Advanced Numerical Models in Practice and Elastoplasticity of Unsaturated Soils

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From Theory to Practice
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Outline

- Advanced Numerical Models in Practice
  - A personal experience: Port of Los Angeles’ Pier 400 Project
  - What are the impediments?
  - How can we overcome these?
- SWCC Using an Elastoplastic Framework
  - Model development
  - Validation
- TeraScale_Dysac: A parallel, 3-D, fully coupled computer code
Port of Los Angeles’ Pier 400: Artist’s Impression (1990)
- 235 ha (580 acres) of new land
- 6.1 km (20,000 ft) of rock dikes
- 46 million m³ (60 million yd³) of dredged material (about 50% of the material dredged for the Suez Canal!!!)

Pier 400: Port of Los Angeles
(June 2001)
Pier 400: 2003 (?)
Cargo Handling Cranes at Pier 400

- Each crane weighs 1,450 tons (or 2.9 million lb)
- 100 ft gauge (rail spacing for supports)
- Total lift capacity is 182 ft.
Maximum Allowable Lateral Dike Movement = 1 m

A cross section through a typical wharf (Phase 1 Container Wharf, Pier 400, Port of Los Angeles)
POLA’s Seismic Criteria

- Two levels of earthquakes
- Probabilistic Seismic Hazard Analysis (PSHA)
- OLE - Operating Level Earthquake
  - Minor non-structural damage to wharf structures
  - Should remain in service
  - PGA = 0.28 g (Return Period = 72 years)
- CLE - Contingency Level Earthquake
  - Some damage to wharf structures expected
  - Total collapse should be prevented
  - Container cranes should be operational after repairs
  - PGA = 0.52 g (Return Period = 475 years)
- Primary hazard from the Palos Verdes Fault
- Some contribution from the Newport-Inglewood Fault
Pier 400 Conceptual Design

- Pier 400 Design Consultants (A joint venture between Frederic R. Harris, Inc. and Moffat & Nichol Engineers)
  - The Prime Consultants

- Fugro West, Inc., Ventura, CA
  - Geotechnical investigations
  - Initial slope stability analyses/lab testing

- Earth Tech, Irvine, CA
  - Dr. (Arul) K. Arulmoli – Project Manager
  - Coordinating the centrifuge testing
  - Lab testing
  - FEM Analyses

Note: Actual Design (2000-2004??): Earth Mechanics, Inc.
Dr. (Arul) K. Arulmoli – Project Manager
**Pier 400 Project**

- Part of POLA’s 2020 plan

- Cost: Landfill = **$500 million**, Infrastructure = **$300 million**

- Seismic deformations of the dikes and landfill is a major design concern

- **DYSAC2** (Muraleetharan et al. 1988) was used for the seismic analyses in the conceptual design phase
  - Bounding surface elastoplastic constitutive models (Dafalias and Herrmann 1986; Yogachandran 1991)

- Centrifuge model tests were performed to validate DYSAC2 as well as to study the potential deformation mechanisms

- DYSAC2 results were combined with traditional embankment analyses for the final design
Centrifuge Model Testing Program

- Specifications provided by Pier 400 Design Team
- University of California, Davis
  - Arulanandan, Zeng, et al.
- Caltech
  - Scott, Hushmand, et al.
Pier 400 Centrifuge Model Configurations
Model Configuration 3: U.C. Davis

- Centrifugal Acceleration = 75 g
- Model Height = 0.140 m
- Prototype Height = 10.5 m
Model Configuration 1: U.C. Davis

Before Shaking

After Shaking
a. **Centrifuge Test**

b. **DYSAC2 Prediction**
Pier 400 Cross Sections: DYSAC2 Analyses

Without Piles

With Piles
What are the impediments to using advanced numerical methods in practice?

- **Threat of litigation**: Nobody wants to try something that has not been tried before.

- **Lack of understanding of benefits among practicing engineers and review agencies**.

- **Codified nature of the structural engineering practice**: E.g., Advanced analyses are allowed, but loads can be reduced only 20%.

- **Lack of collaboration between structural and geotechnical engineers**: For structural engineers soil looks like a spring and for geotechnical engineers structures looks like sticks (beams and columns based on simple bending theories).

- **Determination of material properties for elastoplastic models**:  
  - The constitutive model development has outstripped the ability of engineers to determine properties for these models.
  - Extensive laboratory testing is not possible for all projects.
How can we overcome these impediments?

- Educate the practicing engineers and **review agencies** such as Caltrans: Workshops etc.

- **Find early adapters and big projects:** Port of Los Angeles
  - Remember don’t promise cost savings (not always possible), just better design and more in sight into the behavior

- **Contribute to standards and code developments**

- **Work closely with structural engineers**
  - E.g. EMI, CH2M Hill
  - Educate structural engineers and listen to their needs and concerns

- **Develop better in situ testing techniques to determine the elastoplastic model parameters.**
Soil Water Characteristic Curves (SWCCs)

A Fine Ottawa Sand (SP, $D_{50} = 0.12$ mm)

Chen et al. (2005): Using an automated parallel miniature pressure cell system
• **Bounding Surface Plasticity Theory (Dafalias and Popov 1976)**

**Bounding Curves:**

\[ n^w = n_0^w - a \cdot \tan^{-1} \left[ e^{(s-b)} - e^{-b} \right] \]

\[ n^w = n_0^w - a \cdot \tan^{-1} \left[ e^{(s-c)} - e^{-c} \right] \]
SWCC (cont.)

Predictions

![Graph showing soil water characteristic curve (SWCC) predictions and measured data. The graph plots suction (kPa) on the y-axis against volumetric water content on the x-axis. The bounding curves, predicted data, and measured data are indicated.]
La Conchita Landslide, 1995
Courtesy: U.S. Geological Survey

Failure at the same place again in 2005!!!!!
Embankment No. 3: With Water Infiltration

- Complete failure around 35 g (Height = 6 m)
A Finite Element Framework Based, Parallel, Fully Coupled 3-D Analysis of Soils (saturated and unsaturated) and Structures

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