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Developments in Cold Formed Roof Structures

Développements dans les toitures structurales écrouies à froid

Entwicklungen in kaltverformten Dachtragwerken

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SUMMARY

The advantages of cold formed sections are discussed, with particular reference to two space frame roof systems. Designs methods which are used for lip buckling, flexural torsional, and lateral torsional buckling are outlined. The transfer of forces and moments at the connections is described. The range of structures in which the system have been applied is indicated.

RÉSUMÉ

La communication présente les avantages des sections profilées et formées à froid, en se référant à deux systèmes de toiture tridimensionnels. Les auteurs exposent les grandes lignes des méthodes de calculs utilisées pour déterminer le voilement de bordure, la torsion par flexion et le flambement par torsion en flexion. Ils examinent en outre le transfert des forces et des moments sur les assemblages. Ils présentent la gamme de structures pour lesquelles ces systèmes ont été appliqués jusqu'ici.

ZUSAMMENFASSUNG

Diskutiert werden die Vorteile kaltverformter Profile im Zusammenhang mit zwei Raumfachwerk-Dachsystemen. Dabei sind die Bemessung für Randbeulen, Biegetorsion und Biegedrillknicken und die Einleitung von Kräften und Momenten an den Anschlüssen wichtige Fragen. Die Breite der bisherigen Anwendung auf Tragwerke wird umrissen.

1. INTRODUCTION

As techniques of structural analysis, powerfully assisted by rapidly developing computer hardware and software, reach maturity, the scope and economy of construction depends increasingly on developments in manufacturing methods, construction equipment, and materials. Cold forming, with its associated processes, is opening new avenues for structural design.

Adjustable cold rolling mills now enable purpose designed sections to be produced from a stockholding of steel strip. Holes are pre-punched on the rolling line, members are cut to length by flying shears, and when required, powder coating is then applied. Dimensional tolerances of ± 1mm, and bolt diameter clearances of 1mm are normal. Sections with a perimeter length of up to 1.2m and up to 8mm thick can now be rolled. Pre-galvanised strip with a yield stress of 390 N/mm^2 is available up to 5mm thick. The cold rolled components for a roof structure covering 5000 sq m can typically be produced in 5 working shifts. Components can usually be man-handled. Costs per unit weight are somewhat greater than for hot rolled sections, but this is offset by weight reduction, corrosion protection and response time.

In addition to the production advantages, the designer has the freedom to exercise ingenuity in devising optimum sections to meet architectural and structural requirements. The structural analysis of cold formed members is however considerably more complex than for hot rolled members, because of the various forms of instability which must be considered. Many more developments in production methods, in design, and in applications, can be expected.

The investigations which provide the background for this paper have centred around two patented systems, but the approaches and methods which have been developed have general application.

2. THE HARLEY SYSTEM 80

The Harley joint for a square on square space frame is shown in Figure 1. The guiding principle of the Harley system is to minimise the cost of the nodal connection. Chord splices are located away from nodes, and occur every three or four modules. Joint economy is achieved at the cost of introducing end moments to the chords. The moments are much greater in the inner chords, and are a maximum in the vicinity of columns. The provision of moment capacity across nodes does however exclude the possibility of toggle failure, and enhances the robustness of the structure. The number of components is minimised by bending the flattened ends of the tubular diagonals to enter between the back to back channels, so forming an architecturally neat connection. The creases of compression tubes are not fully supported; this limits the diameter of the tube which can be used, and causes an end eccentricity. Very formable steel is required, and during assembly the tubes are supported only at the lower ends. The length of the end tab is limited by the width of the section, so the end distance limits the tensile strength of the tube. Nevertheless, the system has proved to be economic, and many structures have been built using the Harley system [1].

3. THE MULTIFRAME SYSTEM

This system also uses back to back channels, but the diagonals are connected through wing plates, and the flattened ends of the tubes are not bent (Figure 2). The tab length is not limited by the width of channel, more than one bolt can be used if required, the end distance is not limited, and the end eccentricity of the diagonals is very small. The wing plate transmits the resultant force of the four diagonals to the nodal connection, and leaves no voids between the back to back channels. The greater eccentricity moment is in the longitudinal direction of the wing plate, which therefore assists the transfer of this moment, by virtue of the bending strength of the trough. The cost of the additional components is offset by increased structural efficiency, and by removing the demand on formability imposed by bending the tabs. Also the tube size is not limited, and much greater spans are possible than with the Harley system. The system can also be applied to planar, triangular, and box trusses, and to portal frames.

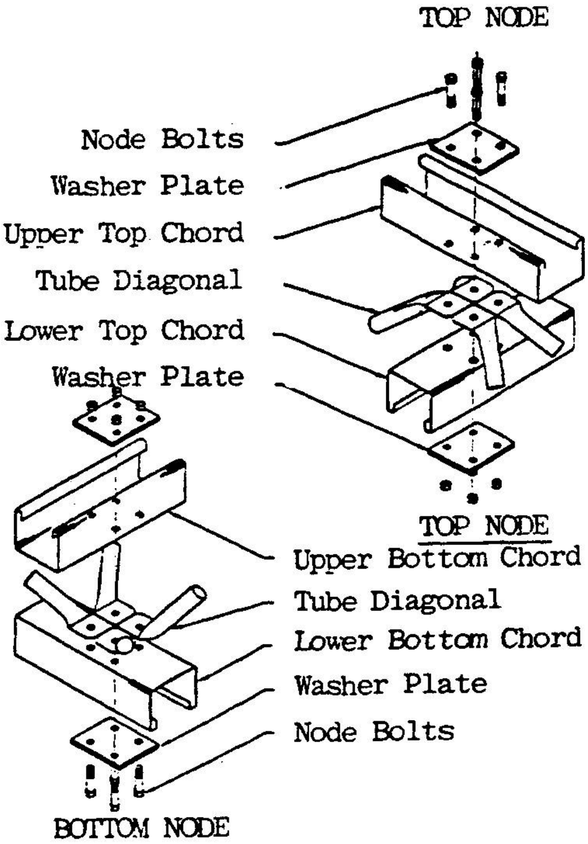

Fig.1. Harley connection

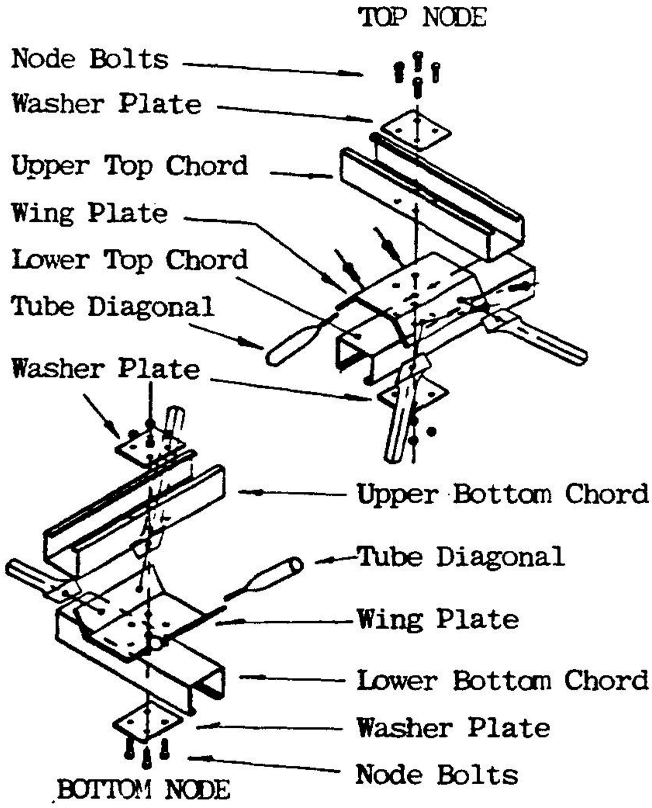

Fig.2. Multiframe connection

4. STRUCTURAL BEHAVIOUR

The following paragraphs outline the phenomena which must be considered in design. A general description of the development is given in [2] and details can be found in [3].

4.1 *Local buckling*

The forces and moments are computed assuming fully effective sections. Section strength checks are then made taking account of loss of effectiveness due to local buckling. The effect of stress level in an element on the effective width may be taken into account. The effect of coupling of the sides of the section may also be considered in calculating the critical stress.

4.2 *Lip buckling*

The lips of the channel can buckle laterally as struts on an elastic foundation, the "foundation" stiffness being provided by the transverse deformational stiffness of the section (Figure 3). An important question to consider was whether local buckling of thin walled sections would significantly reduce the deformational stiffness of the section. Finite element analysis confirmed that for typical lip/local buckling wavelength ratios (about 7:1), the effect of local buckling on lip buckling is insignificant. The lip buckling resistance can be found by assuming an initial deformation (related to manufacturing tolerances) which is affine to the critical lip buckling mode, and using a modified Perry equation [4]. The effect of lip buckling on flexural or torsional flexural buckling can then be taken into account approximately by reducing the yield stress to the lip buckling resistance. There is some evidence however that when torsional buckling develops before lip buckling, so that both lips buckle laterally in the same direction, in a single half wave, lip buckling is thereby inhibited. There are two reasons for this - the lip buckling stress for a single half wave is much greater than for the preferred mode, which typically has three or four half waves, and when the lips buckle in the same direction, the foundation modulus is increased. Systematic studies are now in progress to study, quantify and establish criteria for this interactive behaviour.

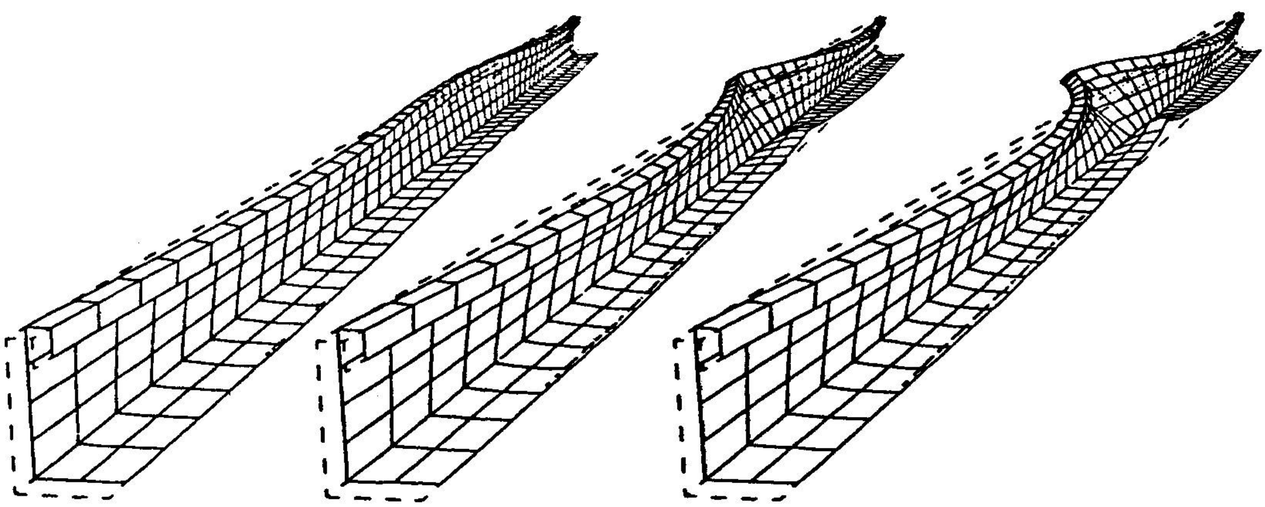

Fig.3. Development of Lip Buckling

4.3 *Torsional buckling*

In current design codes, torsional or torsional flexural buckling is treated by substituting the critical torsional buckling stress for the Euler buckling stress in the Perry equation for imperfect struts. In fact the torsional buckling stress distribution (Figure 4) is quite different from that for flexural buckling, and can be found by applying Young's equation for the deflection of imperfect struts separately to the translation and rotation of a member buckling torsionally[5]. It was also shown that a simple modification to the Perry equation, which then correctly represents torsional buckling of a doubly symmetric section, provides a satisfactory approximation for torsional flexural buckling. The section shown in Figure 3 is prone to lateral torsional buckling, which also can be treated by the method just described.

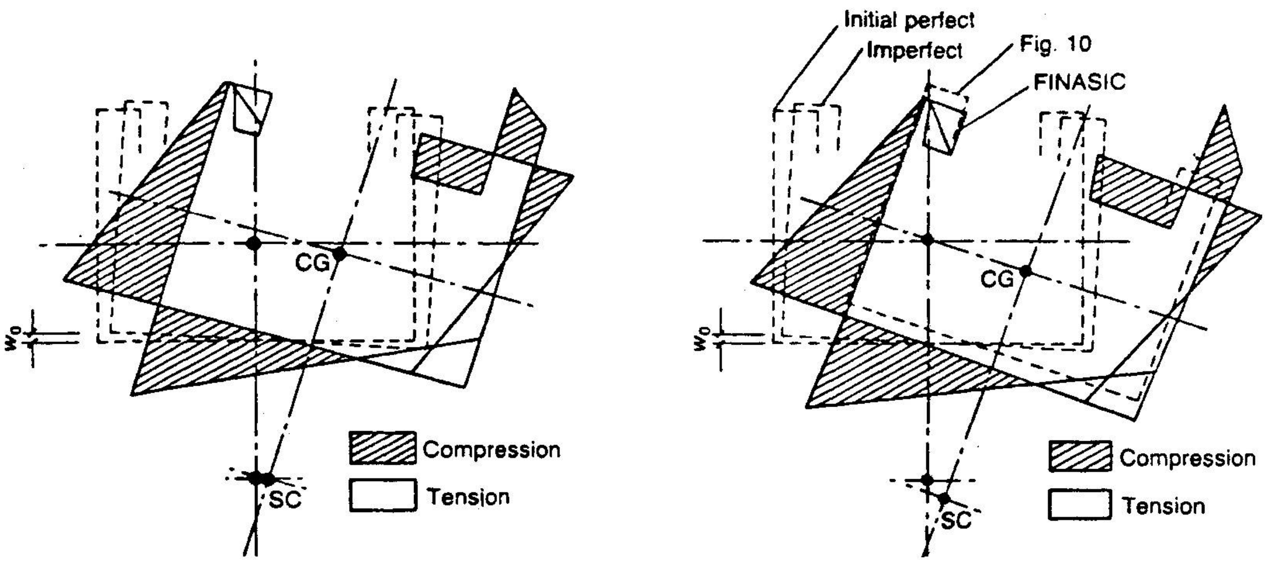

Fig.4. Comparison of Torsional buckling stresses - design model and finite element analysis

Torsional flexural and lateral torsional buckling interact strongly, because both buckling modes consist of rotation and translation of the section, the member buckling in a single half wave. When moment causes lip tension, torsional flexural buckling is inhibited to an extent which depends on the magnitude of the moment. It may conservatively be assumed that the resistance is equal to the torsional flexural buckling resistance, or to the flexural buckling/moment interaction value, whichever is smaller. Similar considerations arise in respect of interaction between axial tension and moment which causes lip compression. The interaction between the buckling modes is an important theme of current research.

4.4 *Nodal forces*

In the Harley system, vertical forces are transferred at the tube creases to the washer plates, which are held together by four bolts, which resist tension and shear. The washer plates transfer components of the horizontal tube forces as axial forces applied to each chord. The washer plates also transfer components of the eccentricity moments to the chord tables and thence to the chord webs, which are therefore subject to vertical forces which vary from tension to compression over the length of the washer plates. The table of the chord is subject to varying vertical shearing forces between the edges of the washer plates and the chord webs. Where necessary, nodal inserts are provided, which prevent web crippling and table shearing. The crease of a compression tube is not supported over its whole length, and the tube size must be limited to prevent crease deformation, and also to limit the eccentricity moment applied to the tube. The crease of a tension tube is fully supported, and the strength is determined by the tab bearing stress, which is limited by the end distance from the bolt hole.

In the Multiframe system, the wing plates and washer plates transfer the resultant forces and moments to the chords. The greater moment is transferred over a length measured from one end of the wing plate to the other end of a washer plate, so the vertical channel web forces are reduced. The flattened ends of the tubes remain straight, which simplifies fabrication and places much less demand on formability. The tubes are axially loaded, a more efficient end distance can be adopted, and more than one bolt can be used if required. The wing plates must have sufficient resistance to bending about the mid-thickness. Bending is caused by eccentricity, and by misalignment, which results from manufacturing tolerances and from joint translations and rotations due to load.

In any system employing flattened tubes, if the strength is not limited by the tensile connection, flattening of the tube can occur before the tensile strength of the tube is attained. In a compression tube which is short enough not to buckle, outward bulging of the end regions can occur, if the tube is sufficiently thin.

5. DESIGN, FABRICATION AND CONSTRUCTION

It will be apparent from the above discussion that many design checks must be made, in addition to the frame analysis. Remembering that many more structures are designed in outline than are actually built, the necessity for computerising the design process is apparent. In fact the development of these systems depends as much on the computer as on the manufacturing process, which itself is computer controlled. The computer executes and couples analysis, design, estimating, scheduling, and the control of manufacture.

The high rate of production necessitates careful pre-checking of component schedules and dimensions. The dimensional accuracy which is inherent in the production system ensures rapid assembly on site.

Roof structures are normally assembled at ground level. In the Multiframe system, the bottom chords are laid out on level stools, and the wing plates are inserted and bolted. The diagonals and top wing plates then provide stable pyramids on which the top chords can be laid and bolted.

Large roof structures are raised by special lifting columns, which ensure that all lifting points are maintained at the same level. This system also has advantages on restricted sites.

6. APPLICATIONS

The Harley system can provide spans with perimeter columns up to about 40m, and internal spans between single columns up to about 26m. The Multiframe system does not have specific limits, but is economically viable for perimeter supported spans up to at least 70m and internal spans up to at least 40m. The systems have been applied to a wide variety of roof structures and canopies, including sports halls, transportation terminals, industrial buildings, and retail facilities.

7. REFERENCES

(1) CODD B E, WHITE S H. Eagle Centre Market refurbishment, Derby. The Structural Engineer. Volume 70, No.5, 1992.
(2) CHAPMAN J C, BUHAGIAR D, DOWLING P J. Developments in cold formed space structures. Conference on space structures, Guildford, Surrey, September 1993.
(3) BUHAGIAR D. Behaviour and design of structures using thin-walled cold-formed sections. PhD thesis, Imperial College, London 1993.
(4) BUHAGIAR D, CHAPMAN J C, DOWLING P J. Design of C-sections against deformational lip buckling. Eleventh international conference on cold-formed structures. University of Missouri-Rolla, October 1992.
(5) CHAPMAN J C, BUHAGIAR D. The application of Young's buckling equation to design against torsional buckling. Proc ICE August 1993.