STEEL BEAM-COLUMN UNDER THERMAL GRADIENT

Combined axial-bending capacity of steel double-T cross-sections subjected to non-uniform temperature distribution

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INTRODUCTION

Beam: Bending moment (Gravity load) + Axial force (Thermal load)

Column: Axial force (Gravity load) + Bending Moment (Gravity + Thermal Load)

→ Beam-Column → Located at the borders of a fire room → Non-uniform temperature distribution

MATERIAL BEHAVIOR

EC3-Part 1.2 → Use of the ambient temperature σ-ε relationship with some additional factors

Ramberg-Osgood equation → ε = f(σ,T) → Inversion of Ramberg-Osgood equation

→ σ = f(ε,T) →

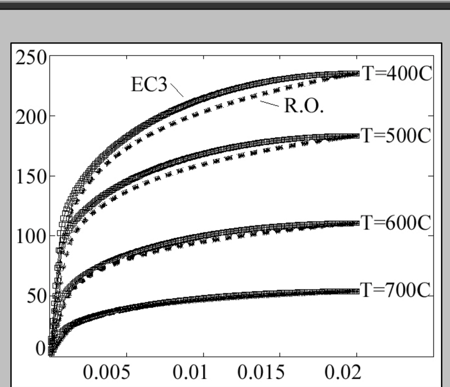


Fig. 1: Stress-strain relationships

- Elastic region: $E_{EC3} > E_{R-O}$
- Plastic region: $E_{R-O} > E_{EC3}$
- R-O equation : More optimistic

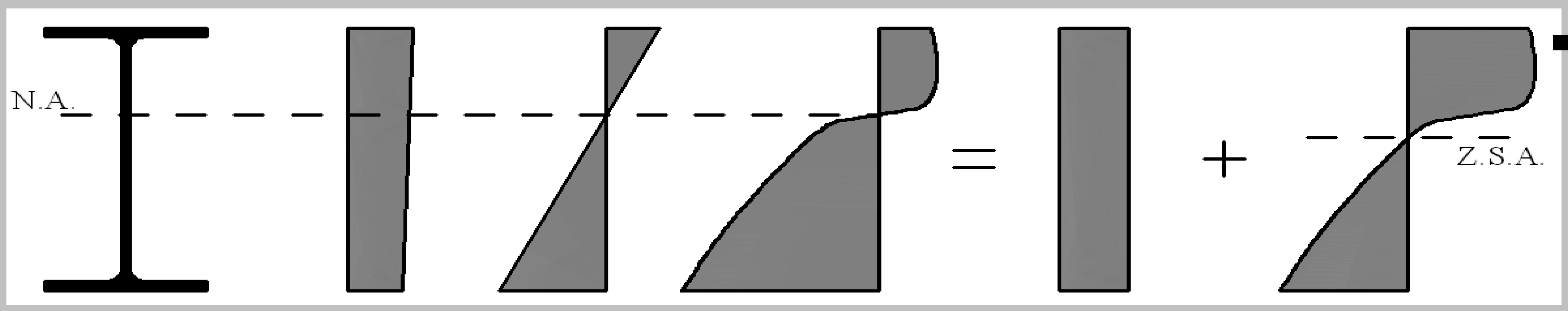
STRUCTURAL BEHAVIOR

Assumptions

- Bernoulli-Navier hypothesis (planarity of the cross-section)
- Transverse normal stresses → negligible
- Focus on the strength at a cross-section level

Implementation

a) Double-T cross-section
b) Linear field of temperatures over the weak axis
c) Linear strain field over the weak axis
d) Higher-order stress-field
e) Stresses contributing to axial force
f) Stresses contributing to bending moment



→ Open question: Higher-order moments ?

Fig. 2

Temperatures at the extreme fibres: from 20⁰C to 700⁰ C

Strains at the extreme fibres from -0.02 to +0.02

$$N = \int_A \sigma_x dA \longrightarrow \sigma_o = \frac{N}{A} \longrightarrow M = \int_A (\sigma_x - \sigma_o) z_{ZSA} dA$$

RESULTS

General

- Several solutions using CASTEM (computer code)
- Each point corresponds to a pair of strains imposed to the upper / lower fibre of the cross-section
- The step used for the coverage of the strain domain is constant
- EC3 capacity envelopes according to Part 1.1 - Cl. 6.36

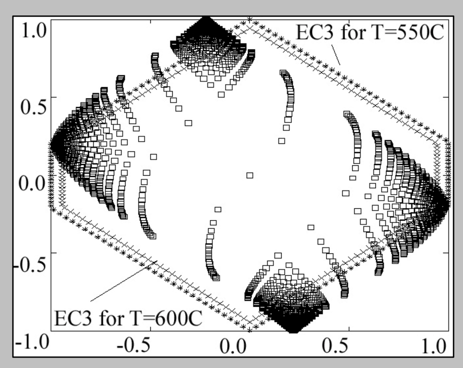


Fig. 3: Normalized M-N capacity for non-uniform temperature (T_{max} = 600⁰ C / T_{min} =500⁰ C) and EC3 capacity envelopes (T = 550⁰ C – External / T = 600⁰ C – Internal)

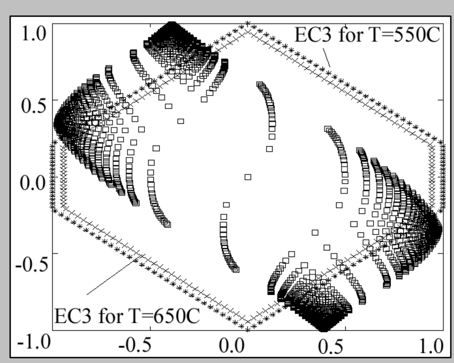


Fig. 4: Normalized M-N capacity for non-uniform temperature (T_{max} = 650⁰ C / T_{min} =450⁰ C) and EC3 capacity envelopes (T = 550⁰ C – External / T = 650⁰ C – Internal)

- In the region where the accumulation of the points falls outside the safety envelopes, EC appears conservative, whilst in the opposite situation, the EC approach appears to be optimistic
- The increase of the density of the images of strain points in the N-M space represents a reduction of the stiffness of the cross-section due to partial plastification
- Collapse whenever hardening is absent :

$$\frac{\partial M}{\partial \varepsilon} \to 0 \qquad \frac{\partial N}{\partial \varepsilon} \to 0$$

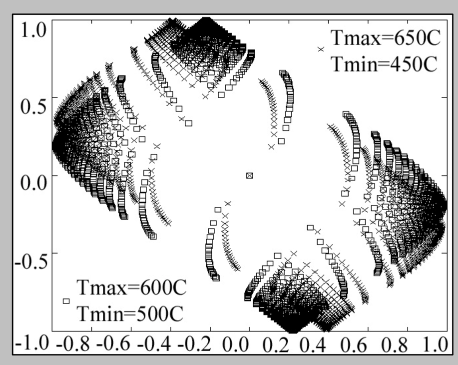


Fig. 5: Normalized M-N capacities for non-uniform temperatures using EC3 stress-strain relationship

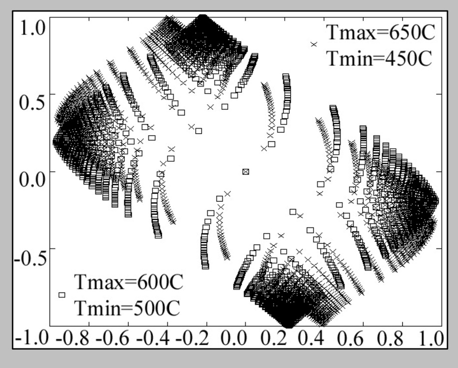


Fig. 6: Normalized M-N capacities for non-uniform temperatures using Ramberg-Osgood stress-strain relationship

- As the slope of the thermal gradient rises, so does the discrepancy regions
- The N-M images of the two approaches are quite similar
- The increase of the density in the edges of the strain span is attributed to the difference of the two stress-strain relationships

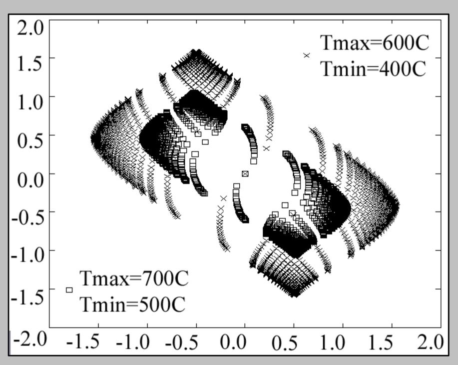


Fig. 7: Normalized M-N capacities for non-uniform temperatures using EC3 stress-strain relationship (Normalized for T=500⁰ C)

- Possible fire history scenario
- The alteration of the region of points shows the way that the growth of the fire affects the capacity of the cross-section

CONCLUSIONS

- The region of safe operation of the cross section presents under that presence of thermal gradient shows a differentiation in shape that is not accounted for by the present regulatory framework
- Extensive parametric research is needed in order to obtain N-M interaction safety regions for the commonly used structural steel cross sections
- The absence of a distinct hardening form of the stress-strain curve at elevated temperatures requires a reconsideration of the concept of allowable stress so as to obtain the same safety margin with the low temperature range

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