Available online at www.sciencedirect.com
ScienceDirect
Journal of Constructional Steel Research 62 (2006) 1171–1177
JOURNAL OF CONSTRUCTIONAL STEEL RESEARCH
www.elsevier.com/locate/jcsr

Design of unbraced multi-storey steel frames

D. Anderson*

School of Engineering, University of Warwick, Coventry CV4 7AL, UK

Abstract

Simple approximate methods for analysis of unbraced frames have played a part in encouraging the use of steel in construction. These methods have been supported by research, to verify and to extend their scope. This paper questions their continued use and further development. It is appropriate to do this at the present time when documentation and software are needed to introduce the Eurocodes. Approximate methods still have a role, in initial design. For unbraced frames early consideration needs to be given to limiting sway in service conditions. A very simple formulation is presented, to enable section sizes to be determined to satisfy this criterion.

Keywords: Frames; Steel; Composite; Steel–concrete; Sway; Analysis; Second-order; Serviceability; Optimisation

1. Introduction

It is expected that Eurocode Parts required for the design of common building structures will be published in 2005. Their preparation has taken much longer than originally expected but the final provisions for steel and composite building structures [1,2] are still recognisably similar to the first drafts published in the 1980s [3,4]. The codes as published therefore benefit from the initial leadership given by Dowling for steelwork and Johnson for composite construction.

During the development of the Eurocodes, the drafting groups sought to meet two principal objectives: that the codes be user-friendly; that the codes reflect structural behaviour accurately. When these are in conflict, preference has been given to accuracy. Publications in support of the Eurocodes can provide simplified recommendations if necessary and the very widespread acceptance of software enables the drudgery of long hand calculations to be avoided.

Software for analysis of structural frames goes back a long way [5]. Despite this, designers have continued to use approximate methods and the research community has provided technical justification. Indeed some such methods have been developed further, to address modern forms of construction and to be compatible with limit states design codes. The analysis of unbraced multi-storey steel frames is a particular example of such endeavour, which has resulted in the wind-moment method [6] and the Merchant–Rankine formula [7] continuing to be used in design. Both methods are of limited scope but avoid taking explicit account of second-order effects due to sway.

These approaches may have encouraged the use of steel in construction. This paper argues though that the Eurocodes provide opportunity for designers to move to methods of general application not dependent on empirical justification. For steel frames, and particularly for frames including composite elements, an attempt to avoid direct treatment of second-order effects resulting from sway is likely to hinder rather than help verification of designs for ultimate limit states.

Measured by the number of design rules, serviceability limit states receive far less attention and yet limitation of sway deflections may well govern section sizes in an unbraced frame, even when the joints are taken as rigid. This paper concludes by describing a new method to generate section sizes to meet limits on sway deflections due to horizontal loading.

2. Wind-moment method

2.1. The basis of the method and its advantages

Fig. 1 illustrates the method. In its basic form, the method assumes:

* Tel.: +44 24 7652 3163; fax: +44 24 7641 8922.
E-mail address: da@eng.warwick.ac.uk.

0143-974X/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jcsr.2006.06.009

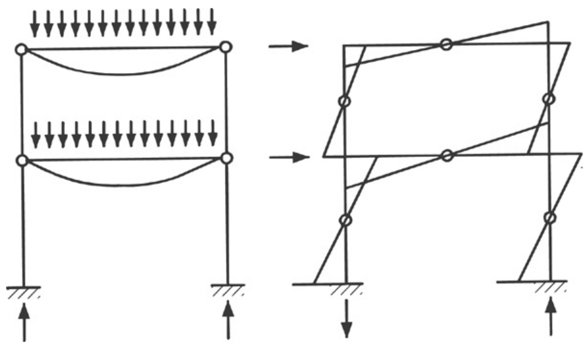

Fig. 1. Bending moments according to the wind-moment method.

- under gravity loads the beam-to-column joints act as pinned connections
- under horizontal wind loads these joints are rigid. Points of contraflexure are assumed to occur at the mid-height of columns and the mid-length of beams.

Members and connections are proportioned initially to withstand gravity load, factored for ultimate limit states (ULS). The frame is then analysed under horizontal wind loads. The internal forces and moments due to gravity load and wind are then combined, using appropriate load factors for each combination. Design for ULS is completed by amending the initial section sizes and connection details where necessary, to withstand the combined effects. Second-order effects due to sway are allowed for by using effective lengths for the columns that are greater than the lengths between floor levels.

The main advantages of the method are its simplicity, its suitability for hand calculation and economy in fabrication of connections. The assumptions render the frame statically determinate and section sizes and connection details can be determined without iteration. Joints are designed to withstand only the forces and moments given by the analyses, rather than being designed to match the resistance of connected members.

2.2. Development of the method

Despite the assumptions inherent in the method, its advantages in practice have proved enduring. Judged by the interest shown by designers, the method has encouraged the use of steel in construction. This interest provided the incentive to develop the method for use with BS 5950, the British limit states steelwork code first published in 1985, and to address caution in use of the method recommended by Nethercot [8]. Rules developed for steel frames [6,9] were justified by second-order elastic–plastic analysis of frames designed by the method [9–11]. In these studies, the analysis accounted for the development of plastic hinges and the semi-rigid nature of typical beam-to-column connections (Fig. 2) in wind-moment frames.

Some justification for the method is also given by the lower-bound theorem of plastic theory. Provided the internal moments and forces are in equilibrium with the loads, and resistances around the frame are not exceeded, the loads will not exceed those for collapse. These conditions are met by the wind-moment method provided that:

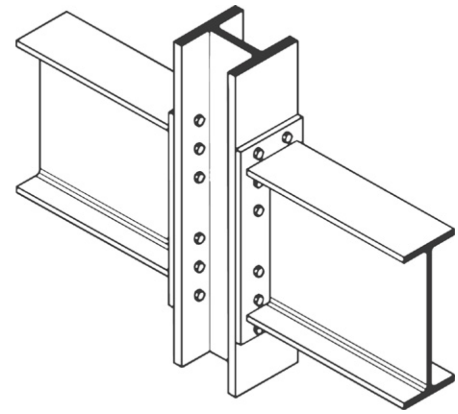

Fig. 2. Typical wind-moment connection.

- the effects of deflections on equilibrium are accounted for
- adequate rotation capacity exists for redistribution of moment.

Based on the frame studies, the compression resistance of a column with sway is determined using an effective length factor of 1.5 and the resistance to lateral-torsional buckling is calculated by the BS 5950 procedures for simple design. The requirement for rotation capacity is met by limiting the sections to Class 1 Plastic and Class 2 Compact and by using only standard end-plate connections [6] whose ductility has been proved using testing [12].

The tendency of the method to under-design columns [8] is offset to some extent by a requirement that moments in these members due to gravity loads be taken from an end restraint moment to each beam equal to 10% of the free bending moment, combined with moments due to eccentricity of beam reactions. In accordance with British practice [7], the reactions are assumed to act at 100 mm from the face of the column.

The frame studies also showed that under service loading the flexibility of the connections resulted in sway deflections significantly larger than those predicted assuming rigid joints. This led to a recommendation that sway deflections calculated on this assumption should be increased, for most frames by 50%.

The studies were inevitably limited to a range of geometry and loading, steel grades and section types, which define the scope of the method.

2.3. Composite beams

In practice multi-storey frames often include composite beams and designers have asked that the method be extended to cover such members. Two further studies have therefore been undertaken.

One [10] examined the use of composite beams in conjunction with the standard ductile steel end-plate connections [6]. It was found that simply replacing a steel beam by a composite member of equivalent moment resistance did not always result in a satisfactory design. With a composite beam, the shallower depth of the steel section could result in standard connections with inadequate resistance to the wind moments.