Finite element investigation of stability bracing force demands of steel moment resisting frame columns under cyclic loading

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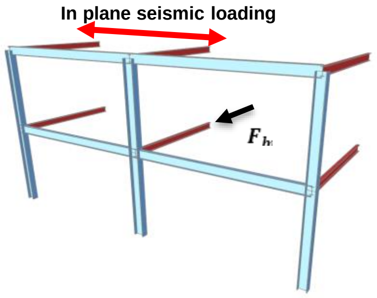
1. Introduction

Goals

- Acquire a thorough understanding of the out-of-plane behavior of steel MRF columns under cyclic loading
- Assess the current standard requirements
- Establish recommendations for the strength and stiffness of the out-of-plane stability bracing



Methodology

- Review of literature and standards
- Development of a FE analysis procedure validated against experimental data (use of ABAQUS 6.16 software)
- Generalization with a FE parametric study and comparison with standards

2. Standards

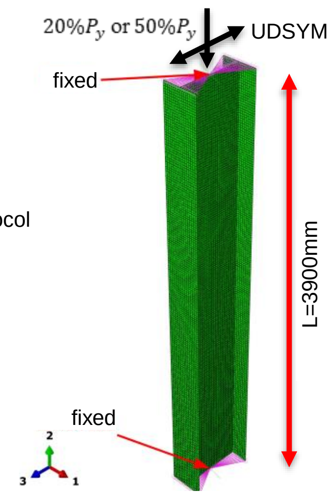
	SIA 263 (2013)	EN 1993-1-1 (2005)	CSA S16:19 (2019)	AISC-360-16 (2016)
Clauses	§4.2.3.7	§5.3.3(4) §6.3.5.2(5)B	§9.5 §9.6.2	§6.4(b)
Strength	$1\%N_{Ed}$	$1.5\%N_{Ed}$	$2\%N_{Rd}$	$1\%P_r + 2\%\frac{M_r C_d}{h_0}$
Stiffness	/	/	indirect	$\frac{1}{\phi}\frac{8P_r}{L_{br}} + \frac{1}{\phi}\frac{10M_r C_d}{L_{br} h_0}$

N_{Ed} : compression force in the column
N_{Rd} : compression strength of the column
P_r : required axial strength of the column
M_r : required flexural strength of the column
ϕ = 0.75 US design procedure (LRFD)
L_{br} : unbraced length of the column
h_0 : distance between flange centroids
C_d = 1.0 or 2.0 if beam is subject to double curvature bending

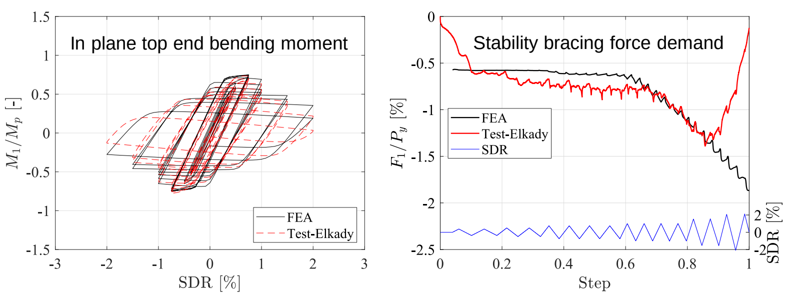
3. Finite element analysis – Validation

Validation against experimental data for 2 cases from Elkady (2012)

- Geometry cross section
  W24x146 equivalent to HEB600
- Boundary conditions
  perfectly **fixed-fixed**
- Loads
  Axial load **20%P_y or 50%P_y**
  In plane **unidirectional symmetric** protocol
- Material
  A992 Gr.50 equivalent to S355
  Voce-Chaboche constitutive law
- Geometric imperfections
  Local imperfections within limits from Elkady & Lignos (2018)
- Residual stresses
  Young's distribution (1971)
- Numerical parameters
  Shell elements **S4R**



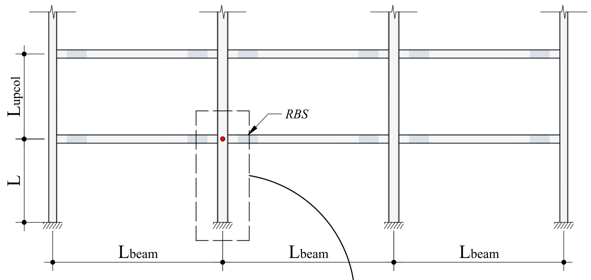
Results for the specimen with 50%P_y axial load



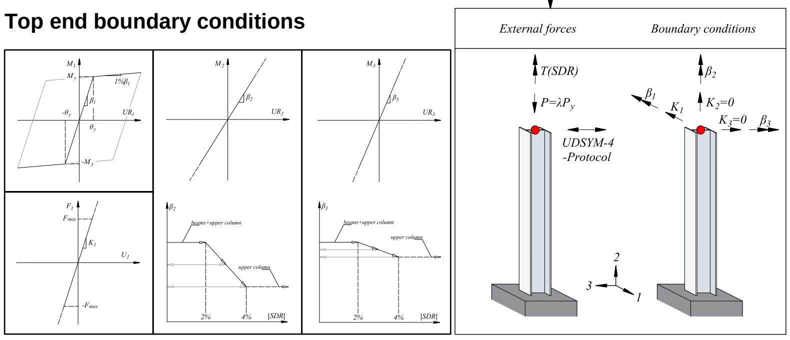
- Excellent match for the in-plane behavior
- Overall good match for the stability bracing force demand
  A shift is accounted for because of the out-of-straightness of the column
  Strong divergence in the last stage

4. Finite element analysis – Parametric study

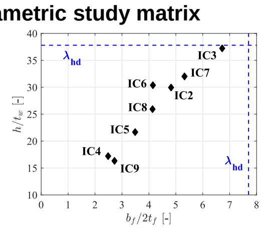
High-fidelity member-level modeling approach



Top end boundary conditions

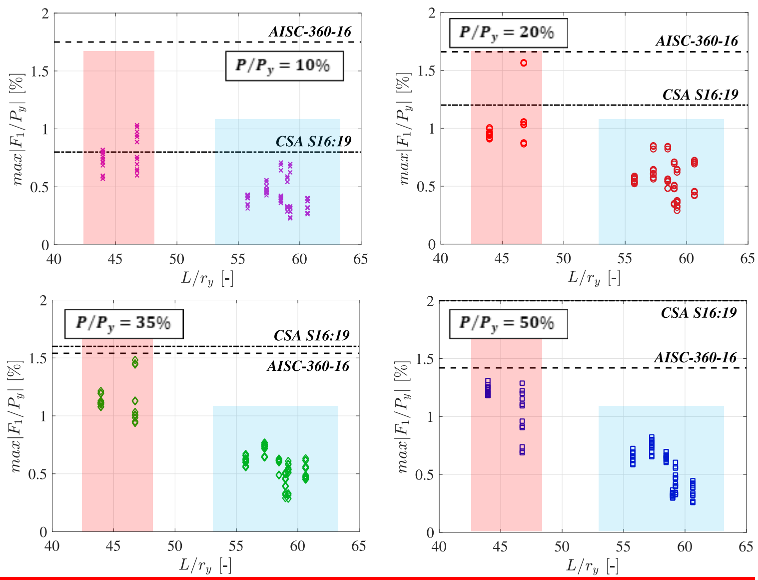


Parametric study matrix



Name		#
Cross section	IC2,…, IC9	8
Offset amplitude	A (L/100), B (L/250)	2
Geometric imp.	Positive, Negative	2
Axial load	10%,20%,35%,50%P_y	4
Brace stiffness	50%,100%,150%K_1	3

Results for the maximum stability bracing force demand



5. Conclusion

- Local geometric imperfections are fundamental to assess the stability bracing force demands
- Current standards are not satisfactory for stocky columns L/r_y<50
- Stability bracing force demands are independent of the level of axial load

Suggestions

- SIA 263 and EN 1993-1-1 : increase strength requirement to 2%P_y
- Other standards could adopt an approach similar to AISC-360-16 regarding the stiffness requirement (P_y is the yielding axial strength of the column)

6. References

- Elkady, A. and Lignos, D.G., "Full-Scale Testing of Deep Wide-Flange Steel Columns under Multiaxis Cyclic Loading: Loading Sequence, Boundary Effects and Lateral Stability Bracing Force demands", *Journal of Structural Engineering* 144.2 (2018). DOI: 10.1061/(ASCE) ST.1943-541X.0001937.
- Elkady, A. "Collapse risk assessment of steel moment resisting frames designed with deep wide-flange columns in seismic regions". PhD thesis. McGill University, (2016).