Strength Envelopes for Florida Rock and Intermediate Geomaterials

FDOT BDV31-977-51

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Tasks: Strength Envelope and Bearing Capacity of Florida Rock and IGM

1. **Acquire and Setup Triaxial Test Equipment for Testing Florida Limestone and Intermediate Geomaterials**

2. **Field Acquisitions of Florida Limestone and IGM**
   - **Index Testing (unit weight, Gs, e, carbonate content, and Saturation)**
     - **Establish correlations between Index Tests and rock strength, qu, qt, etc.**

3. **Triaxial Testing of Florida Limestone and IGM**
   - **Conventional Triaxial Compression ($\sigma_v > \sigma_h$) and Extension ($\sigma_h > \sigma_v$)**
   - **Three Different cell pressures (300 psi, 800 psi and 1200 psi)**
   - **Stress controlled, Loading to Vertical Def. = 5% of Height**

Tasks: Strength Envelope and Bearing Capacity of Florida Rock and IGM

4. **Development of Stress-Strain and Strength Envelope of Florida Limestone and IGM**
   - **Stress-Strain based on Young's Modulus, Poisson Ratio, Loading Direction (Compression, Extension), strength and strain softening**
   - **Strength Envelope function of Loading Direction, and confining stress, may be curved (e.g. Hoek & Brown) – related to qu, qt and Index Test Results**
5. **Numerical Modeling of Laboratory, and Field, along with Recommendation for Bearing Capacity**
   - **Model Triaxial Results and Validate Stress-Strain Model**
   - **Model Footing on deep Florida Limestone or IGM layer**
   - **Model Footing on Layer of Limestone underlain by Sand**
   - **Develop/Recommend Bearing Capacity Equations for single and two layered conditions**

Task 1: **Acquire and Setup Triaxial Test Equipment**

1500 psi
Cell Pressure

40,000 Lbs.
Load Capacity

Monitor Sample
Stress, Strain & Pore Pressure

Task 1: **Acquire and Setup Triaxial Test Equipment**

TruePath Automated Stress Path System(SMO):

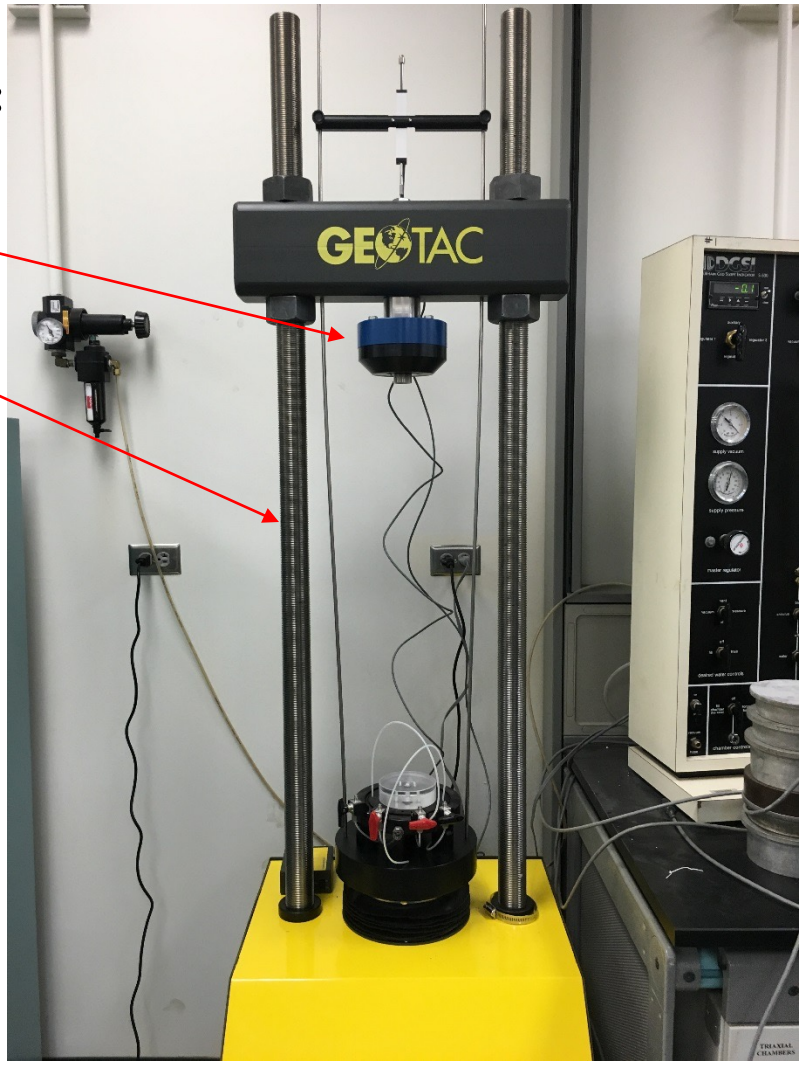
- **40K Load Frame**
- **40K Load Cell and Deformation Sensors**
- **2 Pressure Sensors for PWP**

Triaxial Cell:

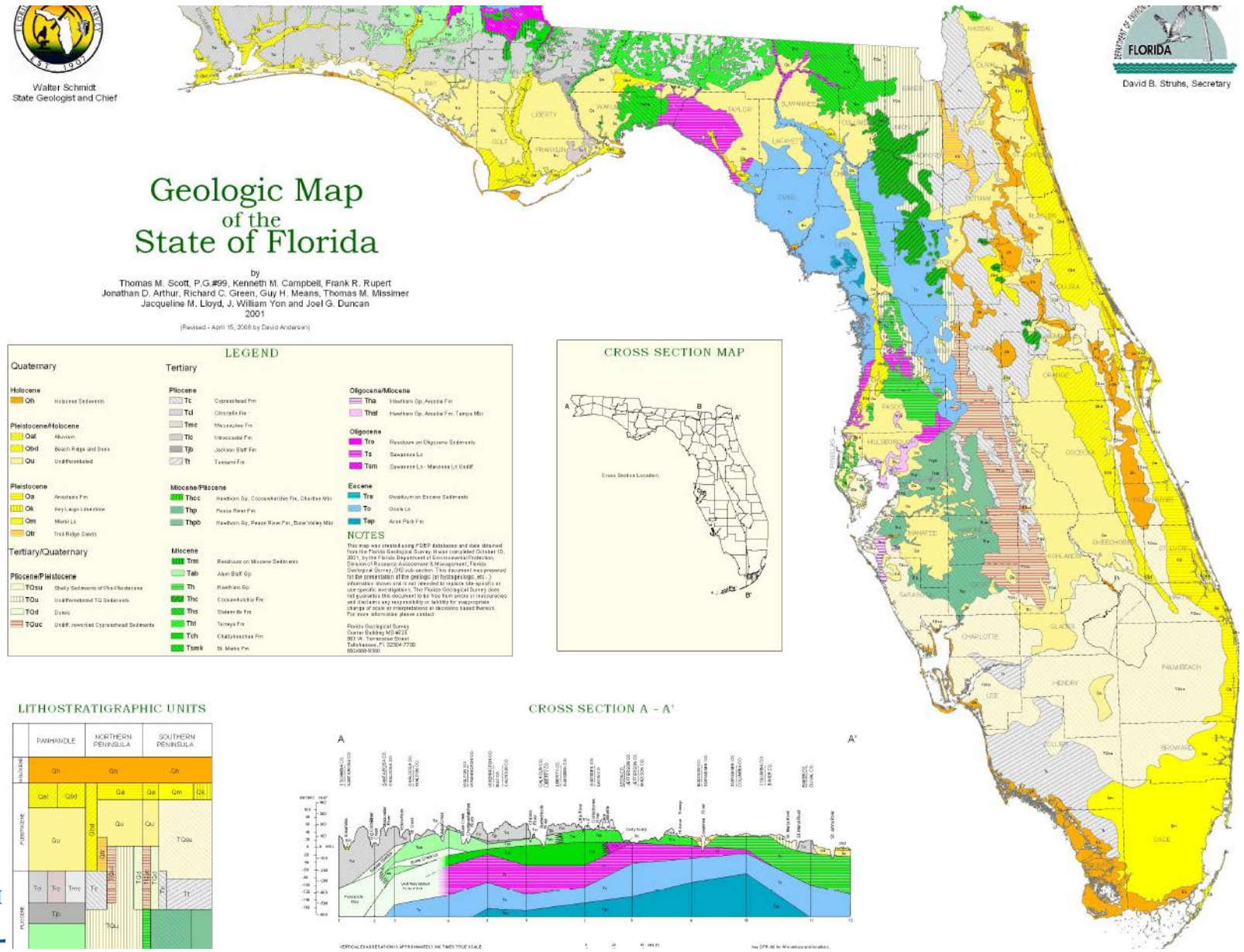
- **Platens for 2” and 4” samples**
- **Chamber for 1500 psi confinement**
- **Pumps for Cell and Backpressure**

Software

- **Automated Stress Path Testing**
- **Monitoring Stress, Deformation and PWP**



Task 2: **Field Acquisitions of Florida Limestone and IGM**

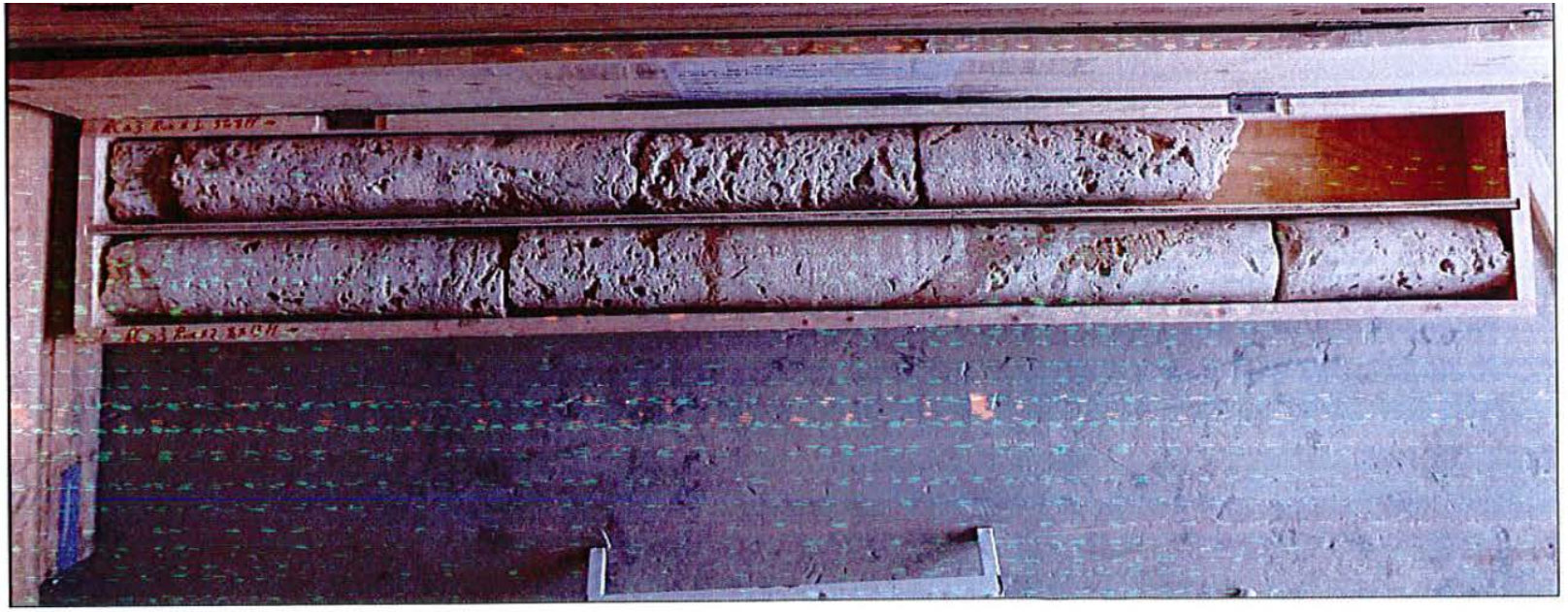


Task 2: **Field Acquisitions of Florida Limestone and IGM**

HR ENGINEERING SERVICES, INC.
SUMMARY OF ROCK CORES LOCATION
FLORIDA DEPARTMENT OF TRANSPORTATION
May 18, 2016

Project Name	TWO No.	Rock Core No.	Northing	Easting	Approximate Ground Elevation, ft.
Site 4 - SR5 at Marvin Adams Waterway - Key Largo	52	RC-1	292713.266	853722.722	+14.0
		RC-2	292680.456	853699.709	
		RC-3	292647.645	853676.696	
		RC-4	292622.132	853660.268	
Site 5 - SR836 at NW 12th Street	50	RC-1	527198.576	855923.576	+8.0
		RC-2	527198.394	855883.783	
		RC-3	527198.288	855860.749	
		RC-4	527198.030	855804.808	
Site 6 - SR997/Krome Avenue at C-102 Canal	51	RC-1	454522.907	828130.757	+9.0
		RC-2	454482.928	828130.914	
		RC-3	454442.950	828131.071	
		RC-4	454402.971	828131.229	

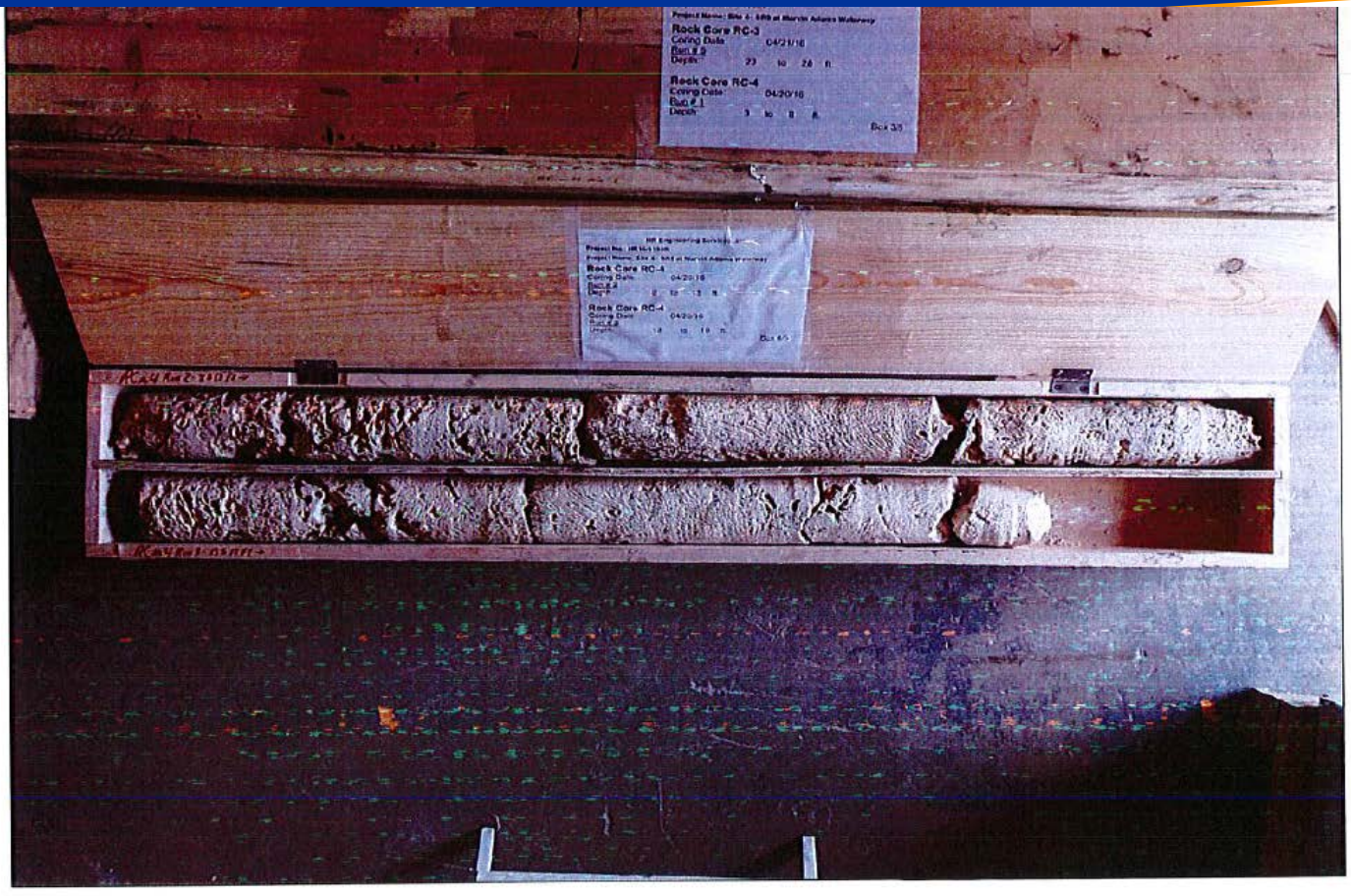
Task 2: **Field Acquisitions of Florida Limestone and IGM**



Rock Core No. RC-3 Runs No. 1 and No. 2

SITE 4 – TWO No. 52 SR5 AT MARVIN ADAMS WATERWAY FLORIDA DEPARTMENT OF TRANSPORTATION - DISTRICT 6 FPID No. 250730-2-32-02 MONROE - DADE COUNTY, FLORIDA	HR ENGINEERING SERVICES, INC. 7815 NW 72nd AVENUE MEDLEY, FLORIDA 33166	PHOTOS OF ROCK CORE SAMPLE	
		DRAWN BY: HRR	DATE: 04/26/2016
		PROJECT:HR16-1189R	SHEET No.

Task 2: **Field Acquisitions of Florida Limestone and IGM**



Rock Core No. RC-4 Runs No. 2 and No. 3

SITE 4 – TWO No. 52 3R5 AT MARVIN ADAMS WATERWAY FLORIDA DEPARTMENT OF TRANSPORTATION - DISTRICT 6 FPID No. 250730-2-32-02 MONROE - DADE COUNTY, FLORIDA	HR ENGINEERING SERVICES, INC. 7815 NW 72nd AVENUE MEDLEY, FLORIDA 33166	PHOTOS OF ROCK CORE SAMPLE DRAWN BY: HRR | DATE: 04/26/2016 PROJECT:HR16-1189R | SHEET No.

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Task 2: **Field Acquisitions of Florida Limestone and IGM**

Rock Core No. RC-2 Runs No. 4 and No. 5

SITE 6 – TWO No. 51 SR997/KROME AVE. AT C-102 CANAL FLORIDA DEPARTMENT OF TRANSPORTATION - DISTRICT 6 FPID No. Not available. MIAMI- DADE COUNTY, FLORIDA	HR ENGINEERING SERVICES, INC. 7815 NW 72nd AVENUE MEDLEY, FLORIDA 33166	PHOTOS OF ROCK CORE SAMPLE DRAWN BY: HRR | DATE: 04/18/2016 PROJECT:HR16-1191R | SHEET No.

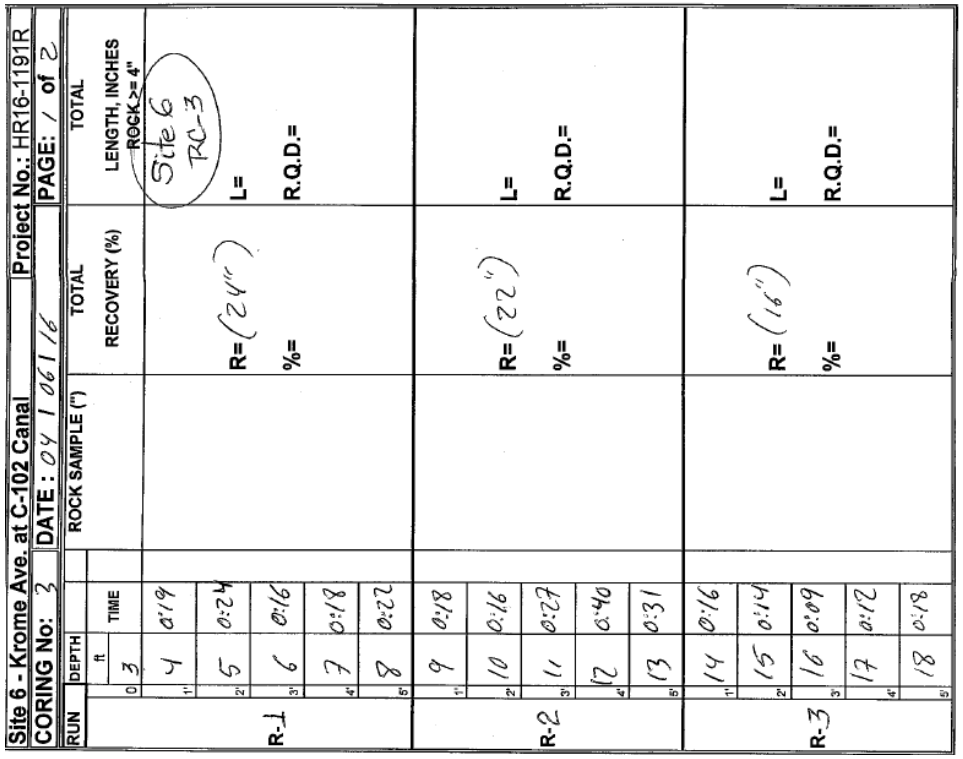
Task 2: **Field Acquisitions of Florida Limestone and IGM**

Rock Core No. RC-3 Runs No. 1 and No. 2

SITE 6 – TWO No. 51 SR997/KROME AVE. AT C-102 CANAL FLORIDA DEPARTMENT OF TRANSPORTATION - DISTRICT 6 FPID No. Not available. MIAMI- DADE COUNTY, FLORIDA	HR ENGINEERING SERVICES, INC. 7815 NW 72nd AVENUE MEDLEY, FLORIDA 33166	PHOTOS OF ROCK CORE SAMPLE DRAWN BY: HRR — DATE: 04/18/2016 PROJECT:HR16-1191R — SHEET No.

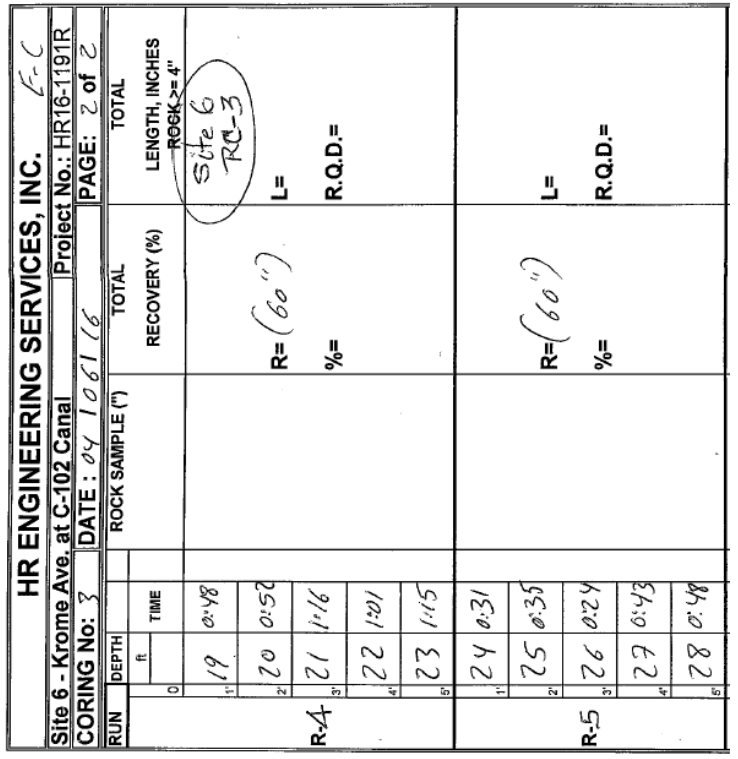
Task 2: **Field Acquisitions of Florida Limestone and IGM**

Krome Ave Recoveries Boring 3 (40%, 36%, 26%, 100%, 100%)



Site 6 - Krome Ave. at C-102 Canal | Project No.: HR16-1191R
CORING No: 2 | DATE : 04 / 06 / 16 | PAGE: 1 of 2

RUN	DEPTH ft	TIME	ROCK SAMPLE (")	TOTAL RECOVERY (%)	TOTAL LENGTH, INCHES ROCK >= 4"
R-1	3	0:19		R=(24") Site 6 RC-3	
	4	0:24		%=	L=
	5	0:16			R.Q.D.=
	6	0:18			
	7	0:22			
R-2	8	0:18		R=(22")	L=
	9	0:16		%=	R.Q.D.=
	10	0:22			
	11	0:40			
	12	0:31			
R-3	13	0:16		R=(16")	L=
	14	0:14		%=	R.Q.D.=
	15	0:09			
	16	0:12			
	17	0:18			



HR ENGINEERING SERVICES, INC.
Site 6 - Krome Ave. at C-102 Canal | Project No.: HR16-1191R
CORING No: 3 | DATE : 04 / 06 / 16 | PAGE: 2 of 2

RUN	DEPTH ft	TIME	ROCK SAMPLE (")	TOTAL RECOVERY (%)	TOTAL LENGTH, INCHES ROCK >= 4"
R-4	19	0:48		R=(60") Site 6 RC-3	
	20	0:50		%=	L=
	21	1:16			R.Q.D.=
	22	1:01			
	23	1:15			
R-5	24	0:31		R=(60")	L=
	25	0:35		%=	R.Q.D.=
	26	0:24			
	27	0:43			
	28	0:48			

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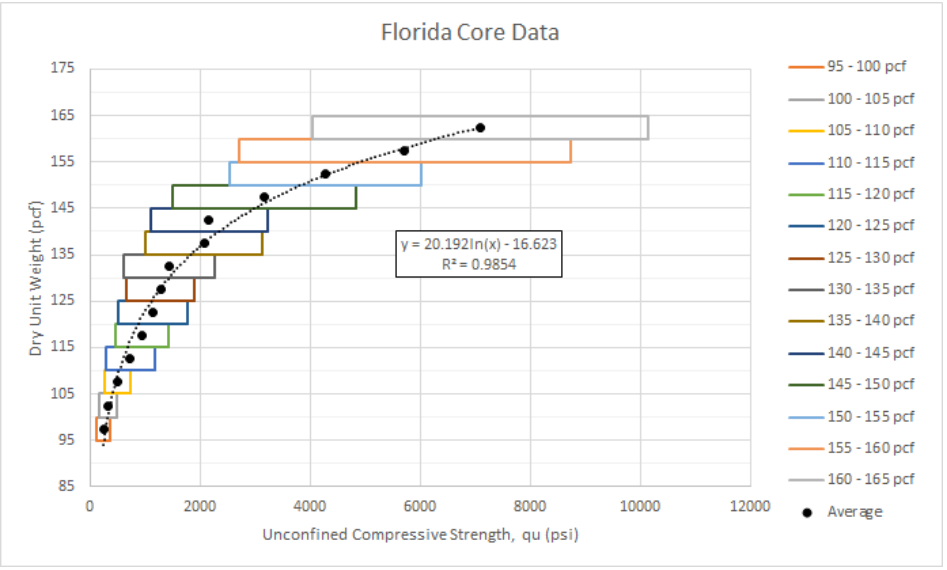
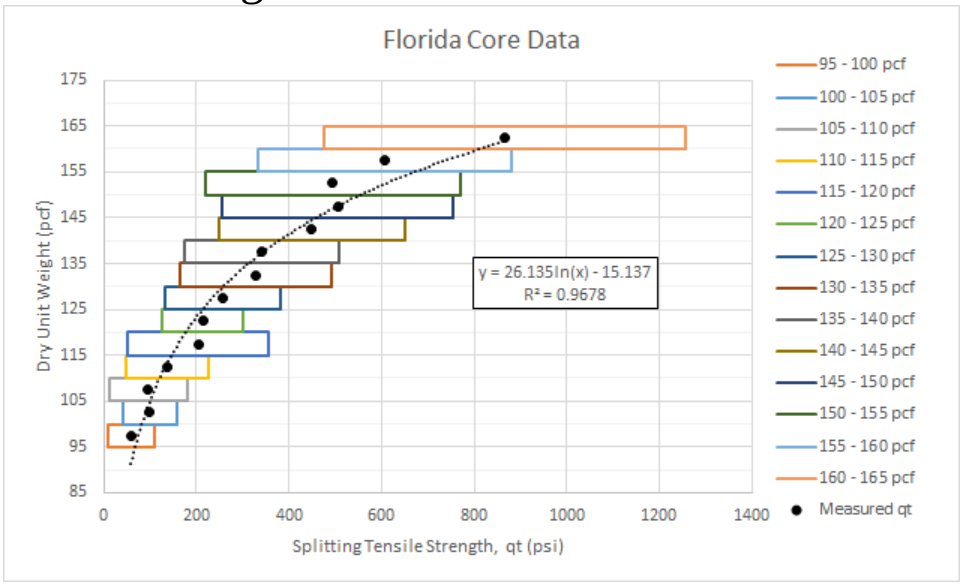
Task 2: **Field Acquisitions of Florida Limestone and IGM**

Miami Formation

Task 2: **Field Acquisitions of Florida Limestone and IGM**

Index Tests For Correlation with Strength Results





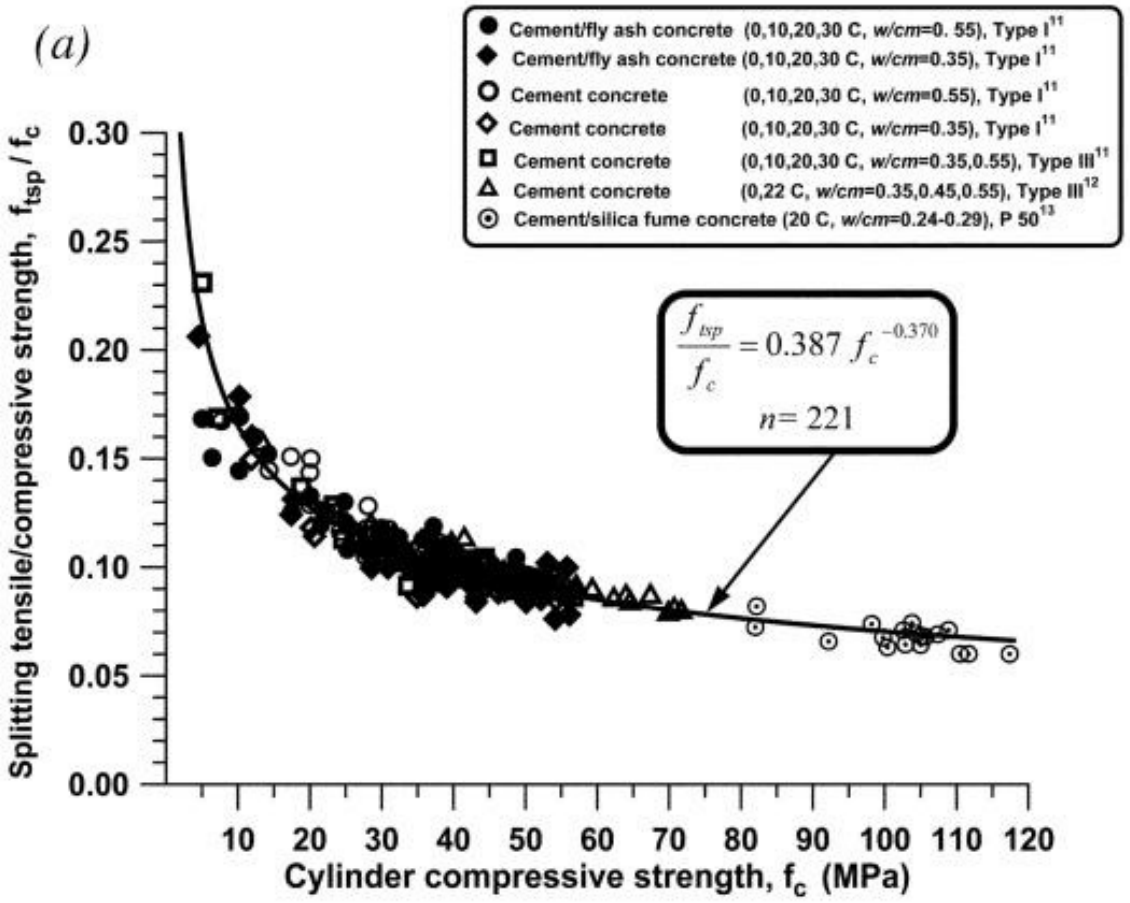
Reduce Spread (CV) by use of multiple Indexes:

- Unit Weight
- Carbonate Content
- Void Ratio
- Specific Gravity (Bulk vs. Crushed)
- Moisture Content

Task 4: **Development of Stress-Strain and Strength Envelope**

Correlation Between Strength Parameters:

Anoglu (2006) – Relationship Between unconfined compression, f_c - q_u , and Split Tension, f_{tsp} - q_t



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Task 4: **Development of Stress-Strain and Strength Envelope**

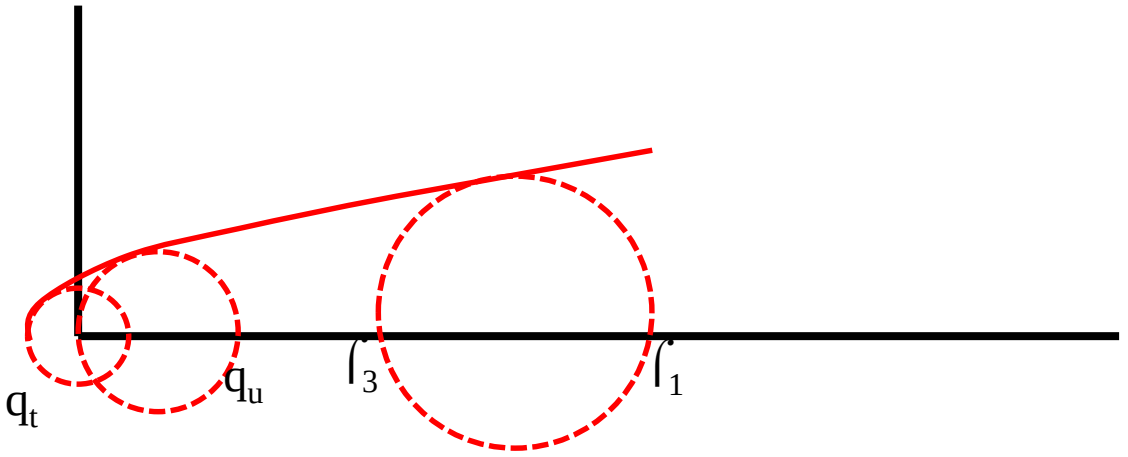
Bearing Capacity (NCHRP 651):

$$q_{ult} = (\sqrt{s} + (m\sqrt{s} + s)^{0.5})q_u$$ Carter & Kulhawy 1988

Employs Hoek-Brown Strength Envelope:

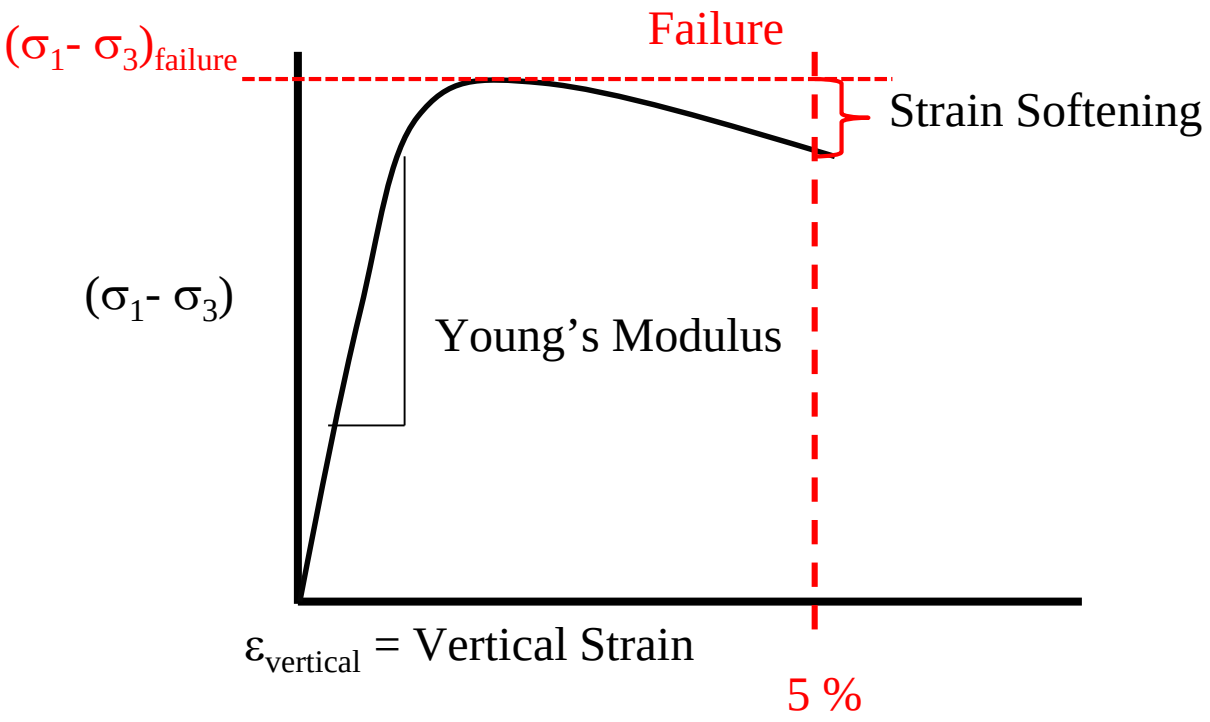
$$\sigma_1' = \sigma_3' + q_u \left(m_b \frac{\sigma_3'}{q_u} + s \right)^a$$

Where m, s, and a are strength parameters



Task 4: **Development of Stress-Strain and Strength Envelope**

Stress – Strain Behavior of Florida Limestone and IGM



Task 4: **Development of Stress-Strain and Strength Envelope**

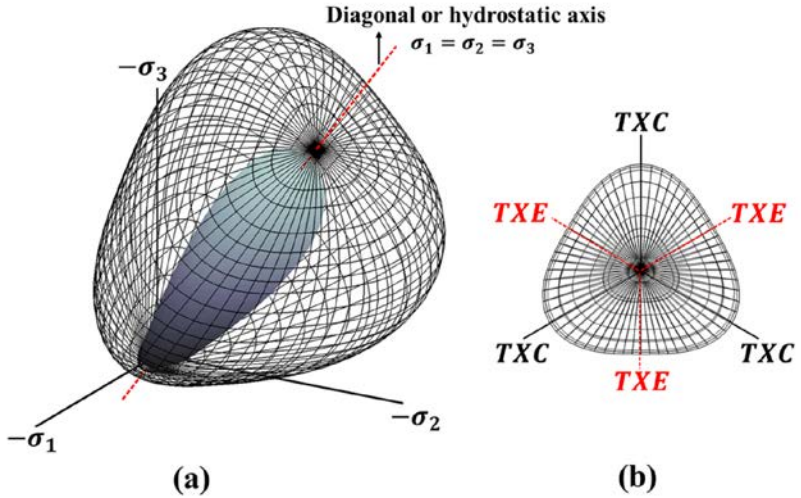
Research FEM Code

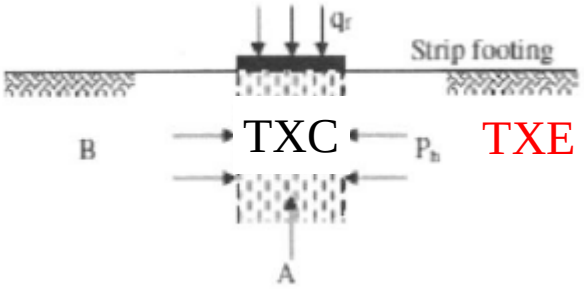
- Written in C++.
- Implemented with MPI for parallel computing for large scale problems.
- Run on Linux computer clusters.
- Material Library: Including typical stress-strain models for soils and rock.
- A user needs to modify the existing material model for Florida limestone.
- Post processing with third party code (open source).

Task 4: **Development of Stress-Strain and Strength Envelope**

Stress-Strain Relationship:

- Constitutive Model: Density dependent critical state model which can capture the strength difference of geomaterials between a compression corner and a extension corner of the yield surface on the deviator (or Pi) plane.

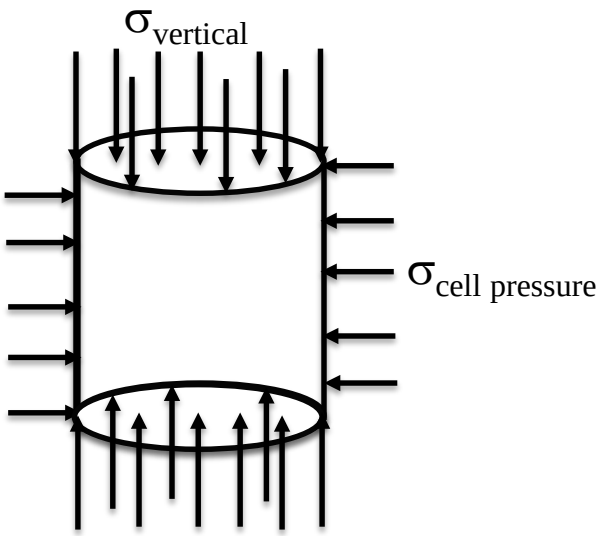


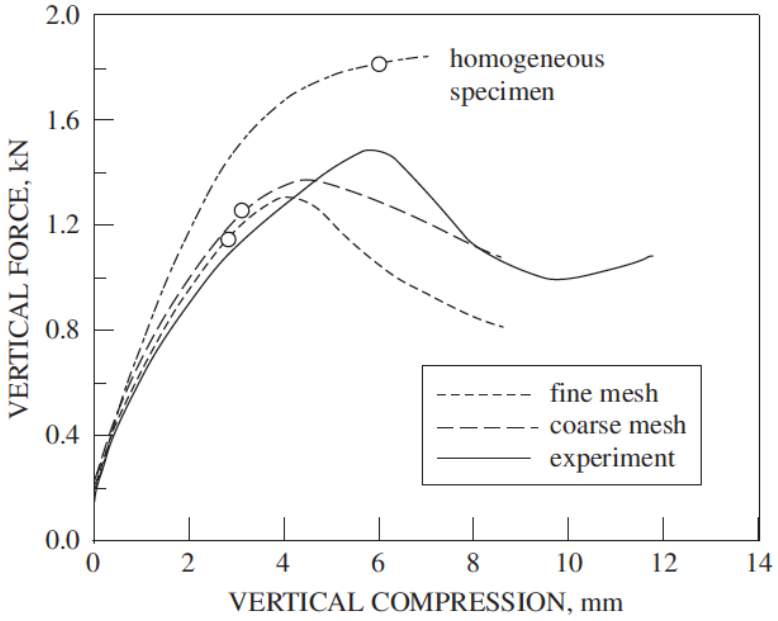


Task 4: **Development of Stress-Strain and Strength Envelope**

Simulations of Homogenous Lab Specimens

- Calibrate and validate the stress-strain model via the laboratory testing results of Florida limestones conducted at SMO.



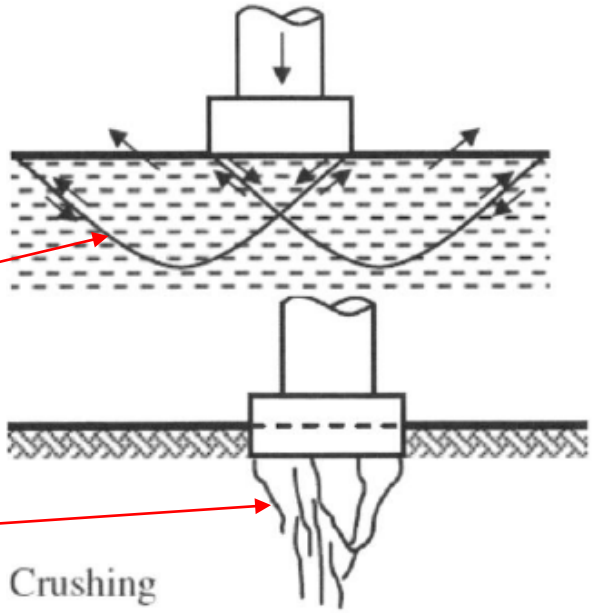


Task 5: **Numerical Modeling of Footing to Assess Stresses & Bearing Capacity**

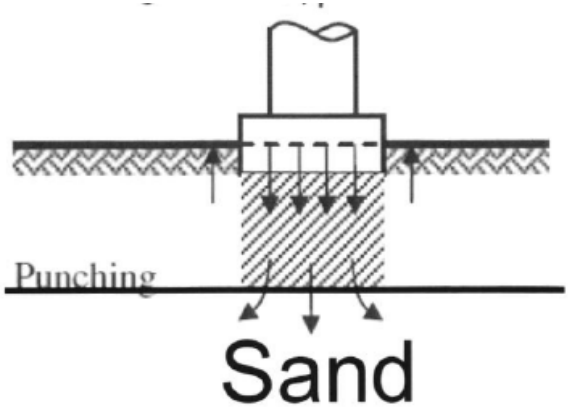
1) Heterogeneous Limestone or IGM:

General Shear Failure

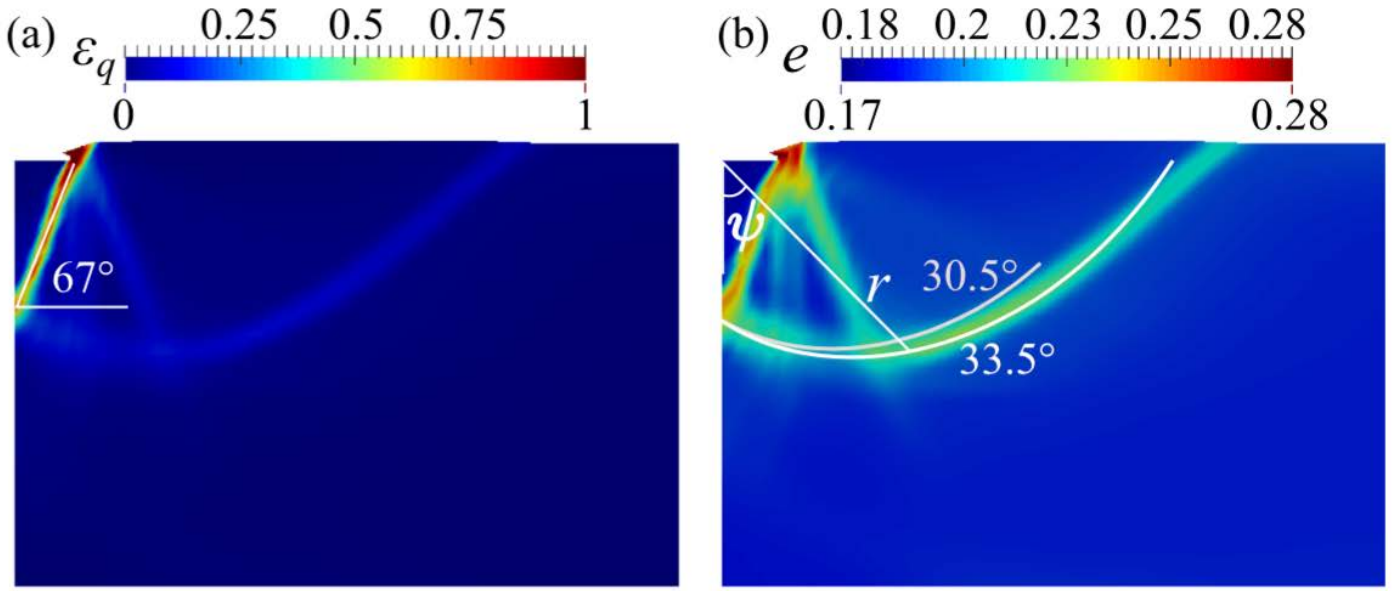
Localized Shear Failure



2) Heterogeneous Limestone or IGM overlying Sand:



Boundary Value Problems: An Example



Contours of (a) accumulated shear strain, (b) void ratio for the footing problem (half domain)

Thank You