GESU project:
LS-DYNA *MAT_SHELL_MASONRY
Description for users

Author: Richard Sturt

Describing LS-DYNA Masonry Model, March 2017

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Contents

Motivation

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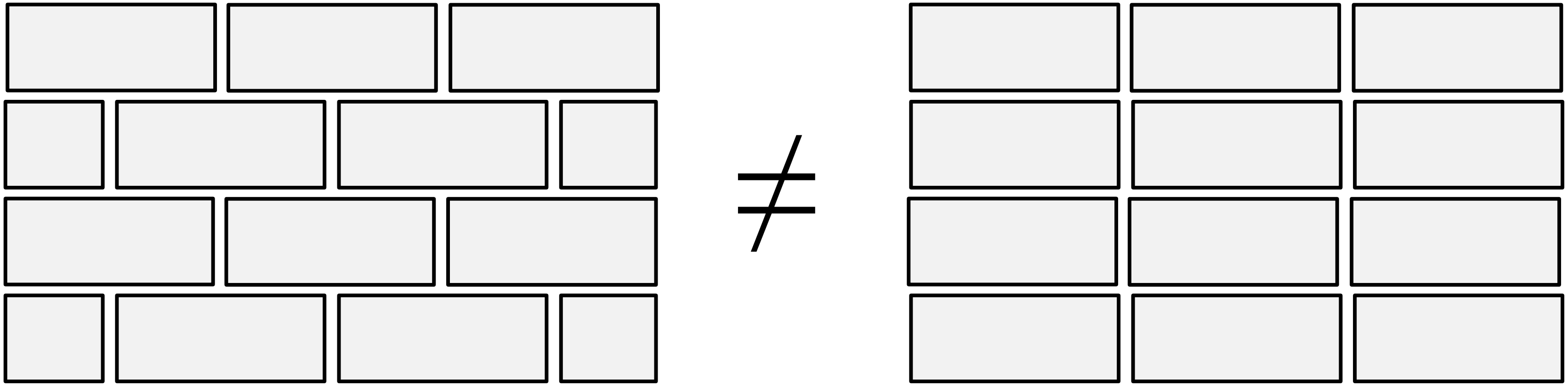
Masonry characteristics

- Masonry is a composite material with complex behaviour.
  - Bricks
  - Mortar
  - Brick-mortar interface
  - Bond pattern influences behaviour



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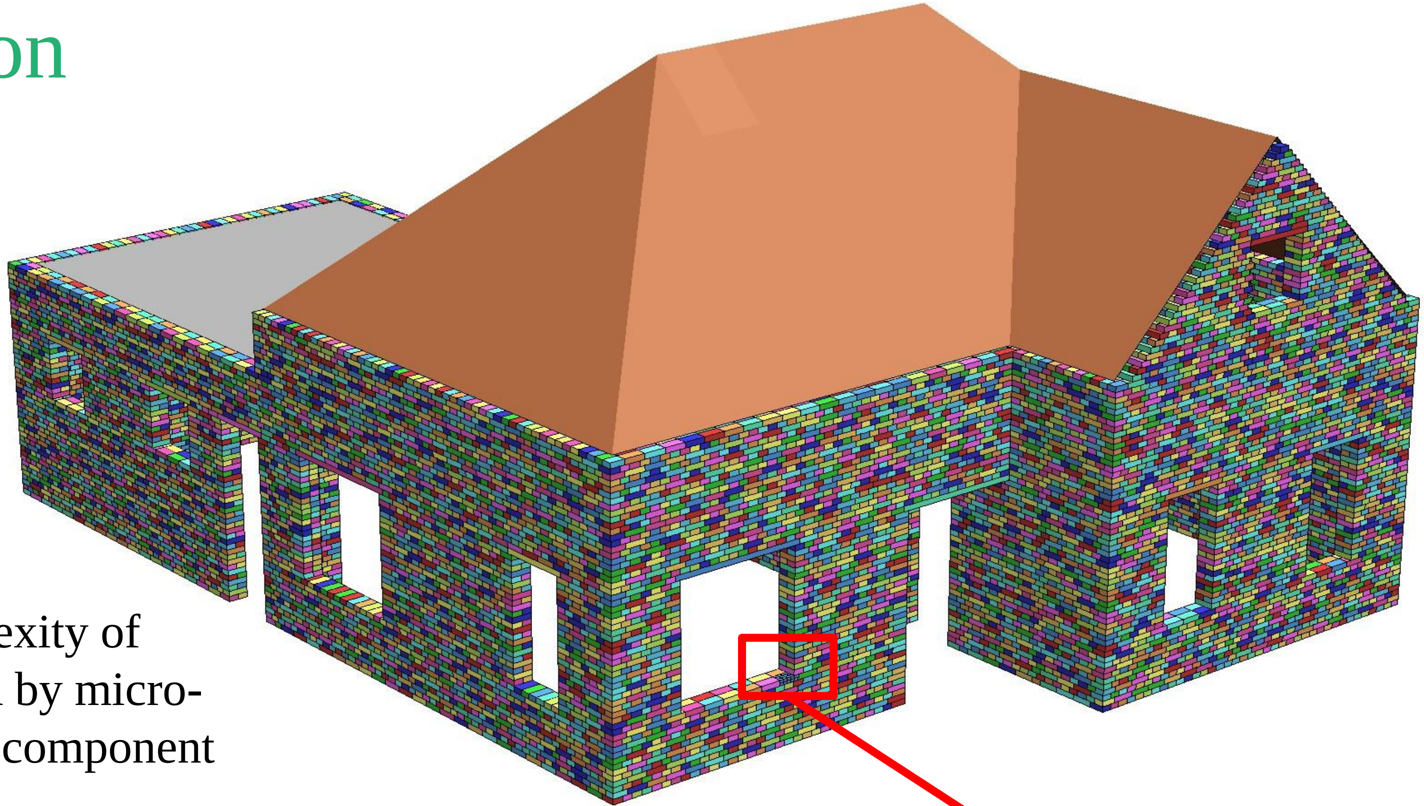
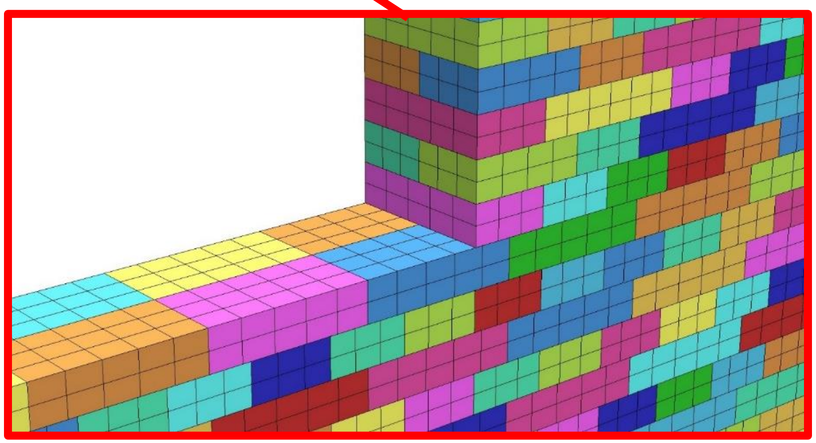
Motivation



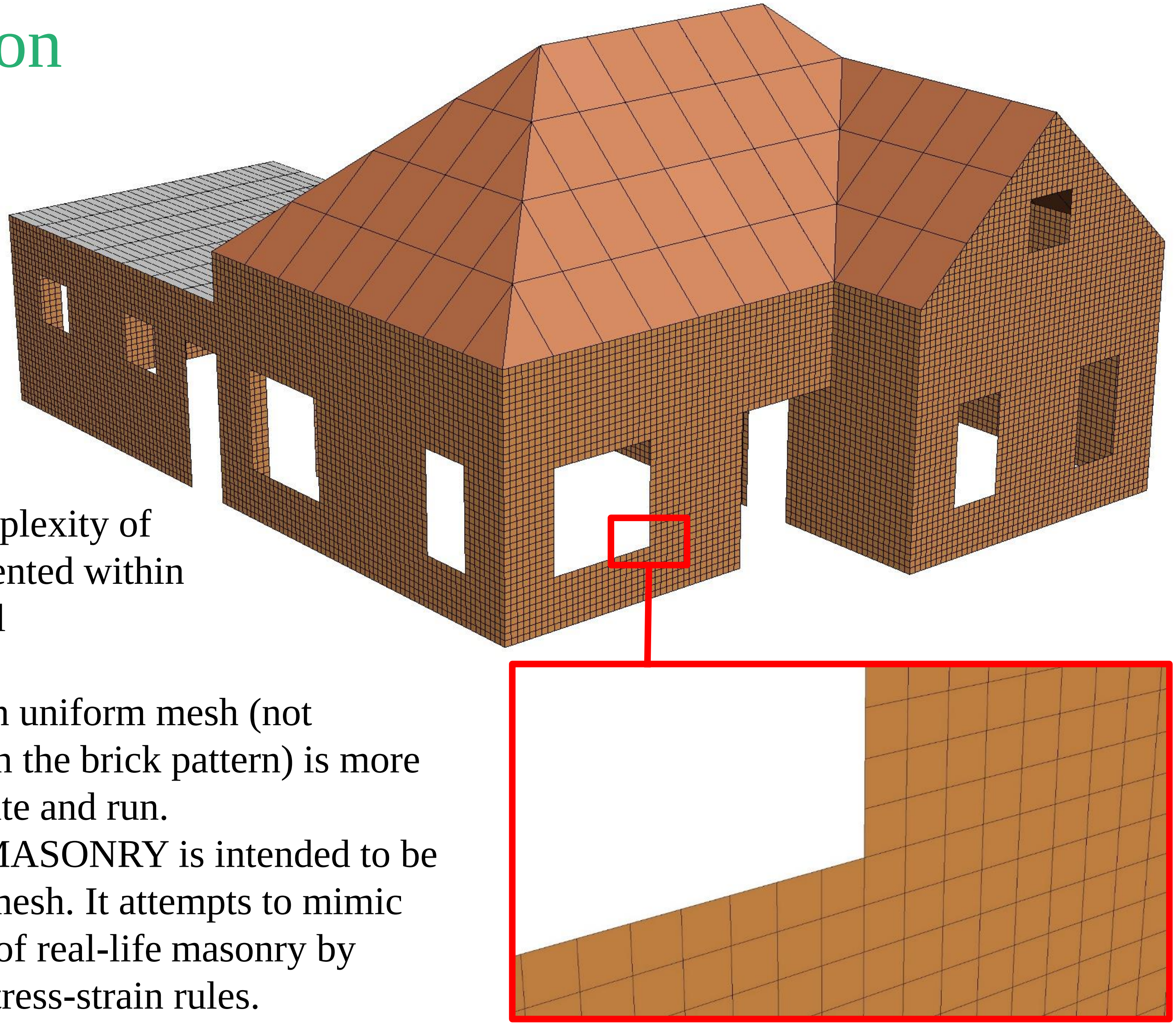
Method A: Complexity of masonry is tackled by micro-modelling of each component

LS-DYNA “Brick-by-brick” models can give realistic results. The bricks are fixed together using “tiebreak” contact that represents the mortar/brick interface.

However, this method is not practical for a whole building: the models are laborious to generate and can take weeks to run.



Motivation



Approach B: Complexity of masonry is represented within the material model

A shell model with uniform mesh (not attempting to mesh the brick pattern) is more practical to generate and run. *MAT_SHELL_MASONRY is intended to be used with such a mesh. It attempts to mimic the failure modes of real-life masonry by applying certain stress-strain rules.

General modelling considerations

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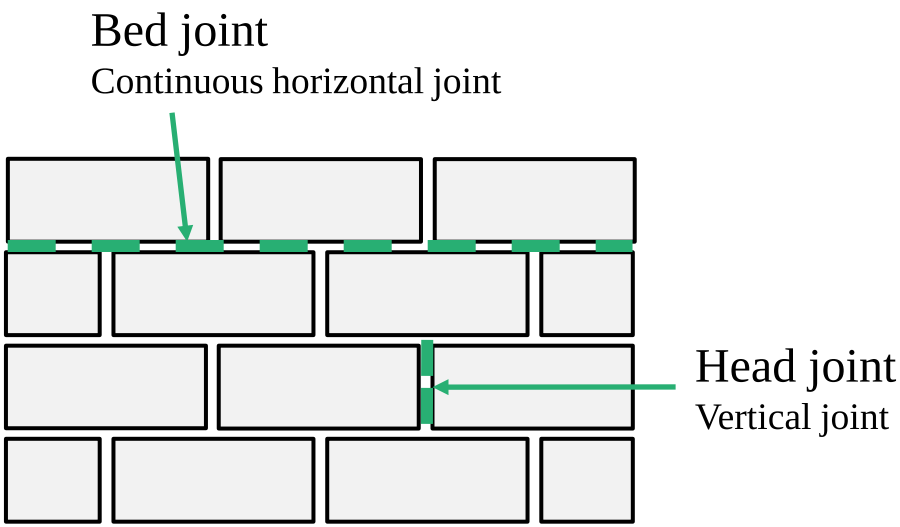
Vocabulary

"Joints" = lines of mortar

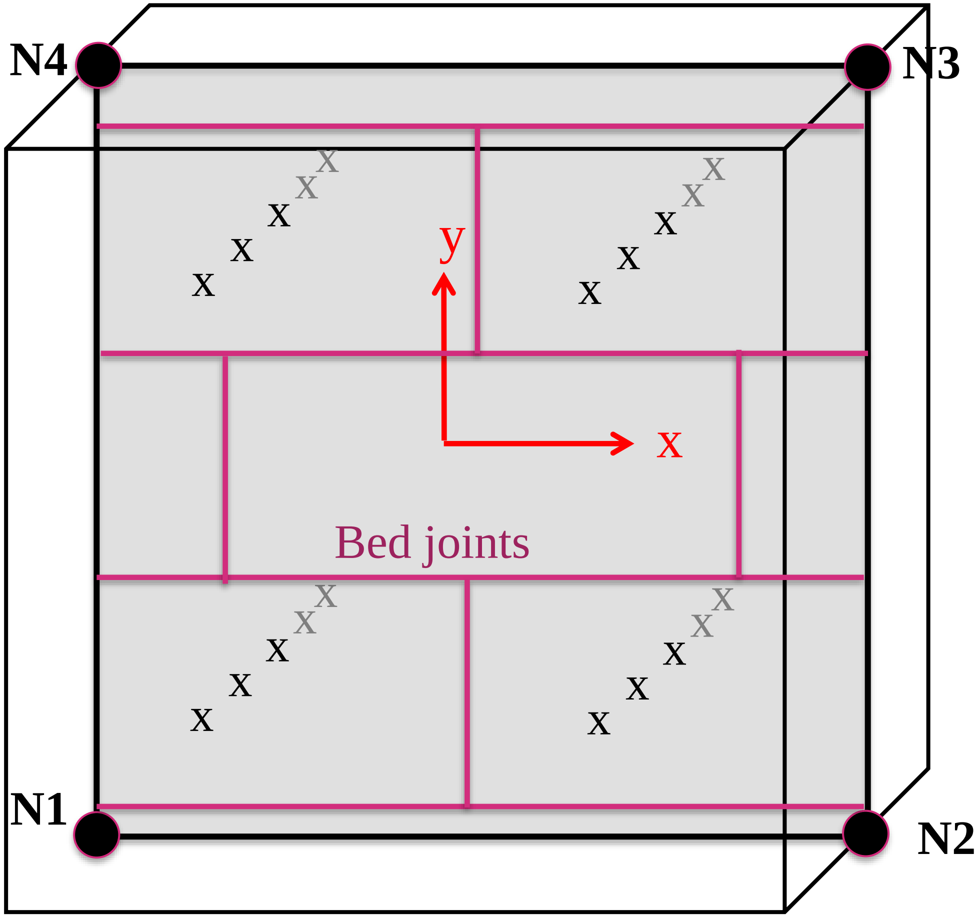
"Wythe" = leaf of brickwork e.g. "single wythe" is a wall made of a single leaf about 100mm thick

"Failure mode" = used here to mean nonlinear deformation e.g. due to joint opening

"Collapse mode" = used here to mean behaviour leading to collapse of wall



Shell element type & orientation



- Use ELFORM=16
- Element local x-axis (N1-N2) is parallel to bed joints (usually horizontal)
- Typically 5 integration points through thickness.
- *MAT_SHELL_MASONRY

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Mesh size and shape

- Calibration of material properties to experiments has been done with 0.1m mesh size, square elements.
- Larger element size is also possible, but some re-calibration of properties may be needed – especially properties controlling collapse. March 2017 version has additional capability to use the same input data across different element sizes (REFSIZE)
- Rectangular shape strongly preferred
- Triangles are allowed, but cannot be used with material input parameter KTH (described on later slides)
- Important: alignment of N1-N2 (local X axis) in bed joint direction.

Input data and failure modes

Manual pages are here…

Location:

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Elastic properties

Density, Young's modulus and Poisson's ratio have their usual meanings

Screen-grab from Manual pages

Card 1	1	2	3	4	5	6	7	8
Variable	MID	RO	E	PR	FC	HARDEN	RATEFF	TYPE
Type	I	F	F	F	F	F	F	F
Default	none	none	none	none	0.0	0.0	0.0	0
Card 2	1	2	3	4	5	6	7	8

TYPE=4 should be used for masonry walls
More on this later…

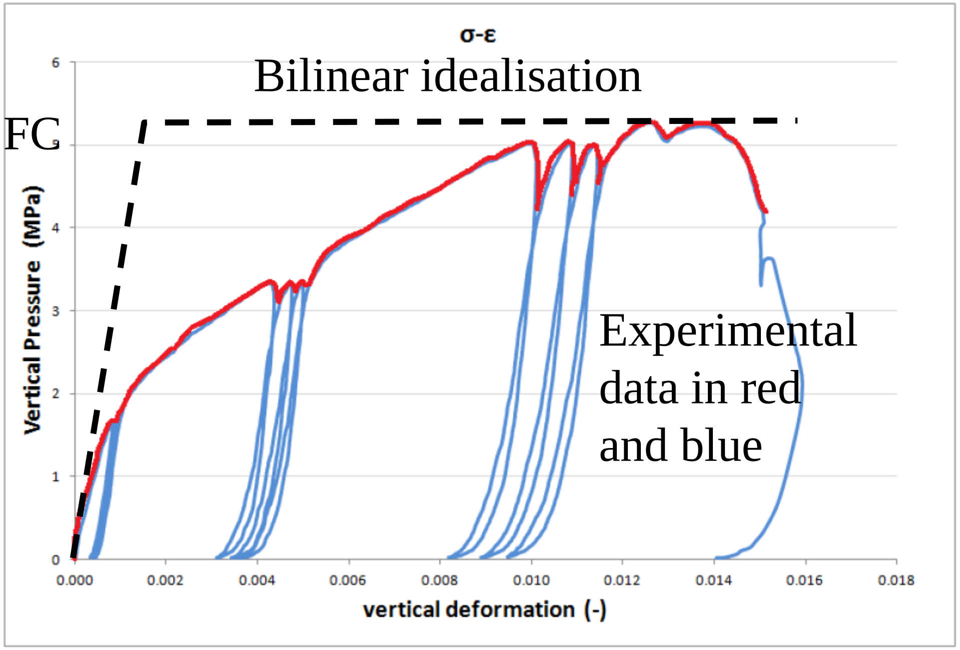
Card 4	1	2	3	4	5	6	7	8
Variable	AOPT	WBR	HBR	FTBR	FSBR	ANGBR	SOFTFAC	GMOD
Type	F	F	F	F	F	F	F	F
Default	0.0	0.0	0.0	0.0	0.0	0.0	0 or 0.5	E/2(1+PR)

It is possible to overwrite the usual value of shear modulus with a different value. This applies to shear defined in the coordinate system of the joints. However, this is not recommended.

Crushing

- The masonry material model offers bilinear elastic-plastic, or stress-strain curve input
- Bi-linear option:
  - FC = compressive strength
  - HARDEN = zero or positive = hardening slope
  - Assumes infinite compressive strain capacity. This is unconservative and can cause overprediction of drift capacity of slender piers
  - NOT RECOMMENDED

Card 1	1	2	3	4	5	6
Variable	MID	RO	E	PR	FC	HARDEN
Type	I	F	F	F	F	F
Default	none	none	none	none	0.0	0.0



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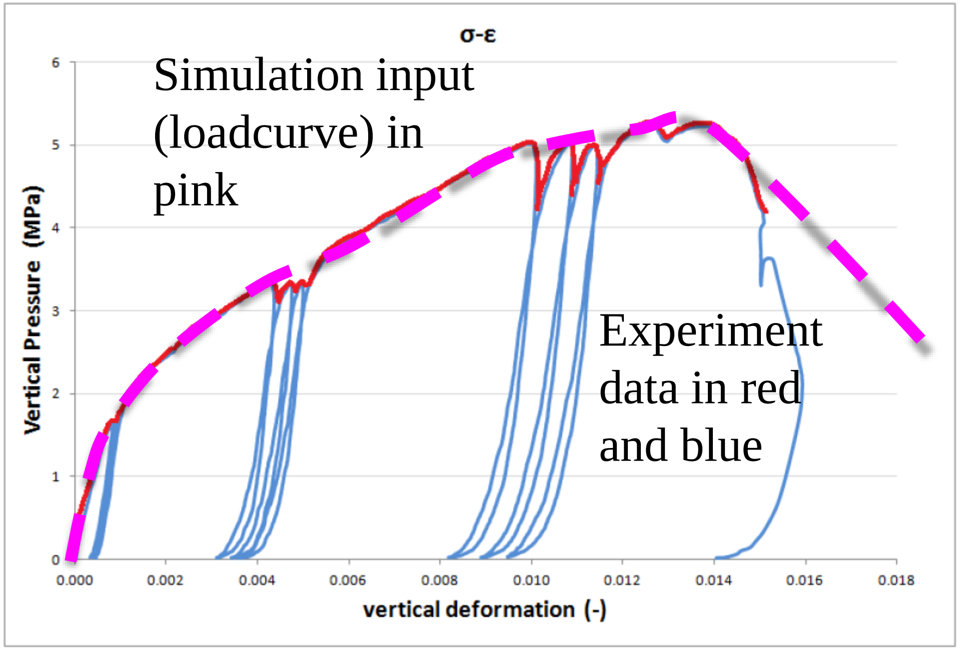
Crushing

- The masonry material model offers bilinear elastic-plastic, or stress-strain curve input.
- Stress-strain curve input:
  - Set HARDEN negative
  - “-1001” = curve ID 1001
  - FC is ignored
  - Curve x-axis = strain (positive in compression; includes elastic strain). Y-axis = stress.
  - Stress-strain curve can be taken from experiment result
  - More on this later…

Card 1	1	2	3	4	5	6
Variable	MID	RO	E	PR	FC	HARDEN
Type	I	F	F	F	F	F
Default	none	none	none	n		

To input a stress-strain curve, set HARDEN = -ve curve ID



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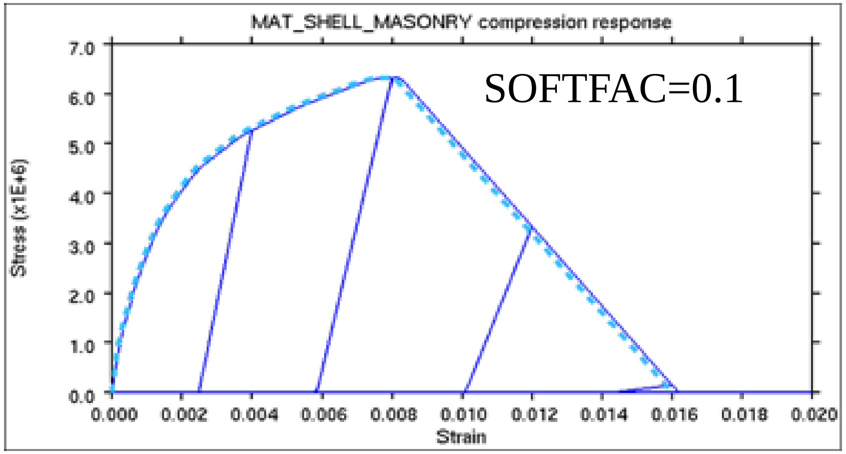
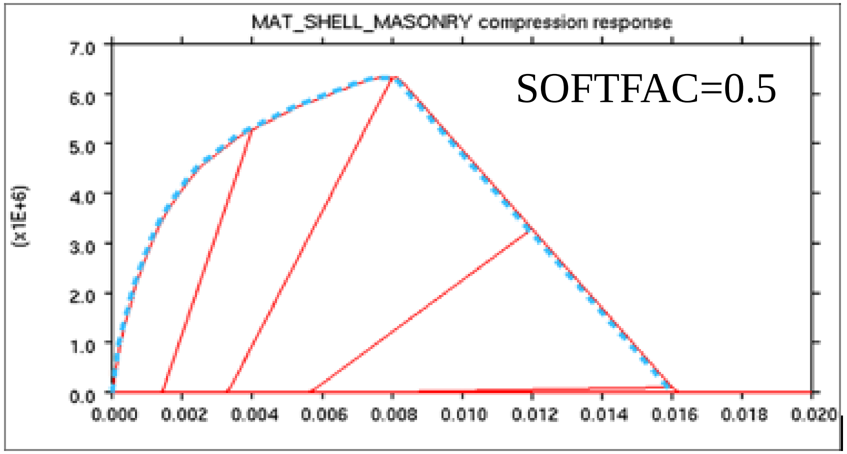
Compression: unload/reload

- Unload/reload is linear elastic but the stiffness reduces with the maximum compressive strain experienced so far, controlled by parameter SOFTFAC. We use SOFTFAC=0.05 based on laboratory compression tests.





Card 4	1	2	3	4	5	6	7	8
Variable	AOPT	WBR	HBR	FTBR	FSBR	ANGBR	SOFTFAC	GMOD
Type	F	F	F	F	F	F	F	F
Default	0.0	0.0	0.0	0.0	0.0	0.0	0 or 0.5	E/2(1+PR)

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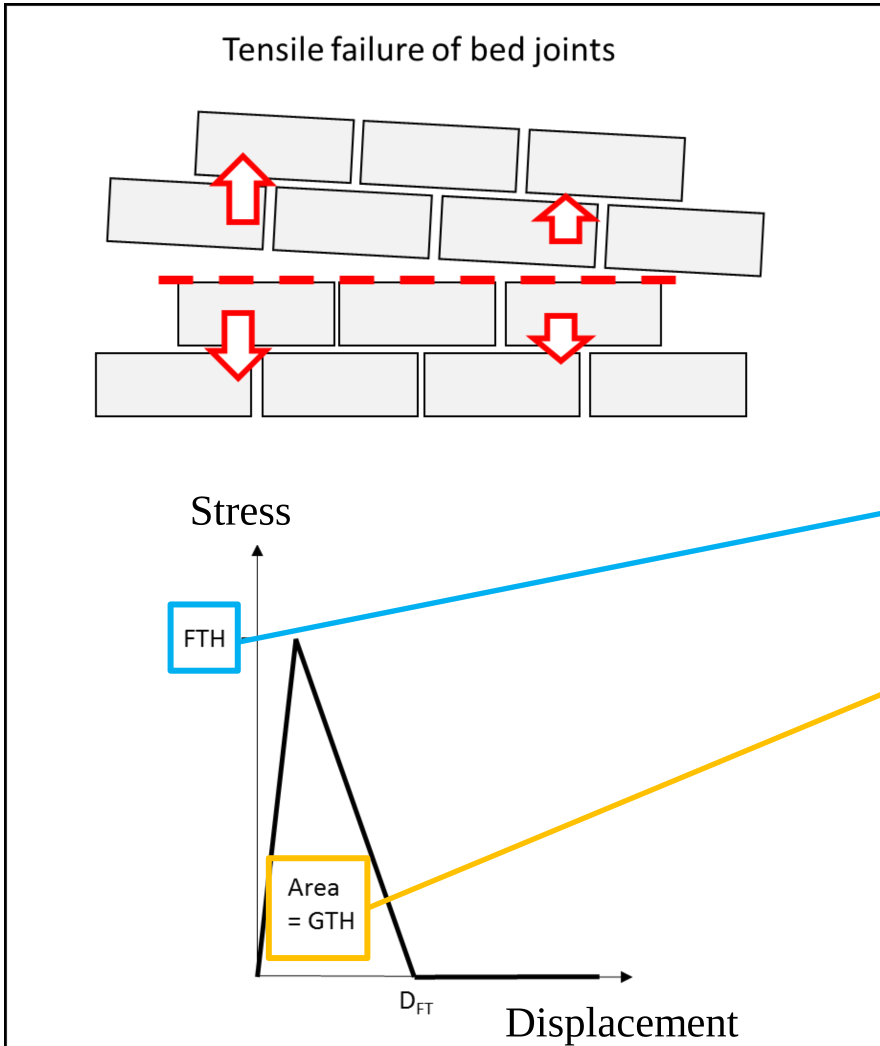
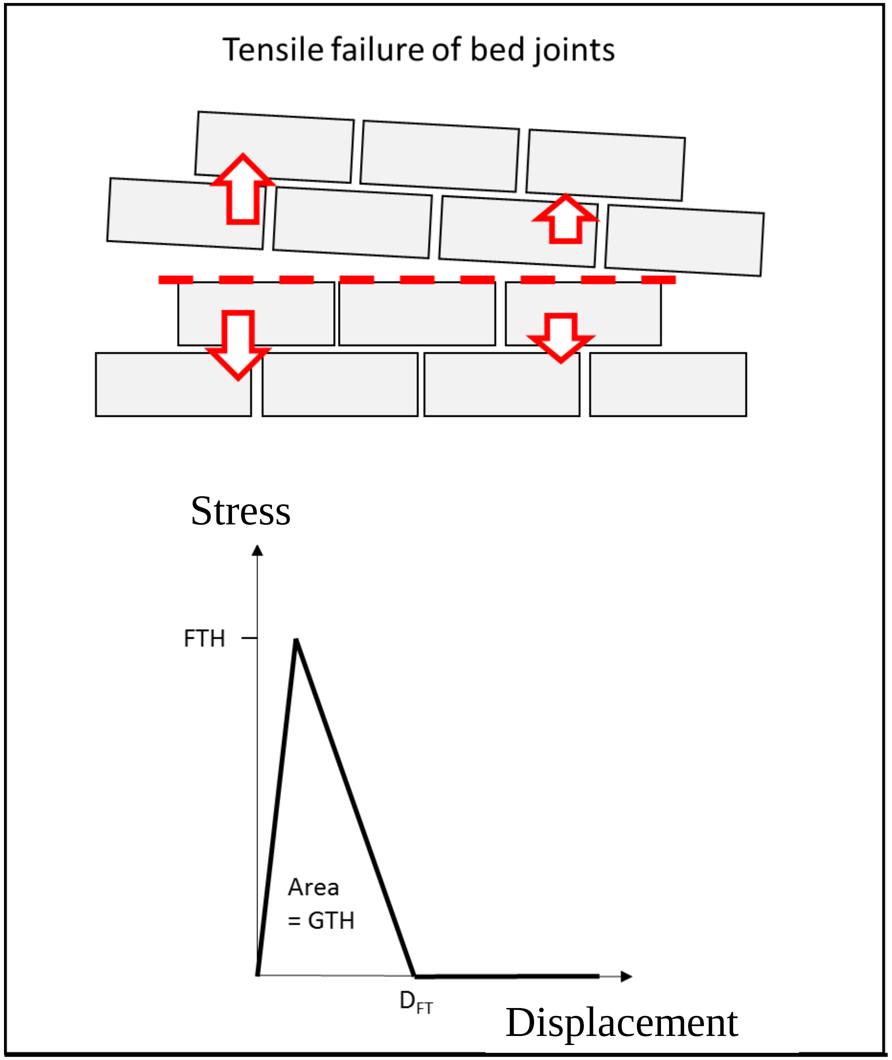
Bed joint tension input data

- Cracks can repeatedly open and close
- Tensile strength is lost permanently according to “high tide” displacement (damage)

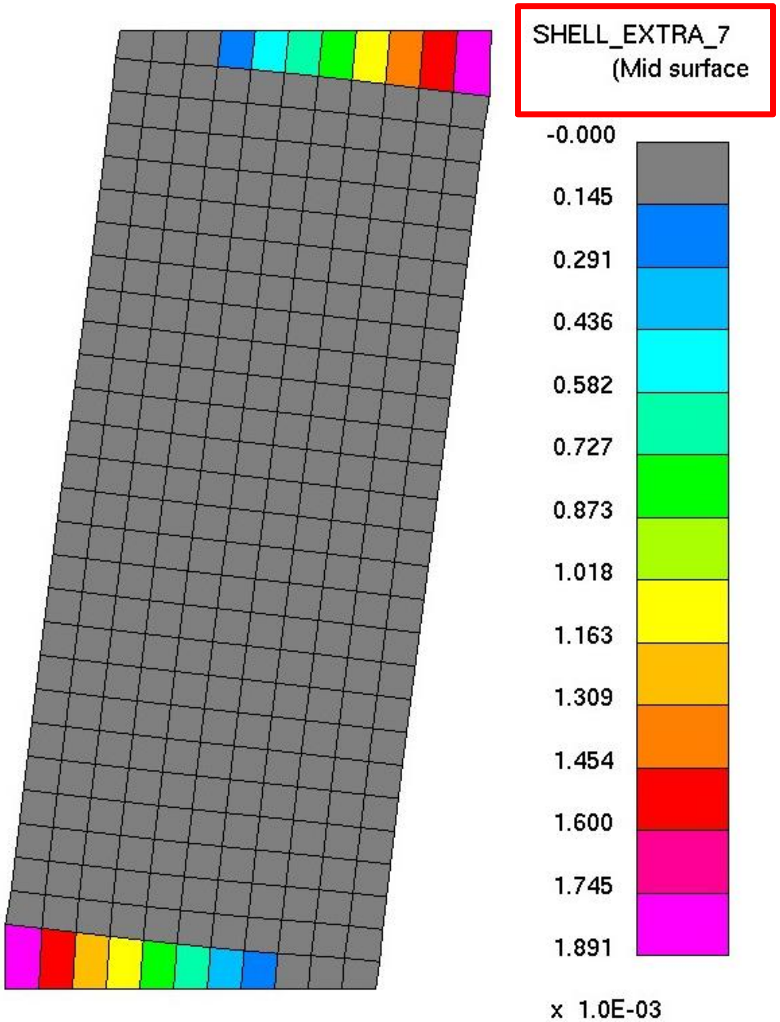


Card 3	1	2	3	4	5
Variable	FTH	GTH	FSH	GSH	ANGH
Type	F	F	F	F	F
Default	0.0	0.0	0.0	0.0	0.0
Card 4	1	2	3	4	5

Bed joint opening during in-plane rocking



Crack opening displacement can be monitored using Extra History Variable 7



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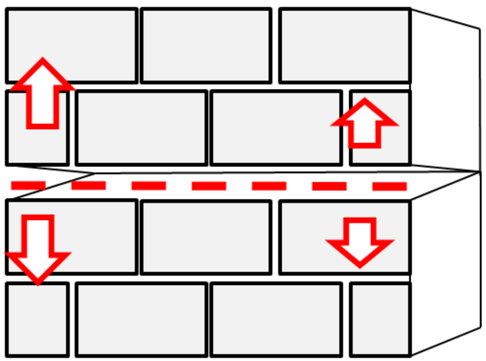
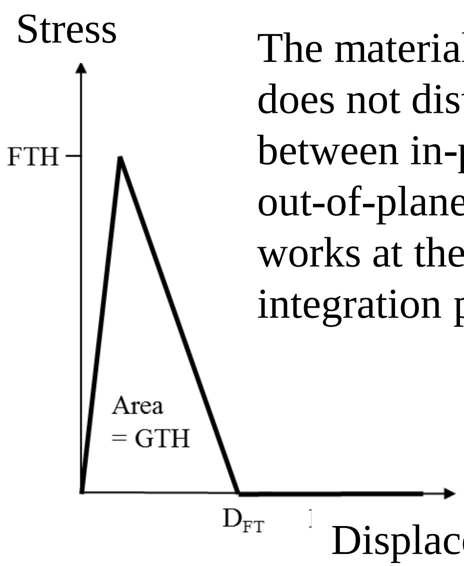
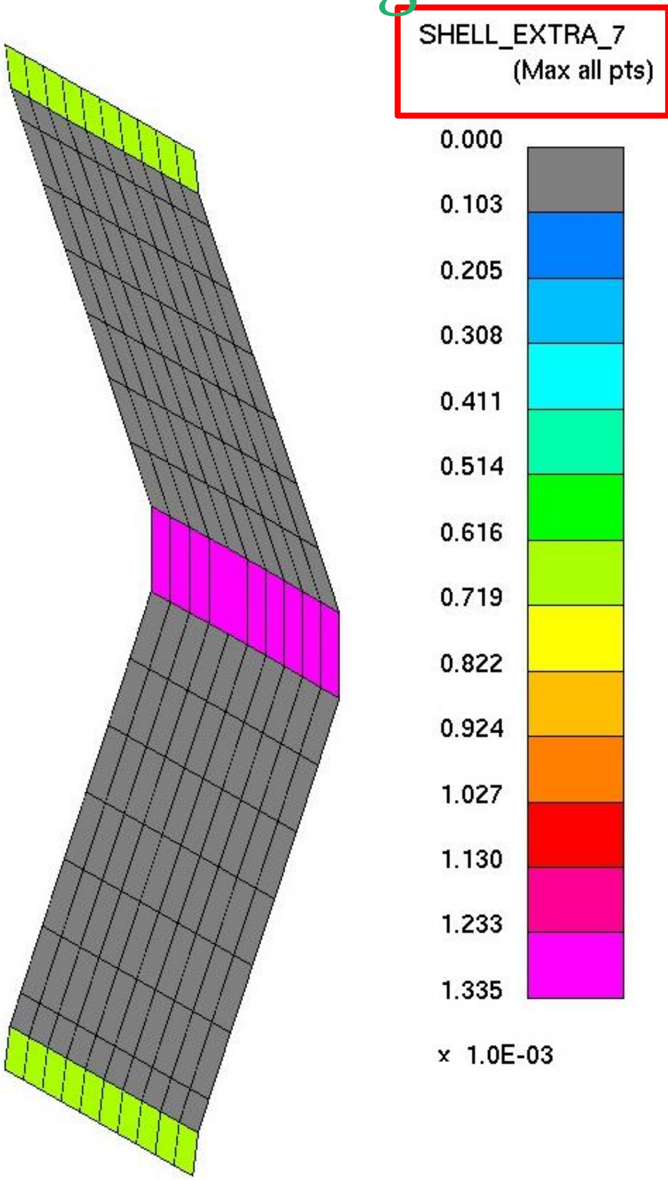
Bed joint opening during out-of-plane rocking

Tensile failure of bed joints





The material model does not distinguish between in-plane and out-of-plane rocking – it works at the level of an integration point.



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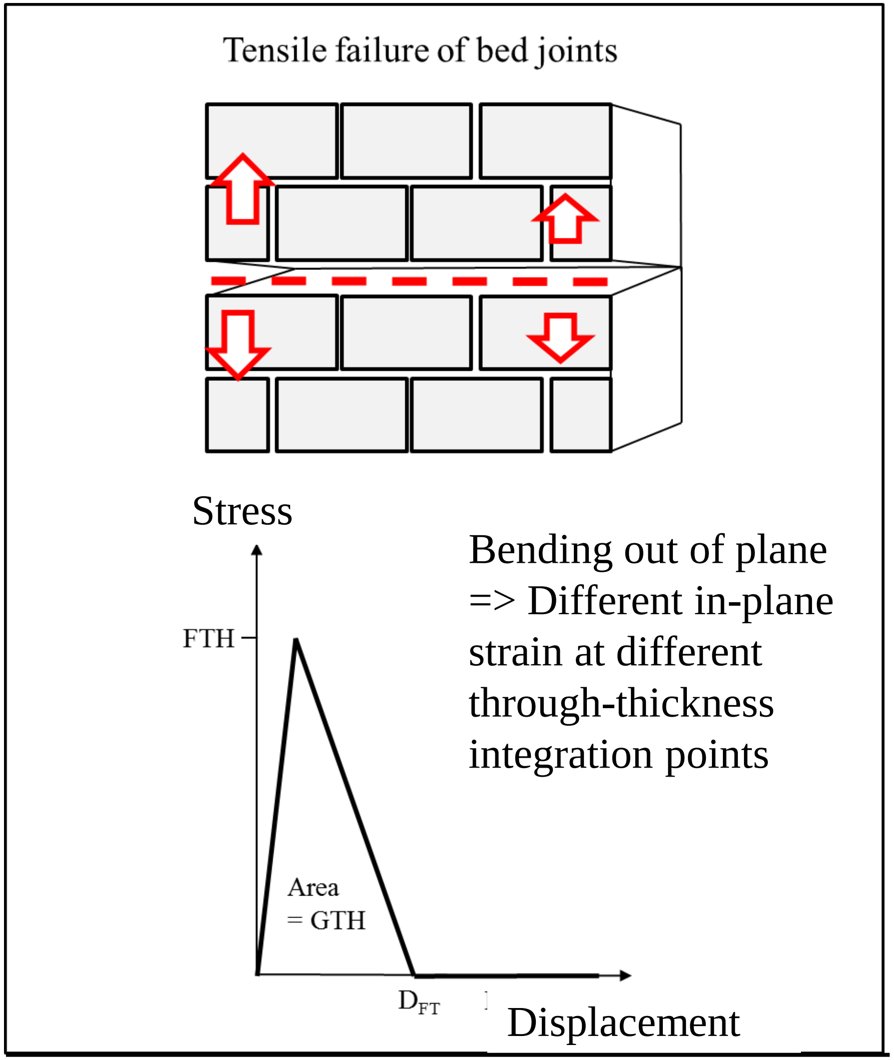
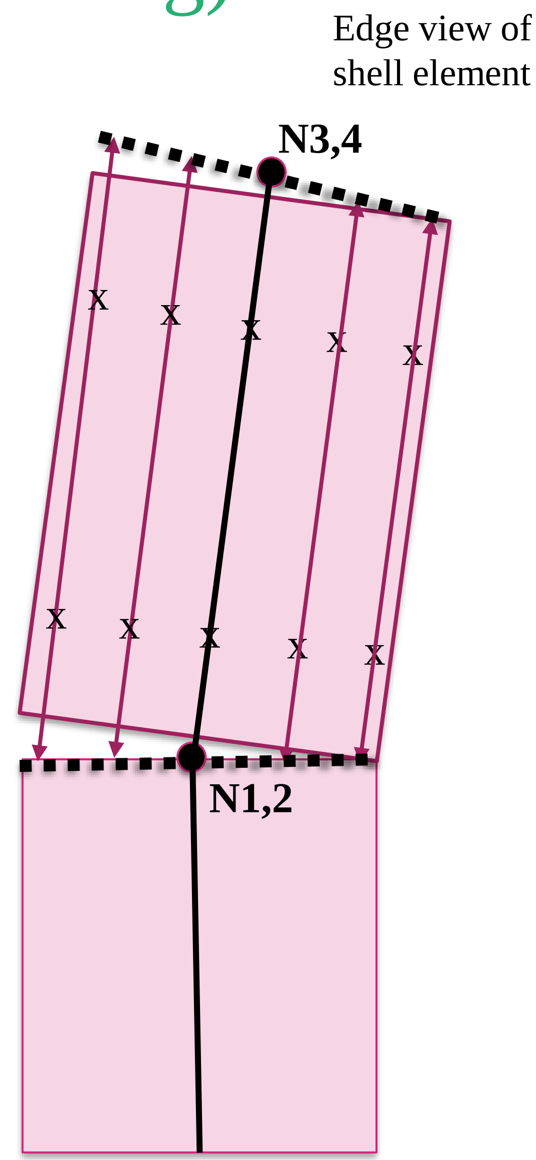
Bed joint tension (out-of-plane bending)



Bending out of plane => Different in-plane strain at different through-thickness integration points



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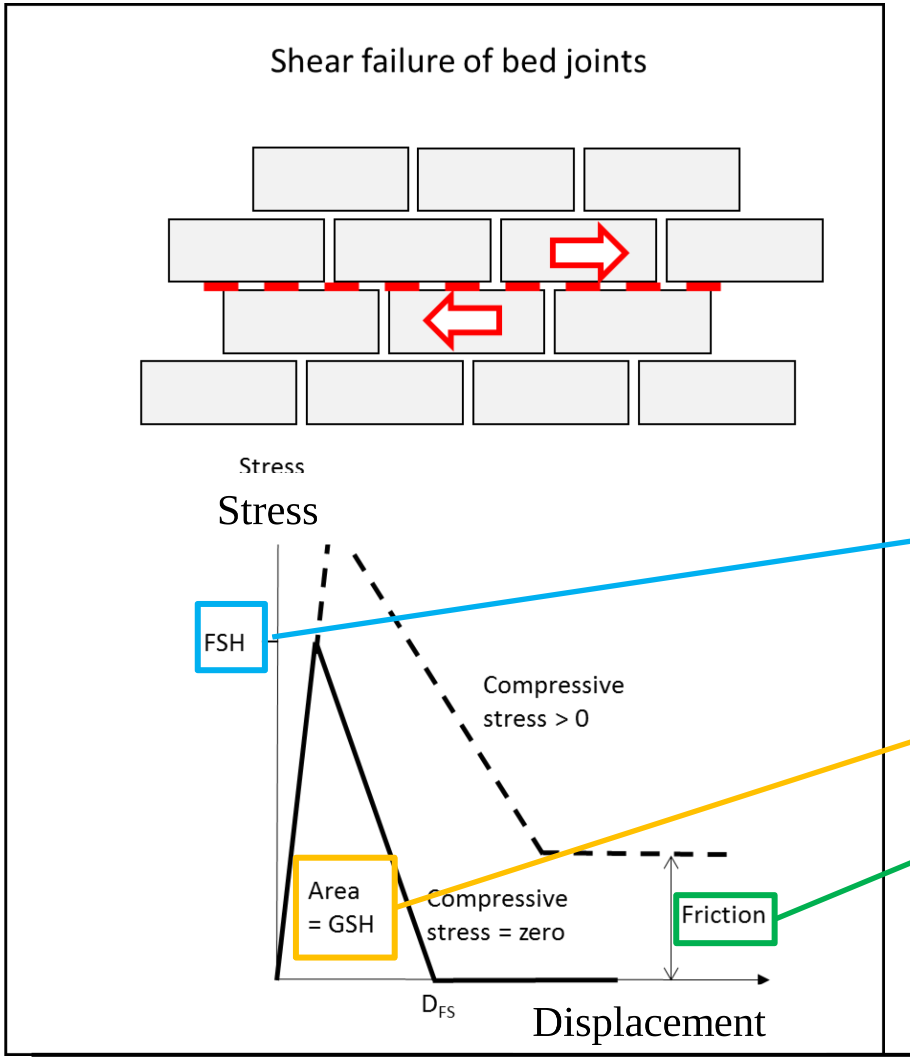
Bed joint shear input data



Cohesive term   Frictional term

$$\tau_{max} = (1\text{-}D_{BJ})*FSH + \tan(ANGH)*\sigma_y$$

Bed joint damage

Input parameters

Compressive normal stress

Default	0.0	0.0	0.0	0.0	0.0
Card 3	1	2	3	4	5
Variable	FTH	GTH	FSH	GSH	ANGH
Type	F	F	F	F	F
Default	0.0	0.0	0.0	0.0	0.0
Card 4	1	2	3	4	5

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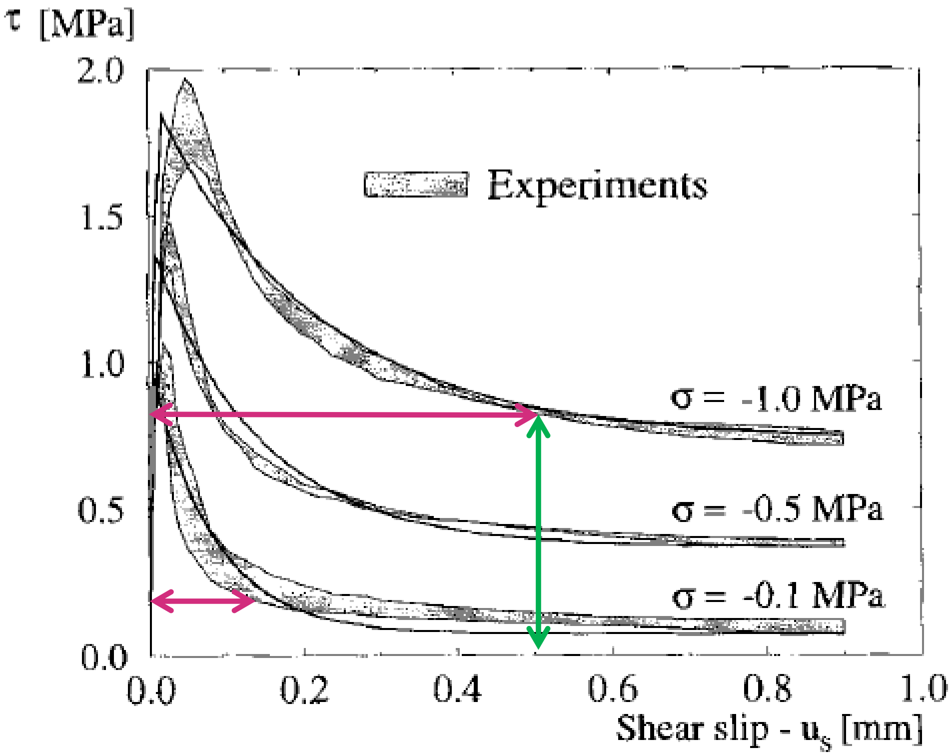
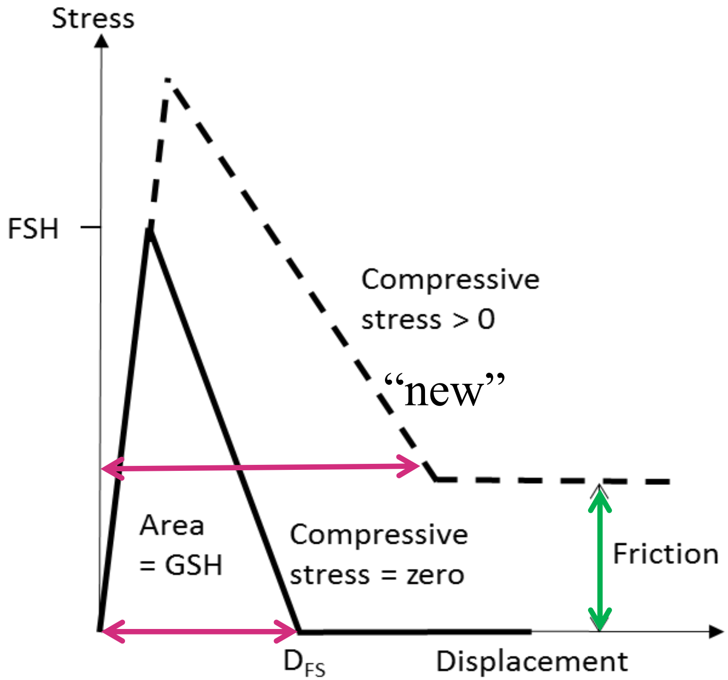
Bed joint shear





The input energy release rate GSH applies when the compressive stress on the joint is zero. The energy release rate is increased, i.e. greater displacement required to achieve complete loss of cohesion, in proportion to the compressive stress. This is in addition to increased energy absorption by friction. See manual pages for further details.

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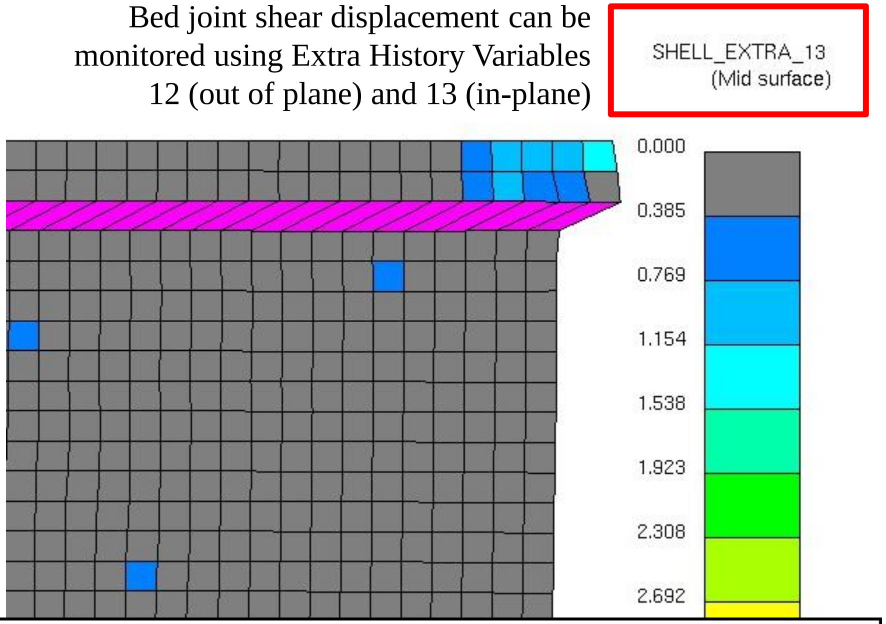
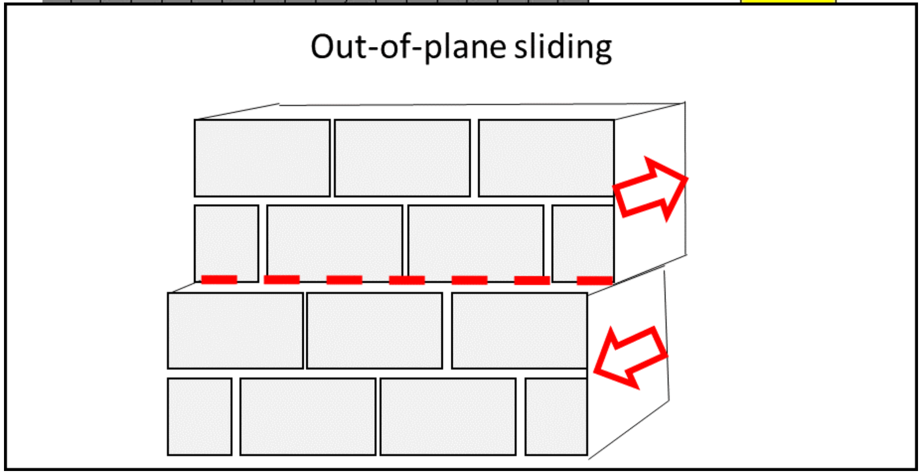
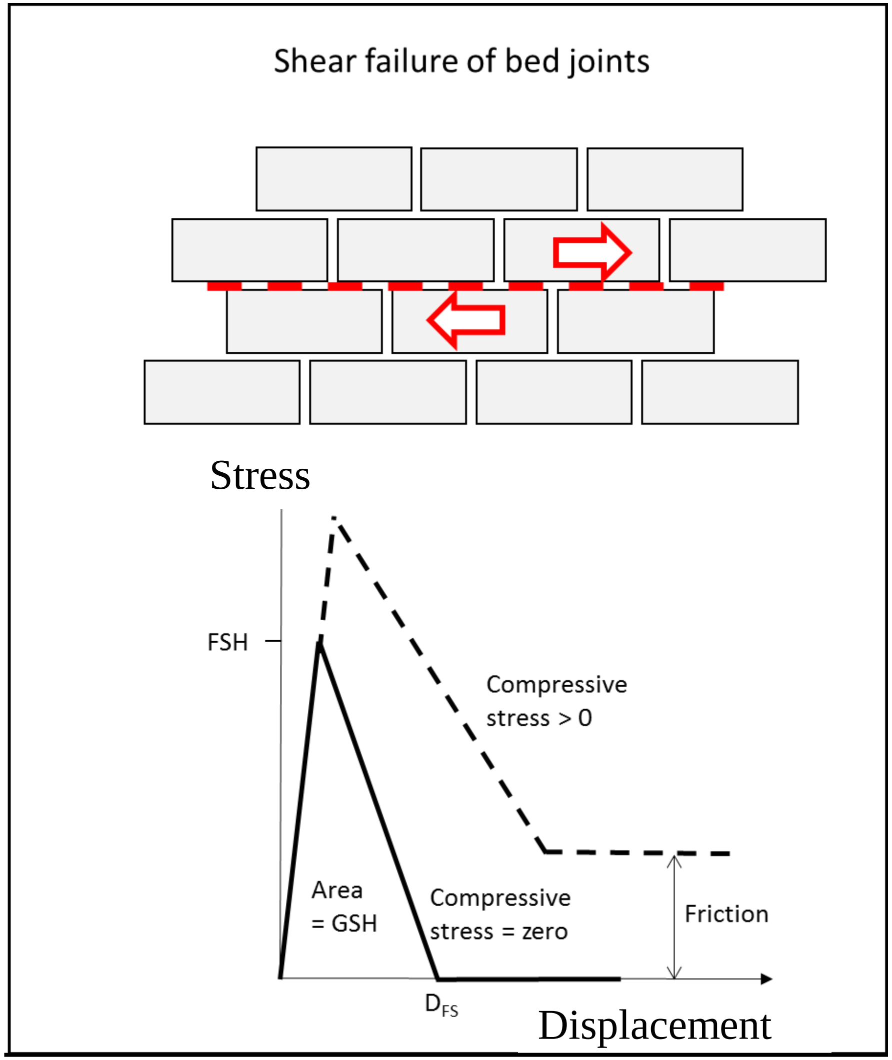
Bed joint shear (sliding, in-plane and/or out-of-plane)

Bed joint shear displacement can be monitored using Extra History Variables 12 (out of plane) and 13 (in-plane)

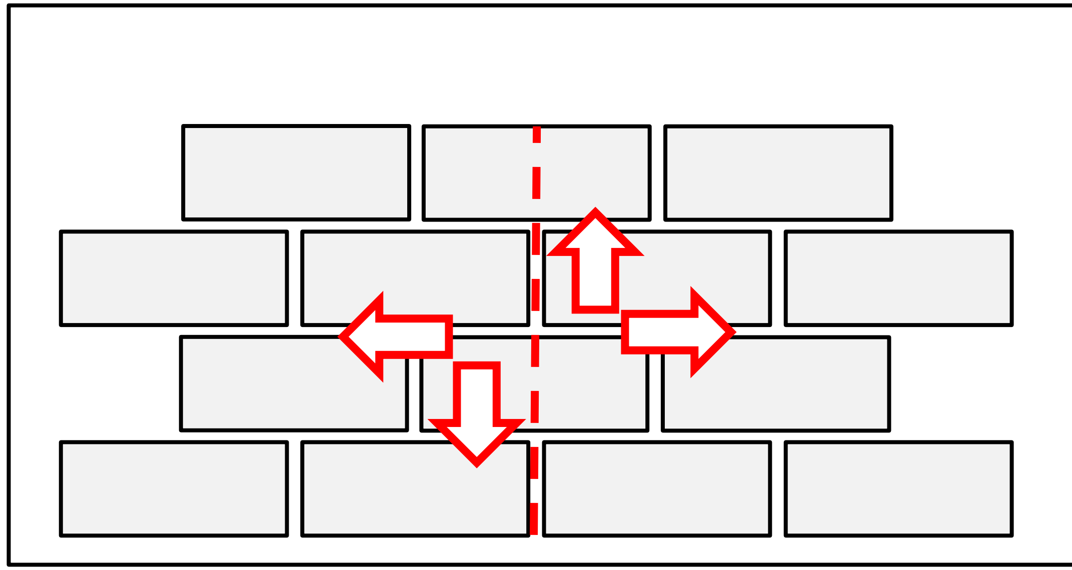






Vertical cracks?

Not often seen in real masonry, except when caused by toe-crushing. “TYPE=4” does not include this deformation mode (inputs are ignored, except that FTV, GTV have some influence on “mode 3” - next slide.).



Row\Col	1	2	3	4	5	6	7	8
1	<Label>	RO F	E F	PR F	FC F	HARDEN F	RATEFF F	TYPE F
	1	1785.0	5.091E9	0.14	5930000.0	0.0	10000.0	4.0
2	FTV F	GTV F	FSVT45 F	GSV F	ANGV45 F	FRCBRV F	FTD F	GTDANG F
	325000.0	15.0	140000.0	14.0	23.27	0.5	56000.0	3.0
3	FTH F	GTH F	FSH F	GSH F	ANGH F			KTH F
	325000.0	15.0	140000.0	14.0	23.27			2.0
4	-CSYS +Flt AOPT I	WBR F	HBR F	FTBR F	FSBR F	ANGBR F	SOFTFAC F	GMOD F
	0.0	0.214	7.2E-2	1.0E9	1.0E9	38.0	0.0	0.0

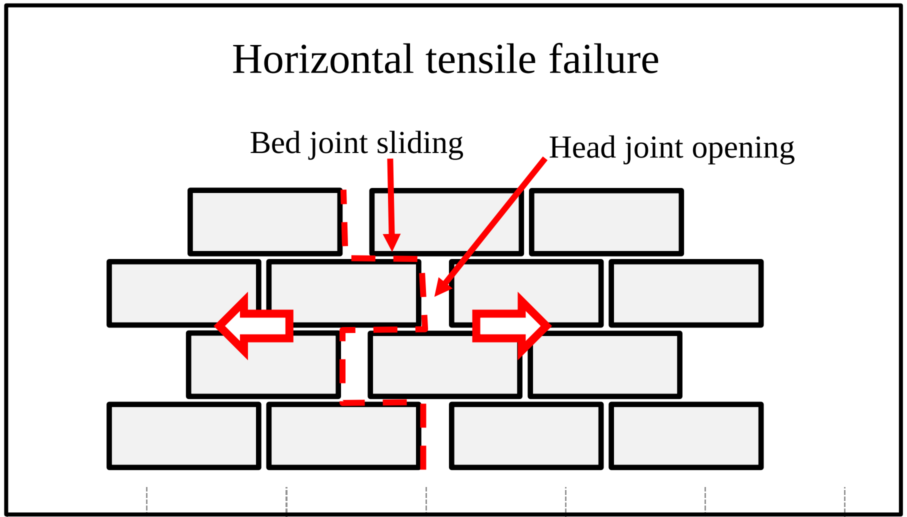
Irrelevant for Type=4

Irrelevant for Type=4

Horizontal tensile failure

Strength T_{max} based on combination of head joint tensile and bed joint shear properties (cohesion and friction).

$$T_{max} = FTV + (WBR/2*HBR)*(FSH + \mu.\sigma_v)$$



Horizontal tensile strength of masonry is typically 3-4 times the tensile strengths in vertical and diagonal directions.

Response of "TYPE 4" in this mode can be too weak – see Limitations section below.

Card 2	1	2	3	4	5	6	7	8
Variable	FTV	GTV	FSV	GSV	ANGV	FRCBRV	FTD	ANGD
Type	F	F	F	F	F	F	F	F
Default	0.0	0.0	0.0	0.0	0.0	0.0	1.e20	0.0

Card 3	1	2	3	4	5	6	7	8
Variable	FTH	GTH	FSH	GSH	ANGH	(blank)	(blank)	KTH
Type	F	F	F	F	F			F
Default	0.0	0.0	0.0	0.0	0.0			0

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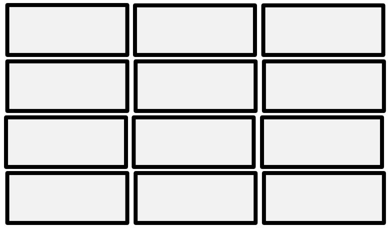
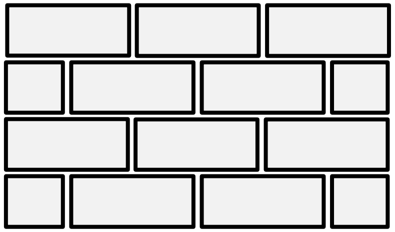
Type 1 versus Type 4

- **Type 1** is a simple joint failure model. OK for modelling masonry joints explicitly (separate bricks and mortar) or other simple situations. Capabilities are as per previous slides:
  - Bed joint tension and shear
  - Head joint tension and shear
  - Horizontal tensile mode
  - Crushing



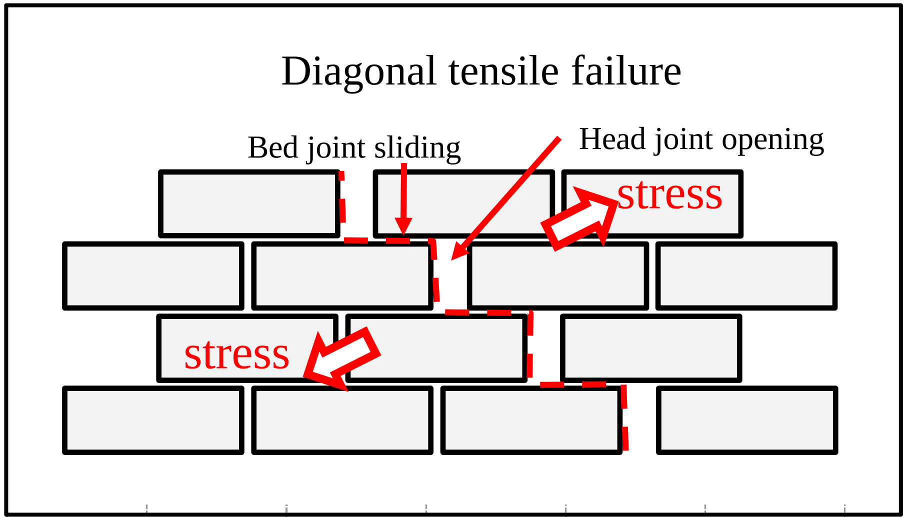
- **Type 4** is suitable for masonry walls. It has the capabilities on the previous slides, plus additional features illustrated on the next slides:
  - Diagonal tensile failure
  - Brick interlock effect
  - Collapse parameters for shear/diagonal modes



Diagonal tensile failure

Separate inputs control diagonal tensile failure. We typically set FTD=0.4*FSH, and ANGD=3, based on experience. However, that “experience” is based on a limited range of masonry types.

$$T_{max} = FTD + \sigma_v .\tan(ANGD)$$



Type 4 only

Card 2	1	2	3	4	5	6	7	8
Variable	FTV	GTV	FSV	GSV	ANGV	FRCBRV	FTD	ANGD
Type	F	F	F	F	F	F	F	F
Default	0.0	0.0	0.0	0.0	0.0	0.0	1.e20	0.0

Card 3	1	2	3	4	5	6	7	8
Variable	FTH	GTH	FSH	GSH	ANGH	(blank)	(blank)	KTH
Type	F	F	F	F	F			F
Default	0.0	0.0	0.0	0.0	0.0			0

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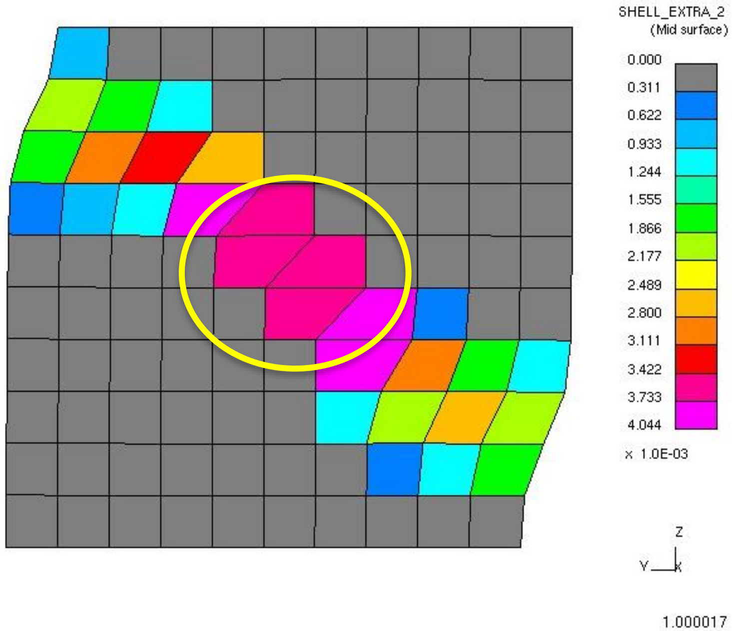
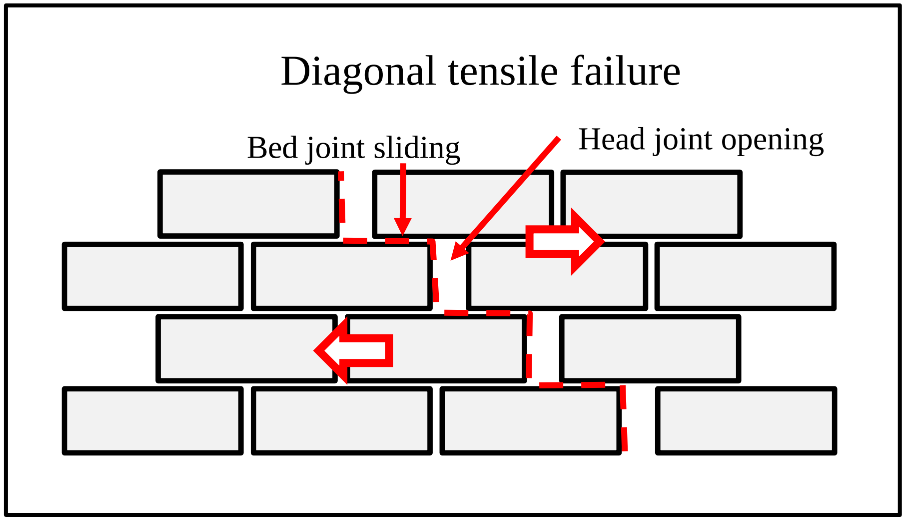
Diagonal tensile failure





This is how diagonal tensile failure typically looks in the LS-DYNA models. This image uses magnified displacements.

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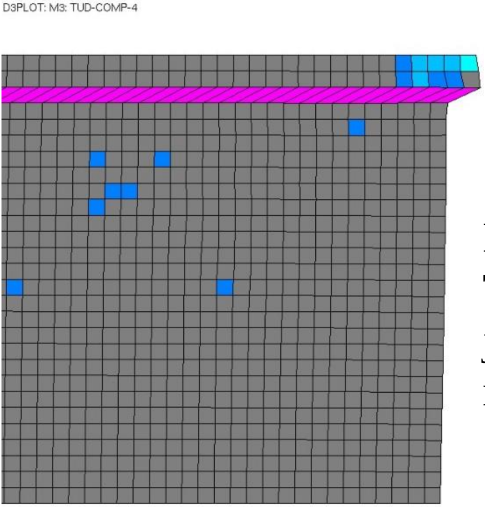
Why do we need special input for diagonal failure?

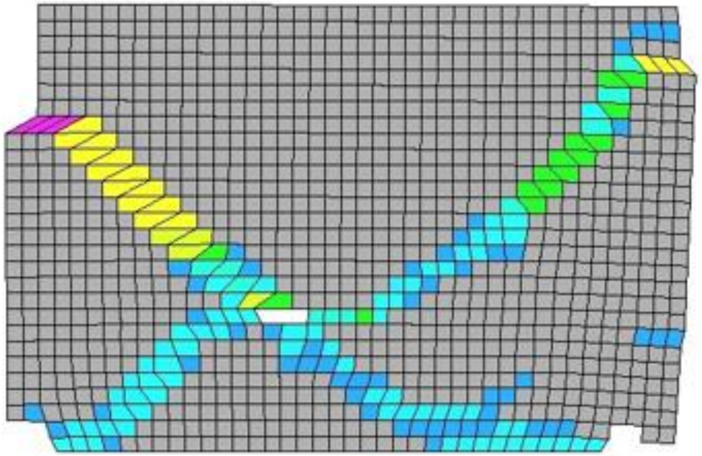
- Experiments rarely show bed joint sliding. Diagonal tensile failure is much more common. This is due to brick interlock effects.

- If only the simple joint failure modes are included, finite element models tend to show bed joint sliding => wrong implications for collapse.



LS-DYNA Type 1 (simple joint failure model)

LS-DYNA Type 4 with diagonal failure capability



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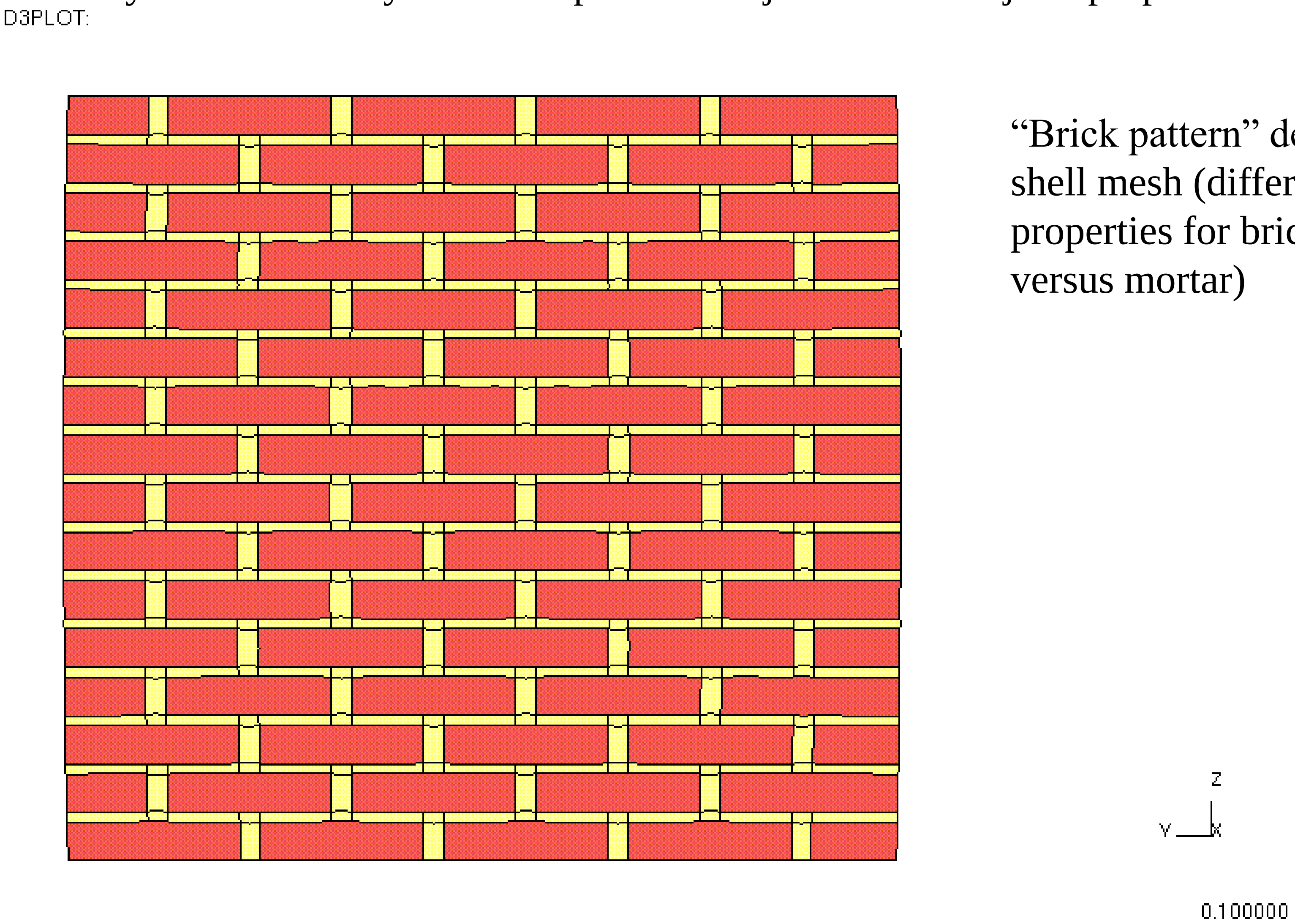
Why does diagonal failure need special inputs?

Surely we should only need to input the bed joint and head joint properties?



"Brick pattern" detailed shell mesh (different properties for bricks versus mortar)

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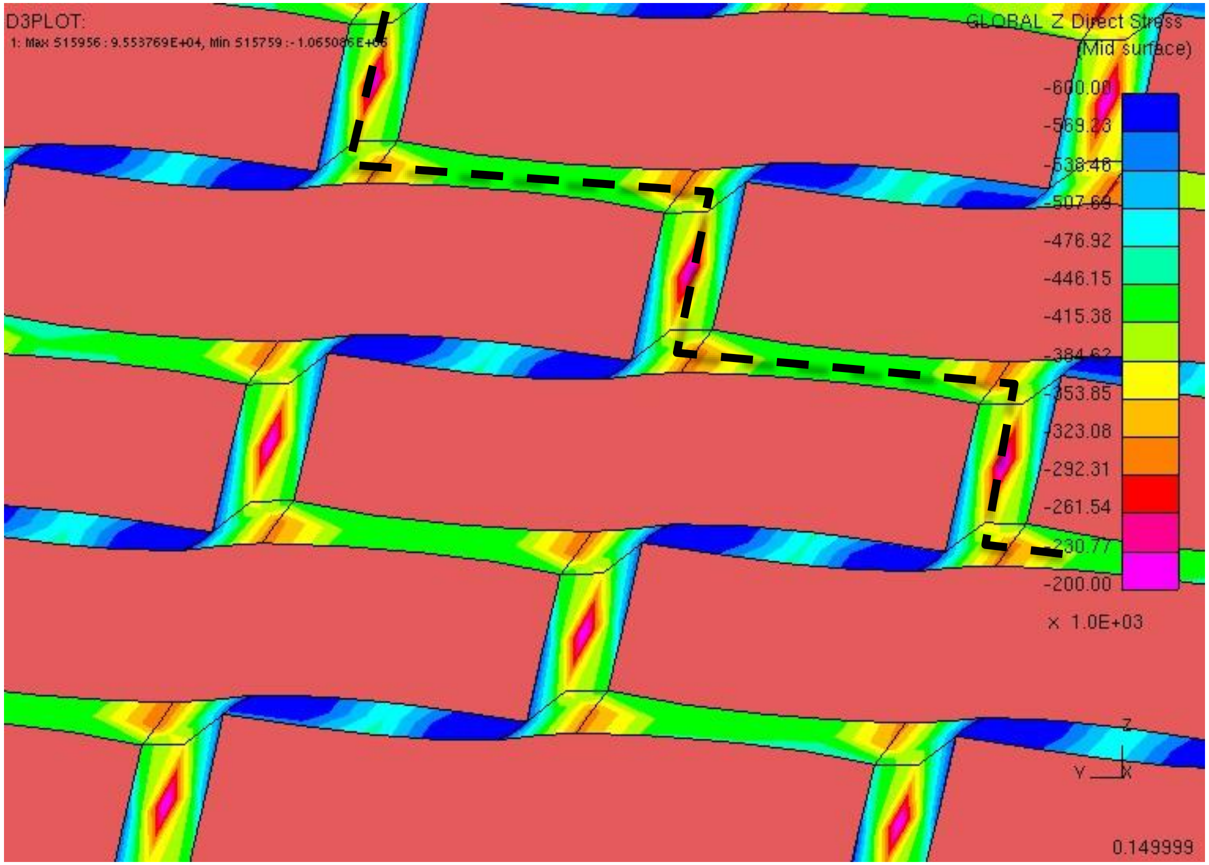
Why does diagonal failure need special inputs?

Contours of vertical stress in joints



Bed joint stress is non-uniform – half heavily loaded, half lightly loaded. Failure occurs through the portions that are lightly loaded.

Uniform shell mesh sees only the average stress - we have to work around this limitation

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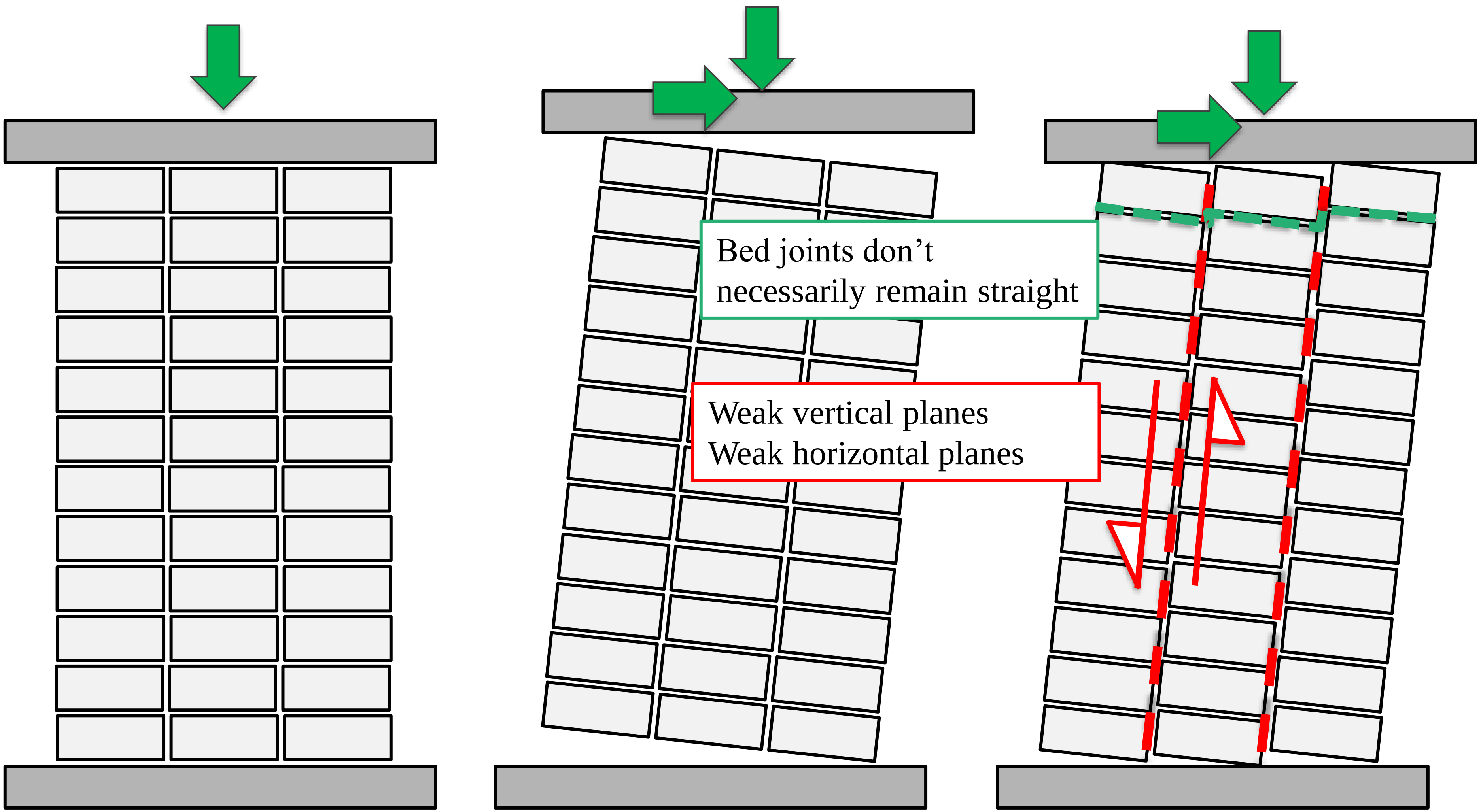
How would walls behave without brick interlock?



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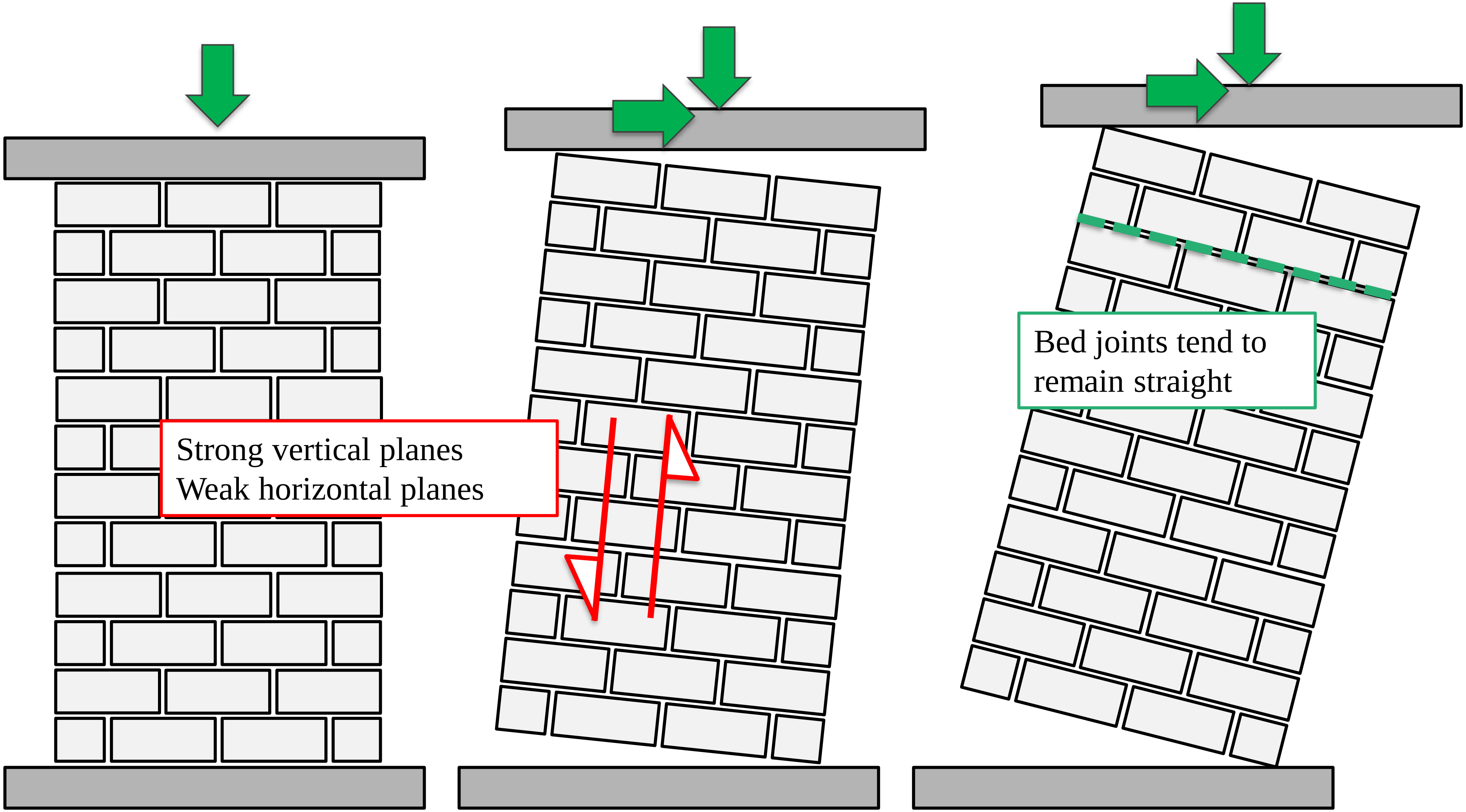
With brick interlock…



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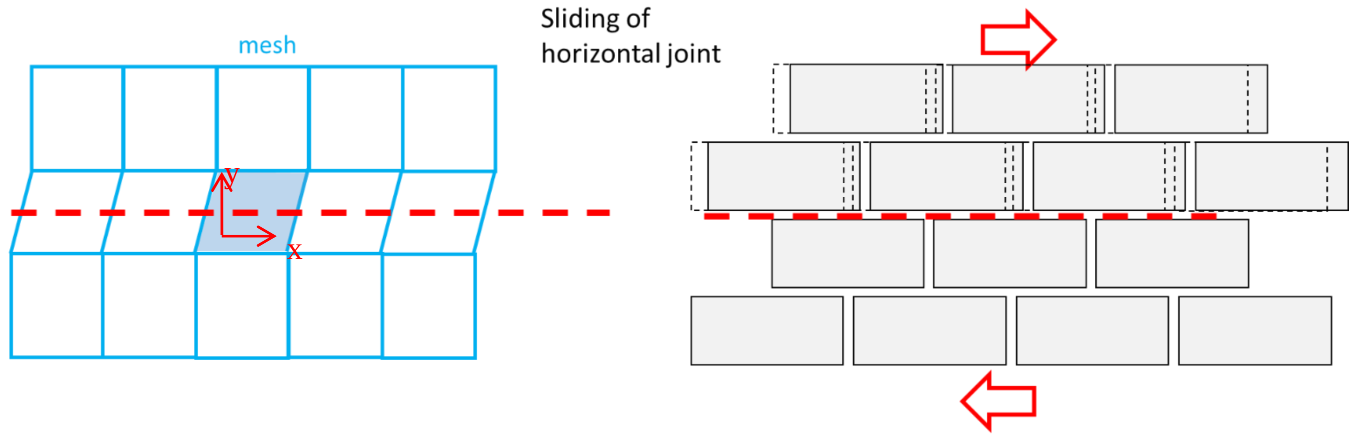
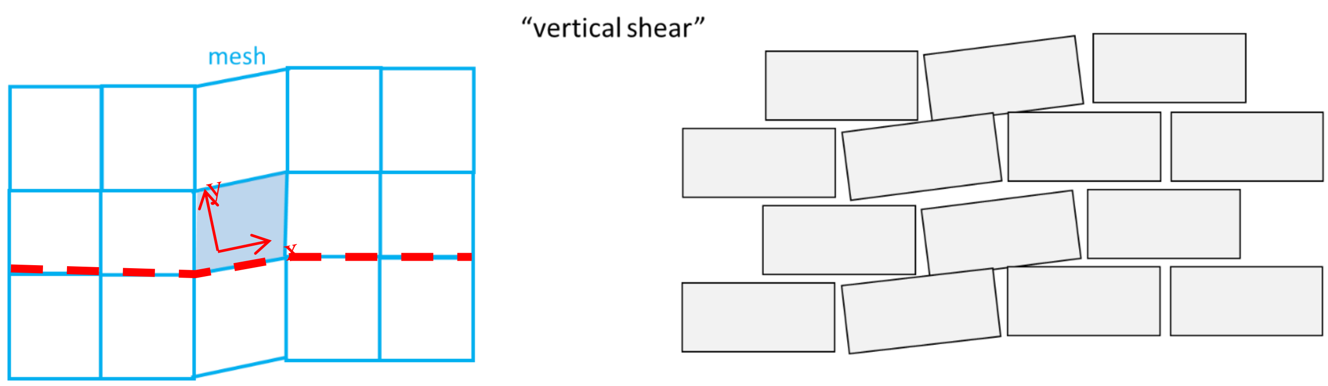
Brick interlock effect

Shear on horizontal plane versus shear on vertical plane: Finite element programs can’t tell the difference.
Both deformation patterns below consist of “shear strain” plus or minus some rigid body rotation

Real masonry is much stronger at resisting shear on vertical planes. Interlock effect => brick cannot rotate easily relative to its neighbours.



Easy



Difficult

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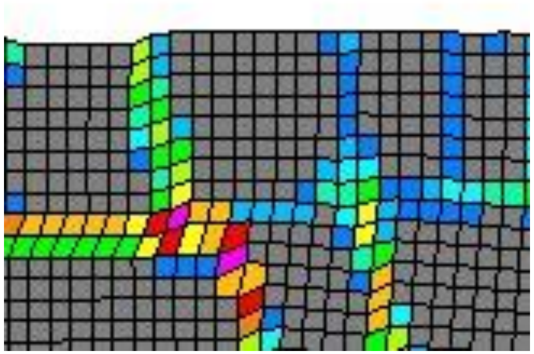
Modelling the brick interlock effect

KTH input provides additional stiffness that keeps the bed joints straight (bricks being unable to rotate relative to their neighbours). Recommended value: 2. Input value is non-dimensional. Inside the code, the stiffness scales with shear modulus.

Card 3	1	2	3	4	5	6	7	8
Variable	FTH	GTH	FSH	GSH	ANGH	(blank)	(blank)	KTH
Type	F	F	F	F	F			F
Default	0.0	0.0	0.0	0.0	0.0			0

Type 4 only

If KTH is omitted, expect to see unrealistic near-vertical cracks like this:



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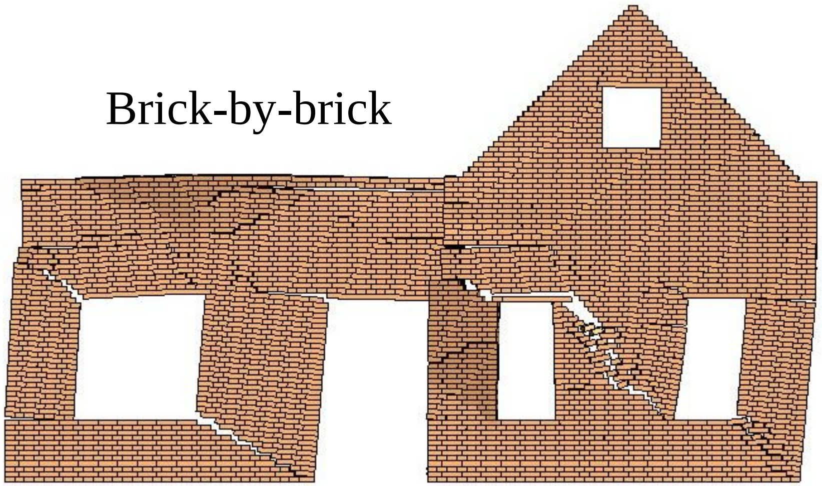
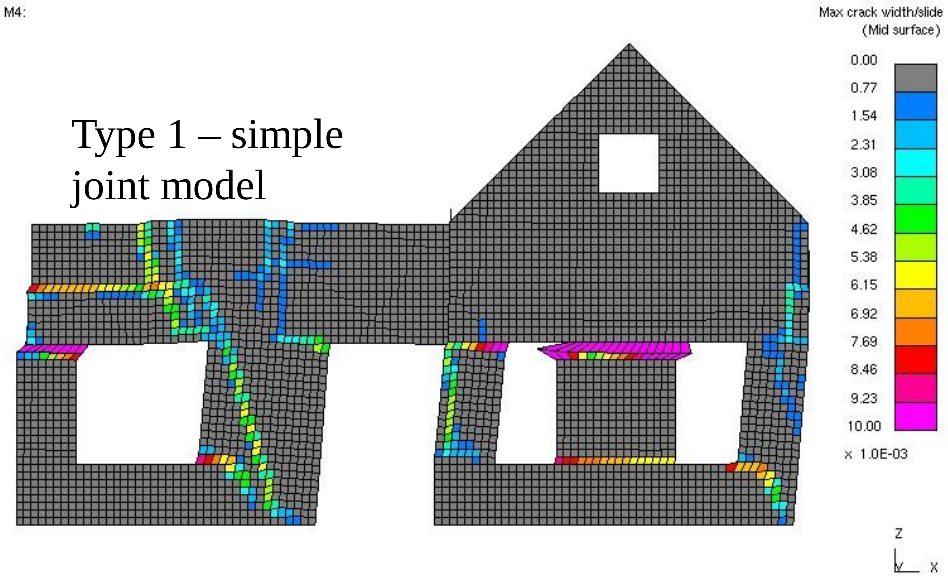
Type 1 versus Type 4

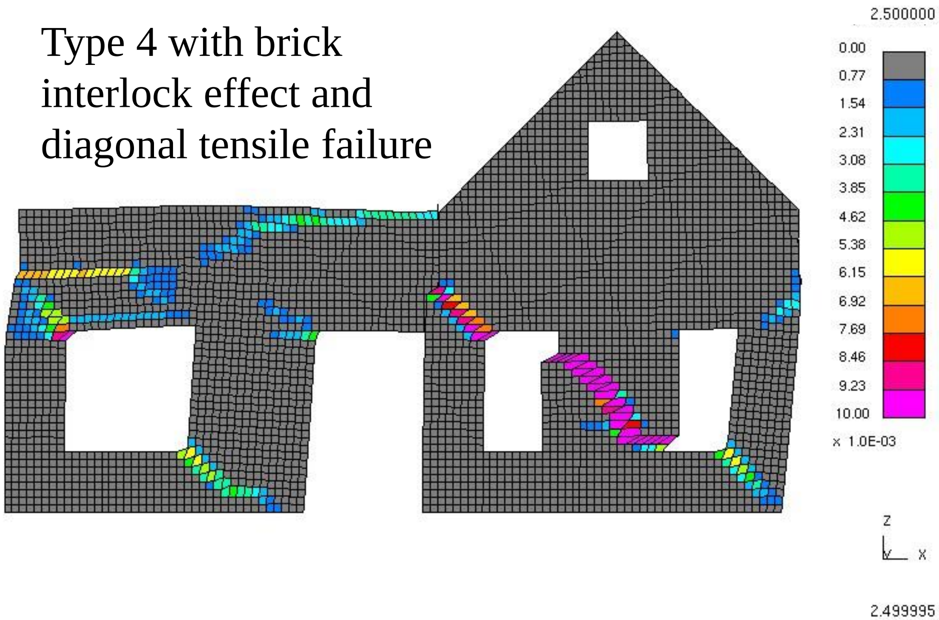
Brick-by-brick



Type 1 – simple joint model



Type 4 with brick interlock effect and diagonal tensile failure



Applied displacement 20mm

Deformations x10

ARUP

AOPT

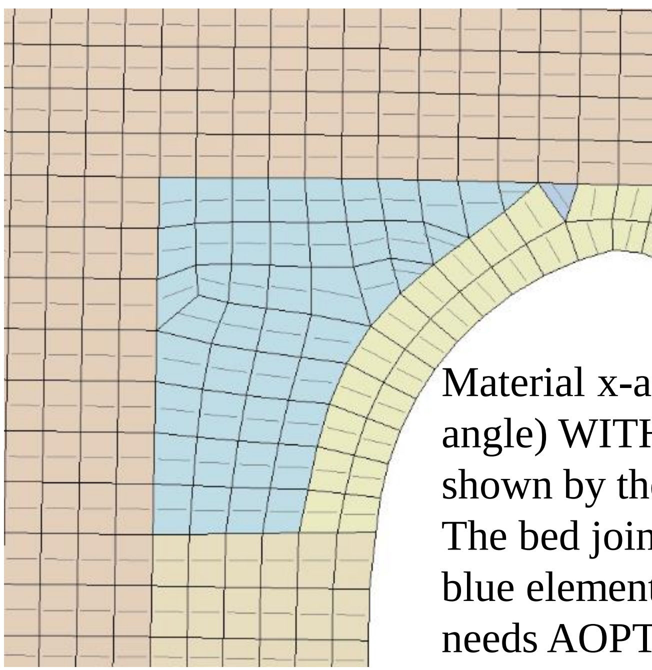
- MAT_SHELL_MASONRY input field AOPT + cards 4a, 4b enable bed joints not aligned to element local X – intended for meshing non-rectangular walls
- Watch out: Brick interlock effect KTH cannot be used with AOPT
- Limit use of AOPT to the elements where it is absolutely needed
- For the meaning of AOPT and associated inputs, see MAT_002 in the main LS-DYNA keyword manual…

AOPT

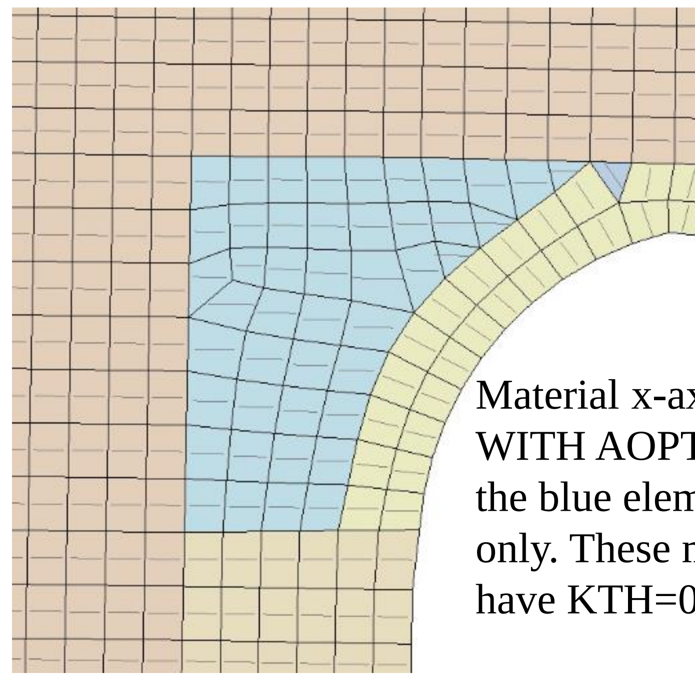
AOPT=2: use fixed global vector (A1, A2, A3) for material x-axis

Example:

material x-axis is (1, 0, 0)



Material x-axis (bed joint angle) WITHOUT AOPT, shown by the grey lines). The bed joint angles in the blue elements are random - needs AOPT

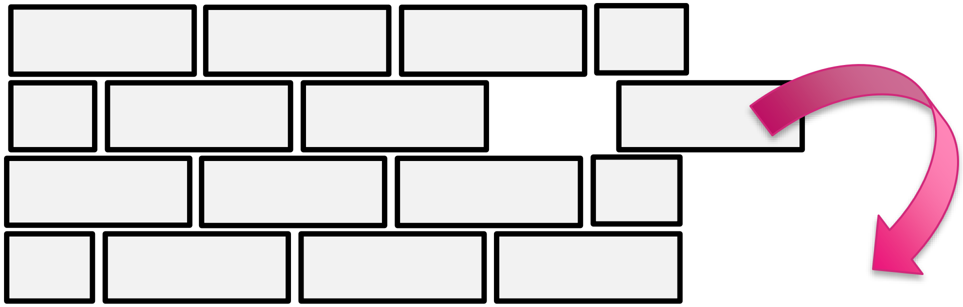


Material x-axis WITH AOPT for the blue elements only. These must have KTH=0.

ARUP

Damage & collapse – default assumptions

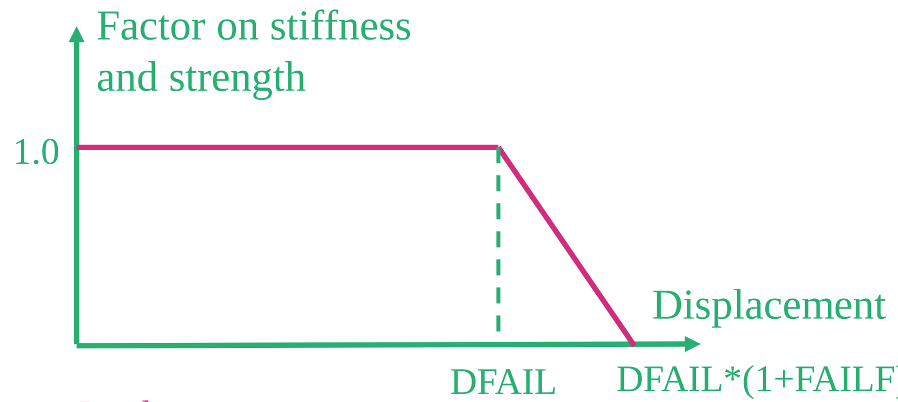
- Real life: pieces of masonry may fall out, or a whole wall may collapse. How can we assess displacement capacity?
- LS-DYNA: the material model includes algorithms for damage and element deletion.
- By default, an element is deleted automatically if the deformation displacement exceeds certain limits that scale with the input brick dimensions:
  - In-plane sliding/diagonal tension sliding > half the brick length
  - Out-of-plane sliding > half the brick thickness
  - Crack opening > half the brick height



ARUP

Damage & collapse – basic options

- Default "failure displacements" can be overridden on Card 5
- Damage law: softening begins at DFAIL. Element deleted at 1.1*DFAIL (actually (1+FAILF)*DFAIL)
- Of the parameters on Card 5, we normally use only DFAILC



Card 5	1	2	Bed joint opening	In-plane shear	In-plane shear damaged bricks	Out-of-plane shear	Crushing	Damage law
Variable	EUD0	EUD1	DFAILB	DFAILI	DFAILIC	DFAILO	DFAILC	FAILF
Type	F	F	F	F	F	F	F	F
Default	1.e20	1.e20	HBR	WBR/2	WBR/4	Thick/2	HBR/2	0.1

Damage & collapse – how to model it

- The **default values are not sufficient** to achieve accurate predictions of the drift at which walls or buildings collapse.

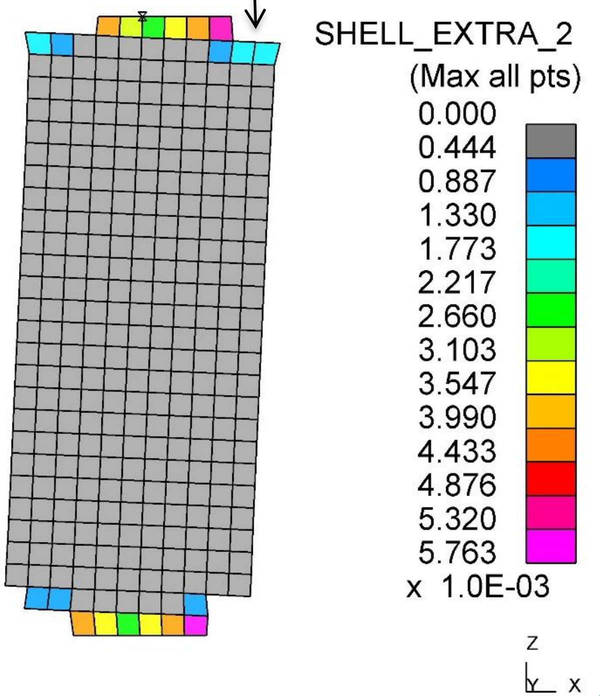
- The 2015 component tests showed near-collapse of specimens for two main reasons:
  - Slender walls collapsed due to toe-crushing.
    - Modelled by the post-peak downward slope of the compressive stress-strain curve together with the parameter DFAILC. The role of DFAILC is to delete the element when the stress strain curve approaches zero.
  - Squat walls collapsed (apparently) due to an accumulation of shearing damage.
    - Modelled by input parameters DFAILA and WFAIL on Card 6.

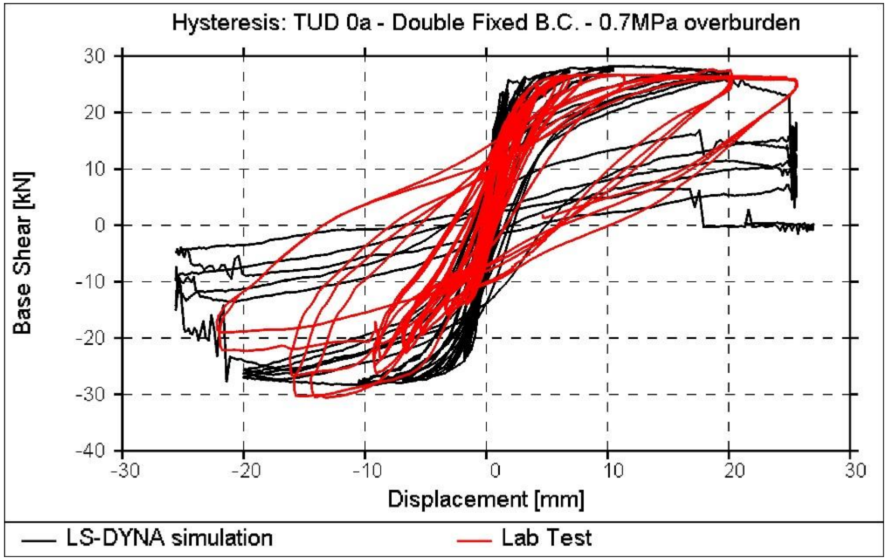
ARUP

Collapse due to toe-crushing (slender walls)

Collapse occurs when corner element is crushed beyond its compressive capacity

Elements deleted when failure criterion is reached



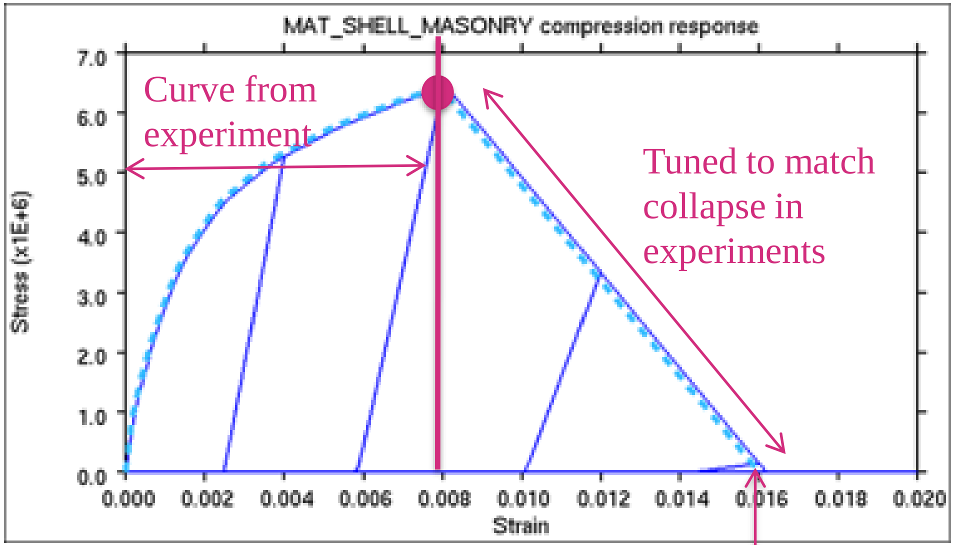


ARUP

Collapse due to toe-crushing (slender walls)

Curve from experiment is used up to maximum load. Down-slope is added and tuned to match collapse in experiments (mesh-size dependent).

DFAILC (length units) = (strain/1.1) * typical element height

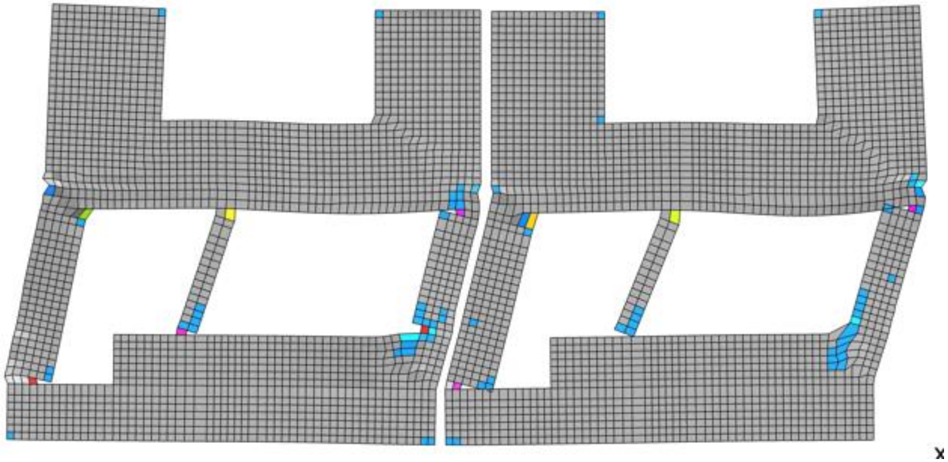


Card 5	1	2	3	4	5	6	7	8
Variable	EUD0	EUD1	DFAILB	DFAILI	DFAILIC	DFAILO	DFAILC	FAILF
Type	F	F	F	F	F	F	F	F
Default	1.e20	1.e20	HBR	WBR/2	WBR/4	Thick/2	HBR/2	0.1

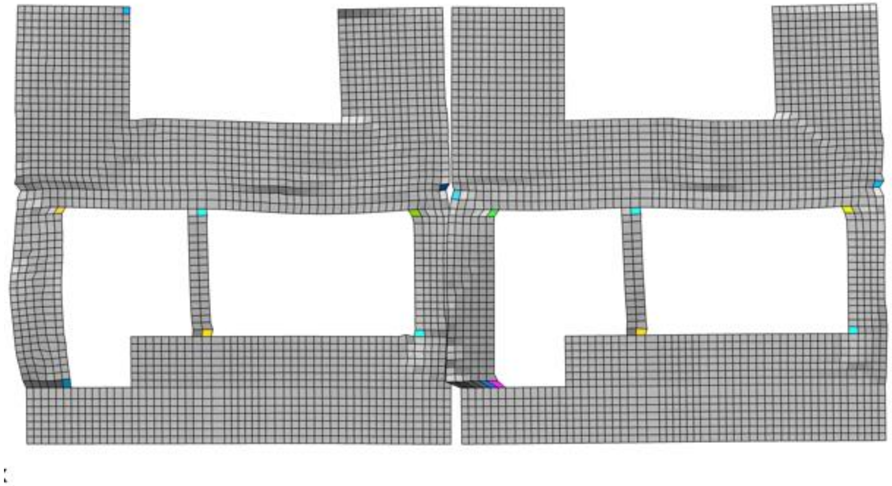
ARUP

Importance of toe-crushing (compression-induced collapse)

- With toe-crushing inputs



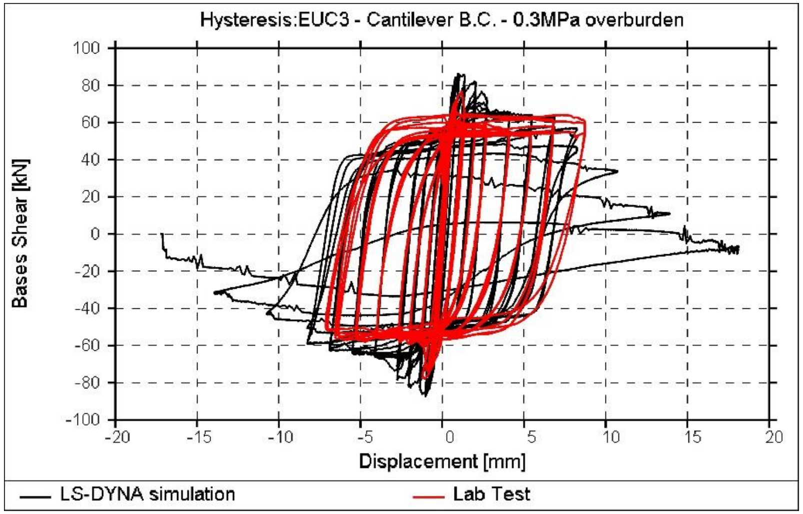
- Without toe-crushing inputs

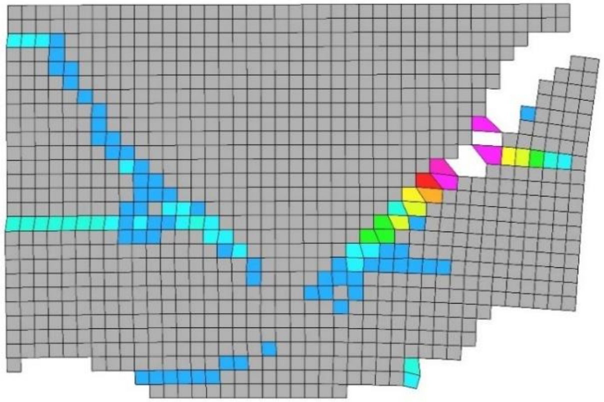


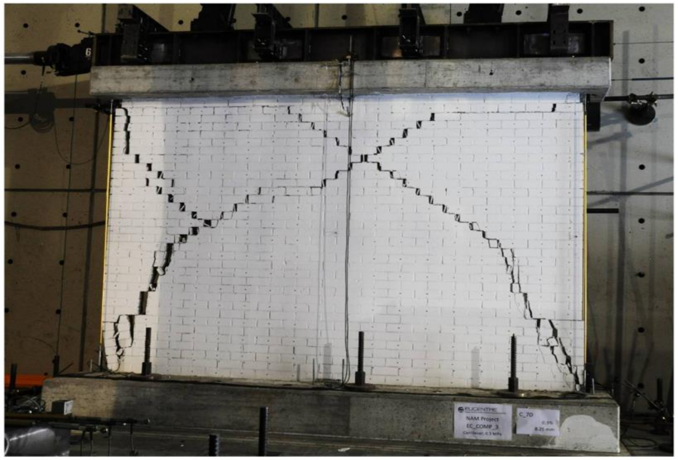
Collapse due to accumulated shear damage

Squat walls typically collapse due to accumulated damage from repeated shearing. Tune these parameters to match collapse in experiments.

- DFAILA: failure due to accumulated shear displacement, independent of stress
- WFAIL: failure due to “grinding energy”: compressive stress x shear displacement integral)



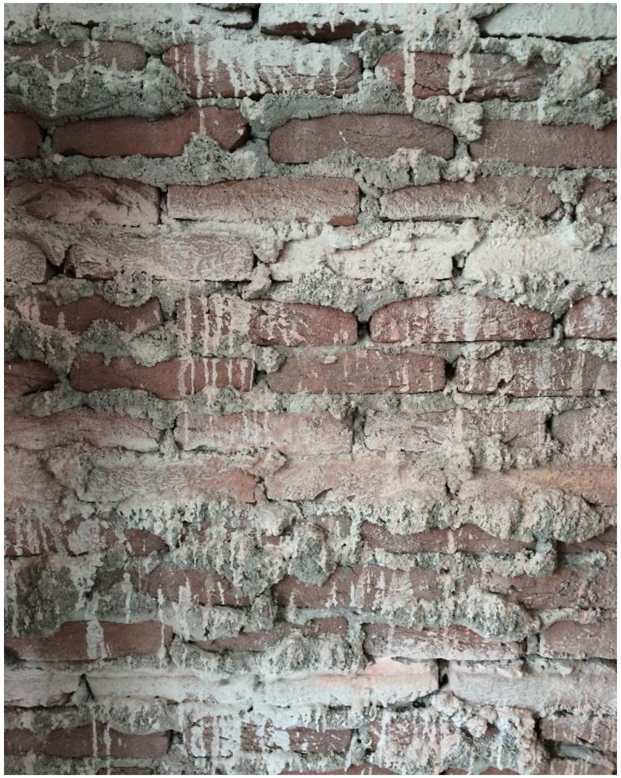




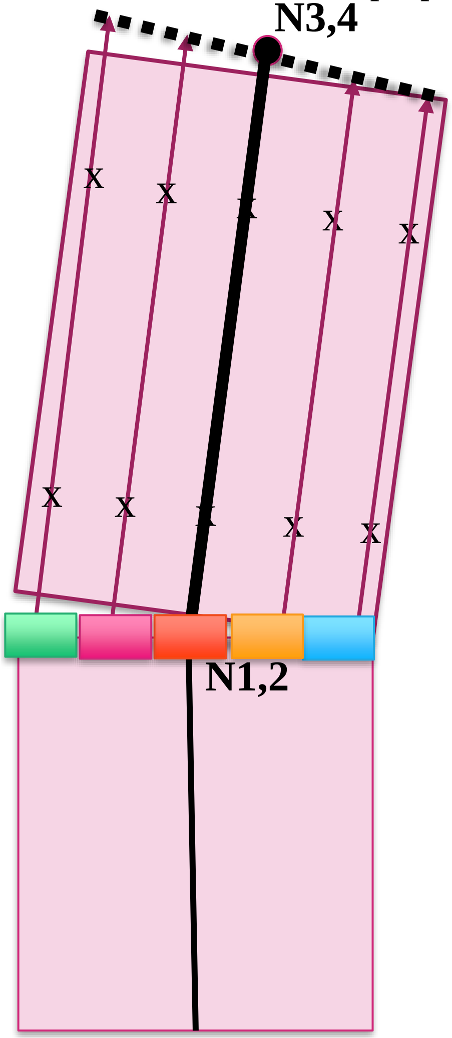
ARUP

Out-of-plane bending – mortar variability

- Mortar quality may vary through thickness
- *PART_COMPOSITE with different Material ID in each layer



Each through-thickness point can have different material properties



ARUP

Damping

- *DAMPING_PART_STIFFNESS with coefficient 0.05 is recommended for *MAT_SHELL_MASONRY, to damp out high-frequency oscillations associated with slip-stick behaviour of the joints.
- This damping card may in turn demand a reduction of timestep: TSSFAC=0.7 if the timestep-controlling elements are MAT_SHELL_MASONRY.
- Additionally, *DAMPING_FREQUENCY_RANGE_DEFORM with damping ratio 0.005 to 0.02 may be applied to the whole building, to provide damping for the elastic response.

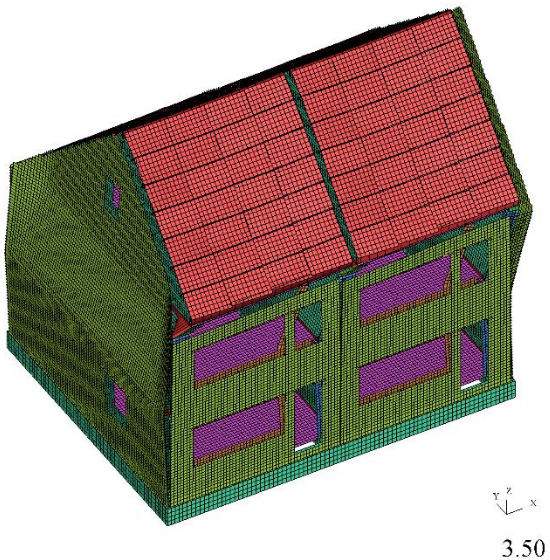
Coarse meshes:
Reducing the effect of element size

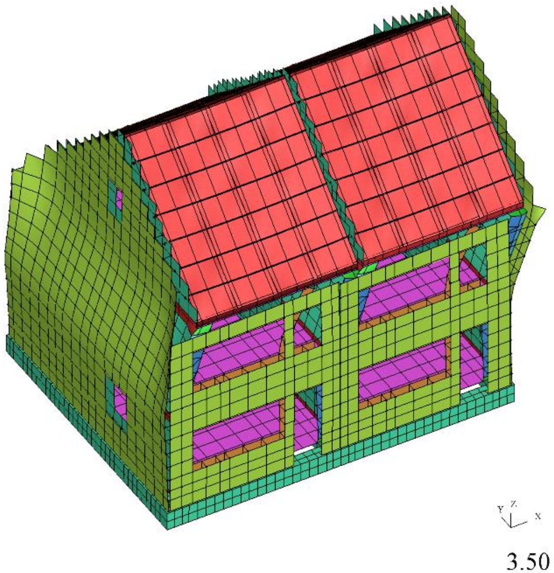
ARUP

Motivation

Superstructure models with elements around 0.4-0.6m can run 30x quicker than 0.1m models. As well as the obvious practical advantage, there is a technical reason why it might be better to do this: we can run a much greater number of variant models, sensitivity studies, etc and obtain information about the variability of the results.

But all this supposes that we can obtain similar answers with fine (0.1m) and coarse (0.4-0.6m) models…





ARUP

Input parameter REFSIZE

We have calibrated the material properties with an element size of 0.1m. By inputting REFSIZE=0.1, we are telling LS-DYNA to try to adjust the material parameters element-by-element, such that the results are as similar as possible to a 0.1m mesh. The adjustments made by LS-DYNA will depend on the actual size of each element.

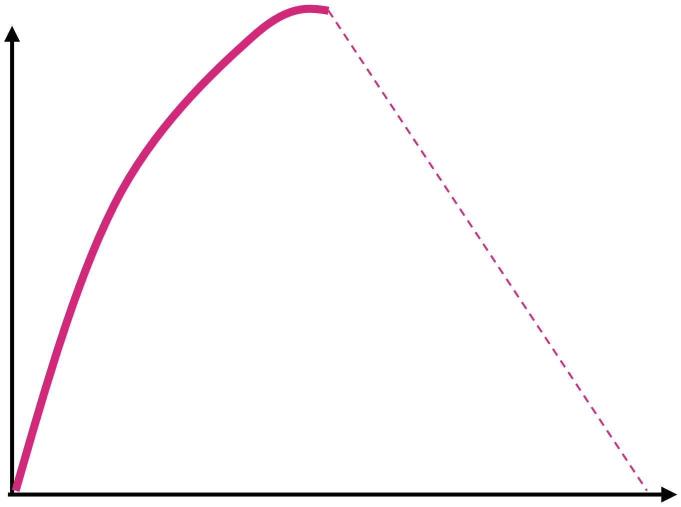
Thus, we need only one set of material data to cover any element size, provided we have input REFSIZE.

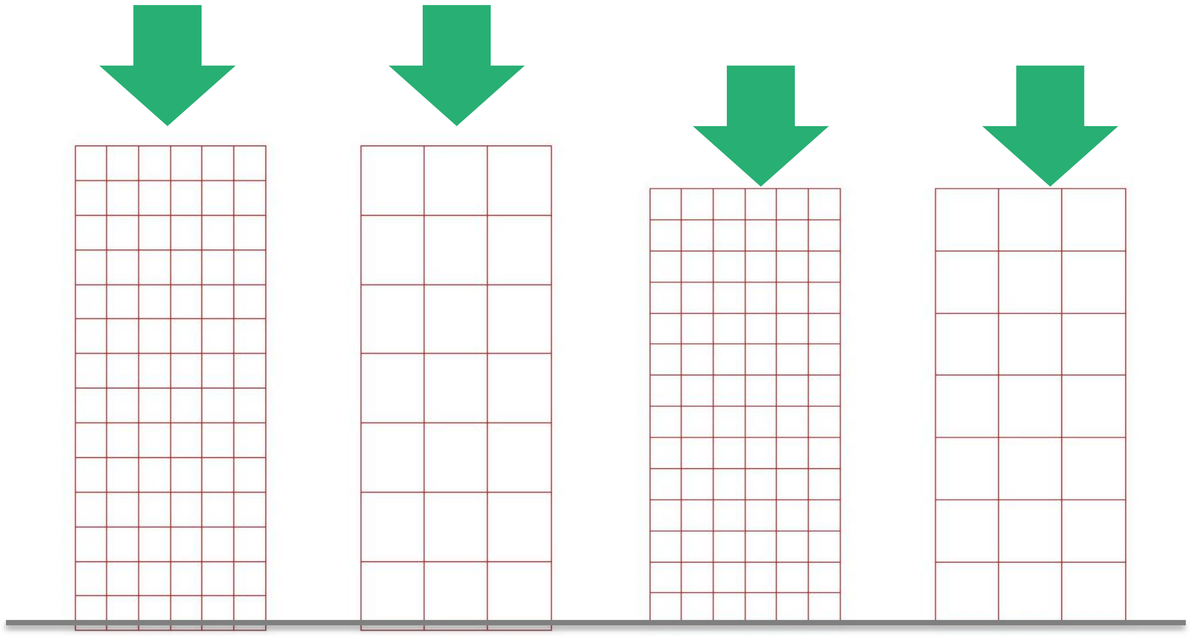
Card 6	1	2	3	4	5	6	7	8
Variable	DIAGOPT	RESID	REFSIZE	blank	DFAILA	blank	WFAIL	blank
Type	F	F	F		F		F	
Default	0	0.1	0		0		0	

ARUP

Actions of REFSIZE

- Consider a simple compression test.
- While in the hardening regime, strains are uniformly distributed up the height of the specimen. In this regime, the same compressive stress-strain input curve should give the same result, whatever the mesh size.

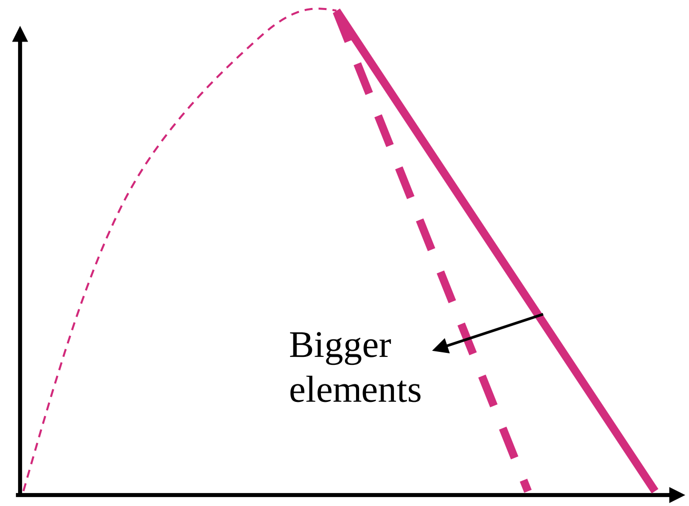


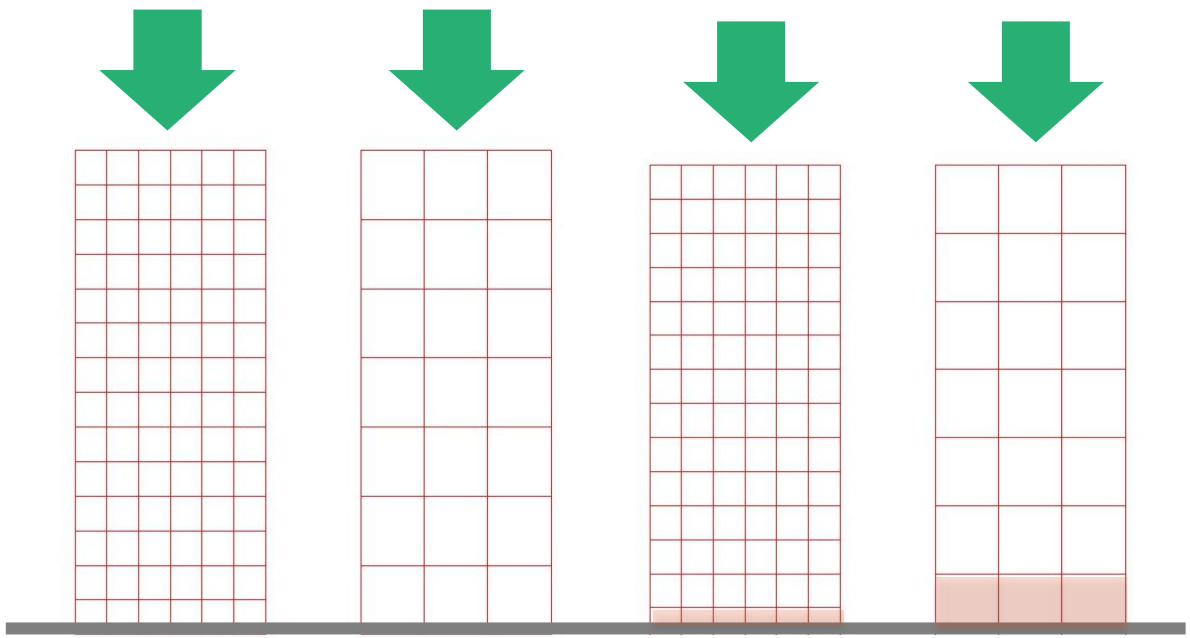


ARUP

Actions of REFSIZE

- When in the softening regime, strains tend to concentrate into one row of elements. Results become mesh size dependent.
- We can counteract this by changing the slope of the softening part of the curve (steeper for larger elements).

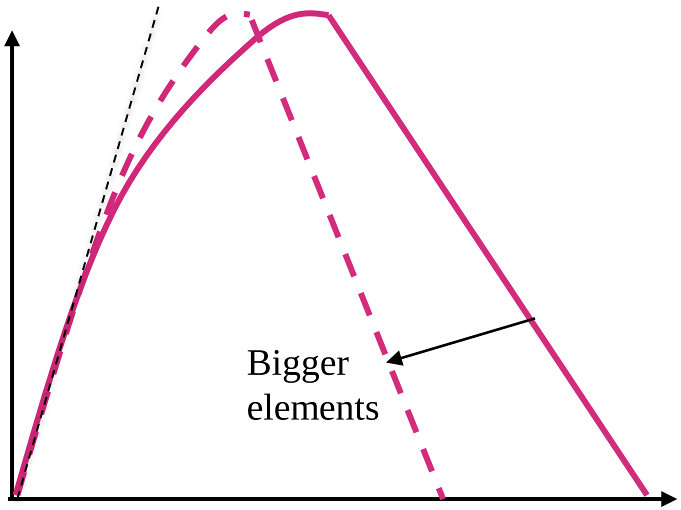


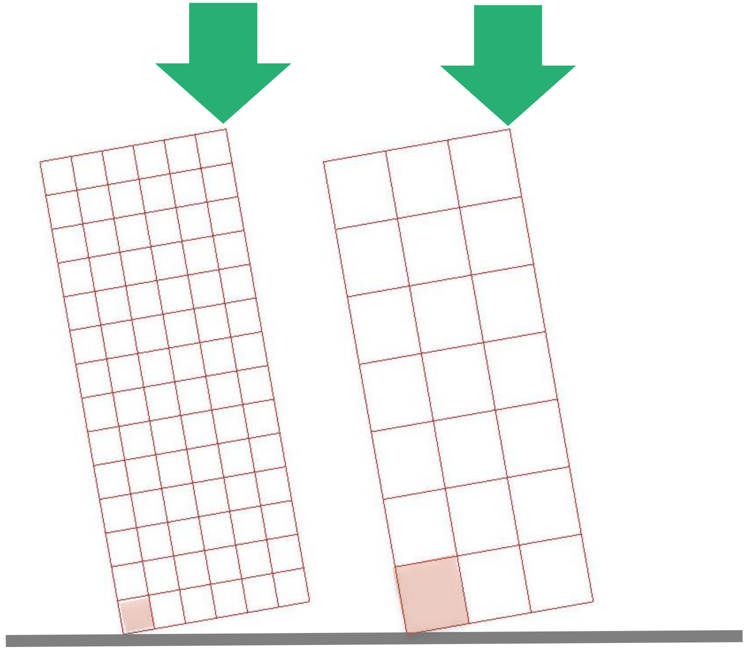


- This is part of the (automatic) action of REFSIZE, but it isn't the whole story…

Actions of REFSIZE

- For walls under uniform compressive loading, stresses tend to be below 1 MPa, in the elastic regime. When the walls undergo rocking, much higher stresses occur in the corner. Even in the hardening regime, strains are somewhat concentrated in one element.



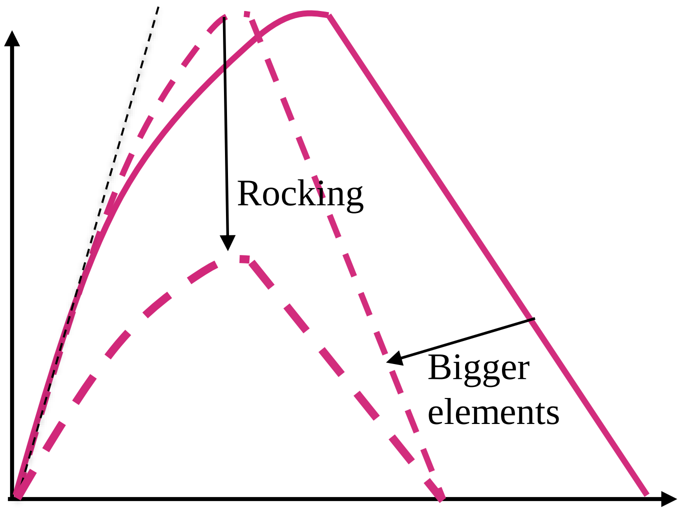


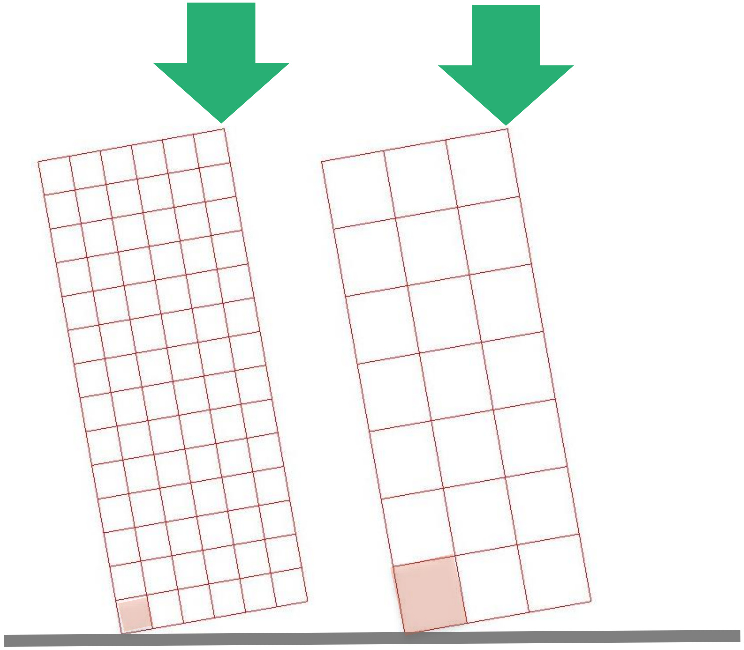
- REFSIZE automatically corrects for this, by compressing the plastic part of the stress-strain curve in proportion to element size.
- Although intended to improve modelling of the corners of walls undergoing rocking, this adjustment is always applied irrespective of the actual type of loading.

ARUP

Actions of REFSIZE

- Toe-crushing collapse depends on the stress in the corner-most integration point reaching the maximum stress on the curve. Therefore, collapse is a function of vertical load as well as drift. However, if the corner element is wider, it will have a smaller stress for the same vertical load.

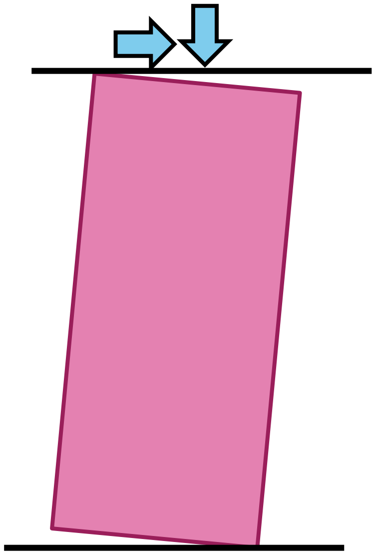


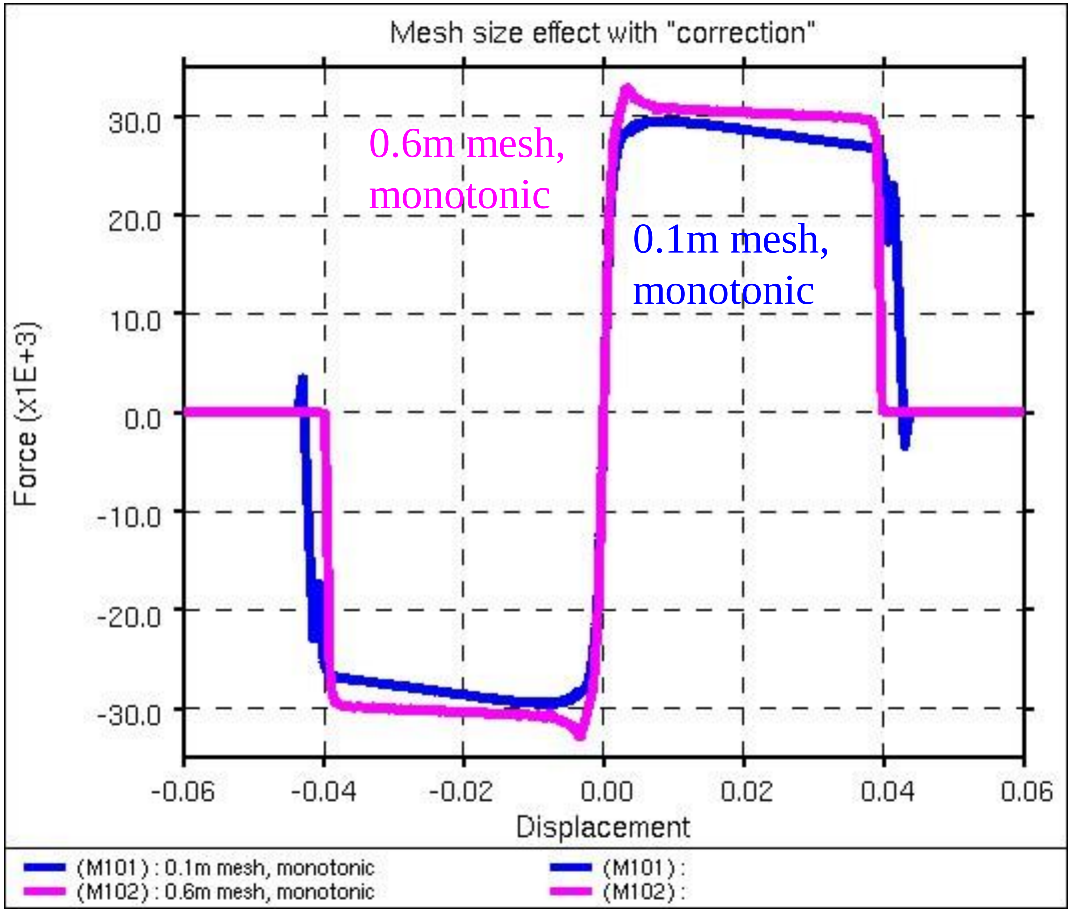


- REFSIZE automatically corrects for this, by scaling down the stress-strain curve as a function of drift and element size. Drift is calculated within the element, based on crack opening at the neighbouring integration point. Thus, no adjustment is made when under uniform compression because no integration points have open cracks.

ARUP

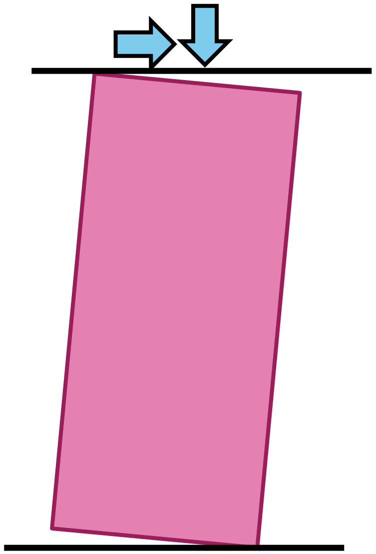
Mesh size corrections: rocking

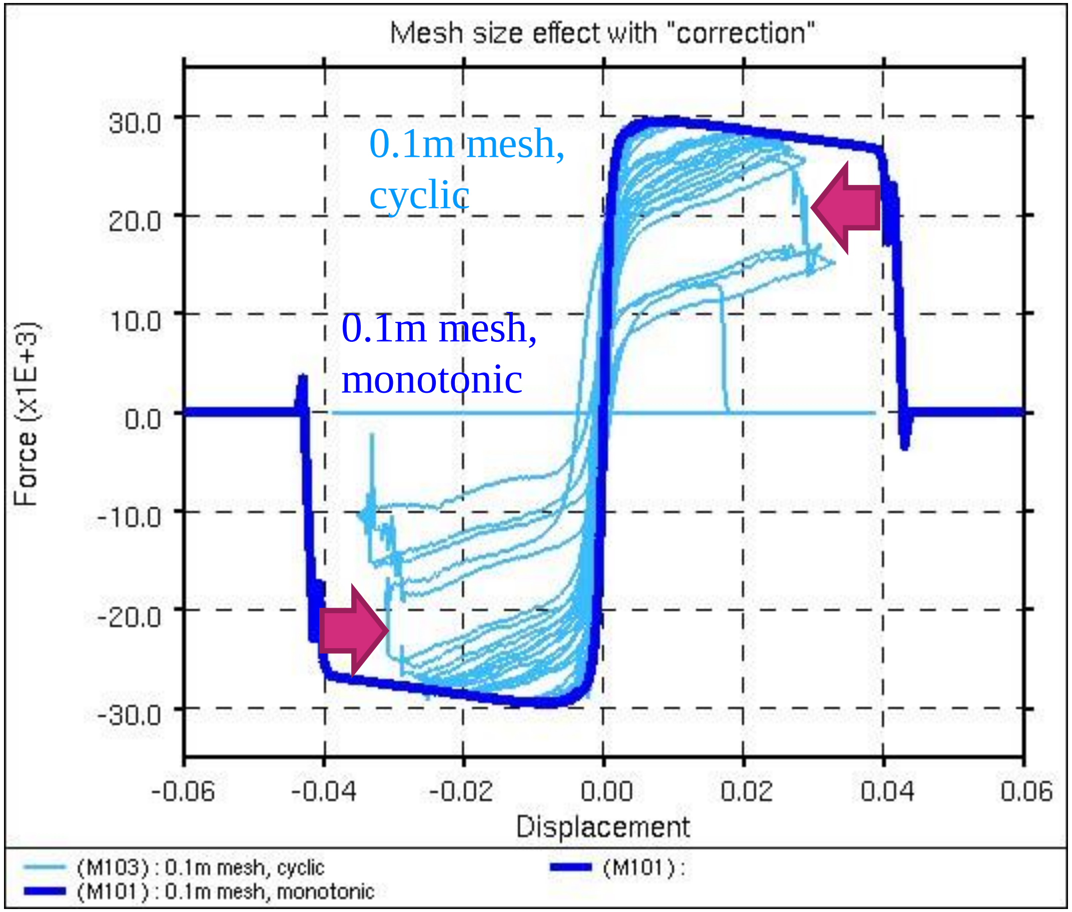




Monotonic loading: collapse due to load concentration on one corner.
Mesh size effect correction (REFSIZE) works well.

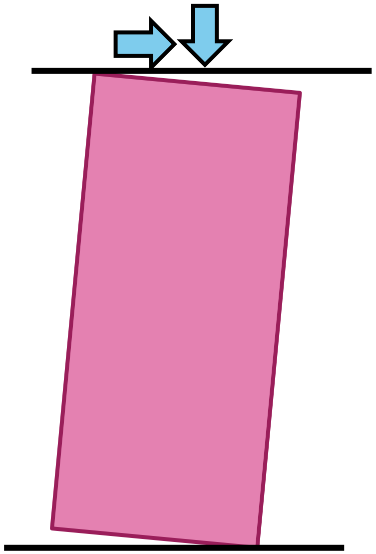
Mesh size corrections: rocking

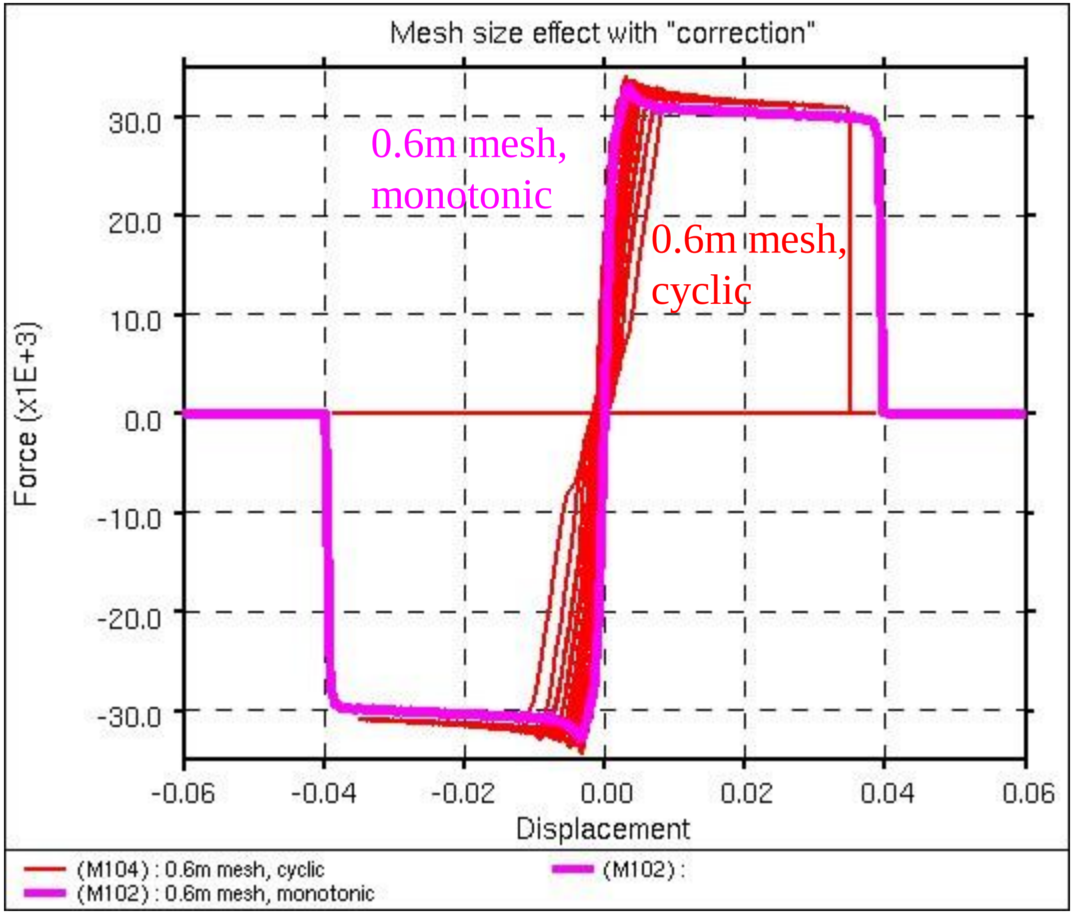




With a fine mesh, cyclic loading results in a reduced drift to collapse and softening response, due to accumulation of damage at the corner

Mesh size corrections: rocking



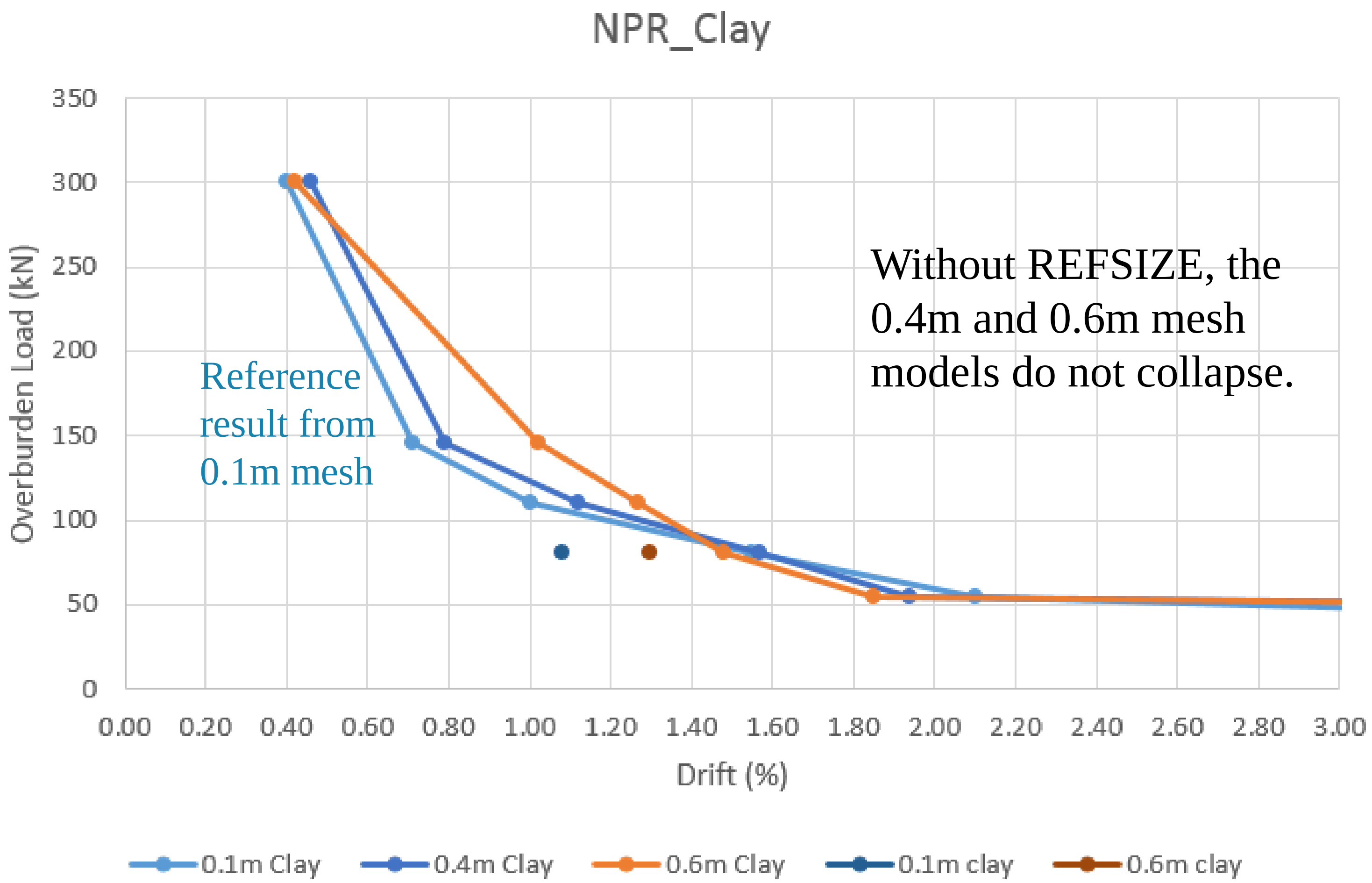


The bigger mesh fails to capture the subtle effects at the corner, giving a rigid body rocking response right up to collapse. This looks non-conservative compared to the fine mesh.

But is it bad enough to worry us?

REFSIZE: results

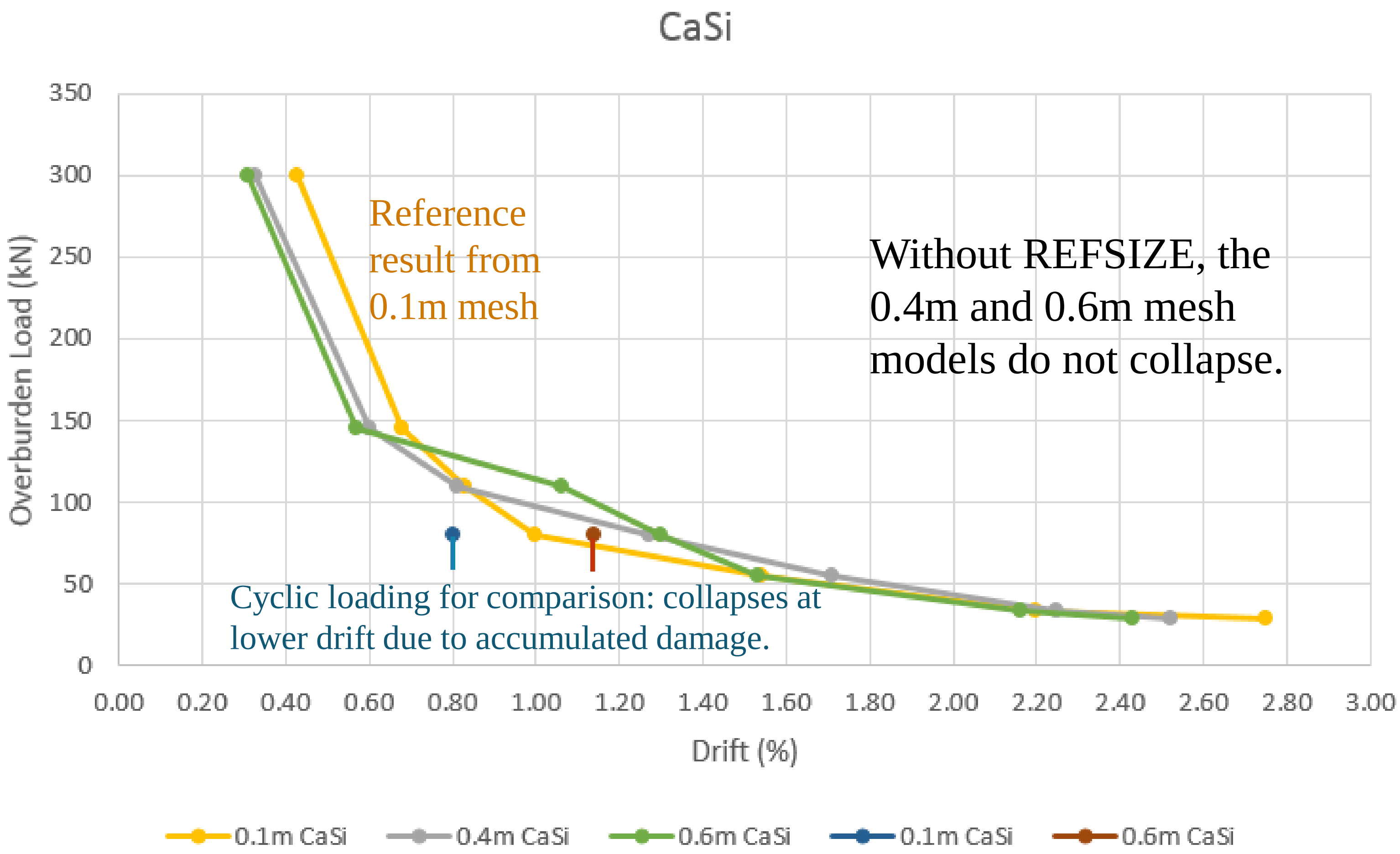
Collapse conditions under monotonic rocking (push-over):



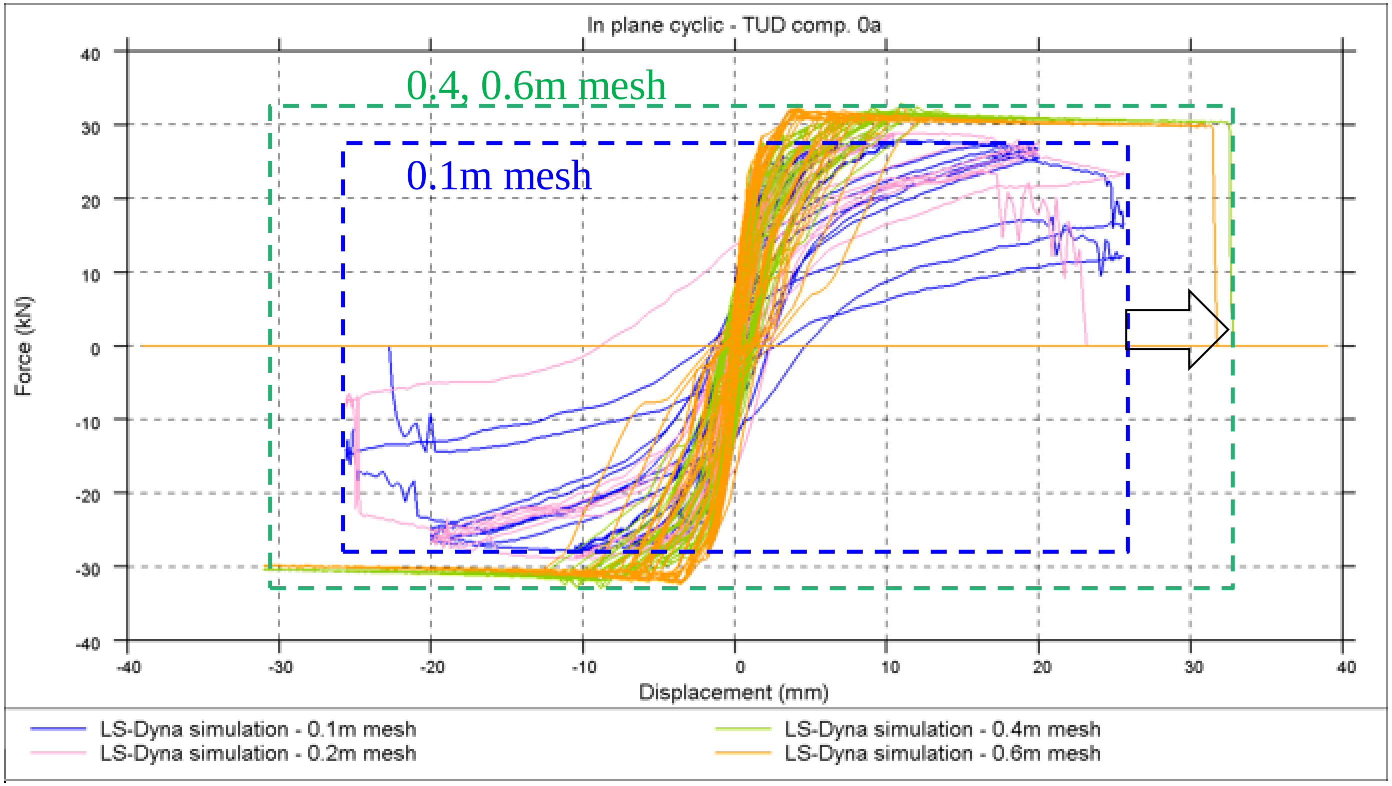
ARUP

REFSIZE: results

Collapse conditions under monotonic rocking (push-over):



REFSIZE: results – cyclic, rocking (TUD-COMP-0a)



Larger mesh sizes miss the accumulated damage effect. They collapse at about the same drift as for monotonic loading.

Larger mesh size shows greater lateral resistance (geometry effect)

Summary table:

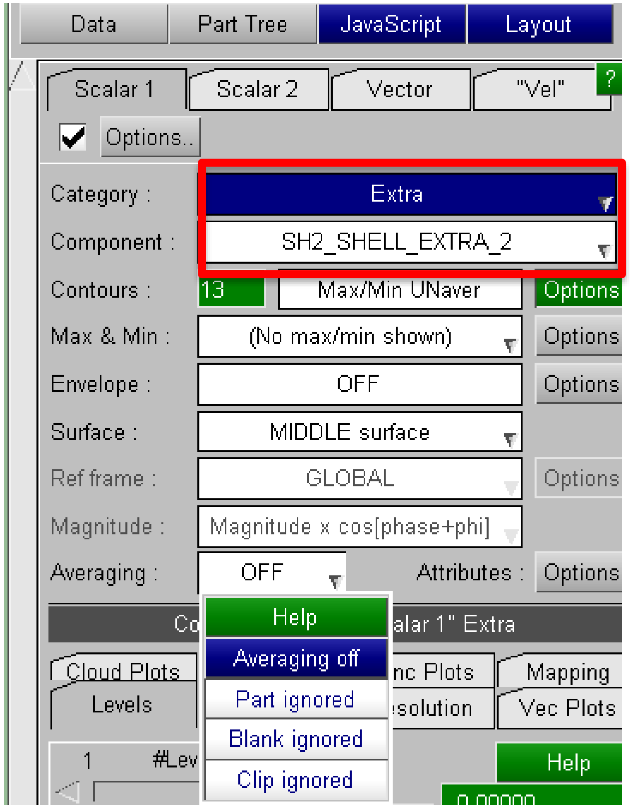
Mesh size (m)	Peak Strength (kN)	Maximum Achieved Drift
0.1	27.9kN	0.8%
0.2	30.0kN	0.8%
0.4	32.9kN	1.2%
0.6	34.6kN +25%	1.2%

ARUP

Post-processing

Plotting results: which data component?

- Plastic Strain – not recommended
  - “Plastic strain” shows damage on a scale of 0 to 1, i.e. whether the cohesive bonds have broken.
  - “Fully damaged” (plastic strain=1.0) could correspond to a crack could be 0.001mm or 100mm wide – you can’t tell. Large areas of masonry appear “fully damaged”.
  - Therefore, plastic strain is not the best data component to plot.

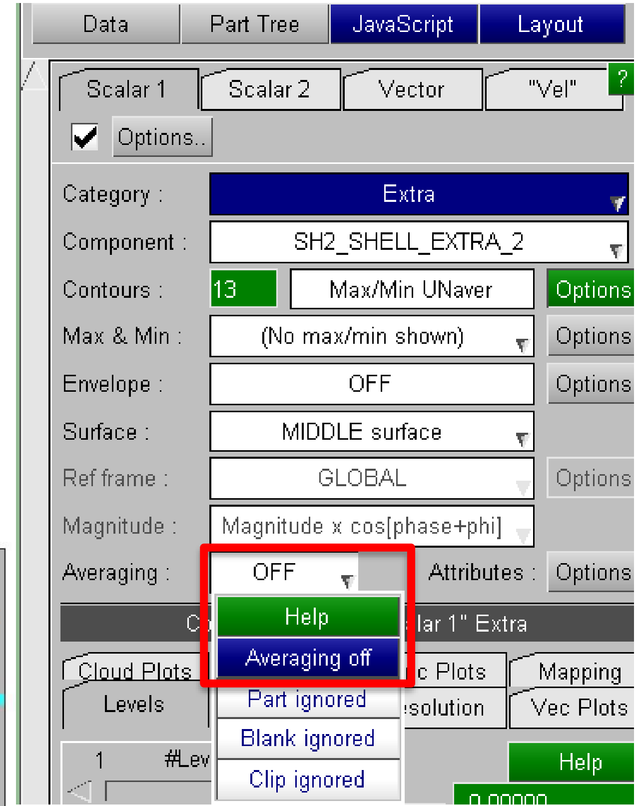


- Extra History Variable 2 – recommended
  - This means the maximum crack opening or sliding that has occurred so far, in any of the joint deformation modes (tensile, sliding, diagonal).

ARUP

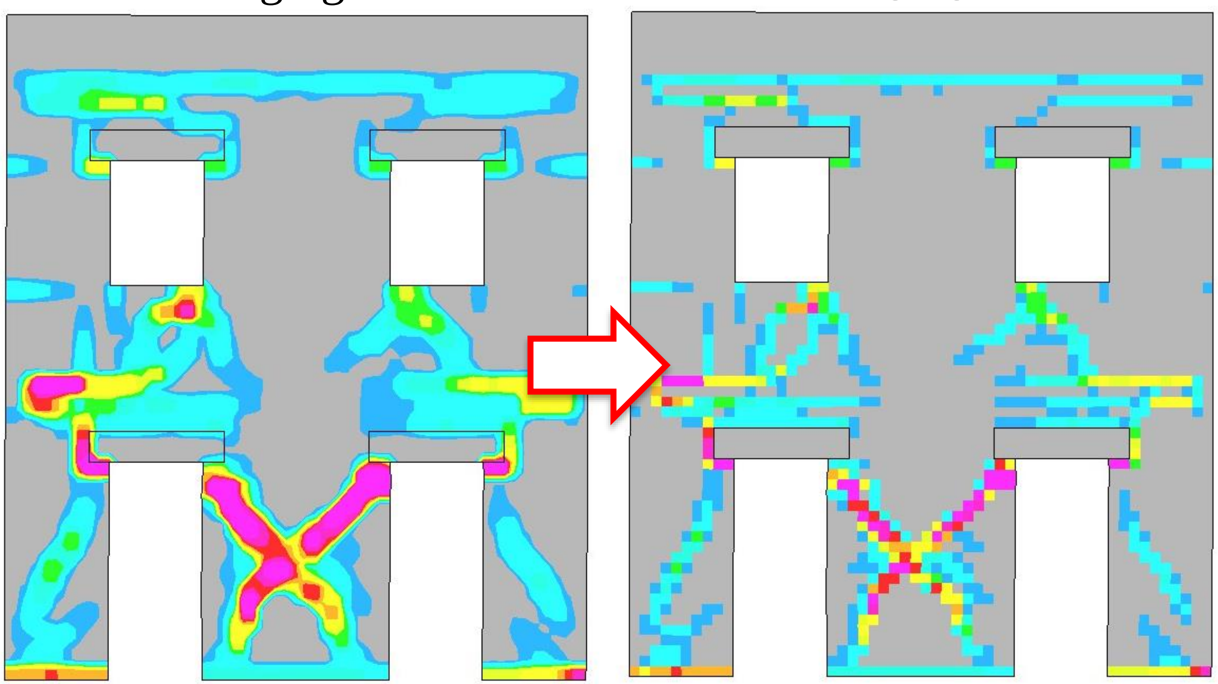
Plotting results

- Averaging across elements:
  - On for stresses – smoother plots
  - Off for crack patterns (Ex His Var 2)



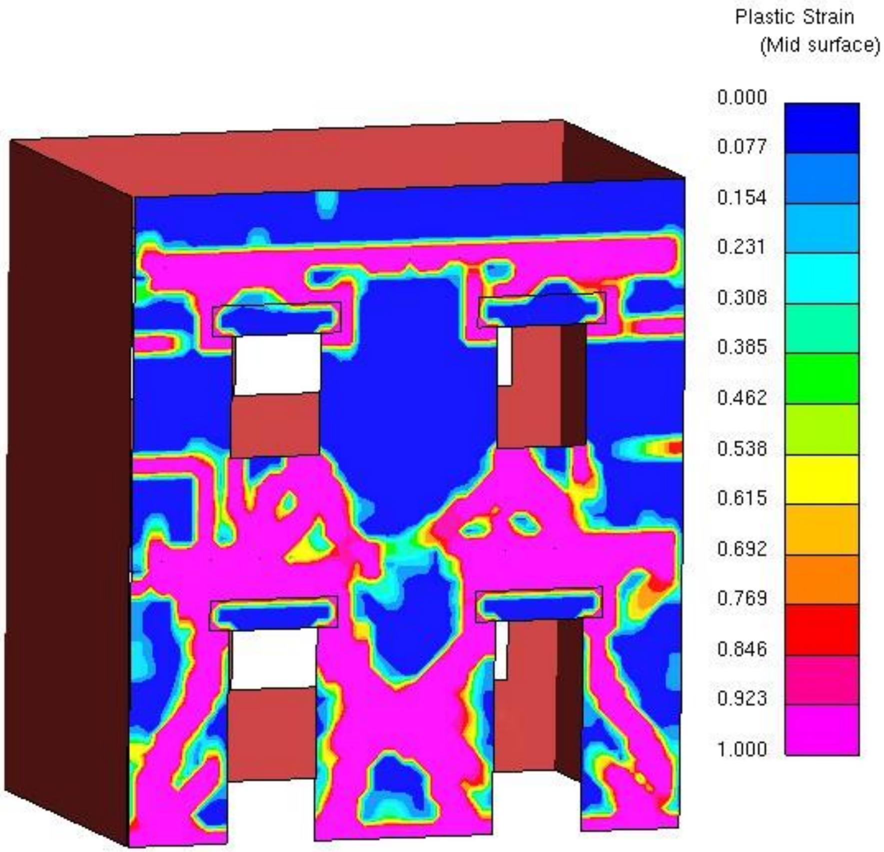
Averaging on

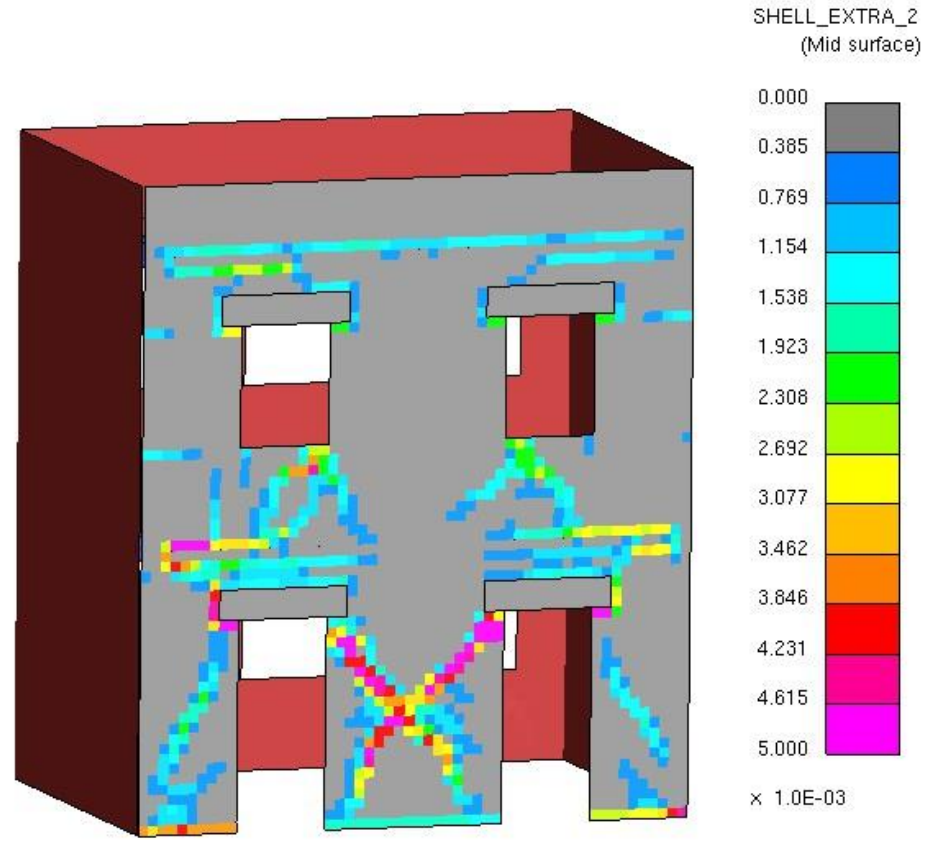
Averaging off



Plotting results

Which plot most clearly shows the crack patterns?



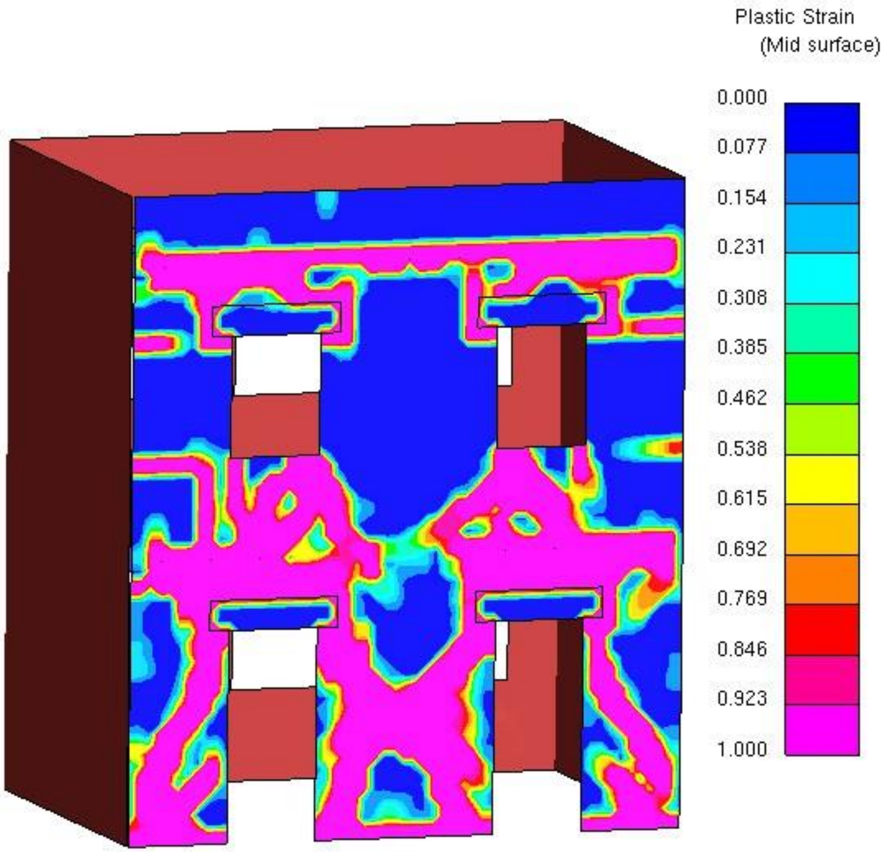


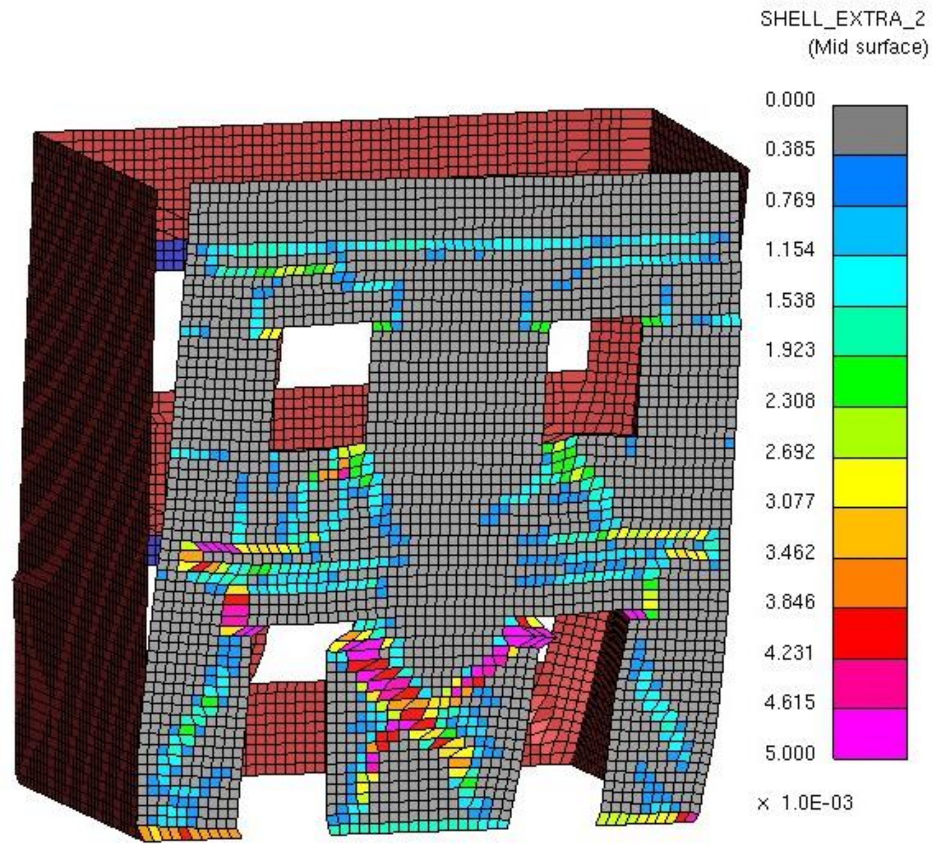
Which D3PLOT settings differ between these two plots?

SHELL_EXTRA_2
Averaging off
Grey lowest contour
Set max contour level

Plotting results

Which plot helps the analyst to understand and check the result?





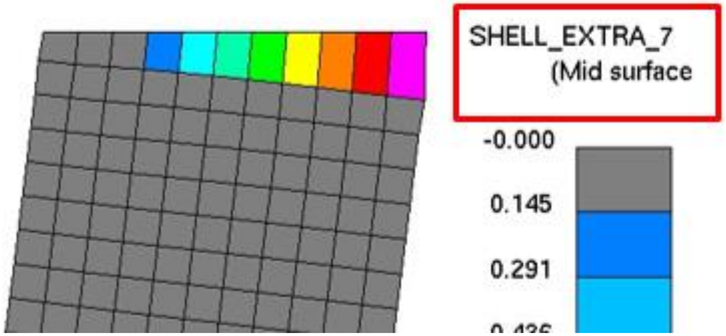
Which D3PLOT settings differ between these two plots?

As before +
Magnified displacements
Element overlay
Overlay colour = black

ARUP

Plotting results

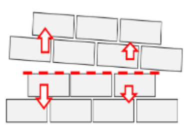
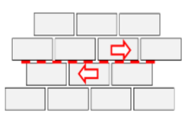
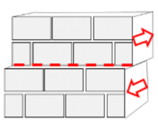
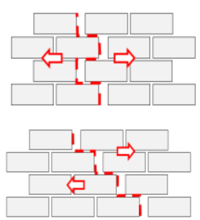
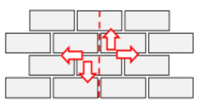
Example:



To understand which cracking mode is active, refer to this table (also given in the manual) and plot the various Extra History Variables.

In this case Extra 7 contains high values. This corresponds to bed joint opening.

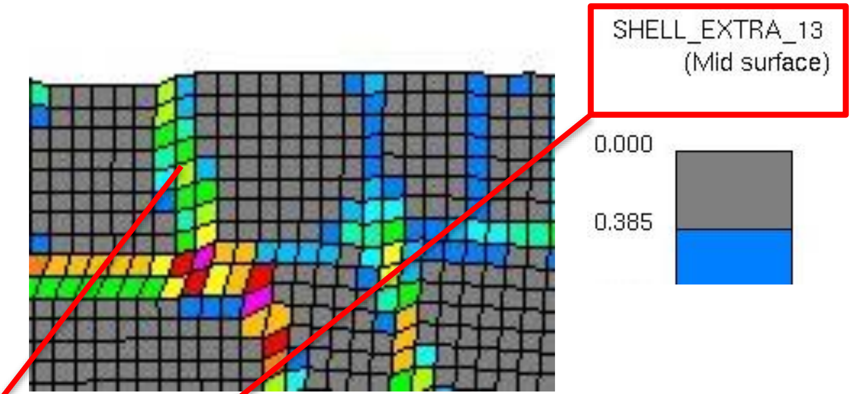
Note – to obtain these Extra History Variables in the output files, set NEIPS=16 on *DATABASE_EXTENT_BINARY

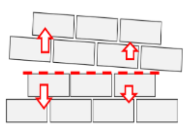
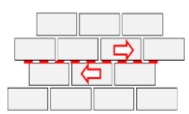
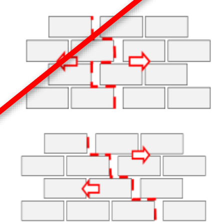
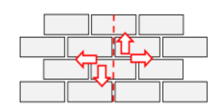
	Bed joint opening 	**In-plane sliding** 	**Out-of-plane sliding** 	**Diagonal** 	**Cracks through bricks** 	**Max all modes**
Damage	EXTRA_3			EXTRA_4	EXTRA_5	Plastic strain
Current displacement	EXTRA_7	-	-	EXTRA_6	EXTRA_8	-
High-tide displacement	EXTRA_10	EXTRA_13	EXTRA_12	EXTRA_9	EXTRA_11	EXTRA_2

ARUP

Why are these elements damaged?

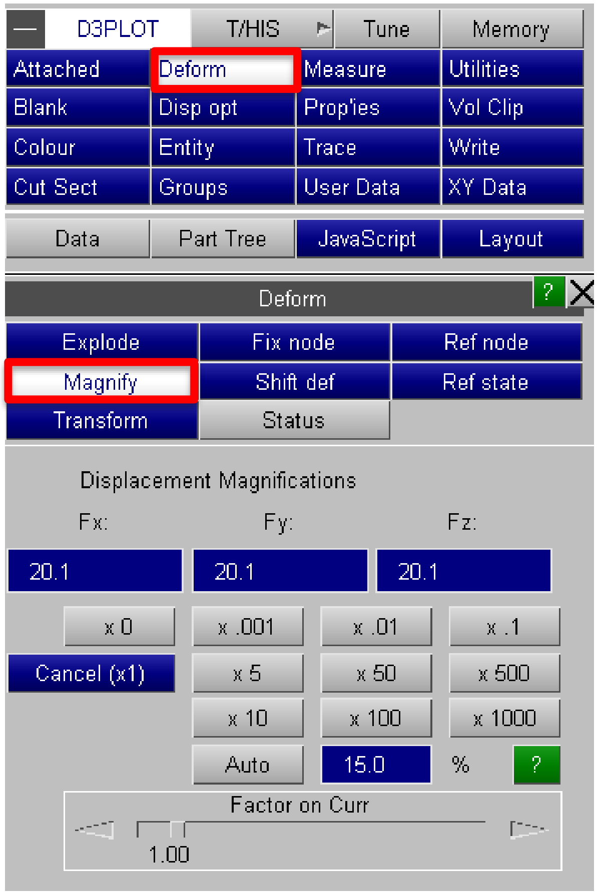
Bed joint sliding => looks wrong

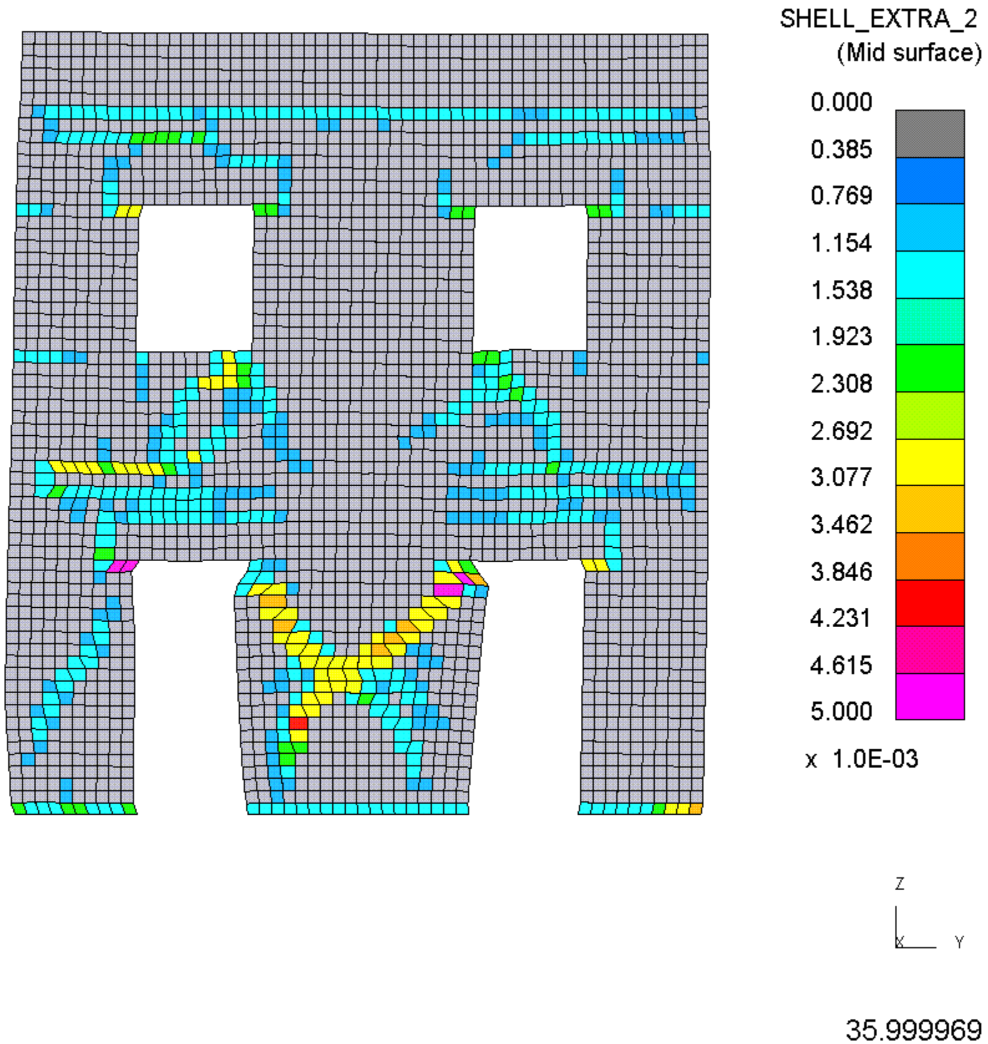


	Bed joint opening 	In-plane sliding 	Out-of-plane sliding 	Diagonal 	Cracks through bricks 	Max all modes
Damage	EXTRA_3			EXTRA_4	EXTRA_5	Plastic strain
Current displacement	EXTRA_7	-	-	EXTRA_6	EXTRA_8	-
High-tide displacement	EXTRA_10	EXTRA_13	EXTRA_12	EXTRA_9	EXTRA_11	EXTRA_2

Understanding what a model is doing - checking

Always use magnified displacements to understand what your model is doing.





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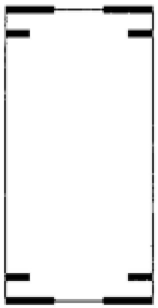
Validation

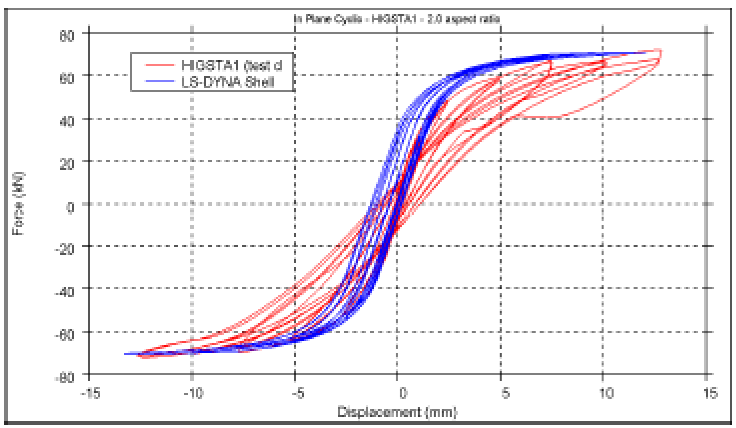
Benchmark tests (from the literature)

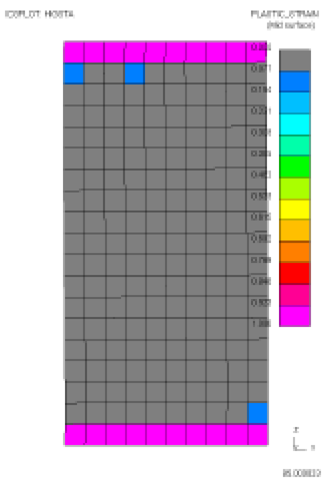


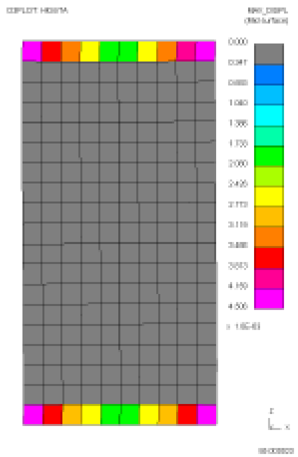
HIGH STA

04-Jun 2015 Executable

FC = 6.2 MPa
KTH = 2
FTD = 84 kPa
GTDANG = 6 deg







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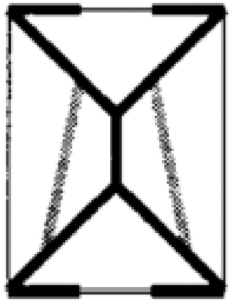
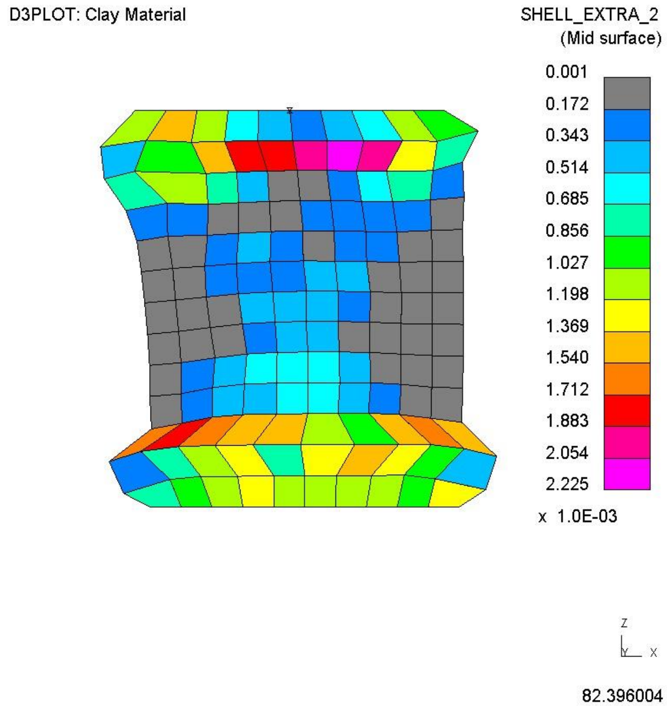
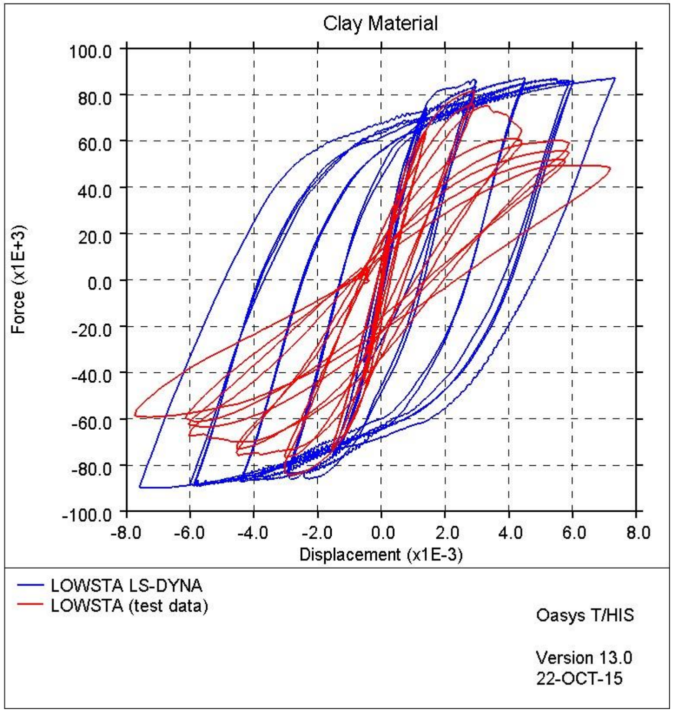
Benchmark tests (from the literature)



LOW STA

04-Jun 2015 Executable





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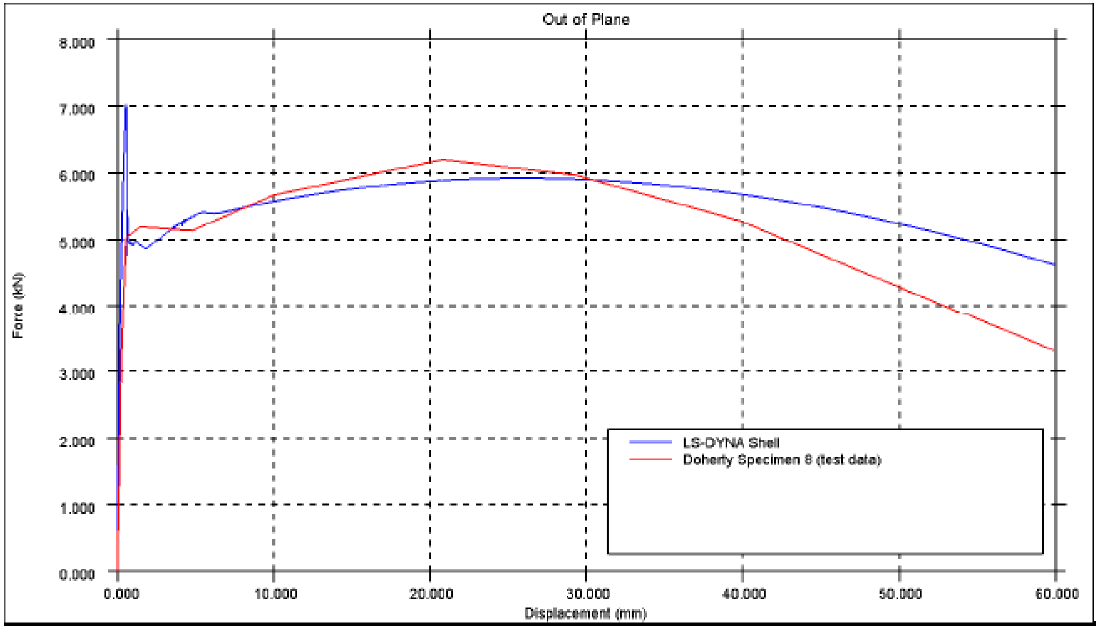
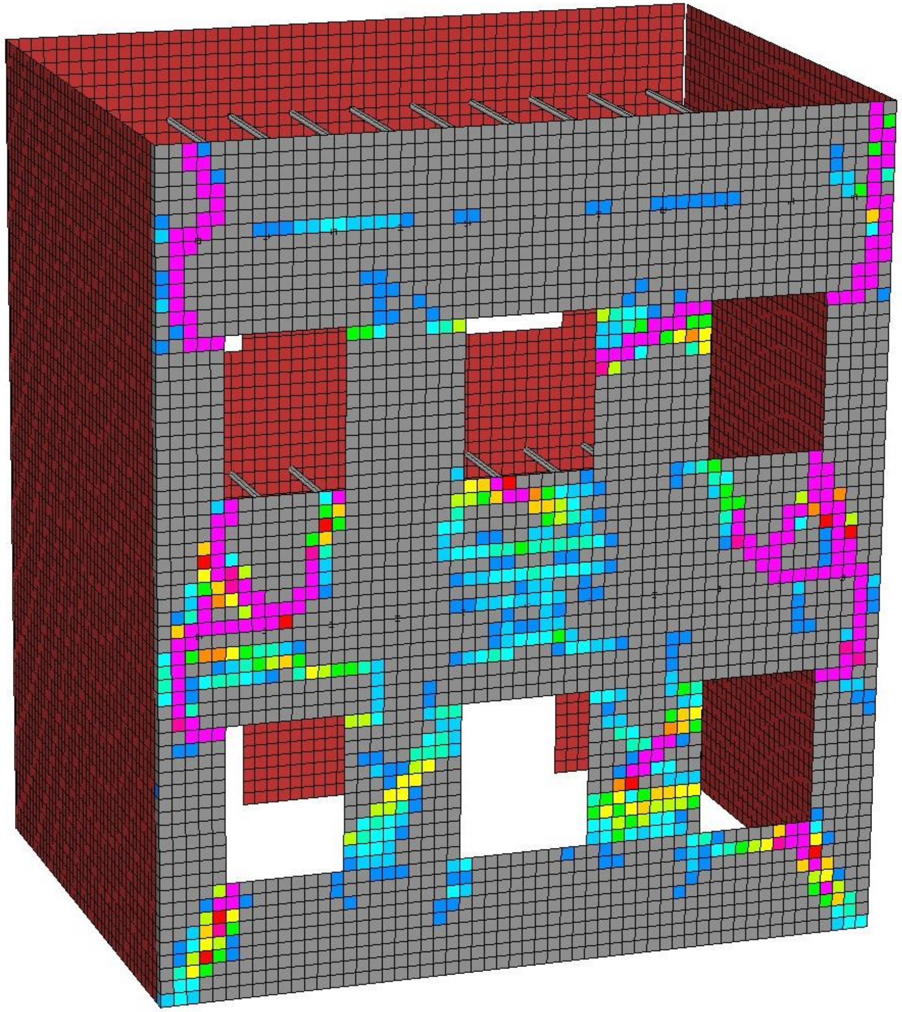
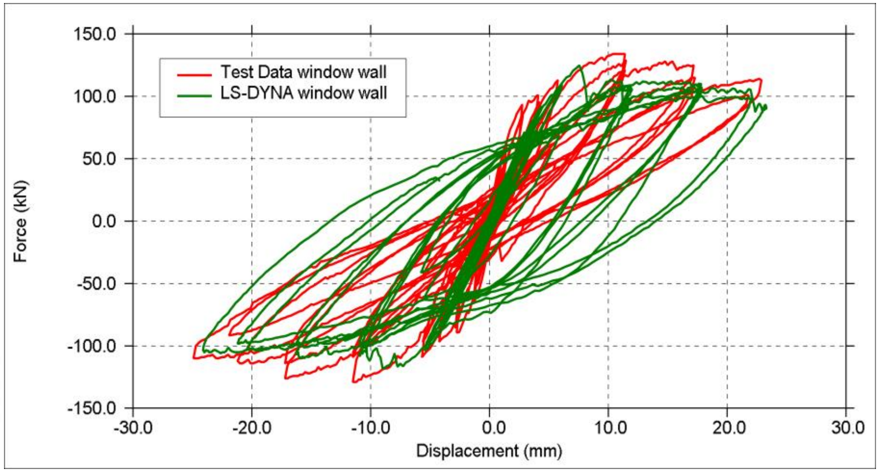
Benchmark tests (from the literature)

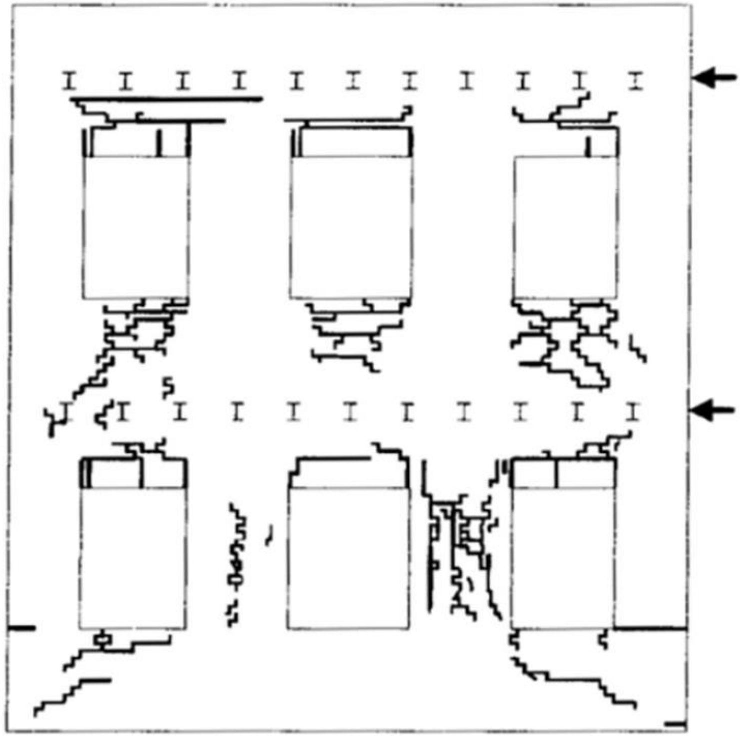
Out of plane static test



PAVIA house







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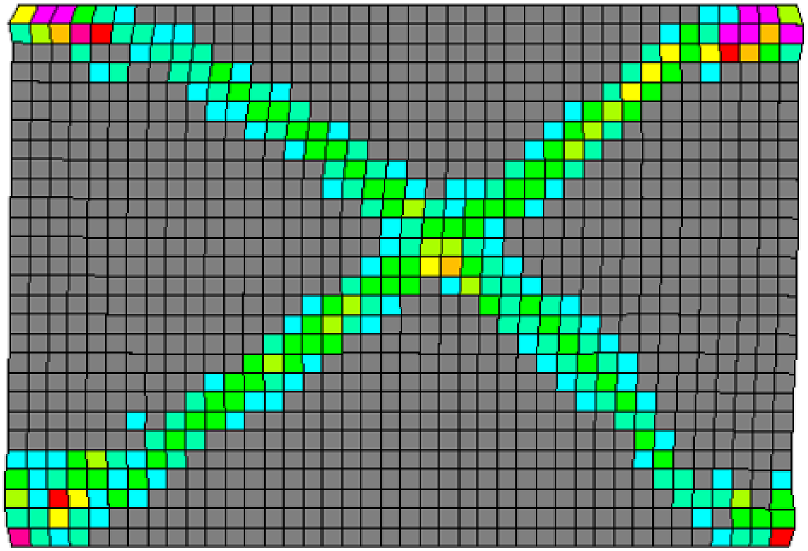
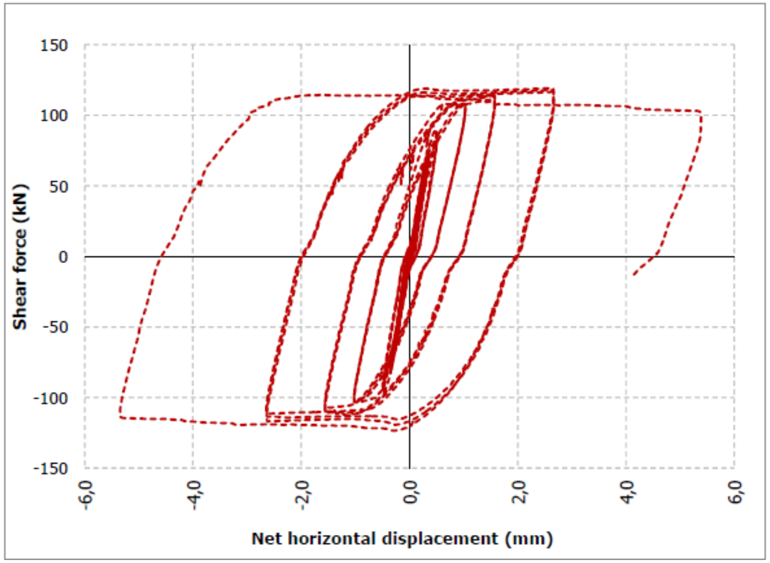
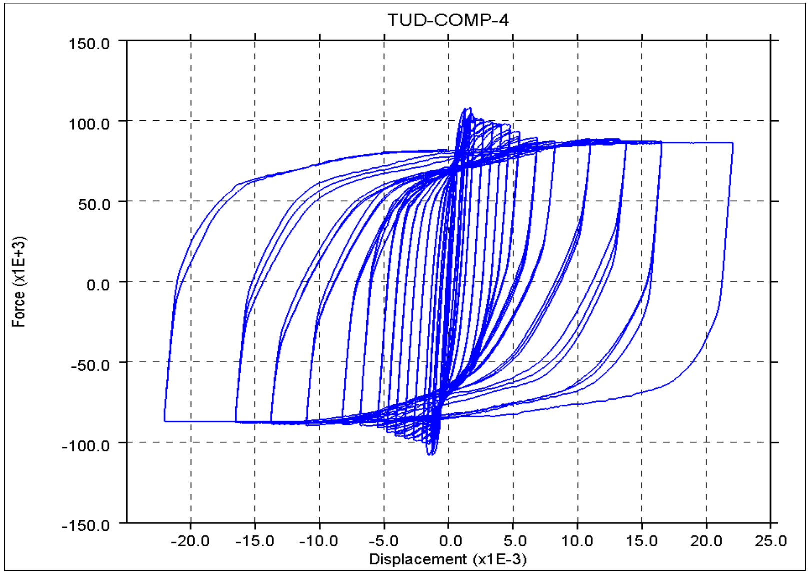
“Blind prediction” tests (P500 project)







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P500 full-scale shake table tests

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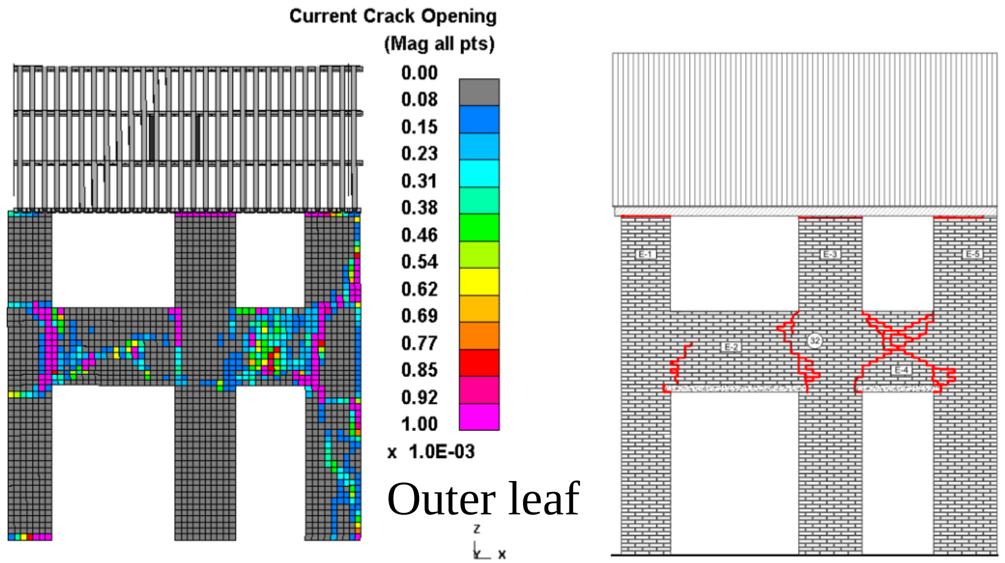
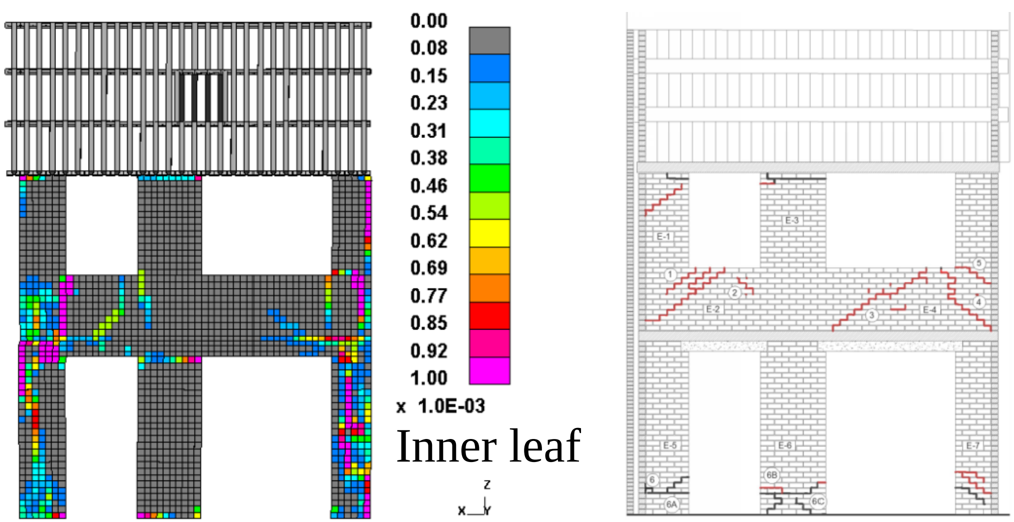
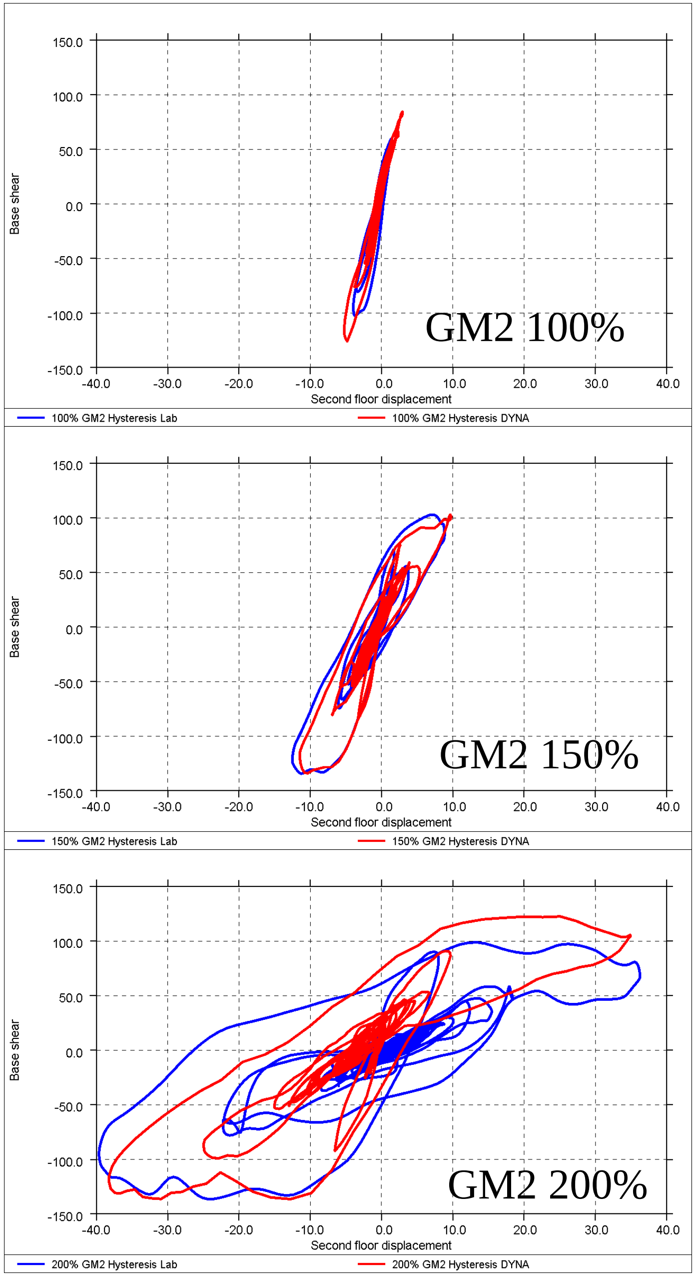
EUC Full-scale shake table test





Post-test analysis



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Tests on connections

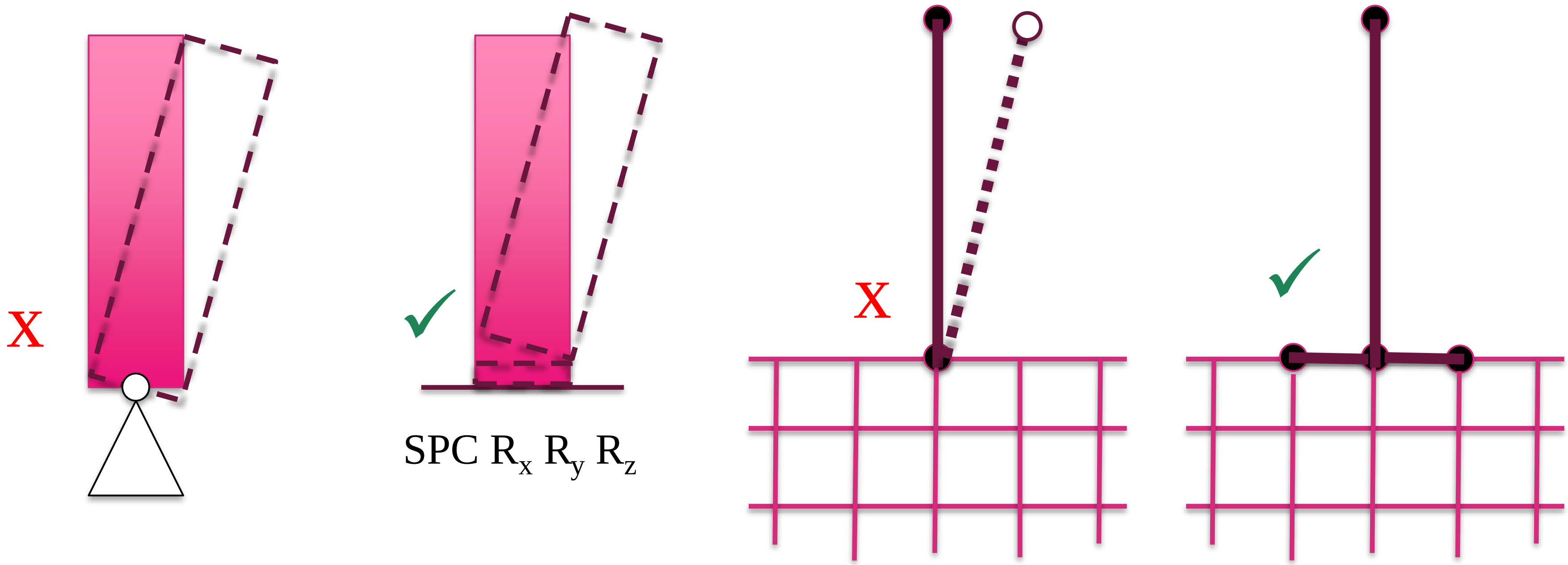
- Here is a list of all the tests we have on connections:
  - Static pull-out of wall tie

- Total number of tests: 1

Watch-its

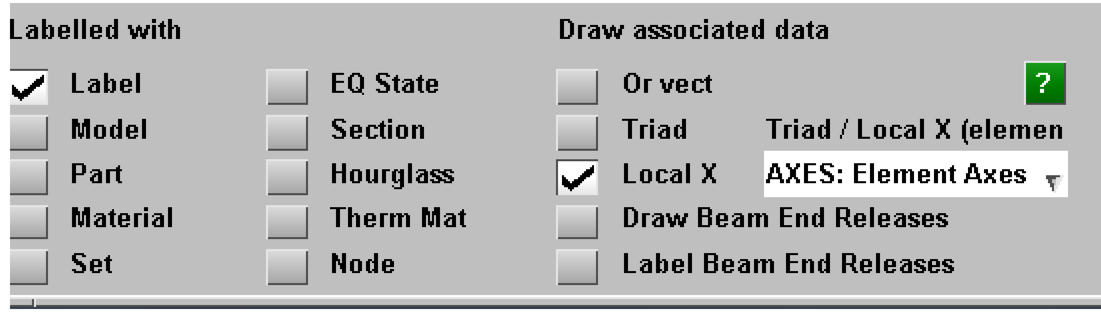
Watch-its

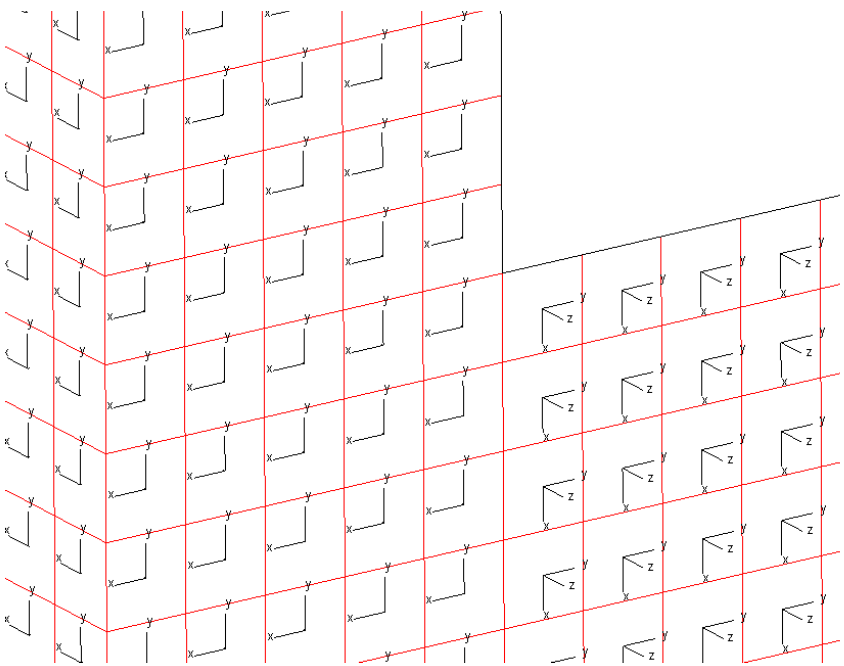
- Ensure base of walls have rotational restraint
  - SPC for rotational DOFs (fixed base model)
  - If meshing onto solid element foundation: model the bottom face of the wall with shells

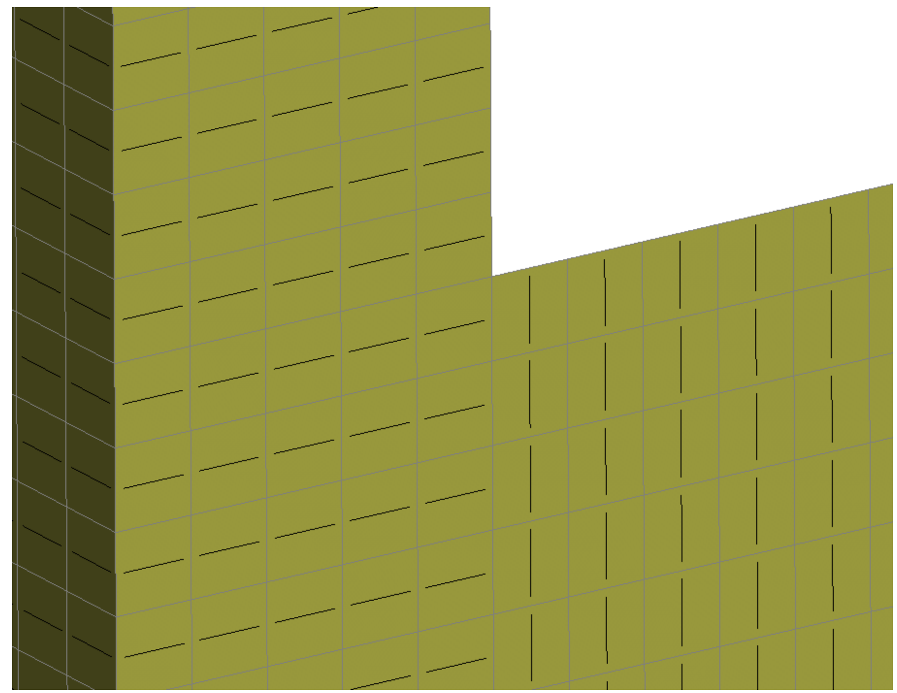


Watch-its

- Local x-axis should align with bed joints
- PRIMER Entity menu => Local X







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Some known limitations

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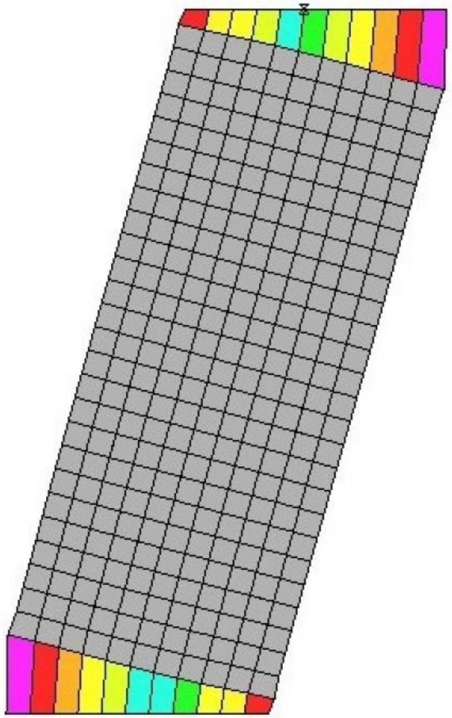
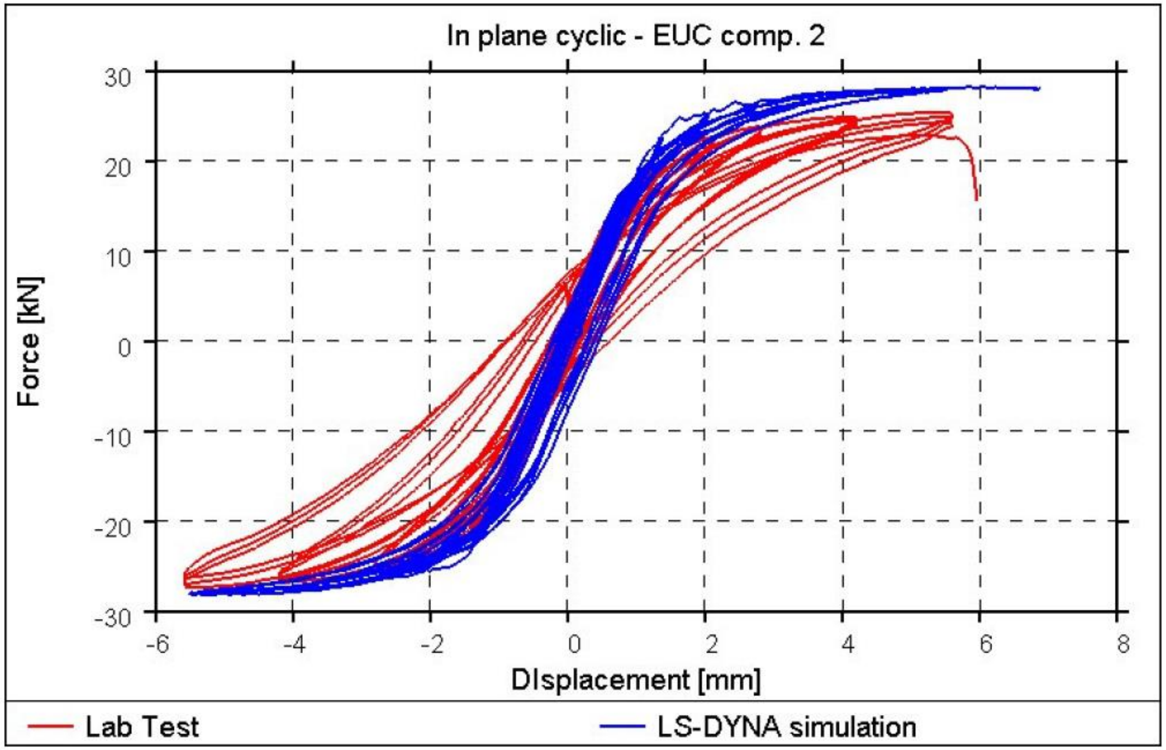
Lack of stiffness degradation and energy absorption during rocking motion

- During tests involving rocking motion, the models show less degradation of stiffness, and less energy absorption, than physical experiments. The models give results closer to what would be expected for rigid-body rocking.





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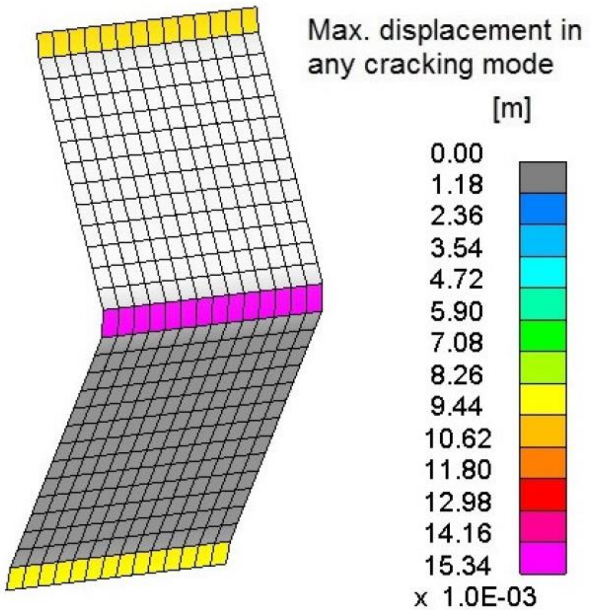
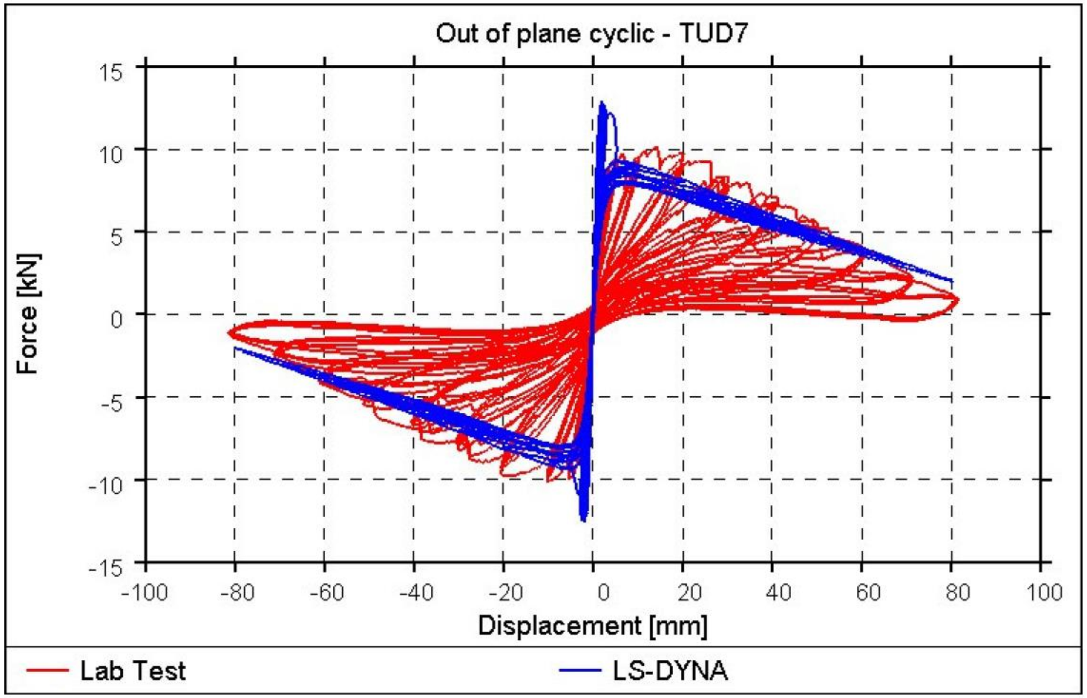
Lack of stiffness degradation and energy absorption during rocking motion

- This is true for out-of-plane as well as in-plane rocking. However, we are uncertain how much of the apparent energy absorption in the experiments may be an artefact of the test set-up. The walls were loaded by an airbag system.





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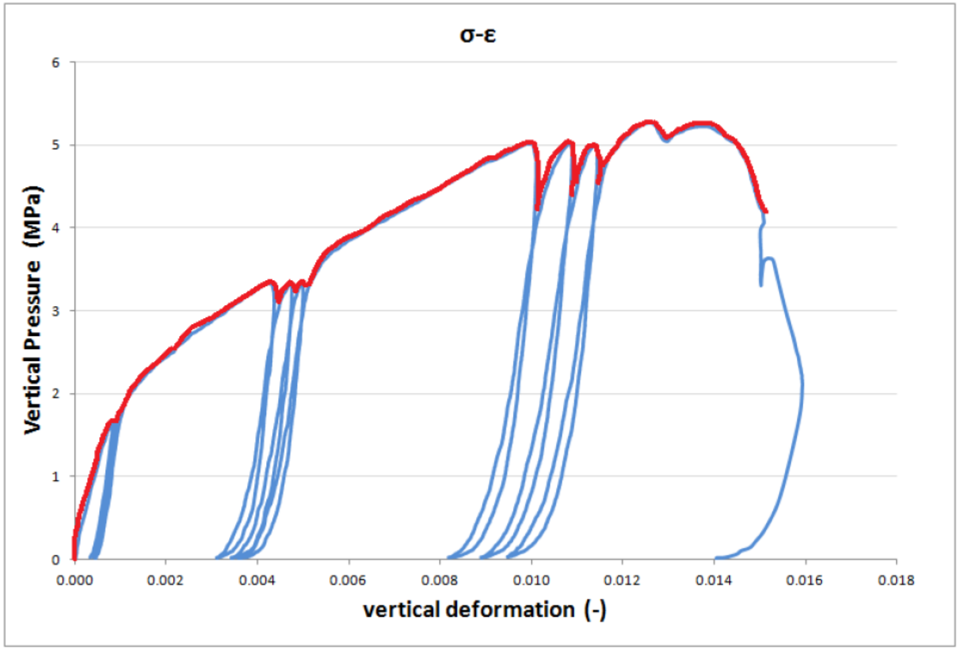
Lack of stiffness degradation and energy absorption during rocking motion

- Is this caused by unrealistic unload-reload behaviour in compression?
- Laboratory compression tests on masonry wallettes show relatively little hysteresis energy during unload/reload. Although there is scope for improving the model in this respect, we do not think this could be the main reason for the large energy absorption in rocking tests.
- We do not truly understand the mechanisms leading to results of rocking tests differing so greatly from the rigid body idealisation. This is the subject of ongoing study.



Compression test on masonry wallette

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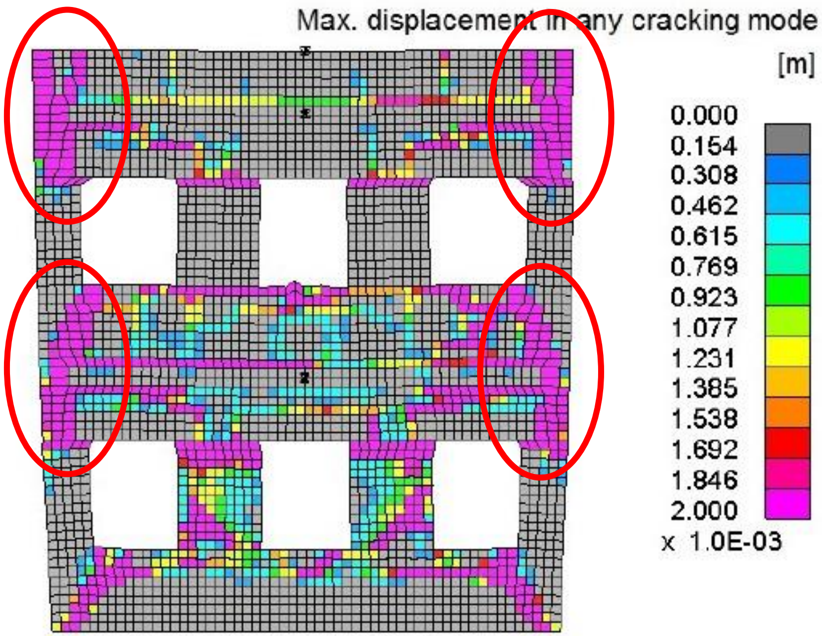
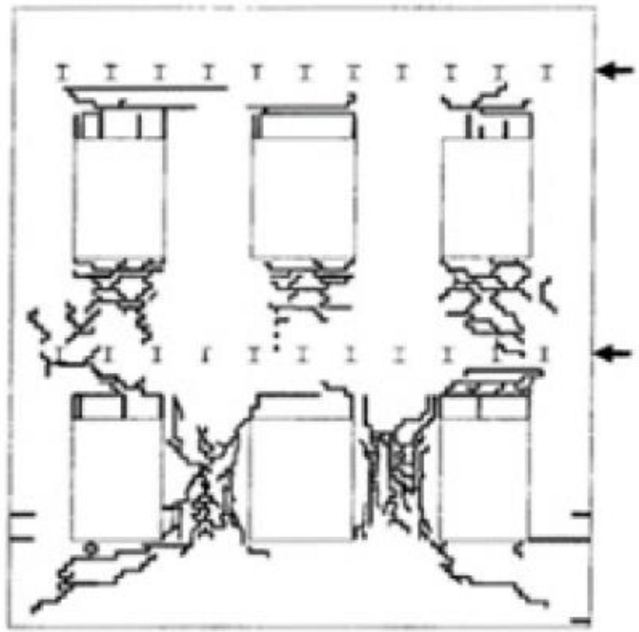
Response to horizontal tension is too weak

- The material model is too weak when resisting horizontal tensile stresses.
- Typical symptoms include vertical cracks, especially near the corners of a building.





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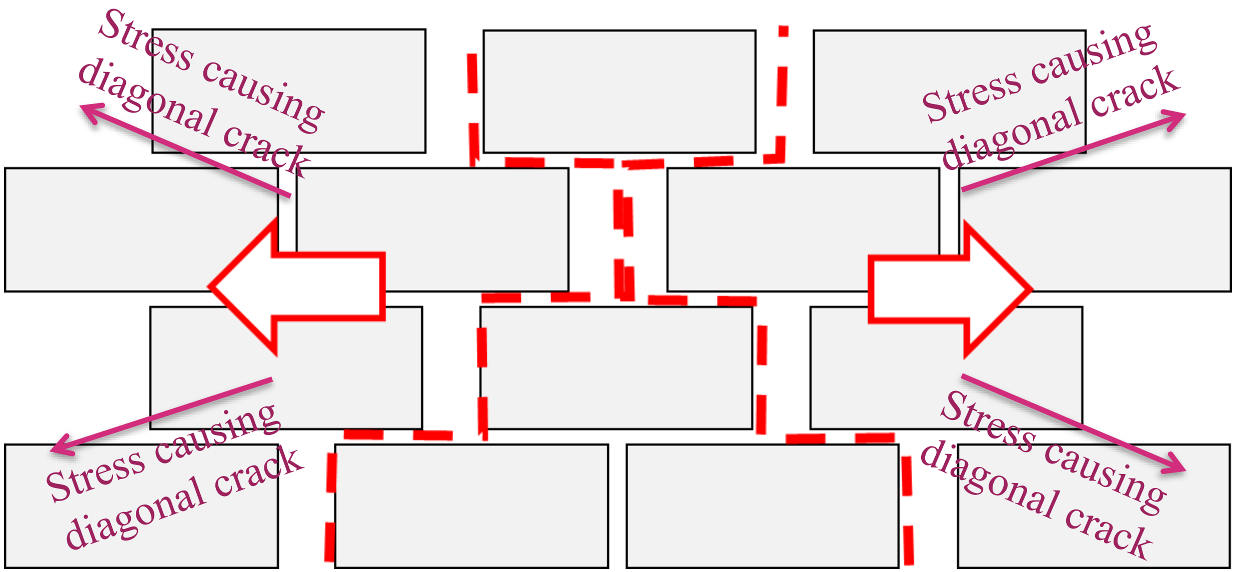
Response to horizontal tension is too weak

- The problem occurs because horizontal tensile deformation can (in the model) arise from a pair of diagonal cracks:



- A small tensile stress at about 25-30 degrees to the horizontal is assumed to cause diagonal cracks. Meanwhile, if the stress is exactly horizontal, a much larger stress should be required to pull the bricks apart (can be 4 or more times greater). The material model is unable to deal with this large difference of behaviour relating to a small change of stress angle. This is a subject of ongoing study.

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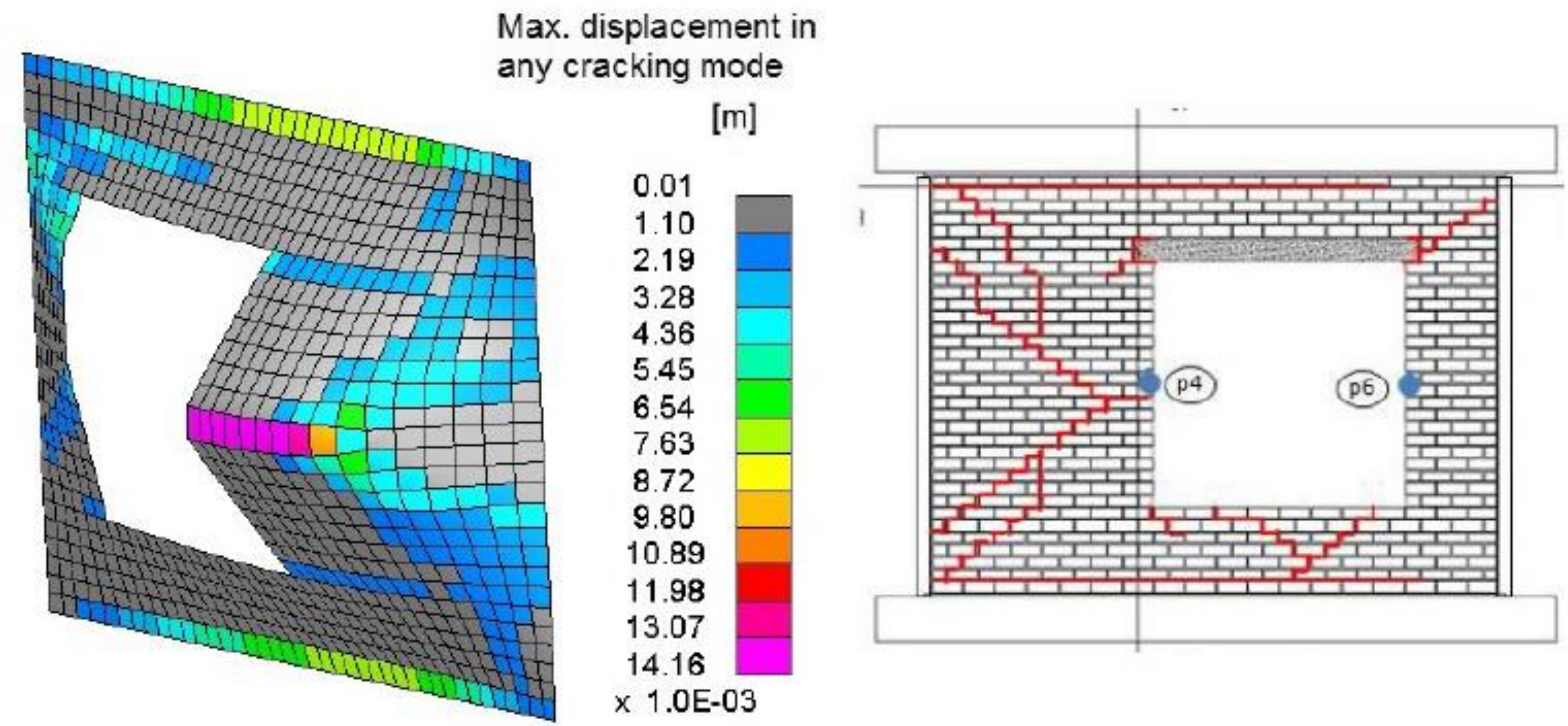
Response to horizontal tension is too weak

- For the same reason, response to bending about the vertical axis is too weak. This may be seen in the simulations of 2-way spanning walls:



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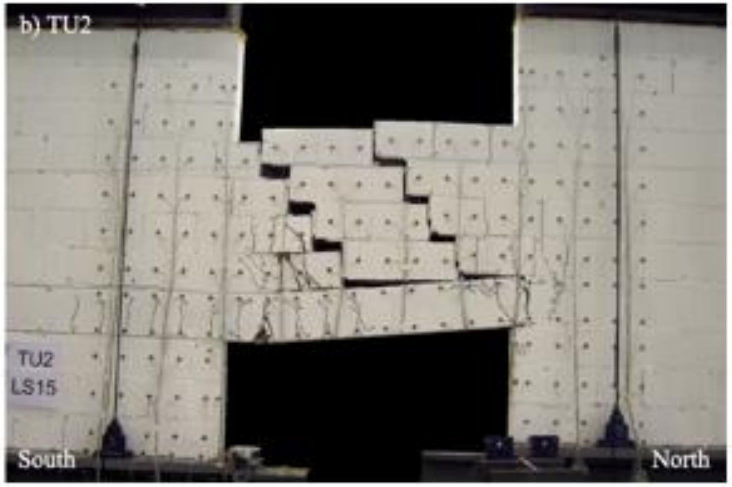
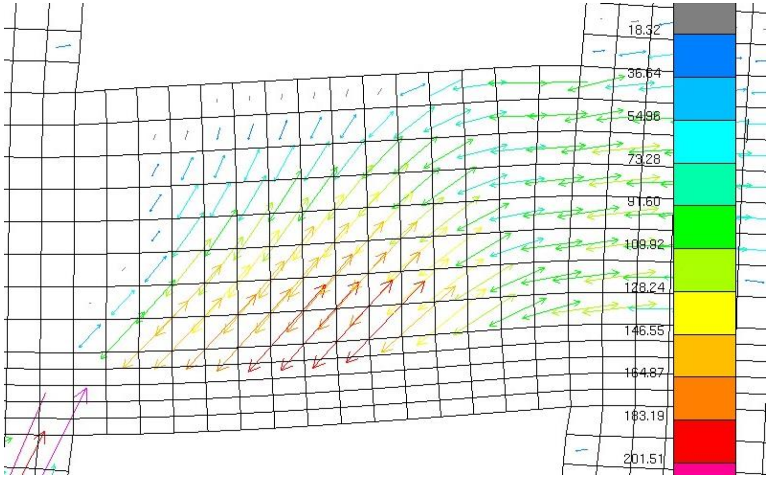
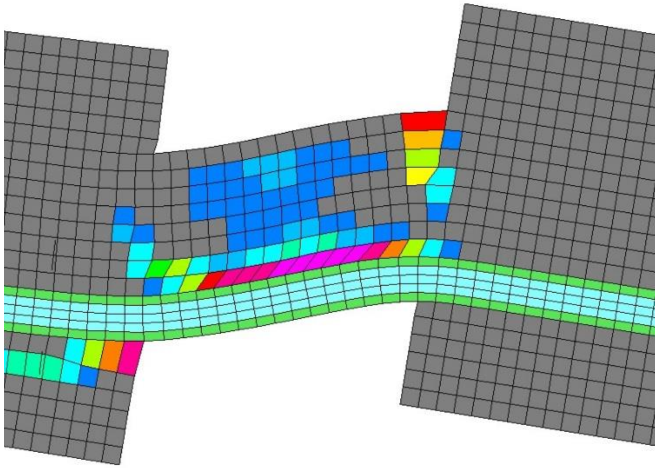
“Spandrel mode”

The material model overpredicts the strength with this type of loading.
Failure force can be 2x experimental value.
The material model needs, but does not yet have, a failure mode dedicated to this type of deformation.



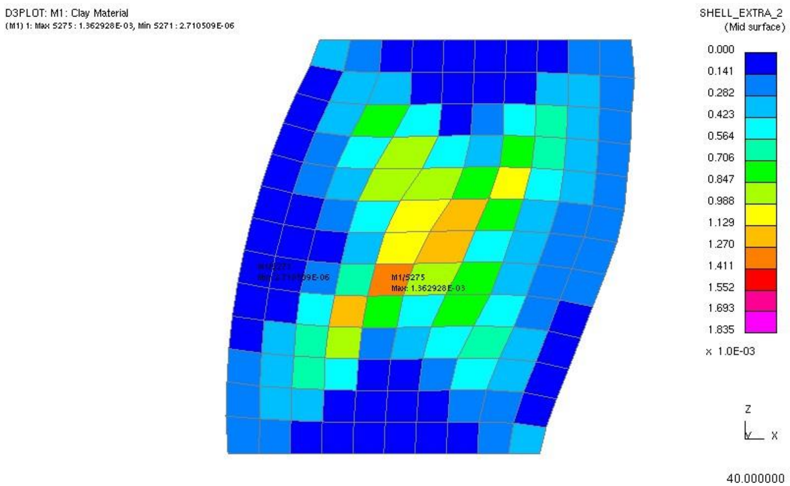
Predictions may be non-conservative

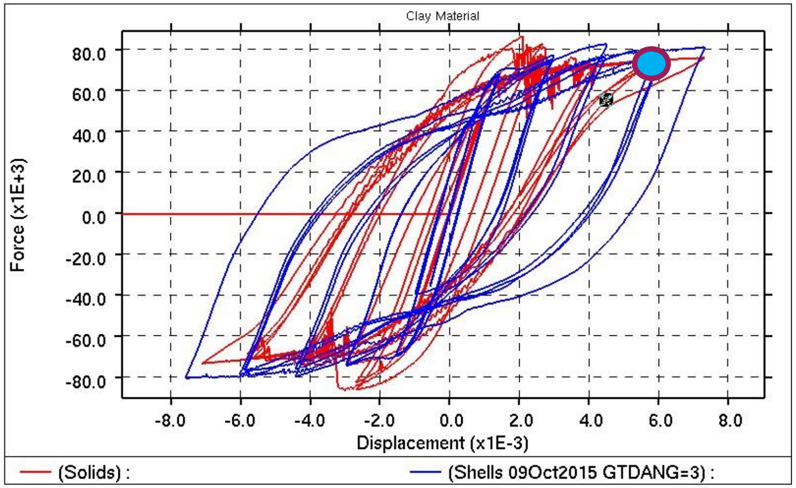


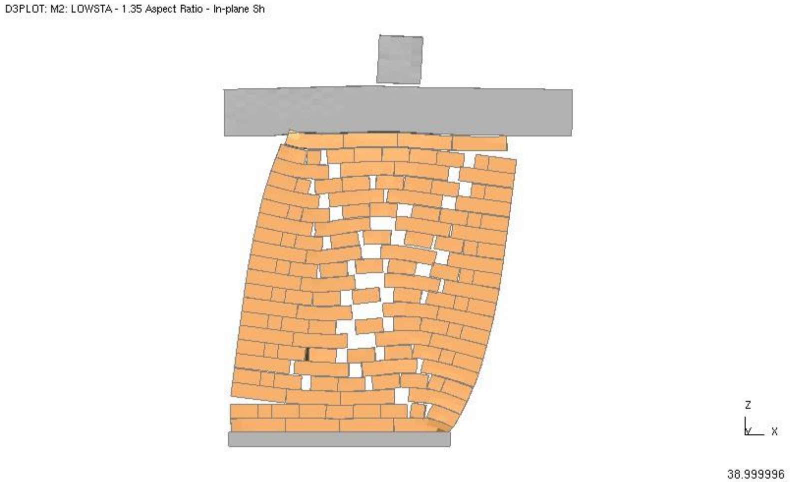


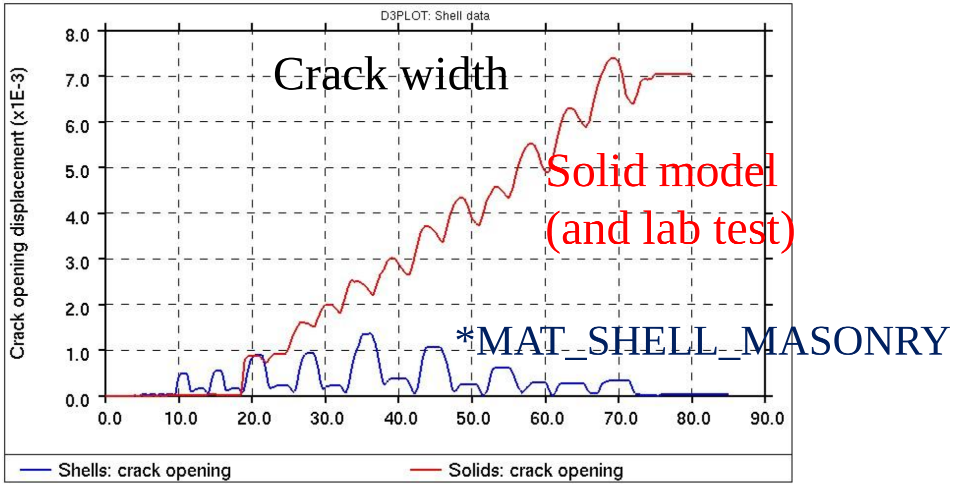
Diagonal cracks keep closing up again

This model behaviour could lead to non-conservative collapse predictions









GESU project:
LS-DYNA *MAT_SHELL_MASONRY
Description for users

Author: Richard Sturt

Describing LS-DYNA Masonry Model plug-in issued March 2017

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