Research on Simulation of Rupture of Rock Mass around Tunnels

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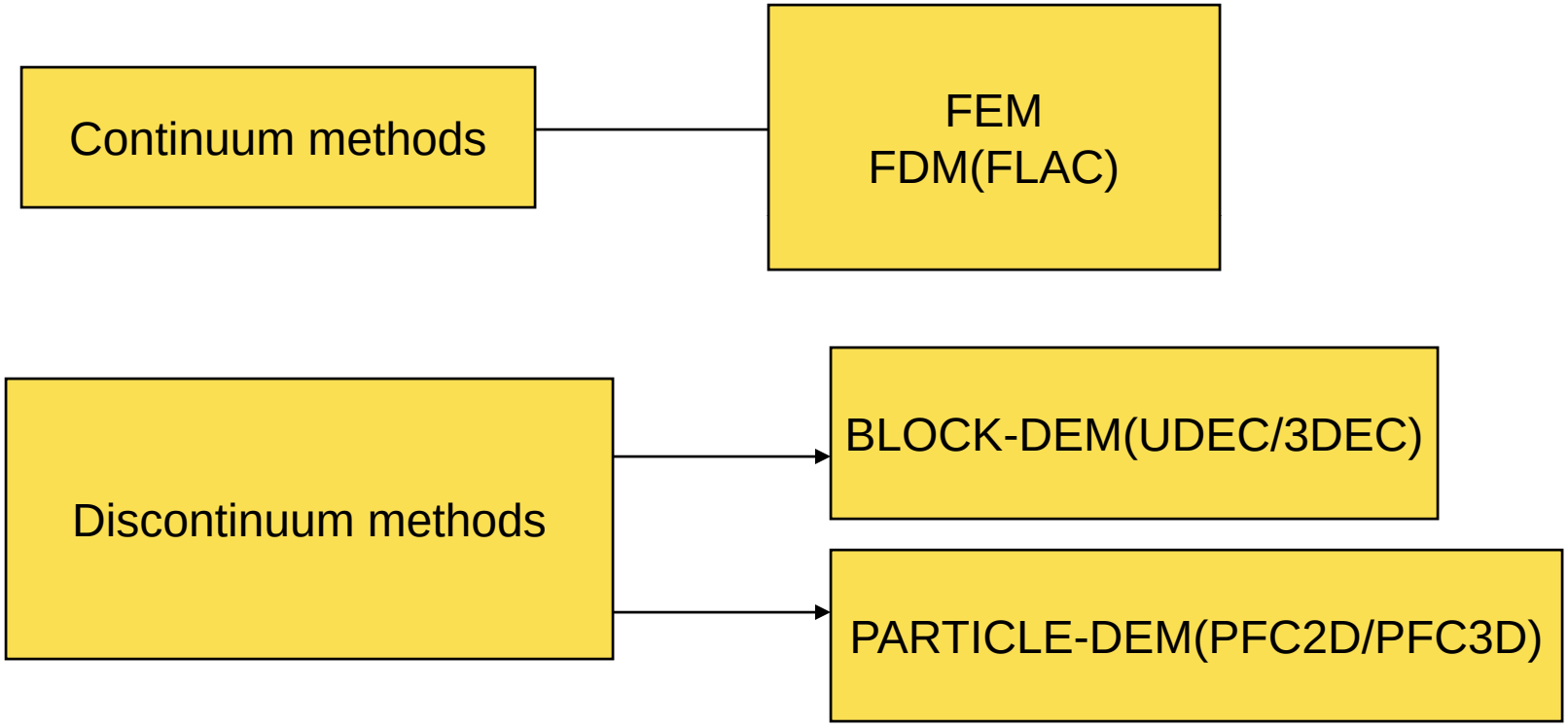
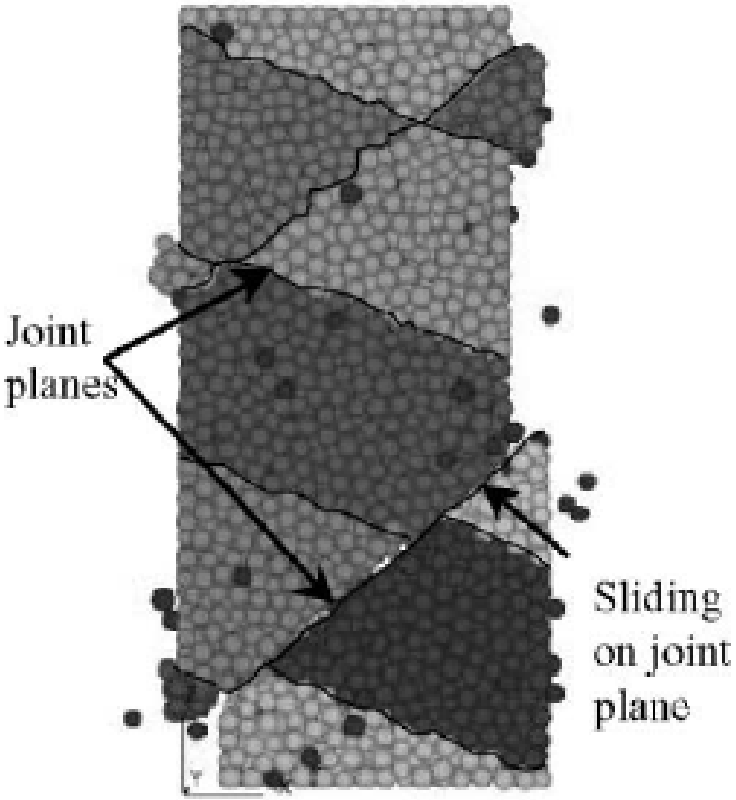
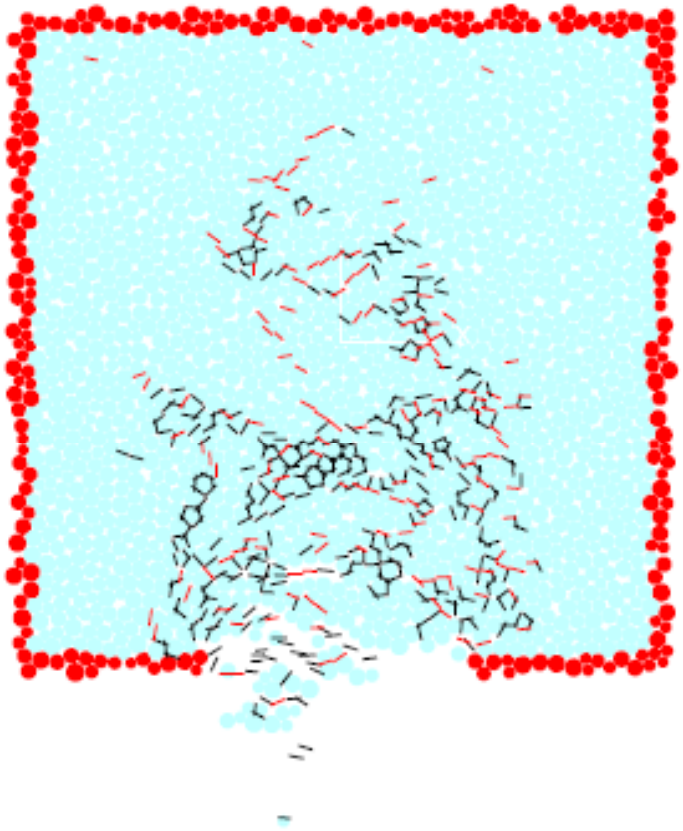
INTRODUCE

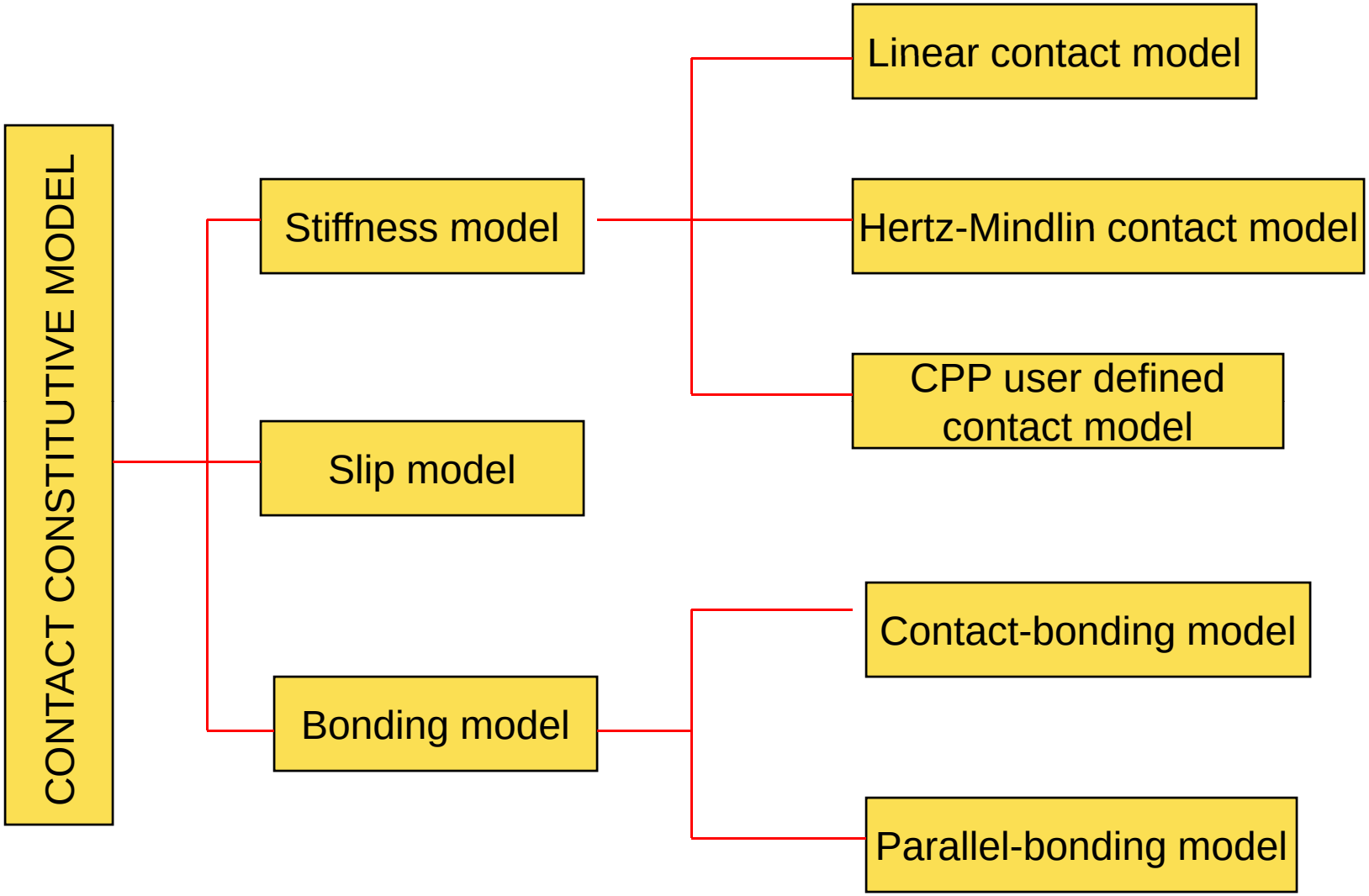

Continuum methods
FEM
FDM(FLAC)
Discontinuum methods
BLOCK-DEM(UDEC/3DEC)
PARTICLE-DEM(PFC2D/PFC3D)





Most rocks close to the Earth's surface are brittle and filled with fractures, cracks . Knowledge of the relationship between rock failure mechanisms and rock discontinuities is fundamental to solve many rock mechanics problems such as rockfalls, slope stabilities, and underground tunnel supports.

THEORY BACKGROUND


CONTACT CONSTITUTIVE MODEL
Stiffness model
Slip model
Bonding model
Linear contact model
Hertz-Mindlin contact model
CPP user defined contact model
Contact-bonding model
Parallel-bonding model

Contact stiffness model

The contact force vector can be resolved into normal and shear components with respect to the contact plane

$$F_i = F_i^n + F_i^s$$

The magnitude of the normal contact force is calculated by

$$F_i^n = K^n U^n n_i$$

The magnitude of the normal contact force is calculated by

and is used to calculate the shear elastic force increment

$$\Delta F_i^s = -k^s \Delta U_i^s$$

The linear contact model

The contact stiffnesses for the linear contact model are computed assuming that the stiffnesses of the two contacting entities act in series. The contact normal secant stiffness is given by

$$K^n = \frac{k_n^{[\mathrm{A}]} k_n^{[\mathrm{B}]}}{k_n^{[\mathrm{A}]} + k_n^{[\mathrm{B}]}}$$

and the contact shear tangent stiffness is given by

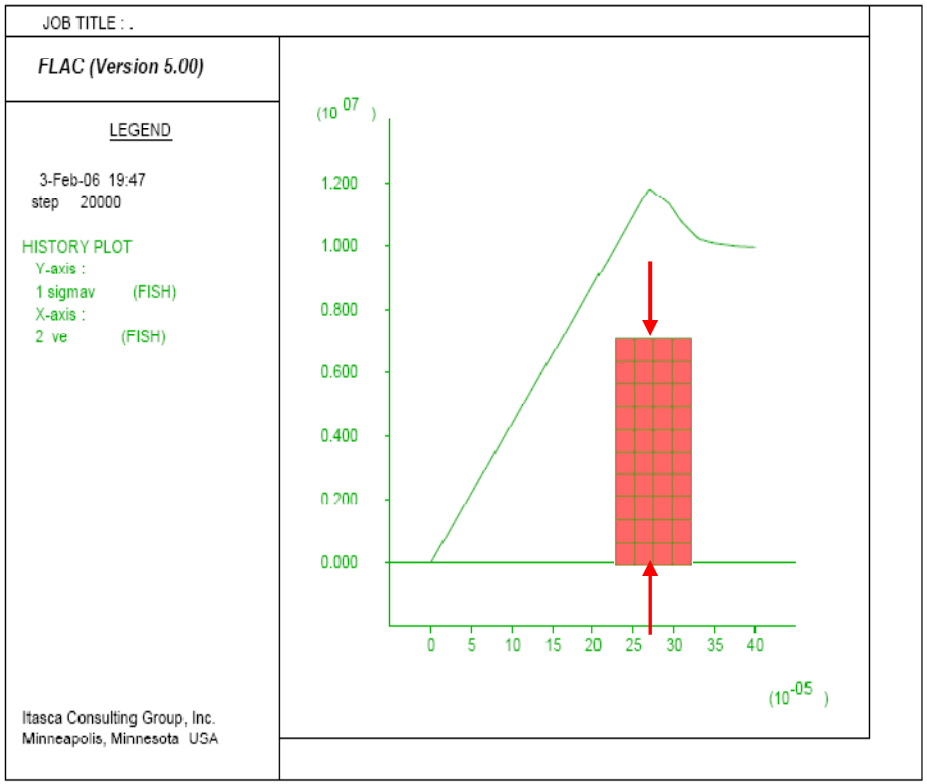
$$k^s = \frac{k_s^{[\mathrm{A}]} k_s^{[\mathrm{B}]}}{k_s^{[\mathrm{A}]} + k_s^{[\mathrm{B}]}}$$

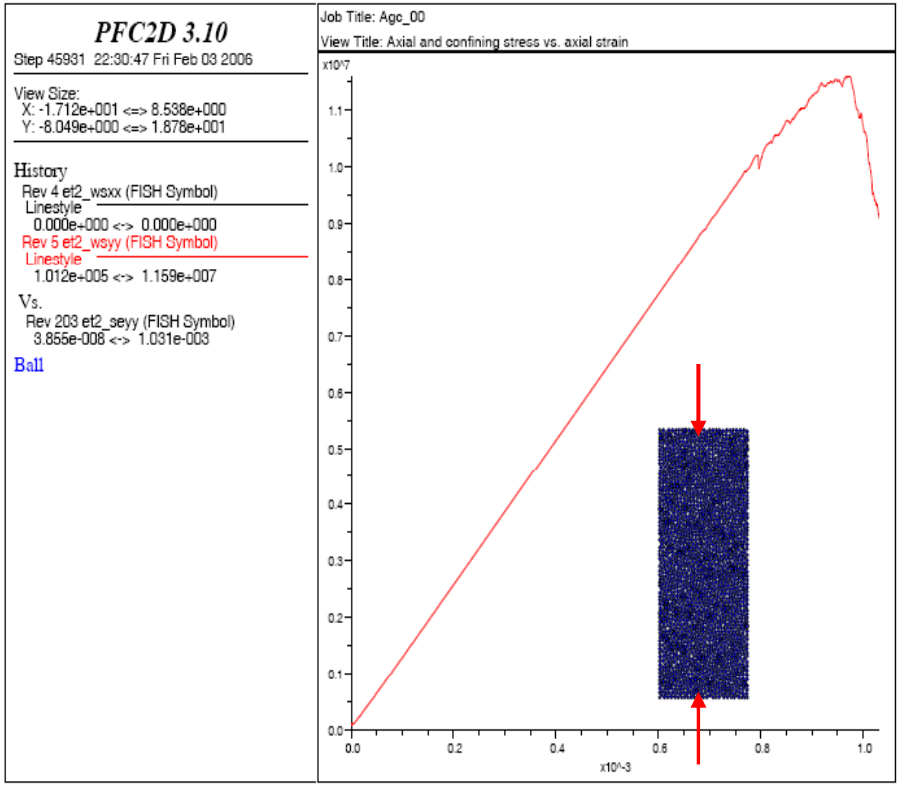
TWO PROBLEMS

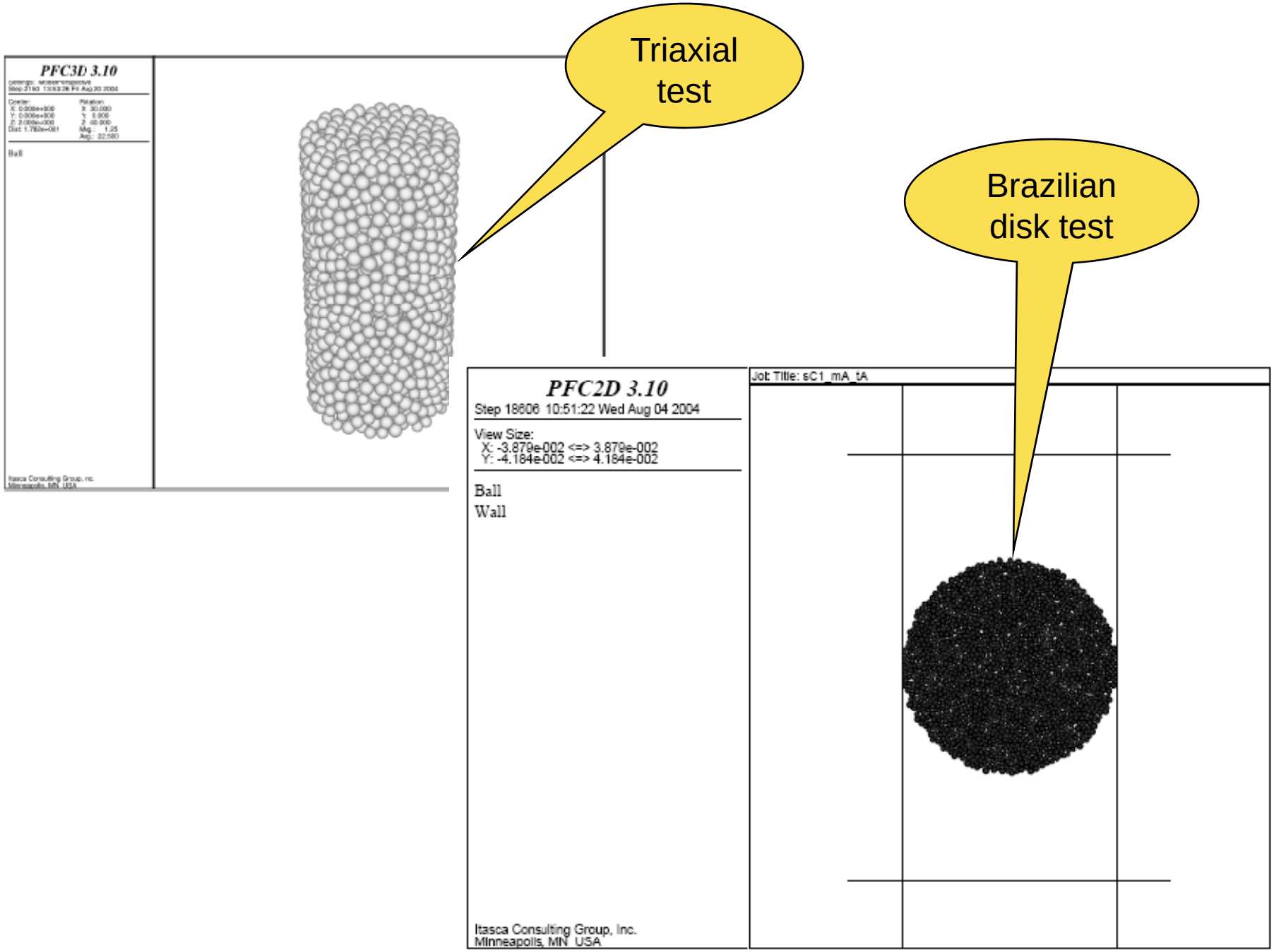
How to determine the micro-parameters

New contact model development

Comparison of UCS between PFC and FLAC model






PFC3D 3.10
Ball
Triaxial test
PFC2D 3.10
Step 18606 10:51:22 Wed Aug 04 2004
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Y: -4.184e-002 <=> 4.184e-002
Ball
Wall
Itasca Consulting Group, Inc.
Minneapolis, MN USA
Job Title: sC1_mA_tA
Brazilian disk test

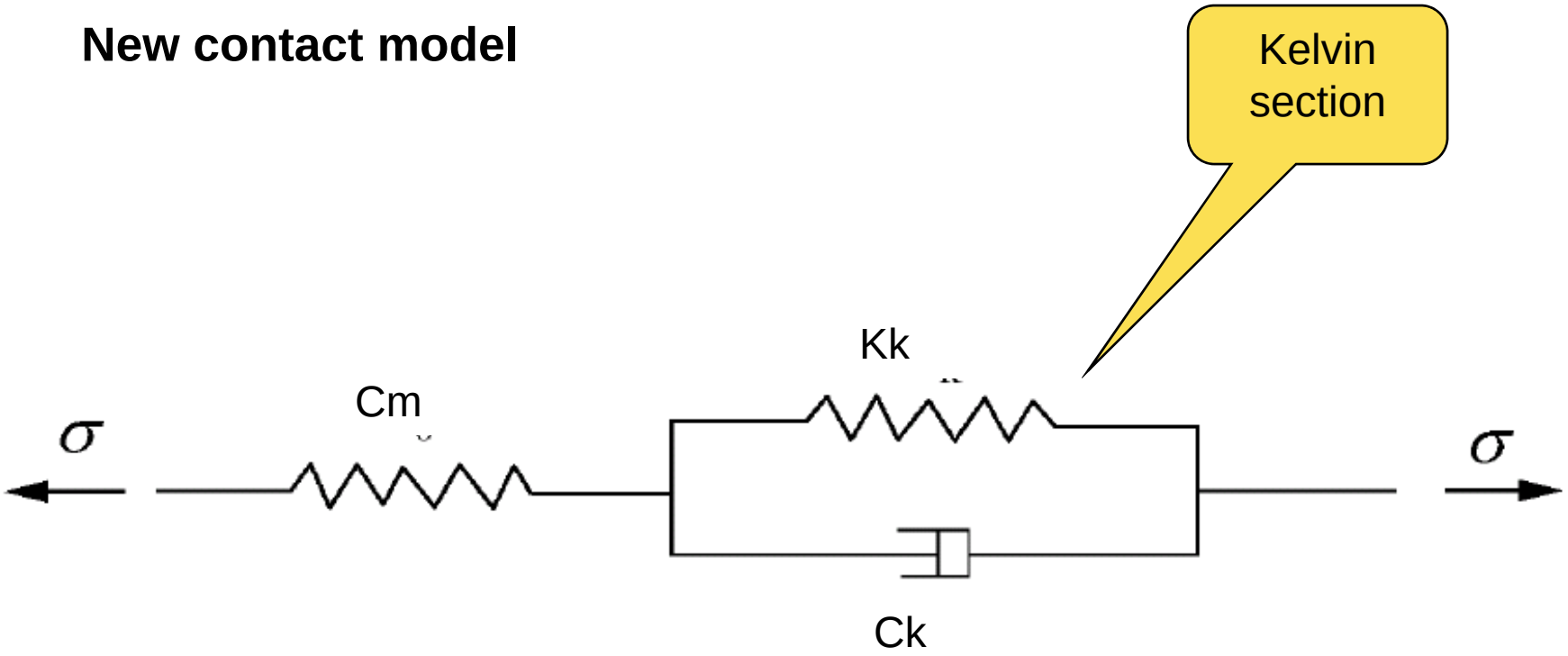
Implemented model

- **Simple viscoelastic model**
- **Simple ductile model**
- **Displacement softening model**

External model

- **Hysteretic damping model**
- **Burgers model**
- **Viscous damping contact model**

New contact model



Generalized Kelvin model

Contact force be calculated from differential scheme

$$f^{t+1} = \frac{2C_k K_m + K_m^2 \Delta t}{2C_k + 2K_m \Delta t}[u^{t+1} - u^t + (\frac{2K_k \Delta t}{2C_k + K_k \Delta t})u_k^t - \frac{-2C_k}{2C_k K_m + K_m^2 \Delta t} f^t]$$

Analytical solution- second order differential equation for contact force

$$\frac{1}{K_m}\ddot{f} + \left(\frac{1}{K_k} + \frac{K_k}{C_k K_m}\right)\dot{f} = \ddot{u} + \frac{K_k}{C_k}\dot{u}$$

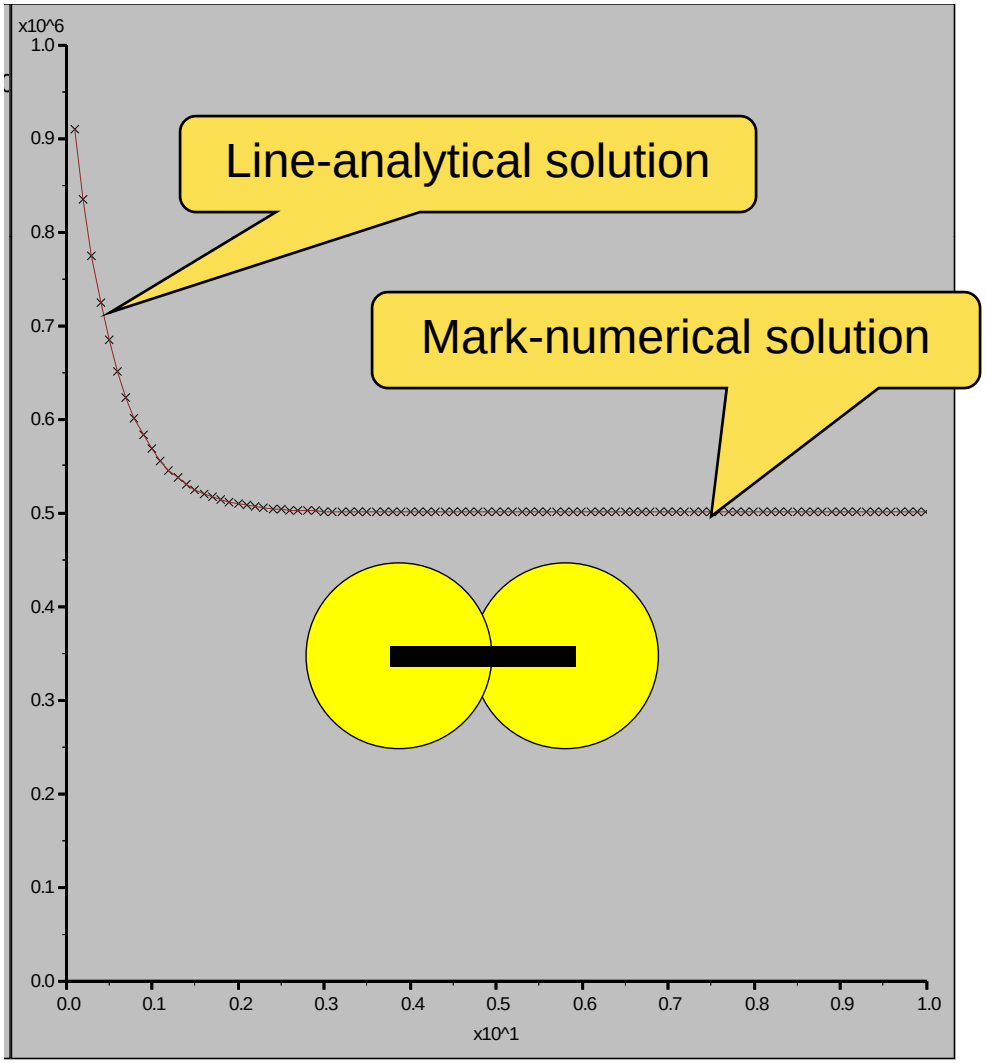
VERIFICATION EXAMPLES

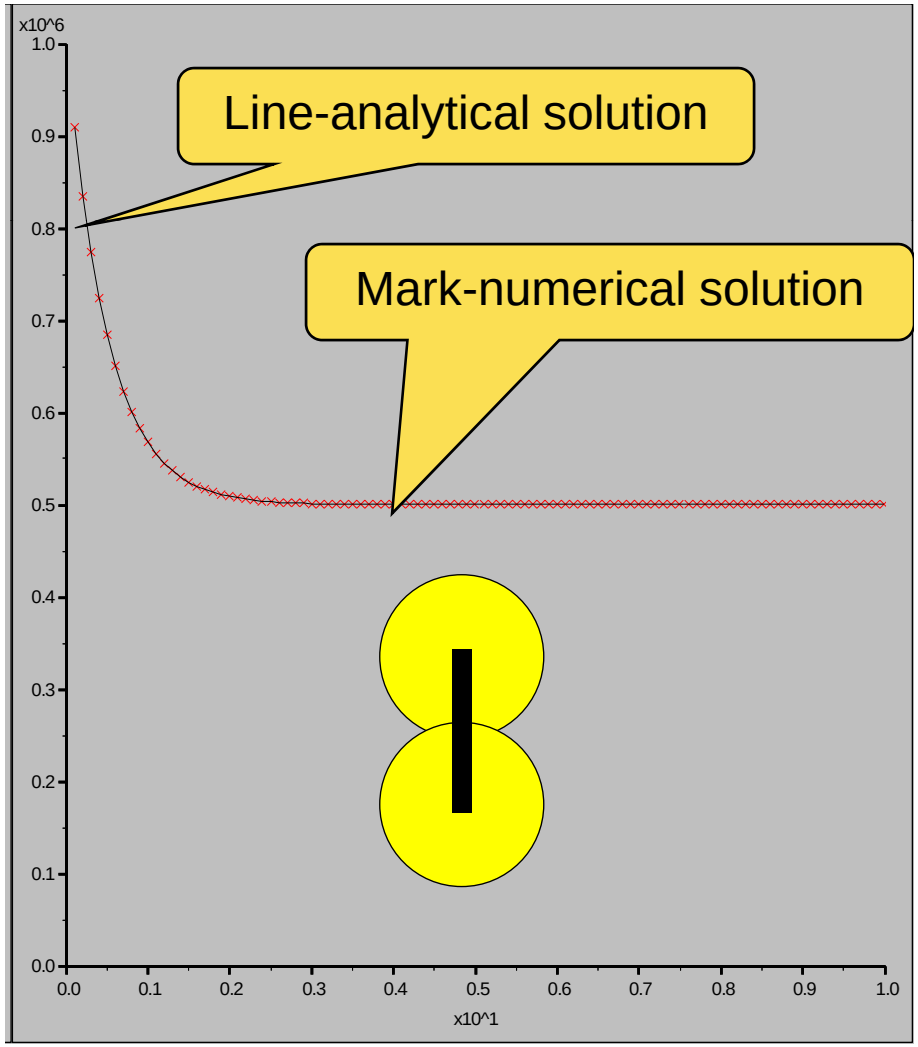
User-defined contact constitutive models can be added to *PFC2D* by writing the model in C++ language, compiling it as a DLL (dynamic link library) file and loading the DLL into *PFC2D* whenever needed.

The user-defined models depend on the following files.
1. CONTMODEL.H — utility structure used to communicate with contact model
2. UMDVECT3.H — specifies a doubles vectors class Mdvect — used only in a 3D compilation

Source and header files called “GKELVIN.CPP”
and “GKELVIN.H.” To create a DLL, the user need modify these files.

```
if (fb.u_n > 0.0 || fb.bflag) {

    // normal force

    fb.n_force = 1.0/conCn*(fb.u_n-u_n0+(1.0-conB_An)*u_nk0-conDn*fn0);

If (bNtension && fb.n_force<0.0)  fb.n_force = 0.0;

    u_nk0 = conB_An*u_nk0+fb.tdel/(2.0*cn_k*conAn)*(fb.n_force+fn0);

    u_n0  = fb.u_n;

    fn0   = fb.n_force;
```


x10^6
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
x10^1
Line-analytical solution
Mark-numerical solution


x10^6
1.0
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0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
x10^1
Line-analytical solution
Mark-numerical solution

ENGINEERING APPLICATION

PFC2D 3.10

Step 44196 16:36:14 Tue Feb 21 2006

View Size:
X: -3.867e+001 <=> 3.867e+001
Y: -4.280e+001 <=> 4.280e+001

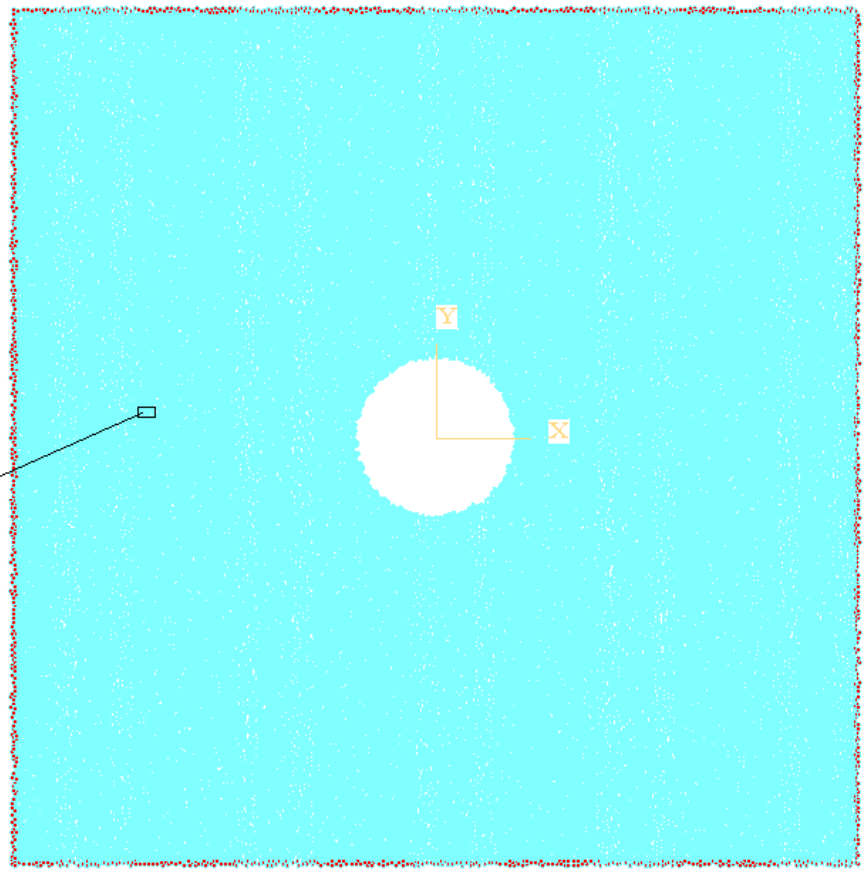
Ball

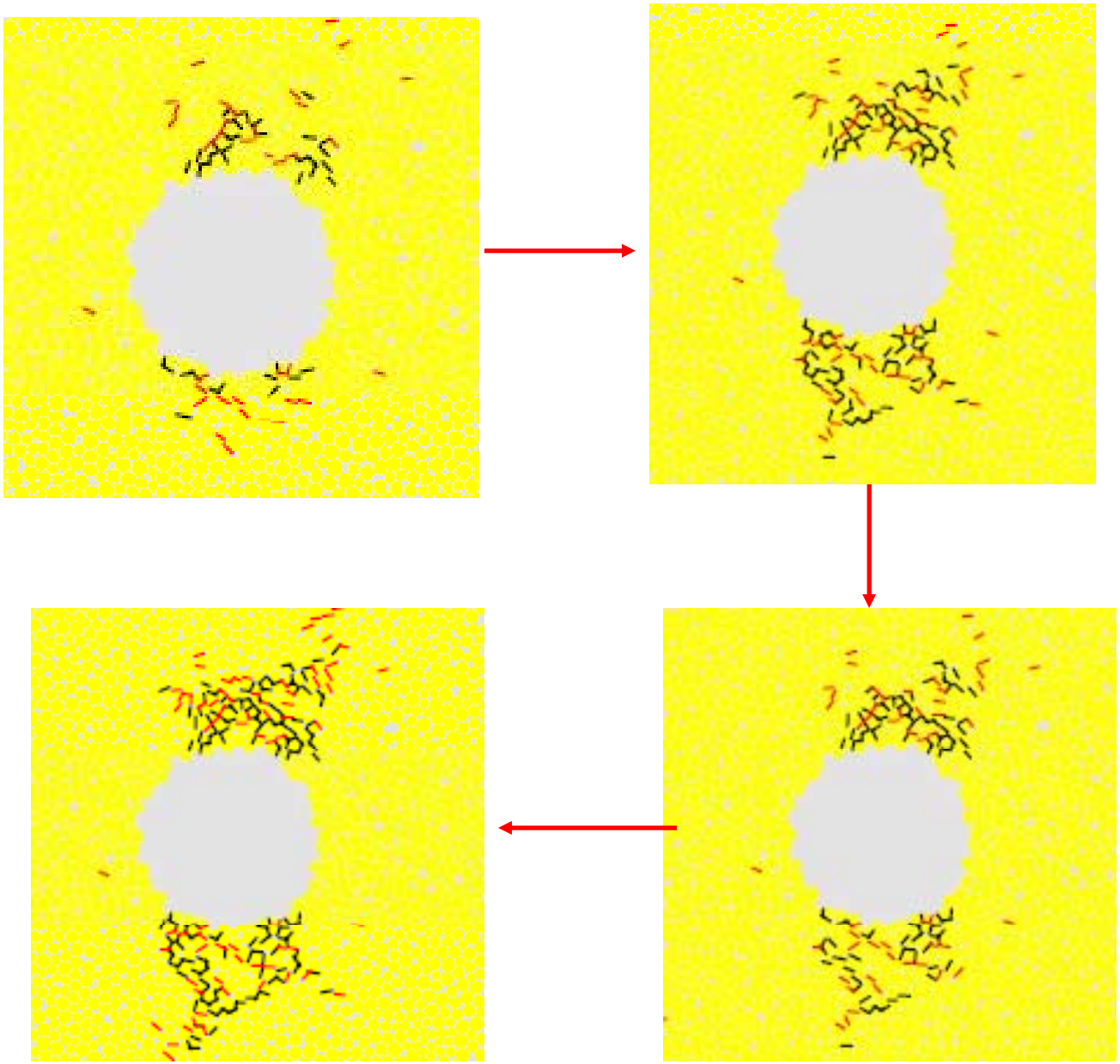
Axes

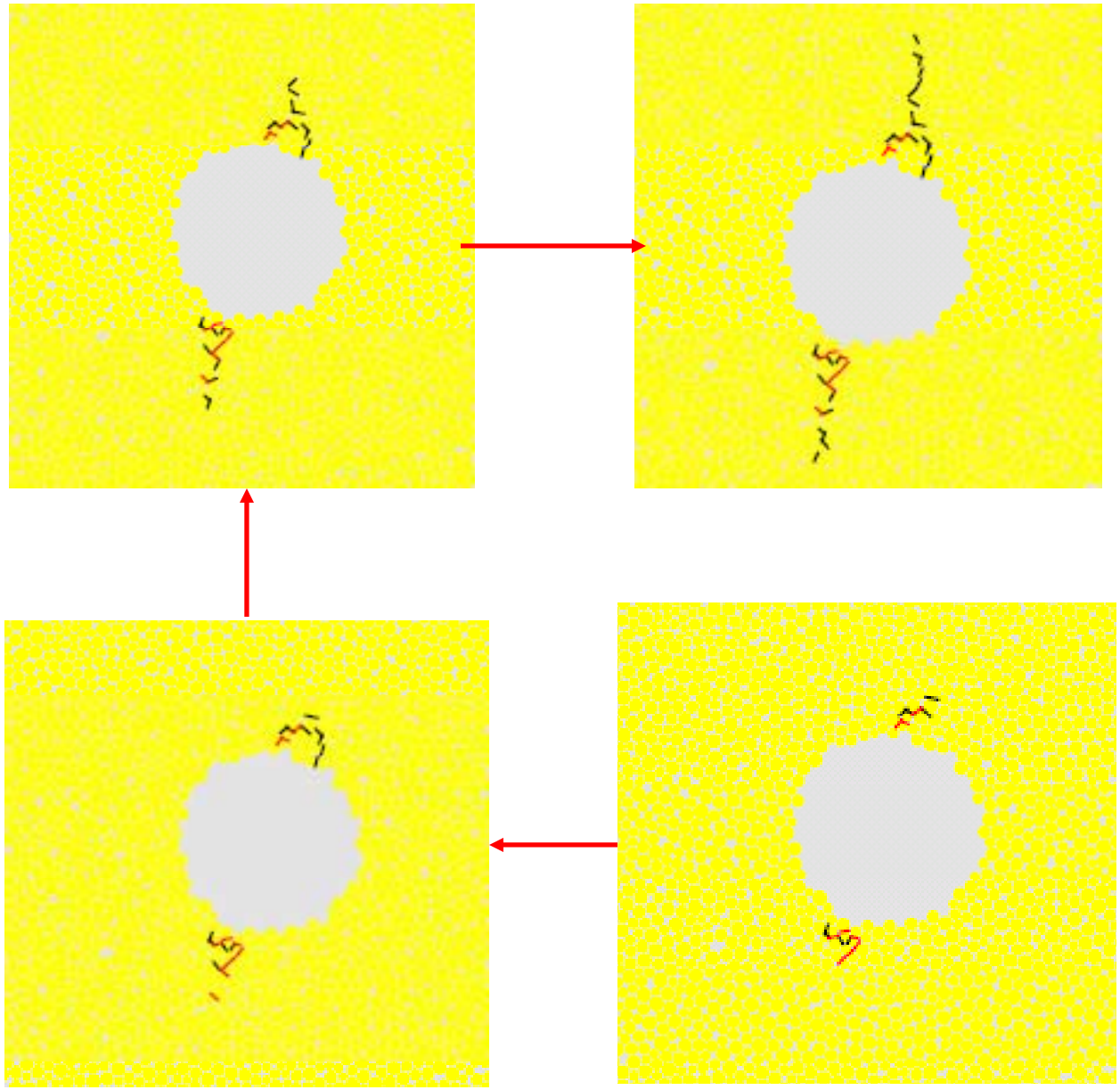
Linestyle

Itasca Consulting Group, Inc.
Minneapolis, MN USA

Job Title: sin1 (Stress-Installation Example: ss_strain_interior=0)







CONCLUSION

Most Rocks are formed by fragments or crystalloid minerals. The textures of rocks determined the mechanics characteristics. PFC has the advantages with respect to theoretics and technique because the small blocks or minerals can be simulated by the particles in the model.

The method used in this presentation on how to develop new contact model in PFC has general significance. After getting the relationship between contact force and displacement, the new contact model can be formed and can be used in the engineering application.

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THANKS FOR YOUR ATTENTION