Residual stress influence on material properties and column behaviour of stainless steel SHS

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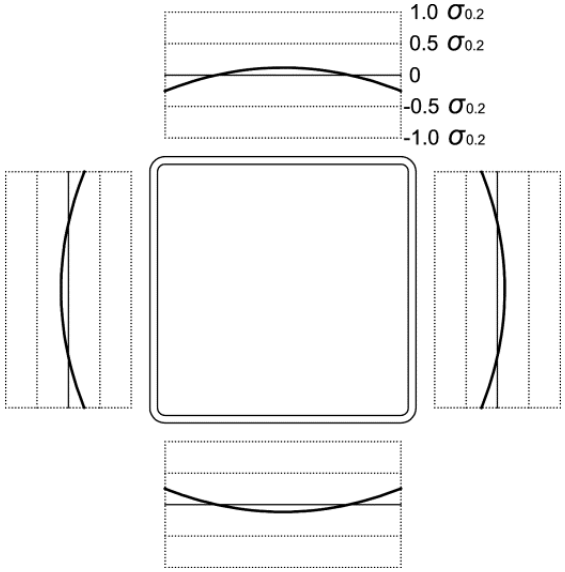
residual stresses:

- austenitic steel grade 1.4301
- cold-rolled SHS
- previous residual stress measurement
- numerical study:
  - FE model
    - influence of residual stresses on column behaviour including different degree of non-linearity
  - Analytical model
    - residual stress influence on material behaviour

residual stresses:

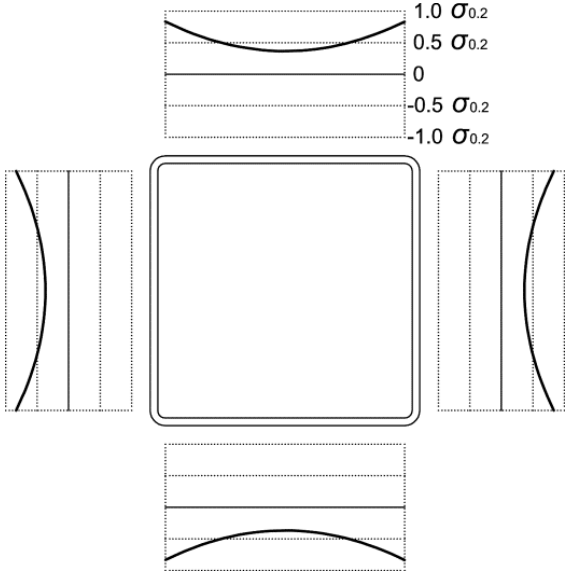
- X-ray diffraction method for through thickness stress pattern
  - rectangular block-like distribution of bending residual stresses
- sectioning method for residual stress pattern along sections

membrane component



$\sigma_m = (-0{,}253+1{,}483(x-x^2))\ \sigma_{0.2}$

longitudinal bending component



$\sigma_{b.pl} = (0{,}833+1{,}866(x-x^2))\ \sigma_{0.2}$

$\sigma_{b.pl.t} = -0{,}376\ \sigma_{0.2}$

column behaviour:

FE model in software Abaqus validated on experiments

1. parametric study of influence of residual stresses based on tested section SHS 120x120x4
   - measured material properties for flat and corner area
   - influence of residual stresses on global and local buckling separately
2. parametric study for material described by Ramberg-Osgood formula with varying hardening exponent *n*

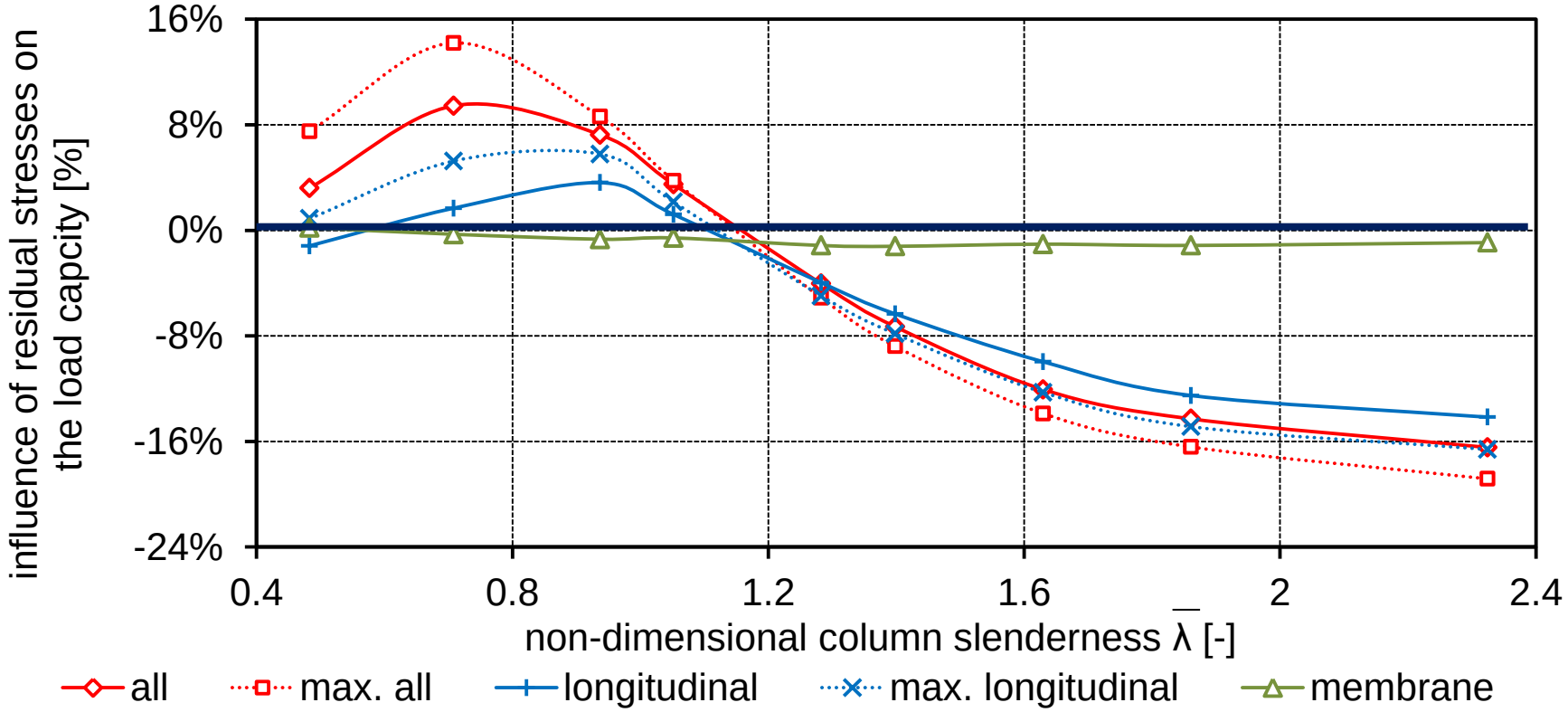
parametric study:

residual stresses introduced in five steps

- *Membrane:* longitudinal membrane stresses only
- Longitudinal: longitudinal membrane and bending stresses
- Max. longitudinal: longitudinal membrane and bending stresses (by the upper bound of the 95% predictive interval)
- All: longitudinal membrane and bending as well as transverse bending stresses
- Max. all: longitudinal membrane and bending stresses as well as transverse bending stresses, the longitudinal bending residual stresses (by the upper bound of the 95% predictive interval)

parametric study:

based on measured material properties - global stability



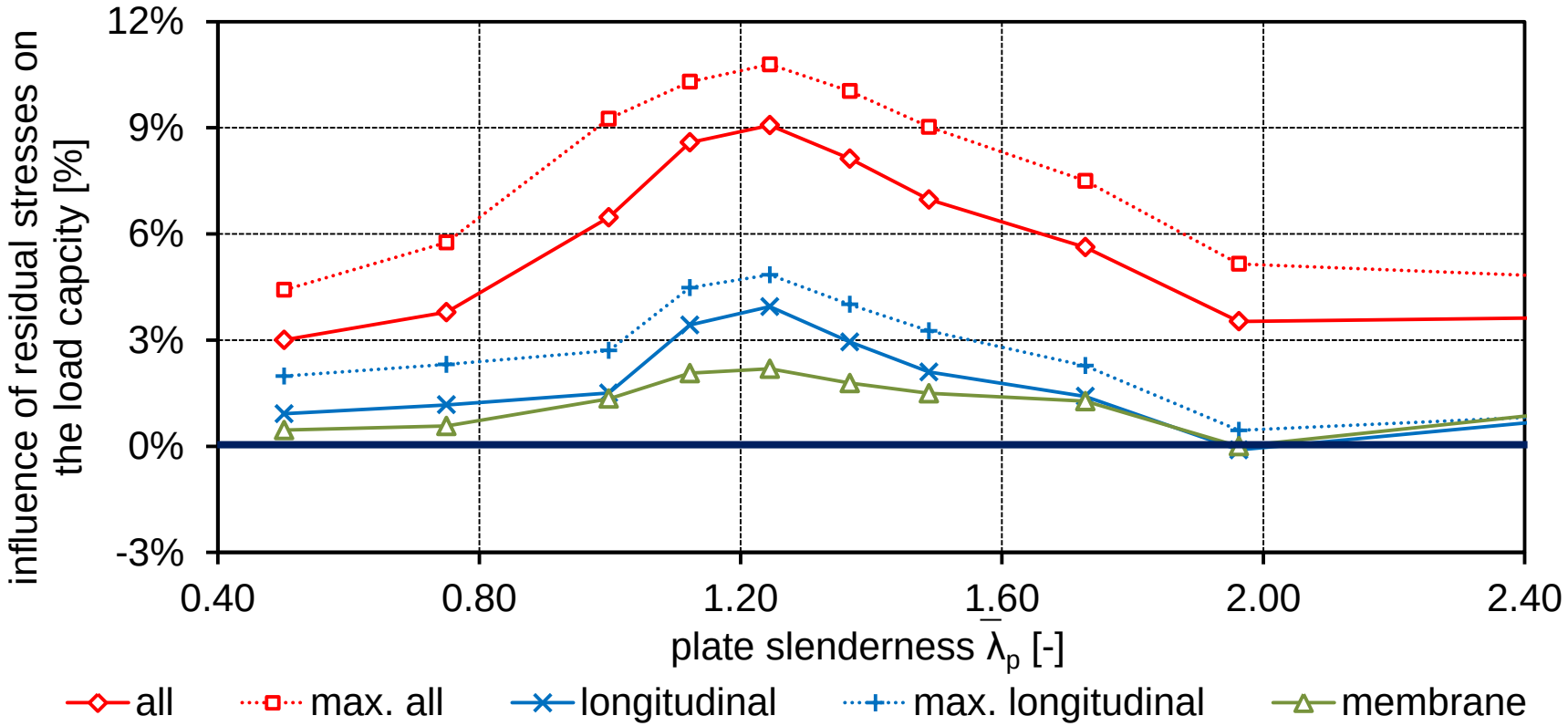
positive influence of residual stresses (up to 10 %) for middle slenderness

negative influence (up to -16 %) for very slender columns

membrane residual stresses not significant

parametric study:

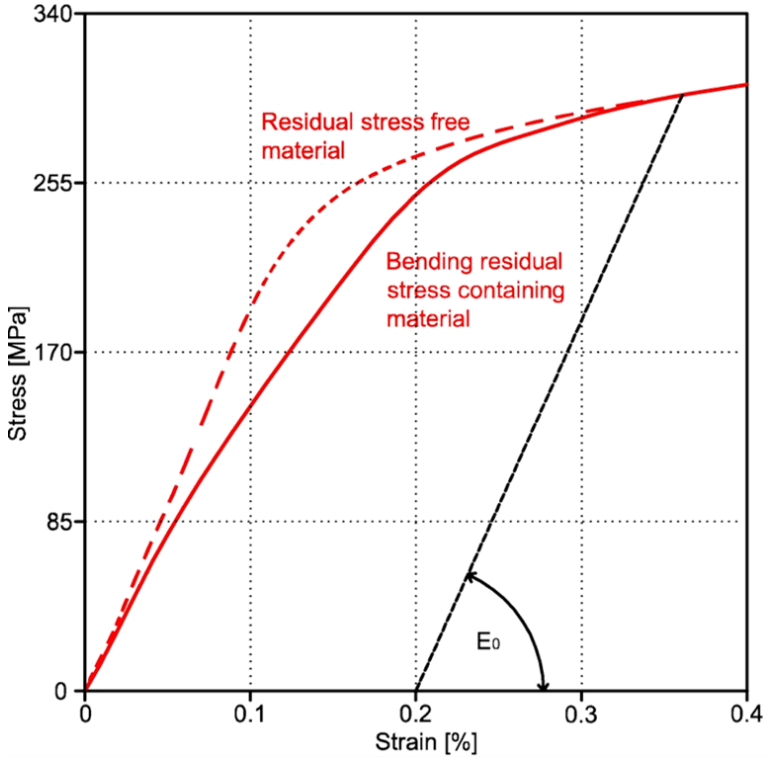
based on measured material properties - local stability

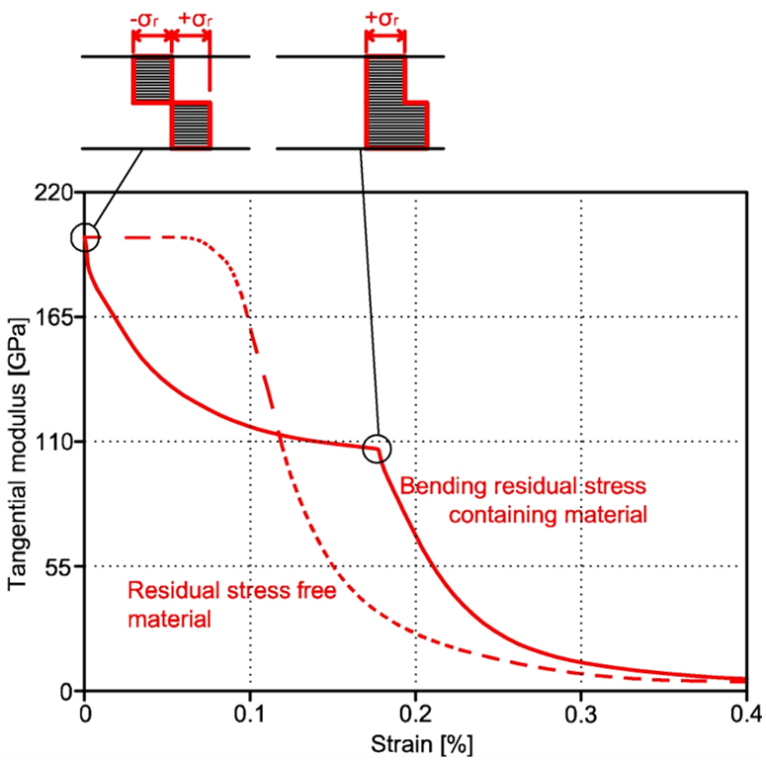


always positive influence of residual stresses (up to 9 %)

parametric study:

influence of bending residual stresses on the stress-strain diagram

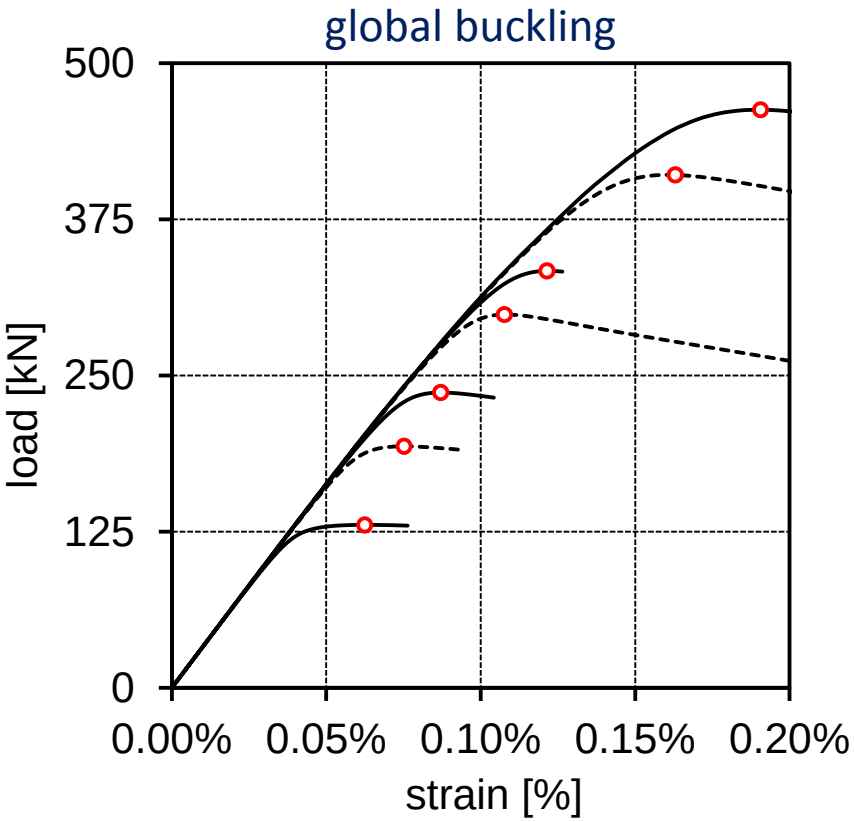




change of the material non-linearity due to the presence of bending residual stress

tangential modulus of elasticity increased for some region

parametric study:
local buckling – the collapse strain



non-dimensional slenderness $\bar{\lambda}$:

0.94 ----- 1.05 —— 1.28 ----- 1.40

1.63 ----- 1.86 —— 2.32

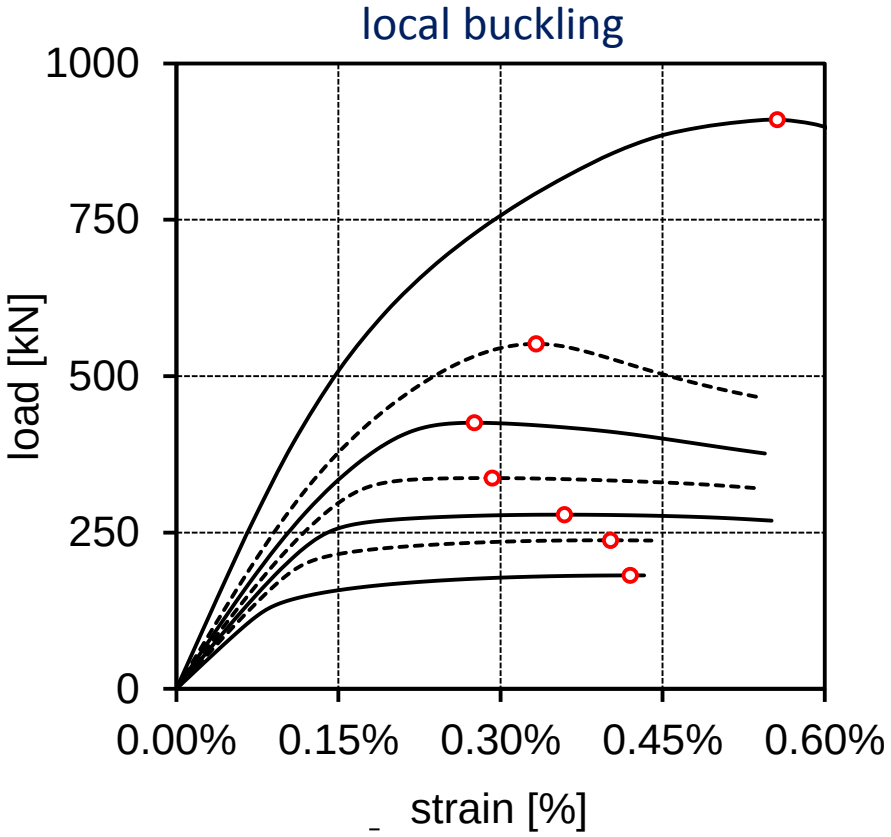


plate slenderness $\bar{\lambda}_p$:

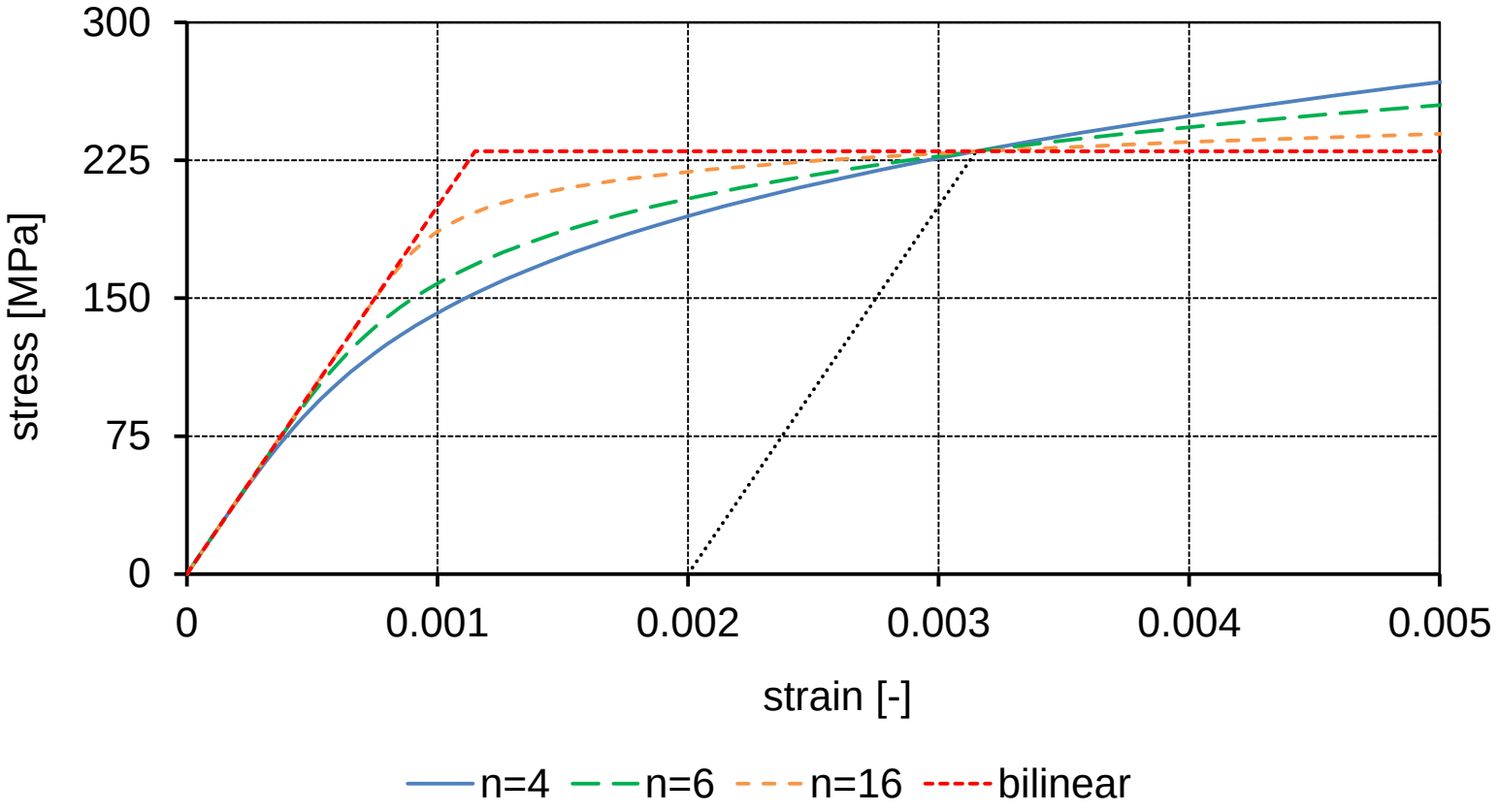
0.75 ----- 1.00 —— 1.12 ----- 1.24

1.37 ----- 1.49 —— 1.73

parametric study:

based on Ramberg-Osgood formula - four different diagrams

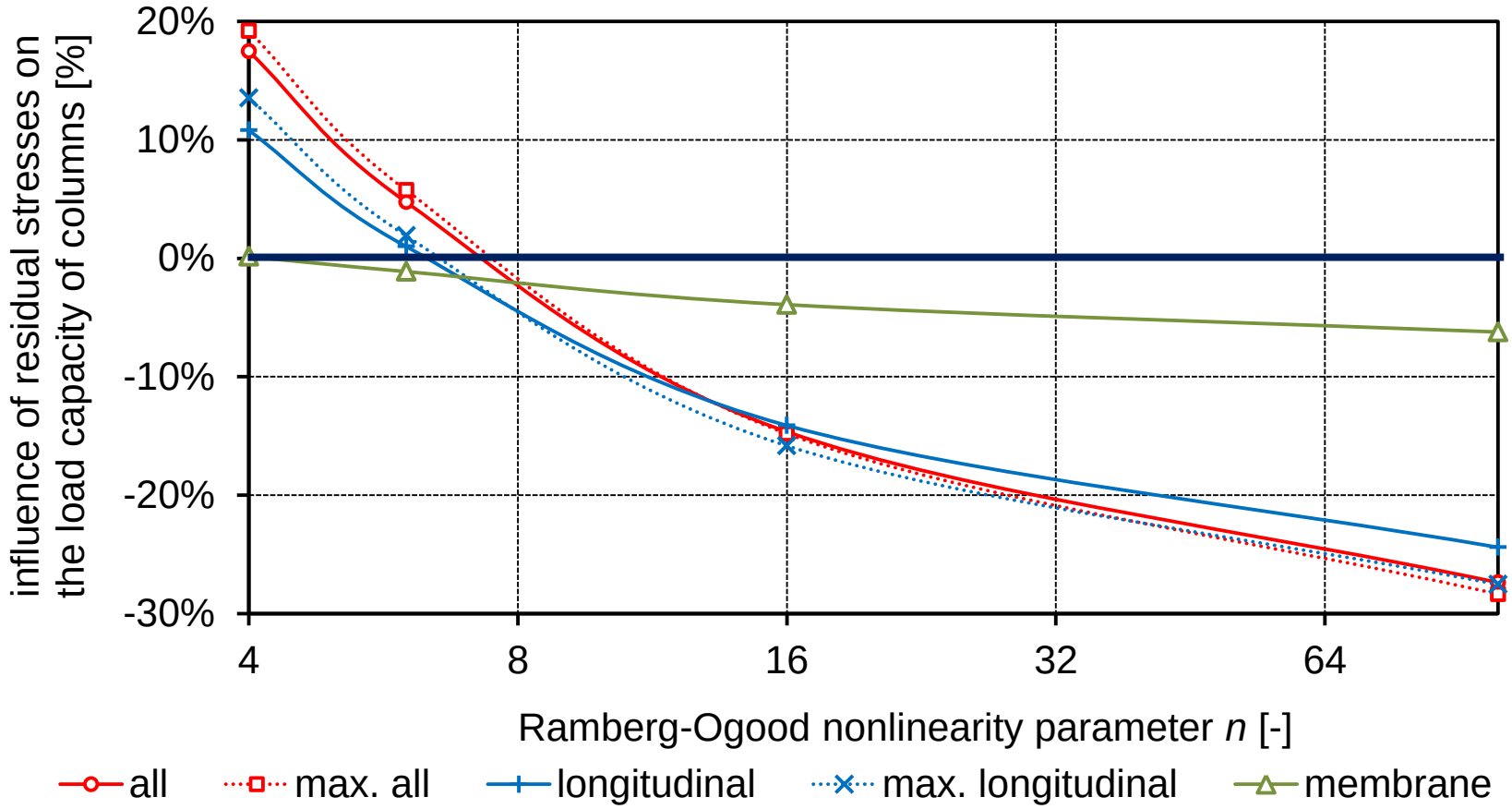
n = 4, n = 6, n = 16, bilinear



parametric study:

global stability, varying Ramberg-Osgood parameter

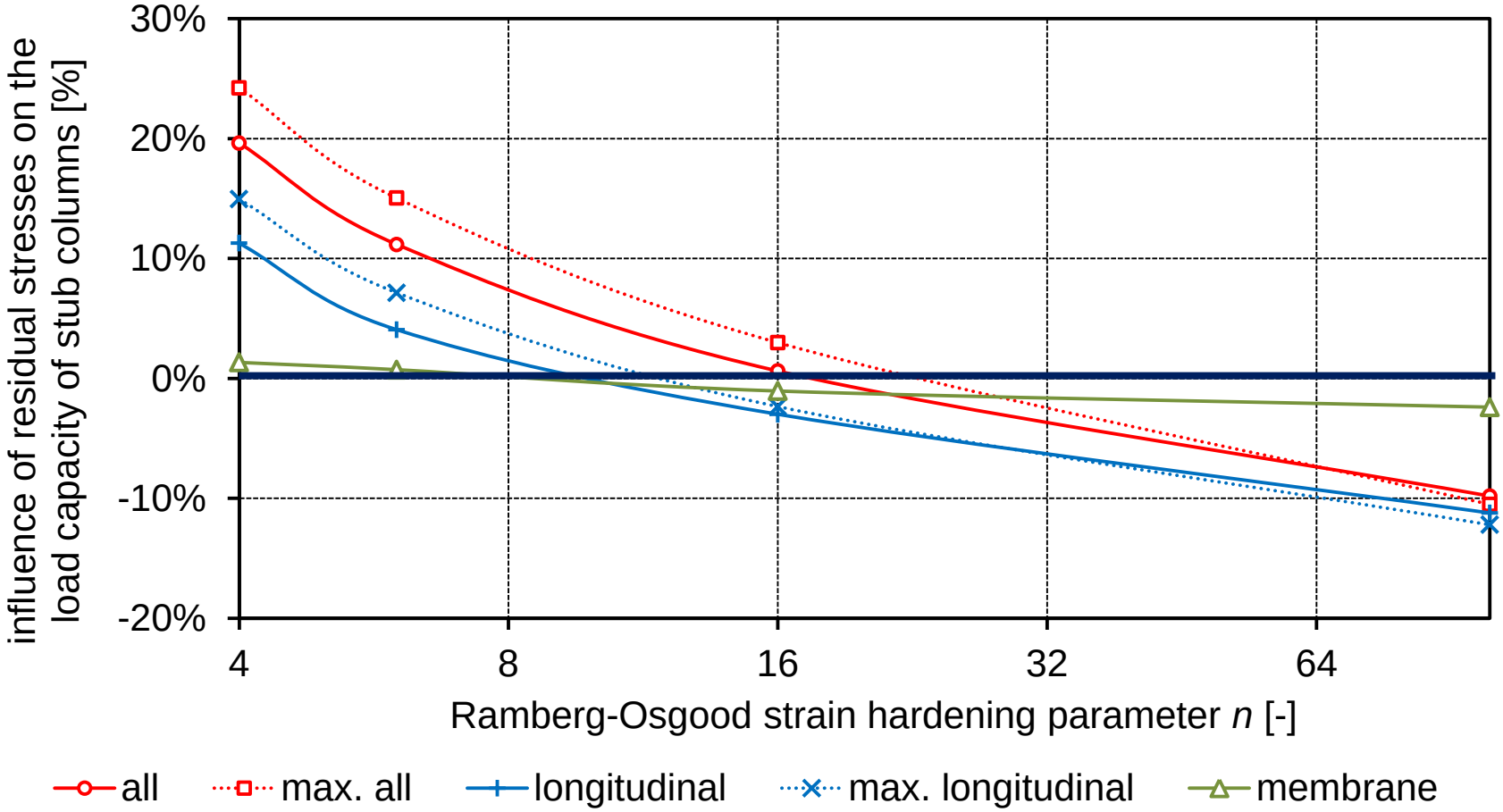
non-dimensional column slenderness 1.0



parametric study:

local buckling, varying Ramberg-Osgood parameter

non-dimensional plate slenderness 1.0



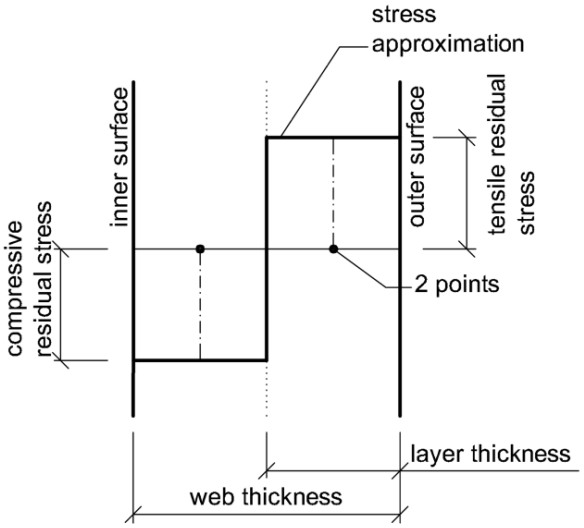
material behaviour:

analytical model of tensile coupon test

– calibrated on tests of coupons taken form web centre of SHS 100x100x3 and SHS 120x120x4 / as delivered and stress relieved (annealed) material tested

Specimen	E_0 [GPa]	$\sigma_{0.2}$ [MPa]	$\sigma_{1.0}$ [MPa]	σ_u [MPa]	n [-]	$n^{0.2,1.0}$ [-]
100×100×3-F	205.8	417	457	753	7.1	2.3
100×100×3-FA*	211.5	429	456	753	13.4	1.5
120×120×4-F	192.0	429	479	783	4.3	2.7
120×120×4-FA*	205.5	405	441	762	8.1	2.1

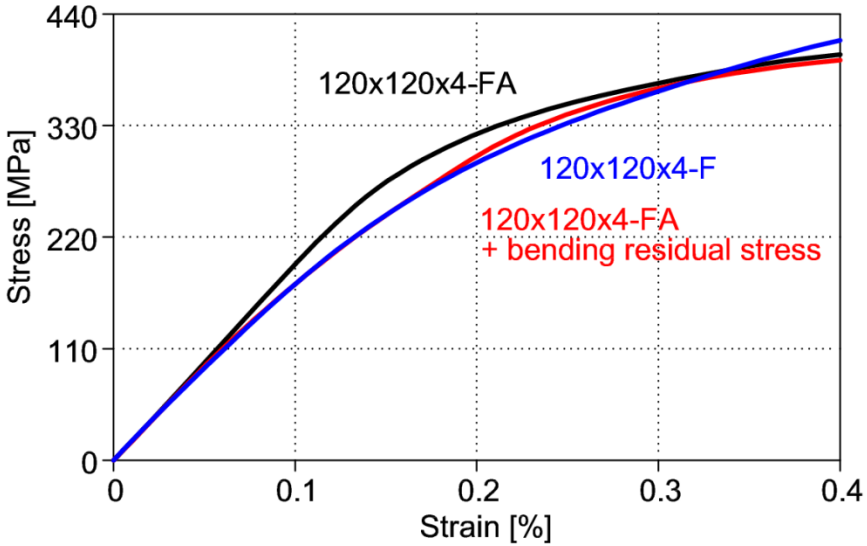
* Stress relieved specimen

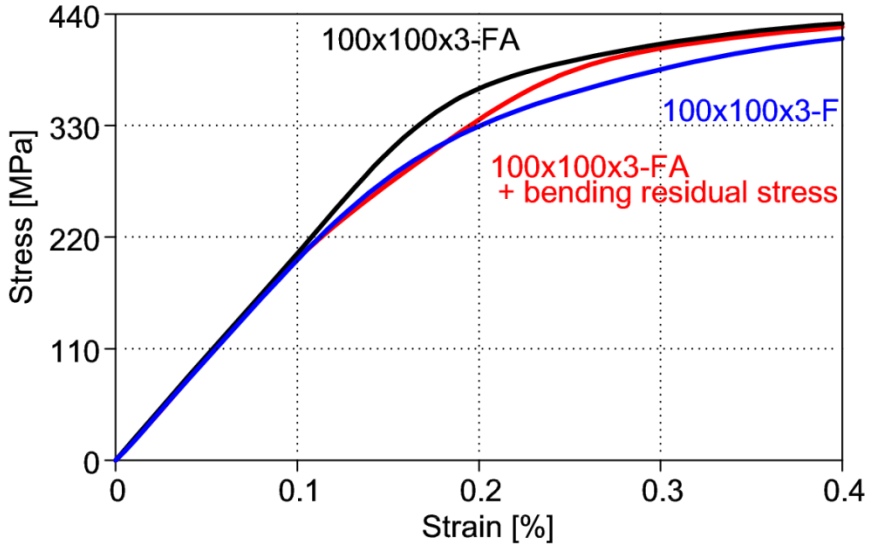


– measured longitudinal bending stress included
for SHS 100x100x3: $\sigma_{b.pl} = 0.354 * \sigma_{0.2} = 0.354 * 416.5 = 147.4$ MPa
for SHS 120x120x4: $\sigma_{b.pl} = 0.380 * \sigma_{0.2} = 0.380 * 429.0 = 163.0$ MPa

analytical model:

analytical model of tensile coupon test





presence of residual stress:

- increase in non-linearity
- slight decrease in the initial modulus of elasticity

conclusions:

- membrane residual stresses may be generally neglected
- bending residual stresses have a significant influence on material nonlinearity (resp. tangential modulus)
- for cold-worked stainless steels the influence of residual stresses on the load capacity ranges:

  +10 to -16 % for elements subjected to global buckling

  up to +9 % for elements subjected to local buckling
- in material behaviour approximated by bilinear stress-strain diagram the same residual stress pattern has a negative influence on the load capacity
- bending residual stress may be considered by increased non-linearity

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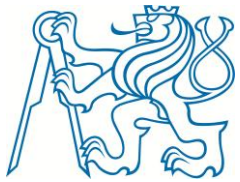

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