TECHNISCHE UNIVERSITÄT BERGAKADEMIE FREIBERG

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Simulation of triaxial compression test with *PFC3D*

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Vienna Austria

Outline

1. Background

2. Sample Reconstruction from CT images

3. Coupled Simulations with PFC3D and FLAC3D

   3.1 Triaxial test with FW approach

   3.2 Permeability evolution simulation

4. Conclusions

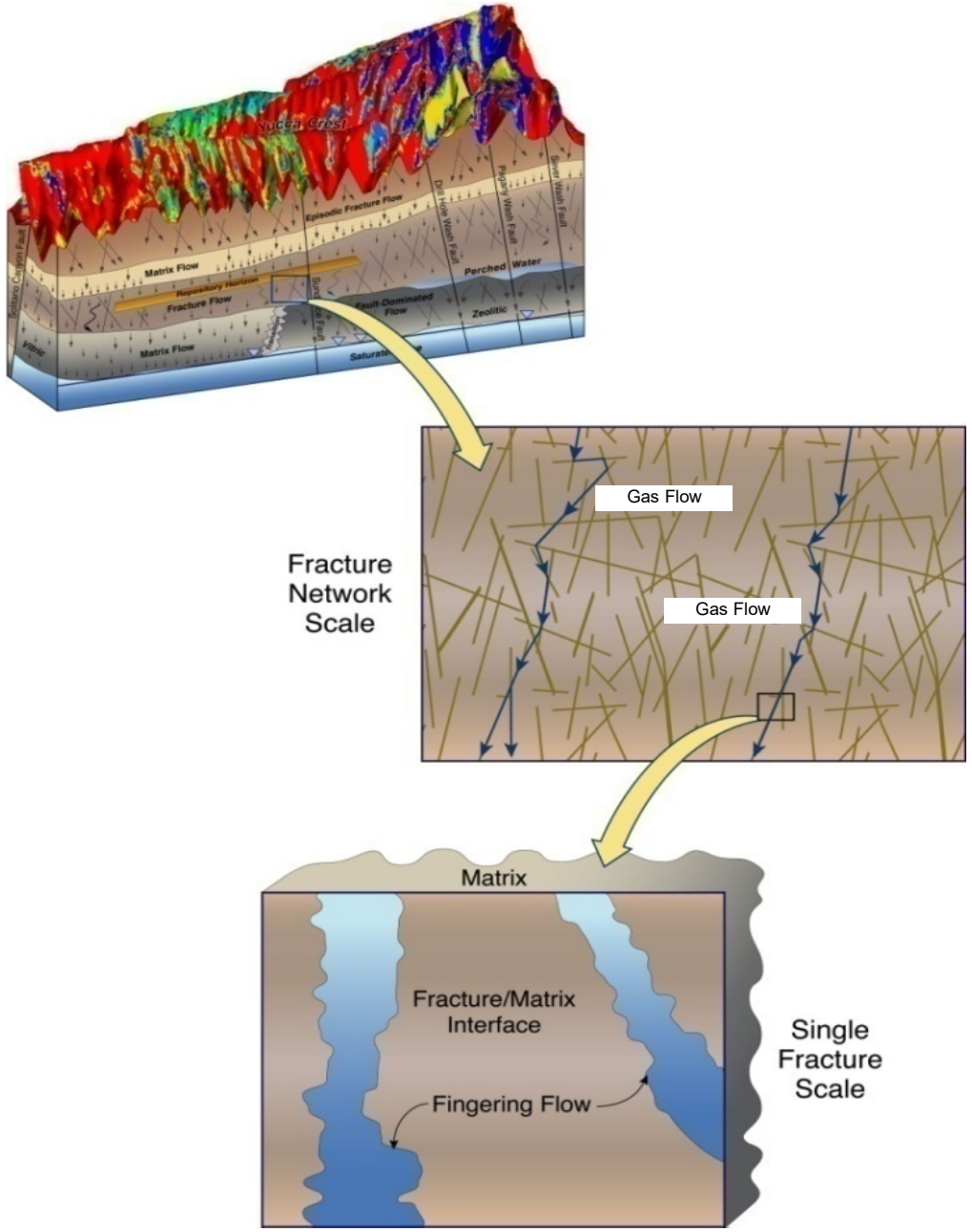
1. Background

Rock (Coal) permeability evolution research

Coal permeability is an important parameter in coalbed methane (CBM) exploration and greenhouse gas storage.

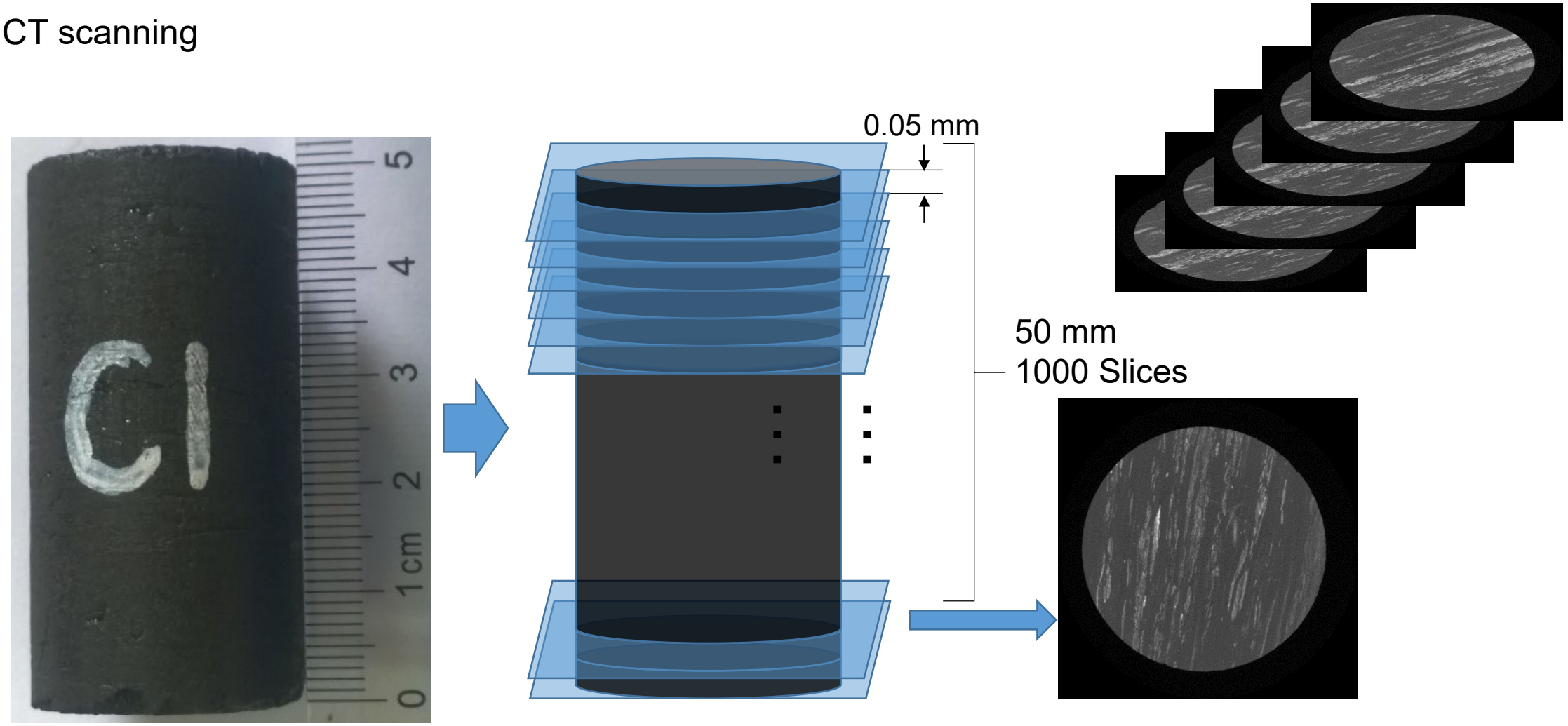
The coal structure deformation determines the state of gas seepage.

Permeability evolution test under Triaxial compression is an effective method.



2. Sample Reconstruction

CT scanning



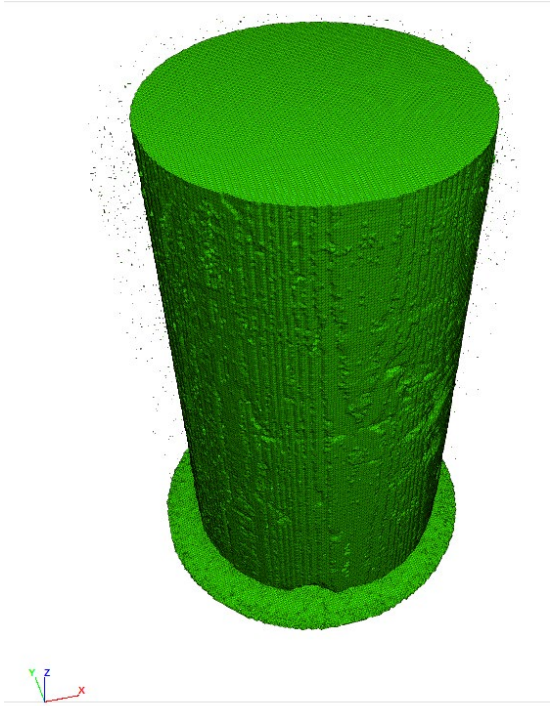
From real sample to image data

2. Sample Reconstruction

Reconstructed in Software: Materialise ® Mimics

Polygon models (.stl format) were successfully generated for visualization.

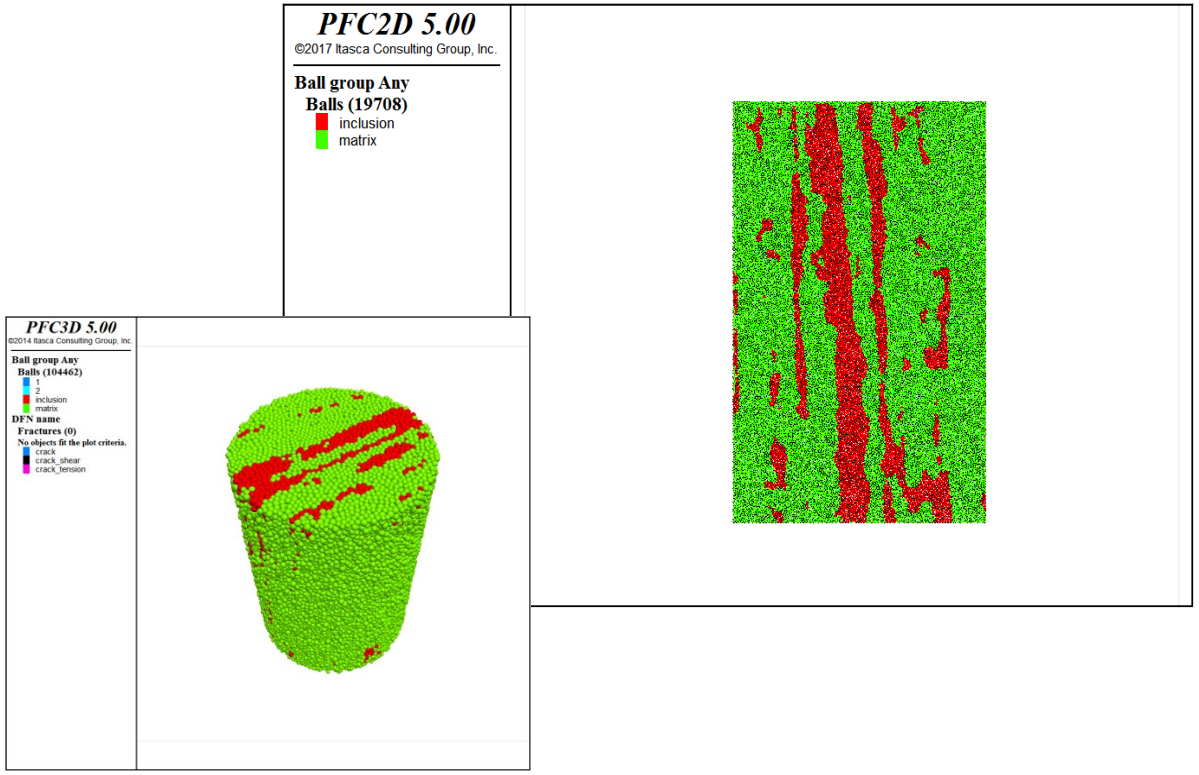
Geometry model of inclusion

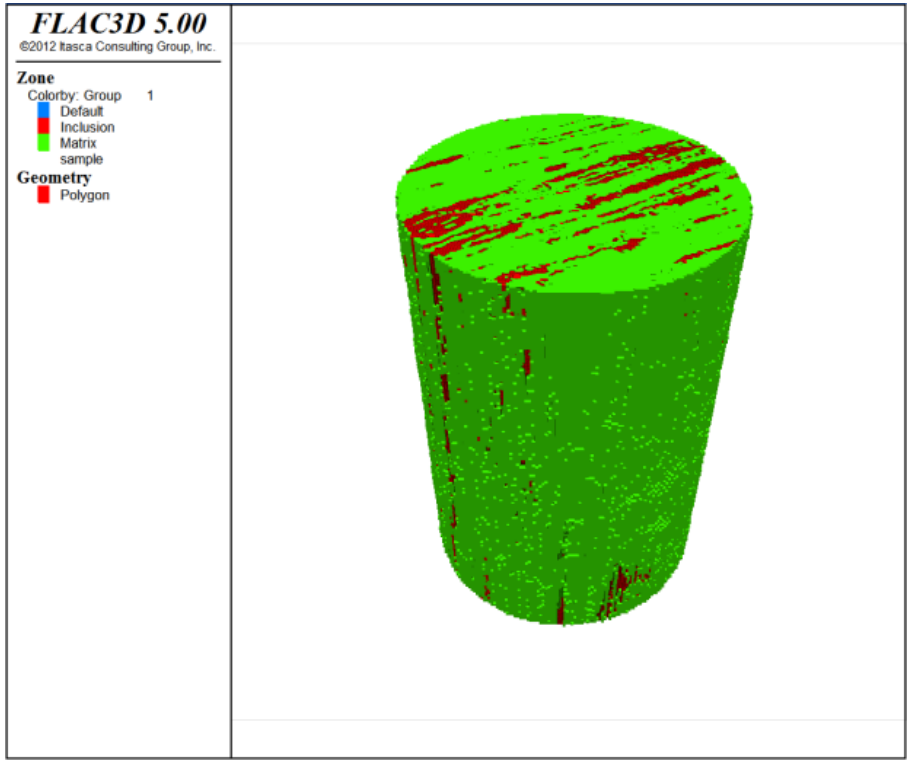


Geometry model of sample

2. Sample Reconstruction

Modeling with DEM and FDM

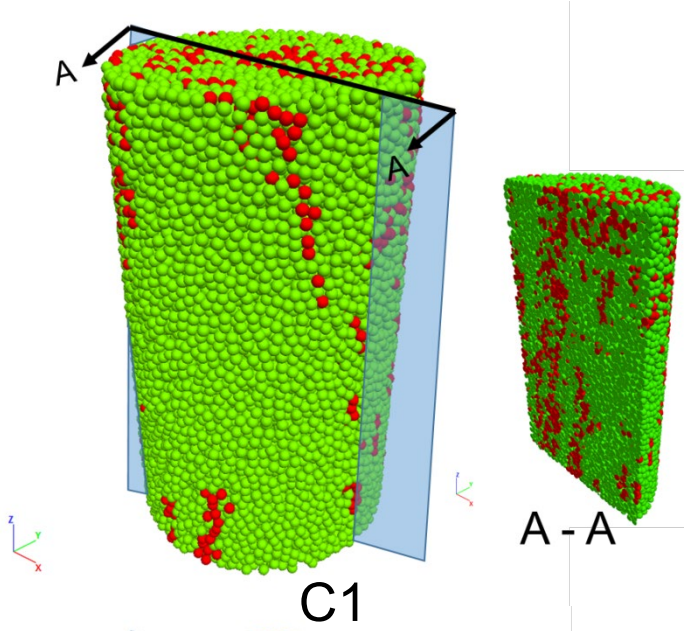




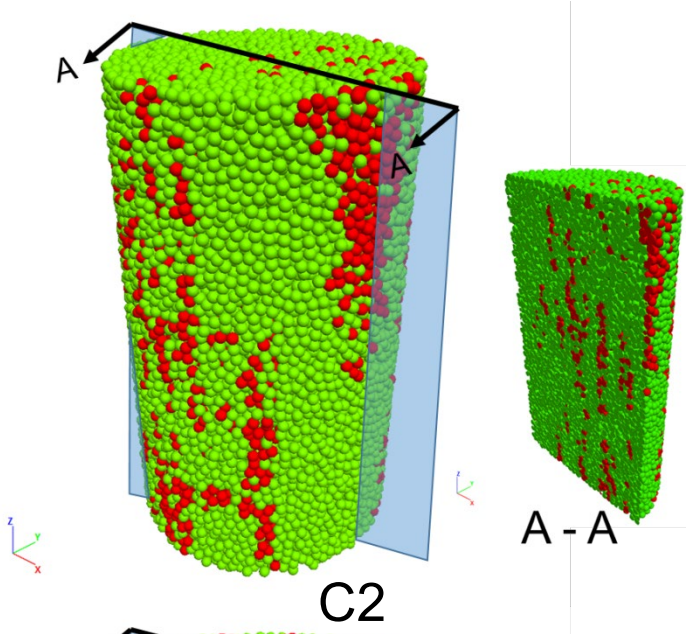
Geometry files (.stl) are imported to *PFC2D*, *PFC3D* and *FLAC3D*.

Models of sample are generated with exact same compositions.

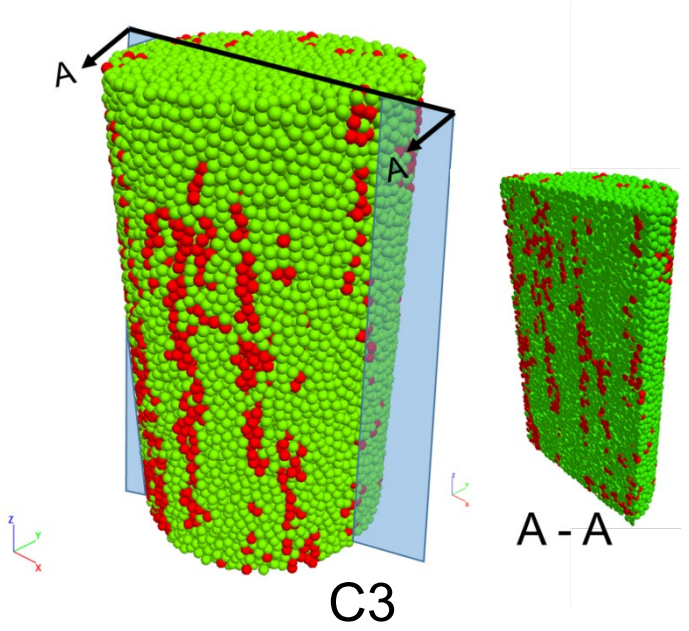
2. Sample Reconstruction



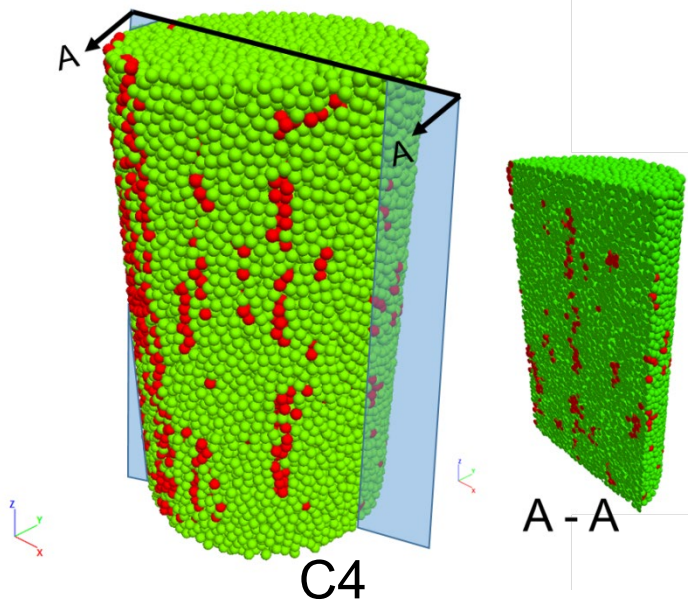
C1



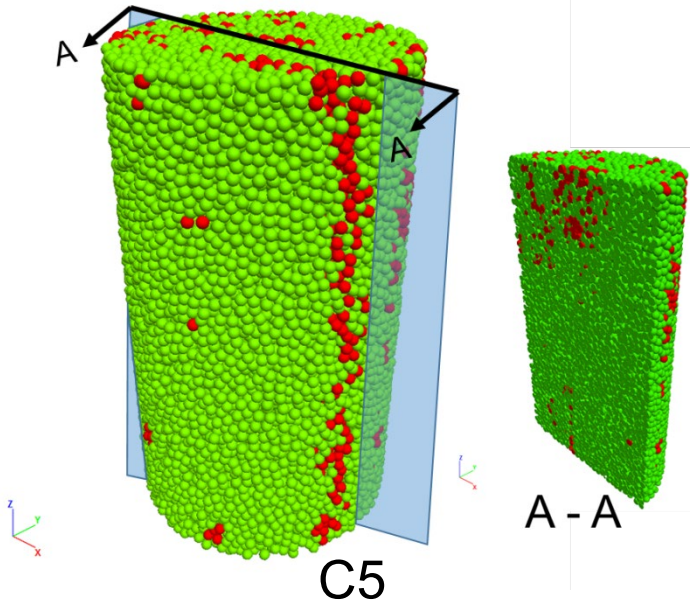
C2



C3



C4



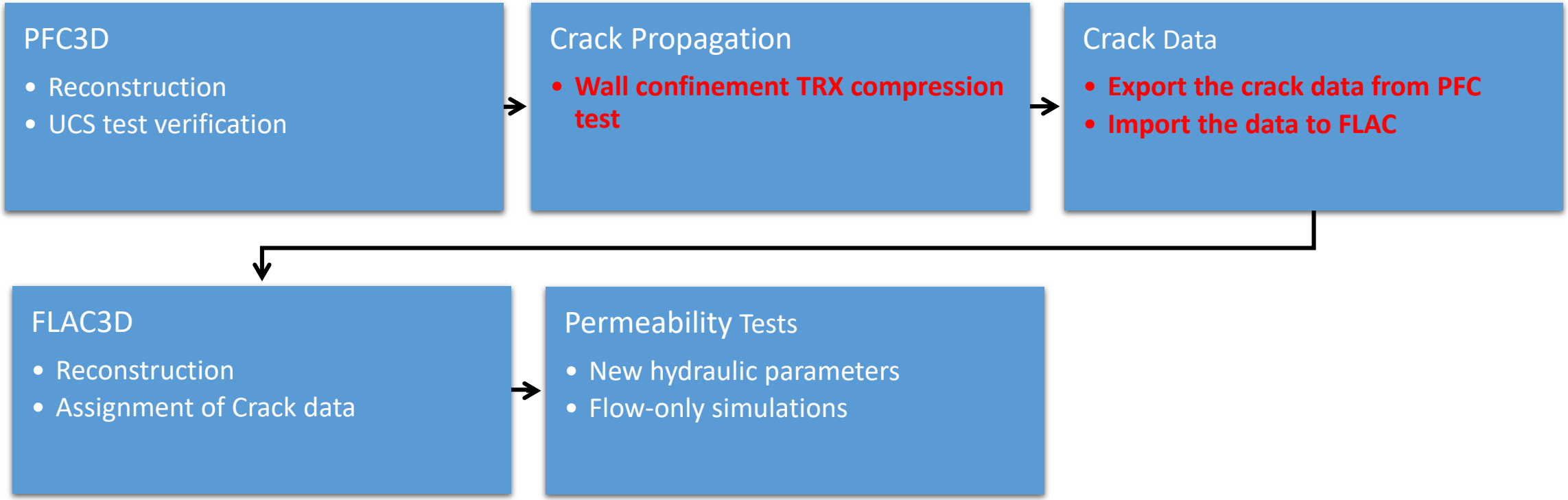
C5

Five coal samples reconstructed with CT techniques

Coal matrix: Green
Inclusions: Red

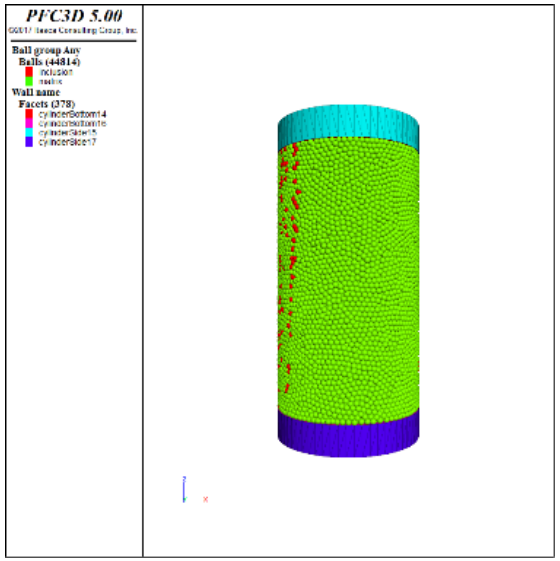
3. Coupled Simulations

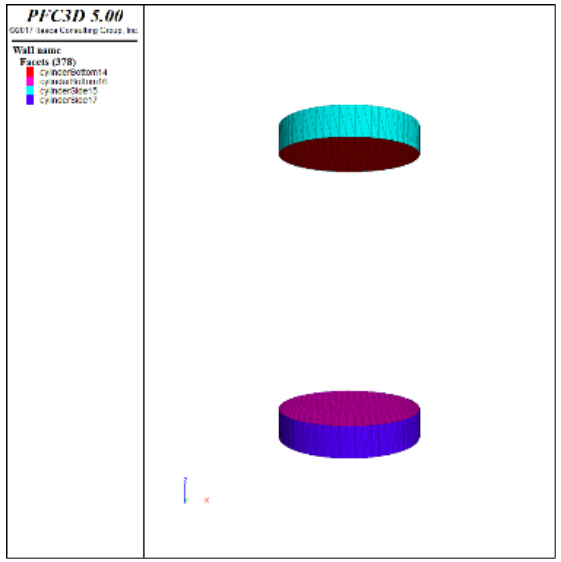
Flow Chart



3. Coupled Simulations: Triaxial test with FW approach

Traditional confinement model

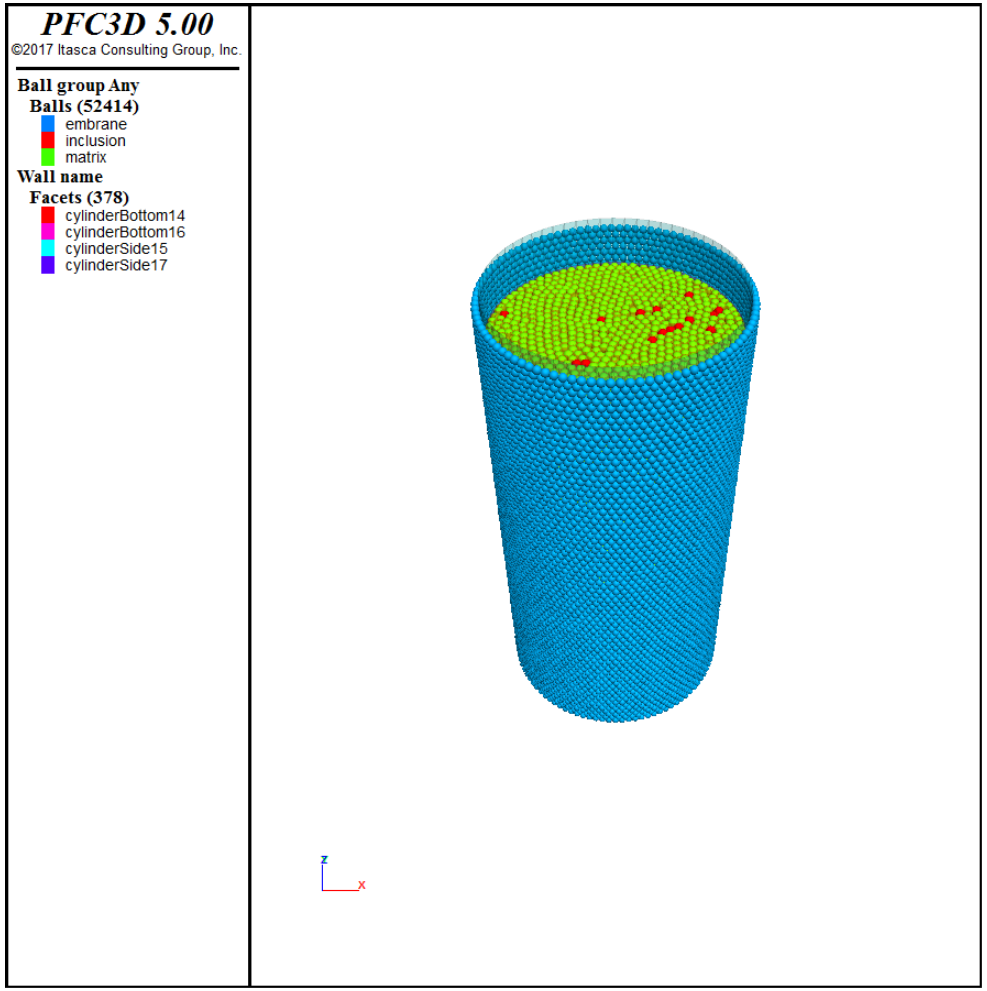




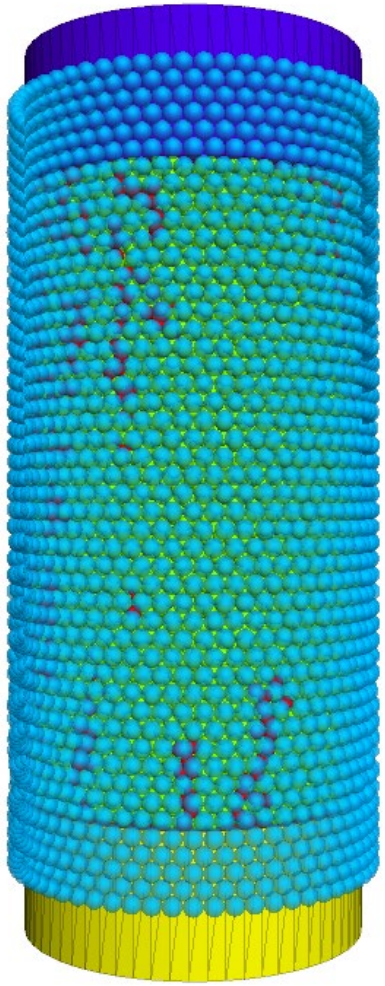
Triaxial test design with ball boundary as membrane

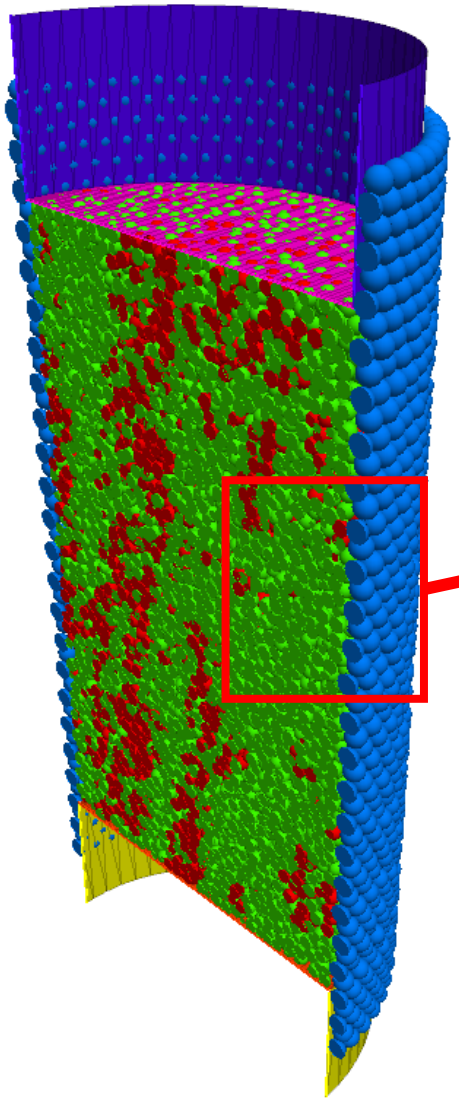
Axial loads: the wall movements

Confining loads: the force applied on each membrane particle towards the axis of sample.

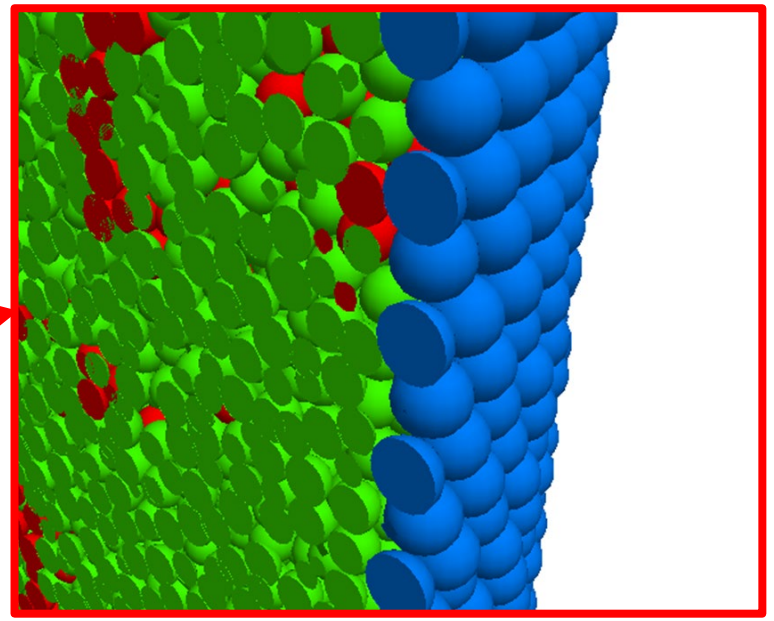


3. Coupled Simulations: Triaxial test with FW approach



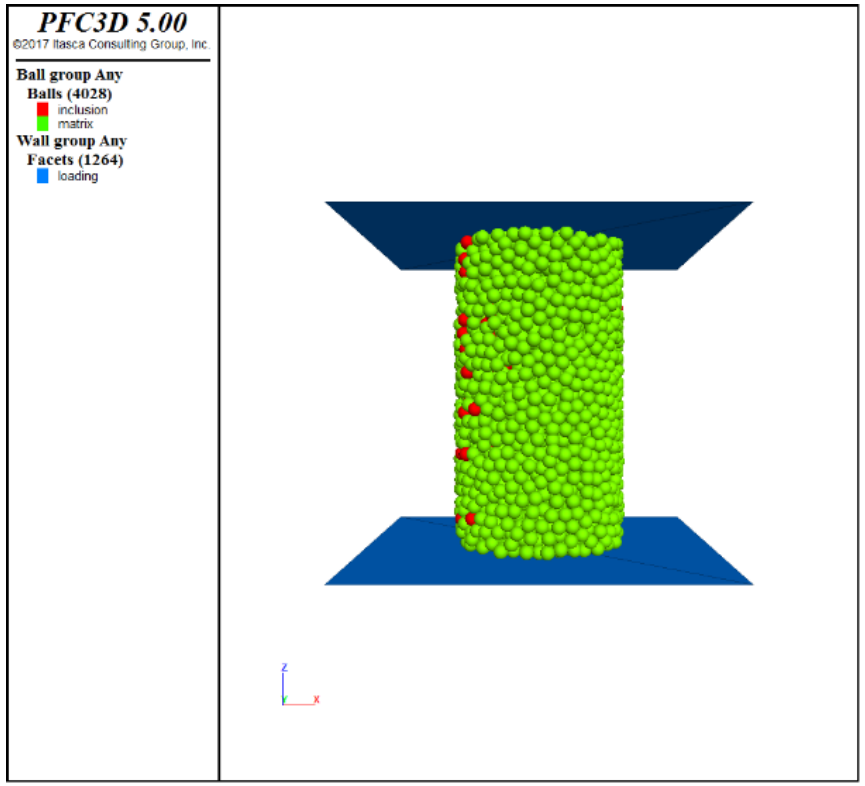


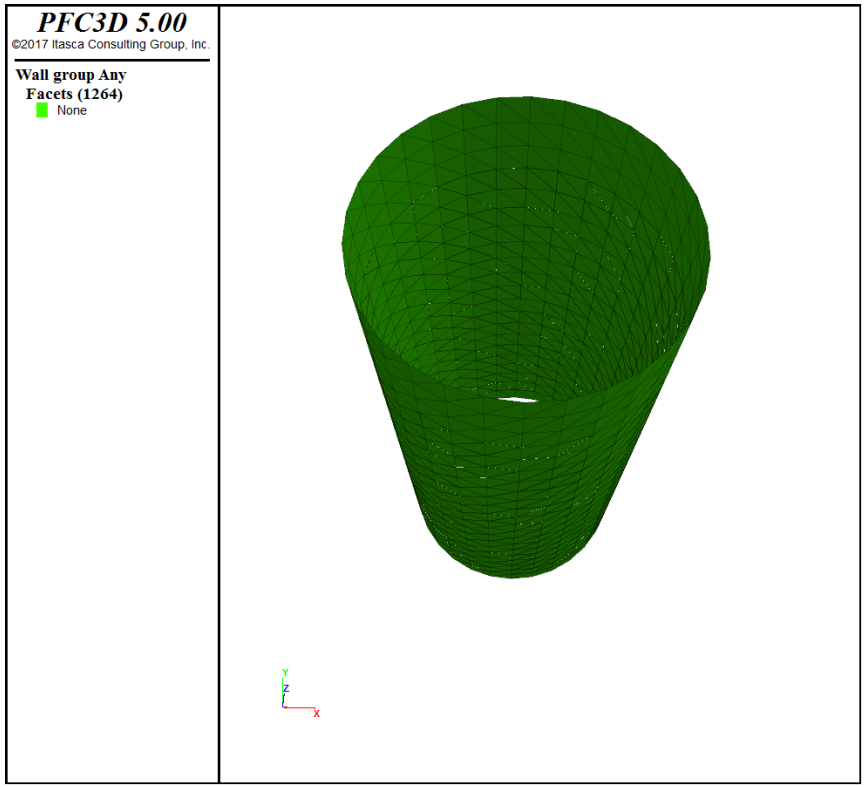
Complex contact boundary between sample and confinement



3. Coupled Simulations: Triaxial test with FW approach

Flexible Wall (FW) approach Triaxial test model





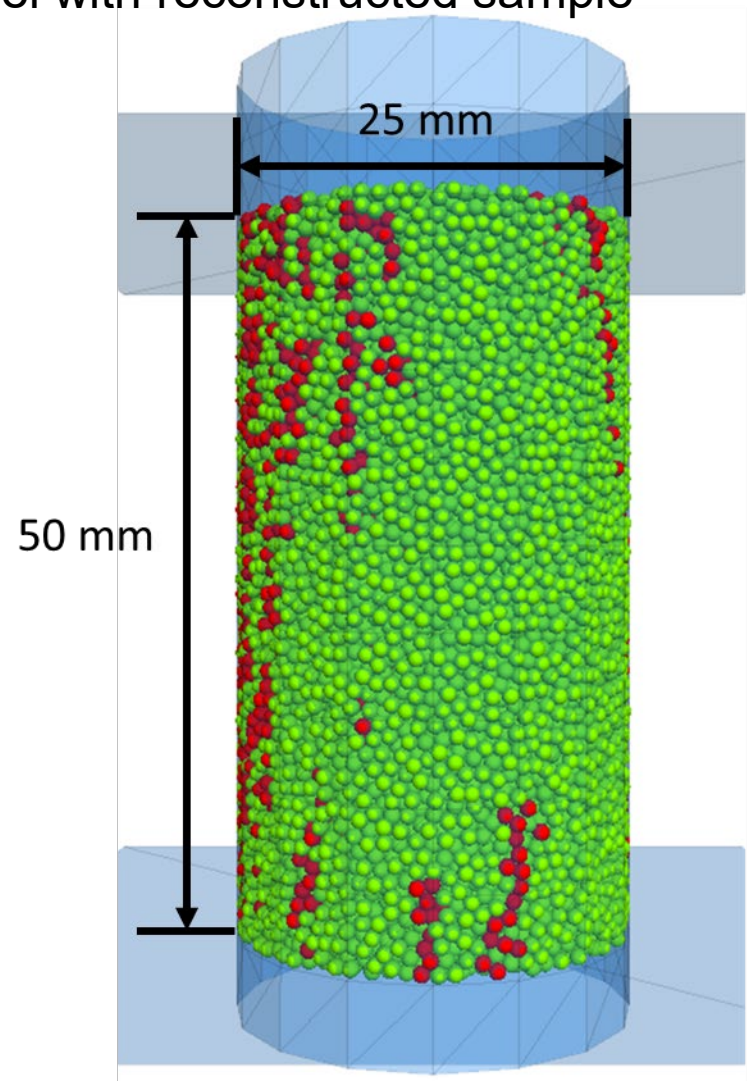
Triaxial test with wall elements as membrane (rubber coat)

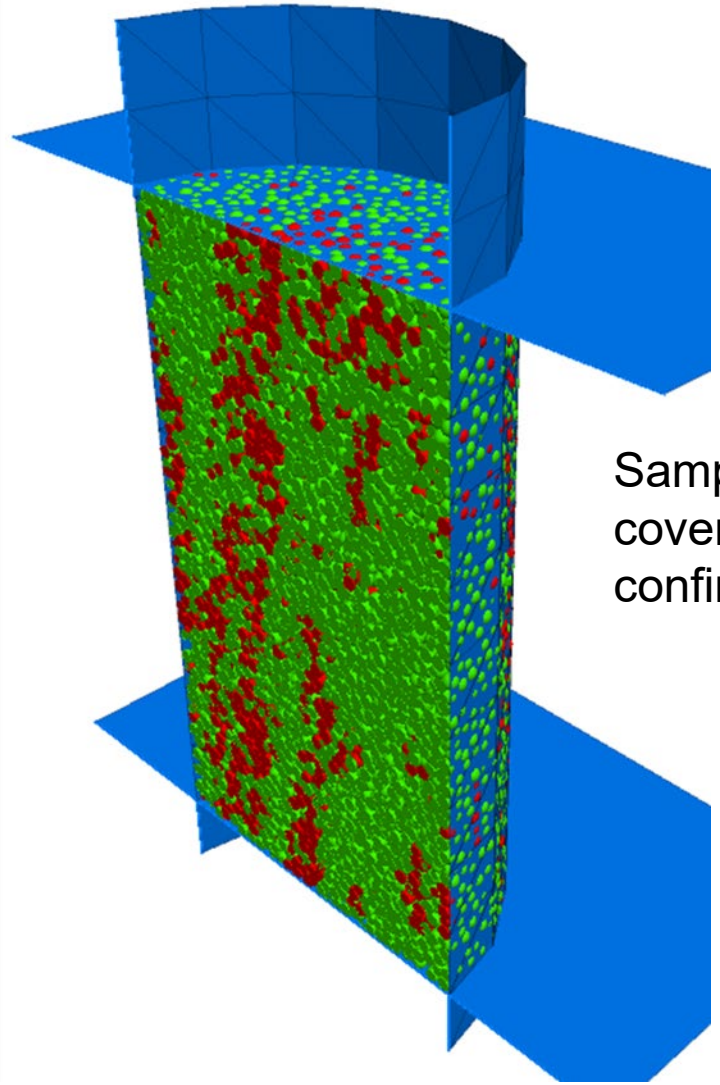
Axial loads: the loading wall movements

Confining loads: the force applied on the wall boundary, and wall-servo commands maintain the constant pressure value

3. Coupled Simulations: Triaxial test with FW approach

New model with reconstructed sample



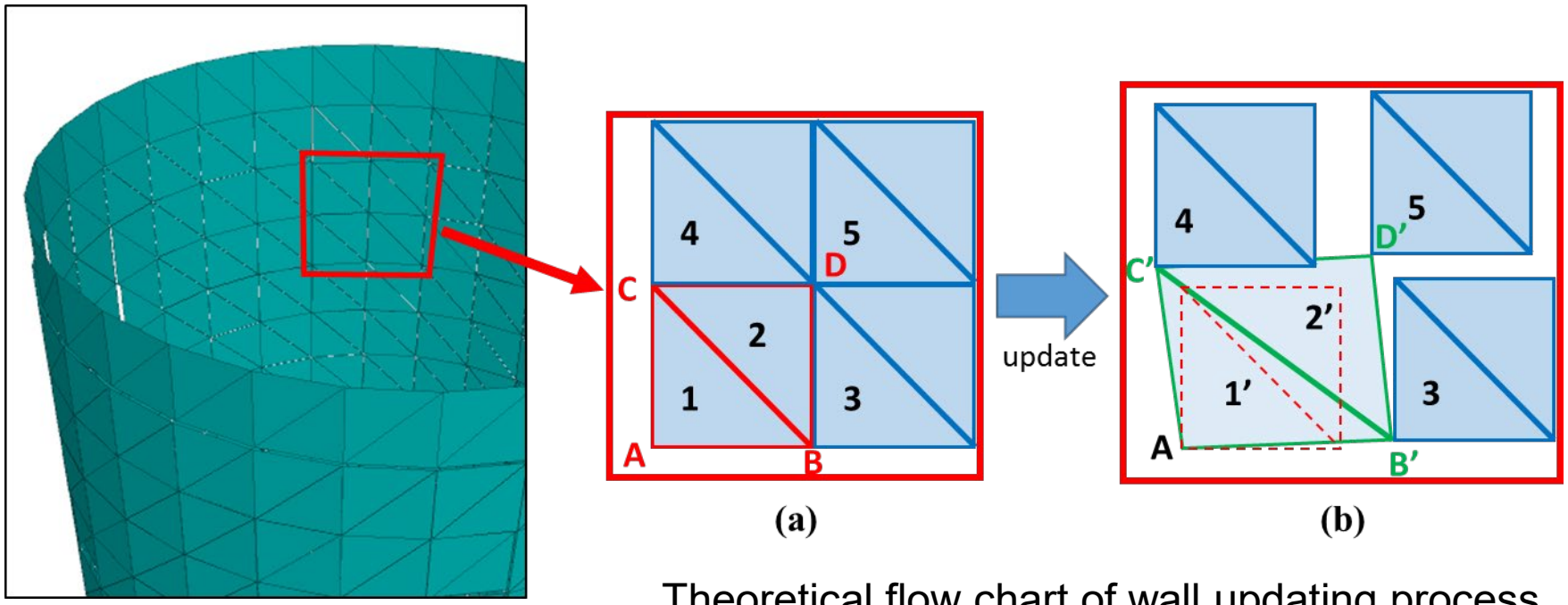


Sample is fully covered by the confined wall.

Core sample with confinement and axial loading plates

3. Coupled Simulations: Triaxial test with FW approach

Wall update procedure during test

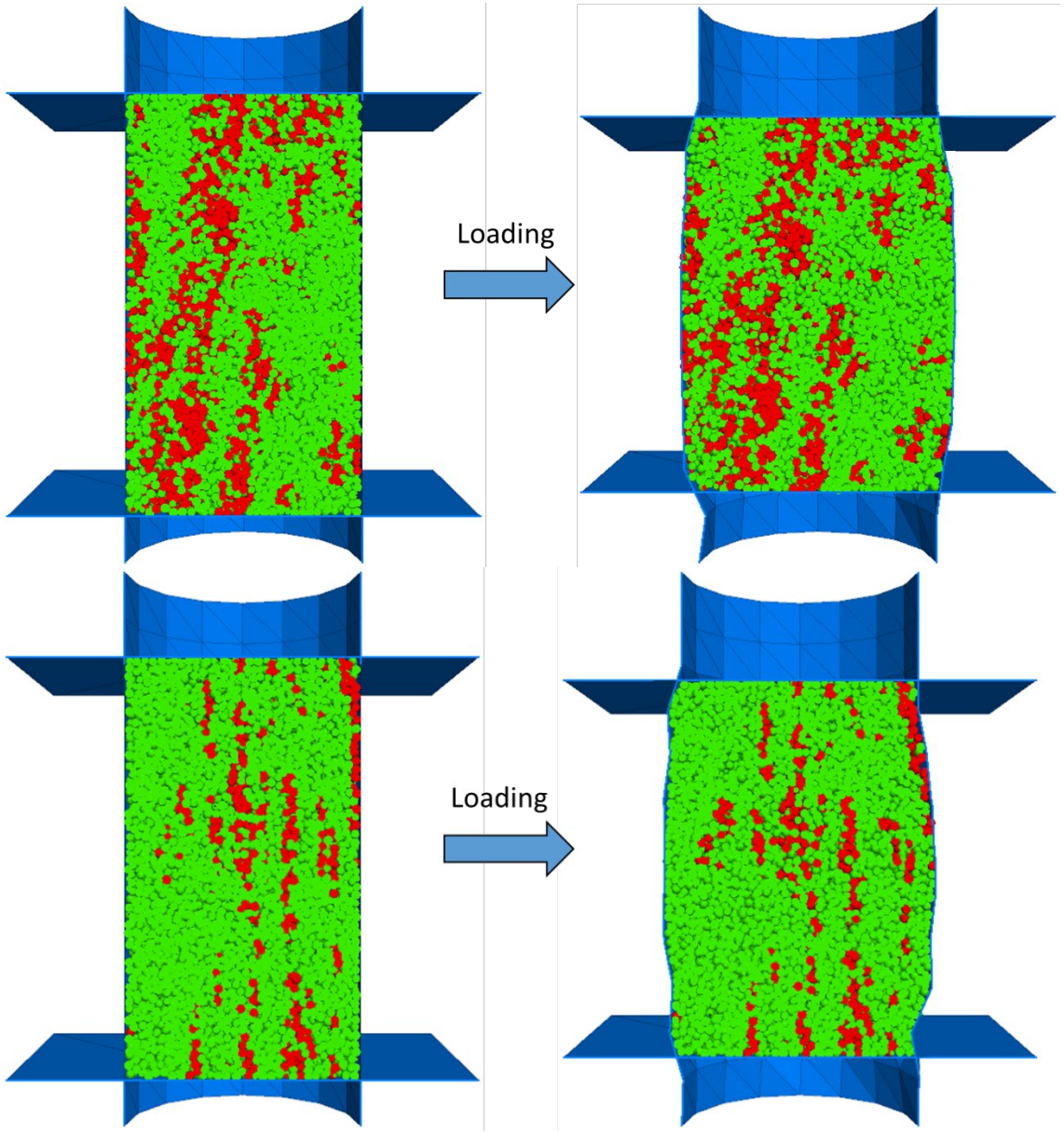


Theoretical flow chart of wall updating process.

New target force on each wall element

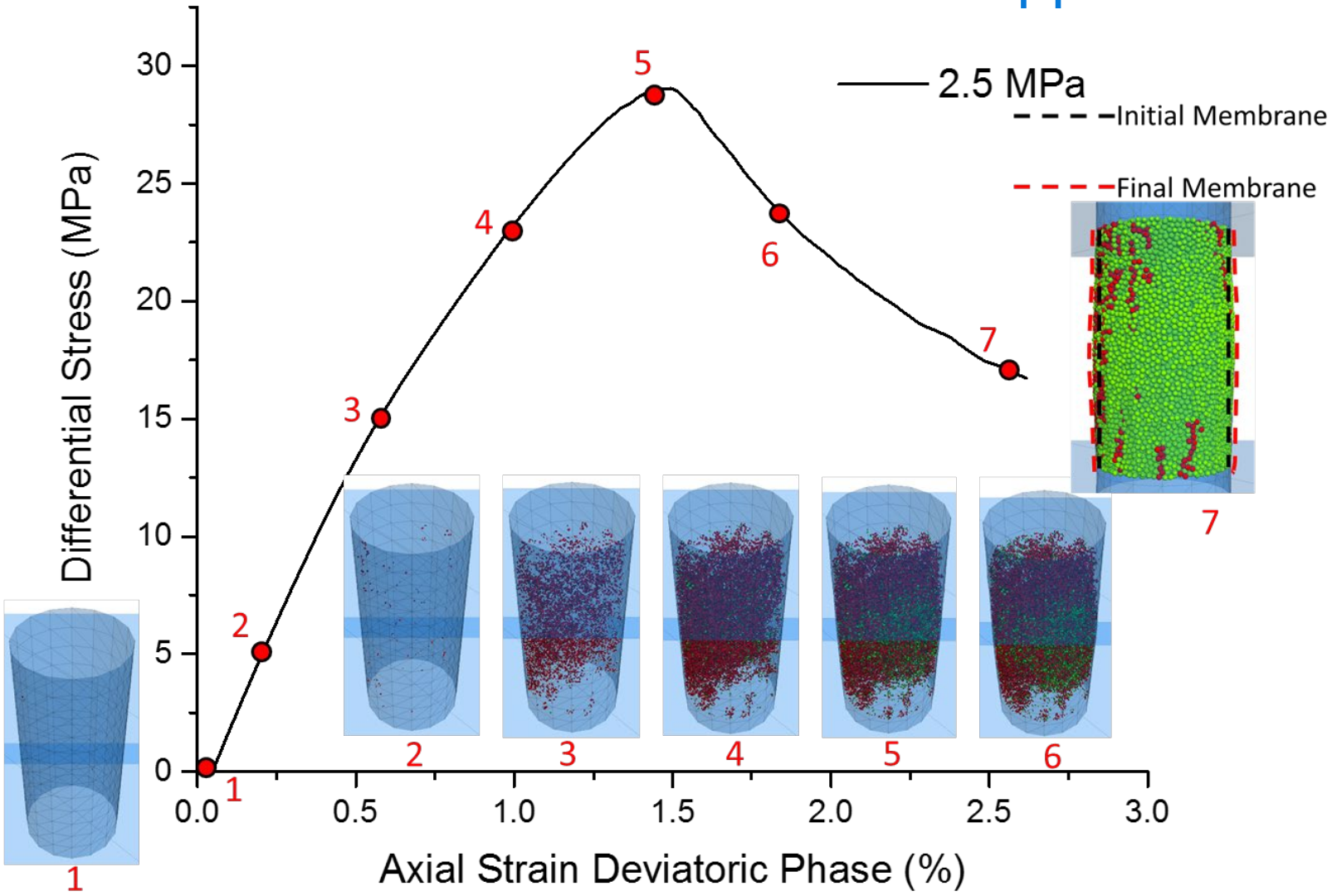
```
110         ar1_ = 0.5 * math.sqrt(((xc11_ * ycu1_ * 1) + (yc11_ * 1 * xcr1_) + (1 * xcu1_ * ycr1_) ...
&111                              - (1 * ycu1_ * xcr1_) - (yc11_ * xcu1_ * 1) - (xc11_ * 1 * ycr1_))^2 ...
&112                              + ((yc11_ * zcu1_ * 1) + (zc11_ * 1 * ycr1_) + (1 * ycu1_ * zcr1_) ...
&113                              - (1 * zcu1_ * ycr1_) - (zc11_ * ycu1_ * 1) - (yc11_ * 1 * zcr1_))^2 ...
&114                              + ((zc11_ * xcu1_ * 1) + (xc11_ * 1 * zcr1_) + (1 * zcu1_ * xcr1_) ...
&115                              - (1 * xcu1_ * zcr1_) - (xc11_ * zcu1_ * 1) - (zc11_ * 1 * xcr1_))^2)
116
117         tf1_ = cons_ * ar1_ ; new target force
```

3. Coupled Simulations: Triaxial test with FW approach



Cross-section of samples before and after simulation show well maintained boundary conditions

3. Coupled Simulations: Triaxial test with FW approach



Simulated stress-strain curves and crack evolution for coal sample with 2.5 MPa confining pressure

3. Coupled Simulations: Crack data export and import

Information of crack in exported file

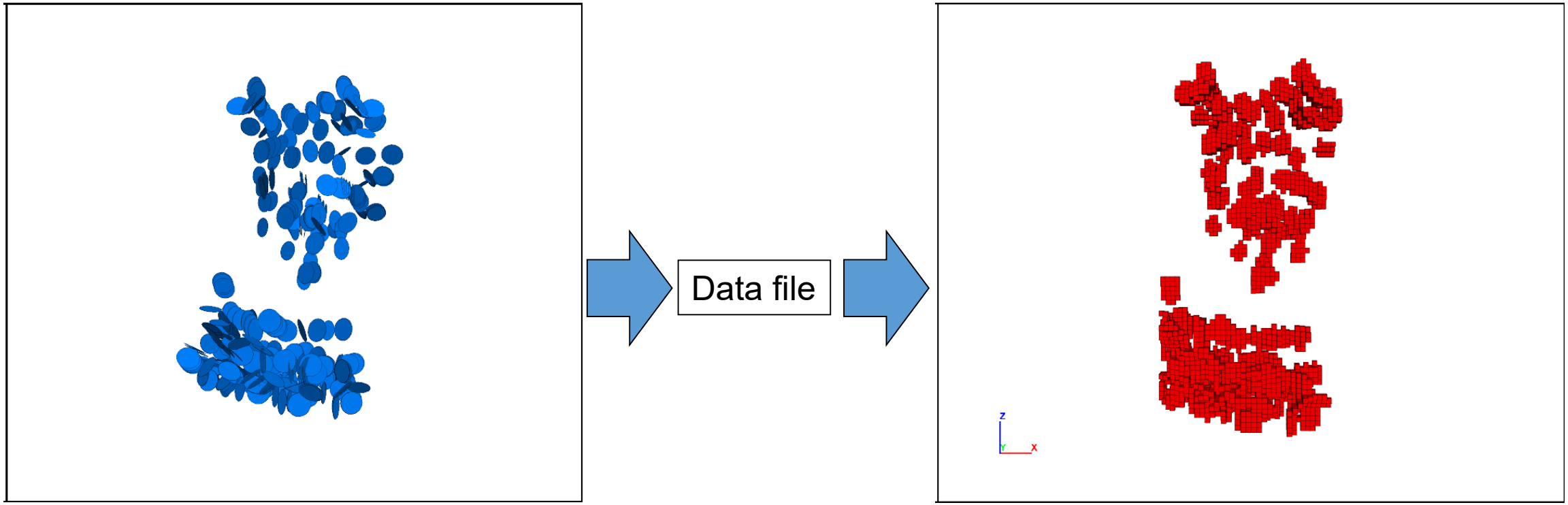
Total number of cracks

```
1861
0.0150249 0.0277143 0.0145819 0.0015 -0.519154 -0.430084 0.738584 0.000281736 0.00133034 230.361 42.389 crack_shear
0.0141102 0.00545103 0.00598283 0.0015 -0.677929 0.261126 0.687186 0 0 291.066 46.5922 crack_shear
0.0146773 0.0267611 0.0119478 0.0015 0.759279 -0.649912 0.0332983 0 0 130.562 88.0918 crack_tension
0.0161835 0.00728025 0.00509354 0.0015 -0.928926 0.358342 0.0932105 0 0 291.095 84.6517 crack_tension
0.00746663 0.0126379 0.011454 0.0015 -0.484798 -0.175629 0.856811 1.98234e-05 0.000345446 250.086 31.0396 crack_tension
0.0191443 0.0270196 0.0148288 0.0015 0.609038 0.266539 0.747014 0 0 66.3639 41.6676 crack_tension
0.00662532 0.0119401 0.00724411 0.0015 0.634336 -0.646879 0.42328 0 0 135.561 64.9582 crack_tension
0.0171052 0.027717 0.0135172 0.0015 0.845576 -0.490186 0.211468 0.000468508 0.00174085 120.101 77.7916 crack_tension
0.00620663 0.014109 0.010532 0.0015 0.297703 0.67492 0.675171 0 0 23.802 47.5326 crack_tension
```

Crack type

3. Coupled Simulations: Crack data export and import

Data transfer from PFC to FLAC (simplified model)



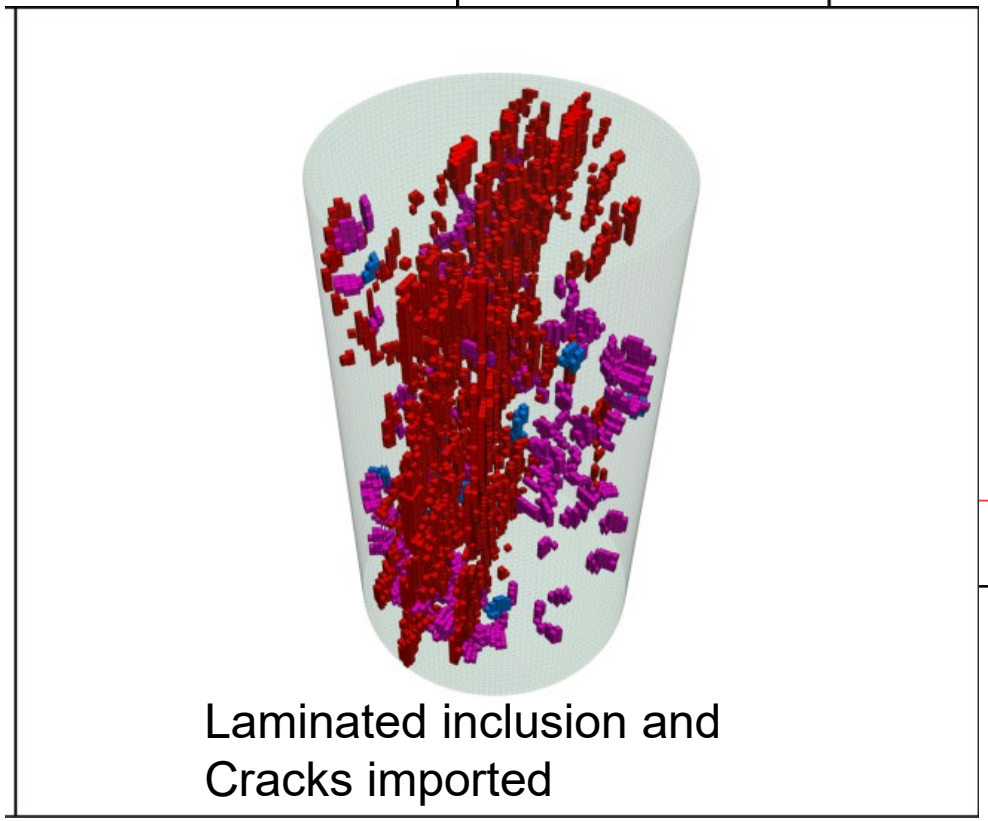
Crack distribution in PFC 3D

“Cracked” zone in FLAC 3D

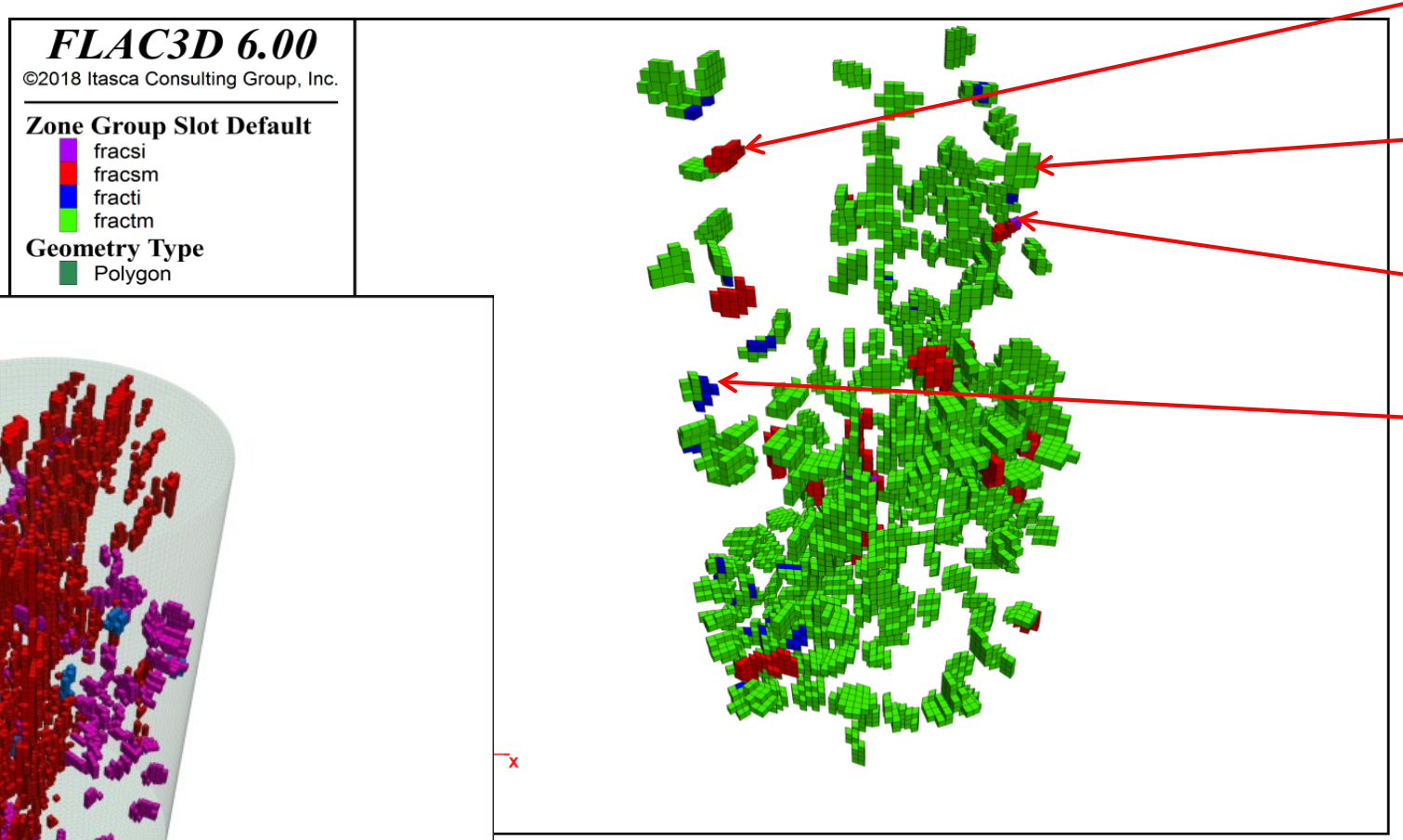
Coupling

3. Coupled Simulations: Crack data export and import

Data transfer from PFC to FLAC



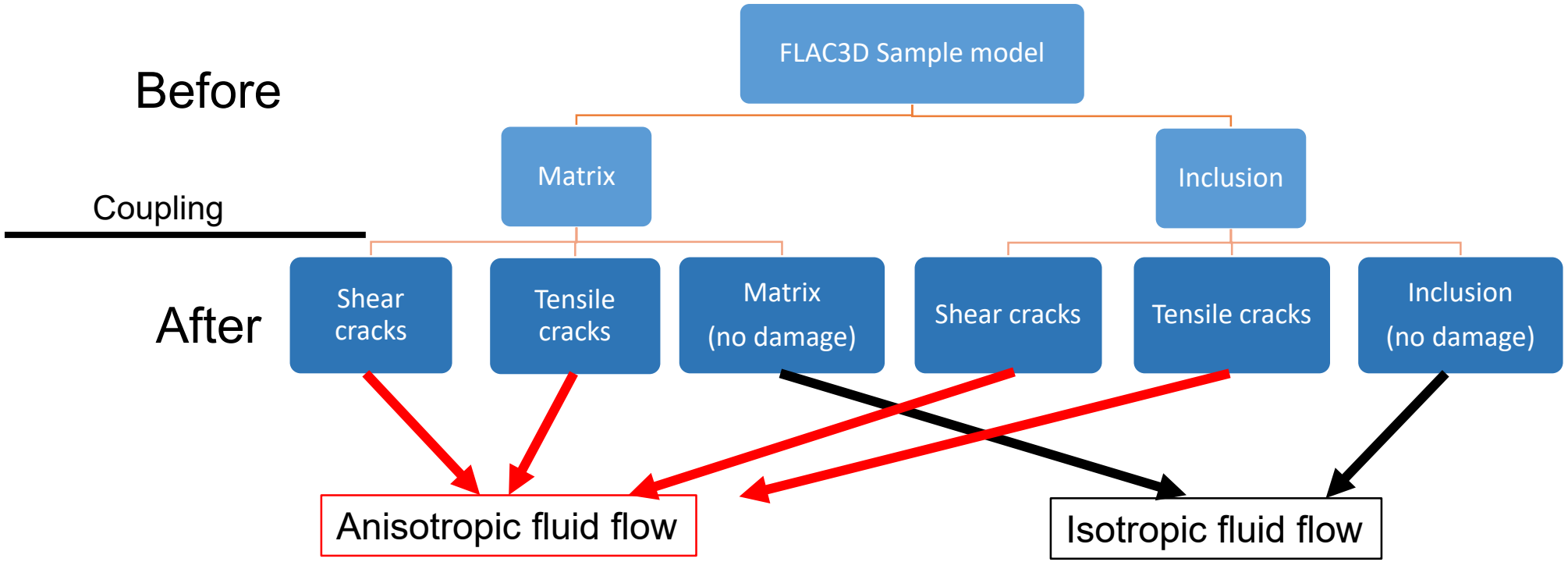
Laminated inclusion and
Cracks imported



Cracks distribution in FLAC3D

3. Coupled Simulations: Crack data export and import

Hydraulic parameter assignment



Flow chart of anisotropic model generation from original sample

3. Coupled Simulations: Permeability evolution simulation

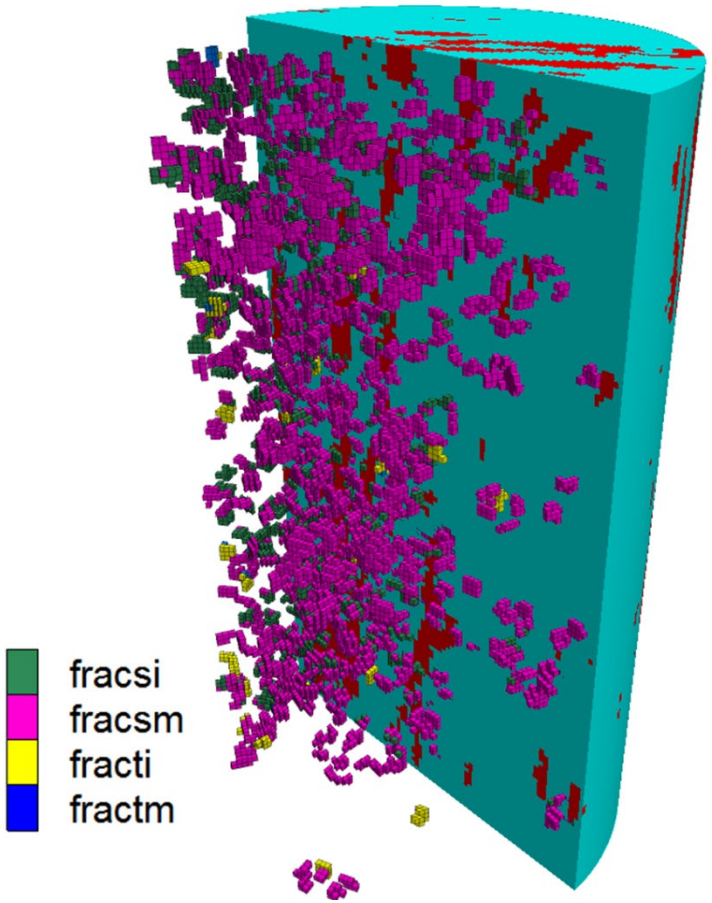
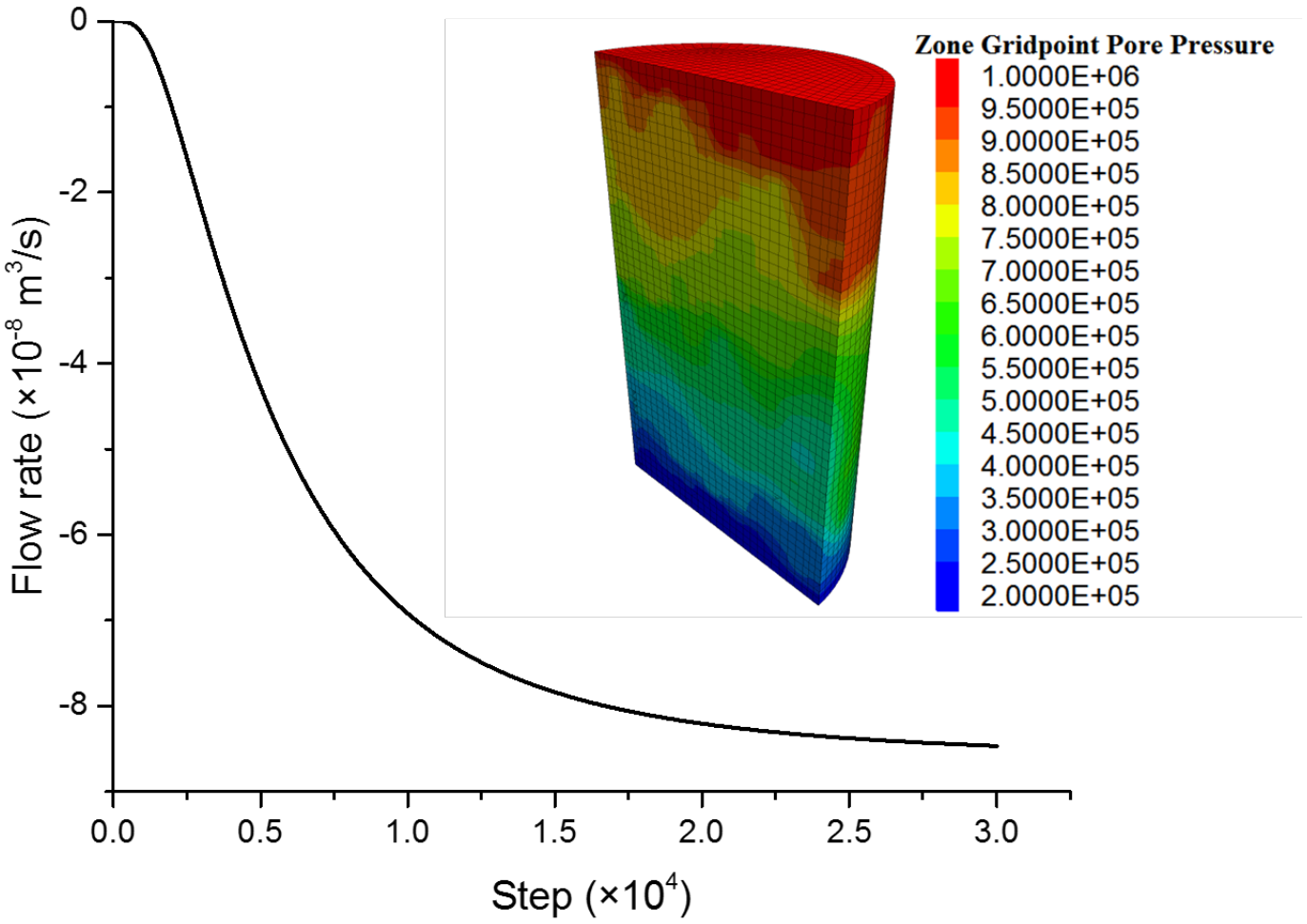


Illustration of FLAC^{3D} model for a specific stress state

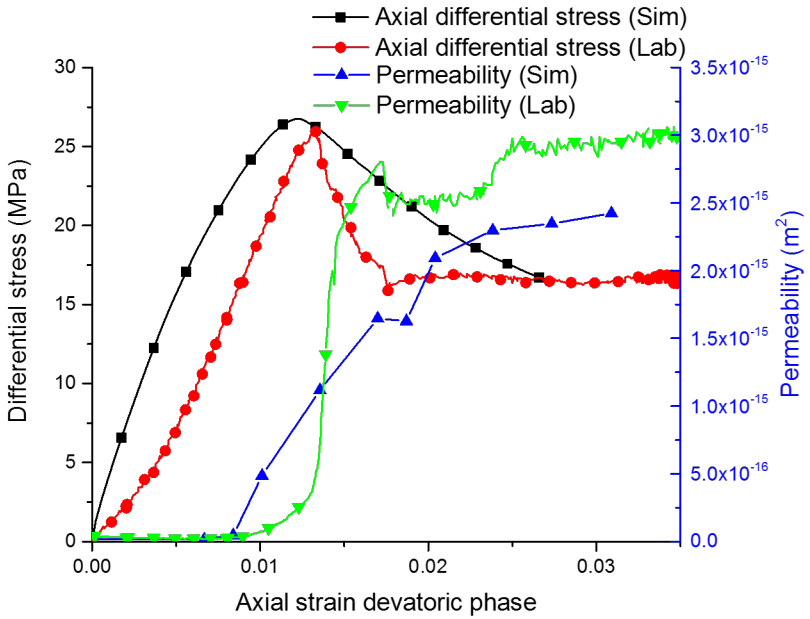
Flow-only simulations in *FLAC3D*



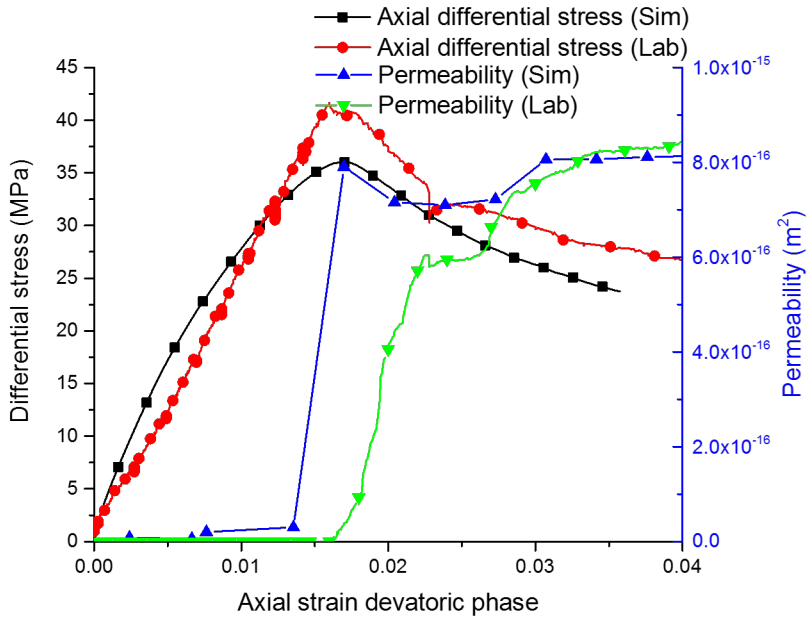
Flow rate evolution as function of calculation steps for model

3. Coupled Simulations: Permeability evolution simulation

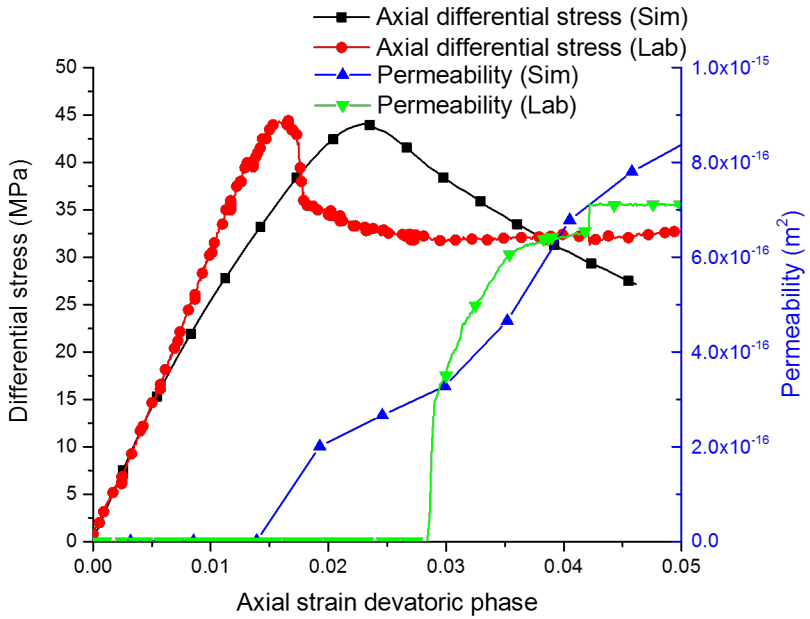
Permeability Evolution under Triaxial compression



Sample C1 2.5 MPa



Sample C3 5.0 MPa



Sample C4 7.5 MPa

Stress-strain curves and permeability evolution for sample C1, C3 and C4 under 2.5, 5.0 and 7.5 MPa confining pressure

4. Conclusions

1. CT techniques can be used to generate the real sample in numerical simulations.

2. FW confinement method can successfully simulate Triaxial compression test.

3. Coupled simulation with *PFC3D* and *FLAC3D* can be used in multiphase flow research.

Thanks for your attention!