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Evaluation of FHWA Pile Design Methods Against the FHWA Deep Foundation Load Test Database (v.2)

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Introduction

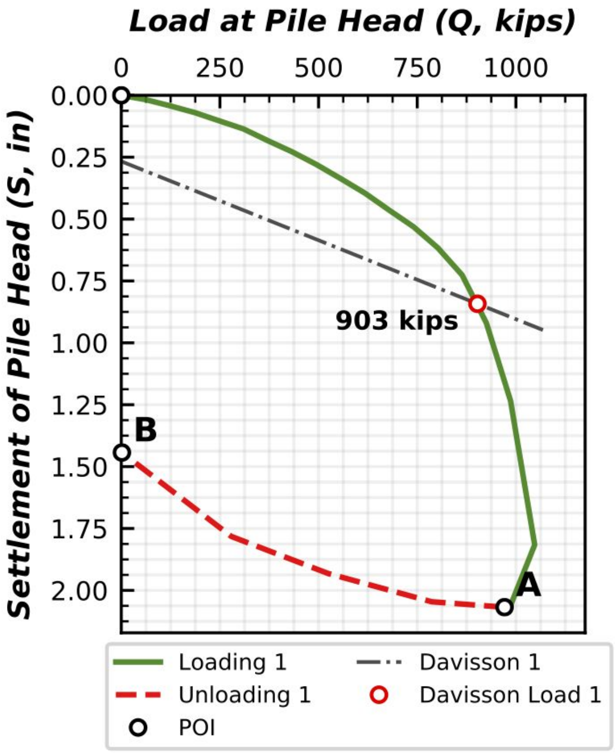
- Large uncertainty in pile capacities in geology does not permit bearing on rock
  - Driven pile design methods are mainly empirical or semi--empirical
  - Pile load tests are expensive and time--consuming
  - Few publicly available databases

- Comparison between calculated and interpreted capacities for large data sets provides insight of suitability of use of current design methods under varying pile and soil conditions.
  - FHWA Database DFLTD v.2 (Petek et al. 2016)
  - FHWA Design Method (Hanigan et al. 2006)

- **Scope:** Impact -driven, un-tapered, steel and concrete piles, loaded in compression, using a static load test.
  - Q_c/Q_m capacity in sands, clays, and mixed soils.
  - Effect of pile type, pile length, and the pile diameter on the Q_c/Q_m is explored.

Q_m: Interpreted (aka. Measured) Capacity

- Interpreted pile capacity calculations occur using load--settlement curve data generated during an axial static load test of a driven pile.
- Several methods can be used to interpret the capacity of a static load test
- FHWA adopts Davisson's (1972) Criterion
- **Batch processing, in Python, produced hundreds of interpreted pile capacities**



Q_c: Predicted (aka. Calculated) Capacity

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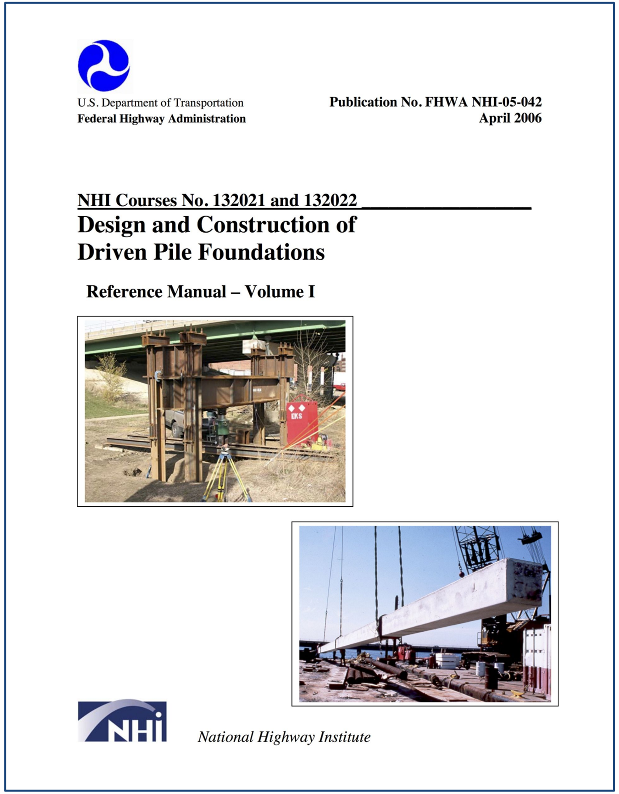
- Dozens of Methods available to calculate the static axial capacity of piles
- FHWA Driven Pile Foundation Manual adopts two methods
  - Nordlund for Cohesionless Soils
  - Tomlinson for Cohesive soils
- **Batch processing, in Python, produced hundreds of calculated capacities.**
- FHWA suggests some approximations to bridge missing data
  - Bowles 1977 (Caltrans 2004)


U.S. Department of Transportation
Federal Highway Administration

Publication No. FHWA NHI-05-042
April 2006

NHI Courses No. 132021 and 132022
Design and Construction of
Driven Pile Foundations

Reference Manual – Volume I

National Highway Institute

Approximations

- When available, angle of friction *φ* and unit weight *γ* were used as stored.
- When not available, *φ* and *γ* where approximated from SPT blow counts as detailed in the FHWA manual (after Bowles, 1977) and additional guidance from CALTRANS 2004

Corrected SPT-N	0 to 4			4 to 10			10 to 30			30 to 50			50+		
Ranges	min	avg	max	min	avg	max	min	avg	max	min	avg	max	min	avg	max
Approximate φ (degrees)‡	25	27.5	30	27	29.5	32	30	32.5	35	35	37.5	40	38	40.5	43
Approximate γ (lb/ft^3)§	70	85	100	90	102.5	115	110	120	130	110	125	140	130	140	150

Uncorrected SPT-N	0 to 2	2 to 4	4 to 8	8 to 16	16 to 32	32+
Approximate q_u (ksf)	0 - 0.5	0.5 - 1.0	1.0 - 2.0	2.0 - 4.0	4.0 - 8.0	8.0+
Approximate γ (lb/ft^3)§	100 - 120	100 - 120	110 - 130	120 - 140	120 - 140	120 - 140

‡ Caltrans guidance for soil friction φ: *SW: use average φ + 1°, SC: use φ, ML use minimum φ + 0.5° , GM and SP use average φ, GC: use average φ -1°, GW: use maximum φ*

§Caltrans guidance for moist unit weight γ: *SW, GW: use maximum γ, SP, GP: use average γ, ML, SC, SM: use minimum γ*

Empirical values for φ, qu, and γ based on SPT Blow Counts (after Bowles, 1977 and CALTRANS 2004)

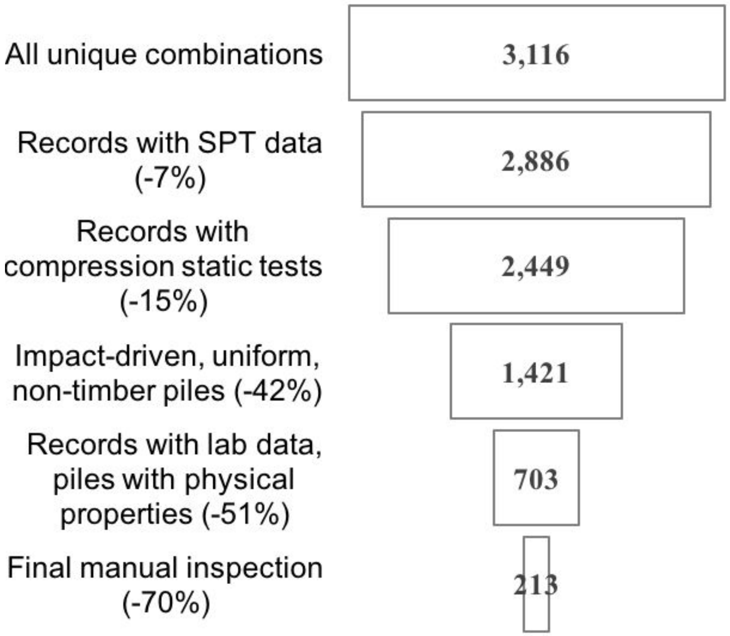
Main US Pile Load Test Databases

- **Nordlund** developed his method of calculating bearing capacity of piles in sand from a database of 41 load tests from 8 different sites
- **Tomlinson** employed a database of 56 piles to develop his popular α-method
- **Olson** (1983) organized first large modern database which led to the development of the popular API RP2A method for capacity of piles in sand, and other methods in clay
- **Briaud** (1987) "Evaluation of API Method Using 98 Vertical Pile Load Tests."
- **Carl Ealy** led FHWA DFLTD (2000) updated by Petek et al in 2016 (**DFLTD v.2**)
- **State DOTs** (2000 to 2016) CALTRANS, Iowa (PILOT), Illinois, Florida, Louisiana (LAPLTD)

No uniformity, highly dissimilar, unstructured, semi-structured or structured databases with little to no data validation

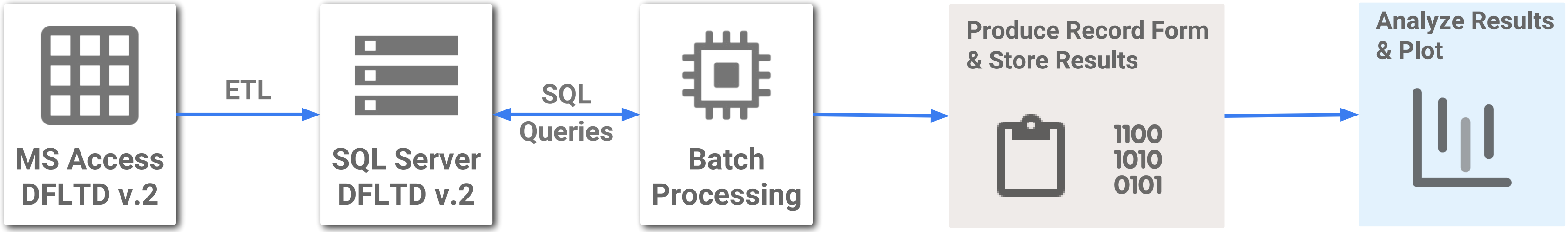
FHWA DFLTD v.2

- Petek et al
  - DFLTD v1 + 155 large diameter open-ended load tests
  - 3,116 unique project/exploration/foundation /test cases (916 projects with 1,798 load tests)
  - MS Access
- Converted to SQL by authors
- **213** records suitable for Nordlund/Tomilinson
  - Data completion
  - Static test results must allow capacity interpretation by the Davisson criterion



Process of filtering available test records

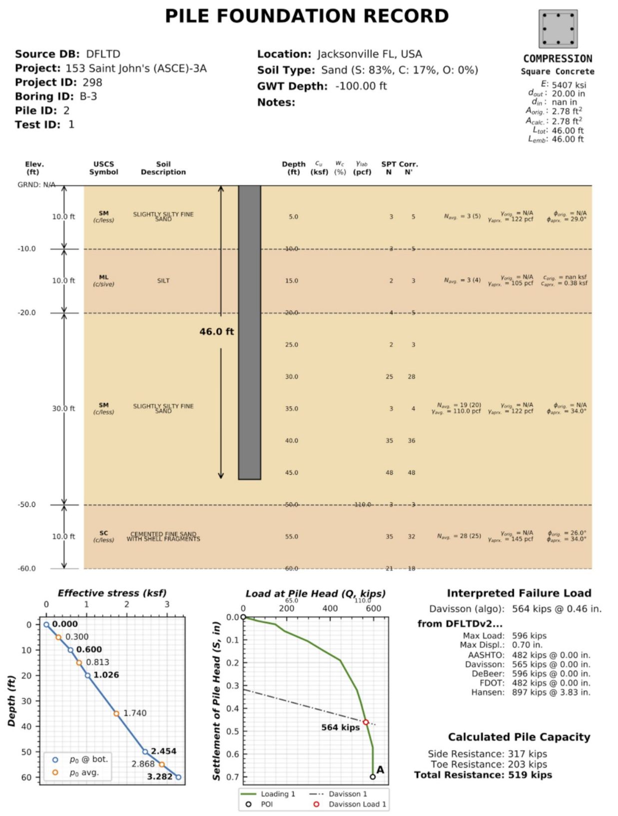
Analytical Procedure



ETL: Extract, Transform & Load

Pile Foundation Record Form

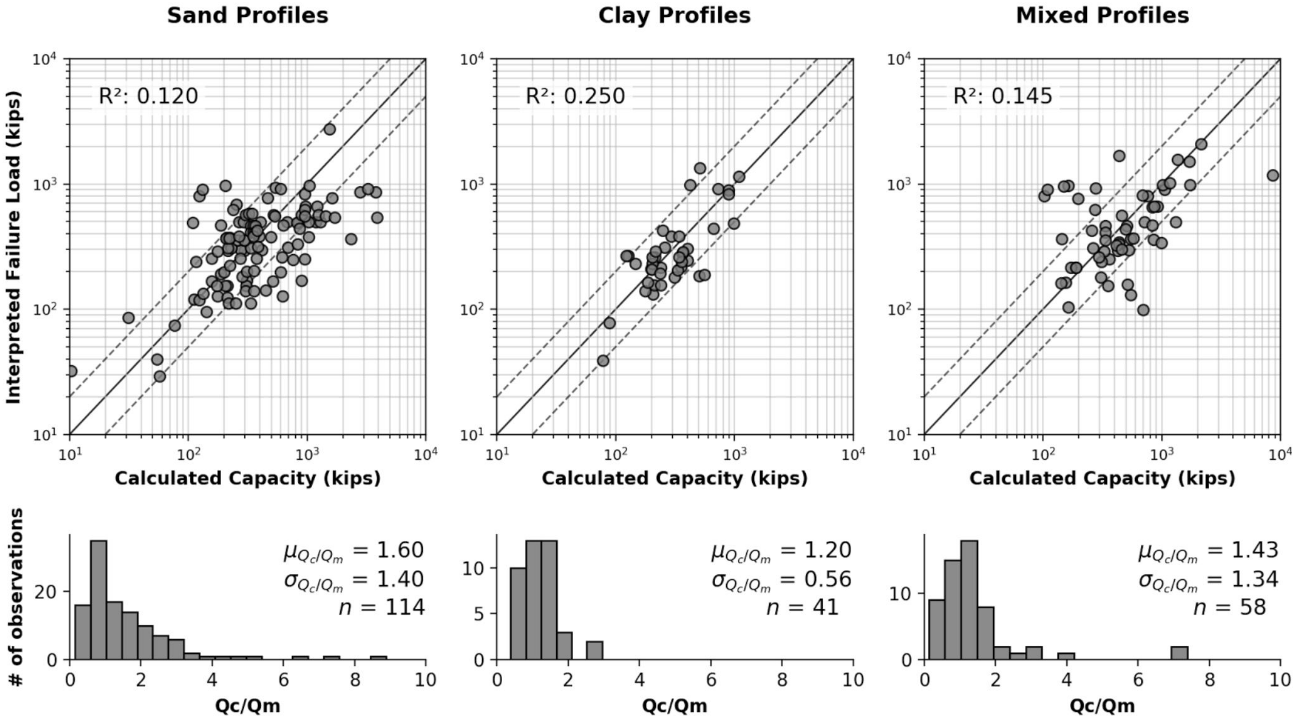
- A pile record form was auto generated for each of the 213 test record employed
  - Visual examination of each record
- Q_m was also auto calculated from the load/settlement curve
- Q_c was computed per FHWA, side and toe resistances presented separately
- The form visualizes all necessary information for the calculation of pile capacity, a marked improvement over DFLTD v.2 GUI



Example of auto--generated pile record form

Qc/Qm in Sand, Clay and Mixed Profiles

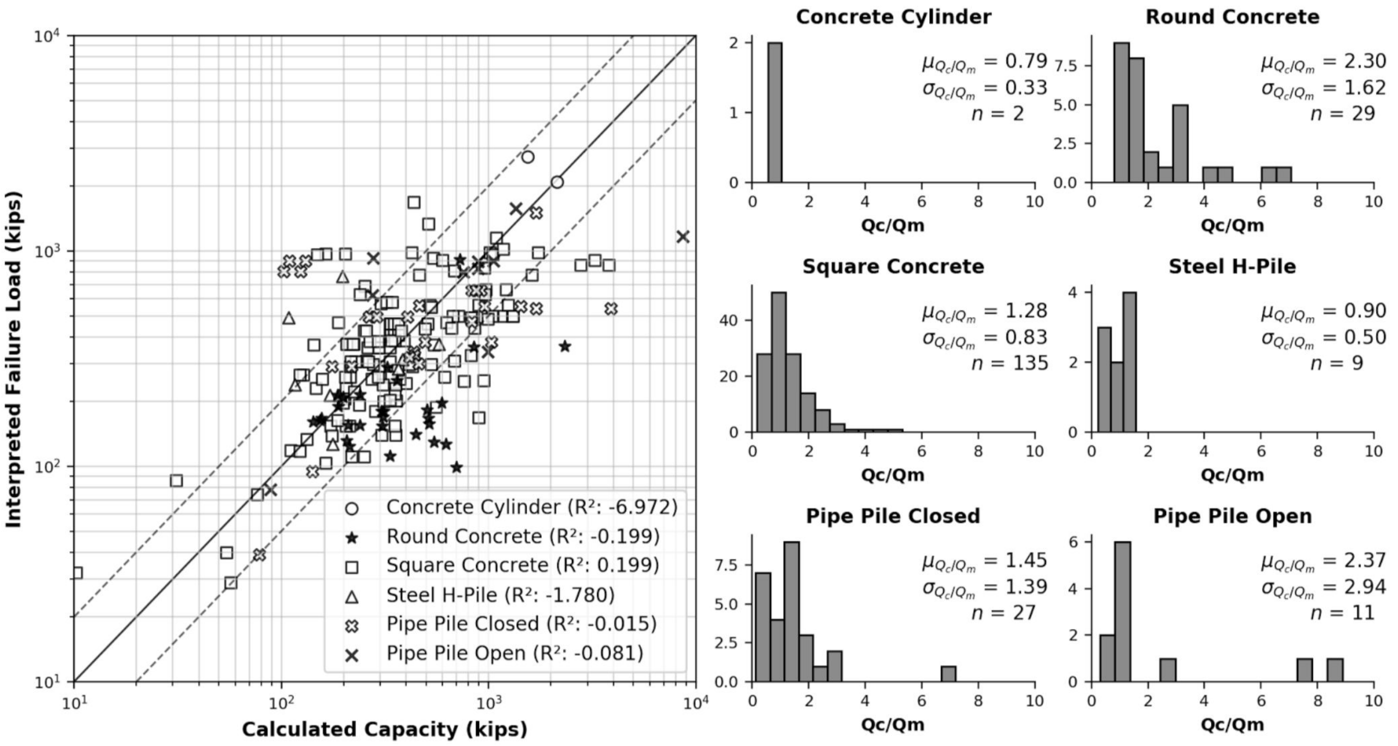
- Better performance in clay than in sand.
- Variation in Qc-Sand could be related to the correlation used for soil friction angle with SPT.



Distribution of calculated (Q_c) v. interpreted (Q_m) capacity for all soil profiles

Performance Based on Pile Type

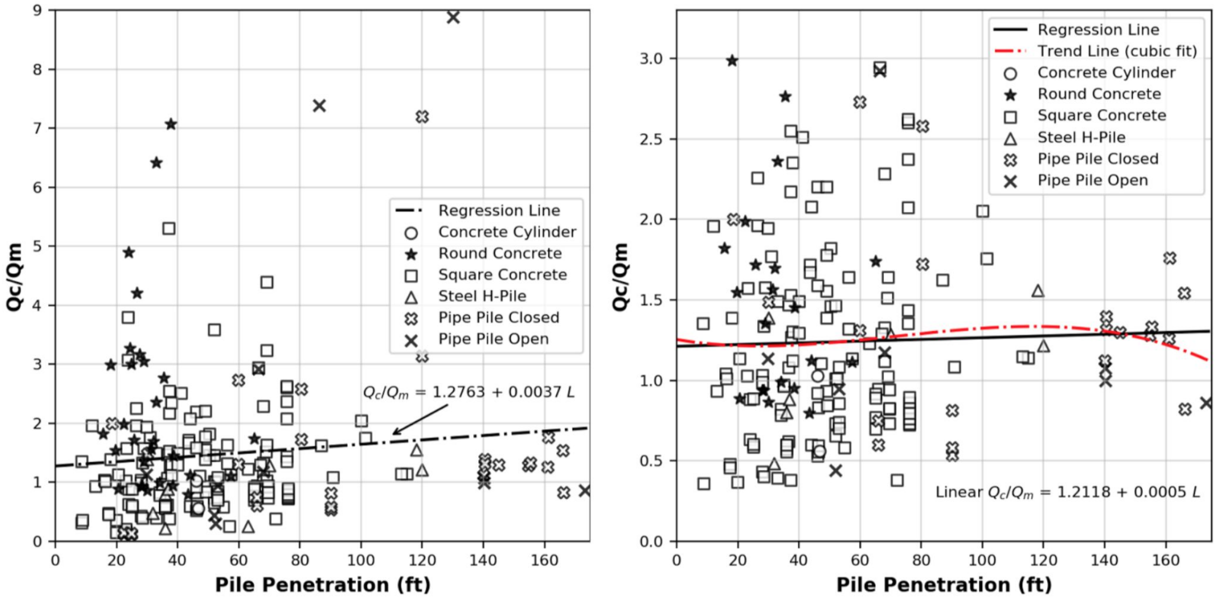
- Difficult to generalize.
- Round concrete piles exhibited the highest average.
- The effect of pile shape on calculated capacity is a point for future exploration.



Distribution of calculated (Q_c) v. interpreted (Q_m) capacity for six pile types

Effect of Pile Penetration Length

- Regression suggests that capacity can be overestimated by 100% for a 250 ft long pile (**LHS**)
- Length effect virtually disappears for piles having $0.33 < Q_c/Q_m < 3$ (**RHS**, 85% of total)
- Fewer than 20 tests with lengths > 100 ft are available, having $0.33 < Qc/Qm < 3$



Effect of Pile Penetration Length on Q_c/Q_m for all pile types. (LHS: All tests. RHS: Outliers removed)

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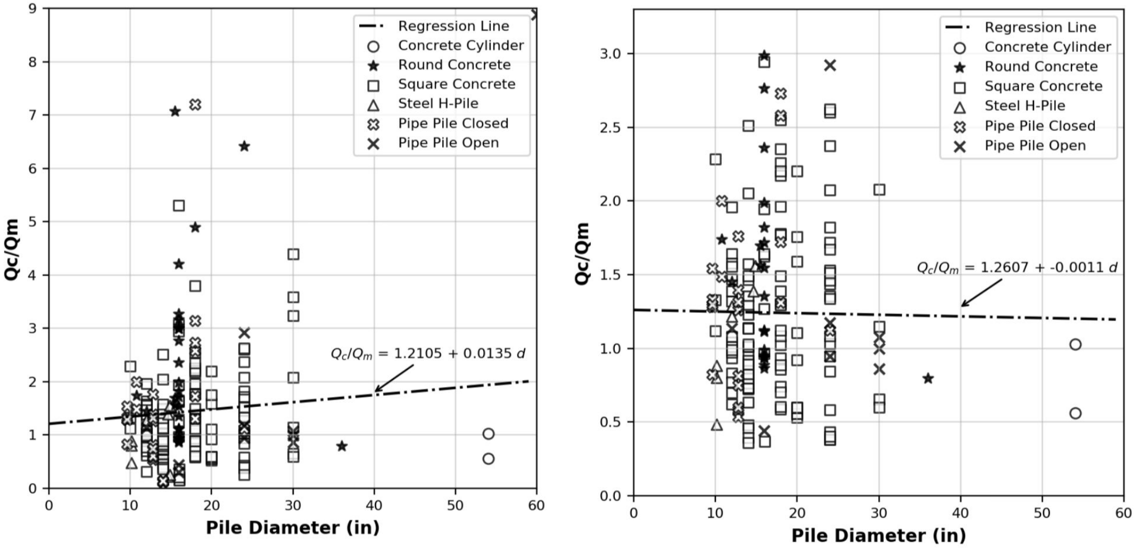
Effect of Pile Diameter

- Capacity can be overestimated by 15% for each additional 12 inch increase in pile diameter (**LHS**)
- Diameter effect reverses for the 183 piles (85% of total) having $0.33 < Q_c/Q_m < 3$ (**RHS**)
- Causes for concern
  - Few large diameter tests
  - Data quality issues



Effect of Pile Diameter on the ratio of calculated (Q_c) to interpreted (Q_m) capacity for six pile types. LHS: All tests. RHS: Outliers removed

Conclusions

- FHWA is a good method, but with high uncertainty
- The range in Q_c/Q_m was from 0.12 to 8.88.
  - Mean Q_c/Q_m = 1.6 in sand
  - Mean Q_c/Q_m= 1.2 is clay
  - Mean Q_c/Q_m= 1.43 in mixed profiles
- Significant scatter between Q_c and Q_m
  - 29% of cases are off by a factor of two or more
  - Data quality manifests itself in length and diameter effects that disappear when analyses are performed with $0.33 < Qc/Qm < 3$
- Method performs better in clay than in sand
  - Influence of approximate relationship between SPT and angle of friction φ and unit weight γ in sand

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Thank You

Questions?