Determining Bearing Resistance of Cantilever Sheet Piles
BDV31-977-90

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Presentation Outline

- Introduction
- Project Background – Sheet pile walls for bearing purposes in Florida
- Project Objectives
- Discussion of Tasks 1 – 4
  - Task 1: Literature Review
  - Task 2: Numerical Modeling
  - Task 3: Physical Modeling and Select or develop an analysis and design methodology
  - Task 4: Field-Testing Protocol

Introduction

FDOT has used sheet pile walls for permanent and temporary lateral support only

FDOT is considering using sheet piles to support both vertical bridge loads and lateral earth loads

a. Sheet pile wall under the construction stage	b. Finished sheet pile foundation walls in below grade parking garages

Figure 1. Steel sheet piles used as permanent foundation and retention systems (Underwood and Greenlee 2010)

Background
Sheet pile walls for vetical loading bearing elements

- The current FDOT practice requires discrete deep foundation (piles or drilled shafts) for bearing purposes which may or may not be combined with permanent sheet piles for lateral retaining purposes

- Some designers has previously considered using sheet piles to support both vertical bridge loads and lateral earth loads. However, the concept has not survived final design due to the inability to confirm the capacity of these elements in the field and accept them as bearing piles

- For end bents of small bridges, there is a potential for realizing savings if we can verify the axial resistance of the sheet piling and eliminate the need for separate deep foundation

- This would also relieve the complications that arise in construction when driving piles and sheet piles in close proximity

Background: Uncertainties and Issues

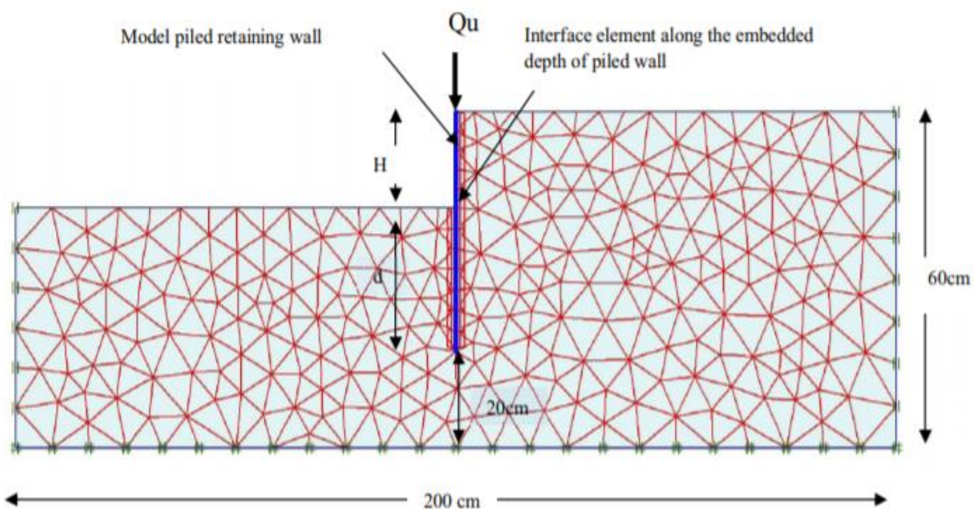
- Evaluation of side friction and end bearing resistance by conventional pile design approaches
- Assessment of soil-sheet pile interaction under combined axial and lateral loading
- Evaluation of buckling potential and plastic hinge formation under axial loading
- Determination of the bearing capacity of axially loaded sheet piles through standardized practical field testing protocols

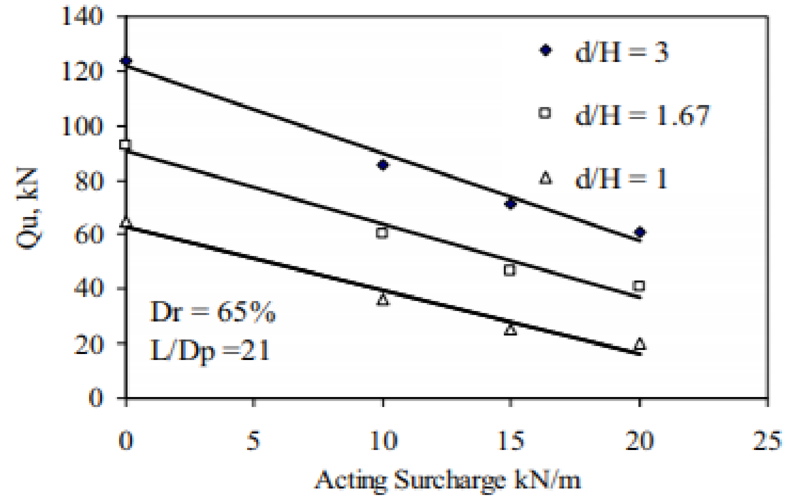
Objectives:

- Quantify the bearing capacity of permanent steel sheet pile walls
- Evaluate both the friction and bearing components
- Develop practical recommendations for designers to estimate the bearing capacity of steel sheet pile walls
- Develop practical methods to determine and verify the bearing capacity in the field

Task 1 - Literature Review of Numerical Modeling (2D simulation)

(Azzam & Elwakil, 2017):

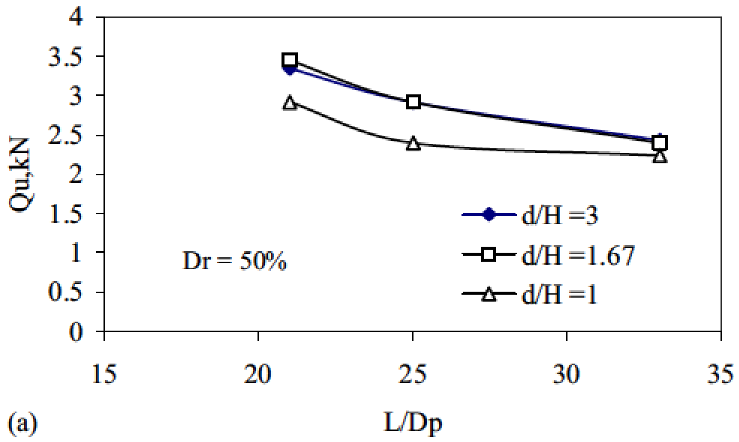


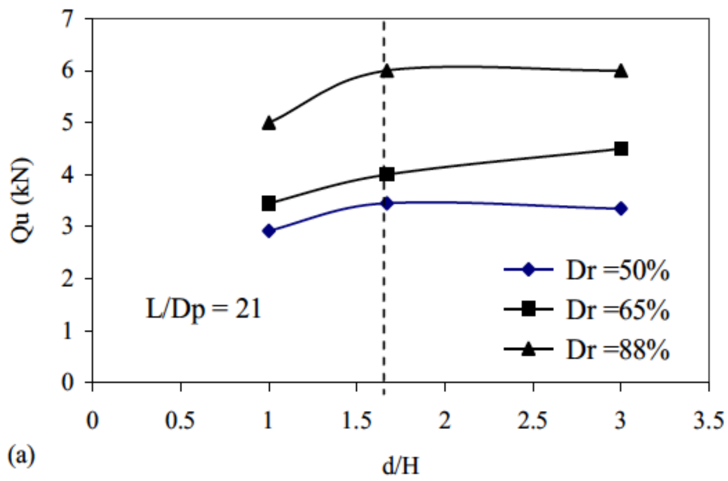


	$\phi = 41$			$\phi = 35$			$\phi = 24$		
Observed parameter for series of $L/Dp = 21$	$d/h = 3$	$d/h = 1.67$	$d/h = 1$	$d/h = 3$	$d/h = 1.67$	$d/h = 1$	$d/h = 3$	$d/h = 1.67$	$d/h = 1$
Qu (kN·m)	225	190	154	124	93	56	84	45	32
$\delta_{H\max}$ (mm)	0.74	0.87	0.99	1.06	1.45	1.29	1.12	1.67	1.87
$S_{v\max}$ (mm)	1.3	1.39	1.48	1.39	1.47	1.67	1.5	1.83	2.21
Maximum bending moment (kN·m/m)	11.3	10.5	9.98	9	8.2	7.87	8.4	6.7	5.35

Task 1 - Literature Review of Small-Scale Field Tests

(Azzam & Elwakil, 2017):





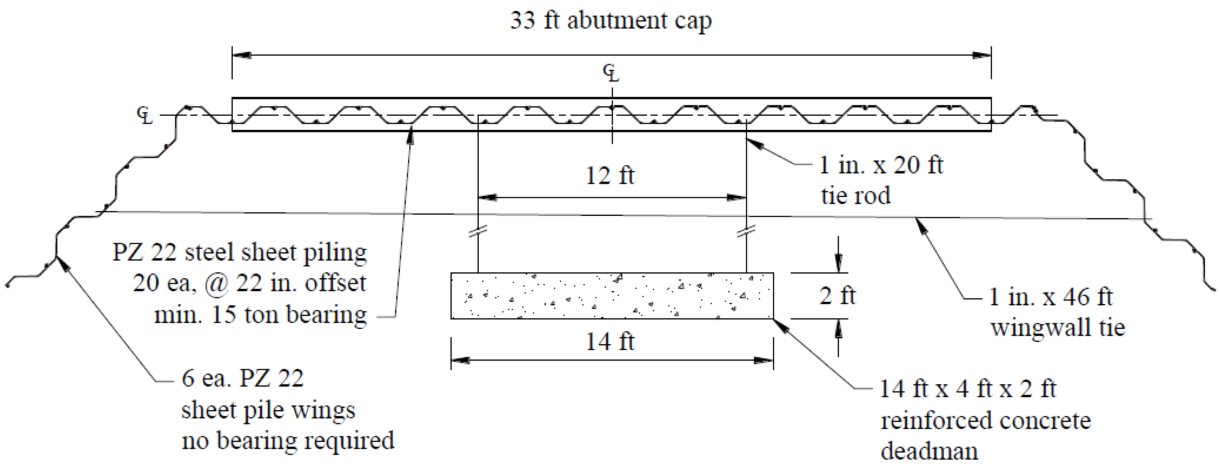
Task 1 - Literature Review of Full-Scale Field Tests

(Sylvain et al., 2017)

Test Pile Type	Measured (Axial load test and PDA dynamic measurements)			Predicted (Static methods)	
	Load at 7 mm Displacement (kN)	Failure Load[1] (kN)	Restrike PDA Capacity[2] (kN)	LCPC[3] (kN)	Meyerhof[4] (kN)
Sheet pile	165	158	196	285	157
H-pile	100	101	40	189	76

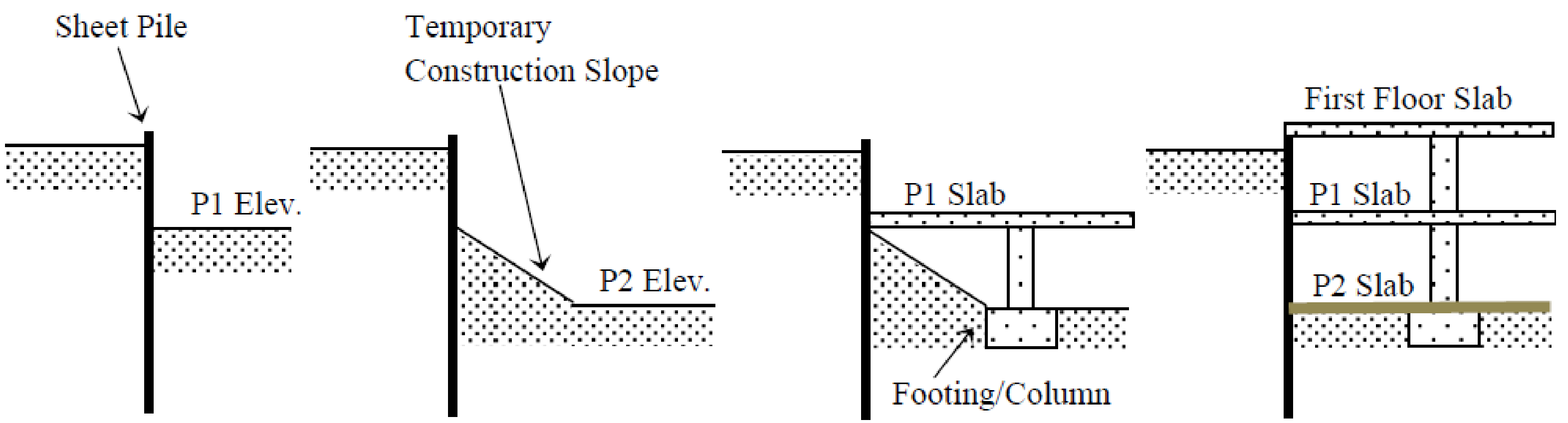
Notes: ([1]): Reported failure load is based on the Chin-Kondner failure criterion (Chin 1970).
([2]): Axial load capacity estimate based on PDA dynamic measurements during restrike (11 days after installation) and the CASE damping model (damping CRX 7).
([3]): LCPC based on Bustamante and Gianeselli (1982).
([4]): Based on Meyerhof (1976).

Task 1 - Literature Review of Full-Scale Field Tests



Evans et al. (2012)

Task 1 - Literature Review of Case Study



Stage 1, 2 Stage 3 Stage 4, 5 Stage 6, 7, 8

Stage 3

Stage 4, 5

Stage 8

Underwood and Greenlee (2010)

Task 1 - Literature Review of Design Methods

- Load test needs to follow the procedures specified in ASTM D1143/D1143M (2013)
- According to AASHTO (2018), the nominal bearing resistance can be determined using Davisson Method (Davisson 1972).

The bearing capacity of driven piles according to AASHTO (2018):

$$R_R = \emptyset R_n = \emptyset_{stat} R_p + \emptyset_{stat} R_s$$

in which:

$$R_p = q_p A_p$$

$$R_s = q_s A_s$$

Nominal bearing capacity according to FDOT guidelines:

- **SPT methodology:** FDOT research bulletin No. 121-A (Schmertmann 1967); and 121-B (Nottingham and Renfro 1972)
- **CPT methodology:** Schmertmann method (Schmertmann,1978); University of Florida method (Bloomquist et al. 2007); and the LCPC method (Bustamante and Gianeselli 1982)

Task 2 - Numerical Modeling

- Conduct extensive nonlinear finite element (FE) modeling representing various scenarios in the filed and identify the effects of different factors that may affect the bearing capacity of sheet pile walls under axial loading.

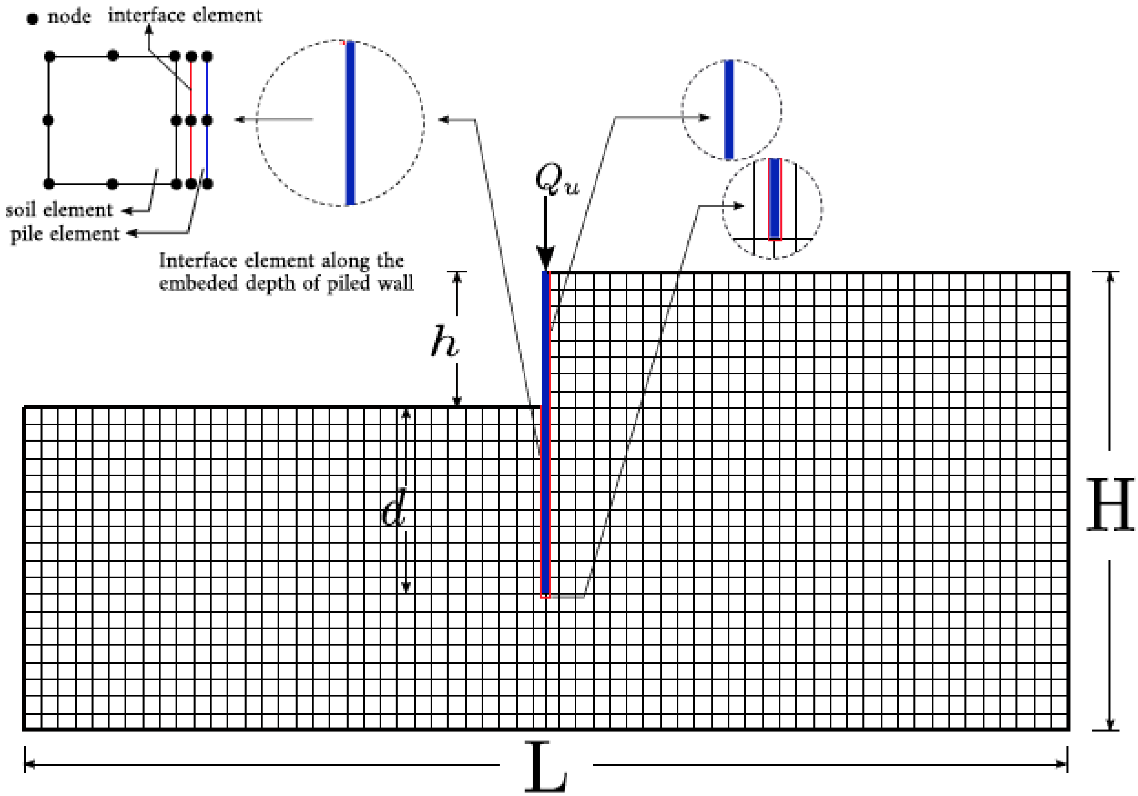
- Calibrate and validate the FE analysis using the closed-form solutions based on the limit equilibrium method as well as centrifuge testing results (task 3).

- Conduct numerical analysis with parametric study to investigate the behavior of prototype-scale axially loaded sheet pile walls under a variety of conditions.

- Predicted bearing capacity will be checked against FDOT and AASHTO design guidelines for obtaining bearing resistance and will also be compared with results in the literature (e.g., Evans et al. 2012)

Task 2 - Nonlinear FE Program

- ❑ FEM3m – an in-house nonlinear finite element code written in C++ and implemented on a parallel computing platform.
- ❑ PLAXIS 3D – A user-friendly commercial FE package for 3D analysis of deformation and stability in geotechnical engineering and rock mechanics.



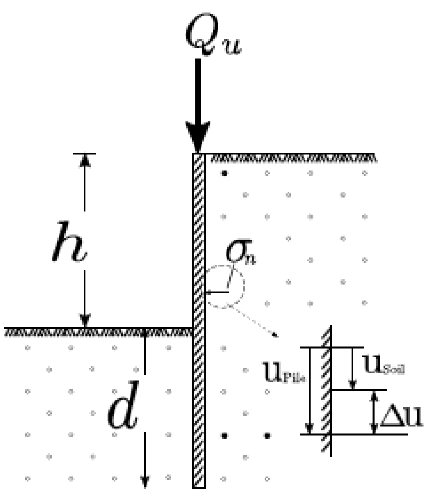
- We will conduct the major numerical analysis (Table 2) using PLAXIS 3D.
- We will present an step-by-step guideline for modeling and analyzing the behavior of axially loaded sheet piles using PLAXIS 3D.

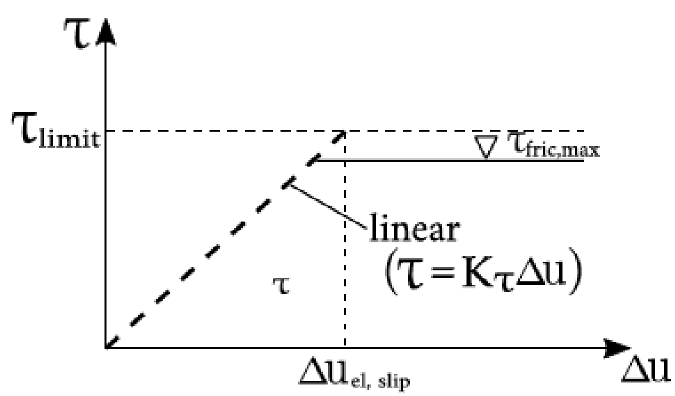
Task 2 - Numerical Model

- Sands: Elasto-plastic Mohr-Coulomb model by continuum elements.
- Sheet pile wall: an elastic model by a structural element.
- The interface: a perfect (rigid) plastic model (slip-friction model).

Table 1. Reference soil parameters for the numerical analysis (Azzam and Elwakil 2017)

Material model	Mohr-Coulomb		
Soil	Loose sand	Dense sand	Very dense sand
Parameters			
Young's modulus ($kN \cdot m^2$)	50,000	100,000	113,000
Cohesion	0.0	0.0	0.0
Poisson's ratio	0.30	0.30	0.30
Friction angle [ϕ(°)]	24	36	41
Angle of dilatancy [$\psi = \phi - 30$(°)]	0	6	11



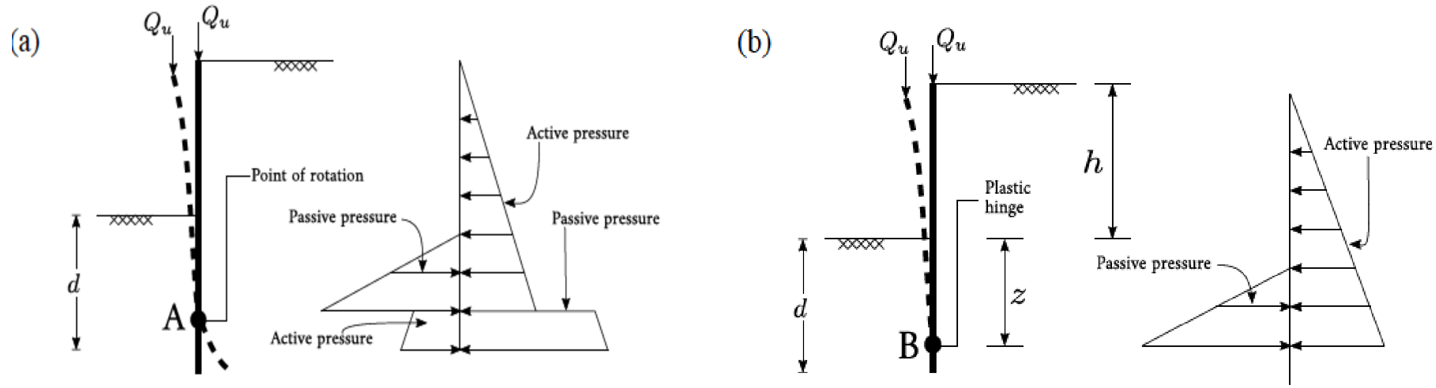


Task 2 - Calibration and validation

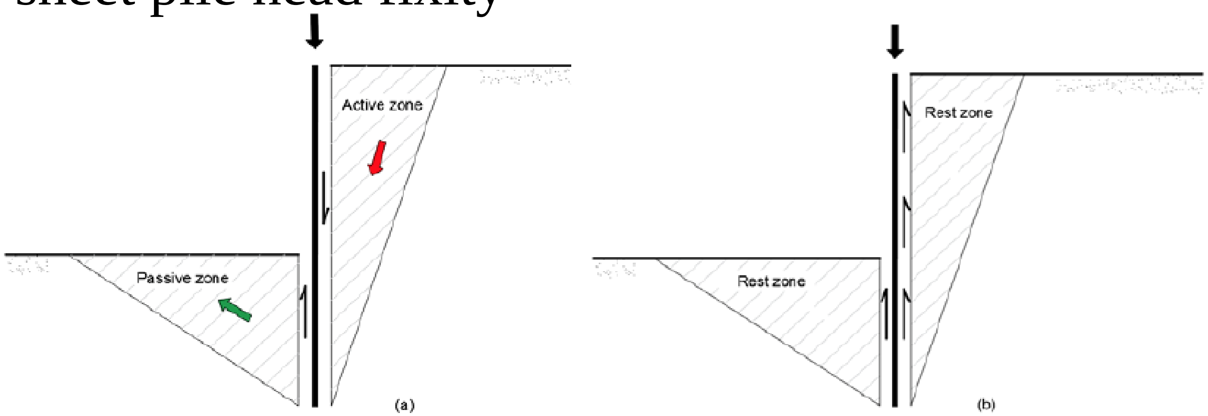
- Validation against closed-form solutions obtained by Coulomb's theory
- Validation against the results in the literature (e.g., Bustamante and Gianeselli, 1991, and Evans et al., 2012)
- Validation against the centrifuge testing results (Task 3)

Task 2 - Simulation Scenarios

- Effect of penetration depth and unsupported length



- Effect of sheet pile wall stiffness
- Effect of sand relative density and layering
- Effect of the sheet pile head fixity

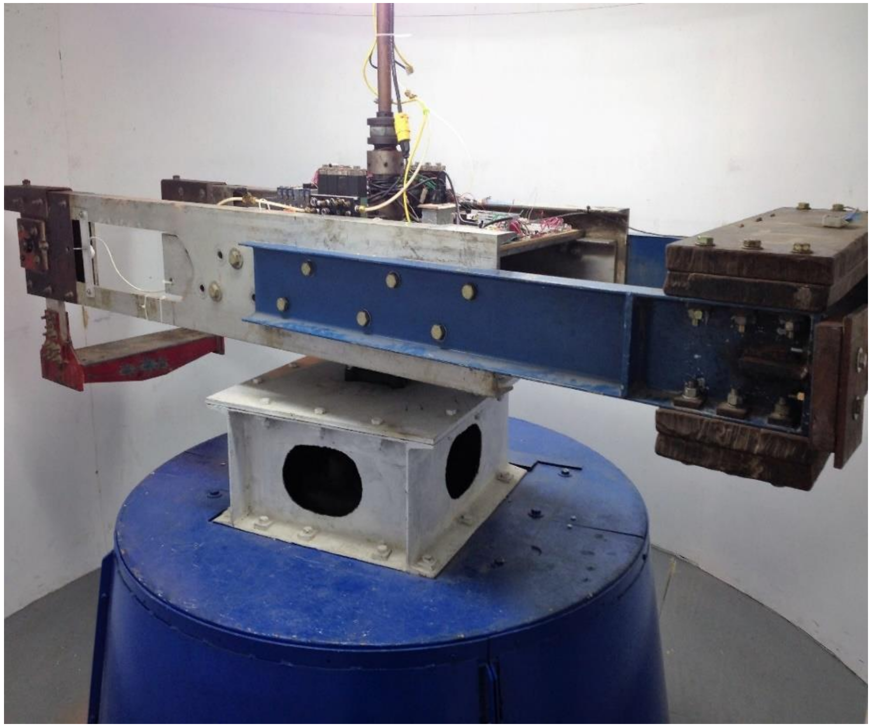


- Effect of surcharge load

Task 3 - Centrifuge Testing

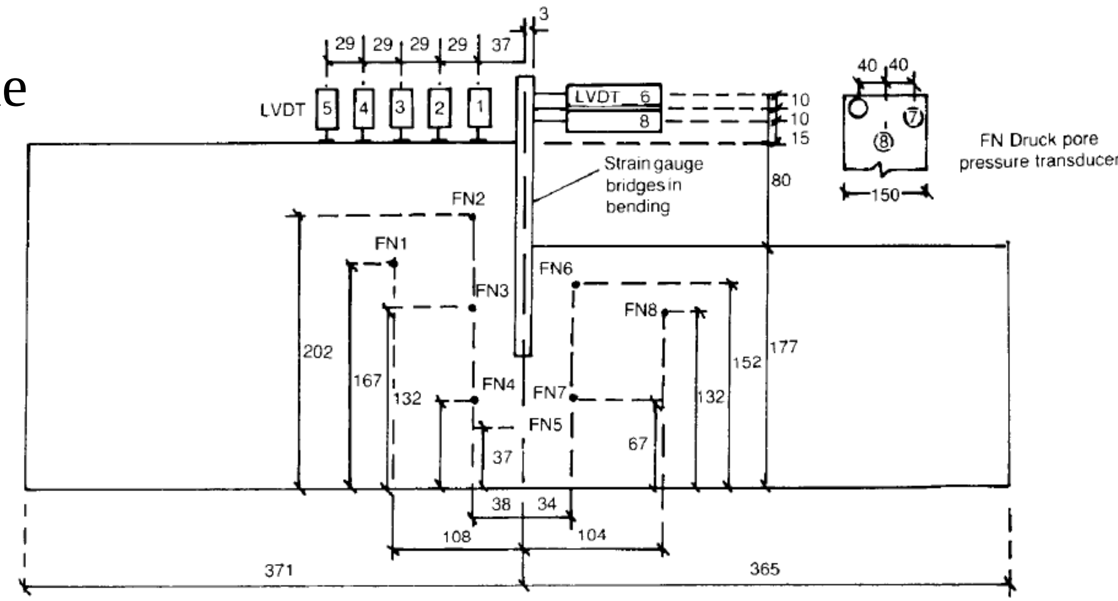
UF Centrifuge
Radius = 1.5 m
Max. Payload = 12.5 g-ton
Max. Acceleration = 80 g

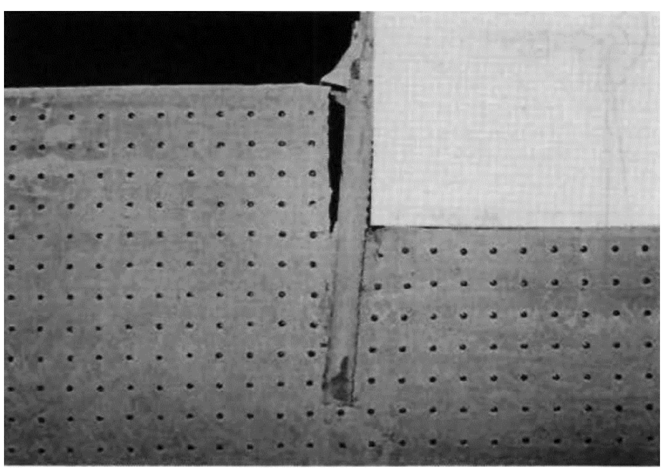
Centrifugal Acceleration = 50 g



Task 3 - Centrifuge Tests

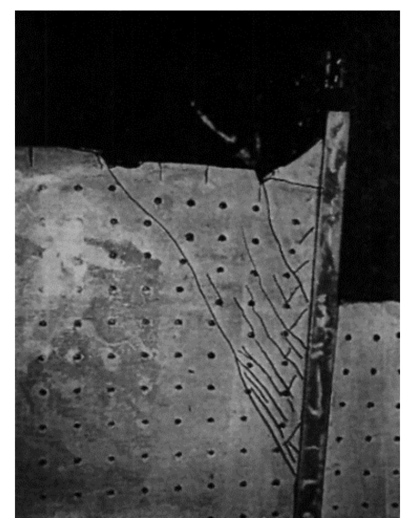
Bolton and Powrie
(1987, 1988)





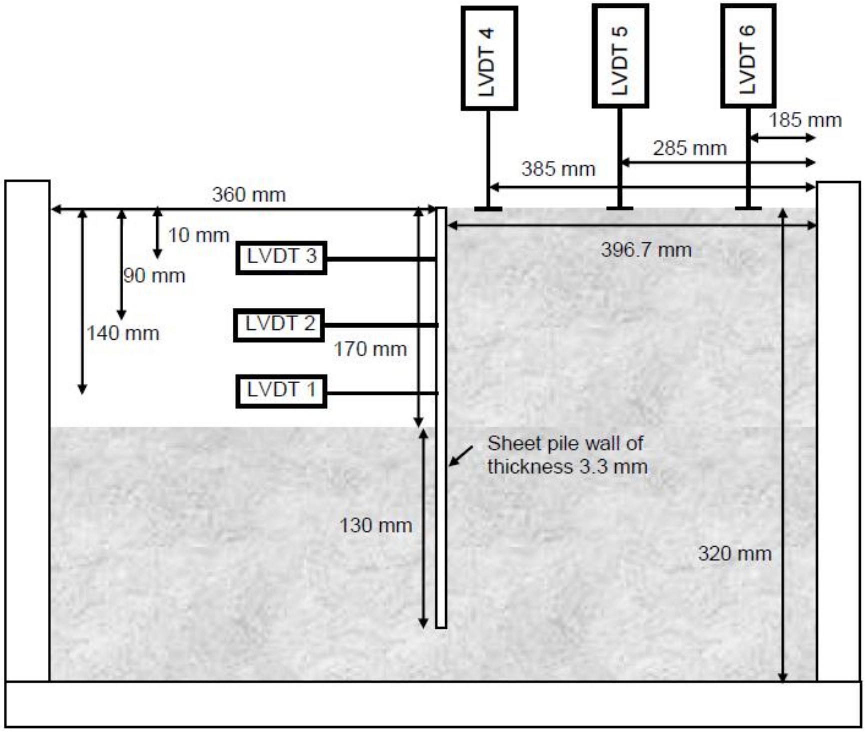
Shallow Penetration

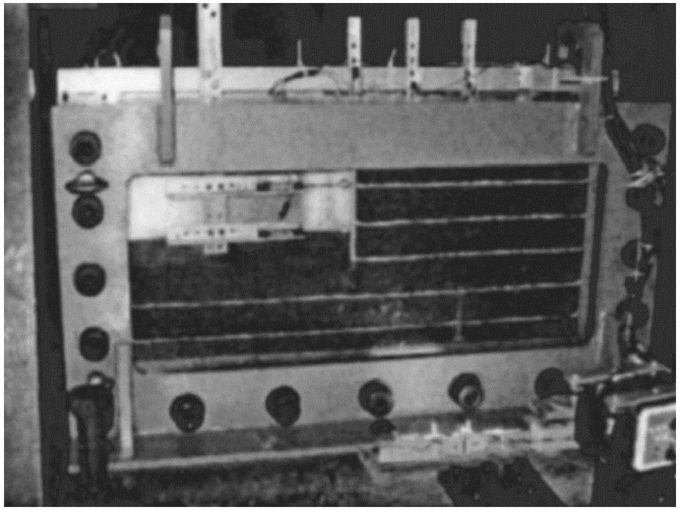
Deep Penetration

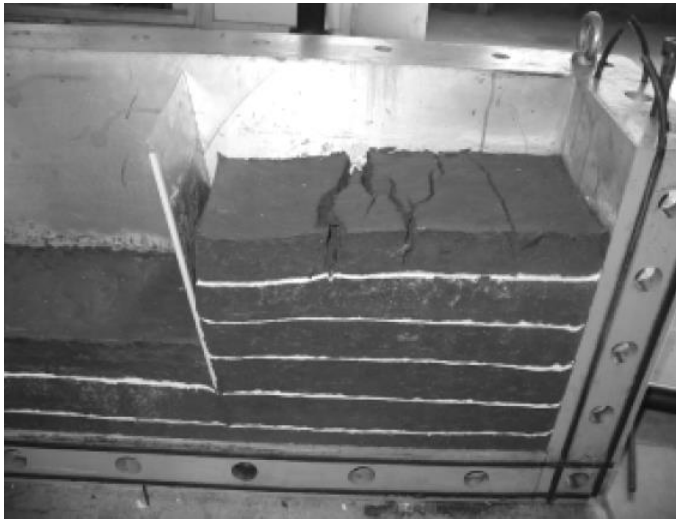


Task 3 - Centrifuge Tests:

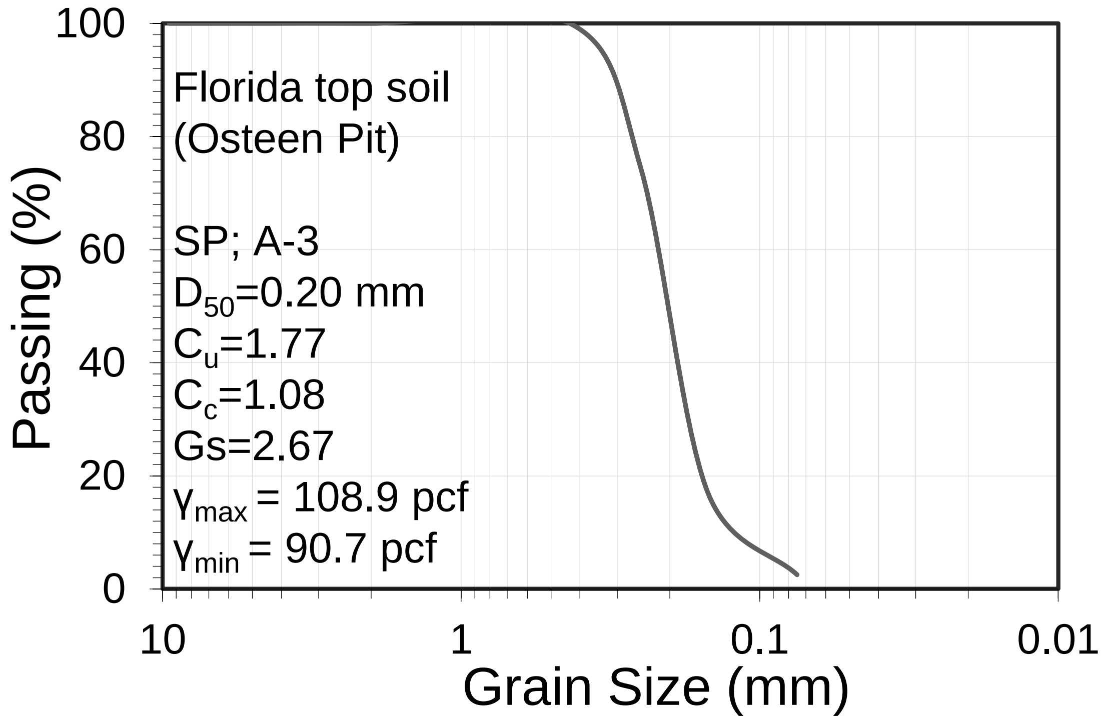
Madabhushi and Chandrasekaran (2005, 2008)



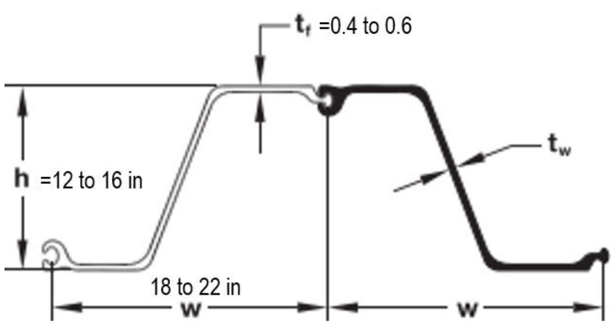




Task 3 - Centrifuge Testing



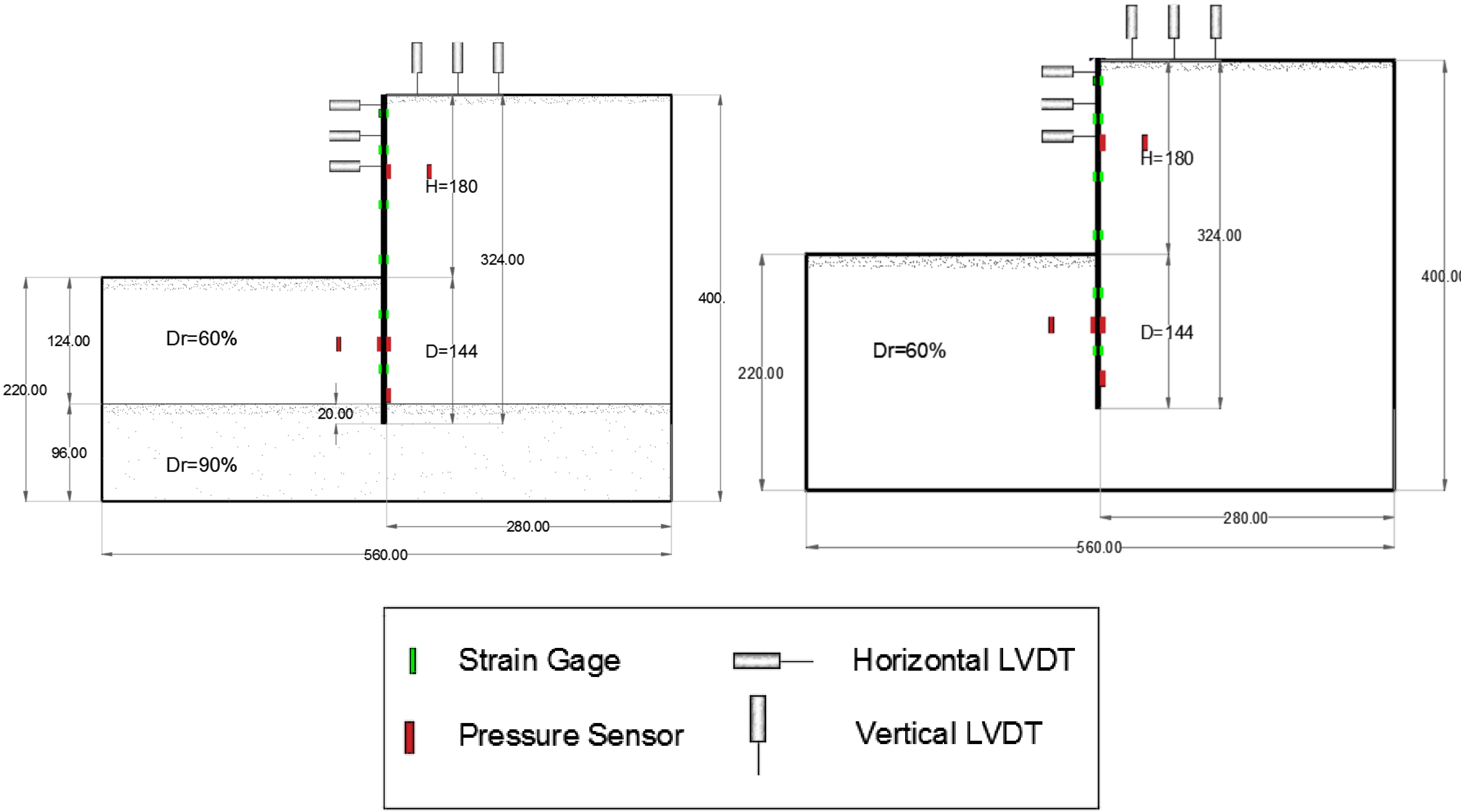
Target relative densities of FL sand (by pluviation) = 60% and 90%



Plan view of a typical steel sheet pile wall

Task 3 - Centrifuge Tests

Schematic elevation view of the centrifuge model

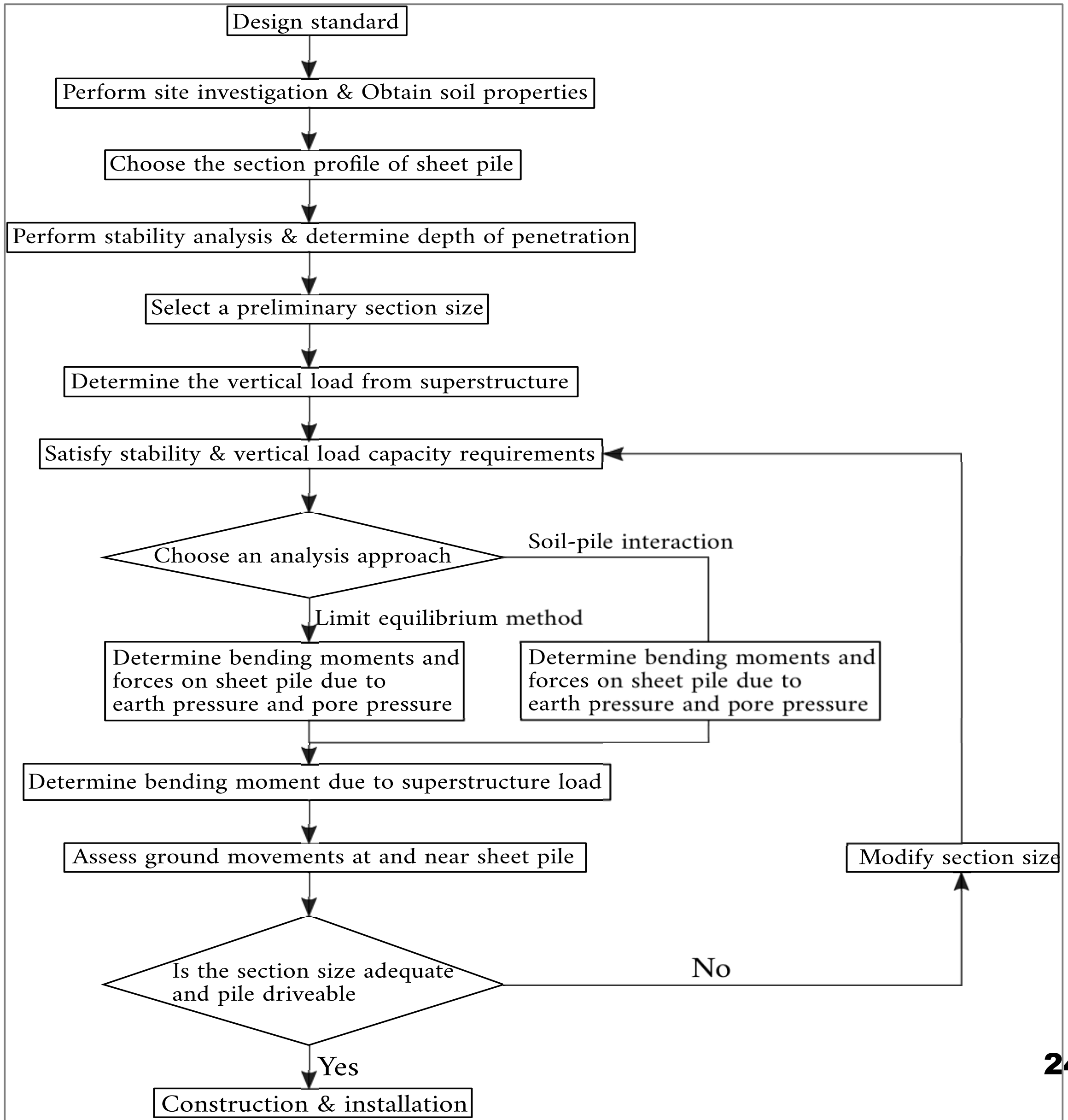


Task 3 - Centrifuge Testing Scenarios

- Axial load transferring mechanism: end bearing and friction
- Penetration depth and unsupported length
- Sheet pile stiffness
- Boundary conditions
- Axial load testing of sheet pile abutments: static and quasi-static

Task 3 - Element-Scale Laboratory Tests

- Direct shear tests – to determine the friction angle between the sheet pile and sand.
- Isotropically consolidate drained triaxial compression test (CIDC) on sand samples.



Task 4 - Field testing protocol

- Types of sheet piles to be tested an guidelines on the maximum unsupported length, the minimum embedment length, and buckling critical length.
- Construction methods of sheet pile walls including driving.
- Size and capacity of basic sheet pile driving equipment to be furnished.
- Driving criteria and special installation methods.
- Required testing equipment and instrumentation considering both axial loads and lateral earth pressures on the wall.
- Types of tests (i.e. static and quasi-static) and maximum testing capacity to be furnished.
- Data to be recorded and reported
- Methodology to interpret the dynamic and static load testing results.

Thank You!

Q&A