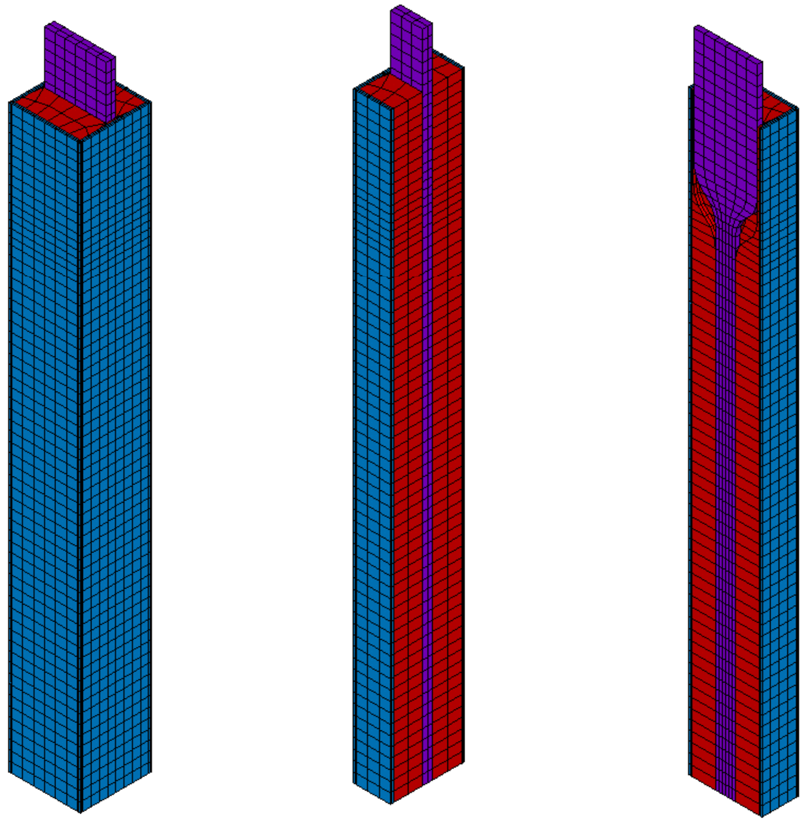
Chaboche-based Cyclic Material Model for Steel and Its Numerical Application

- 9th fib International PhD Symposium in Civil Engineering -



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Introduction

The global ductility of seismic resistant framed structure is very important in the seismic design --- it depends on the local behaviour of structural elements and joints:

Braced frame, bridges, NLD device

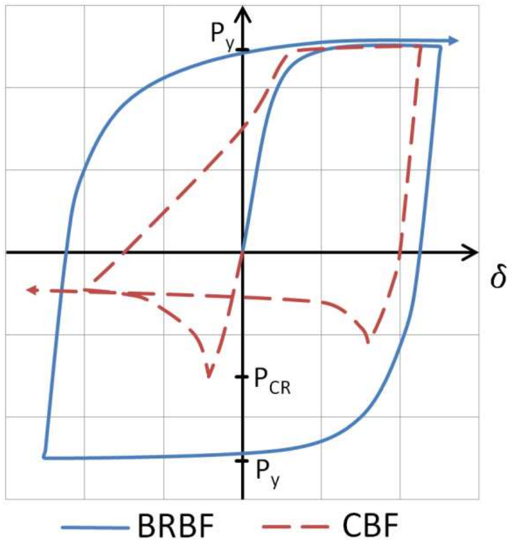
Steel core: elastic and plastic part – energy dissipation

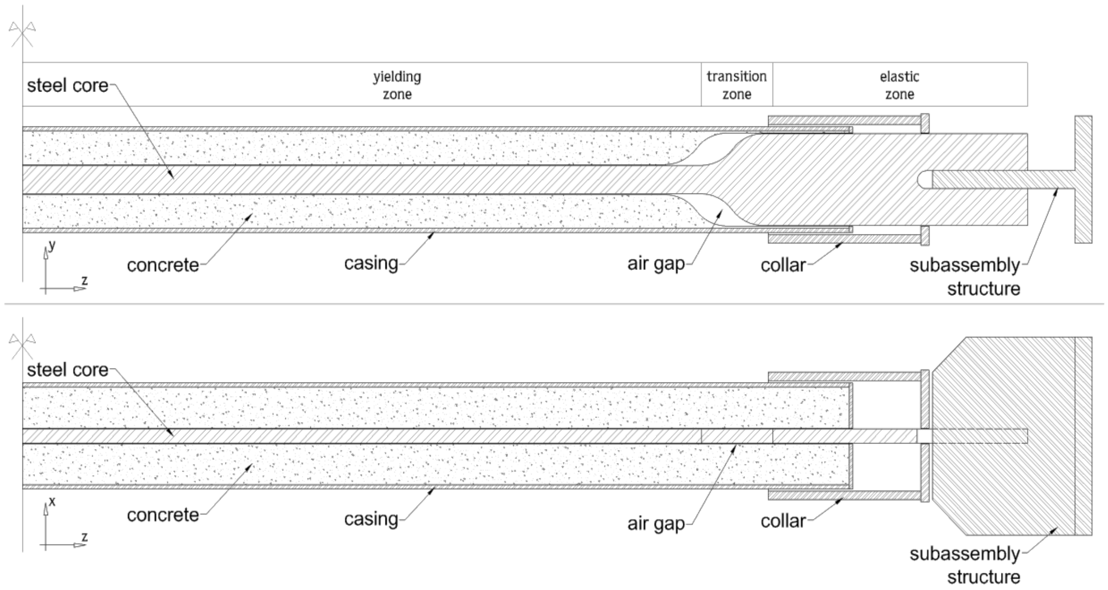
Concrete & Steel casing: continuously supporting

Numerical model for dissipative steel devices – Buckling Restrained Brace

Between: air gap, lubricant

No cyclic degradation, effective plastic energy dissipation





Aims

The developed numerical BRB moedel has to take in consideration the following parts

- cyclic plastic model of steel material
- cyclic buckling phenomena
- contact problem
- friction of steel on concrete

Investigation of special cyclic phenomena of BRB

- increased resistance at compression loading
- effect of friction conditions
- distribution of strain

Long-range aims

- reliable numerical model
- numerical tests of BRB
- developing BRB devices

Development of material model

Numerical model for dissipative steel devices – Buckling Restrained Brace.

- cyclic plastic model of steel material
- cyclic buckling phenomena
- contact problem
- friction of steel on concrete

First step: modeling cyclic steel material behaviour

- cyclic steel material behaviour is very complex
- many numerical material model for steel
- 1.) not describes all the cyclic phenomena
- 2.) useable numerical application is missing

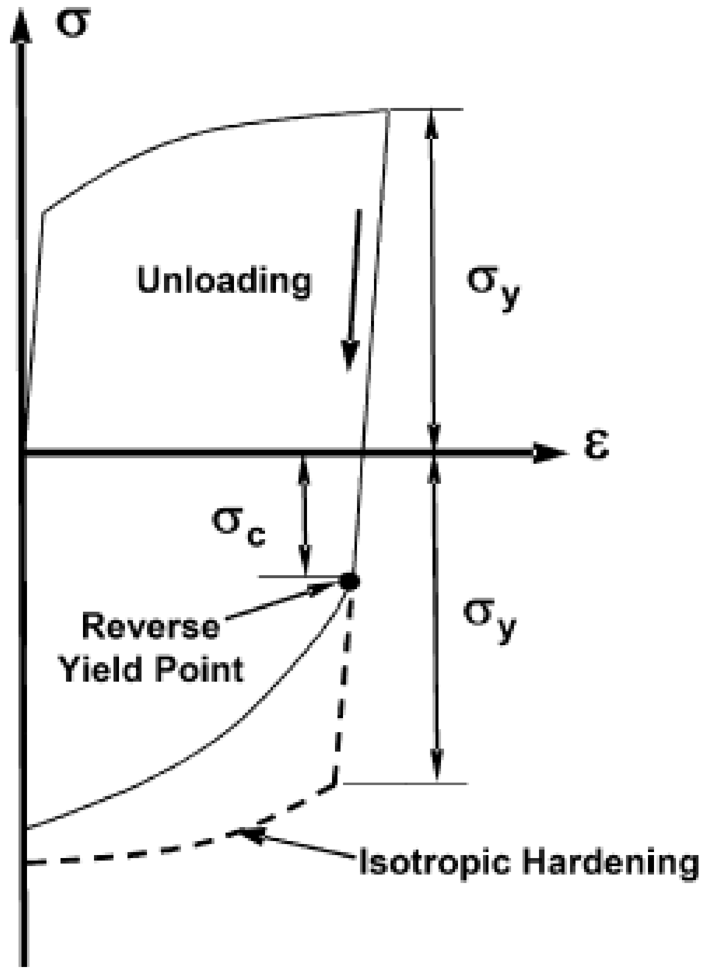
→ **Develop an efficient material model**
Implement it an final element program

- accuracy, convergence, computational time

Physical features

Most important physical phenomena:

- Bauschinger effect



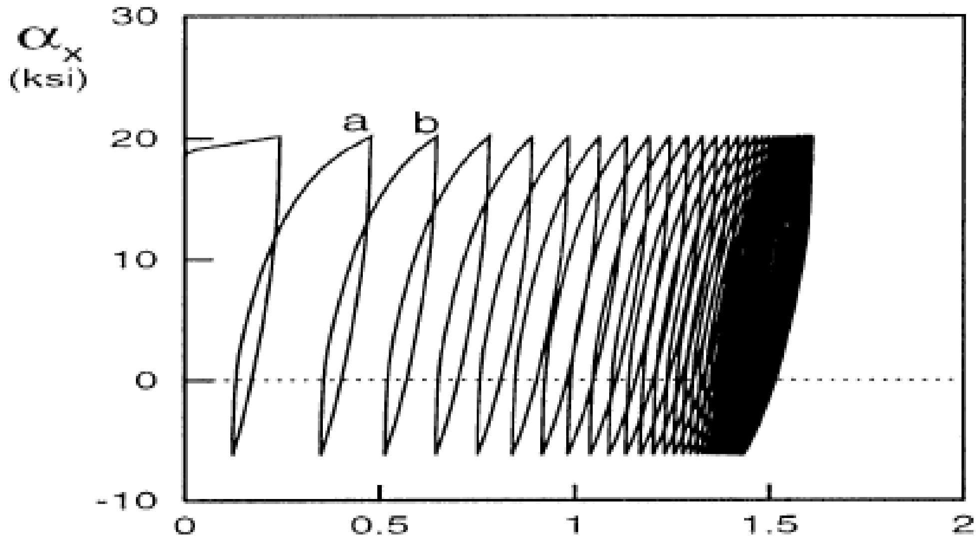
When the steel material subjected to plastic loading then the loading turns in the opposite direction, the yield strength under compression is reduced.

Physical features

Most important physical phenomena:

- Bauschinger effect
- Racheting effect

At non-symmetrical stress controlled loading, the plastic strain increases from cyclic to cyclic.



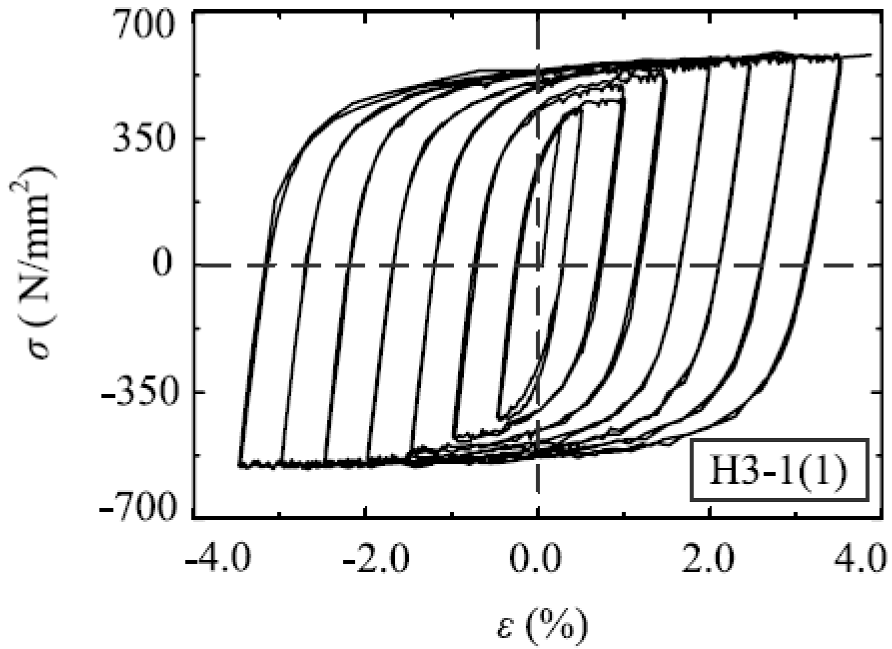
(a)

Physical features

Most important physical phenomena:

- Bauschinger effect
- Racheting effect
- Combined hardening

The yielding surface the yield surface dominantly moves with some expansion.

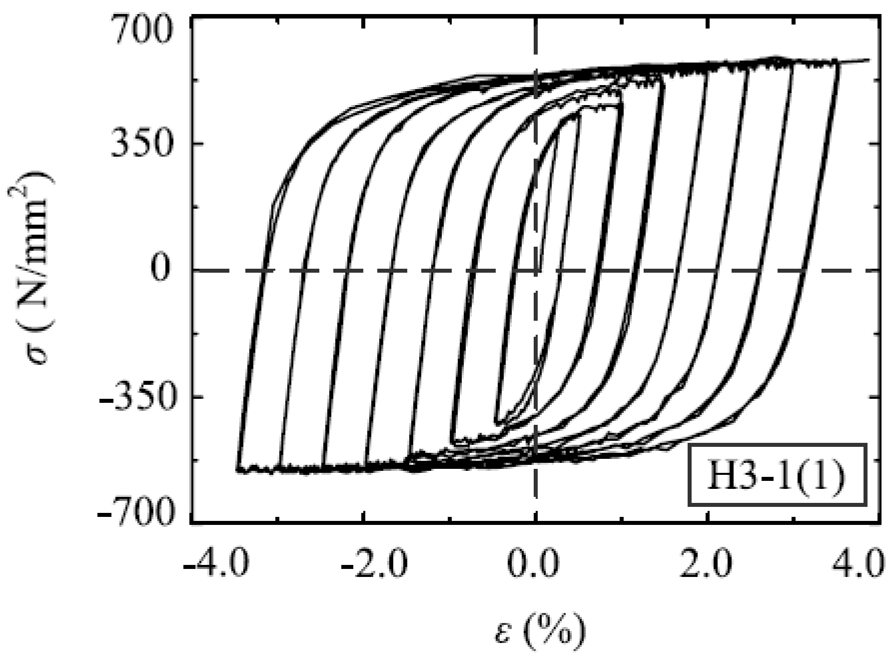


Physical features

Most important physical phenomena:

- Bauschinger effect
- Racheting effect
- Combined hardening
- Hardening memory effect

The stress-strain relationship does not depend only on the accumulated plastic strain, but the previous load history is also important.

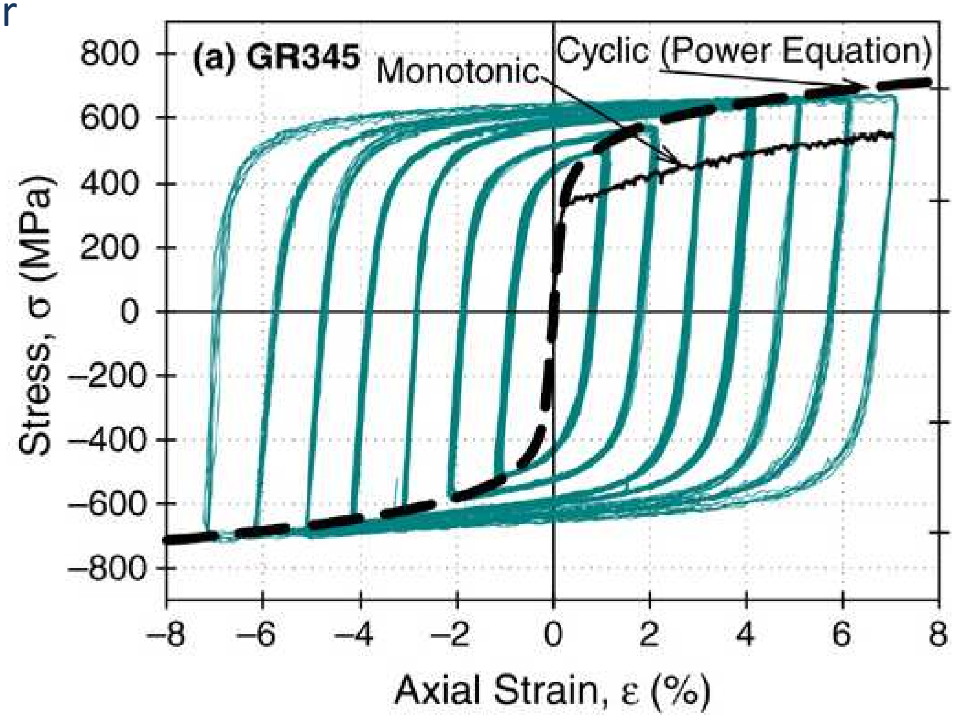


Physical features

Most important physical phenomena:

- Bauschinger effect
- Racheting effect
- Combined hardening
- Hardening memory effect
- Different monotonic and cyclic behaviour

The initial yield stress range is reduced to approximately 50-70% for structural steel. Furthermore as crystal slipping increases, the Bauschinger effect saturates and the yielding plateau gradually disappears.



Chaboche model

- nonlinear kinematic hardening model
- loading and limit surface
- two parameters: initial hardening modulus (C)
  nonlinear recall parameter (γ)

- possible to combine several simple Chaboche model
- possible to superpose with isotropic hardening

	Simple Chaboche	Combined Chaboche+ isotropic	PRESCOM
Bauschinger effect	+	+	+
Racheting effect	+	+	+
Combined hardening	-	+	+
Hardening memory effect	-	-	+
Different monotonic and cyclic behaviour	-	-	+

PRESCOM material model

Parameter Refreshed and Strain Controlled combined Chaboche Model with isotropic hardening

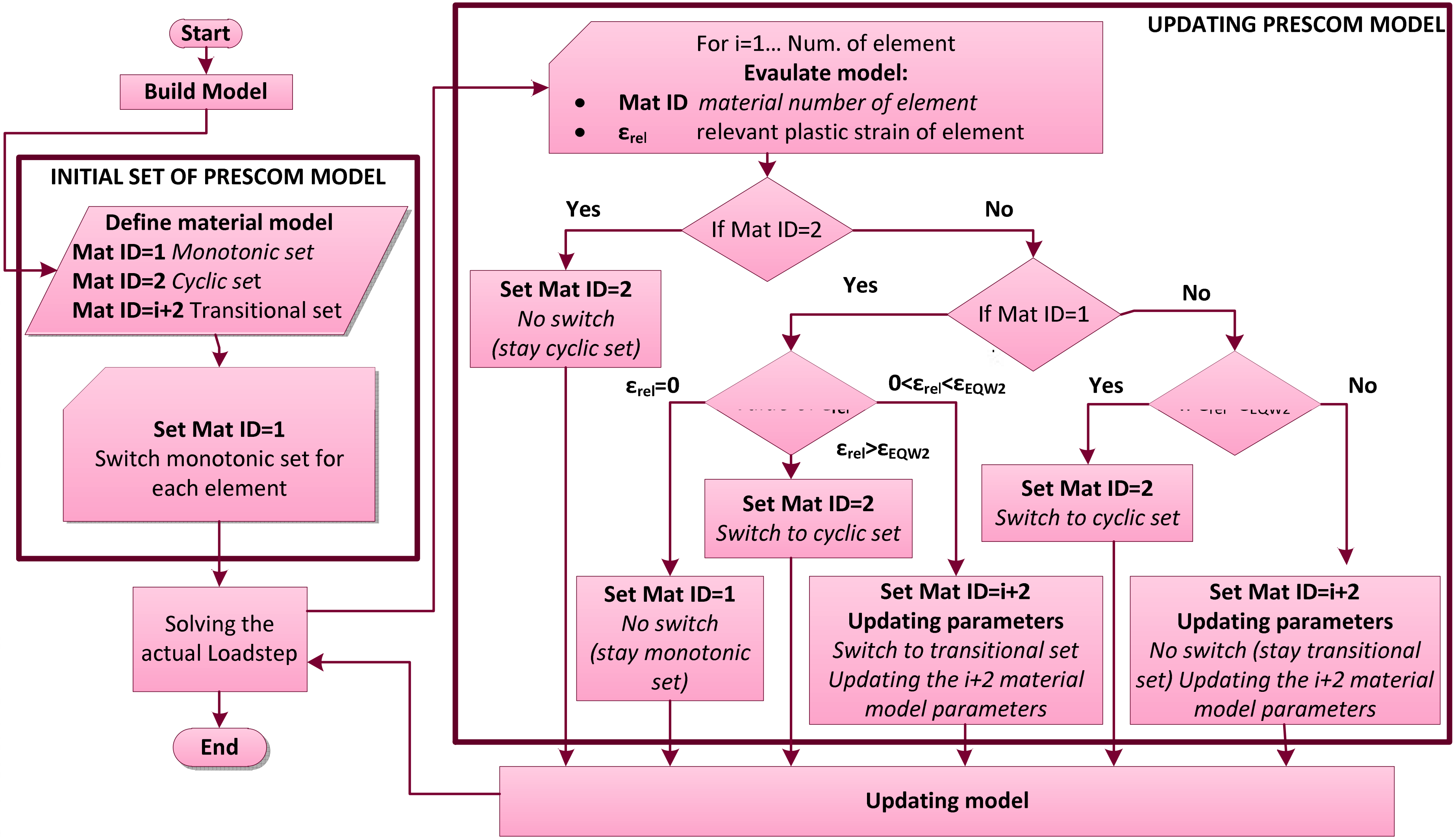
→ Superposition of five simple Chaboche model and combination of multi-linear isotropic hardening

→ **Monotonic set**
Cyclic set
Transitional set

change in the function of relevant plastic strain

$$\varepsilon_{RPL} = \max(\varepsilon_{EQW}, dp_{MAX})$$

Dynamic parameter calculation



Dynamic parameter calculation

#1 Chaboche modell: $\gamma_1 = \frac{\beta}{\varepsilon_{RPL}} \qquad C_1 = \gamma_1 \sigma_\Delta$

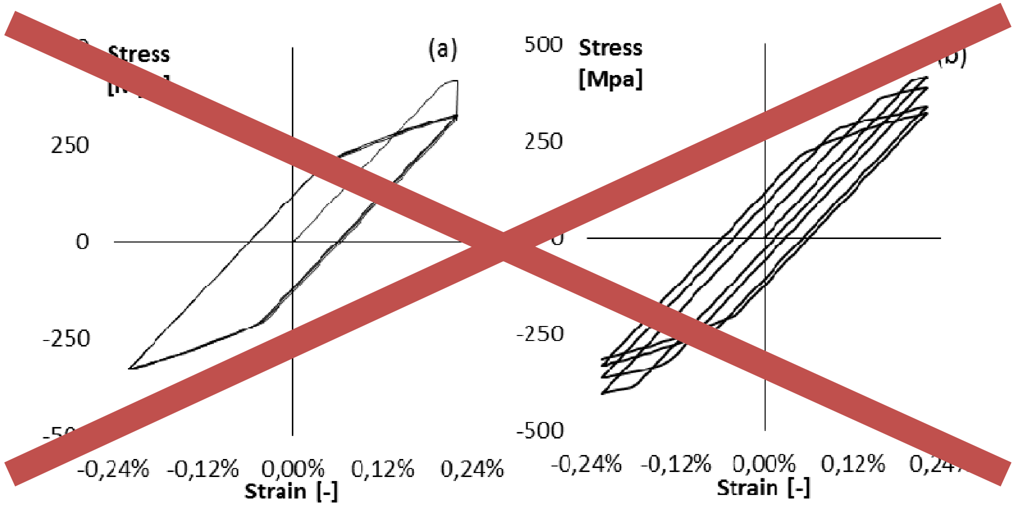
#2, 3 Chaboche modell: $C_i = \left(\frac{\varepsilon_{RPL}}{\varepsilon_{EQW2}} \right)^\alpha C^0{}_i$ where α=1.5

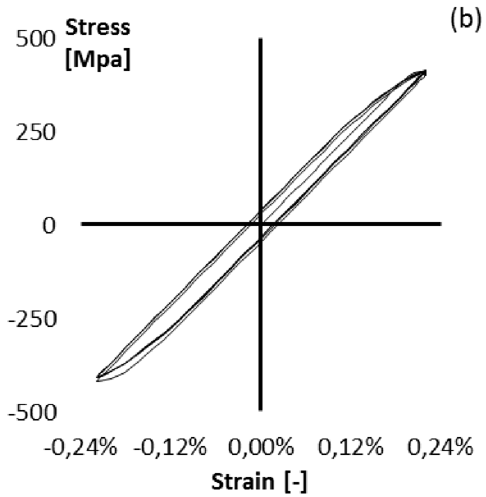
#5 Chaboche modell: $C_5 = C^0{}_5 \left(\alpha_L - \frac{\varepsilon_{RPL}}{\varepsilon_{EQW2}} \right)$ where α_L=2

Results

Effect of parameter updating

- Five Chaboche models and multilinear isotropic hardening

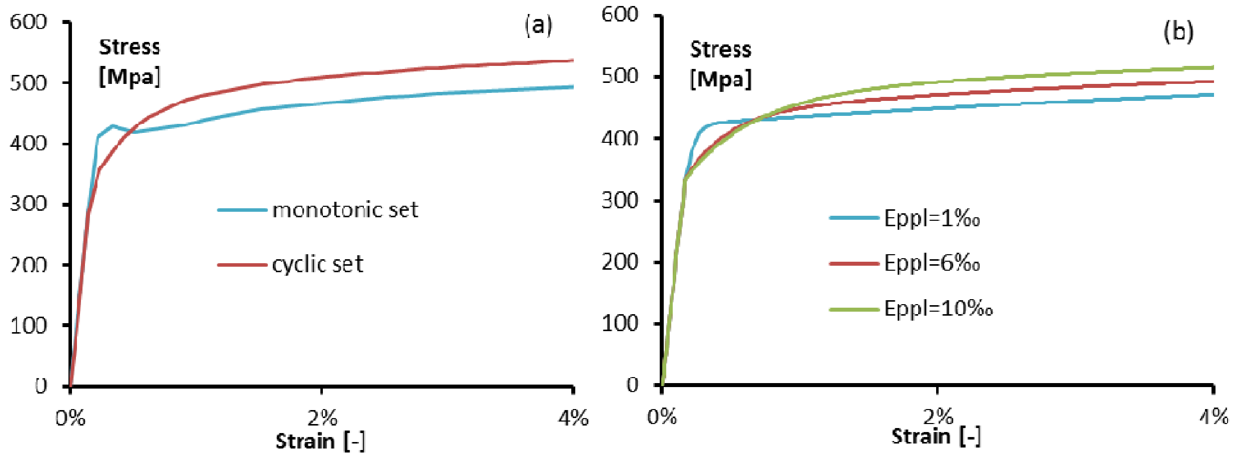




- only two parameter set
- do not use dynamic parameter calculation
- approximation of PRESCOM model

Results

Monotonic results

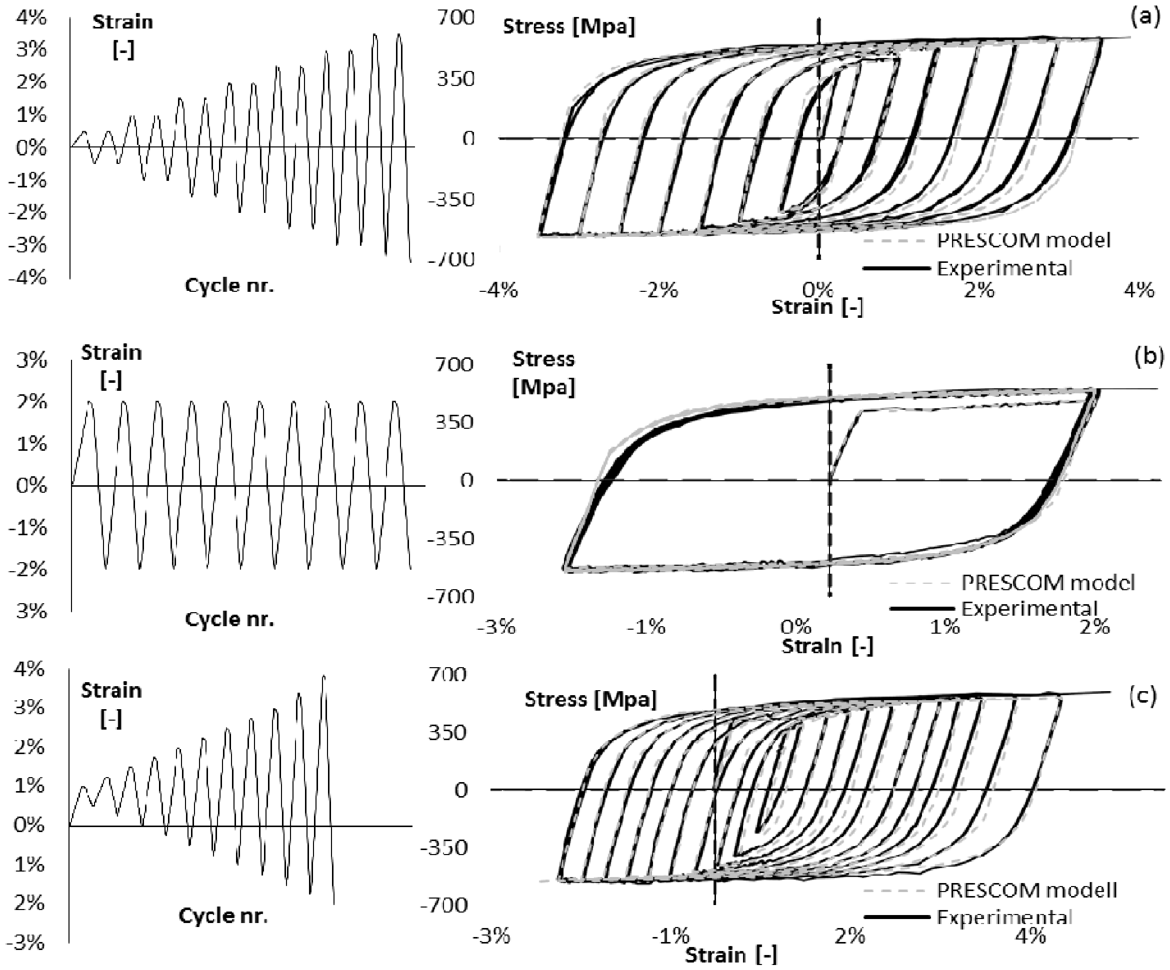


Monotonic steel behaviour depends on the previous loading conditions (depends on the relevant plastic strain)

The updating of model parameters causes correct transition between pure monotonic and cyclic behaviour.

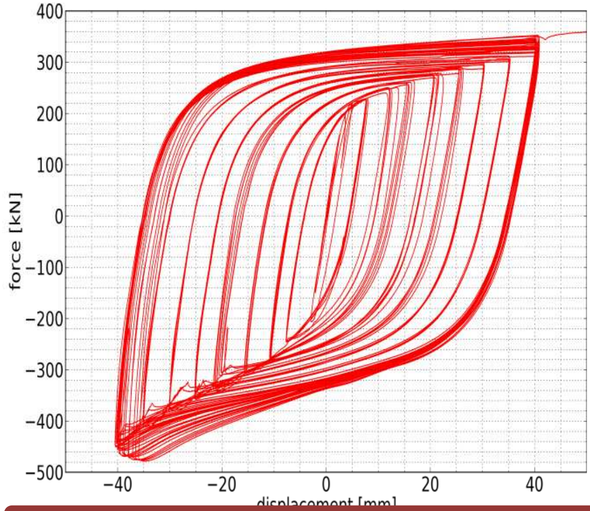
Results

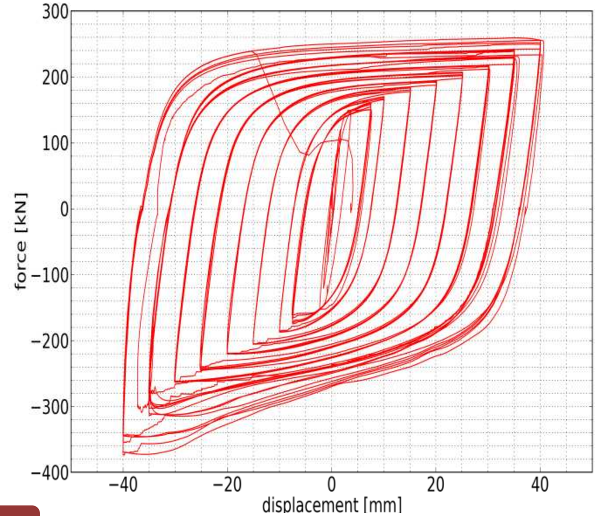
Cyclic results

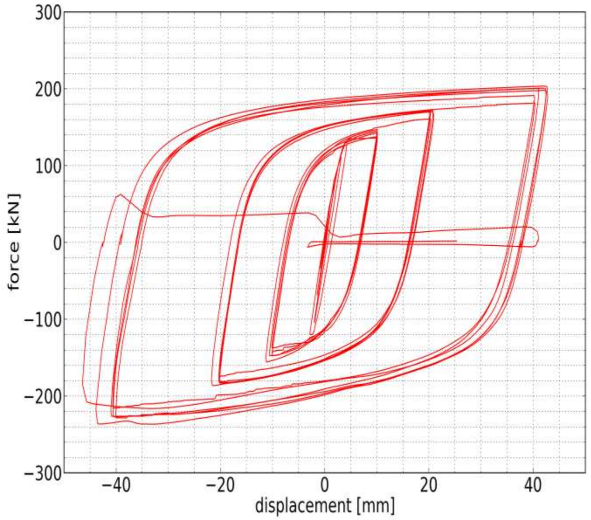


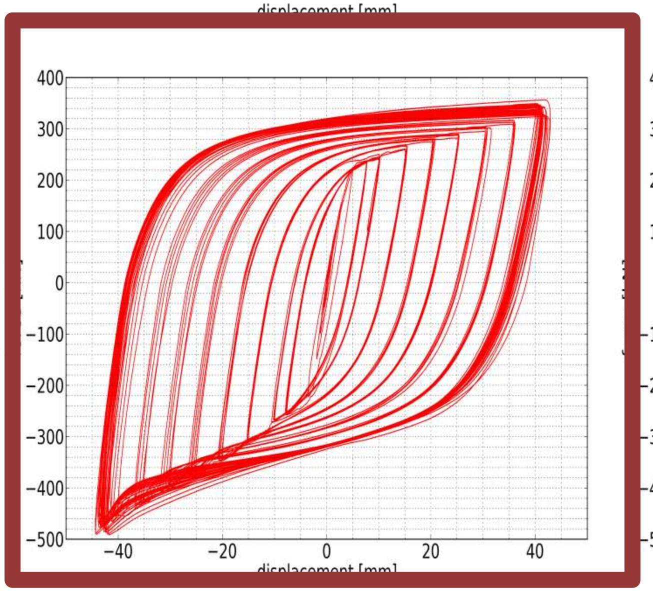
Numerical BRB model

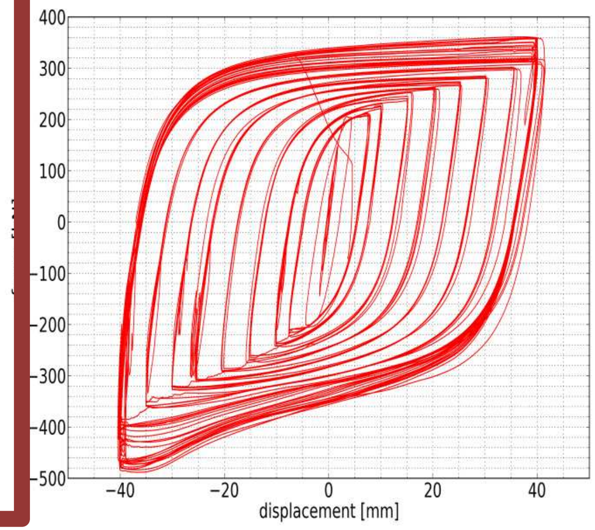
European WildCat (EWC 800)
- steel core area: 20x40
- lab work:
  Dep. of Structural Eng.



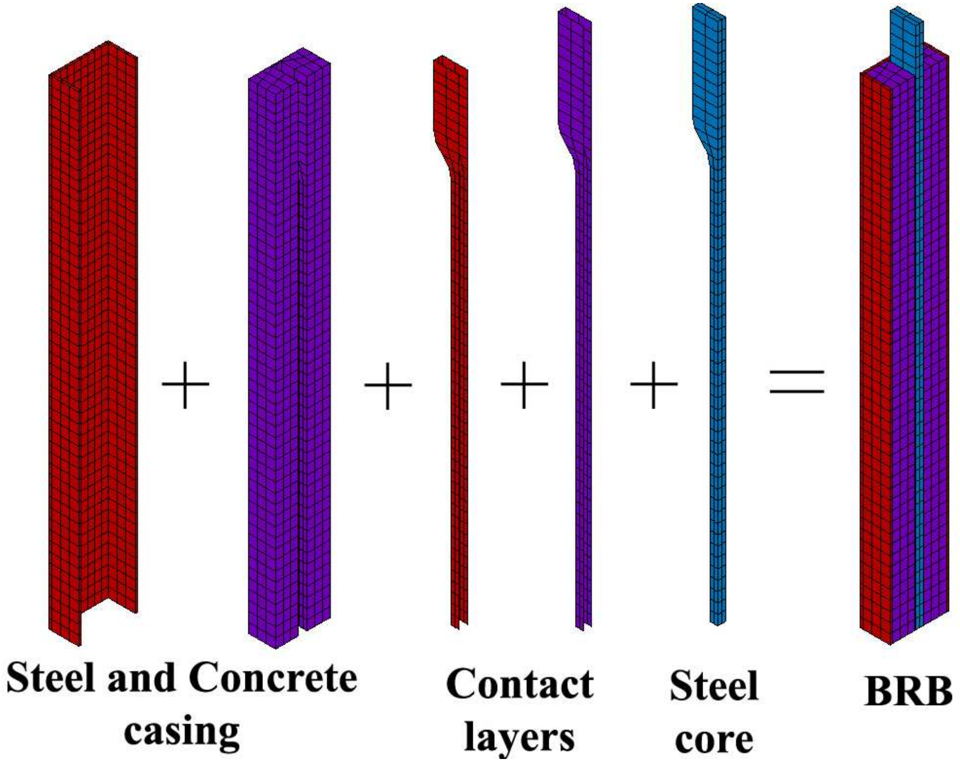








Numerical BRB model



Steel section
Linear elastic (E=210 GPa, v=0.3)
Solid 186 element
Element size: 25mm

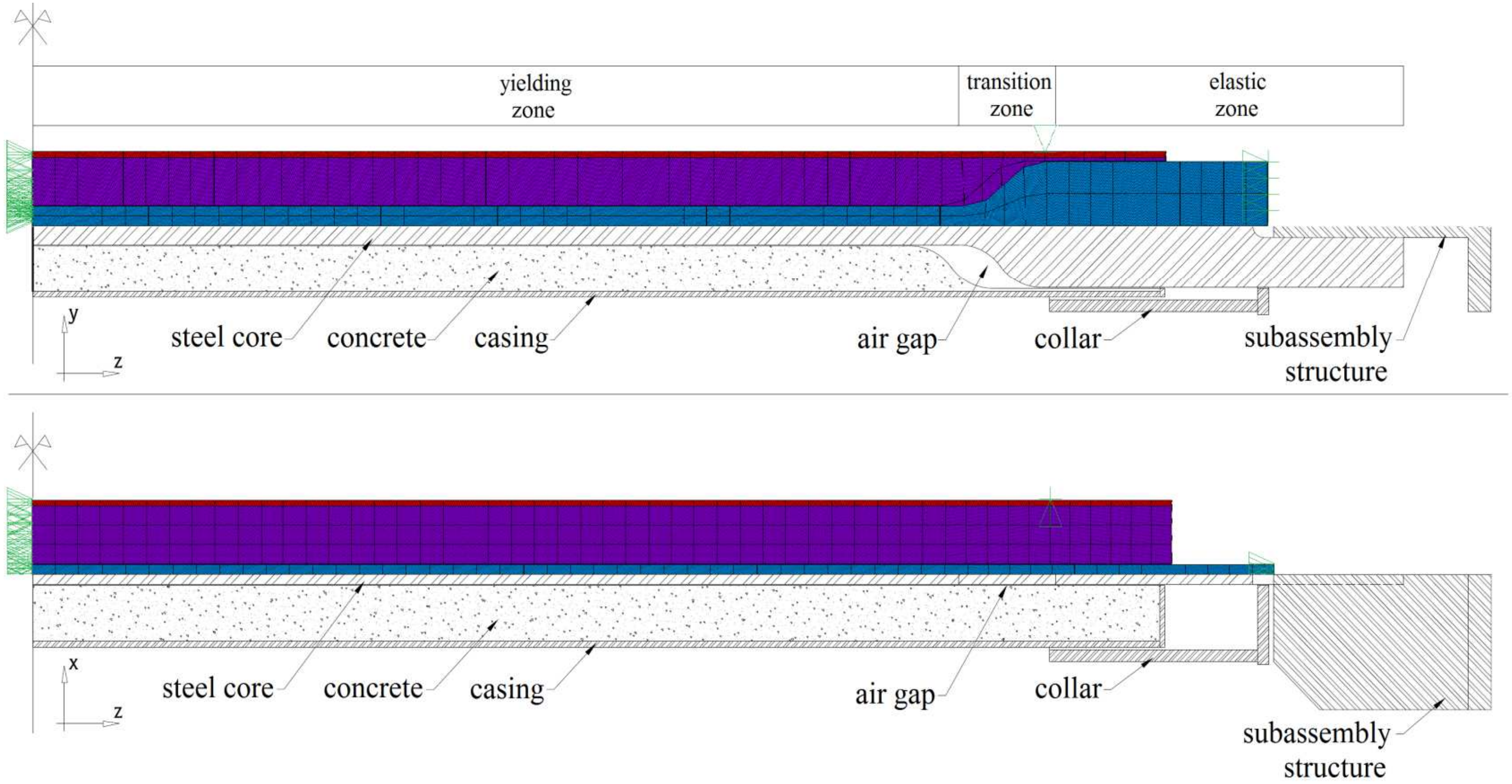
Concrete
Linear elastic (E=21 GPa, v=0.18)
Solid 186 element
Element size: 20-40mm

Steel core
Combined material model (PRESCOM)
Solid 186 element
Element size : 10-40mm

Modelling contact problem
Conta 174 + Target 170

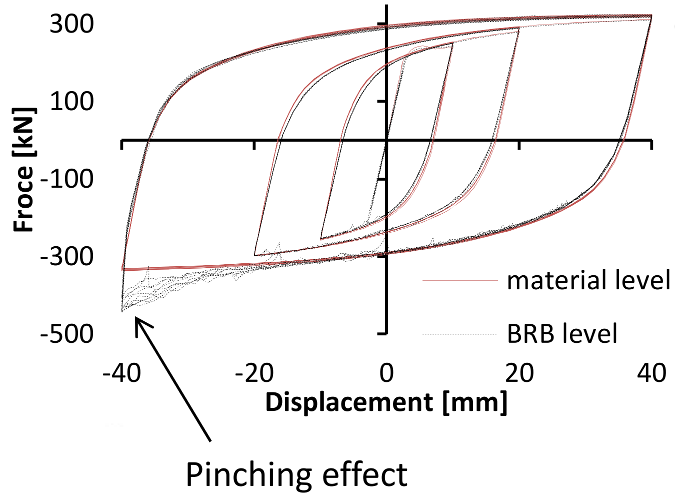
Boundary Condition

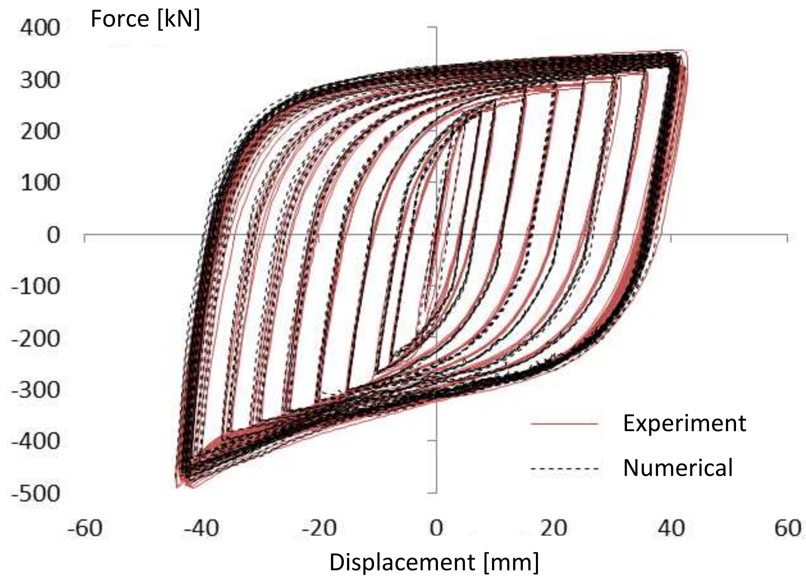
- Symmetry boundary condition
- Loading: displacement controlled quasi-static
- Model: degree of freedom 34446, total number of element: 2640



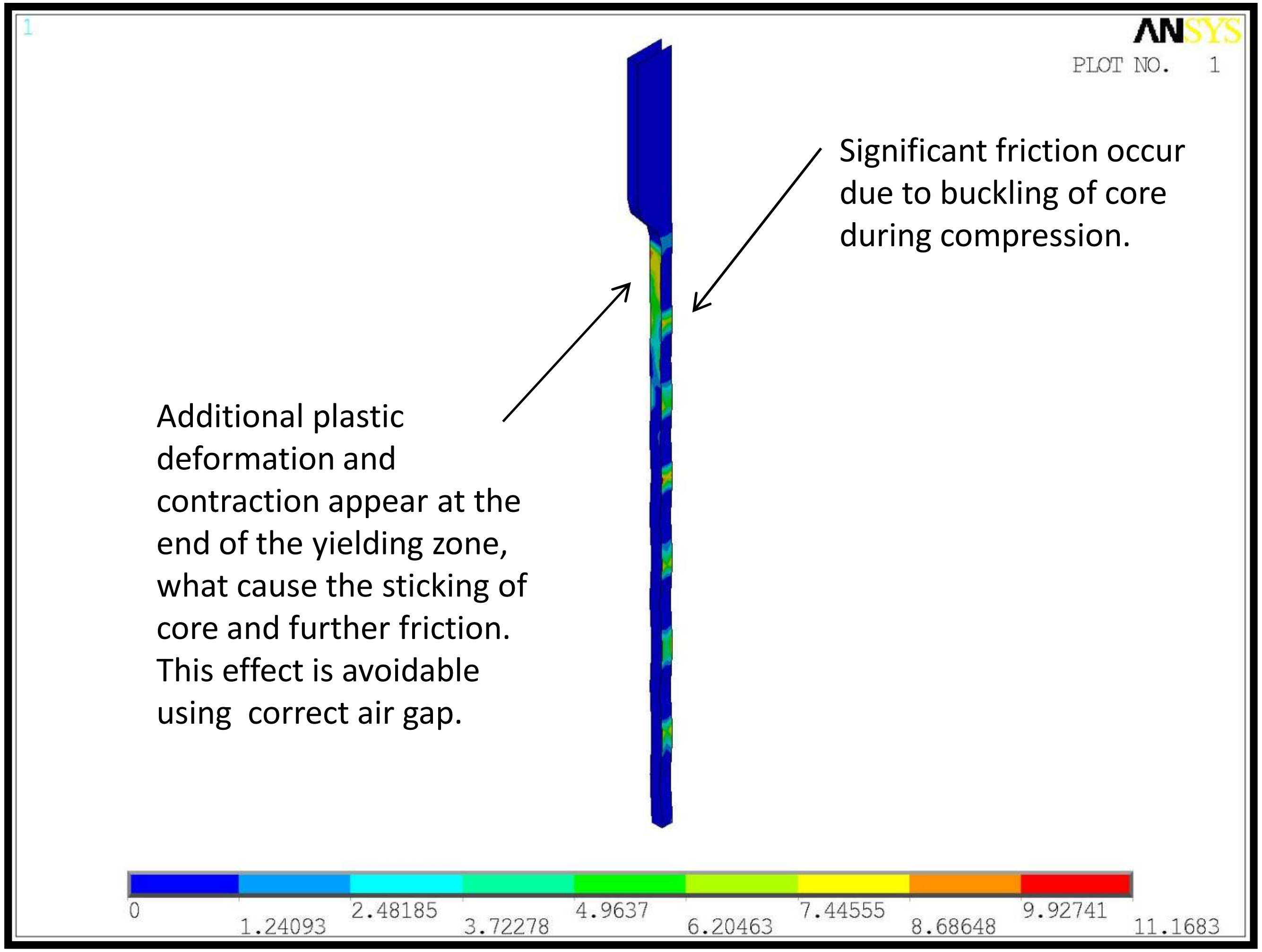
Results

- Significant additional resistance at compression, caused by friction.
- Contact stiffness, friction coefficient, air gap interaction
- Compared to experimental results





Results


ANSYS
PLOT NO. 1
Significant friction occur due to buckling of core during compression.
Additional plastic deformation and contraction appear at the end of the yielding zone, what cause the sticking of core and further friction. This effect is avoidable using correct air gap.
0
1.24093
2.48185
3.72278
4.9637
6.20463
7.44555
8.68648
9.92741
11.1683

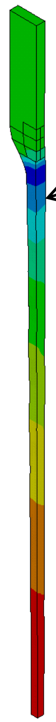
Results

The plastic compressed deformation is concentrated in the end of the yielding zone.

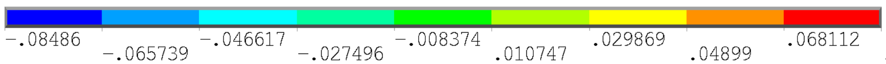
Distribution of plastic strain is not balanced

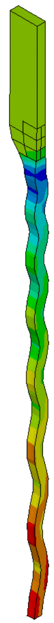
Compressed deformation is remained during tension, and tensile during compression

The tensile plastic strain is concentrated in the middle of the core.

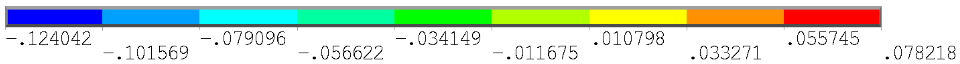


Tension

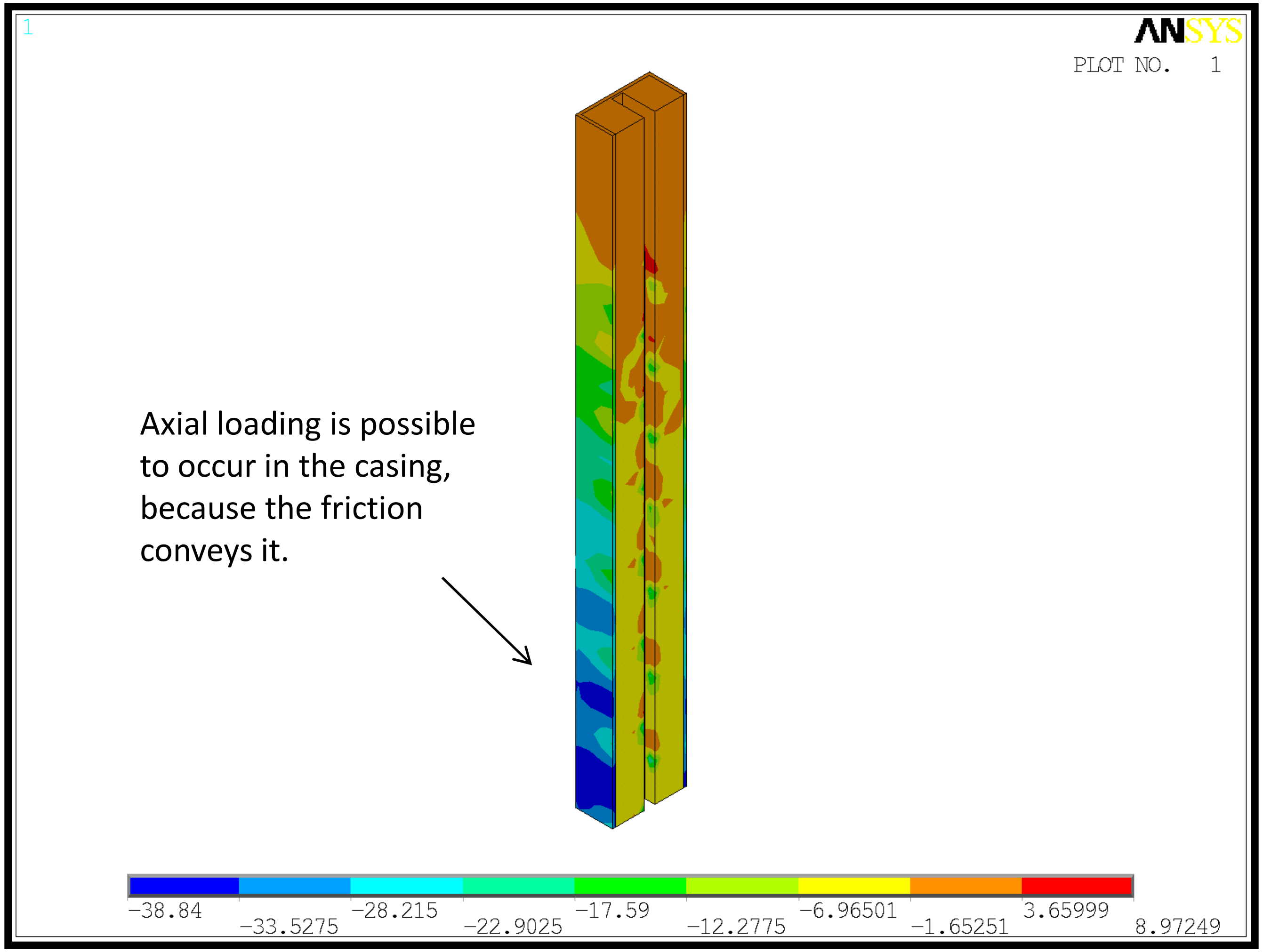




Compression



Results


ANSYS
PLOT NO. 1
Axial loading is possible to occur in the casing, because the friction conveys it.
-38.84
-33.5275
-28.215
-22.9025
-17.59
-12.2775
-6.96501
-1.65251
3.65999
8.97249

Conclusions

- The discussed material model developed in **ANSYS** finite element code.
- Developed material model is able to describe all the important cyclic phenomena.
- Using the three set and the parameter updating method the material model **can follow the transition** form monotonic to cyclic behaviour.
- The material model was successfully implemented into a complex VEM model of BRB.

- The developed BRB model includes:
  - (i) the cyclic steel material model
  - (ii) plastic buckling
  - (iii) opening-closing contact problem and friction -> **all the necessary requirements**

- The Contact stiffness, friction coefficient air gap **interaction**
- Plastic **deformation is not balanced**
- Less friction coefficient causes more balanced strain distribution, less contraction, less sticking and at least less additional resistance.
- The decrease of friction coefficient and the use of right air gap can restrain the pinching effect.

Future research

- Calibrate for other experimental results (USA and Europe)
- Examine other loading condition
- Parametric air-gap investigation
- Effect of the parameters of cross section of core
- Stochastic distribution of friction conditions

- Minimize the pinching effect
- Maximize the hysteretic behviour (loading amplitude, cycle number)

Thank you for your attention!

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