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

JAMES KAKLAMANOS
Assistant Professor of Civil Engineering
Merrimack College • North Andover, Massachusetts, USA

with: Kyle T. Elmy, Graduate Student, Merrimack College

2016 ASCE Geotechnical and Structural Engineering Congress
Phoenix, Arizona
16 February 2016
Development of a Geotechnical Engineering Software Package in R and Its Implementation in the Civil Engineering Curriculum

James Kaklamanos

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

James Kaklamanos

1. Project background
2. Why R?
3. The geotech package
4. Implementation in the curriculum
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.
**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)
Development of a Geotechnical Engineering Software Package in R and Its Implementation in the Civil Engineering Curriculum

James Kaklamanos

1. Project background
2. Why $R$?
3. The geotech package
4. Implementation in the curriculum
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

```
> ## 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

$s
 [1]  0  0  624 1248
```
The R statistical language and environment

- **Rstudio**: an integrated development environment for R

---

**R Script**

```r
# Determine critical depths
if(all(is.na(depth)) == TRUE){
  depth <- cumsum(
}
if(all(is.na(zout)) == TRUE){
  zout <- sort(unique(

# Calculate stresses
sigmaZ.profile <- function(gamma, thk = NA, depth = NA, zw, zout = NA, gammaW =

# Example: Vertical stress profile
# Site with constant unit weight = 100 lbf/ft, GWT at 10 ft depth
> temp <- sigmaZ.profile(gamma = rep(100, 3),
> depth = c(10, 20, 30),
> temp <- sigmaZ.profile(gamma = rep(100, 3),
> u <- temp$u
> sigmaEff <- temp$u
> sigmaTotal <- sigmaTotal,
> sigmaZ.plot(depth = depth, u = u)
```

**R Environment**

**R Console (Command Line)**

**Plots**

---

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

James Kaklamanos

1. Project background
2. Why R?
3. The geotech package
4. Implementation in the curriculum
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

Author  James Kaklamanos <kaklamanosj@merrimack.edu> and Kyle Elmy <elmyk@merrimack.edu>
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](http://cran.r-project.org/web/packages/geotech/index.html)
  - My research website: [http://www.kaklamanos.com](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

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

James Kaklamanos

1. Project background
2. Why \textit{R}?
3. The \textit{geotech} package
4. Implementation in the curriculum
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)

- **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
Contact information

• **Email:**
  KaklamanosJ@merrimack.edu

• **Web:**
  http://www.kaklamanos.com
References


