Development and uses of the UCD Hollow Cylinder Apparatus

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Background

• In 1995, Geotechnics Research Group (headed by Dr. Tom Widdis) began HCA project at Department of Civil Engineering, UCD.

• Identify and develop niche area in geotechnical laboratory research

• Decision to develop state-of-the-art hollow cylinder apparatus (HCA)

• Personnel: Brendan O’Kelly (PhD 1995–2000); Patrick Naughton (PhD 1998–2002); Frank Dillon and George Cosgrave.

• Presentation will include overview of HCA development,
  – its versatility in simulating complex stress conditions in ground foundations
  – experimental studies undertaken,
  – key publications.

Why need for HCA testing

(i) Example: Yielding of ground foundation (plain strain)
Stress axes rotate to vertical direction ($\alpha_\sigma$)
Values of three perpendicular stresses change independently (generalized stress conditions)

- Ground is anisotropic; mechanical response depends on stress magnitude and direction
- Sedimentary deposits often cross-anisotropic
Principle of HCA testing

• Test specimen: hollow cylinder, 100mm outer diameter, 71mm inner diameter, 200mm in length

• Apply system of axial and torsional loads, inner and outer confining pressures

• Within specimen wall thickness, control rotation of stress axes ($\alpha_\sigma$), and magnitude of 3D stresses ($\sigma_1, \sigma_2, \sigma_3$)

• Measure 3D deformational response, and

• Calculate stiffness and strength properties
• **The UCD HCA**

**Layout of apparatus**

- Pressure cell
- Test specimen
- Loading mechanisms
  - Screw-spline shaft actuated by stepper motors
- Pressure actuators
- Reaction frame

**Instrumentation**

- Local to specimen (submerged)
- Outside pressure cell


Set up of specimen inside pressure cell

Sealing specimen from pressurized water in cell chamber and inner bore cavity of specimen

Mechanism to measure radial displacement of inner wall surface
   Proximity transducer
   Positioned remotely using gear mechanism
Transducer measures axial load and torque applied along length of specimen

Strain measurement capabilities of 10^{-3} to 10\% strain (pseudo-elastic to failure strain levels for geomaterials) covering full range of engineering interest

Automatic closed-loop control of apparatus

Stress distribution within HCA specimen

- Stress non-uniformity arises due to curvature of specimen wall
  - variation in torsional stress across wall thickness, etc.
- Require near uniform stress distribution for accurate interpretation of experimental data
- Studied degree of stress non-uniformity
  - that occurs across specimen wall thickness when probing different regions of 3D stress space
  - for test specimen of sand material


Method of preparing hollow cylinder specimens of sand

Deposit sand grains into water contained between inner and outer specimen moulds

Apply suction to specimen so that free standing

Remove specimen moulds

Assemble pressure cell

Apply inner and outer hydrostatic confining pressures to specimen walls

**Study 1: Yielding of sand under generalized stress**

*Stress probing to determine points on yield surfaces*

- Identify series of points on yield surface
- Onset of yielding determined from measured strain response

Map yield surface in generalized stress space

3D stress space
Study 2: Validate whether existing yield criteria can be extended for generalized stress conditions

- Matsuoka-Nakai (1985) and Lade (1975) yield criteria developed for 2D stress conditions

- Used experimental HCA data to show these criteria can be used to adequately predict onset of yielding in sedimentary sand deposits

Study 3:
Inherent anisotropy and mechanical behavior

- Many sedimentary sand deposits have inherent cross-anisotropic soil fabric due to mode of deposition through water
- Deposits are densified to different levels (very loose to very dense)
- Study effect of soil fabric on subsequent mechanical behavior under generalized stress conditions


Summary

• Versatile UCD hollow cylinder apparatus is state-of-the-art in geotechnical laboratory testing
  – facilitates generalized stress path testing, including rotation of stress axes

• Many unique features
  – can measure mechanical response at pseudo-elastic strain levels
  – automatic closed-loop control to target a stress path

• Can simulate complex field loading (stress) conditions
  determine more reliable stiffness and strength values from measured strain response; e.g. for use in numerical analysis

• Used to study fundamental behavior of sedimentary sand deposits
  – validated extension of existing yield criteria to generalised (3D) stress conditions

...............future research possibilities are numerous
Thank you

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