Development of a Geotechnical Engineering Software Package in R and Its Implementation in the Civil Engineering Curriculum

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2016 ASCE Geotechnical and Structural Engineering Congress

Phoenix, Arizona
16 February 2016

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1. Project background

2. Why *R*?

3. The *geotech* package

4. Implementation in the curriculum

Development of a Geotechnical Engineering Software Package in R and Its Implementation in the Civil Engineering Curriculum
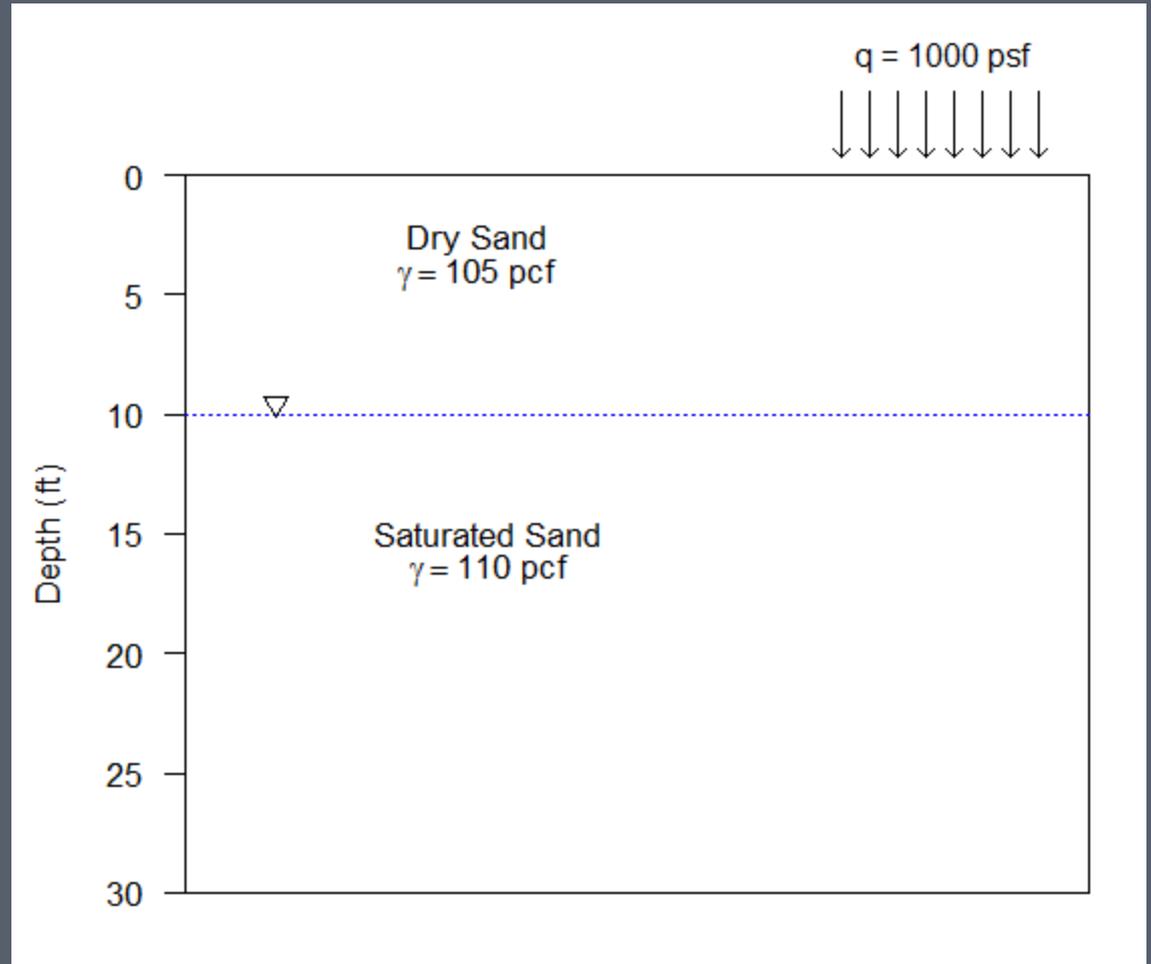
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Problem-solving examples

EXAMPLE 1:
Determine the variation of effective vertical stress with depth at a site with an induced surface pressure as shown. Consider points located below the centerline of the loading.

Problem-solving examples

EXAMPLE 2: A soil's grain-size distribution and Atterberg limits are provided below. Classify this soil according to the Unified Soil Classification System (USCS).

Grain-size distribution
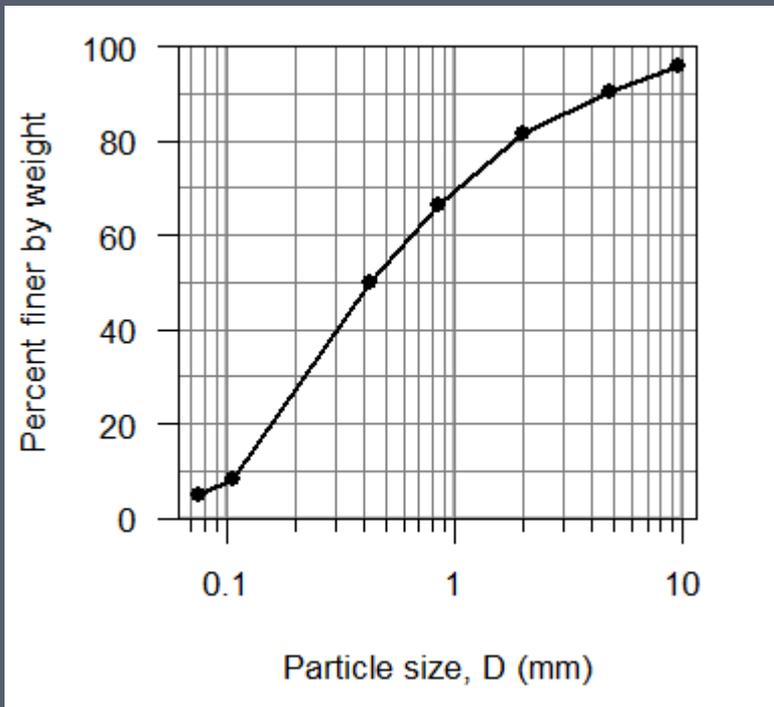
Plasticity data

Liquid Limit, LL = 30
Plastic Limit, PL = 25

Problem-solving tools:
- Hand calculation (Pen and paper)
- Spreadsheet (Microsoft Excel)
- Worksheet (Mathcad)
- **Programming (R)**

Purpose of project

- **Project purpose** is to develop a geotechnical engineering software package in the statistical language and environment R

- The **contribution of this project** is an open-source, freely available software package for broad usage in geotechnical engineering education, research, and practice

- Funded by the first special project grant awarded by the United States Universities Council on Geotechnical Education and Research (USUCGER)

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The R statistical language and environment

- **R** is an object-oriented language and environment for computing

- Derived from the S programming language developed at Bell Laboratories

- Gaining popularity in the scientific and engineering community

- Free and open-source

- Covers much of the functionality of MATLAB

- User interfaces:
  - Command line
  - RStudio
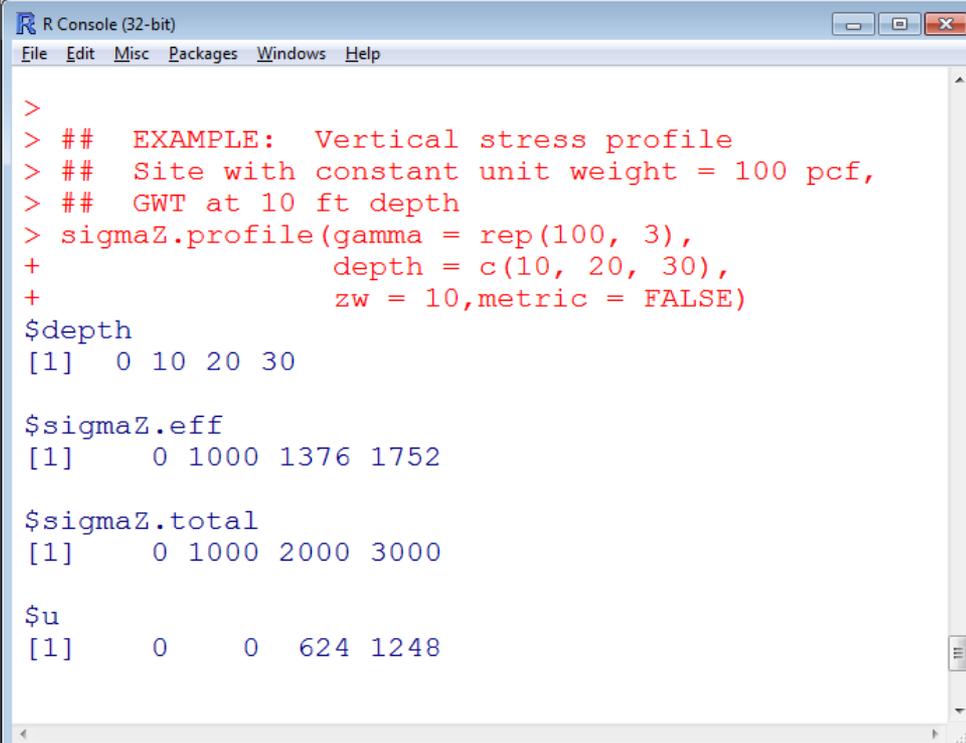

```
R Console (32-bit)
File  Edit  Misc  Packages  Windows  Help

>
> ##   EXAMPLE:   Vertical  stress  profile
> ##   Site  with  constant  unit  weight = 100  pcf,
> ##   GWT  at  10  ft  depth
> sigmaZ.profile(gamma = rep(100, 3),
+                depth = c(10, 20, 30),
+                zw = 10,metric = FALSE)
$depth
[1]   0 10 20 30

$sigmaZ.eff
[1]     0 1000 1376 1752

$sigmaZ.total
[1]     0 1000 2000 3000

$u
[1]     0     0   624 1248
```

Command line interface

The R statistical language and environment

- Rstudio: an integrated development environment for R

RStudio interface

Advantages and disadvantages of R

- **Advantages**
  - Free and open-source
  - Extensive help documentation
  - Strong network of R users
  - Repeatable and reliable
  - Powerful, customizable graphics
  - Users can contribute "R packages" for specific methods or data sets

- **Disadvantages**
  - Resistance of some users to command-line programs
  - Relatively steep learning curve

R packages

- **R packages** are add-on user-contributed software codes, which fulfill a programming need in a specific area
  - Computational methods
  - Visualization
  - Data
- Usually packages are composed of **sets of functions** or other objects specific to the problem at hand
- Users of R can easily download these add-on packages once they have R installed on their computers
- Over 7000 user-contributed packages exist in R, but no comprehensive packages on geotechnical engineering had been composed prior to the *geotech* package

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geotech R package

- Composed of sets of structured functions related to soil mechanics and geotechnical engineering
  - Calculations
  - Graphics
- Focuses on the types of calculations that arise in an introductory geotechnical engineering course
- Intended for usage by
  - Students
  - Educators
  - Researchers
  - Practitioners

Package 'geotech'

February 12, 2016

Title Geotechnical Engineering

Date 2016-02-01

Version 1.0

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Maintainer James Kaklamanos <kaklamanosj@merrimack.edu>

Description The geotech package is composed of sets of functions that are used to perform calculations and create plots that commonly arise in geotechnical engineering and soil mechanics. The types of calculations that are currently included are: (1) phase diagrams and index parameters, (2) grain-size distributions, (3) plasticity, (4) soil classification, (5) compaction, (6) groundwater, (7) subsurface stresses (geostatic and induced), (8) Mohr circle analyses, (9) consolidation settlement and rate, (10) shear strength, (11) bearing capacity, (12) lateral earth pressures, (13) slope stability, and (14) subsurface explorations. Geotechnical engineering students, educators, researchers, and practitioners will find this package useful.

License GPL-3

Imports graphics, stats

Setting up the *geotech* package

- Package may be installed using the package manager within R, or by downloading a zip file from
  - The R project website for this package:

    http://cran.r-project.org/web/packages/geotech/index.html
  - My research website: http://www.kaklamanos.com
- Once installed, load the package using the command `library(geotech)`
- Extensive help documentation associated with the package is available in three formats:
  - PDF reference manual
  - HTML reference manual; access by typing `help.start()`
  - Source code for individual functions

Function categories

- Outline of functions in the *geotech* package:
  - Phase diagrams and index parameters
  - Grain-size distributions and plasticity
  - Soil classification
  - Compaction
  - Groundwater
  - Subsurface stress
  - Mohr circle analyses
  - Consolidation settlement and rate
  - Shear strength
  - Bearing capacity
  - Lateral earth pressures
  - Slope stability
  - Subsurface exploration
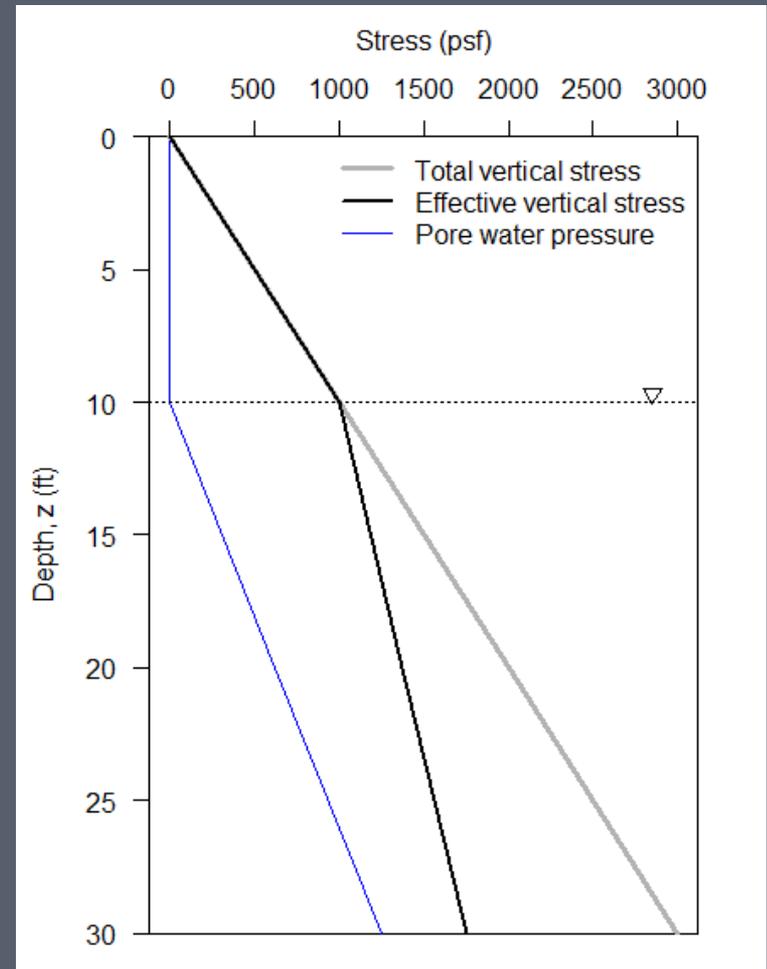
Output from the sigmaZ.plot function

Example functions

- Plot phase diagrams and calculate index parameters
- Classify a soil using the AASHTO or USCS methods
- Determine a sample's liquid limit using the flow curve from Atterberg test data
- Plot compaction curves and determine the maximum dry unit weight and optimum moisture content
- Calculate the induced stress at a depth in the subsurface due to a point load
- Plot profiles of horizontal or vertical stress versus depth
- Calculate the amount and rate of consolidation settlement
- Determine corrections to N-values obtained from the standard penetration test
- Many others...

Demonstration of the *geotech* package

- Loading the package
- Accessing help documentation
- Defining variables and performing basic calculations
- Using a previously-defined function
- Analyzing output
- Creating graphics
- Customizing functions and graphics
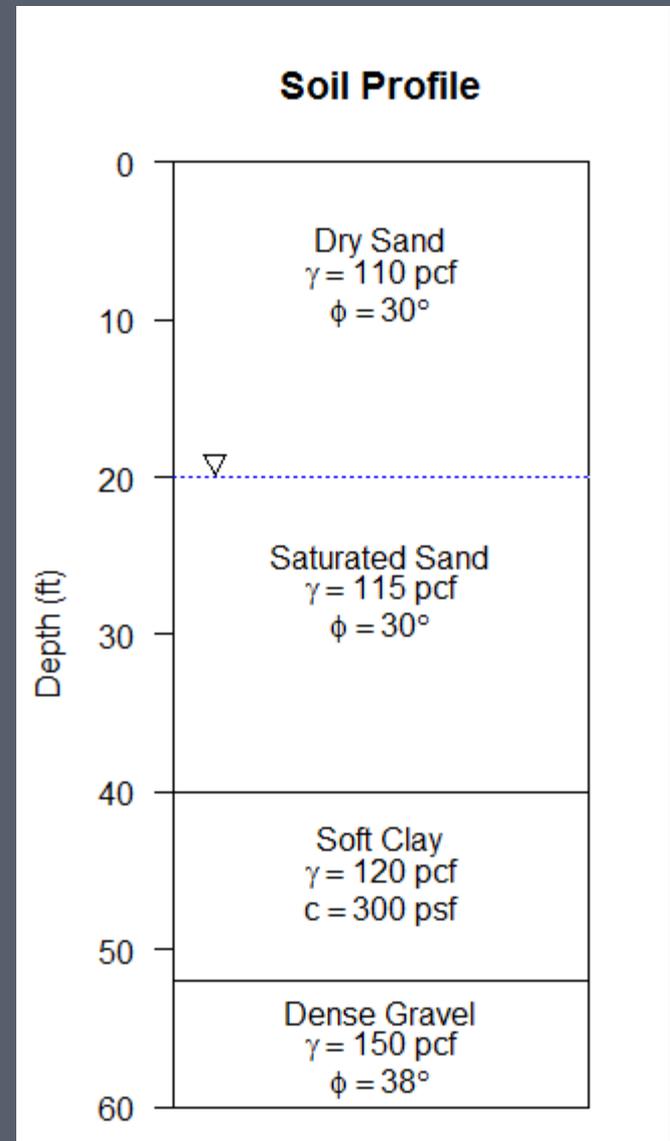
Soil Profile

Depth (ft)

0

Dry Sand
$\gamma = 110$ pcf
$\phi = 30°$

10

20

Saturated Sand
$\gamma = 115$ pcf
$\phi = 30°$

30

40

Soft Clay
$\gamma = 120$ pcf
$c = 300$ psf

50

Dense Gravel
$\gamma = 150$ pcf
$\phi = 38°$

60

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Implementation in the curriculum

- **Study location:** Merrimack College, in North Andover, MA (north of Boston), is an independent institution in the Catholic tradition

- College-wide enrollment:
  - Total undergraduates: 3000
  - Total graduate students: 400

- Enrollment in civil engineering:
  - Undergraduates: 115
  - Graduate enrollment: 25

Geotechnical engineering courses:

Introductory (junior level): Geotechnical Engineering

Design electives (senior level):
- Foundation Engineering
- Earth Slopes & Retaining Struct.

Options for incorporating *geotech* in class

- **Pilot implementation:** Civil Engineering 3020 (Geotechnical Engineering), Fall 2015
- Two options considered:
  - Option 1: Introduce the software at the beginning of the course, and include at least one problem on each homework assignment throughout the semester that requires students to use the software package.
  - Option 2: Introduce the software at the end of the course, and have students complete a comprehensive assignment in which they apply the software package on concepts they have learned throughout the semester.

End-of-semester lab activity

- Occurred during final 2.5-hour lab session of the semester

- **Prior to lab:** students performed background reading on R

- **At beginning of lab:** Thirty-minute presentation on the fundamentals of R

- **Main activity:** Two-hour workshop involving R functions, calculations, graphics, incorporating material from throughout the entire semester

Future incorporation in the curriculum

- Junior-level geotechnical engineering course
  - Further refinement of activities involving the package throughout the semester
- Senior-level geotechnical design courses
  - Homework assignments
  - Open-ended design projects
- Use existing functions as a productivity tool for parametric studies
- Develop new functions for additional calculations and graphics

Summary

- **More sources of information:**
  - Package help documentation (PDF and HTML)
  - Final summary report (USUCGER website)
  - Conference paper: Kaklamanos, J., and K.T. Elmy (2016). Development of a geotechnical engineering software package in R and its implementation in the civil engineering curriculum, *ASCE Geotechnical and Structural Engineering Congress 2016*
- **Acknowledgments:**
  - United States Universities Council on Geotechnical Education and Research (USUCGER)
  - Kyle Elmy, Merrimack College
  - Amy Byrnes, Merrimack College
  - CEN 3020 Fall 2015 students, Merrimack College

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References

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