolts against the finplate or beam web.
iii Weld resistance in shear.
iv Block shear failure of the beam web.
v Block shear failure of the finplate.
vi Equilibrium of the internal forces.

Explicit formulae for these and for the equivalent conditions for angle cleats and endplate (5) arrangements have been derived. From Fig.1 it is also necessary to check for overstressing of the beam web and column web. Item vi above is used to ensure that a consistent and achievable set of forces is finally used to calculate the moment capacity from:

$$M_c = P_v\, x$$

in which P_v = attainable connection shear
x = shear span

This approach has been fully validated using both the complete set of all appropriate test data and the supplementary numerical results

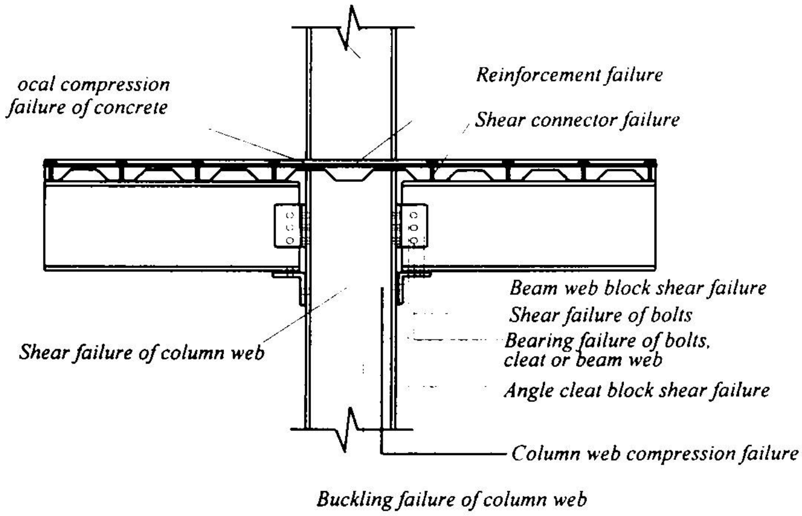


Figure 1. Composite angle cleated connection with possible failure modes

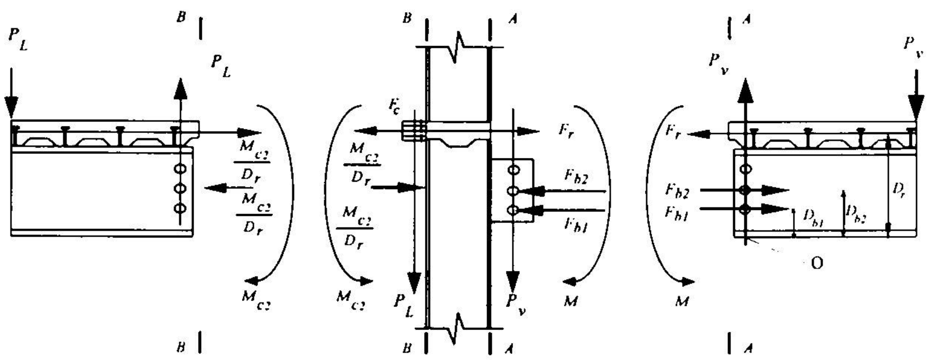


Figure 2. Free body diagram of the connecting parts showing internal forces (finplate connection and cleated connection with web cleats only)

4 Initial Stiffness K_c

Since both finplate and cleated arrangements involve the occurance of slip at uncertain stages due to the use of (normally) untorqued bolts in clearance holes subject to shearing action, accurate stiffness prediction is impossible. However, for endplates the model of Fig. 3 may be used to derive an explicit expression for K_I in terms of the various component stiffnesses, values for which may be obtained by considering the basic behaviour of the particular component in question (6).

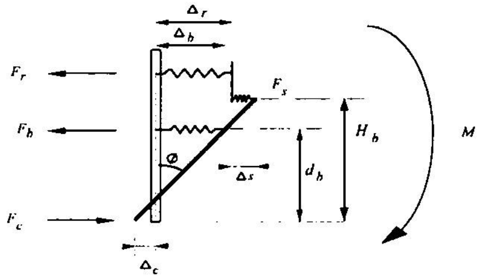
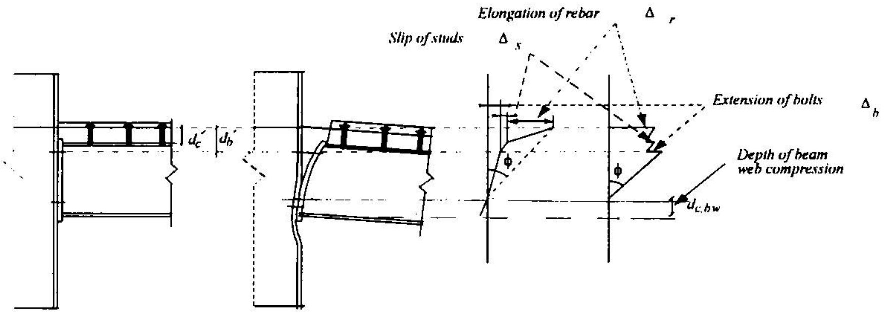


Figure 3. Spring model for initial stiffness of composite flush endplate connections

5 Rotation Capacity ϕ_u

Similarly, the model for predicting the available rotation capacity of endplate connections shown in Fig. 4 leads to an explicit expression for ϕ_u in terms of connection geometry and component stiffness (6). Although rather less reliable test data for both K_I and ϕ_u are available, comparisons against all thirtytwo suitable results show that both the above prediction methods give consistently good results.



(a) (b) (c) (d)

(a) Connection before deformation
(b) Connection after deformation
(c) Deformation of components at connection face
(d) Representation of deformations for rotation calculation

Figure 4. Beam to column connection rotation capacity model

6 Frame Design

For strength design of non-sway composite frames the preferred approach uses the strong column / weak beam concept i.e. failure is controlled by collapse of the beams. Providing buckling effects are suppressed, collapse of any beam segment will occur by the formation of a 3-hinge mechanism. Possibilities for different levels of support moment (corresponding to different levels of M_c, including full beam capacity "fixed ends") are illustrated in Fig. 5. Examination of a wide variety of cases (7) has shown that the joints may be expected to reach their capacity before the mid-span region attains the sagging resistance of the composite section. Therefore formation of the final mechanism requires redistribution of moments from the supports to the span, a condition that necessitates some plastic rotation in the connections - hence the need to be able to predict ϕ_u.
Of the three potential limiting conditions:

- i span moment reaches beam's sagging capacity
- ii support moment reaches joint capacity
- iii joint rotation reaches joint rotation capacity

the simplest design procedure corresponds to deliberately satisfying i & ii, whilst ensuring that iii is not violated. Studies show that since joint rotation and degree of moment redistribution are directly linked, iii may more easily be satisfied if the span moment is taken as less than the full sagging capacity (8,9). This additional design freedom is helpful in cases where the required joint rotation (for the formation of the mechanism of Fig. 5d) cannot easily be achieved by the preferred form of connection.

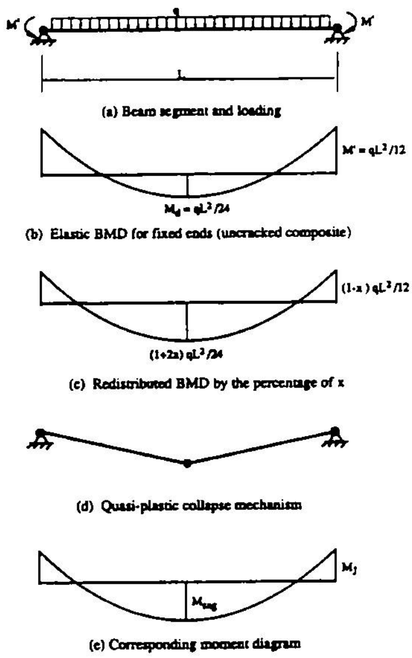


Figure 5. Moment redistribution and quasiplastic design

7 Conclusions

Recent research into the behaviour of composite beam to column connections, including their influence on the overall response of complete non-sway frames, has been reviewed. From this work a fully detailed design procedure has been developed.

8 Acknowledgements

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