# Immediate Settlement Analysis Using Finite Element Analysis Models of FB-MultiPier

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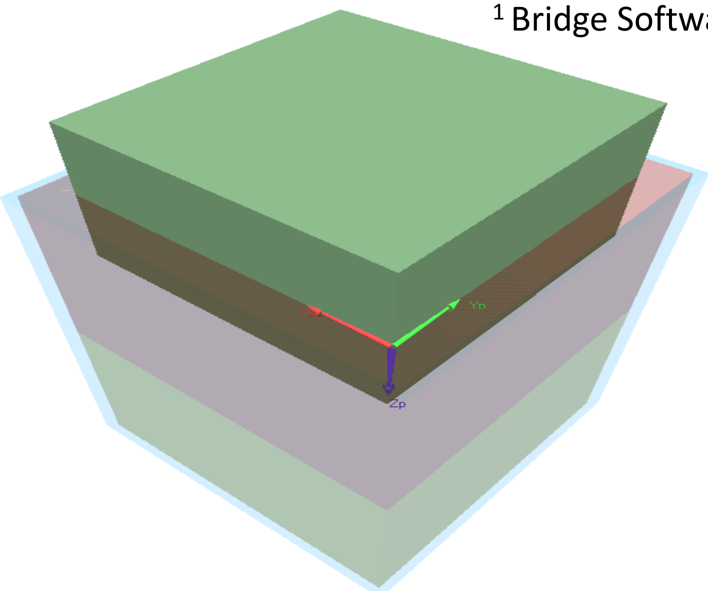

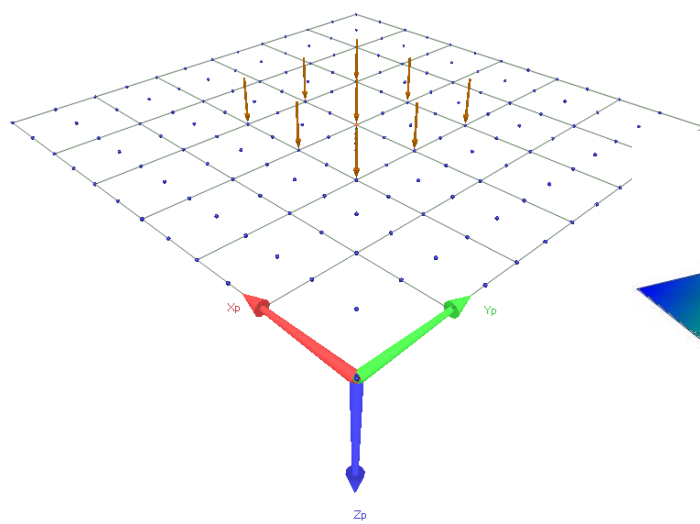


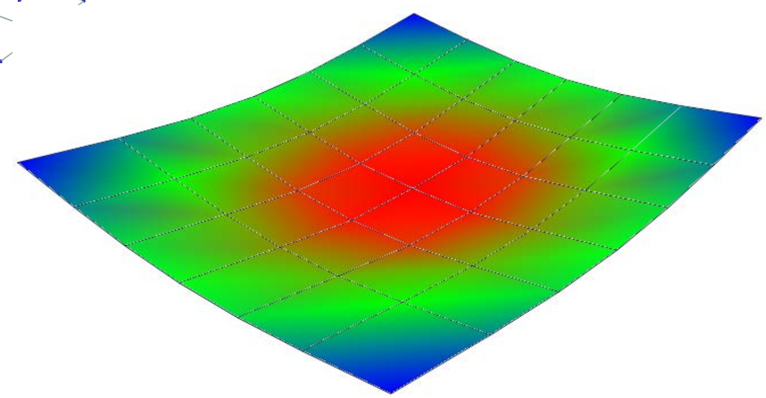

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Presented at Geotechnical Research in Progress (GRIP) Meeting
State Materials Office (SMO)
Florida Department of Transportation (FDOT)
Gainesville, Florida
August 21, 2015

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# Agenda

- Project Goals
- Research Tasks
  - Literature review
  - Implementation of extended Winkler model
  - Development of algorithm for calculating ultimate bearing resistance
  - Development of soil lateral and rotational spring models
  - Reporting of findings and design-oriented model applications
- Outcomes
- Timeline

# Project Goal

- **Develop FB-MultiPier module to compute immediate settlements for FE models of shallow foundations**

- Implementation based on:
  - Extended Winkler model (with constitutive nonlinearity)
  - Weighted averaging (multiple soil layers, influence depth)
  - Newton-Raphson method (equilibrium iterations)

- Accounts for:
  - Vertical (linear and nonlinear), horizontal (linear) resistance
  - Local, general, punching shear failures (lower bounds)
  - Compression-only stiffness

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# Research Tasks

- **Project duration: 24 months**
- Task 1. Literature Review, Scenario Identification, and Field-Data Acquisition
- Task 2. Implementation of Extended Winkler Model
- Task 3. Development of Algorithm for Calculating Ultimate Bearing Resistance
- Task 4. Development of Soil Lateral and Rotational Spring Models
- Task 5. Reporting of Findings and Design-Oriented Recommendations
- Task 6. Final Report

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# Research Tasks

- **Task 1. Literature Review, Scenario Identification, and Field-Data Acquisition**
  - Collect data from the literature
  - Establish capabilities and limitations of extended Winkler model
  - Identify and characterize model input parameter values

- Sources
  - Technical literature
  - DOT data
  - NCHRP reports
  - FHWA circulars


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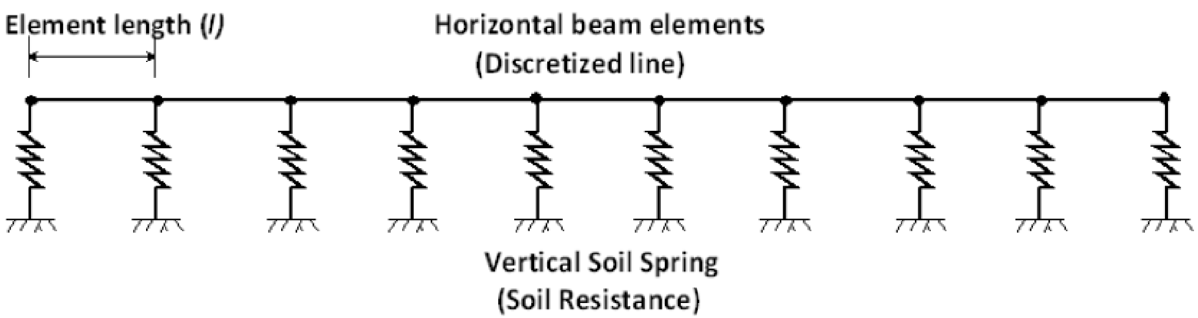
# Research Tasks

- **Task 2. FB-MultiPier Implementation of an Extended Winkler Model**
  - Concept of discretization with application of Euler beam theory




$E$ : Modulus of elasticity, e.g., ACI eqn. $E = 57000\sqrt{f_c'}$

$I$ : Moment of inertia $= \frac{1}{12} b \cdot t^3$

$EI$ : Flexural rigidity of Euler beam

$k_s = kbl$

$k$ : the coeff. of subgrade reaction ($kips / in^3$ or $KN / m^3$)

$l$ : beam element length ($ft$ or $m$)

$b$ : beam width ($ft$ or $m$)

$$\theta = \frac{dv}{dx} \quad (\tan\theta \approx \theta)$$

$$\kappa = \frac{d\theta}{dx} = \frac{d^2v}{dx^2}$$

$$EI\kappa = M$$

$$\frac{dM}{dx} = V, \quad \frac{dV}{dx} = -q, \quad \frac{d}{dx}\left(\frac{dM}{dx}\right) = -q$$

$$\frac{d}{dx^2}(EI\kappa) = -q, \quad EI\frac{d^4v}{dx^4} = -q$$

$$EI\frac{d^4v}{dx^4} = -q$$

$$q = -k_s v$$

$$EI\frac{d^4v}{dx^4} = k_s v$$

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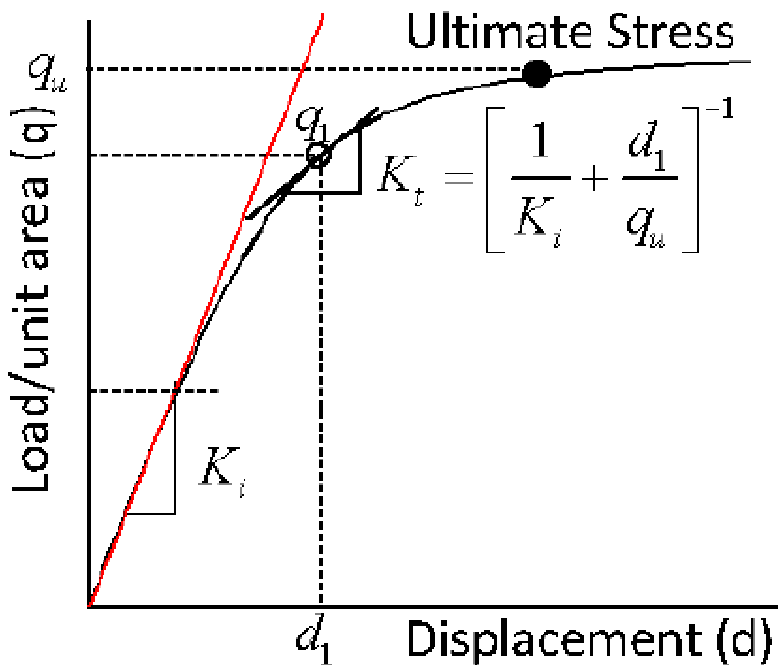
# Research Tasks

- **Task 2. FB-MultiPier Implementation of an Extended Winkler Model**

  Nathan Newmark's solution for Boussinesq's problem plus Ducan and Chang's hyperbolic constitutive relationship.

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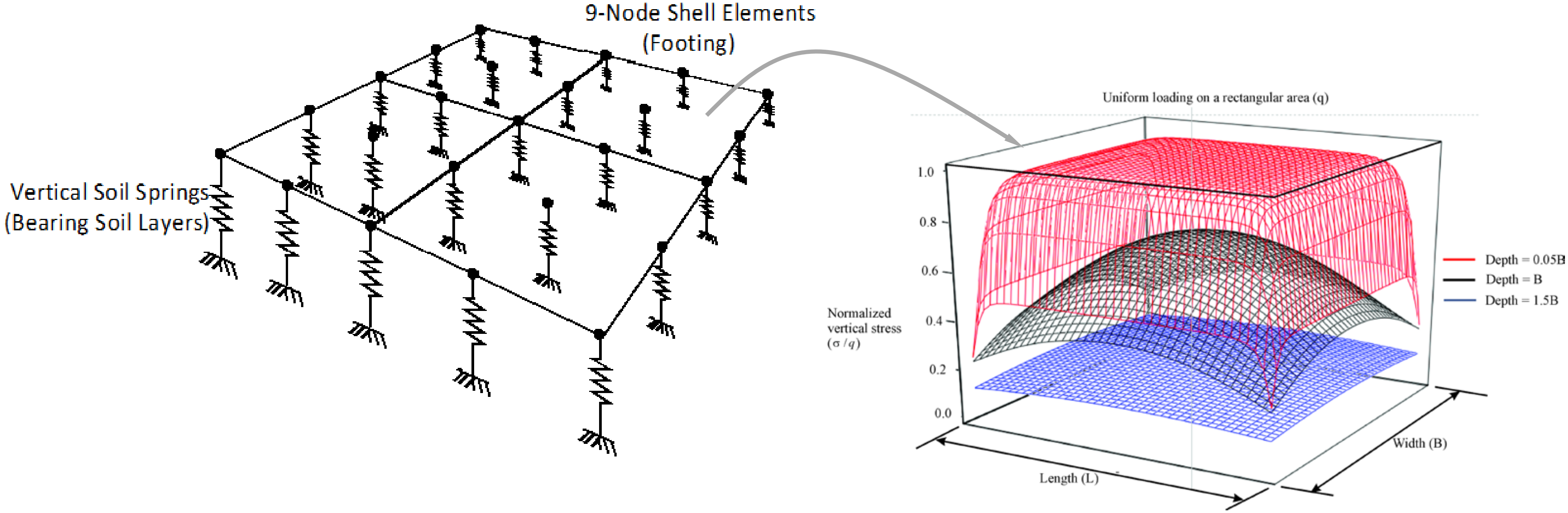
# Research Tasks

- **Task 2. FB-MultiPier Implementation of an Extended Winkler Model**
  - Extension to two dimensions

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# Research Tasks

- **Task 3. Development of Computational Algorithms to Determine Ultimate Bearing Stress**
  - General shear failure (Meyerhof 1963)

$$q_u = cN_cF_{cs}F_{cd}F_{ci} + qN_qF_{qs}F_{qd}F_{qi} + \frac{1}{2}\gamma BN_\gamma F_{\gamma s}F_{\gamma d}F_{\gamma i}$$

$c$ = cohesion (undrained shear strength)

$q$ = effective stress at the level of the bottom of the pile cap

$\gamma$ = total unit weight of soil

$B$ = width of the pile cap (or diameter of a circular pile cap)

$N_c, N_q, N_\gamma$ = bearing capacity factors

$F_{cs}, F_{qs}, F_{\gamma s}$ = shape factors

$F_{cd}, F_{qd}, F_{\gamma d}$ = depth factors

$F_{ci}, F_{qi}, F_{\gamma i}$ = load inclination factors

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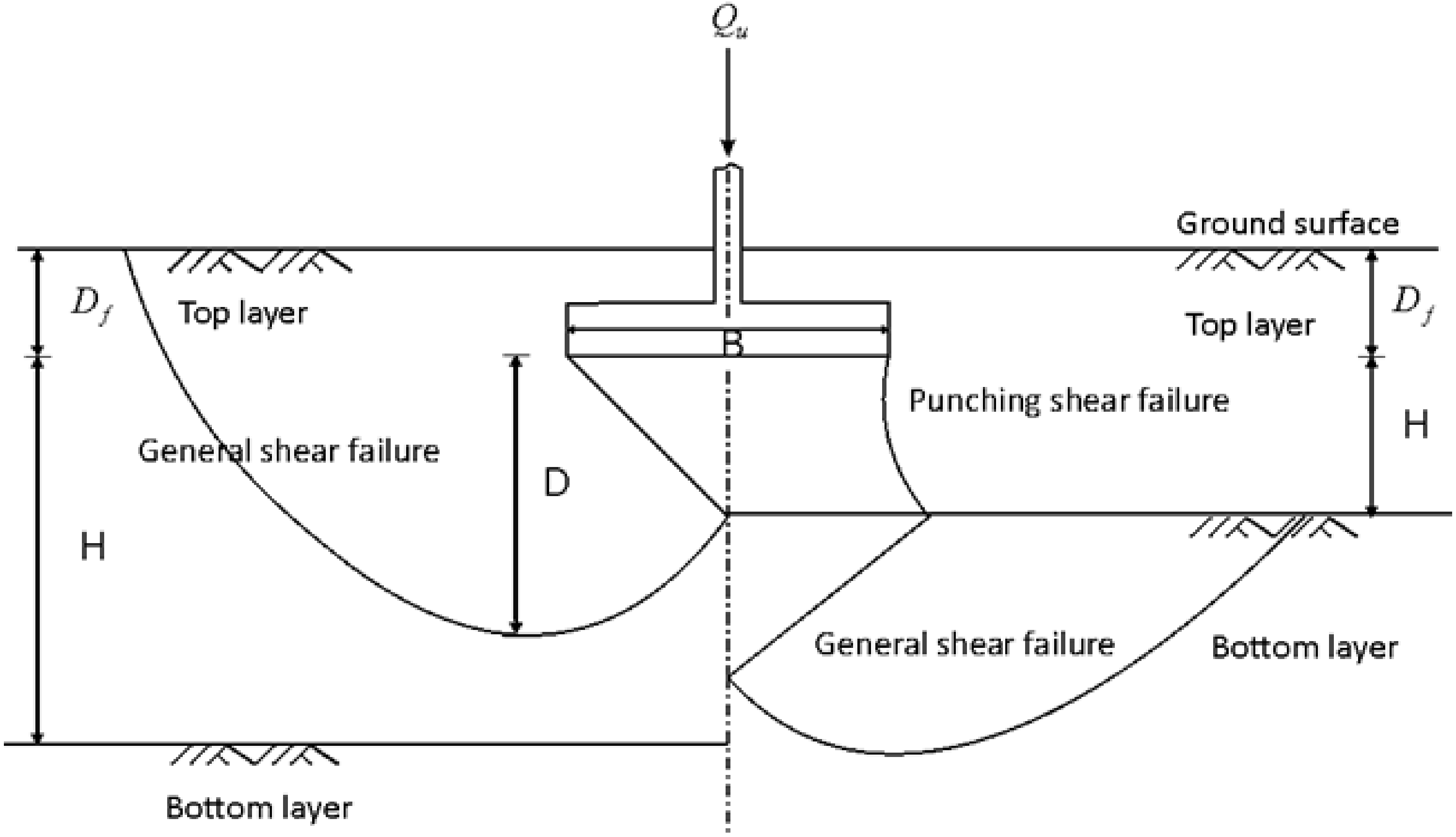
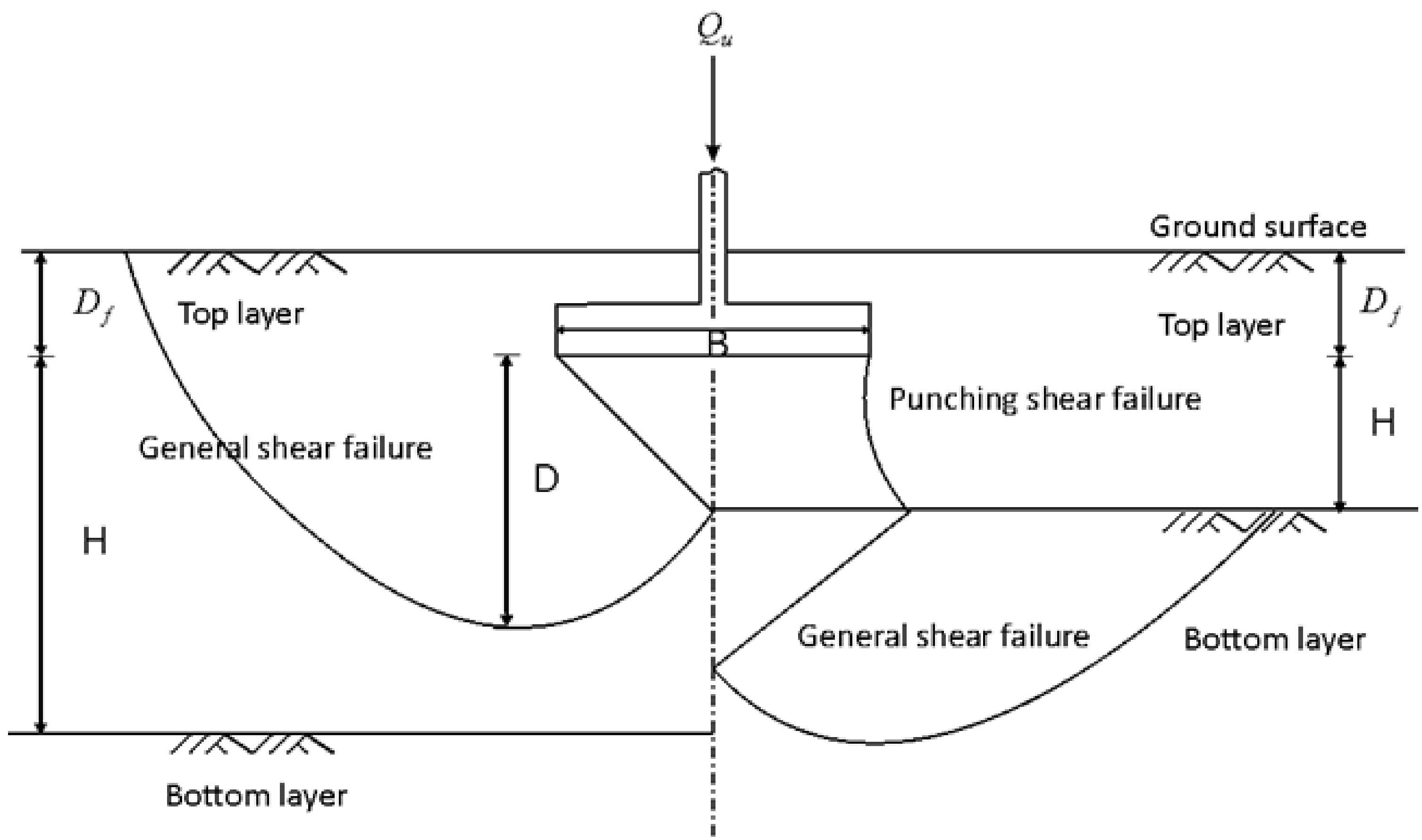
# Research Tasks

- **Task 3. Development of Computational Algorithms to Determine Ultimate Bearing Stress**
  - General shear failure



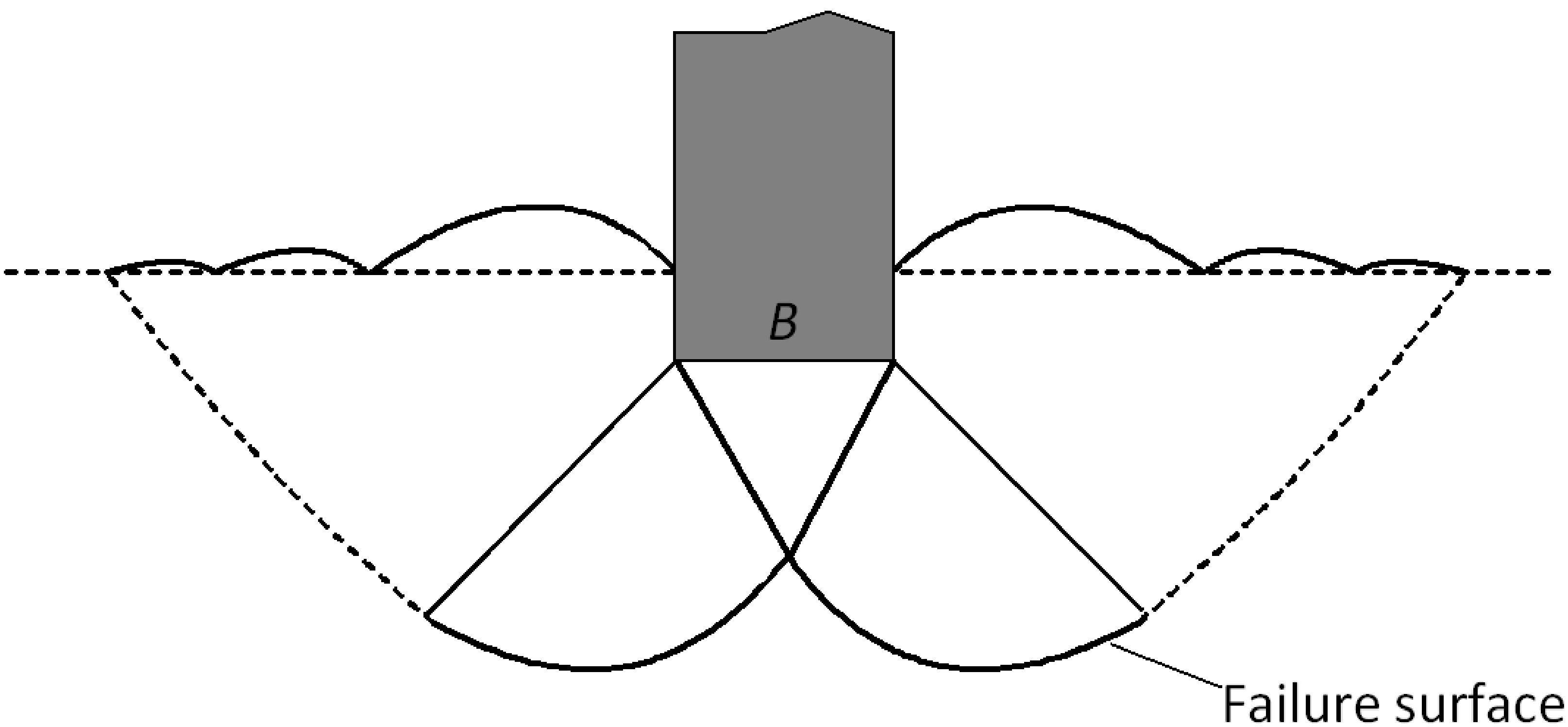
# Research Tasks

- **Task 3. Development of Computational Algorithms to Determine Ultimate Bearing Stress**
  - Punching shear failure



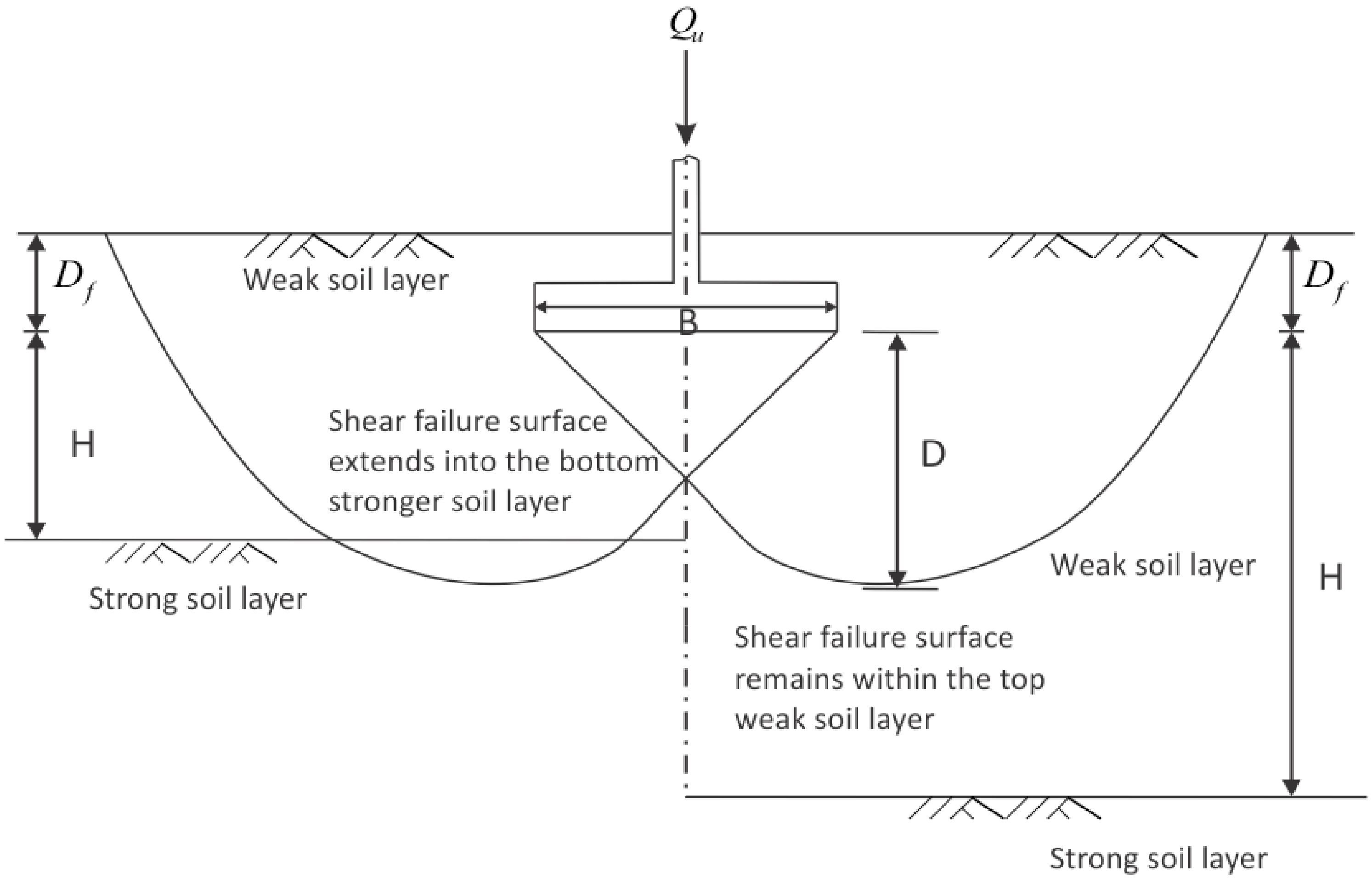
# Research Tasks

- **Task 3. Development of Computational Algorithms to Determine Ultimate Bearing Stress**
  - Local shear failure



# Research Tasks

- **Task 3. Development of Computational Algorithms to Determine Ultimate Bearing Stress**
  - Calculation of critical depth

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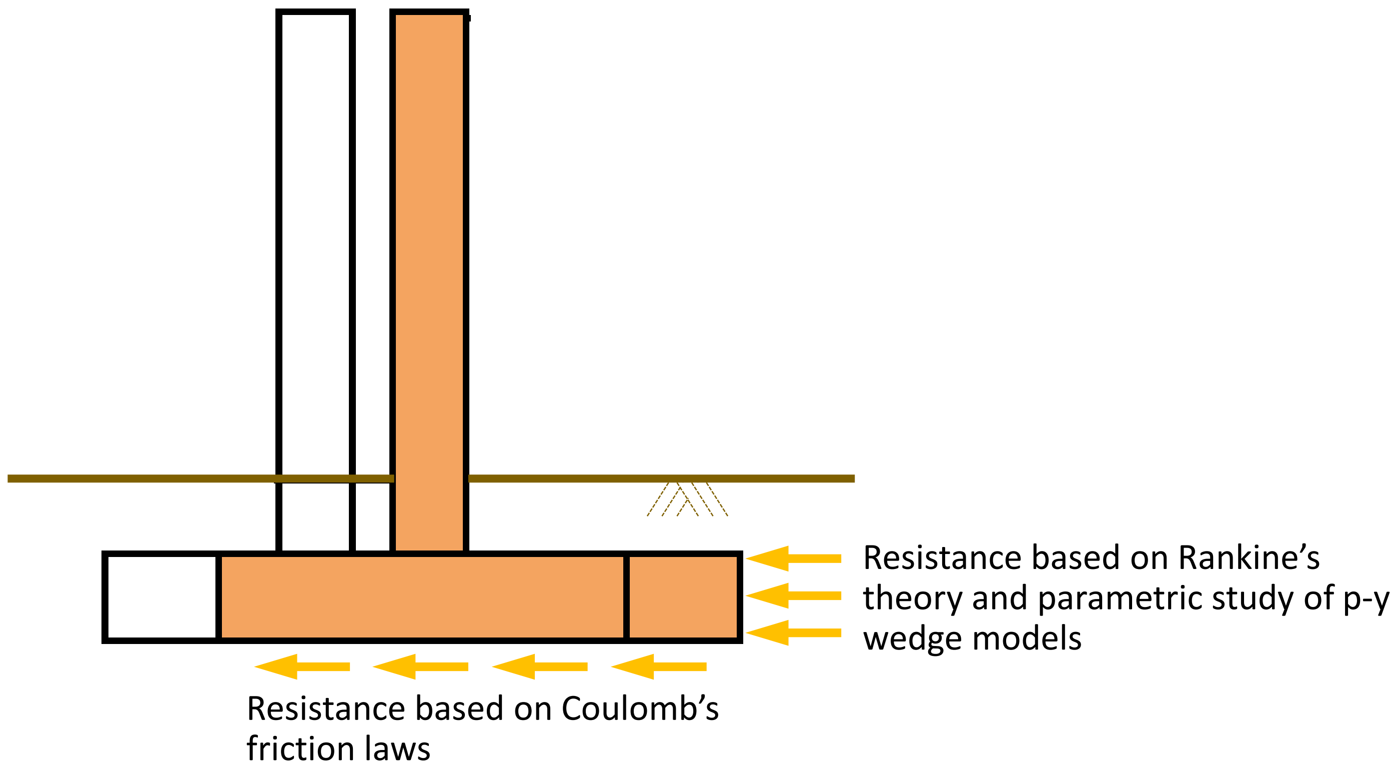
# Research Tasks

- **Task 4. Development of Soil Lateral and Rotational Spring Models**
  - Sliding friction along base of footing
  - Lateral resistance along leading edge of footing

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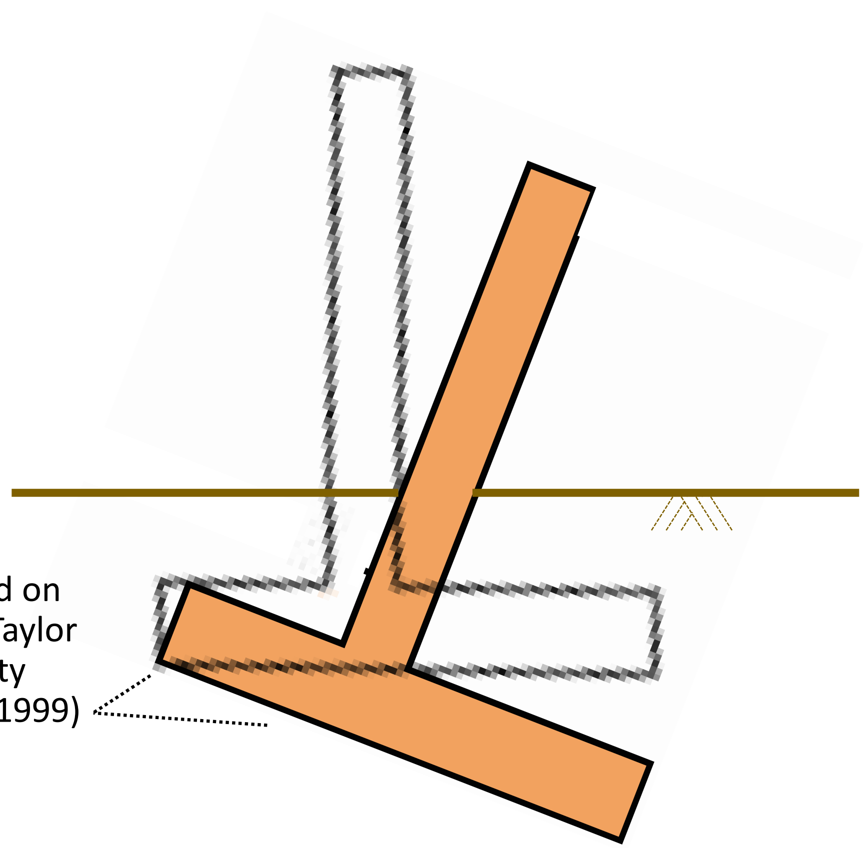
# Research Tasks

- **Task 4. Development of Soil Lateral and Rotational Spring Models**
  - Resistance encompasses point of rotation and along base
  - Validation against semi-empirical methods (Poulos and Davis 1974)



Resistance to rotation based on secant stiffness approach (Taylor 1967) and foundation rigidity factors (Mayne and Poulos 1999)

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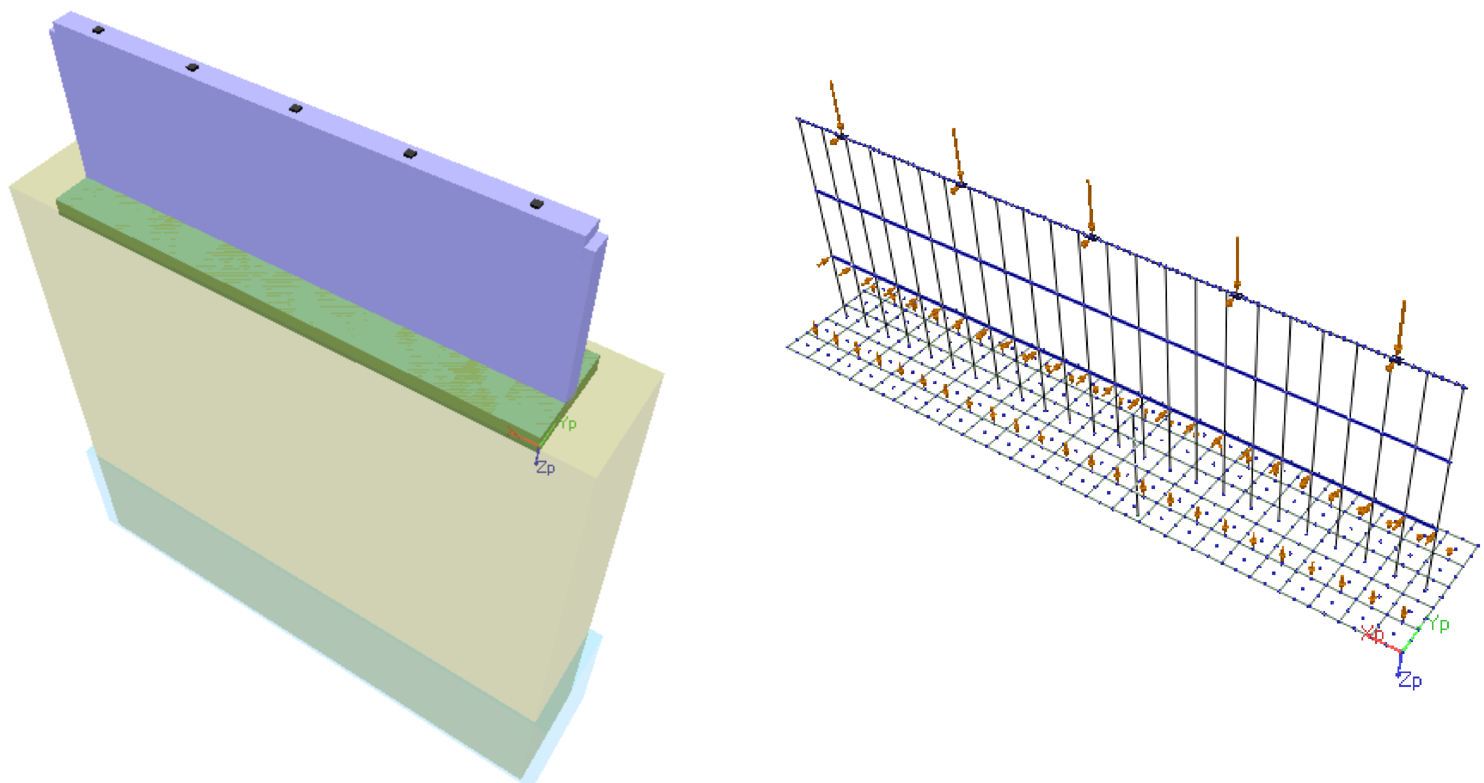
# Research Tasks

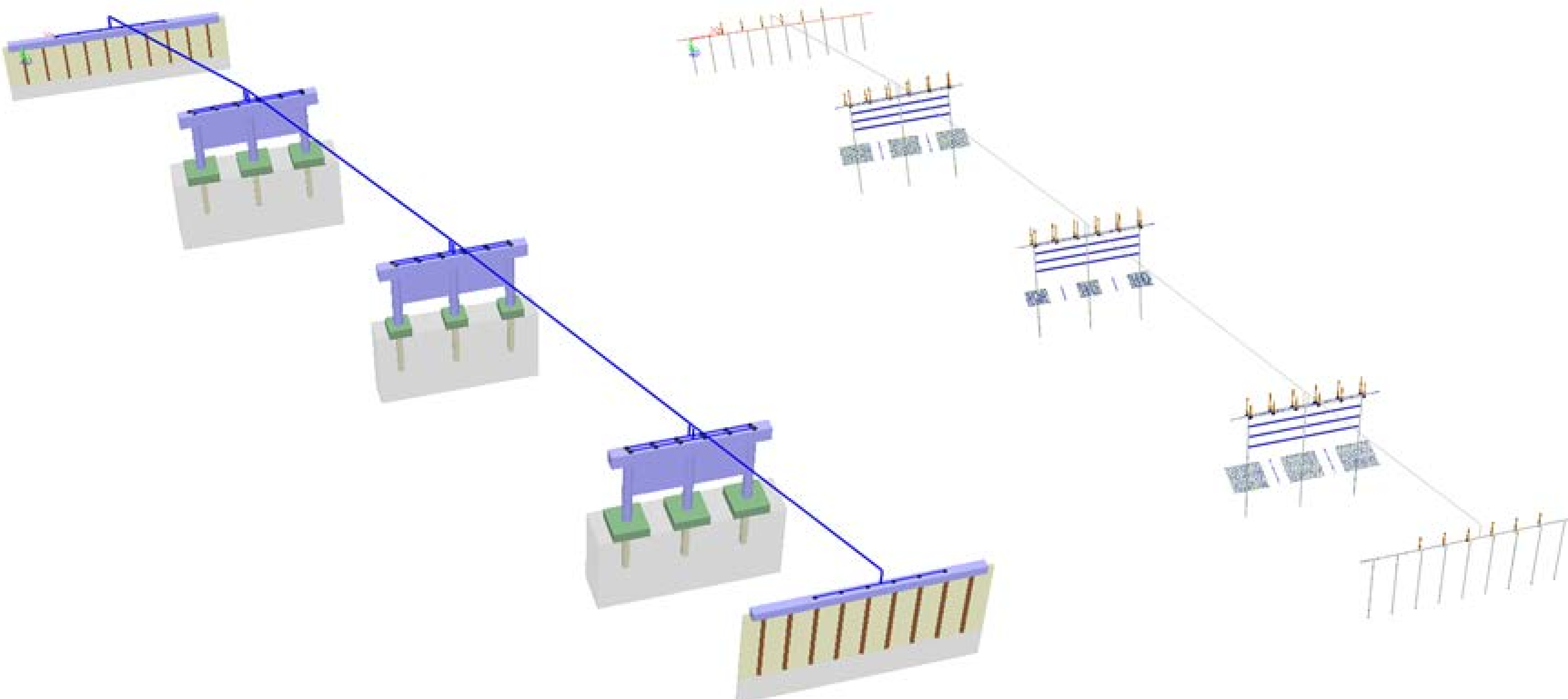
- **Task 5. Reporting of Findings and Design-Oriented Model Applications**
  - Develop inventory of example models




Example model of bridge abutment with spread footing foundation

# Research Tasks

- **Task 5. Reporting of Findings and Design-Oriented Model Applications**
  - Document use of models in design scenarios



Example model of integral abutment bridge with piled and spread footing foundation types

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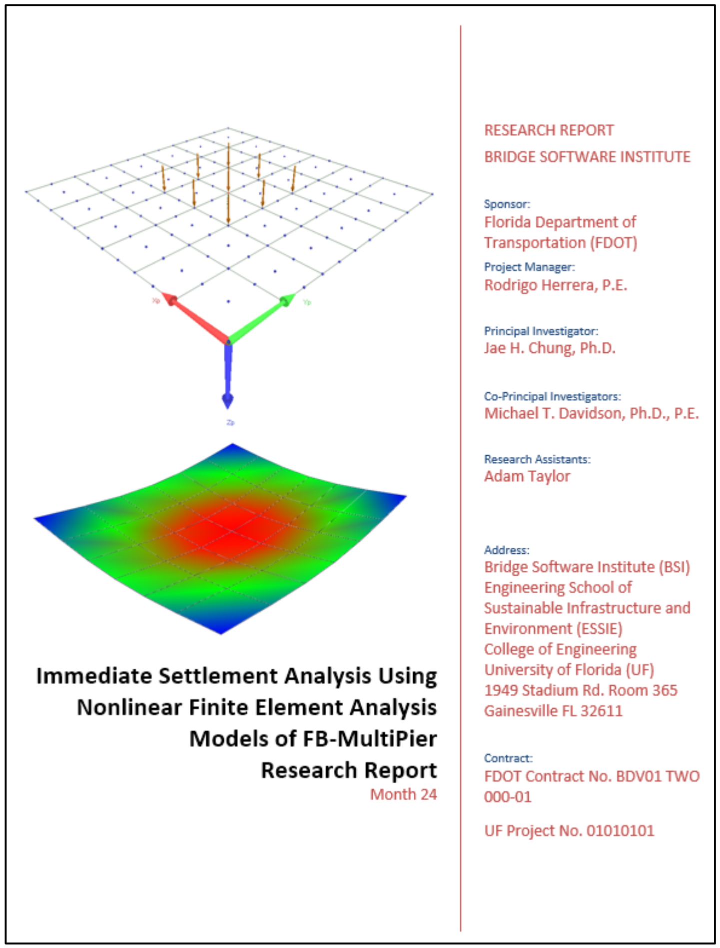
# Research Tasks

- **Task 6. Prepare and Submit Draft and Final Reports**
  - Document findings and implementation efforts from Task 1. through Task 5.



Immediate Settlement Analysis Using Nonlinear Finite Element Analysis Models of FB-MultiPier
Research Report
Month 24

RESEARCH REPORT
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Contract:
FDOT Contract No. BDV01 TWO 000-01

UF Project No. 01010101

# Outcomes

- Module will be implemented/documented in design-oriented software for computing immediate settlements of shallow foundations

- Establishes FB-MultiPier as one-of-a-kind software package for analyzing deep, shallow, and piled raft foundation systems

- **ROI for FDOT:** Module will be of immediate use to practicing engineers, and promotes more cost efficient design

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# Timeline: Year 1 of 2

| Research Task | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1. Literature review | | | | | | | | | | | | |
| | 25 | 50 | 75 | 100 | | | | | | | | |
| 2. Implementation of extended Winkler model | | | | | | | | | | | | |
| | 8 | 17 | 25 | 33 | 42 | 50 | 58 | 67 | 75 | 83 | 92 | 100 |
| 3. Development of computational algorithms for Ult. Brg. | | | | | | | | | | | | |
| | 8 | 17 | 25 | 33 | 42 | 50 | 58 | 67 | 75 | 83 | 92 | 100 |
| 4. Development of soil lateral and rotational spring models | Tasks 4. through 6. to be completed in Year 2 | | | | | | | | | | | |
| 5. Report findings and design-oriented model applications | | | | | | | | | | | | |
| 6. Prepare and submit final report | | | | | | | | | | | | |

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# Timeline: Year 2 of 2

| Research Task | Month 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Literature review | Tasks 1. through 3. to be completed in Year 1 | | | | | | | | | | | |
| | | | | | | | | | | | | |
| 2. Implementation of extended Winkler model | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| 3. Development of computational algorithms for Ult. Brg. | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| 4. Development of soil lateral and rotational spring models | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | |
| | 11 | 22 | 33 | 44 | 56 | 67 | 78 | 89 | 1 | | | |
| 5. Report findings and design-oriented model applications | | | | | | | | | ■ | ■ | ■ | |
| | | | | | | | | | 33 | 67 | 100 | |
| 6. Prepare and submit final report | | | | | | | | | | | | ■ |
| | | | | | | | | | | | | 100 |

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# Thank you.

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