Numerical Techniques Covered in this Course
○ Finite Difference Method (FDM)
○ Finite Element Method (FEM) (Introduction)

Commercially Available Software Packages
○ FLAC (Fast Lagrangian Analysis of Continua) (General FDM)
○ ABAQUS (FEM) (General FEM with some geotechnical relations)
○ ANSYS (FEM) (Mechanical/Structural)
○ PLAXIS (FEM) (Geotechnical)
○ SIGMA/W (FEM) (Geotechnical)
○ SEEP/W (FEM) (Seepage Analysis)
○ MODFLOW (FEM) (Groundwater Modeling)

FLAC and PLAXIS are the most commonly used by advanced geotechnical consultants

Common Applications of Modeling in Geotechnical Engineering

○ Numerical approximation for various types of differential equations commonly encountered in geotechnical engineering

○ LaPlace’s Equation (governing equation for 3D steady-state flow)

$$\nabla^2 V = \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = 0$$

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Groundwater Flow Equation (3D transient flow)

\[
\frac{\partial h}{\partial t} = \alpha \left( \frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} \right) - G.
\]

\( \alpha = \frac{k}{S_s} = \text{hydraulic conductivity / Specific Storage} \)

\( G = \text{source/sink term} \)

Equation of motion for forced damped vibration system

The behavior of the spring mass damper model when we add a harmonic force takes the form below. A force of this type could, for example, be generated by a rotating imbalance.

\[ F = F_0 \cos(2\pi ft). \]

If we again sum the forces on the mass we get the following ordinary differential equation:

\[ m\ddot{x} + c\dot{x} + kx = F_0 \cos(2\pi ft). \]

See next page for solution for homogeneous material; however heterogeneous materials require numerical methods.
Wave equation for solid materials

The wave equation is an important second-order linear partial differential equation of waves, such as sound waves, light waves and water waves. It arises in fields such as acoustics, electromagnetics, and fluid dynamics (from Wikipedia).

\[
\frac{\partial^2 u}{\partial t^2} = c^2 \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right)
\]
In deformation analysis we seek to estimate how much the slope will move or deform. This is much more of an involved process than simply calculating the factor of safety against failure from pseudo-static techniques.

○ Deformation Analysis of Tunnels
Dynamic Analyses

Rocking analysis of a geofoam embankment undergoing earthquake excitation.

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Reading
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○ FLAC v. 5.0 User's Guide, Section 1: Introduction
○ FLAC v. 5.0 User's Guide, Section 2 (p. 2-1 to 2-12)
○ Applied Soil Mechanics, Ch. 1 Properties of Soils
Assigned Reading
- Install FLAC v 5.0 software on your computer
- Run the following code to check the model (see FLAC manual Example 4.8 Slip in a bin-flow problem)

```plaintext
config
grid 7 10
model mohr i=1,5
model elastic i=7
gen 0,0 0,5 5,5 3,0 i=1,6 j=1,6
gen 3,0 5,5 6,5 6,0 i=7,8 j=1,6
gen 5,5 5,10 6,10 6,5 i=7,8 j=6,11
fix x y i=7,8
fix x i=1
prop dens=2000 shear=1e8 bulk=2e8 fric=30 i=1,5
prop dens=2000 shear=1e8 bulk=2e8 i=7
int 1 Aside from 6,1 to 6,11 Bside from 7,1 to 7,11
int 1 ks=2e9 kn=2e9 fric=15
set large, grav=10
step 3000
ret
```