A new path-following constraint based on elastic unloading angle for damage analysis of quasi-brittle materials

Ir. Amir Fayezioghani*, Dr. Ing. Bram Vandoren

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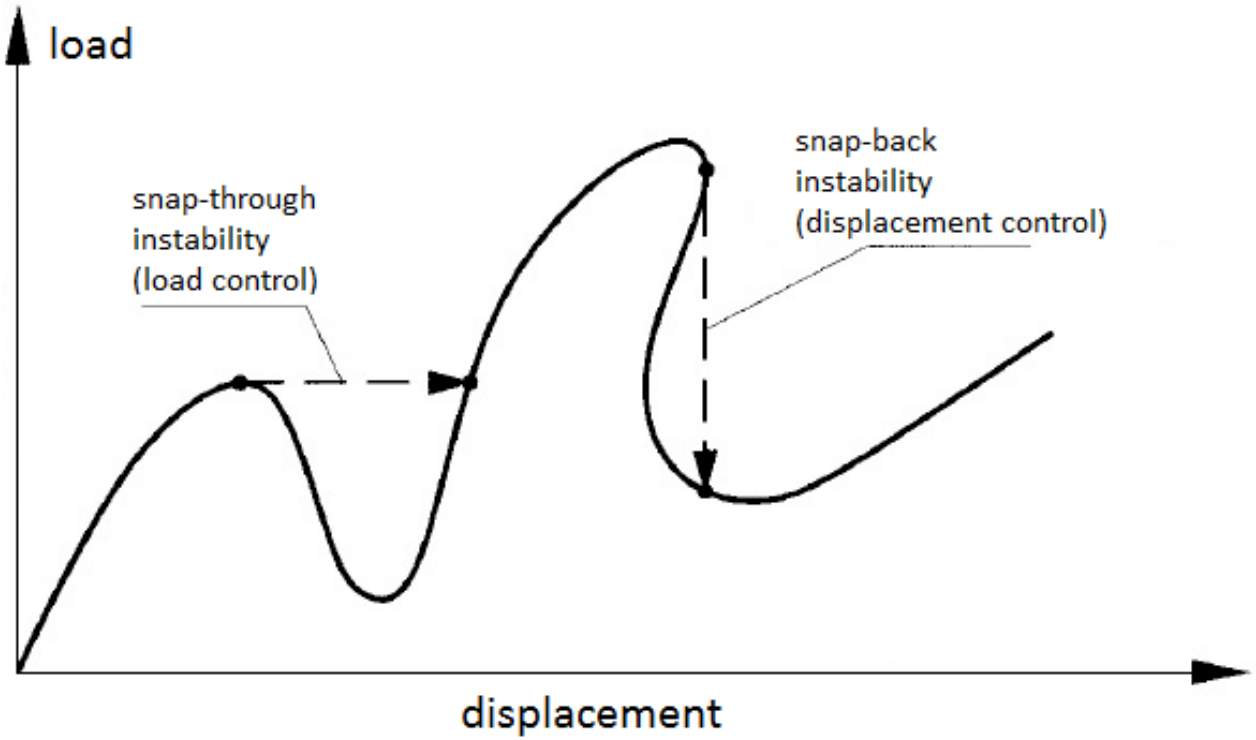
Problem

- Numerical instability of load control and displacement control in quasi-static analysis of quasi-brittle materials

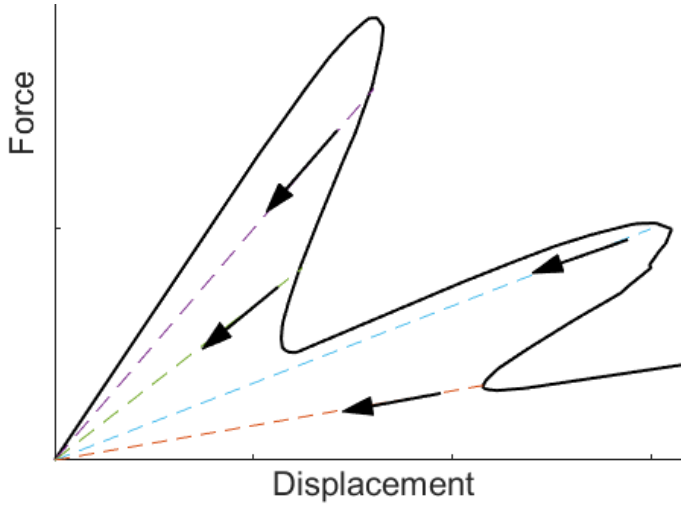


Literature

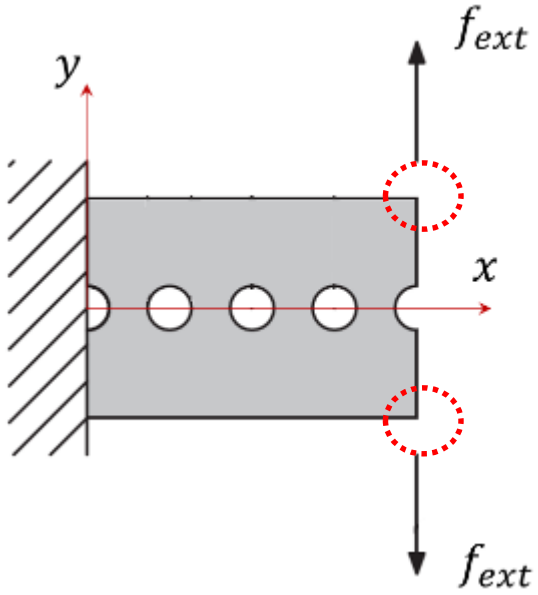
Control Constraint Type	**Global**	**Local**
Area of Control	whole problem	some fixed/adaptive areas of problem
Examples	• arc-length • dissipated energy • elastic unloading angle	• crack mouth opening displacement (CMOD) • elastic unloading angle
Pros & Cons	• based on simple principles • often numerically robust • insensitive to very local events	• fixed areas cannot completely trace moving events • adaptive areas need definition of some criteria • sensitive to desired local events

The Idea

- Angle of elastic unloading to the origin in an analysis



- Involving only the dofs having equivalent external nodal forces



Formulation

$\boldsymbol{r}(\boldsymbol{a}, \lambda) = 0$: equation of unbalanced force

$g(\boldsymbol{a}, \lambda, \eta) = 0$: path-following constraint equation

where, $g = \theta_0 - \theta - \eta$ in which

η : the constraint increment

θ_0 : virgin augmented elastic angle

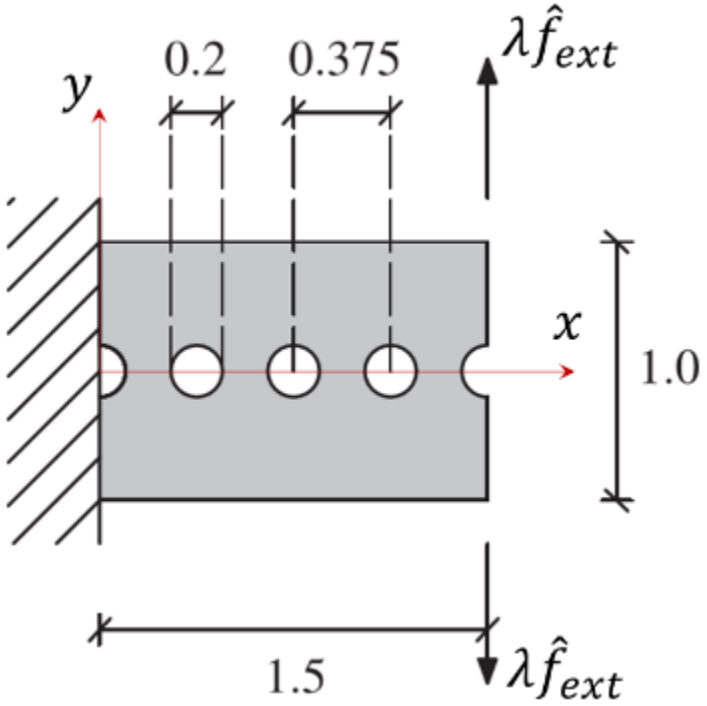
θ : augmented elastic unloading angle

$$\theta = \arctan \sqrt{\frac{1}{m} \sum_{j=1}^{m} \left(\frac{\bar{\lambda}}{\bar{a}_j} \right)^2}$$

where, $\bar{a}_j = a_j / a_{max}$ and $\bar{\lambda} = \lambda / \lambda_{max}$

Numerical Example

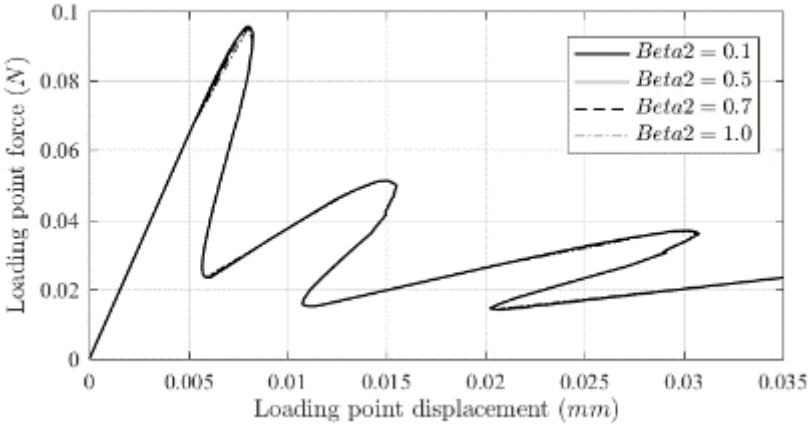
- Perforated beam
  - mode-I fracture
  - continuum elastic triangular elements
  - predefined plane of cohesive zone in the middle by interface elements

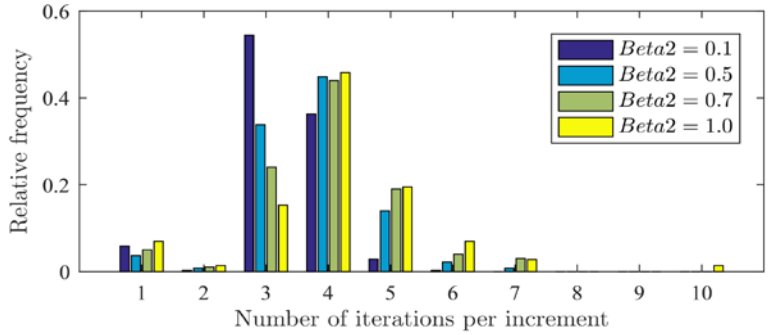


Numerical Example

Angle Control

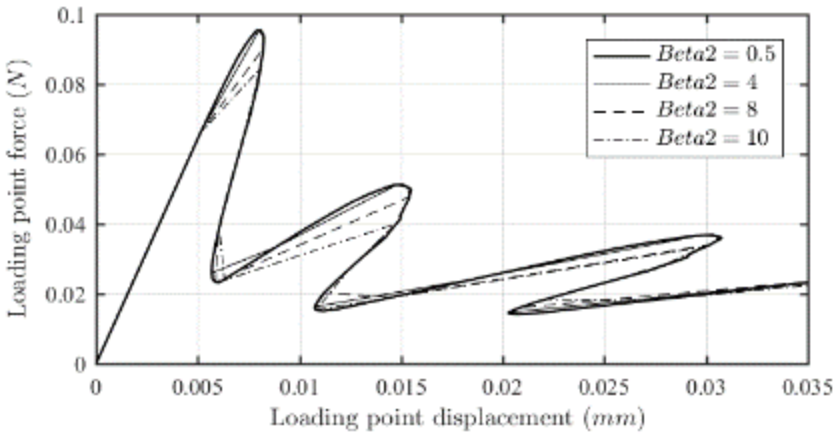
$$\eta = Beta2 * \frac{\pi}{180} Rad$$

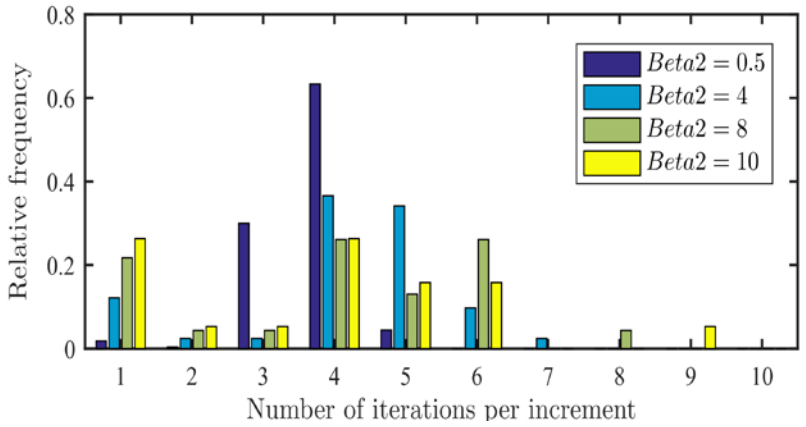




Dissipated Energy Control

$$\eta = Beta2 * 10^{-8} J$$

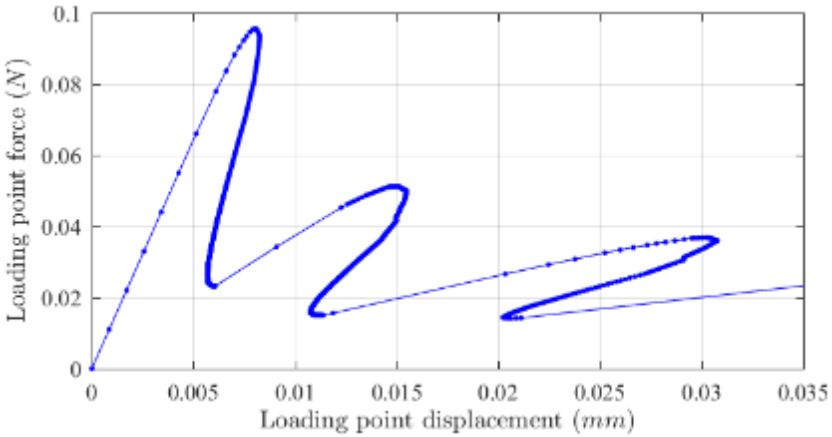


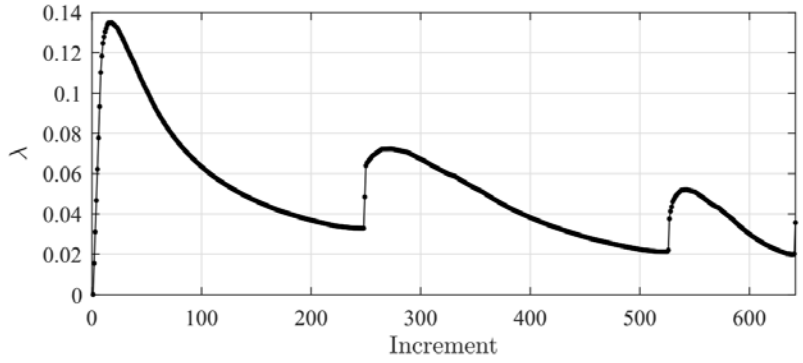


Numerical Example

Angle Control

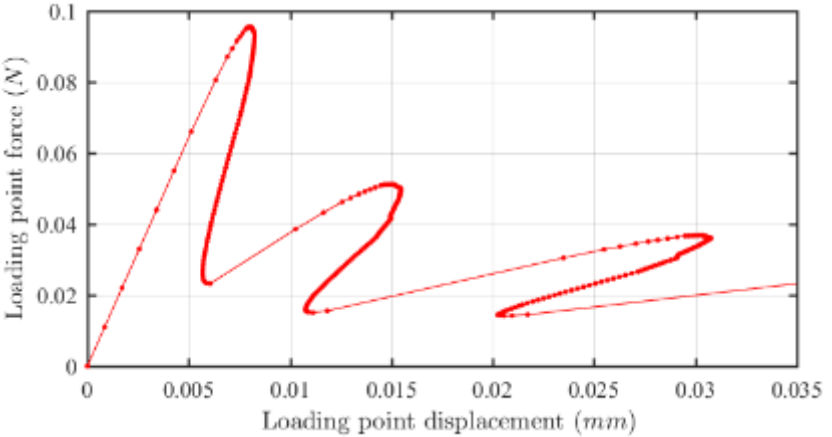
$Beta2 = 0.1$

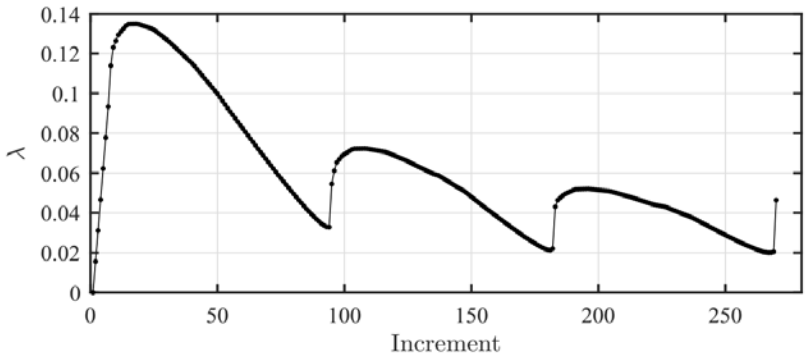




Dissipated Energy Control

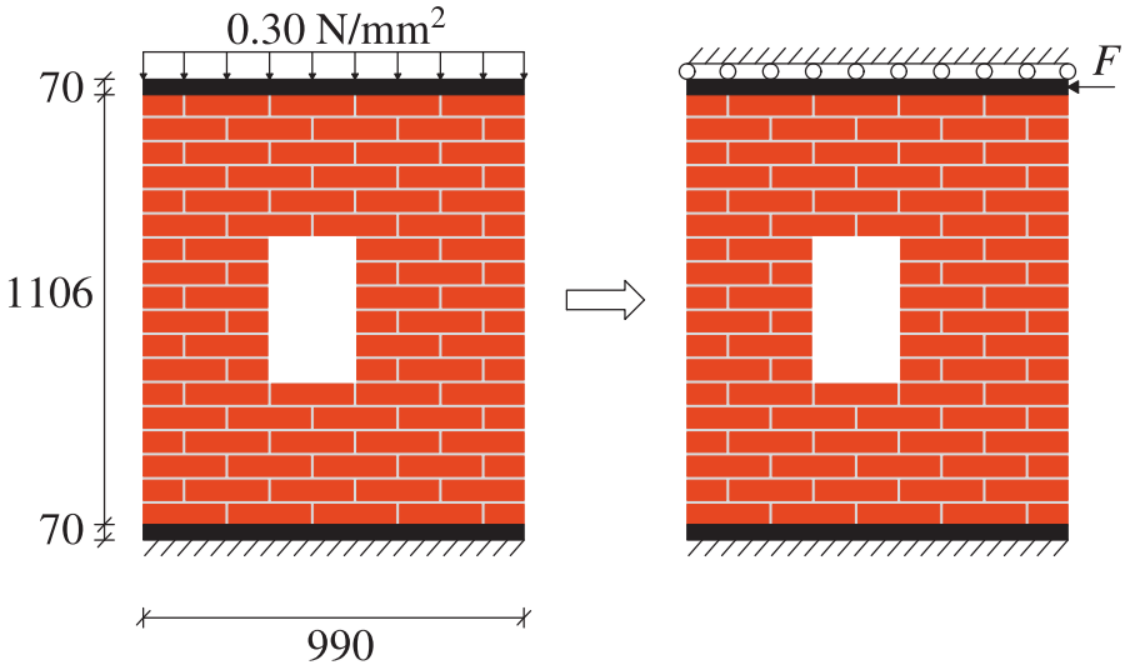
$Beta2 = 0.5$





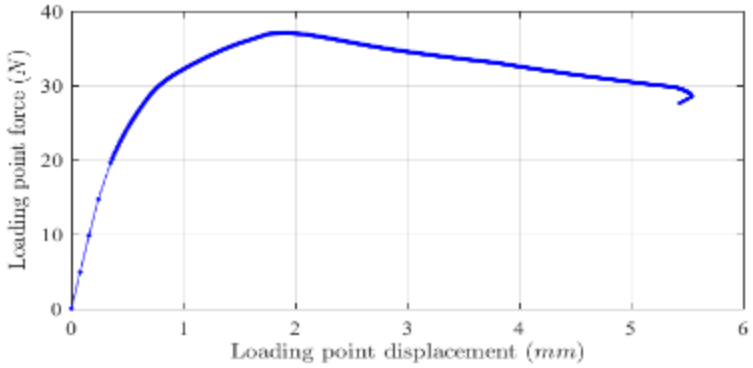
Numerical Example

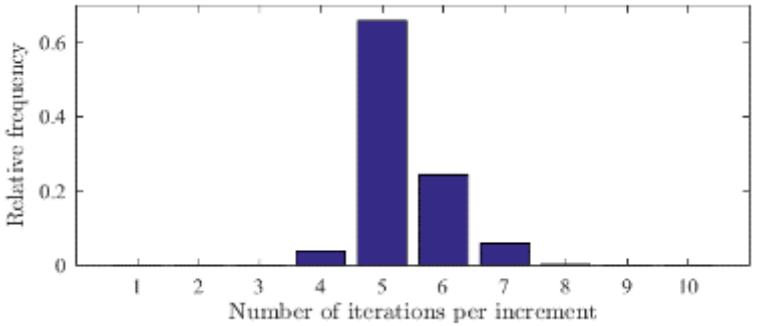
- Shear wall
  - two-step loading: confining compression followed by a horizontal force
  - continuum elastic elements for bricks
  - predefined planes of crack propagation inside of mortar by interface elements

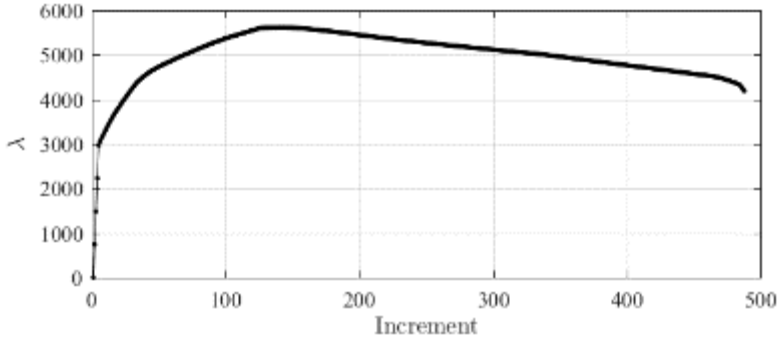


Numerical Example

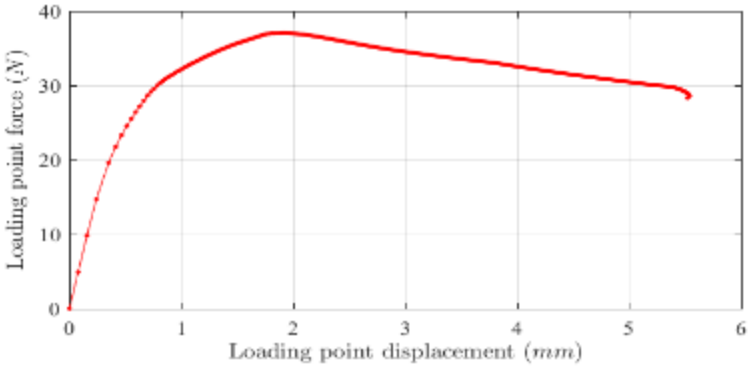
Angle Control

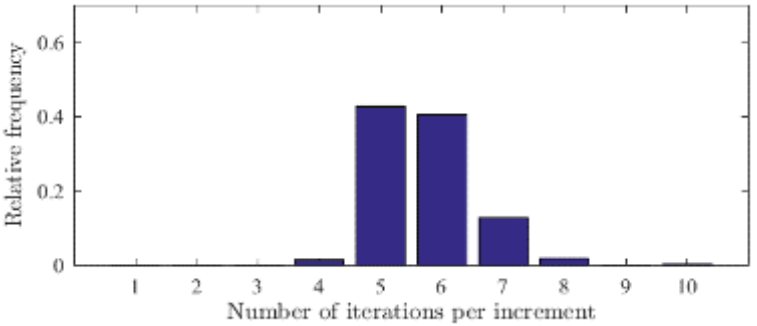


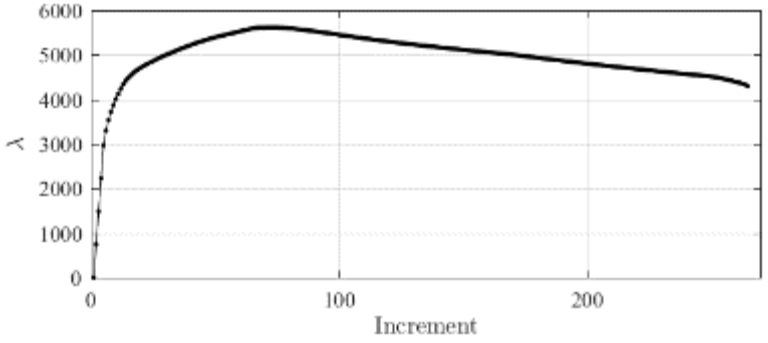




Dissipated Energy Control







Summary and Concluding Remarks

- Being easy to understand and use, it is almost as robust as dissipated energy control in tracing snap-backs and snap-throughs.
- It enjoys the possibility to be global (using all of the dofs) or local (choosing some dofs and including them in the formulation).
- Although we have proposed a specific augmented angle, the constraint has flexibility for mentioned angles to be combined in any way a designer desires according to his/her problem.
- When solving problems associated with quasi-brittle materials, it finds smoother curves close to turning points.

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Ir. Amir Fayezioghani
PhD Construction Engineering Group
University of Hasselt

amir.fayezioghani@uhasselt.be
+32 488 19 39 32

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