Application of Direct Strength Method to Cold-Formed Thin-Walled Steel Columns in Fire

Ashkan Shahbazian
ashkan.shahbazian@postgrad.manchester.ac.uk

Supervisor: Professor Y. C. Wang

April 2012

The Steel in Fire Forum
In: The Institute of Structural Engineers, London, UK
Outlines

• Introduction
• Design methods at ambient temperature
• Why direct strength based method?
• Understanding of buckling curve and modes
• Behaviour of columns in fire
• Developed direct strength based method
• FE validation and parametric study
• Results and discussion
• Conclusions
Introduction

The use of Cold-formed Thin-walled steel structures in both industrial and residential constructions has grown in the last few years:

• mainly because unusual cross-section configurations can be produced economically (structural part)
• mostly because of the lightness, ease of fabrication and etc. (construction part)
Common application of cold-formed thin-walled steel sections is in **wall panels**.

They are used as load bearing members (stud) and covered by gypsum/plaster boards on both sides. These boards do not carry vertical loads, however, they provide lateral rigidity and fire resistance to the steel studs.

*typical wall panel*
Design Methods at Ambient Temperature

For predicting the load carrying capacity of CF-TW steel structural members, the traditional effective width method has been followed, but in recent years the Direct Strength Method (DSM) is becoming more popular as it avoids lengthy calculations of the effective widths.

This new method now has been adopted by AISI for ambient temperature applications.

Note: There is no method for CF-TW members in fire condition in standard codes (BSI, EN, AISI and etc).
Effective Width Method (EWM)

- The effective width method considers each element of a cross section separately and analyses the members by ignoring the rotational restraints provided by the adjacent elements.
- Procedure of using effective width method for column (EN1993-1-3 and 1-5):
  1. Calculating effective section properties of the flanges and/or lips in a compression: included at least 3 steps and some iterations
  2. Calculating effective section properties of the web
  3. Calculating effective cross-section properties
  4. Resistance check
Direct Strength Method (DSM)

- In fact, the DSM is an extension of the use of column curves for global buckling. However, in this method local and distortional instabilities are also considered.

- By having critical buckling loads (local, distortional and global) and squash load \( (F_y * A_g) \), the ultimate strength of the column can be calculated by using buckling curves.
Why DSM based Method?

- DSM enables the structural engineers to predict the strength of CF-TW members with complex cross sections (such as lipped channels with multiple stiffeners).
• The DSM is a new and viable choice for developing or optimising sections.

• For CF-TW steel members exposed to fire condition from one side, using the effective width method is calculation-intensive because of non-uniform distributions of the mechanical properties of steel.
Buckling Curve and Buckling Modes

• The buckling curve shows buckling loads for different lengths which can be calculated by simple, fast and free Finite Strip computer programs such as CUFSM. Also buckling curve helps us to understand behavior of section.

• The buckling mode is the shape that a member buckles into.
Application of Direct Strength Method to Cold-Formed Thin-Walled Steel Columns in Fire

**Local**
- Rotation only

**Distortional**
- Rotation

**Global**
- Translation

**Mode Shape**

- **LB**: involves only rotation, not translation at the fold lines (flange/lip) of the member. Local buckling involves distortion of the cross-section.
- **DB**: involves both translation and rotation at the fold line of a member. DB involves distortion of a portion and rigid response of another portion.
- **GB**: involves translation (flexural) and/or rotation (torsion). There is no distortion in the elements.
Behaviour of Columns/Studs in Fire

- When a cold-formed thin-walled steel member is exposed to fire from one side, the temperatures on the exposed side and unexposed side will be different.

- Due to this non-uniform temperature distribution, two additional effects happen which was observed in the experimental studies by Professor Wang’s research group and this research numerical and sensitivity studies.
Additional effects:

- Thermal bowing: caused by differential thermal expansion on the two sides of the cross-section.
- Shift of centre of resistance: due to non-uniform distribution of resistance (yield stress) of the steel.

\[
\delta_m = \frac{\alpha L^2 T}{8d}
\]

- \(\alpha = 0.000014 \, ^\circ\text{C}^{-1}\) (Expansion Coefficient)
- \(L = \) Column Length
- \(T = \) Temperature Difference between Exposed and Unexposed side
- \(d = \) Depth of cross-section
- \(\delta_m = \) Lateral deflection caused by thermal bowing
Developed Direct Strength Based Method

• We developed a new methodology for calculating elastic buckling and squash load to take into consideration the thermal bowing and shift of centre of resistance effects. This method has been applied to columns undergoing all three buckling modes.

• For the elastic buckling load calculation, by defining different mechanical properties of the steel at different elevated temperatures, the shift of centre of resistance is already included, but the thermal bowing effect should be considered as an additional bending moment.
Because of the presence of a bending moment:

- The original column under axial load becomes a beam-column with combined axial load and bending moment. Therefore, the squash load of the member is the axial load value that causes the cross section with non-uniform temperature to reach the cross-section limit under combined axial load and bending.

- This is termed “effective” squash load in this research.
FE Validation and Parametric Study

To have more realistic FE model, 8 full panel tests (non-uniform) and 10 short column tests (uniform) has been validated.

Example of FE Validations
The numerical parametric studies were performed to investigate the effects of varying the following design parameters:

- cross-section **shapes and dimensions**
- column **length**
- temperature **profiles** (to simulate different possible temperature distributions)
- with and without **intermediate support conditions**
Ambient Temperature Validation

Application of Direct Strength Method to Cold-Formed Thin-Walled Steel Columns in Fire

A. Shahbazian
Uniform Elevated Temperature Validation

Application of Direct Strength Method to Cold-Formed Thin-Walled Steel Columns in Fire
Non-Uniform Elevated Temperature Validation

Global Buckling

Local Buckling

Distortional Buckling
Proposed Buckling Curves for Columns in Fire

The ultimate strength of the column in fire is minimum of:

\[ P_{ne} = \left(0.495 \lambda_c^2\right) P_y \]
\[ P_{ne} = \left(\frac{0.462}{\lambda_c^2}\right) P_y \]
\[ P_{nl} = P_{ne} \]
\[ P_{nl} = \left(1 - 0.22 \left(\frac{P_{cr1}}{P_{ne}}\right)^{0.75}\right) \left(\frac{P_{cr1}}{P_{ne}}\right)^{0.75} P_{ne} \]
\[ P_{nd} = P_y \]
\[ P_{nd} = 0.65 \left(1 - 0.14 \left(\frac{P_{crd}}{P_y}\right)^{0.7}\right) \left(\frac{P_{crd}}{P_y}\right)^{0.7} P_y \]

- \( P_y \) - Effective squash load based on proposed methodology
- \( \lambda_c \) - Slenderness of related buckling mode
- \( P_{cr} \) - Critical elastic buckling load based on proposed methodology
Calculating Temperature of Studs in Wall Panel

A simple method based on energy balance has been proposed to calculate temperature of studs, and wall surface on both sides (exposed and unexposed).

- For designing ultimate strength of steel studs
- For designing thermal insulation

Steel Construction Institute (1993) P129:
- MAX Temperature $\leq 180^\circ$C
- AVE Temperature $\leq 140^\circ$C
Conclusions

a) For ambient temperature applications direct strength method is easy, simple and accurate even for complex cross-sections which is more effective for daily design.

b) For uniform temperature applications direct strength method is applicable and there is no need for modification for local and global buckling, but there is a need for small modification for distortional buckling which has been proposed.

c) For non-uniform temperature applications, by adopting the new methodology which developed in this research with proposed buckling curves, it is possible to predict ultimate strength of columns/studs in fire condition.
Available Programs and Tools

- CUFSM: Finite Strip Method program (link)
Developed programs and tools in this research: (link)

a) DSM calculator for columns (ambient)

b) Global buckling for LC (ambient)

c) Calculating effective squash load (elevated)

d) 1D heat transfer FDM for one layer material (transient)

e) Calculating temperature in thickness of wall panel assemblies (transient)
For further information:

- **Web:**
  
  [http://personalpages.manchester.ac.uk/postgrad/Ashkan.Shahbazian/](http://personalpages.manchester.ac.uk/postgrad/Ashkan.Shahbazian/)

- **Email:**
  
  ashkan.shahbazian@postgrad.manchester.ac.uk  
  yong.wang@manchester.ac.uk

- **Publications:**

  1. Calculating the global buckling resistance of thin-walled steel members with uniform and non-uniform elevated temperatures under axial compression, Thin-Walled Structures, 49 (2011) 1415-1428.  

     [http://dx.doi.org/10.1016/j.tws.2011.08.005](http://dx.doi.org/10.1016/j.tws.2011.08.005)

     [http://dx.doi.org/10.1016/j.tws.2012.01.006](http://dx.doi.org/10.1016/j.tws.2012.01.006)