5th Annual BEAR PGR CONFERENCE 2014

University of Birmingham,
College of Engineering and Physical Sciences
School of Civil Engineering

Numerical study of the structural response of S460 & S690 Beams

M. Gkantou[1], C. Baniotopoulos[1], M. Theofanous[1], H. Hemida [1]
[1]School of Civil Engineering, University of Birmingham, UK
m.gkantou@bham.ac.uk

Birmingham, 15/12/2014

High Strength Steel (HSS) in Structural Applications..

Friends Arena, Sweden

Airbus Hangar, Frankfurt

Millau Viaduct, France

Shanghai World Financial Center, China

National Stadium, China

Akashi Kaikyo bridge, Japan

….What is defined as HSS and what are the benefits and considerations regarding the use of HSS in structural engineering?

High Strength Structural Steel ⟹ fy>400MPa

Benefits from the use of High Strength Steel

- Freedom in design, more elegant and iconic solutions (architectural benefit)
- Reduced deadweight
- Lighter structure (less structural and welding material, smaller foundations)
- Lower construction costs and transportation workloads

Sustainability Design

- Energy savings
  - reduced raw material
  - lower carbon emissions
  - reduced energy use
- Cost savings
- Time savings

Considerations regarding the use of High Strength Steel

- Limited design coverage (guidance up to limited tensile strength – design specifications for HSS have been mostly based on tests of normal strength steel members)
- Buckling and serviceability limit state issues (stiffness and not strength governs the design of HSS slender structures)
- Welding issues
- Restricted market availability ⟷ Increased material price

} Need for the **structural response of HSS** under various loading configurations to be further investigated

The current study focuses on the flexural response of HSS beams

What is the research already conducted on the flexural response of HSS?

Name	Authors	Journal	Year	Sections	Steel Grade
Plastic Bending of A514 Beams	J.F. McDermott	Journal of Structural Division, ASCE	1969	**I-shaped**	ASTM A514 (fy=690MPa)
Role of strain-hardening in structural performance	B. Kato	ISIJ International	1990	**H-section**	ASTM A514 (fy=690MPa)
Slenderness Limit of Class 3 I Cross-sections Made of High Strength Steel	D. Beg, L. Hladnik	Journal of Constructional Steel Research	1996	**I-shaped**	NIONICRAL 70 (fy=700Mpa)
High-strength steel: implications of material and geometric characteristics on inelastic flexural behavior	J. M. Ricles, R. Sause, . S. Green	Engineering Structures	1998	**I-sections**	HSLA-80 (fy=550MPa)
Strength and ductility of HPS flexural members	P.S. Green, R. Sauseb, J.M. Ricles	Journal of Constructional Steel Research	2002	**I-shaped**	HSLA-80 (fy=550MPa)
Strength and ductility of HPS 100W I-Girders in negative flexure	R. Sause, L.A. Fahnestock	Journal of Constructional Steel Research	2002	**I-sections**	HPS-100W (fy=690Mpa)
Flexural Strength and Rotation Capacity of I-Shaped Beams Fabricated from 800-Mpa Steel	Cheol-Ho Lee, Kyu-Hong Han, Chia-Ming Uang, Dea-Kyung Kim, Chang-Hee Park, and	Journal of Structural Engineering, ASCE	2013	**I-shaped**	HSB800, HSA900 (fu=800Mpa)

- Knowledge gap: Which is the flexural response of **HSS hollow sections?**

- What is the typical **methodology** followed by the researchers who study numerically the structural response of structural components/members?

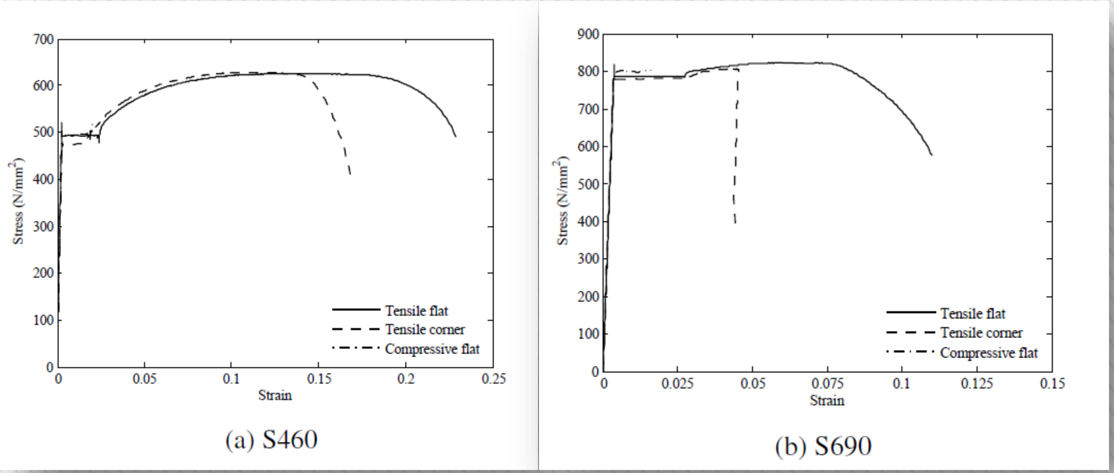
Methodology for the numerical investigation of the structural response of structural members

- Development of FE model
- Validation of the FE model against experimental results
- Execution of parametric studies
- Evaluation of the results
- Assessment of Design Code Specifications

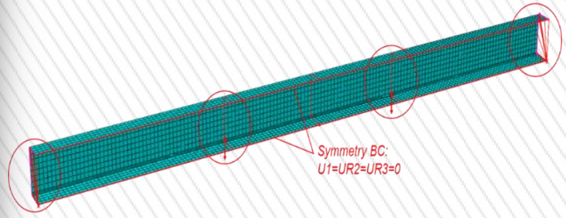
Following the aforementioned **methodology** the **flexural response of S460 and S690 hollow section beams** was investigated

Development of the finite element model

- Element type: Shell elements S4R (4-noded with reduced integration)
- Material properties: elastic – plastic with isotropic strain hardening material
- Analysis: linear elastic buckling (Eigenbuckling) – non-linear buckling (Riks)

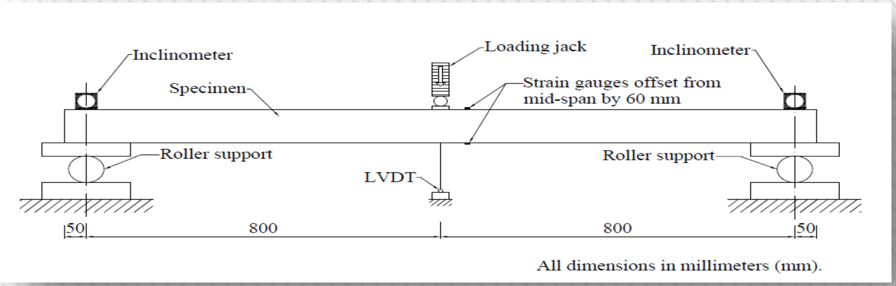


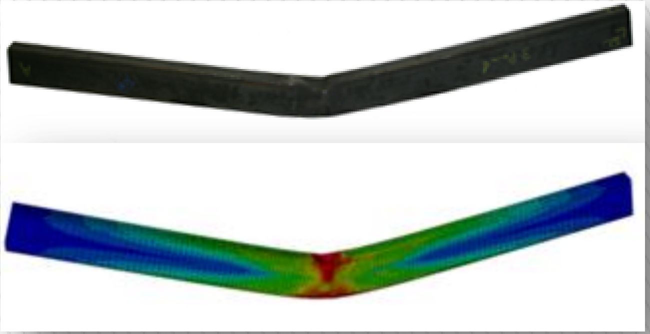
Averaged stress-strain curves of S460 and S690 based on the tensile coupon tests of HILONG project



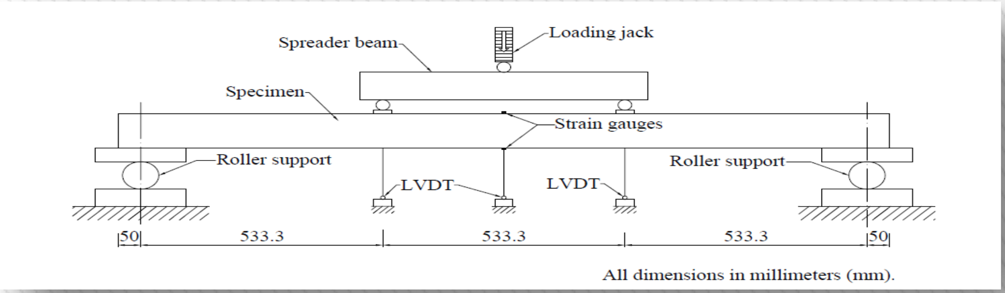
FE beam model developed in ABAQUS 6.12.2

Validation of the FE model against the experimental results of HILONG project





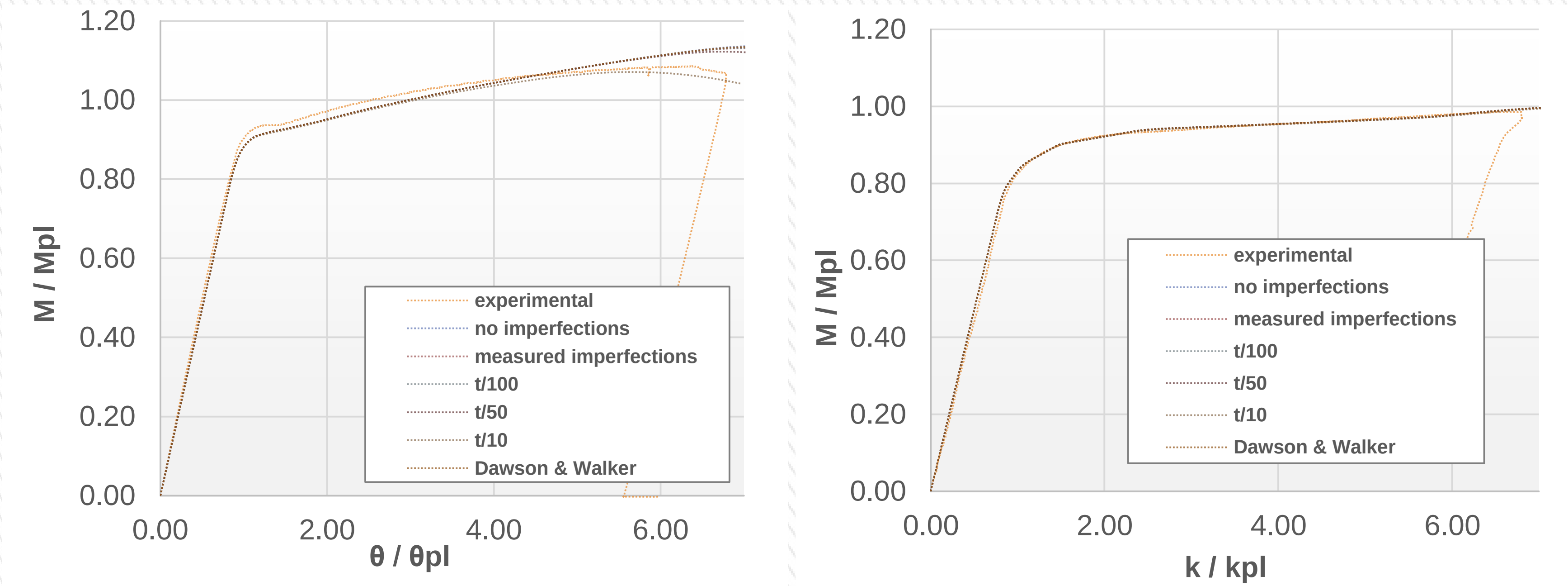
Setup configuration of 3pt bending tests and
typical experimental and numerical failure modes of RHS 3pt bending tests



Setup configuration of 4pt bending tests and
typical experimental and numerical failure modes of SHS 4pt bending tests

Validation of the FE model against the experimental results of HILONG project

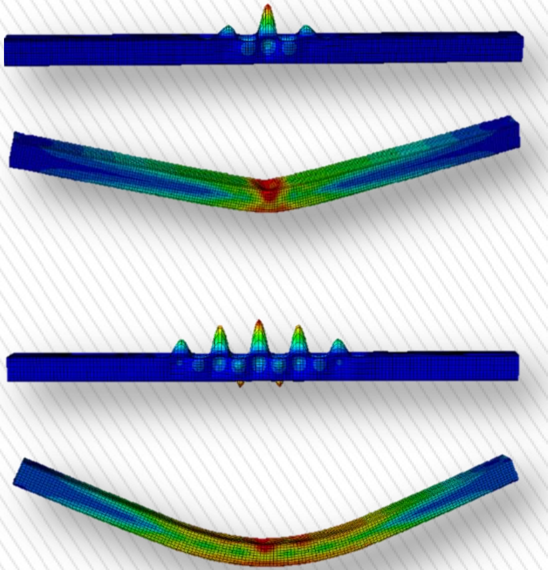
- $Mu_{(FE)}/Mu_{(exp)}$ for 3pt bending tests : mean=**1.01**, COV=**0.03**
- $Mu_{(FE)}/Mu_{(exp)}$ for 4pt bending tests : mean=**0.99**, COV=**0.04**



Typical moment-rotation curve for 3pt and moment-curvature for 4pt bending tests

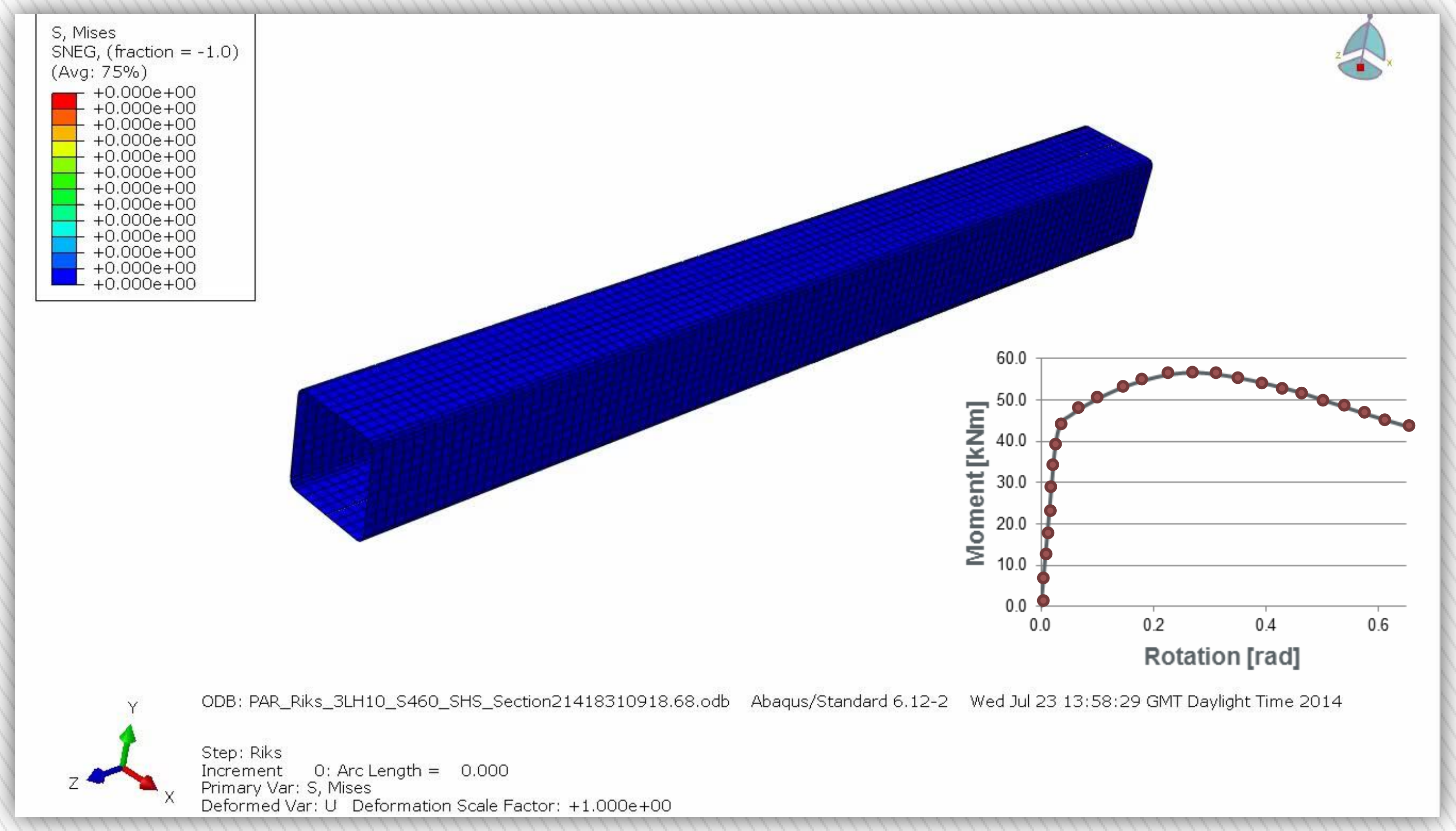
Parametric studies (216 additional tests)

- Three sections with aspect ratios 1.0, 2.0 and 2.44:
  - SHS 100x100 (H/B=1)
  - RHS 200x100 (H/B=2)
  - RHS 200x100 (H/B=2.44)
- Varying thickness to provide cross-sectional slenderness ct/ε = 10÷90
  - t = 1.52÷10.03mm for steel grade S460
  - t = 1.89÷11.71mm for steel grade S690
- Three testing configurations
  - three point bending test with beam span of L=10xH
  - three point bending test with beam span of L=20xH
  - four point bending test with beam span of L=20xH



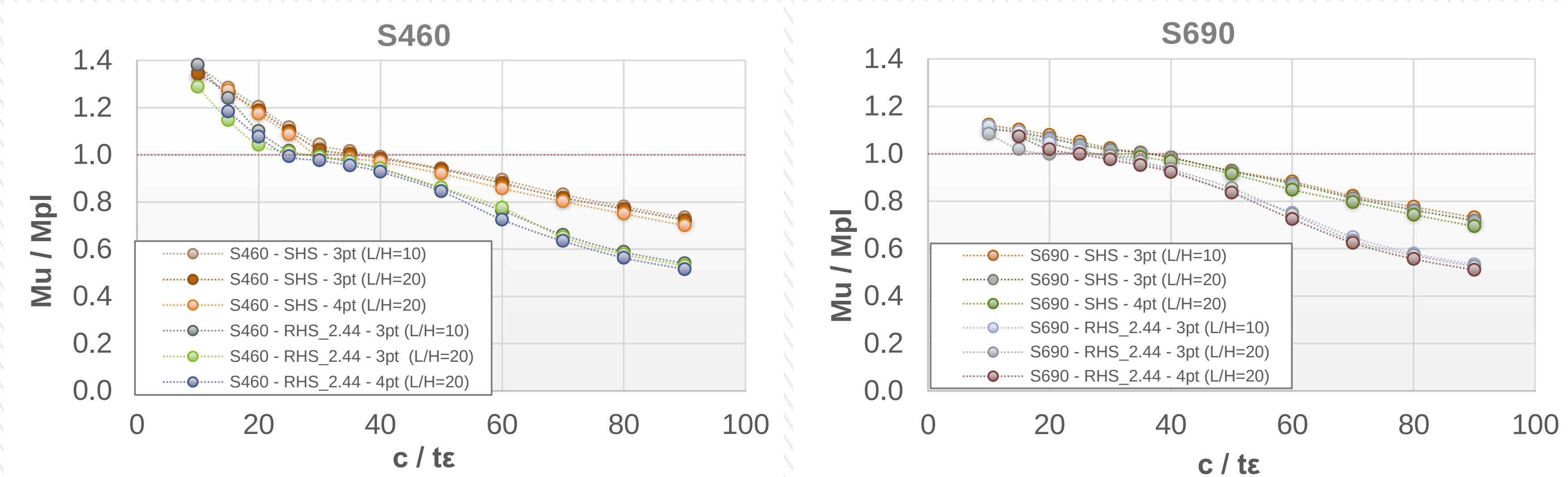
Typical linear and non-linear buckling for SHS 3pt and 4pt bending tests respectively

Parametric studies



Typical non-linear static analysis for SHS 3pt bending test (100 increments)

Evaluation of the results



Normalized plastic moment capacity against the cross-sectional slenderness for S460 and S690 respectively

Effect of key parameters on the flexural response of HSS beams

- Aspect ratio (B/H) ⟹ increased B/H decreases Mu/Mpl
- Strain hardening (SH) ⟹ increased SH increases Mu/Mpl
- Cross-section slenderness (c/tε) ⟹ increased c/tε decreases Mu/Mpl

How can these results be utilized for the assessment of Eurocode?

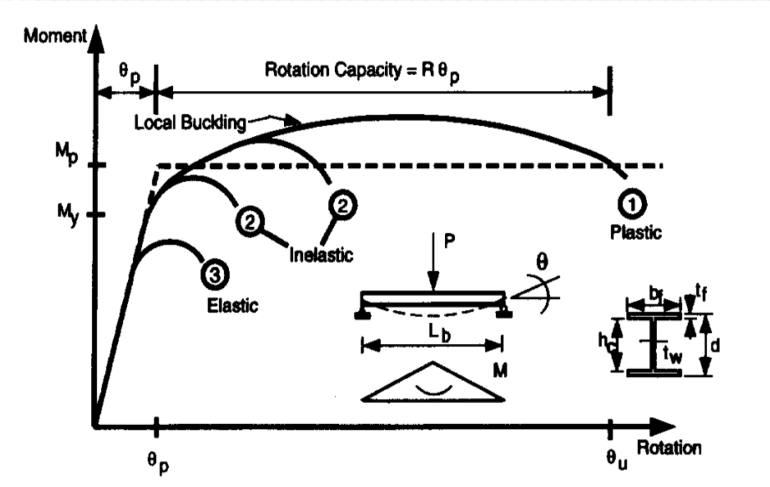
Assessment of Eurocode 3, Part 1.1, Table 5.2
(i.e. Assessment of Eurocode slenderness limits)

What is the slenderness of a plate element (c/tε)?

- Codified treatment of local buckling (i.e local failure due to compressive forces)
- Depends on the end supports of the constituent plate elements, the stress distribution of the constituent plate elements and the material properties

What are they used for in Eurocode 3? For the cross-section classification

- **Class 4** or slender sections
- **Class 3** or fully effective sections
- **Class 2** sections
- **Class 1** sections

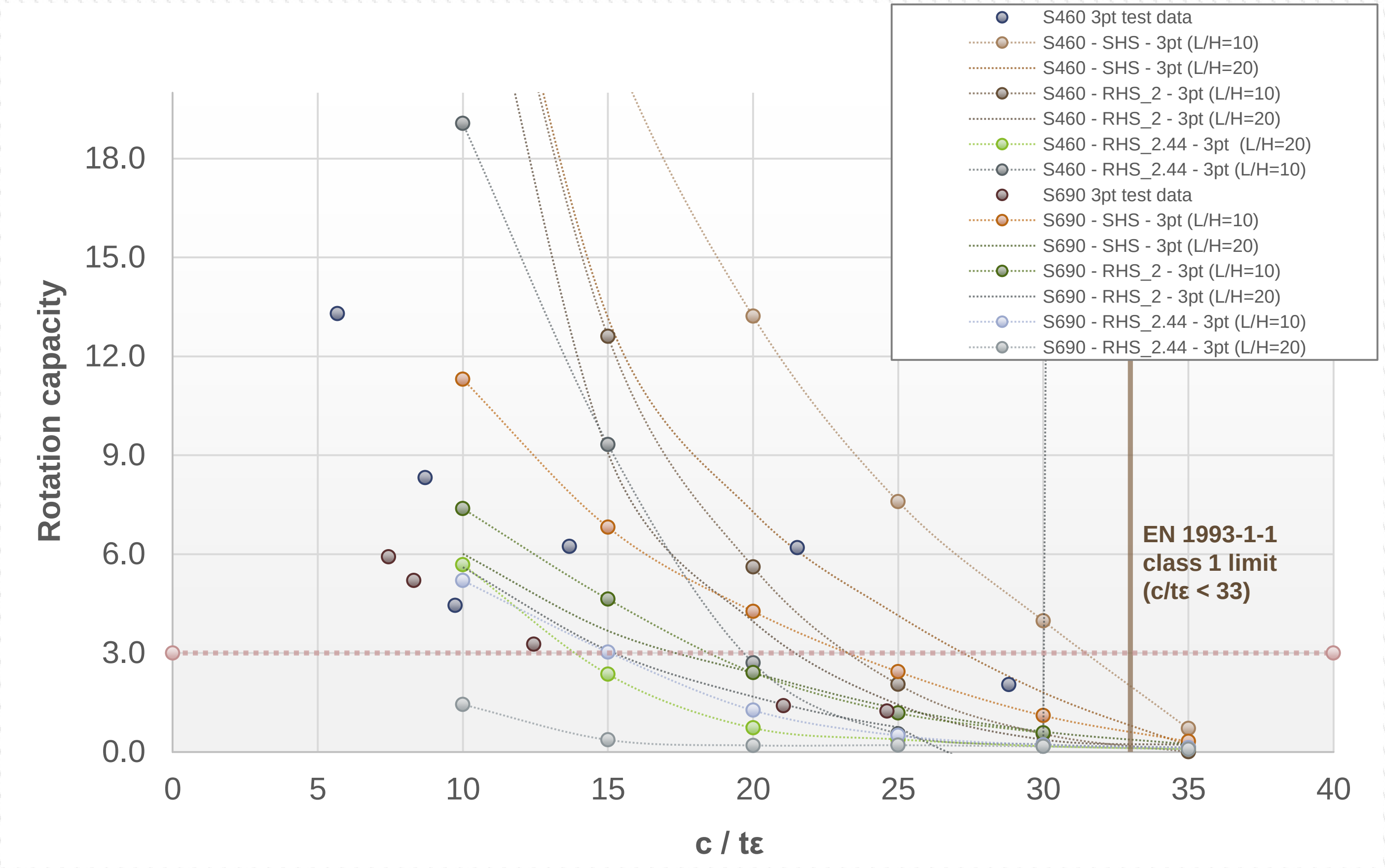


General flexural behavior of a beam (Ricles et al., 1998)

Assessment of Eurocode 3, Part 1.1, Table 5.2

(i.e. Assessment of Eurocode slenderness limits)

➢ **Class 1 limit** ➡ unsafe results, HSS not suitable for plastic design

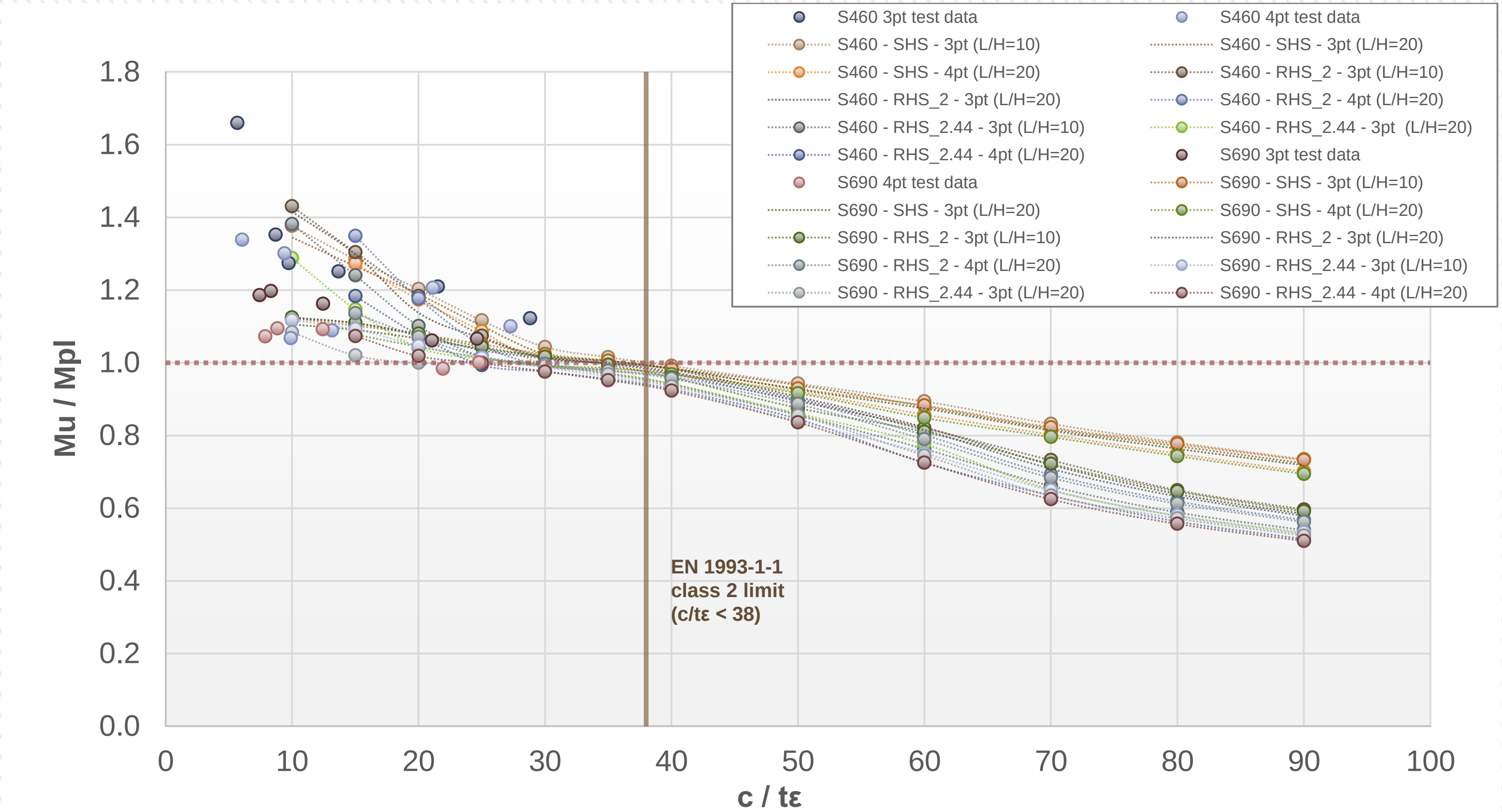


Assessment of Class 1 limit

Assessment of Eurocode 3, Part 1.1, Table 5.2

(i.e. Assessment of Eurocode slenderness limits)

- **Class 2 limit** ➡ slightly unconservative

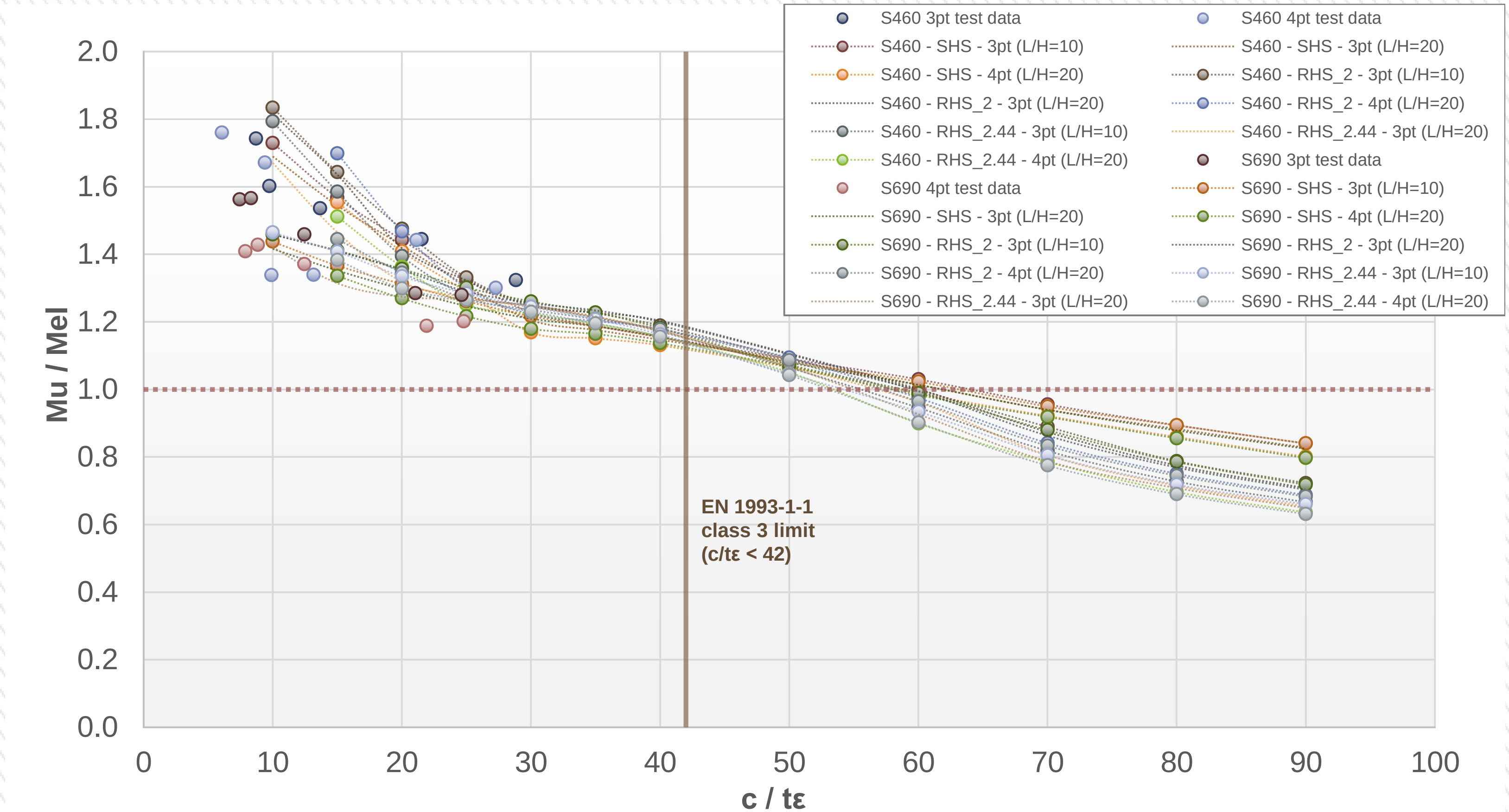


Assessment of Class 2 limit

Assessment of Eurocode 3, Part 1.1, Table 5.2

(i.e. Assessment of Eurocode slenderness limits)

- **Class 3 limit** ➡ safe but uneconomic design values



Assessment of Class 3 limit

Conclusions

- Overall very good **agreement** between experimental and numerical results was achieved
- The cross-sectional aspect ratio, the cross-section slenderness and the strain hardening material properties have all pronounced effect on the **flexural performance of HSS beams**
- Conclusions regarding the applicability of **Eurocode slenderness limits for HSS hollow sections**:
  - Class 1 limit unsafe
  - Class 2 limit slightly unconservative
  - Class 3 limit non-economic
- **Further research** on the structural response of hollow sections HSS members under various loads is needed

Thank you!