Plastic failure mechanisms of eccentrically loaded thin-walled cold-formed steel members

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1. Introduction
What is a plastic failure mechanism?

1. Introduction
1. Introduction

What is wrong with the conventional “Effective width” method given in design codes worldwide?

- Requires numerous iterations
- Complicated for nonstandard cross-sections

To obtain the members’ load capacity
1. Introduction

• Thin-walled cold-formed (TWCF) steel structures are usually made of class 4 sections which are prematurely susceptible to local or distortional buckling in the elastic range

• Failure of these members in compression and bending is always initiated by local-global interactive buckling of plastic-elastic type

• This interaction manifests as a plastic failure mechanism

• Examination of the complete collapse response is needed, particularly for design under extreme loads

BREAKDOWN

• Subject: thin-walled cold-formed (TWCF) steel members - class 4 sections

• Loading: compression, bending and their interaction

• Phenomenon: plastic-elastic interaction of local/distortional and global buckling → local plastic failure mechanism

• Analysis:
  • FE simulation (Abaqus)
  • Analytical (yield line analysis)
1. Introduction

Buckling interaction

Two forms of interaction occur:

1. Interaction of local buckling modes

2. Local-global interactive buckling
1. Introduction

• Local-global interaction
• Factors that influence PFM
  1. \( f_y \)
  2. Type of cross-section
  3. b/t
  4. Geometrical imperfections
  5. Residual stresses

• Not a linear superposition of M+N!!
• Hard to determine \textit{a priori}
2. State of art review
2. State of art review

- Murray and Khoo (1981) observed 5 mechanisms that repeatedly manifested for plane channels in compression – 5 basic mechanisms
- Various researchers performing experiments since the 1960s
3. Numerical analysis
3. Numerical analysis

- **Subject:** lipped-channel (C-section)
- **Loading:** eccentric compression
3. Numerical analysis

- Boundary conditions: pinned-pinned
- Imperfections: eigenmode
3. Numerical analysis

Input

- \( f_y = 355 \frac{N}{mm^2} \); \( E = 210\,000 \frac{N}{mm^2} \); \( \nu = 0.3 \)
- \( h = 150 \, mm \)
- \( b = 50 \, mm \)
- \( c = 15 \, mm \)
- \( t = 1.5 \, mm \)
- \( L = 450 \, mm \)
3. Numerical analysis

Negative eccentricities

e = -20

e = -10

e = -5

e = 0

Positive eccentricities

e = +5

e = +15

e = +30

e = +50
3. Numerical analysis
4. Analytical analysis
Yield line analysis

theoretically **zero-width** lines of yielded material

(a) classical yield-line analysis of a simply supported plate (slab) with out-of-plane load, yield-lines and patterns develop from *first-order* forces and moments

(b) generalized yield-line analysis of a simply supported plate with in-plane load, yield-lines and patterns develop from consideration of *second-order* forces and moments
4. Analytical analysis

Slab VS Beam/column differences

1. Out-of-plane vs in-plane loading
2. No way to predict the mechanism – not necessarily the one with the lowest loading capacity!
4. Analytical analysis

Proposed mechanism model

• Model for failure in positive eccentricity
• Based on observations of FE simulation
4. Analytical analysis

Proposed mechanism model

• Flanges and lips of the element are in compression
• Web in tension
• Yield lines in lips of the section were not accounted for
• All walls are considered inextensible and incompressible - all deformation happens along the yield lines only
4. Analytical analysis
4. Analytical analysis

- Load vs displacement, $e=0$
- Load vs displacement, $e=+5\text{mm}$
- Load vs displacement, $e=+10\text{mm}$
5. Final remarks
5. Final remarks

• Short TWCF columns in eccentric compression fail by forming a plastic collapse mechanism – confirmed

• Agreement of the theoretical and numerical curve is not very good - the model needs more work

• Detailed derivation of the mechanism model and load capacity expressions will be presented in a MSc thesis of the same title
Thank You for your attention!