Pile Setup

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Research Significance

- Evidence of pile setup (or increase of pile capacity as a function of time compared to End of Driving - EOD) is well documented in the literature.
- If accounted for, design will be more cost-effective resulting in a reduced number and/or length of piles.
- The mechanisms of pile setup are related to remolding of soil, increase of lateral soil stresses and dissipation of pore water pressure.
- Shortcomings of available methods to estimate pile setup:
  - Most do not incorporate soil properties
  - Require the determination of pile capacity at some time other than EOD (examples: 1 day after EOD, 14 days or long time)

Pile Setup Equations

Reference	Setup equation	Limitations
Pei and Wang (1986)	$\frac{R_t}{R_{EOD}} = 0.236[\log(t) + 1]\left(\frac{R_{max}}{R_{EOD}} - 1\right) + 1$	Purely empirical Site specific No soil property Unknown or difficult to determine R_{max}
Zhu (1988)	$\frac{R_{14}}{R_{EOD}} = 0.375S_t + 1$	Only predict pile resistance at 14th day No consolidation effect is considered
Skov and Denver (1988)	$\frac{R_t}{R_o} = A\log\left(\frac{t}{t_o}\right) + 1$	Require restrikes Wide range and non uniqueness of A
Svinkin and Skov (2000)	$\frac{R_t}{R_{EOD}} = B[\log(t) + 1] + 1$	Require restrikes B value has not been extensively quantified No clear relationship between B value and soil properties.
Karlsrud et al. (2005)	$\frac{R_t}{R_{100}} = A\log\left(\frac{t}{t_{100}}\right) + 1$; $A = 0.1 + 0.4\left(1 - \frac{PI}{50}\right)OCR^{-0.8}$	Assumed complete dissipation after 100 days is not true Not practical to use R_{100}

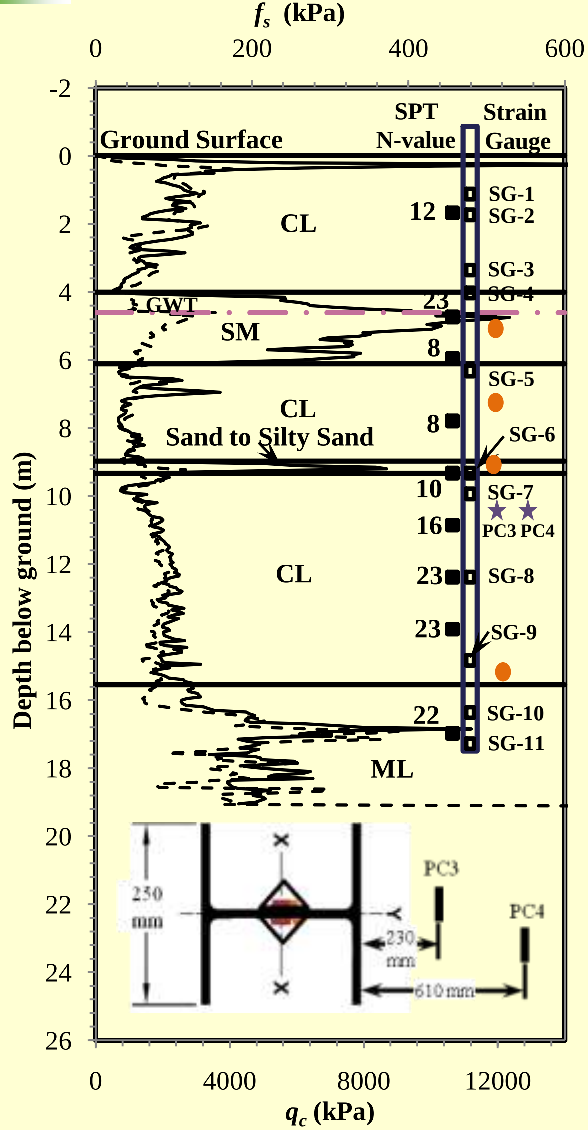
R_t: pile resistance at any time t after EOD; R_{EOD}: pile resistance at EOD; R_{max}: maximum pile resistance after completing soil consolidation; R_o: reference pile resistance; R_{14}: pile resistance at 14 days after EOD; R_{100}: pile resistance at 100 days after EOD; S_t: soil sensitivity; A: pile setup factor of 0.6 defined by Skov and Denver (1988); B: pile setup factor defined by Svinkin and Skov (2000); PI: plasticity index; and OCR: overconsolidation ratio.

Our Study

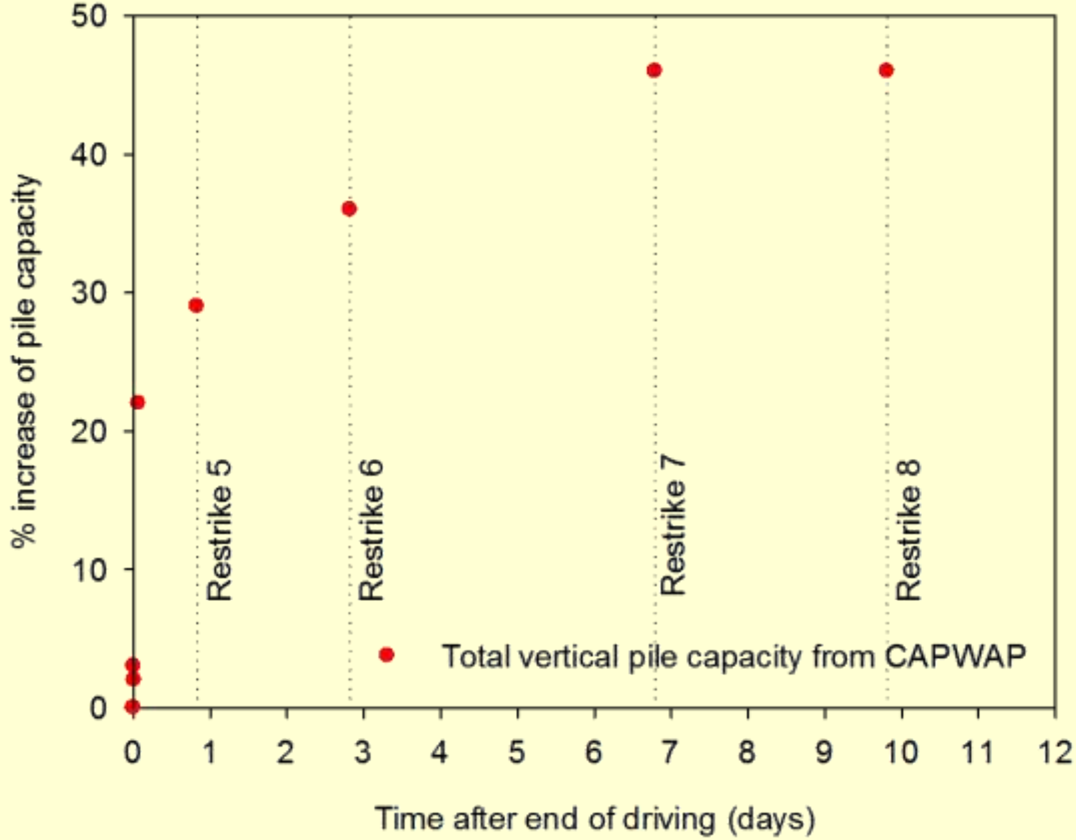
- Experimental study with full-scale tests (10 tests – five in clay)
  - Used Steel H-piles. Why?
  - Piles were instrumented with strain gauges
  - PDA and CAPWAP at different times
  - Push-in pressure cells to measure change of soil stresses and dissipation of pore water pressure as a function of time
  - Soil characterization using SPT, CPTu (with dissipation tests), laboratory tests including consolidation tests

- Analytical study to develop an equation to estimate pile setup
- How to incorporate pile setup in LRFD Approach

Experimental Study – Soil Properties



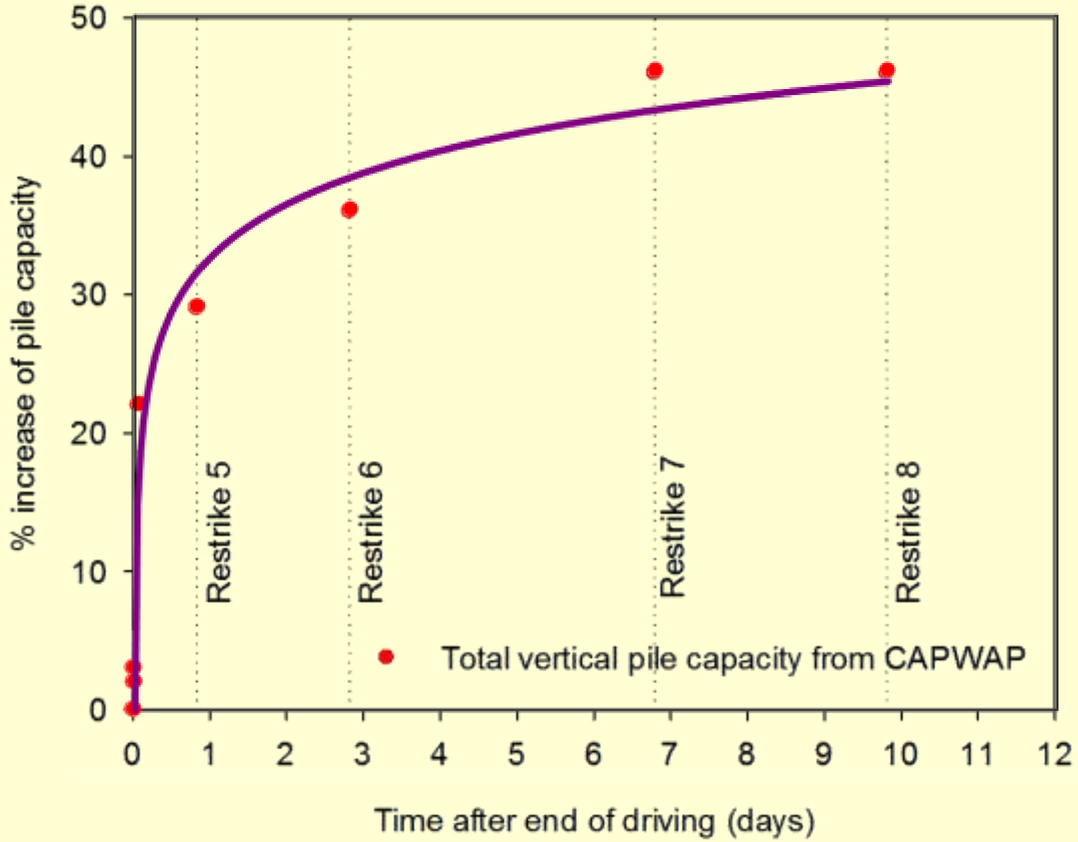
Experimental Study –Pile Capacity with time



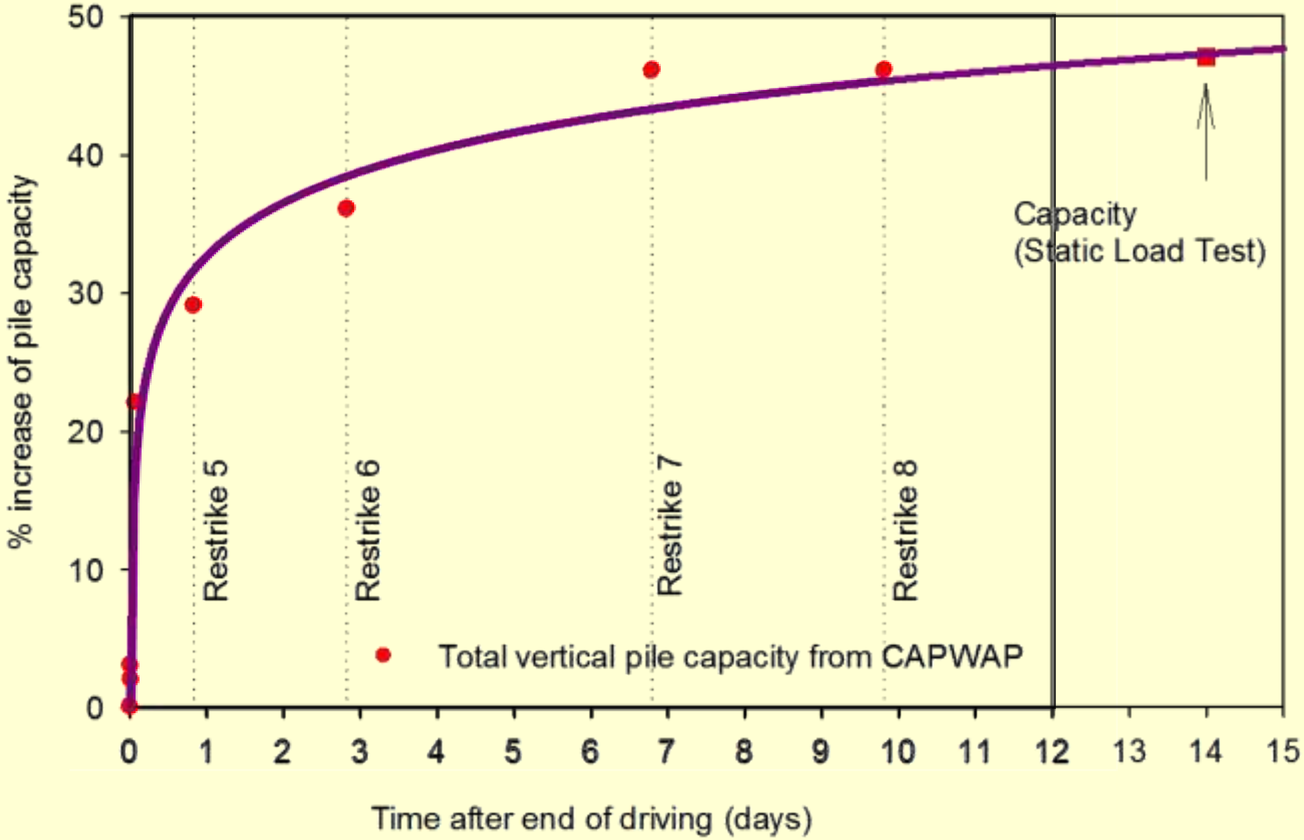
Driving & Re-strikes

PDA and CAPWAP

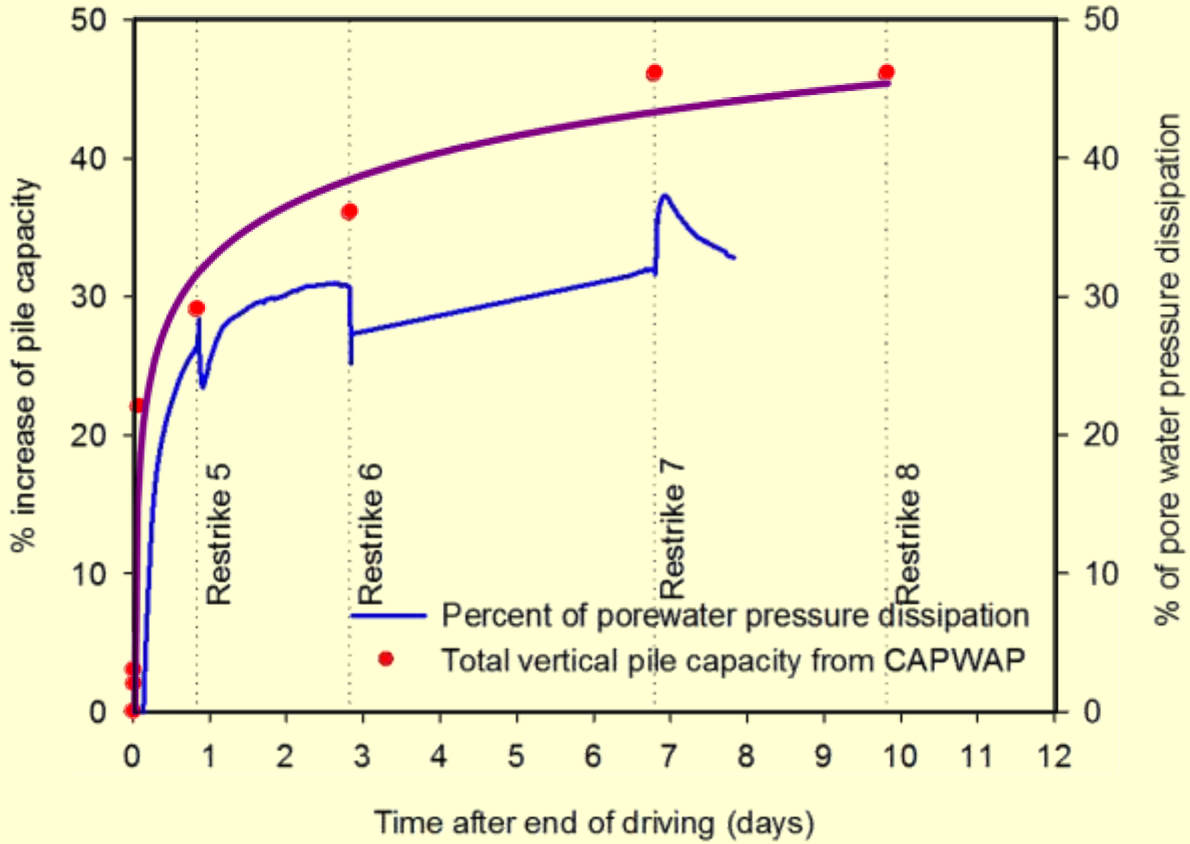
Experimental Study –Pile Capacity with time



Experimental Study –Pile Capacity with time



Experimental Study – Pore Pressure Dissipation



Analytical Study

- Based on five full-scale tests with available soil data, we:
  - Found that pile setup is related to:
    - Horizontal coefficient of consolidation (C_h) [vertical coef. Of cons. showed good results too]
    - SPT N value or CPT
    - Pile size
  - Developed a relationship between SPT N value and C_h
  - Developed this equation to estimate pile setup knowing soil properties

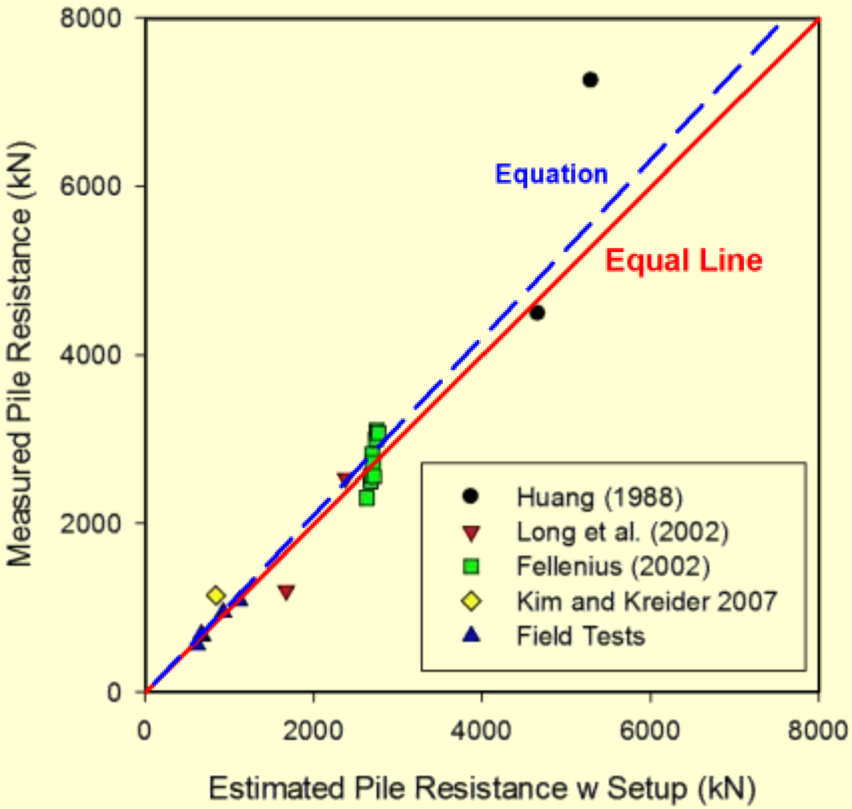
$$\frac{R_t}{R_{EOD}} = \left[\left(\frac{39.05C_h}{N_a r_p^2} + 0.09\right)\log_{10}\left(\frac{t}{t_{EOD}}\right) + 1\right]\left(\frac{L_t}{L_{EOD}}\right)$$

  - Assumed t_{EOD} = 1 min
  - Accounted for length change due to restrike

Analytical Study

- Validation with H-Piles from Literature

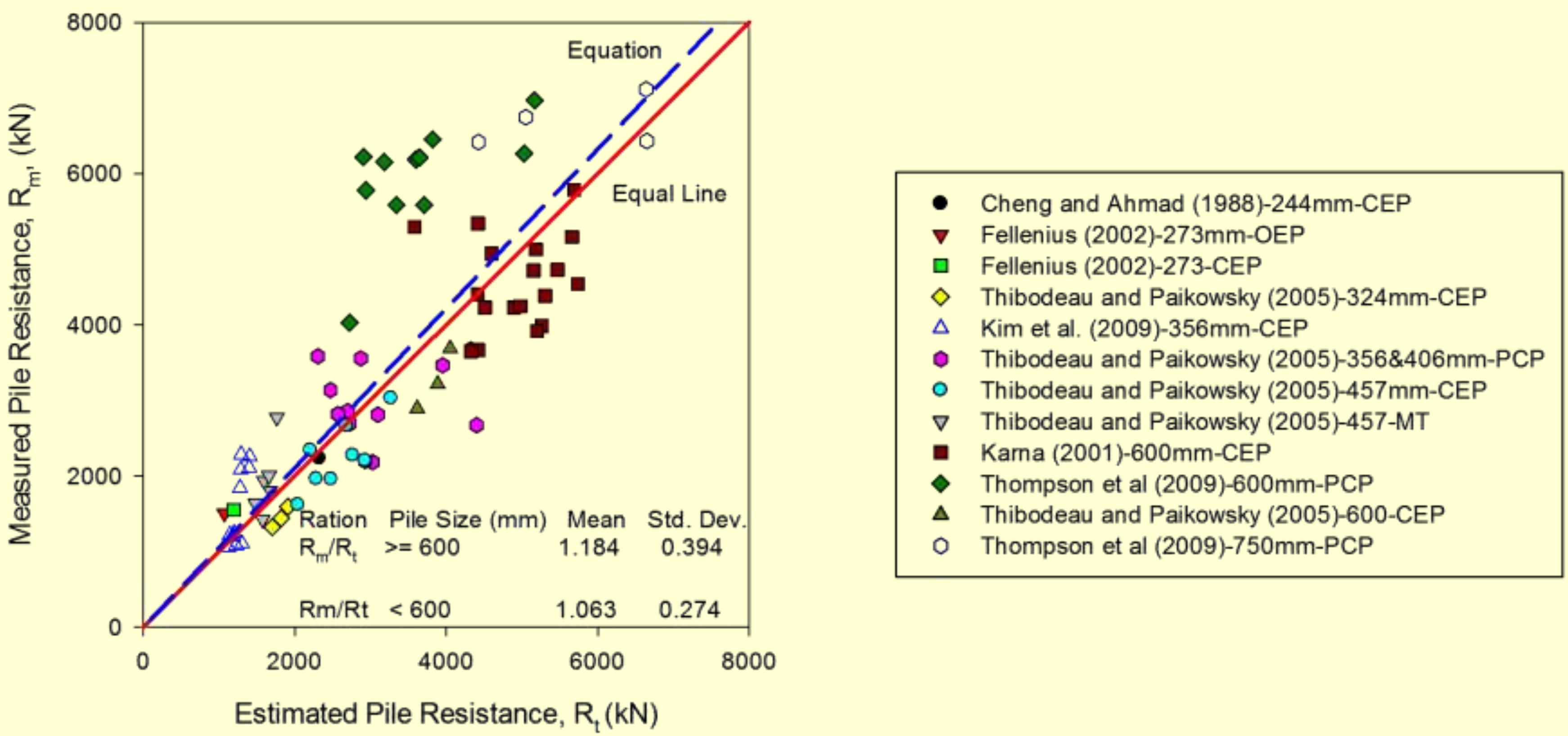
$$\frac{R_t}{R_{EOD}} = \left[\left(\frac{39.05C_h}{N_a r_p^2} + 0.09\right)\log_{10}\left(\frac{t}{t_{EOD}}\right) + 1\right]\left(\frac{L_t}{L_{EOD}}\right)$$



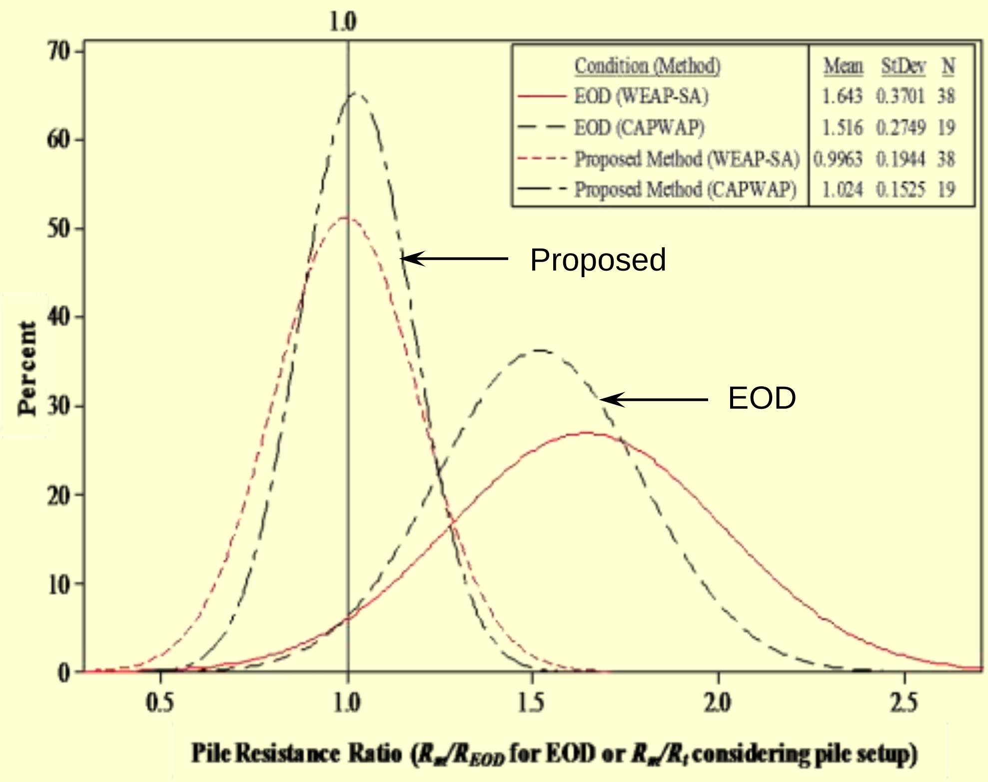
Analytical Study

- Validations with other Piles Types from Literature

$$\frac{R_t}{R_{EOD}} = \left[\left(\frac{39.05C_h}{N_a r_p^2} + 0.09\right)\log_{10}\left(\frac{t}{t_{EOD}}\right) + 1\right]\left(\frac{L_t}{L_{EOD}}\right)$$



Pile Setup in LRFD



Pile Setup in LRFD

- Recommended resistance factor

$$\varphi R_t = \varphi_{EOD} R_{EOD} + \varphi_{setup} R_{setup}$$

Pile type	Proposed pile setup method	Resistance Component	Sample Size	λ	COV	$\beta_T = 2.33$	
						φ	φ/λ
Steel H-pile	CAPWAP	EOD[a]	19	1.044	0.159	0.73	0.70
		Setup	19	1.097	0.366	0.35	0.32
	WEAP-SA	EOD[a]	38	1.146	0.220	0.73	0.64
		Setup	35	0.910	0.343	0.32	0.36
Displacement pile (diameter less than 600 mm)	CAPWAP	EOD[a]	14	0.970	0.238	0.60	0.62
		Setup	42	1.236	0.704	0.18	0.14
Displacement pile (diameter equal or greater than 600 mm)	CAPWAP	EOD[a]	23	1.341	0.310	0.72	0.53
		Setup	36	1.591	0.834	0.15	0.10

[a] – measured pile resistances at EOD ($R_{m\text{-}EOD}$) were back-calculated using the proposed setup Eq. (9) from measured pile resistances obtained from SLTs.

Thank you and Questions

If you have data that we can incorporate in our study, please let me know

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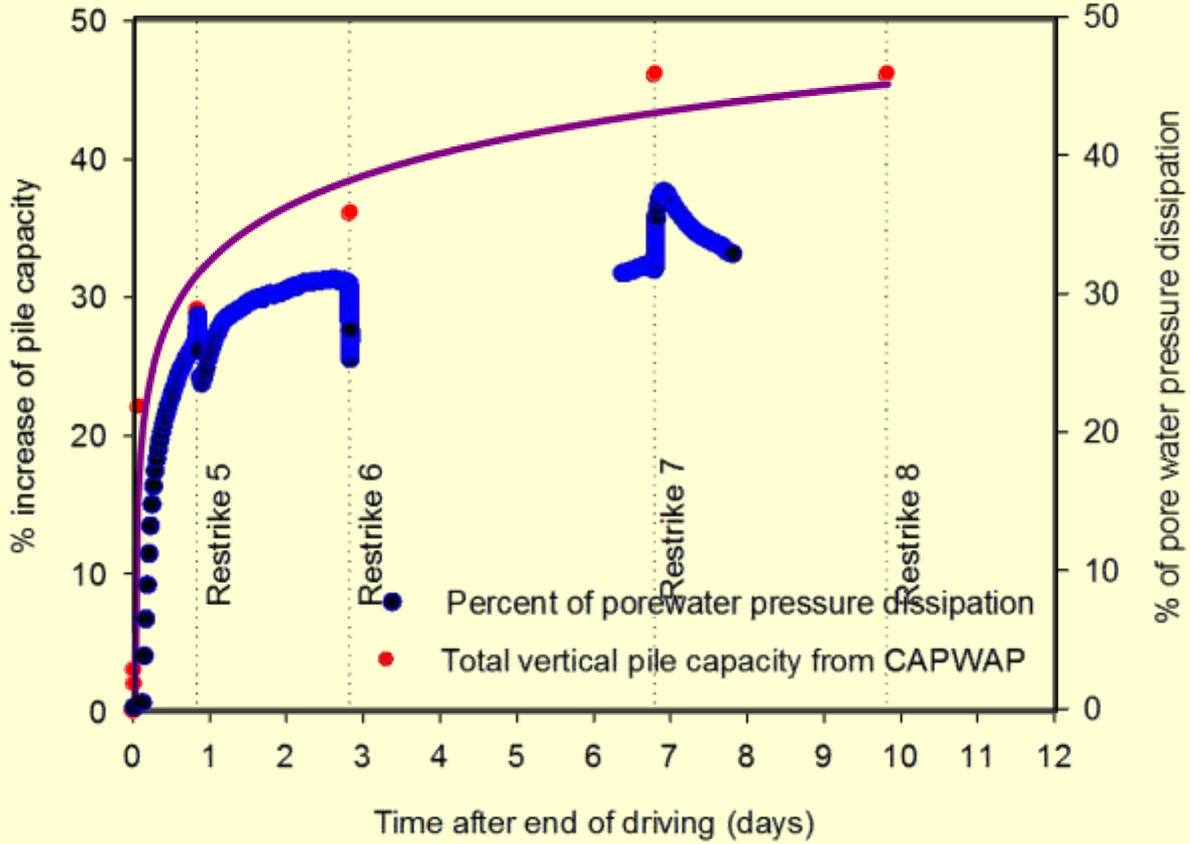
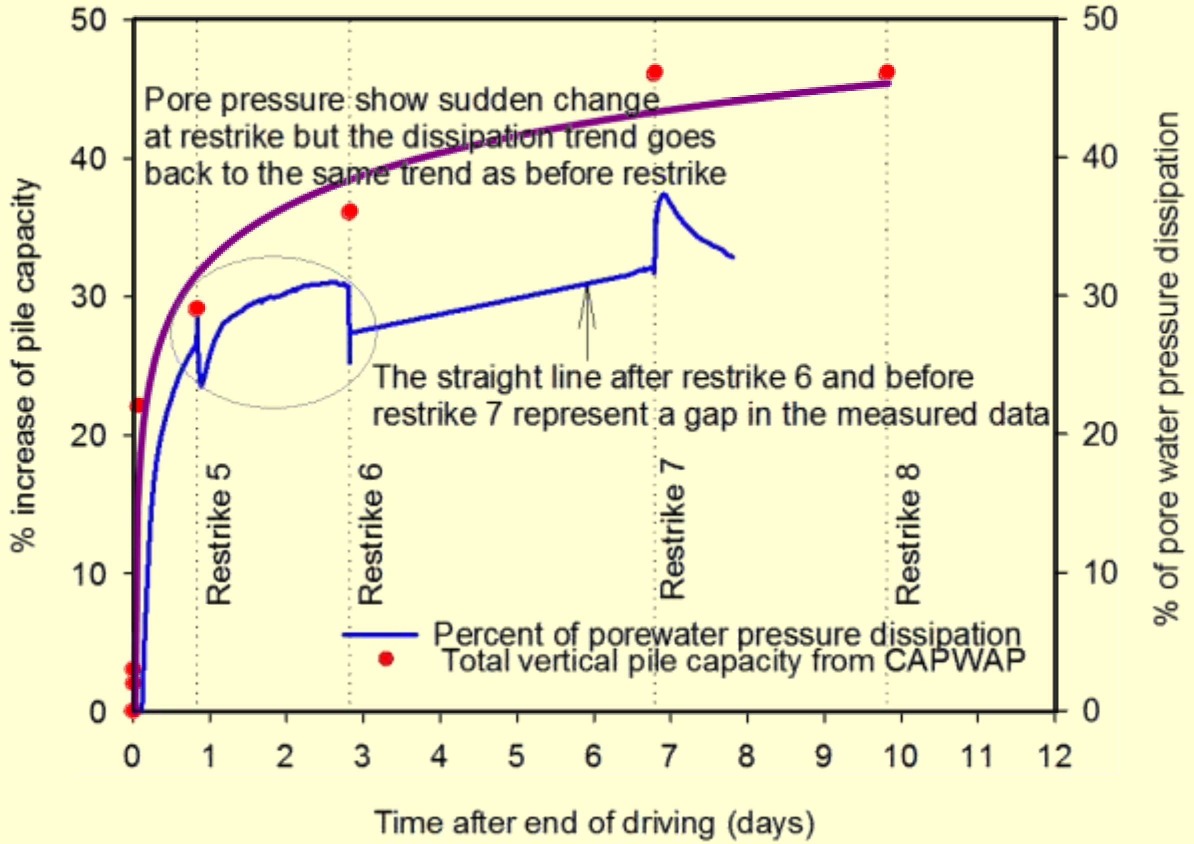
Thank you and Questions

Experimental Study – Pore Pressure Dissipation



Experimental Study – Pore Pressure Dissipation



Experimental Study

Steel H-Pile Instrumentation

Driving & Re-strikes

Dynamic Pile Test

Static Load Test

Pile Setup in LRFD

- Recommended resistance factor

$$\varphi R_t = \varphi_{EOD} R_{EOD} + \varphi_{setup} R_{setup}$$

$$\varphi_{setup} = \frac{\lambda_{setup}\left[\dfrac{\gamma_D\left(\dfrac{Q_D}{Q_L}\right)+\gamma_L}{1+\left(\dfrac{Q_D}{Q_L}\right)} - \varphi_{EOD}\alpha\right]}{\dfrac{\left(\dfrac{\lambda_D\left(\dfrac{Q_D}{Q_L}\right)+\lambda_L}{1+\left(\dfrac{Q_D}{Q_L}\right)}\right)e^{\beta_T\sqrt{\ln\left[\left(1+COV_{R_{EOD}}^2+COV_{R_{setup}}^2\right)\left(1+COV_{Q_D}^2+COV_{Q_L}^2\right)\right]}}}{\sqrt{\dfrac{\left(1+COV_{Q_D}^2+COV_{Q_L}^2\right)}{\left(1+COV_{R_{EOD}}^2+COV_{R_{setup}}^2\right)}}} - \lambda_{EOD}\alpha}$$