Particle Dynamic Simulation

Principal Issues

- Packing fraction and flow control through exposed region (bridging, acceleration)
- Particle ejection (scattering)
- Multi-zone flows (mixing, shear flows)
- Heat transfer
- Heat exchanger optimization

Particle Dynamic Simulation

Computational Tools

- During the past few years, direct simulation models have become available for solving the momentum equations for large assemblies of particles

- The **PFC2D code** was used for simulating the flow in APPLE:

  * 2D cylinders (or 3D spheres in PFC3D)
  * ability to define individual pebbles or create large assemblies with a single command
  * memory-efficient explicit solution
    16 MB ram corresponds with 40,000 particles
  * runs on a PC

- These models have been tested and applied to a wide variety of applications in soil mechanics, seismic response, mechanics of materials and material mixing.

- Heat transfer is not included, but can be incorporated using pebble positions, rotations, and contact information from PFC.

PFC Code Description

Particle Simulation:

- All particles are circular (but can be clumped into complex shapes)
- Particles are treated as rigid bodies
- Contact occurs at a point
- A soft-contact approach allows particles to overlap at contacts
- The magnitude of overlap is related to the contact force
  via force-displacement law

Contact Models:

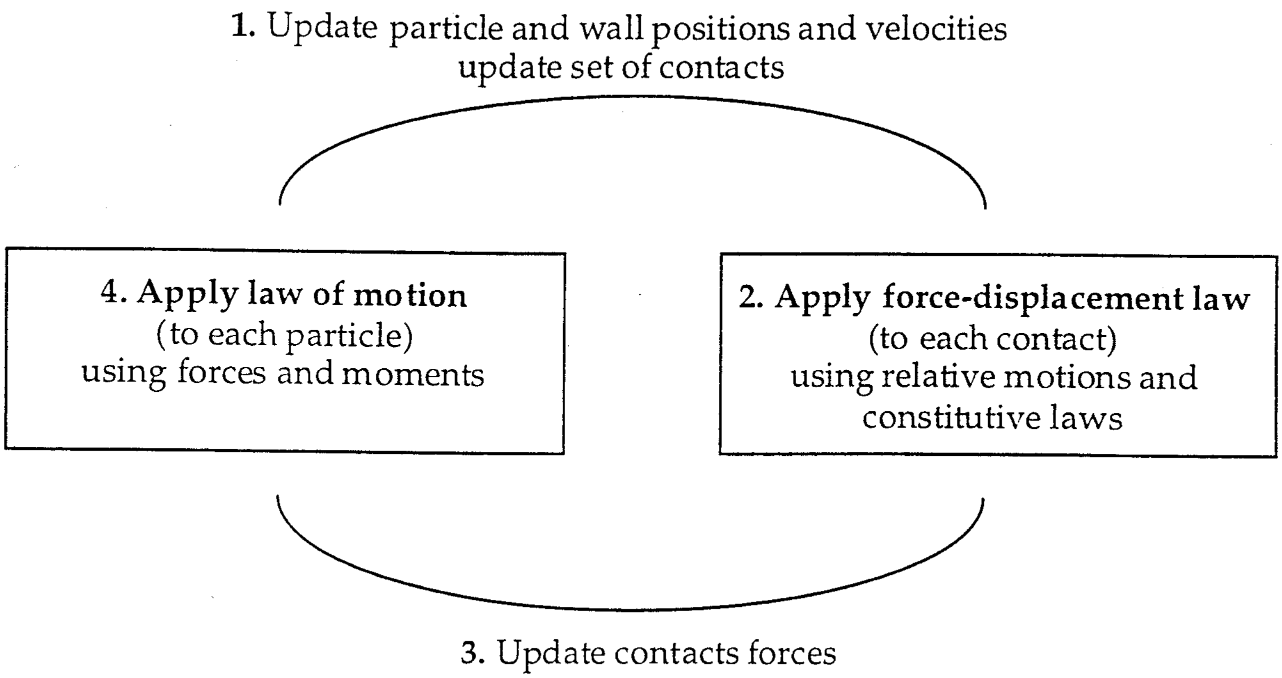
- Linear or Hertz contact
- Static and sliding friction
- Finite normal and shear stiffness
- Bonding forces

Numerical Approach

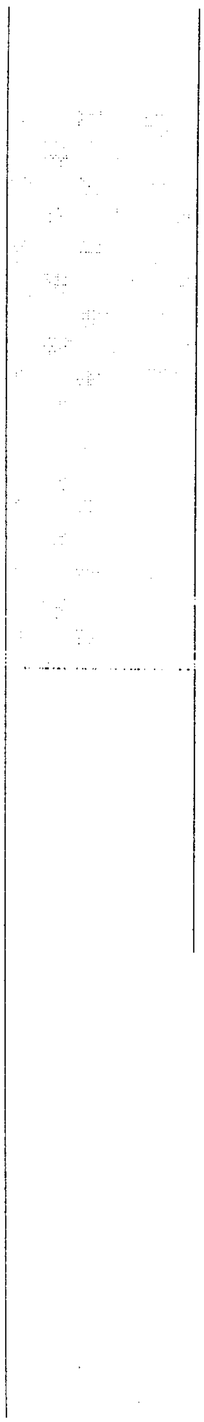
- Distinct Element Method (DEM)*
- Translation and rotation included
- Time step is optimized from stiffness matrix, $m\ddot{x} + kx = 0$
  $\tau_{crit} = \sqrt{m/k}$
- Dissipation by frictional sliding, non-viscous damping can be applied to Equations of Motion for optimal static convergence

* P. A. Cundall, *Int. J. Rock Mechanics, Mineral Science and Geomechanics Abstracts*, 1988.

Calculation Cycle in PFC



Example Problem: Flow from a Vertical Chute



Wall Geometry:

10-cm chute width

upper compaction zone	35 cm
guided flow zone	15 cm
free-fall zone	50 cm

friction coefficient = 0.2

Pebble Properties:

10,000 spheres

1-mm uniform diameter

friction coefficient = 0.5

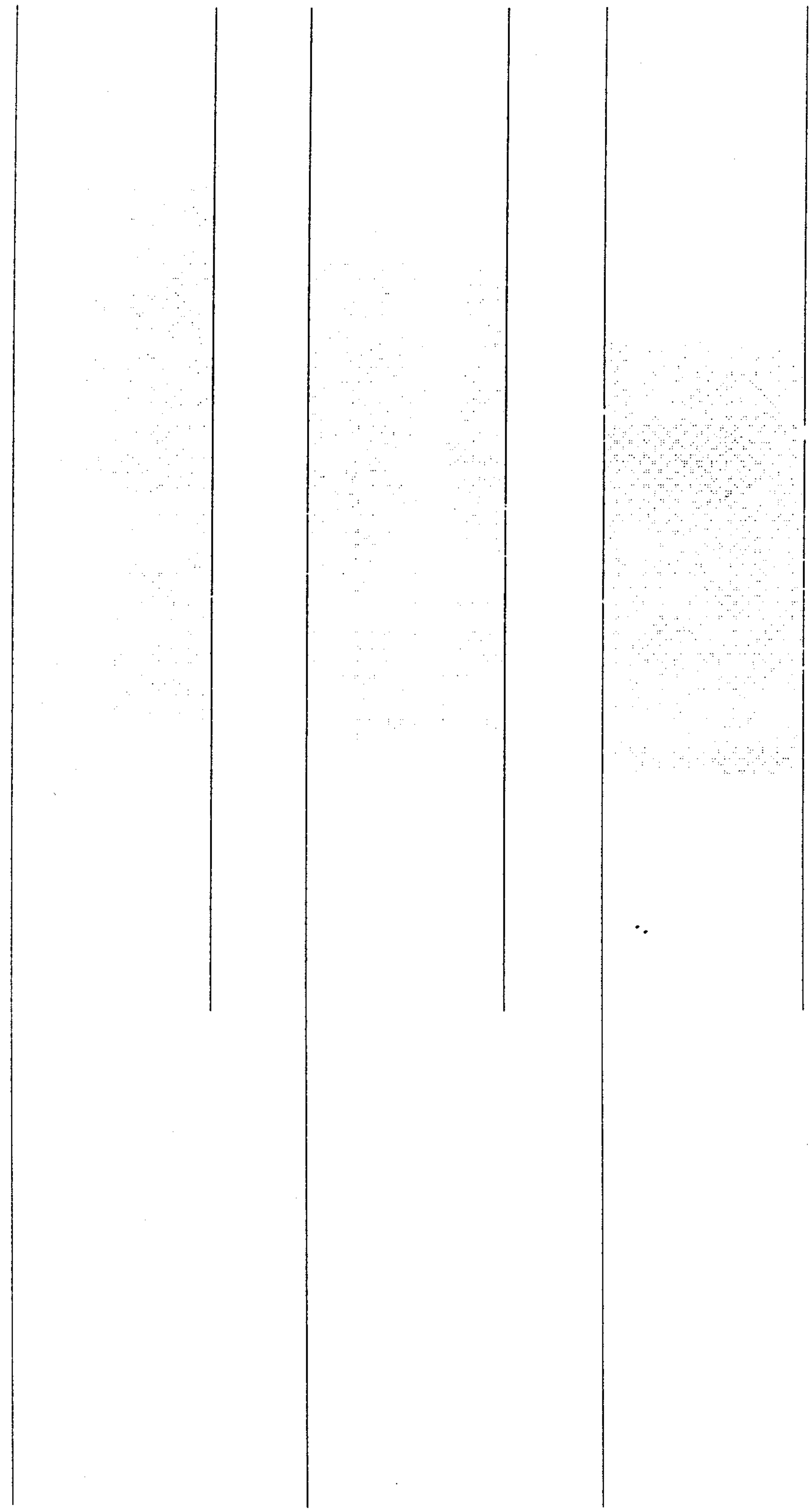
density = 2000 kg/m^3

linear force-displacement, $k=10^6$ N/m

Time Sequence:

1. dispersely fill upper zone (0.65–1.0 m)
2. partial compaction for 2 s
3. remove wall at z=0.65
4. track pebble dynamics for 5 s

Bed Geometry and Forces, t=0.5-1.5 sec.



Observations

1. No observed tendency for particles to be ejected

   Low packing fraction, Low shear observed

2. Tight packing is difficult to maintain in the free-fall zone

   Intenal forces are important in free-fall, even with $L/r \geq 10$

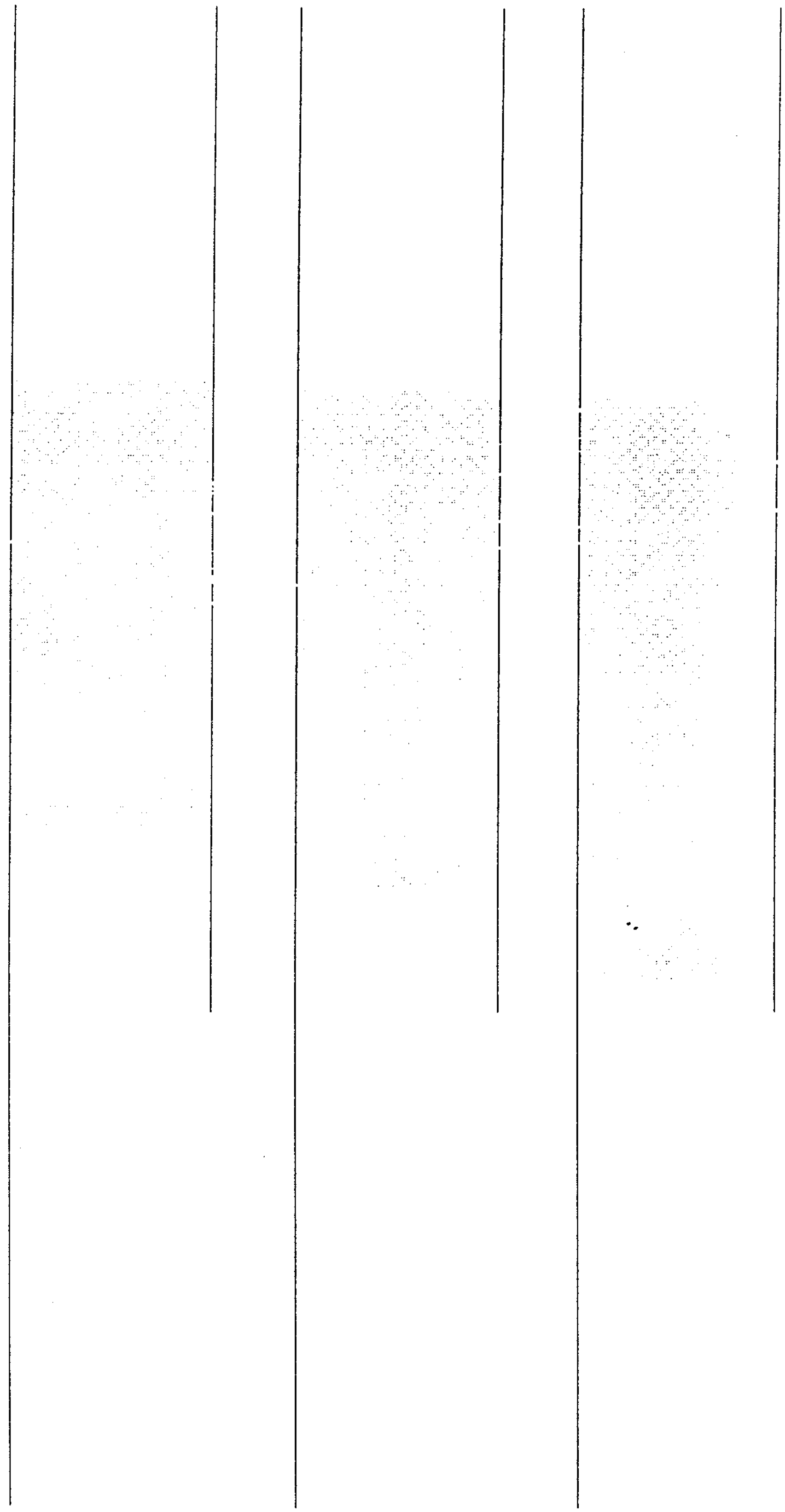
3. Need to explore baffle arrangements and/or curved walls

4. The code is very easy to use – scoping of new geometries and multi-layer flows will be done in the near future

5. Addition of heat transfer will be a major undertaking

   - contact conduction
   - radiation transport

Bed Geometry and Forces, t=2.0-3.0 sec.



Bed Geometry and Forces, t=3.5-4.5 sec.