U.S. Department of Transportation
Federal Highway Administration

CELEBRATING 50 years 1968-2018

DRILLED SHAFT CONSTRUCTION POLICY CHANGES

50 YEARS OF FHWA GEOTECH!!

- Formed in 1968 as a small group of experts placed in regional offices to address a number of slide related issues during interstate construction
  - Rock Slides
  - Degradable Shales
  - Failing Soil Embankments
- Focus during early years primarily on earthworks, and "expertise" among that group was variable
- Primary role –Technical assistance

50 YEARS OF FHWA GEOTECH!!

- In the mid-1980's, the geotechnical group was moved from construction and maintenance division to the bridge division
- Geotechnical function evolved to support different highway design functions
- Coincided with early significant research efforts, including:
  - Allowable stress on piles
  - Group behavior
- Static analysis really didn't exist in practice to date, and structural engineers performed most foundation design

SIGNIFICANT IMPACTS ON GEOTECHNICAL PRACTICE

- Dynamic Testing for Driven Piles
- Introduction of MSE to the United States
- Widespread Use of Ground Improvement Techniques
- Guidance Manual and Training Development
- Geotechnical Monitoring and Risk Management
- Impact of Geosynthetics
- Evolution of Design Platforms
- Software Development
- Innovative Contracting for Project Delivery

FHWA GEOTECHNICAL PROGRAM

FHWA STRATEGIC PLANNING

Strategic Planning/Roadmap

- In alignment with Agency Strategic Planning
- Roadmap informs the annual Geotechnical Spending Plan for FHWA
- Roadmap is reviewed and updated on an annual basis
- Roadmap is informed through feedback from State DOTs, FHWA Division offices, industry, and academia

GEOTECHNICAL FOCUS AREAS

- Extreme Events, Geohazards and Sustainable Geotechnics
- Performance Management
- Reliability Based Design and Construction
- Advanced Geotechnical Modeling
- Alternative Delivery Methods
- Design and Construction Optimization
- Site Characterization
- Quality Assurance

SELECT FUNDED TOPICS

- Geotechnical Asset/Performance Management
- Geohazards
- Calibration at the Service Limit State
- DIGGS/Communication of Geotechnical Data
- Probabilistic Design – Geotechnical Site Characterization
- Scour Evaluation
- Corrosion of Buried Steel Elements
- Design of Large Diameter Open Ended Piles

GEOTECHNICAL POLICY SUPPORT

- FHWA Geotechnical Engineering Circulars (GECs).
  - Recently published:
    - GEC 5 Geotechnical Site Characterization (FHWA-NHI-16-072)
    - GEC 7 Soil Nail Walls (FHWA-NHI-14-007)
    - GEC 12 Design and Construction of Driven Piles (FHWA-NHI-16-009, FHWA-NHI-16-010, and FHWA-NHI-16-069)
    - GEC 13 Ground Modification Methods (FHWA-NHI-16-027 and FHWA-NHI-16-028)
    - GEC 14 Assuring Quality in Geotechnical Reporting Documents (FHWA-HIF-17-016)
  - In development:
    - GEC 9 Design Lateral Load on Deep Foundations (100% complete)
    - GEC 10 Drilled Shafts (100% complete)

RECENTLY PUBLISHED RESEARCH

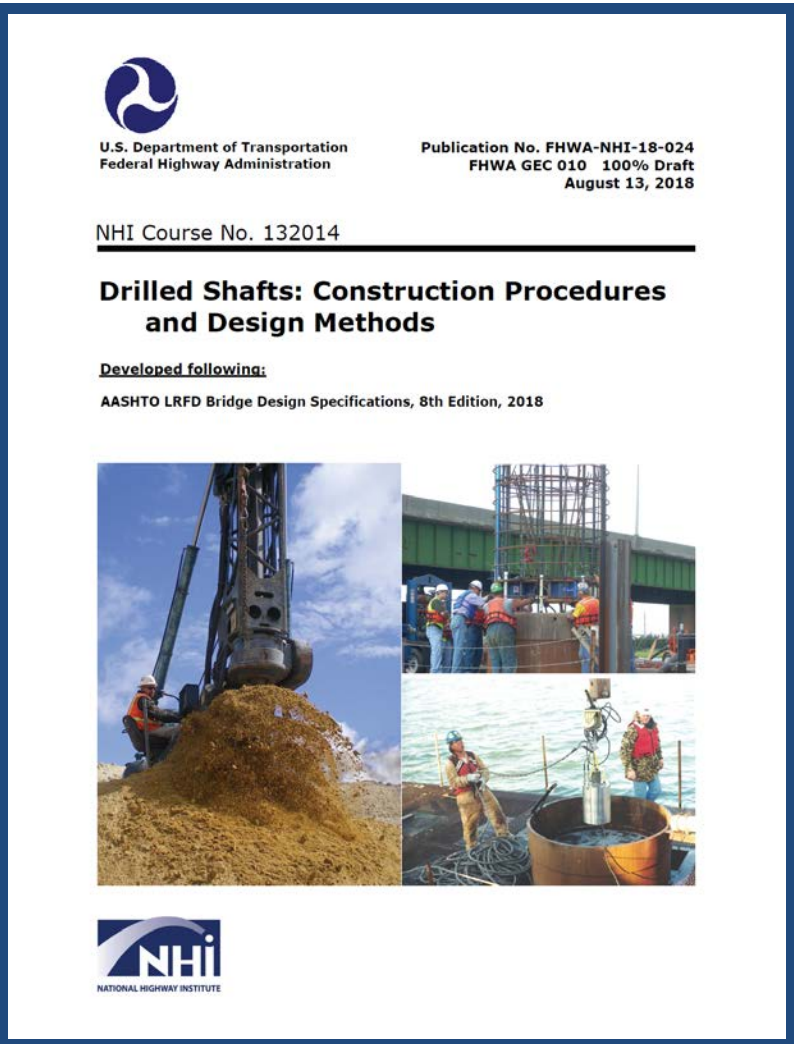
- Evaluation and Guidance Development for Post-Grouted Drilled Shafts for Highways (FHWA-HIF-017-024)
- Protocols for the Assessment and Repair of Bridge Foundations (FHWA-HIF-17-044)
- Selection of Spread Footings on Soils to Support Highway Bridge Structures (FHWA-RC/TD-10-001)
- I.D.E.A Protocol and Electronic Tracking System
- Liquefaction-Induced Downdrag on Continuous Flight Auger Piles from Full-Scale Tests Using Blast Liquefaction (FHWA-HRT-17-060)
- Deployment of the Geosynthetic Reinforced Soil Integrated Bridge System from 2011 to 2017 (FHWA-HIF-17-043)
- Limit Equilibrium Design Framework for MSE Structures with Extensible Reinforcement (FHWA-HIF-17-004)

LOAD TESTING AND THE EMERGENCE OF LARGE DIAMETER FOUNDATION ELEMENTS

LOAD TESTING AND THE EMERGENCE OF LARGE DIAMETER FOUNDATION ELEMENTS

- Over two decades, evolution of foundation construction has been significant
- Load magnitude and general demand per element is greatly increasing
- Demand on geotechnical and structural materials increasing
- As a result, nominal dimensions are increasing rapidly to accommodate more complex loading conditions
- This is made possible by advances in load testing and in construction equipment

GEC-10 DRILLED SHAFTS (UPDATE 100% COMPLETE)



U.S. Department of Transportation
Federal Highway Administration

Publication No. FHWA-NHI-18-024
FHWA GEC 010 100% Draft
August 13, 2018

NHI Course No. 132014

Drilled Shafts: Construction Procedures and Design Methods

Developed following:

AASHTO LRFD Bridge Design Specifications, 8th Edition, 2018

NATIONAL HIGHWAY INSTITUTE

FHWA DESIGN AND CONSTRUCTION ISSUES

Evolution of drilled shaft construction over 20 years has led to:

- Much larger shaft diameters
- Much deeper shafts
- New means and methods for installation
- Much longer concrete pours
- Much larger load carrying capacity
- Efforts to optimize load transfer

USE OF PROTOTYPE SHAFTS

Current guidance allows for the use of prototype shafts for load tests with following stipulations:

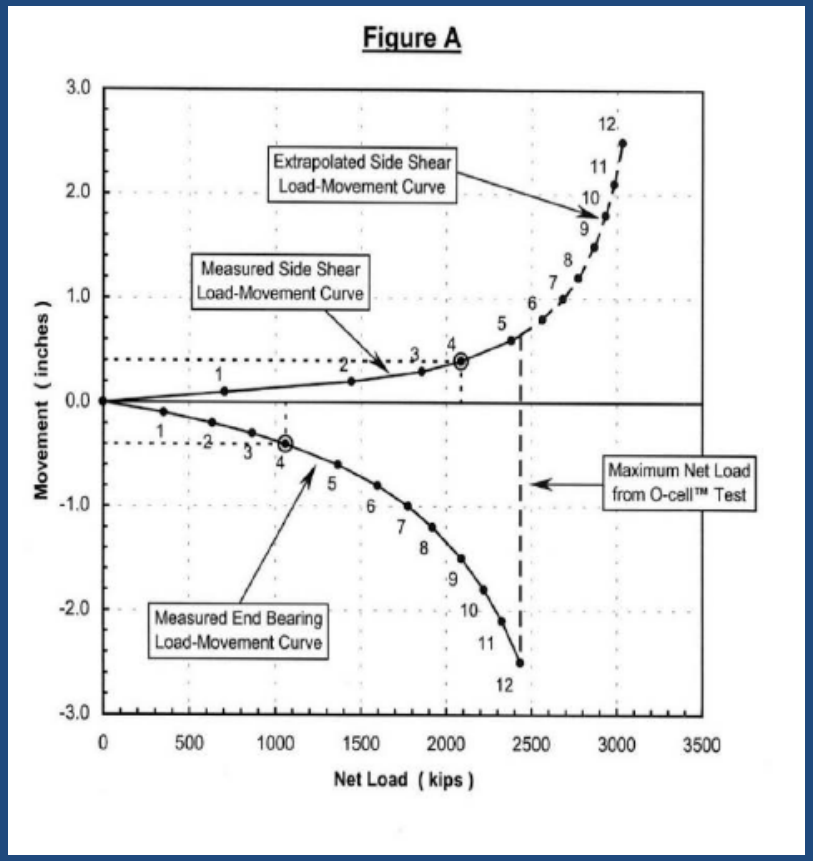
- Should be at least ½ the diameter of the production shaft
- Should be a minimum of 30 inches
- Should be constructed using similar tools and construction techniques
- If exposure time is of importance, the test should replicate the exposure time of the full-size shaft
- Displacements at which unit values of side and base resistance are mobilized should be interpreted with respect to diameter

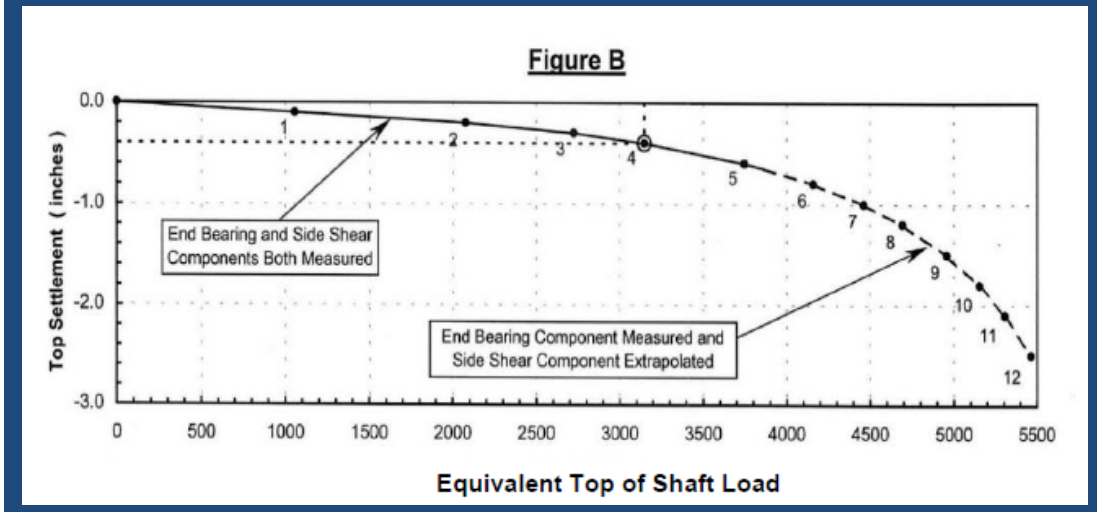
NEW FHWA GUIDANCE ON PROTOTYPE SHAFTS

Design phase load tests will be differentiated from construction phase load tests:

- Design phase tests used for determination of design parameters remain unchanged.
- Construction phase tests **must** be the same as largest production shaft on the project to replicate:
  - Construction means and methods
  - Time for concrete pour
- Purpose is to assure that contractor can construct project in accordance with requirements to justify higher resistance factor

INTERPRETATION OF BI-DIRECTIONAL LOAD TESTS





ADDITIONAL GUIDANCE ISSUES

- Full-depth steel requirements
  - Guidance currently requires steel to be extended a minimum of 10 feet below the plane where soil provides fixity
  - This is not only subjective currently, but does not allow for acceptance testing
  - Language is being adjusted to require minimum amount of steel for the full length of the shaft
- Concrete pour requirements
  - Guidance is being re-written to require a minimum amount of concrete on site prior to beginning a pour.

ADDITIONAL FHWA RESEARCH

FHWA is currently leading a research effort in High Performance Concrete to address issues specific to mass pours in geotechnical applications:

Focus on understanding factors contributing to performance of concrete including:

- Thermal Issues
- Bleed and Segregation Issues

Effort is underway using numerical models and laboratory scale testing

POST-GROUTING OF DRILLED SHAFTS FOR HIGHWAYS (FHWA-HIF-17-024)

Evaluation and Guidance Development for Post-Grouted Drilled Shafts for Highways

March 2017

U.S.Department of Transportation
Federal Highway Administration

Sponsored by
Federal Highway Administration
Office of Infrastructure
FHWA-HIF-17-024

FHWA RESEARCH OBJECTIVES

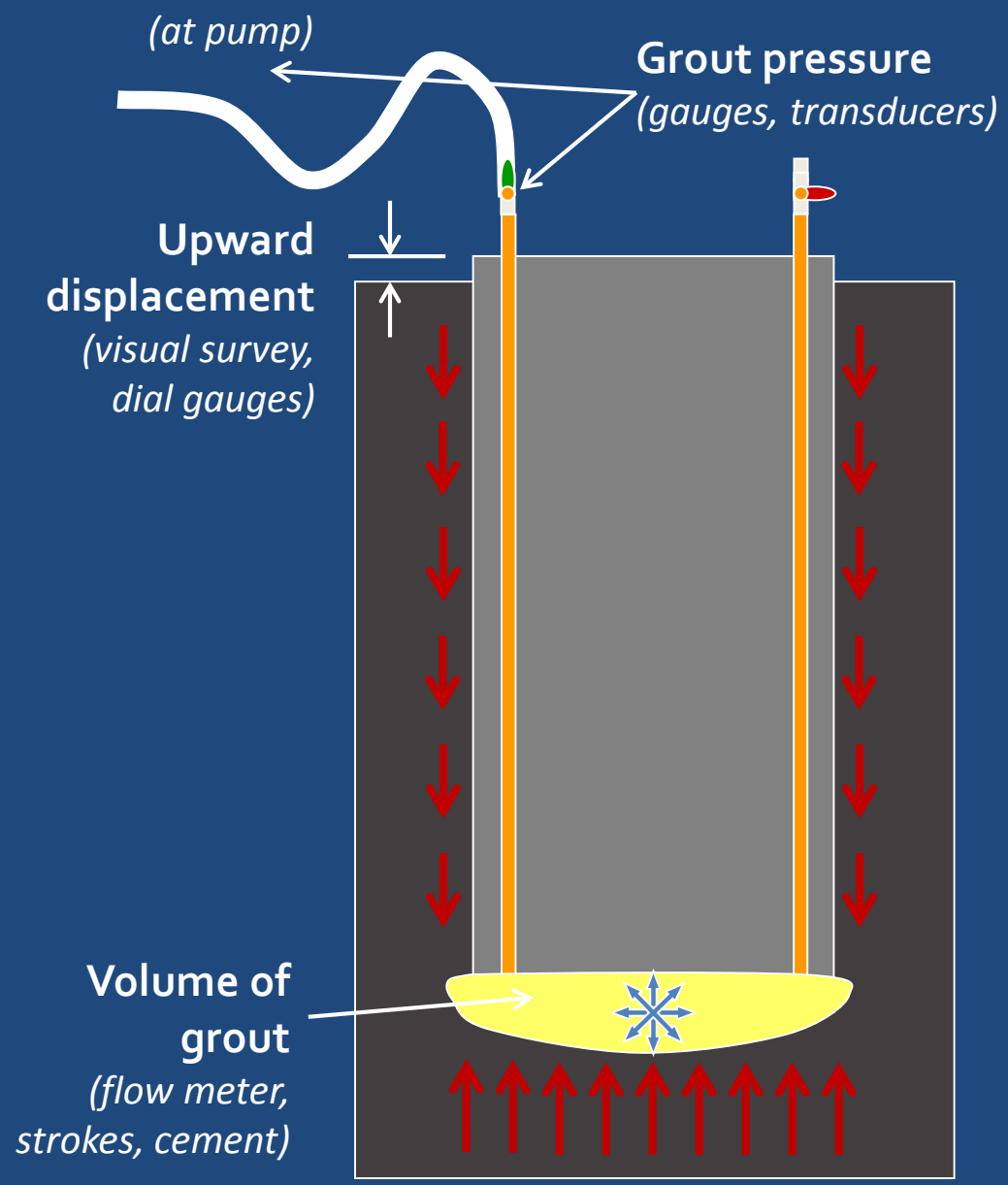
- Bound use of post-grouting for current state of knowledge
- Quantify improvement mechanism(s) for post-grouting
- Develop design methodology(ies) for appropriate use
- Provide method(s) for verification

ULTIMATE GOALS

- Recommendations for implementation into PGDS practice
  - Design Methods
  - Construction and Post-grouting operations
  - QC/QA
  - Specifications
  - Contracting practices in the U.S.
  - Economic Benefits

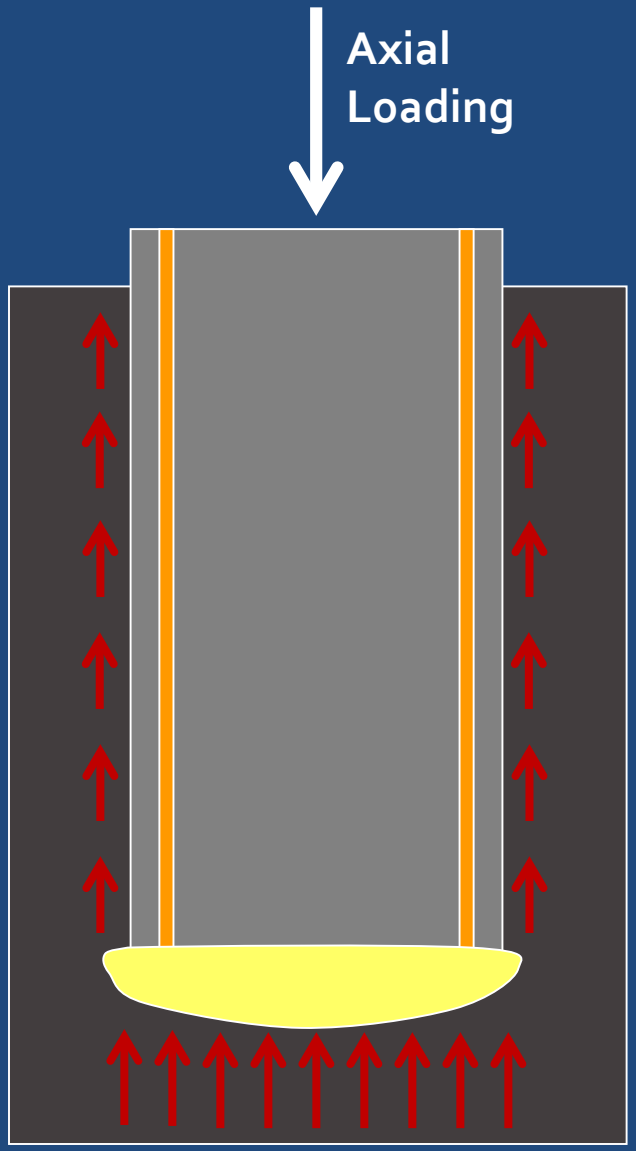
PGDS GENERALIZED PROCESS

- Injection of grout continued until criteria is achieved
  - Pressure
  - Displacement
  - Volume (net)
  - Strain (maybe)
- Bi-directional force induced at tip mobilizes
  - Negative side resistance
  - Positive tip resistance

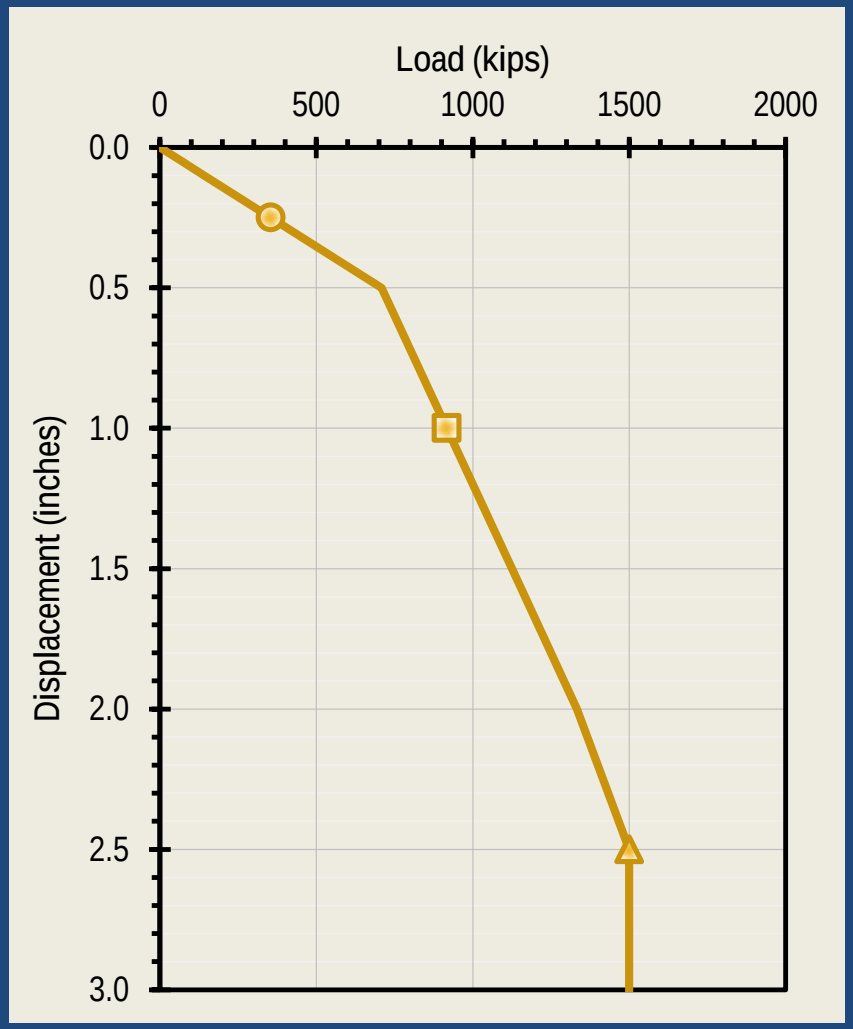


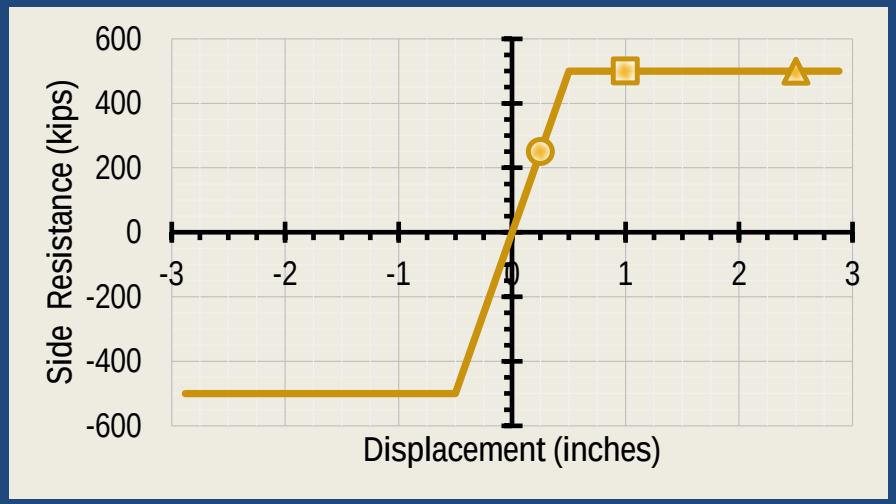
PGDS GENERALIZED PROCESS

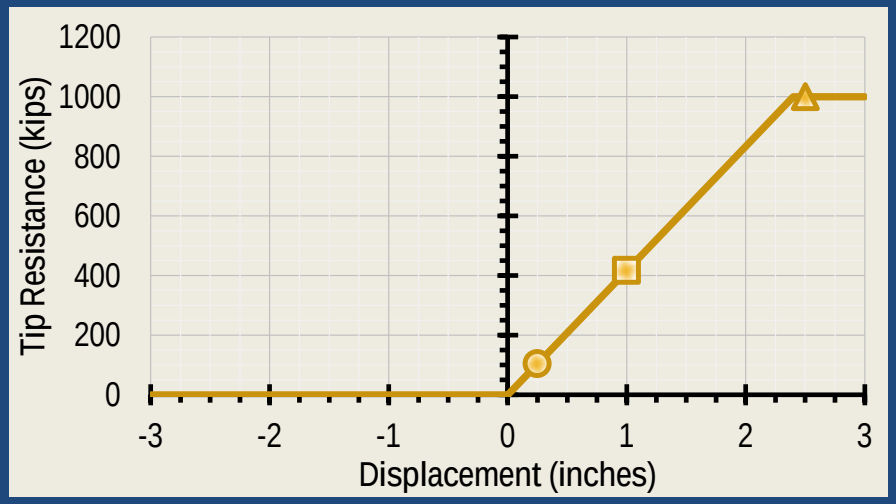
- Following post-grouting, base resistance has been mobilized (or pre-loaded)
- Also some ground improvement (densification, permeation)
- Reversal of side resistance to resist axial loading
  - Positive side resistance
  - Positive tip resistance



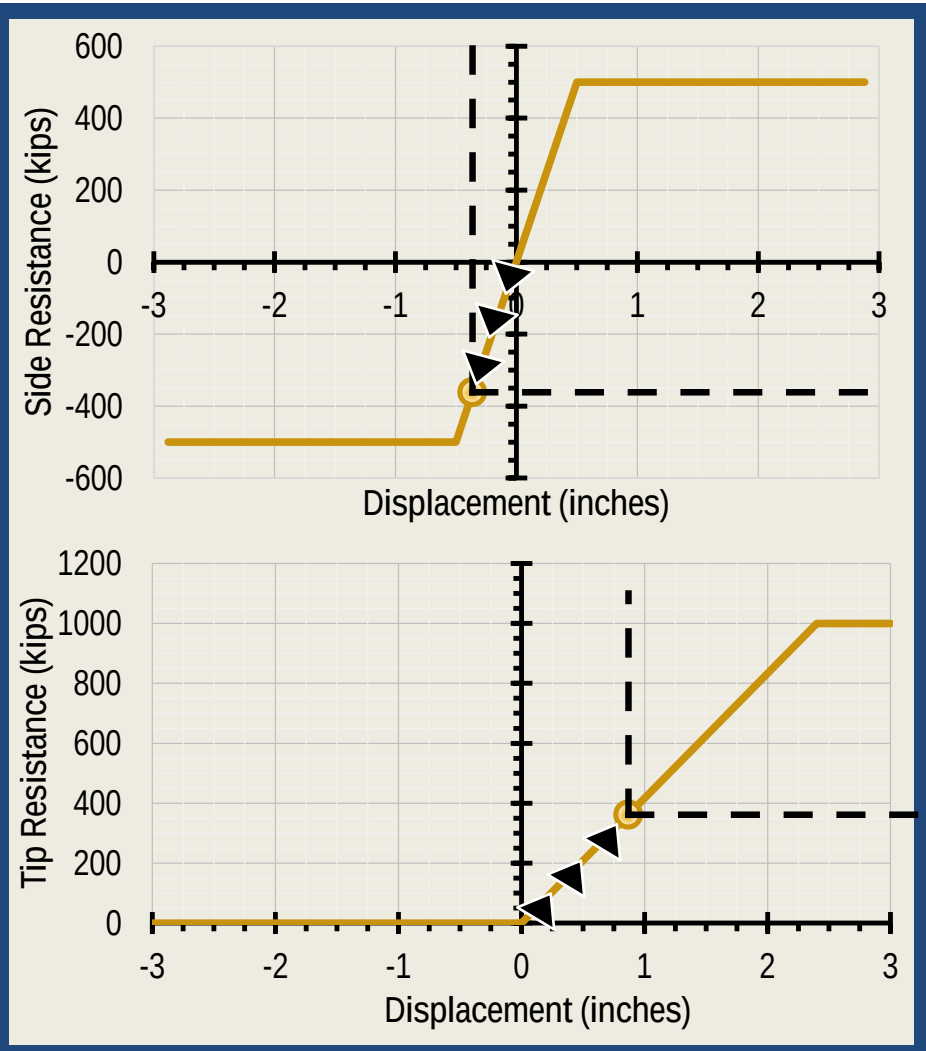
TOP-DOWN LOADING – CONVENTIONAL SHAFTS



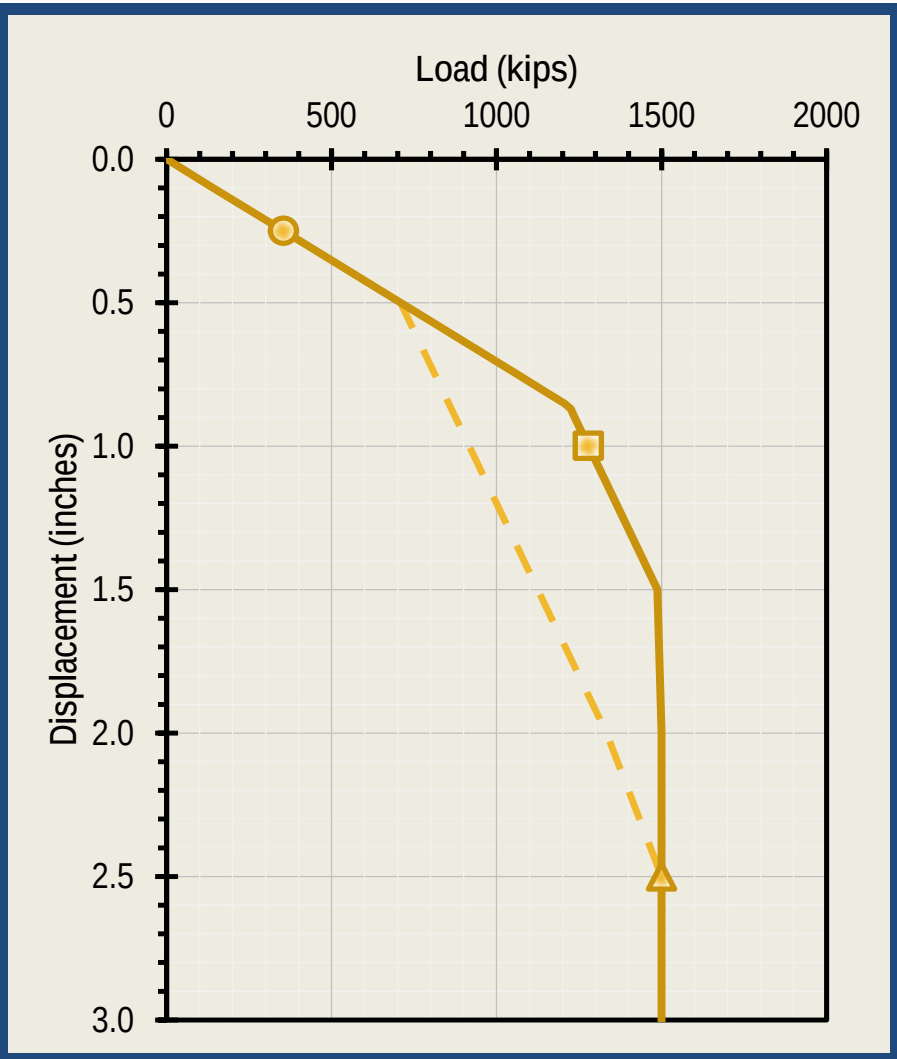


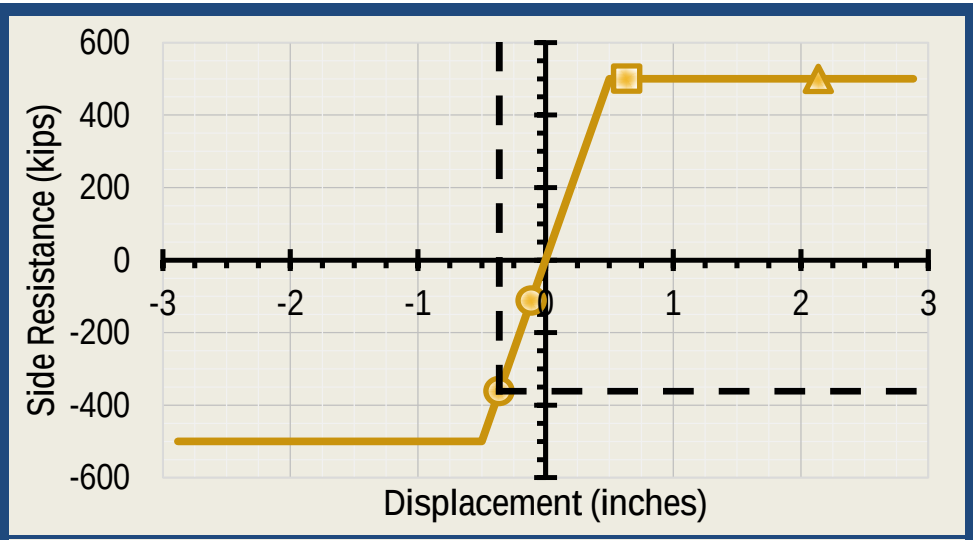


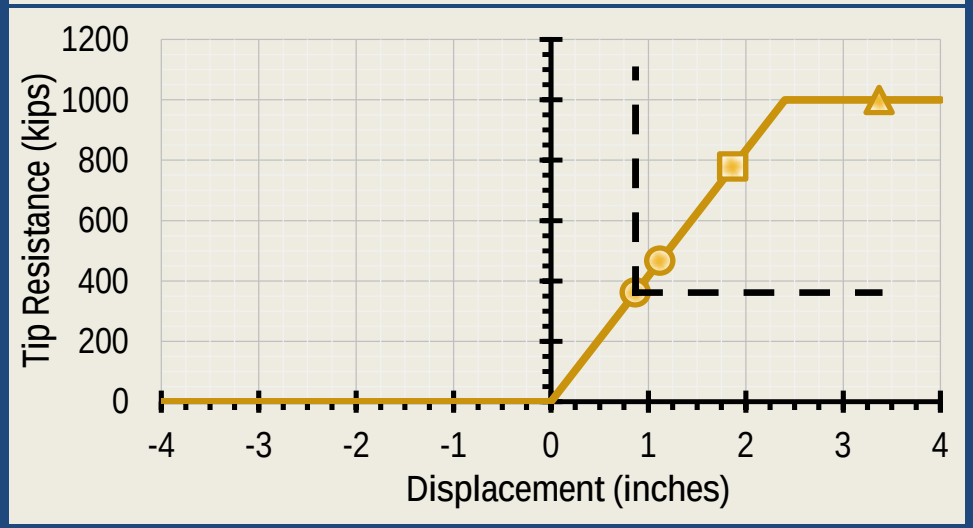
LOADING DUE TO POST-GROUTING



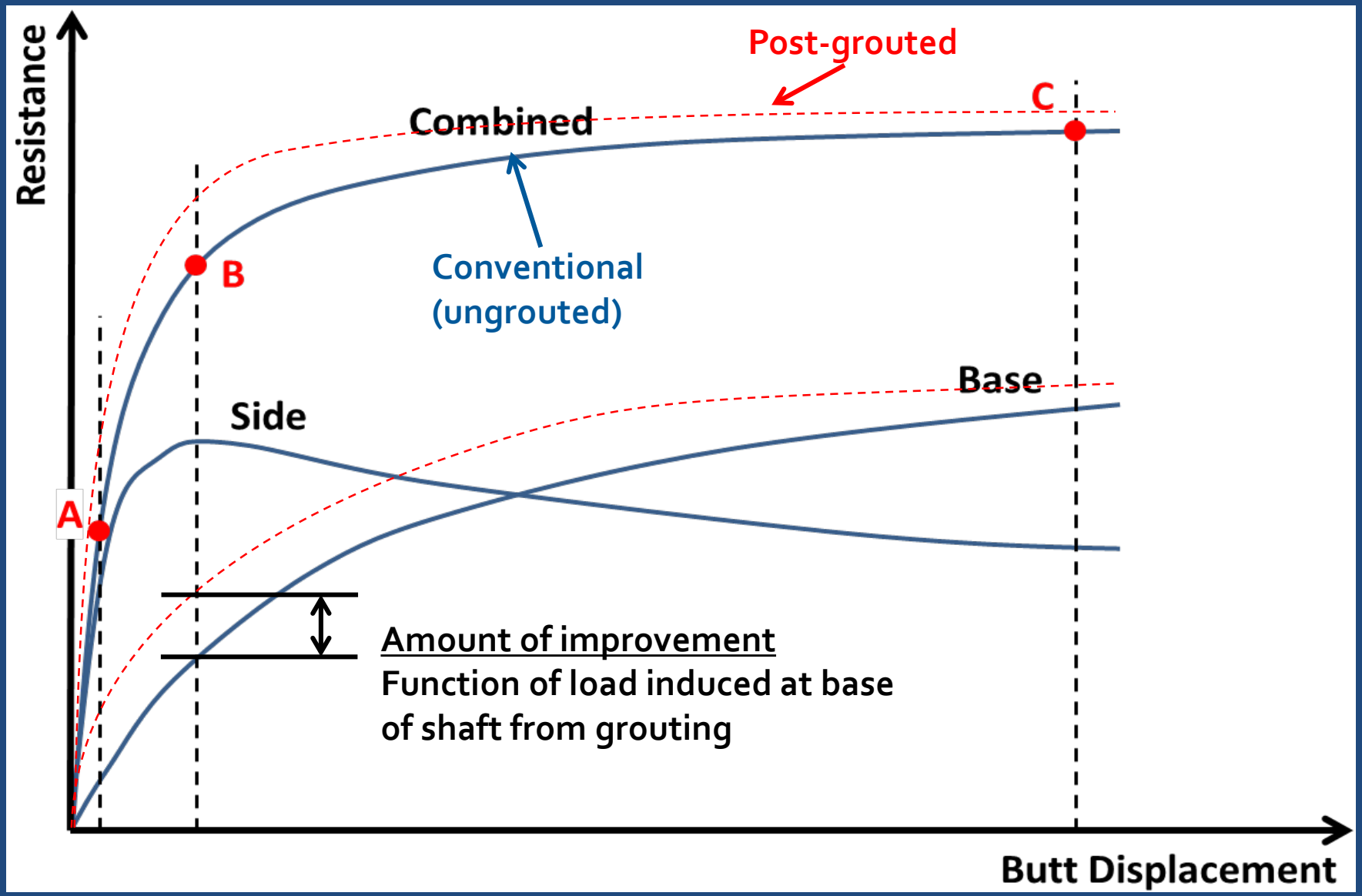
TOP-DOWN LOADING - PGDS







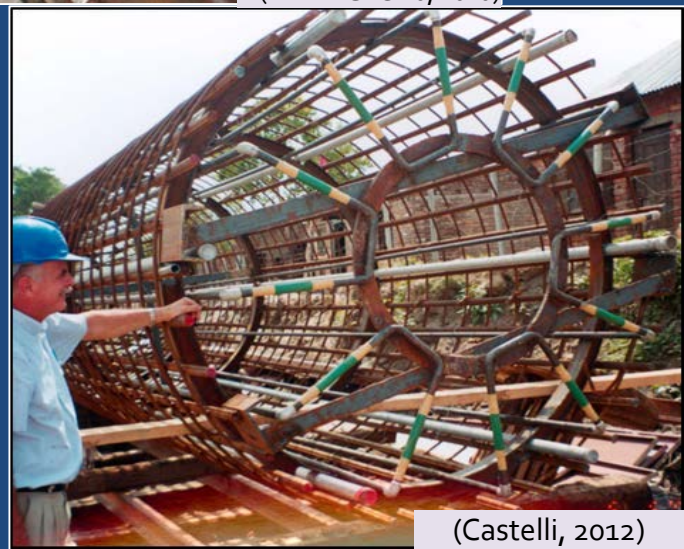
LOAD TRANSFER – POST-GROUTED SHAFTS



GROUT DISTRIBUTION SYSTEMS - OPEN TYPE

- Sleeve-port (tube-à-manchette, TAM) distribution system
- Redundant system (multiple, independent U-tubes)
- Grout does not act across entire base area at same time
- Can use NDT tubes
- Well-suited for all shaft sizes, esp. larger diameter shafts
- Well-suited for phase grouting

(FHWA GEC-10, 2010)



(Castelli, 2012)

GROUT DISTRIBUTION SYSTEMS - CLOSED TYPE

- Flat-jack distribution system
- Grout acts across area of plate at same time
- Good for smaller diameter shafts (≤ 6 ft in diameter)
- Requires separate grout tubes - cannot use NDT tubes
- No redundancy in system
- Not conducive to phase grouting

(Applied Foundation Testing)

DESIGN METHODS

- Tip Capacity Multiplier Approach
  (Mullins et al, 2006)
- Component Multiplier Approach
  (Hu et al, 2001; Xiao et al, 2009; Guoliang et al, 2012)
- Axial Capacity Multiplier Approach
  (Ruiz, 2005; Ruiz et al, 2005)
- Truncated Cone Approach
  (Liu and Zhang, 2011)
- Simplified Approach
  (McVay, 2010)

ADDITIONAL RESEARCH NEEDS

- Acceptance requirements
  - Metrics verifying improvements
  - Methods for measurement
- Design methodology

RELATED EXTERNAL DEEP FOUNDATIONS RESEARCH

- Quality Assurance of Post-Grouted Drilled Shaft Foundations
  - University of Missouri
- Thermal Integrity Testing (TIP) for Drilled Shafts
  - University of Missouri/University of Illinois
- Interpretation of Crosshole Sonic Logging (CSL) for Drilled Shafts
  - Deep Foundations Institute
- Use of High Strength Steel in Bored Piles
  - Oregon State University

QUESTIONS

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