Amirkabir University of Technology
(Tehran Polytechnic)

DEEP FOUNDATIONS INSTITUTE

46th Annual Conference on Deep Foundations

Uncertainty and Reliability Appraisal of CPT-Based Methods for Axial Pile Bearing Capacity

(PID1259064)

By:
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Las Vegas, 12-15 October 2021

Outline

1	Generals
2	CPT and Pile Databases
3	Statistics and Probabilistic Criteria
4	Reliability-Based Approach
5	Discussions and Assessment
6	Remarks and Conclusions

1-Generals

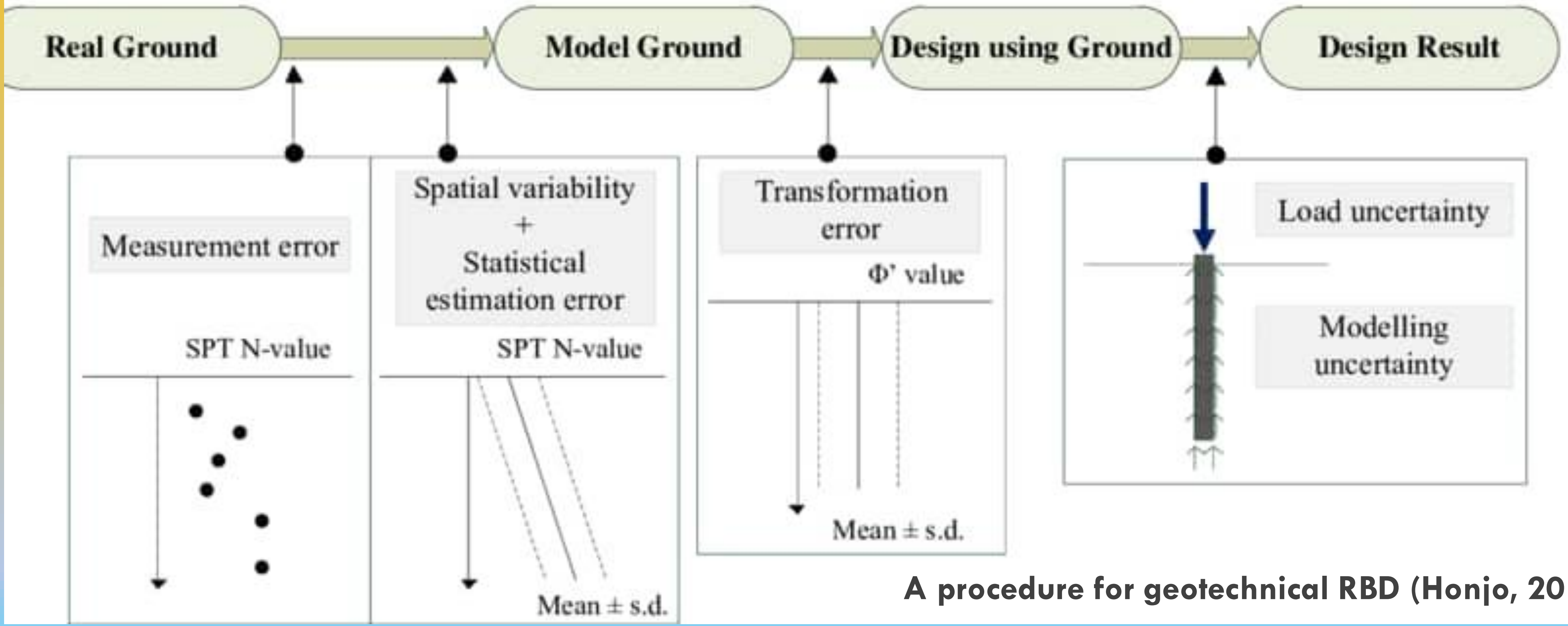
Data Sources in Geotechnical Engineering

Sources of Data:

1. Maps
2. Site visit
3. Drilling, boring, and sampling
4. Non-destructive tests (Geophysical tests)
5. On-situ tests
6. In-situ penetrating tests
7. Laboratory element testing
8. Laboratory physical modeling (model scale)
9. Full-scale testing
10. Instrumentation and Monitoring

1-Generals

Uncertainty in Geotechnical Engineering



A procedure for geotechnical RBD (Honjo, 2011)

- Soil and rock; the most variable of all engineering materials.
- Uncertainties In Geotechnical designs
- Role of judgement

1-Generals

Uncertainty in Geotechnical Engineering

Variability from in-situ testing (Phoon and Kulhawy, 1999)

Test	Equipment	Oper./proc.	Random	Total[a]	Range[b]
Standard penetration test (SPT)	0.05[c]–0.75[d]	0.05[c]–0.75[d]	0.12–0.15	0.14[c]–1.00[d]	0.15–0.45
Mechanical cone penetration test (CPT)	0.05	0.10[e]–0.15[f]	0.10[e]–0.15[f]	0.15[e]–0.22[f]	0.15–0.25
Electric cone penetration test (ECPT)	0.03	0.05	0.05[e]–0.10[f]	0.07[e]–0.12[f]	0.05–0.15
Vane shear test (VST)	0.05	0.08	0.10	0.14	0.10–0.20
Dilatometer test (DMT)	0.05	0.05	0.08	0.11	0.05–0.15
Pressuremeter test, pre-bored (PMT)	0.05	0.12	0.10	0.16	0.10–0.20[g]
Self-boring pressuremeter test (SBPMT)	0.08	0.15	0.08	0.19	0.15–0.25[g]

[a] $COV(total)^2 = COV(equipment)^2 + COV(operator/procedure)^2 + COV(random)^2$.

[b] Because of statistical estimation uncertainty and subjective judgment involved in estimating COVs, ranges represent plausible magnitudes of measurement uncertainty for field tests.

[c,d] Best- to worst-case scenarios, respectively, for SPT.

[e,f] Tip and side resistances, respectively.

[g] It is likely that results may differ for p_0, p_f and p_L, but data are insufficient to clarify this issue.

1-Generals

Uncertainty in Geotechnical Engineering

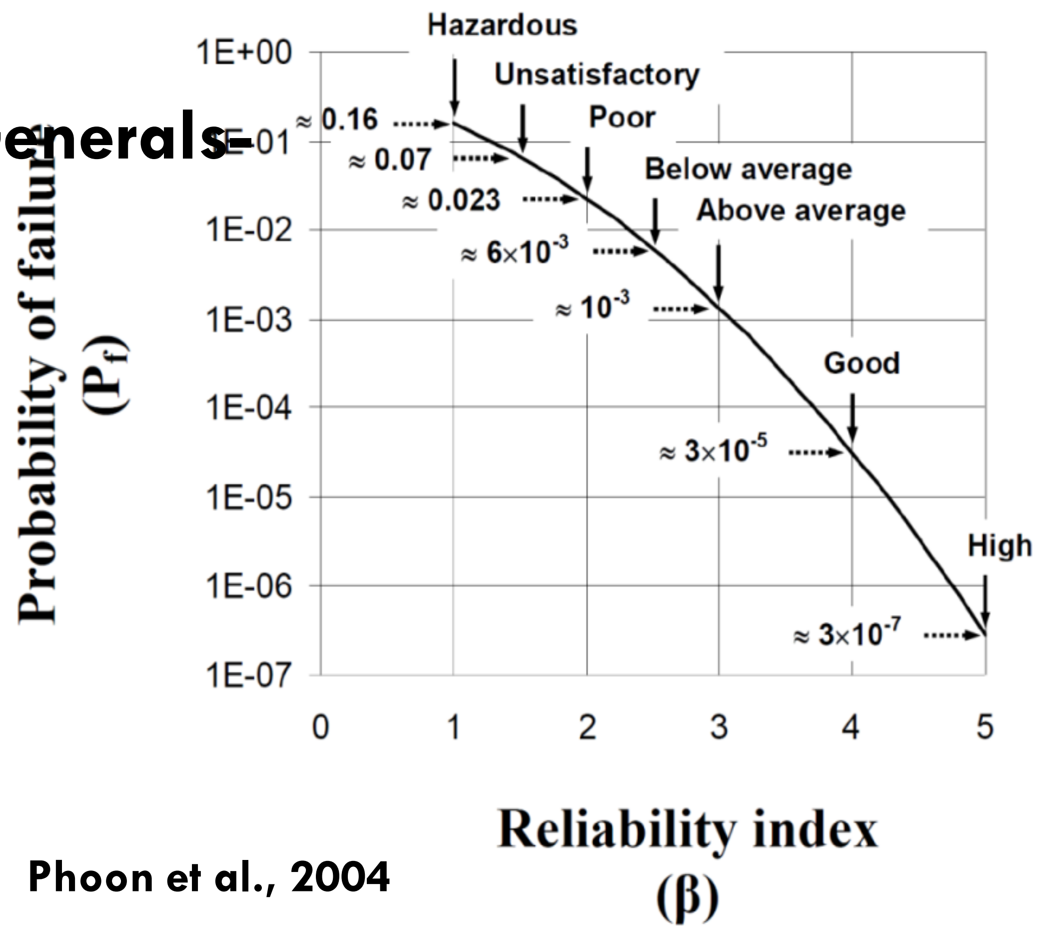
Variability from laboratory testing (Phoon and Kulhawy, 1999)

Test	*Property*	*Soil type*	*Coefficient of variation (%)*	
			Range	*Mean*
Atterberg tests	Plasticity index	Fine grained	5–51	24
Triaxial compression	Effective angle of friction	Clay, silt	7–56	24
Direct shear	Shear strength, C_u	Clay, silt	19–20	20
Triaxial compression	Shear strength, C_u	Clay, silt	8–38	19
Direct shear	Effective angle of friction	Sand	13–14	14
Direct shear	Effective angle of friction	Clay	6–22	14
Direct shear	Effective angle of friction	Clay, silt	3–29	13
Atterberg tests	Plastic limit	Fine grained	7–18	10
Triaxial compression	Effective angle of friction	Sand, silt	2–22	8
Atterberg tests	Liquid limit	Fine grained	3–11	7
Unit weight	Density	Fine grained	1–2	1

1-Generals

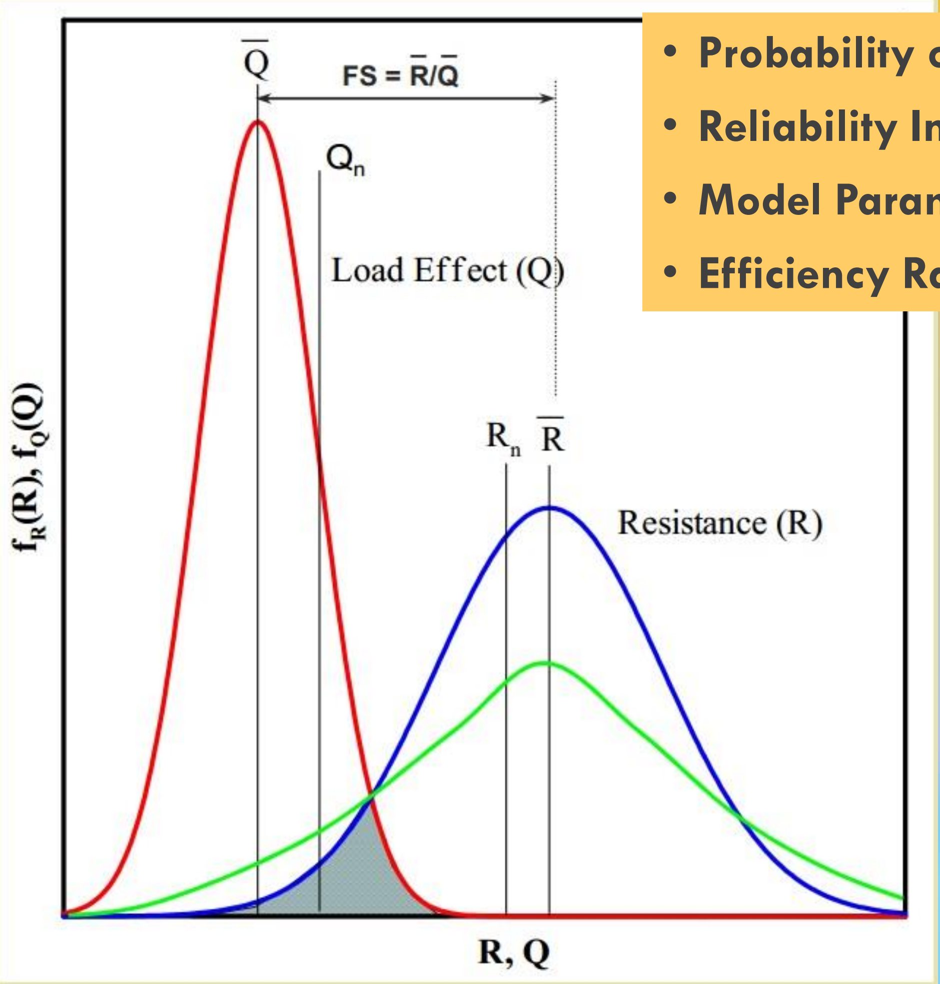
Reliability Index & Load and Resistance Factor Design (LRFD)

Generals-



Phoon et al., 2004

$$\beta = -\Phi^{-1}(p_f) = \Phi^{-1}(1 - p_f)$$



- Probability of Failure
- Reliability Index
- Model Parameter
- Efficiency Ratio

Outline

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2-CPT and Pile Databases

In-situ Testing vs. Laboratory Testing

Laboratory Tests Problems

- Difficulties for undisturbed sample
- Soil disturbance
- Soil volume change
- Omitting confinement pressure
- Size effect and size limits

In-Situ Tests

- Overcome sampling difficulties
- Simple and fast
- Economical
- Generally applicable in foundation engineering

In-situ testing and Laboratory testing are complementary.

2-CPT and Pile Databases

Cone Penetrometer (CPTu) Probes and Terminology

- ASTM D 5778 procedures
- No boring, No samples, No spoil
- Hydraulic Push at 20 mm/s
- Range of sizes:10 cm^2 and 15 cm^2 probes

Advantages:

- Fast and continuous profiling
- Repeatable and reliable
- Continuous records of q_c, f_s, u per 2.5 cm
- Strong theoretical basis for interpretation

Disadvantages:

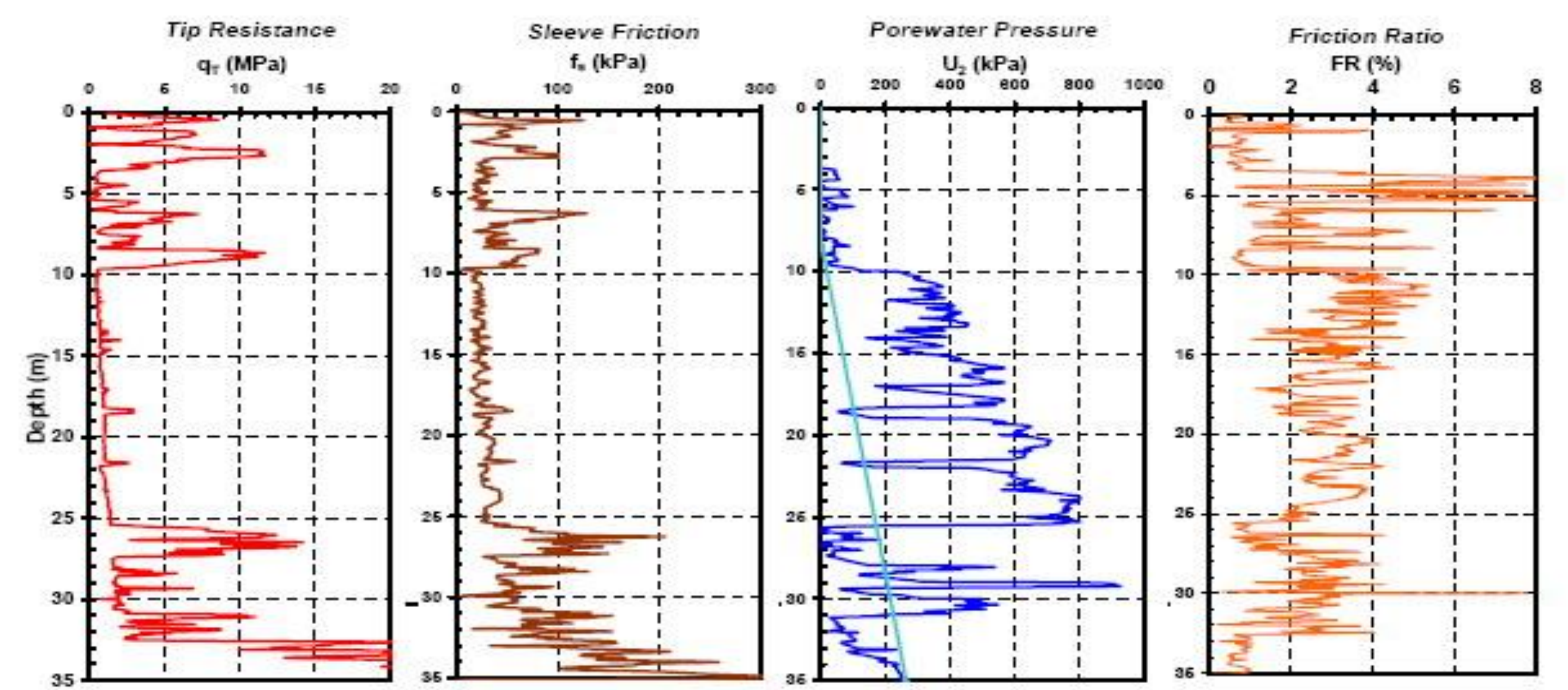
- High capital investment
- Requires skilled operators
- Limitation of use in gravel or cemented soils

2-CPT and Pile Databases

Cone Tracks, Trucks and Special Rigs

2-CPT and Pile Databases

CPTu: Graphical Records and Log

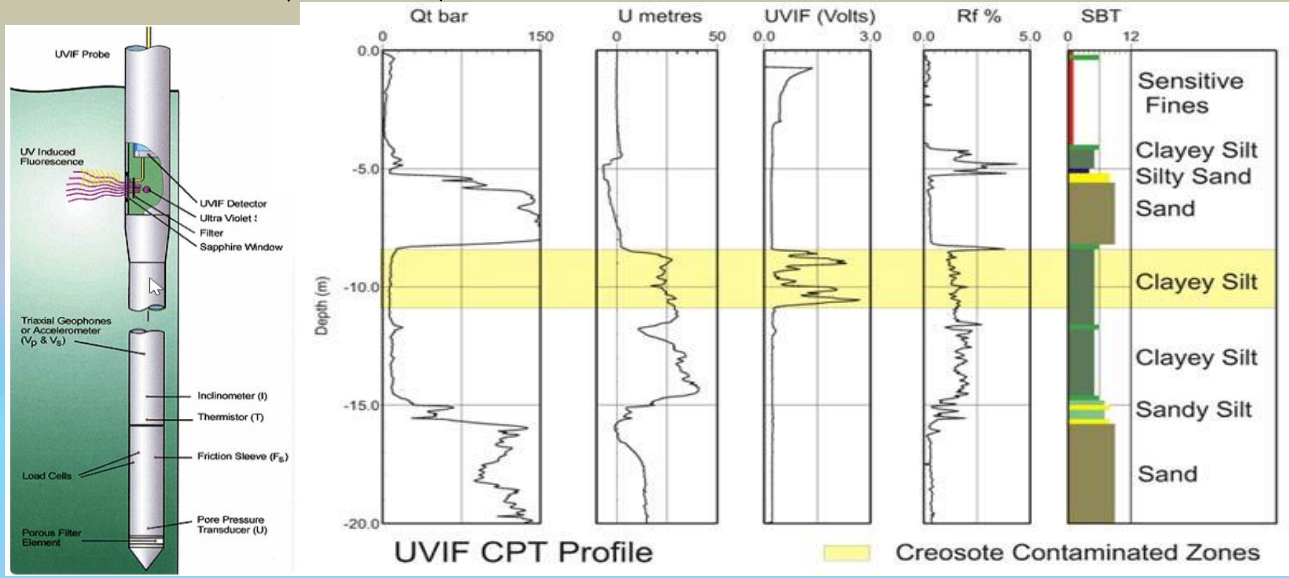


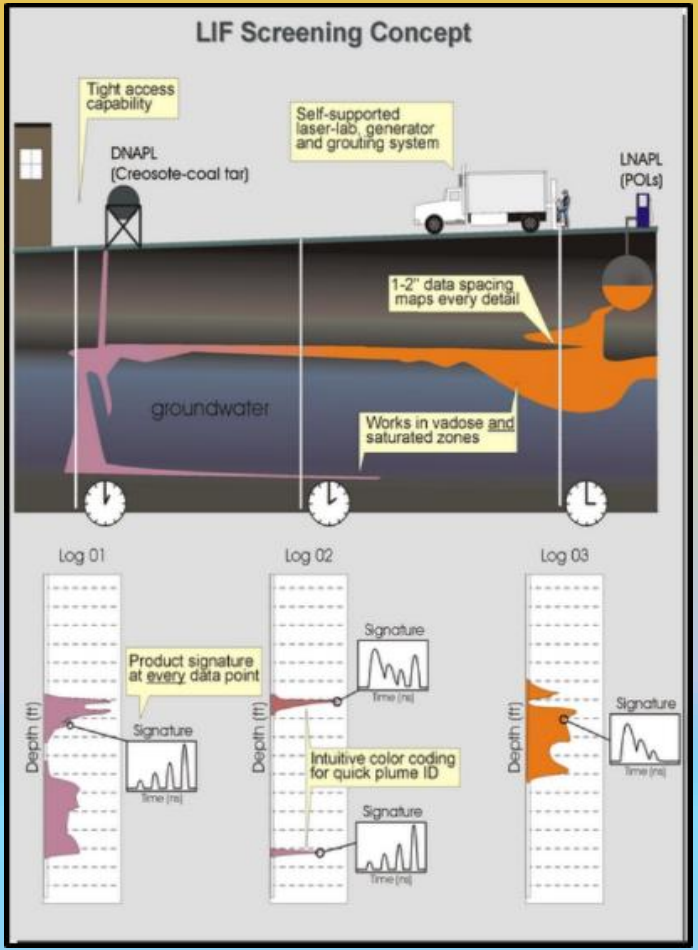
Vancouver, Canada (Campanella et al., 1989)

2-CPT and Pile Databases

Special Piezocones

- Resistivity Cone Penetration Test (RCPTu)
- Seismic Cone Penetration Test (SCPTu)
- Piezovibrocone
- Ultra violet induced fluorescence Cone Penetration Test (UVIF CPT)
- MiniCone and Camera Cone
- Cone Pressuremeter (CPMT)





2-CPT and Pile Databases

APPLICATIONS OF CPT IN GEOTECHNICAL ENGINEERING

Soil Behavior Classification (SBC) & Profiling

- Estimating soil strength and stiffness parameters
- Soil improvement assessment
- Problematic soils recognition

Foundation Engineering

- Direct approaches
- Indirect approaches

Geo-environmental Engineering

2-CPT and Pile Databases

Bearing Capacity Estimation Methods

1. Static Methods
2. **In-situ Tests**
3. Static Loading Test
4. Dynamic Methods
5. Numerical Analysis

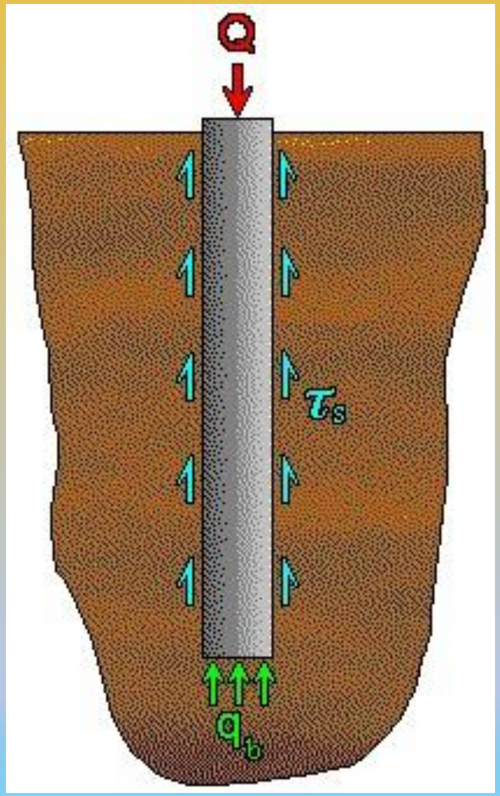
1- Direct Approaches:

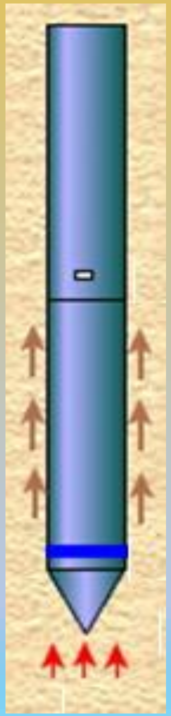
$f_s \rightarrow r_s$

$q_c \rightarrow r_t$

2- Indirect Approaches:

$q_c,\ f_s \rightarrow c,\ \phi \rightarrow q_{ult}$





f_s

q_t

Similarities between the cone penetrometer and piles

Penetrometer can be realized as a model pile.

2-CPT and Pile Databases

Bearing Capacity Direct CPT and CPTu-based methods: Pile Bearing Capacity

No.	Method/ Reference	No.	Method/ Reference
1	Begemann (1963, 1965, 1969)	15	Fugro-05 (Kolk et al. 2005)
2	Meyerhof (1956, 1976, 1983)	16	UCD-05 (Gavin and Lehane 2005)
3	Aoki and Velloso (1975)	17	ICP-05 (Jardine et al. 2005)
4	Nottingham (1975), Schmertmann (1978)	18	UWA-05 (Lehane et al. 2005)
5	Penpile (Clisby et al.1978)	19	NGI-05 (Clausen et al. 2005)
6	Dutch (de Ruiter & Beringen 1979)	20	Cambridge-05 (White & Bolton 2005)
7	Philipponnat (1980)	21	Togiliani (2008)
8	LCPC (Bustamante & Gianeselli 1982)	22	German (Kempfert and Becker 2010)
9	Cone-m (Tumay & Fakhroo 1982)	23	UCD-11 (Igoe et al. 2010, 2011)
10	Price and Wardle (1982)	24	V–K (Van Dijk and Kolk 2011)
11	Gwizdala (1984)	25	SEU (Cai et al. 2011, 2012)
12	UniCone (Eslami & Fellenius 1997)	26	HKU (Yu and Yang 2012)
13	KTRI (Takesue et al. 1998)	27	UWA-13 (Lehane et al. 2013)
14	TCD-03 (Gavin and Lehane 2003)	28	Modified UniCone (Niazi and Mayne 2016)

Databases

- **Databases are collections of data which are organized in order to facilitate access and retrieving data when they are needed.**

- **Topics of some Databases in**
- **Geotechnical Engineering:**
  1. Geohazards
  2. Earthquake induced liquefaction
  3. Pile loading test
  4. Retaining walls and displacement
  5. In-situ tests
  6. Geotechnical zones and micro-zoning
  7. Geotechnical aspects of shallow foundations

Advantages and Applications:

I. Cost saving and project execution time
II. Optimization of design methods
III. Evaluation of design methods
IV. Development of new methods
V. Improvement of geotechnical studies

Pioneers in CPT and Pile Databases:

Nottingham (1975)	Florida, USA
Meyerhof (1976, 1983)	Canada and USA
Schmertmann (1978)	FHWA Guidelines
de Ruiter & Beringen (1979)	North Sea, Europe
Bustamante & Gianesselli (1982)	LCPC, French Method
Tummay & Fakhroo (1982)	Louisiana, USA

2-CPT and Pile Databases

Later developed CPT and Pile Databases:

Briaud and Tucker (1988) Database

- 98 case studies of steel and concrete piles with square, H, circular cross sections

Alsamman (1995) Database

- 95 case records of axial load testing on bored piles from29 sites and 8 countries

Eslami and Fellenius (1997) Database

- 102 case studies from 40 sites and 13 countries

Abu-Farsakh & Titi (2004) Database

- 35 case studies of prestressed square concrete piles

2-CPT and Pile Databases

Later developed CPT and Pile Databases:

UWA (Lehane et al., 2005) Database

- 77 tensile and compressive loading tests for driven concrete piles in sands

ZJU-ICL Database (Yang et al., 2015)

- Zhejiang University/Imperial College London (ZJU-ICL) database
- 115 driven piles in sand

Kempfert & Becker (2010)

- German method
- 1000 case records

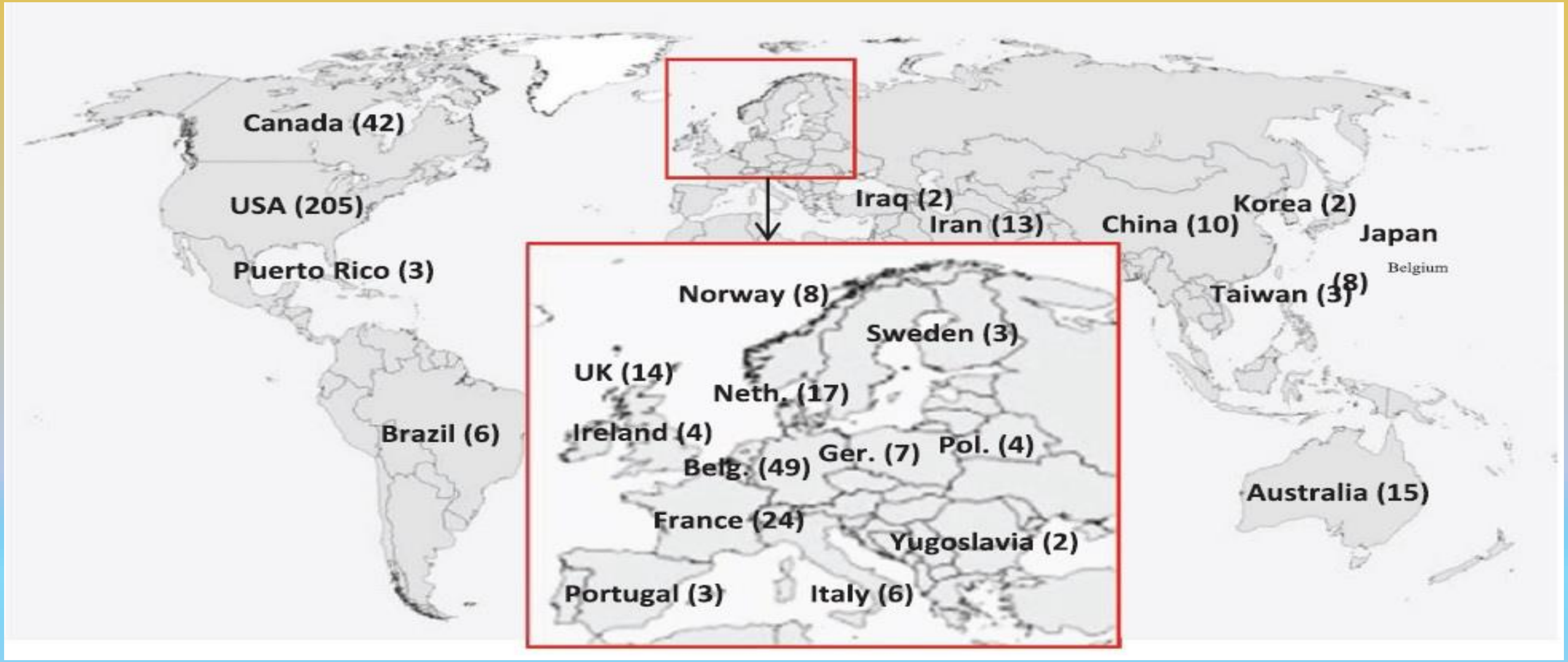
AUT:Geo-CPT&Pile Database

GEOTECHNICAL INFORMATION, CPT AND CPT_U DATA AND PILE LOADING TESTS RECORDS

- 600 Records of pile axial loading tests along with adjacent CPT or CPTu profiles.
- Digitizing load-displacement diagrams derived from loading tests and CPT profiles
- Soil Properties
    - Includes a wide range of clayey, silty and sandy soils.
    - Classified within three categories: Sandy, Clayey and Mixed soils

2-CPT and Pile Databases

600 Records of pile axial loading tests along with adjacent CPT or CPTu profiles.



2-CPT and Pile Databases

AUT:Geo-CPT&Pile Database-Piles Specifications

Embedment Depth → Mainly from 5 to 75 m

Cross Section → Mainly from 100 to 900 mm

Cross Section Shape →
- Round
- Square
- Pipe
- Triangle

Material →
- Steel
- Concrete
- Composite (steel and concrete)
- CFG (Cement, Fly ash, Gravel)

Installation Method
- Driven
- Bored
- PGDS (Pressure Grouted Drilled Shaft)
- APGD (Augured Pressure Grouted Displacement)
- DCIS (Driven Cast in-situ)
- Jacked
- Vibro
- CFA
- Pressed
- Helical
- Atlas (DD)
- Fundex (DD)
- Olivier (DD)
- Omega (DD)
- De Waal (DD)

2-CPT and Pile Databases

Moshfeghi & Eslami (2015-2019)

Taylor & Francis

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Study on pile ultimate capacity criteria and CPT-based direct methods

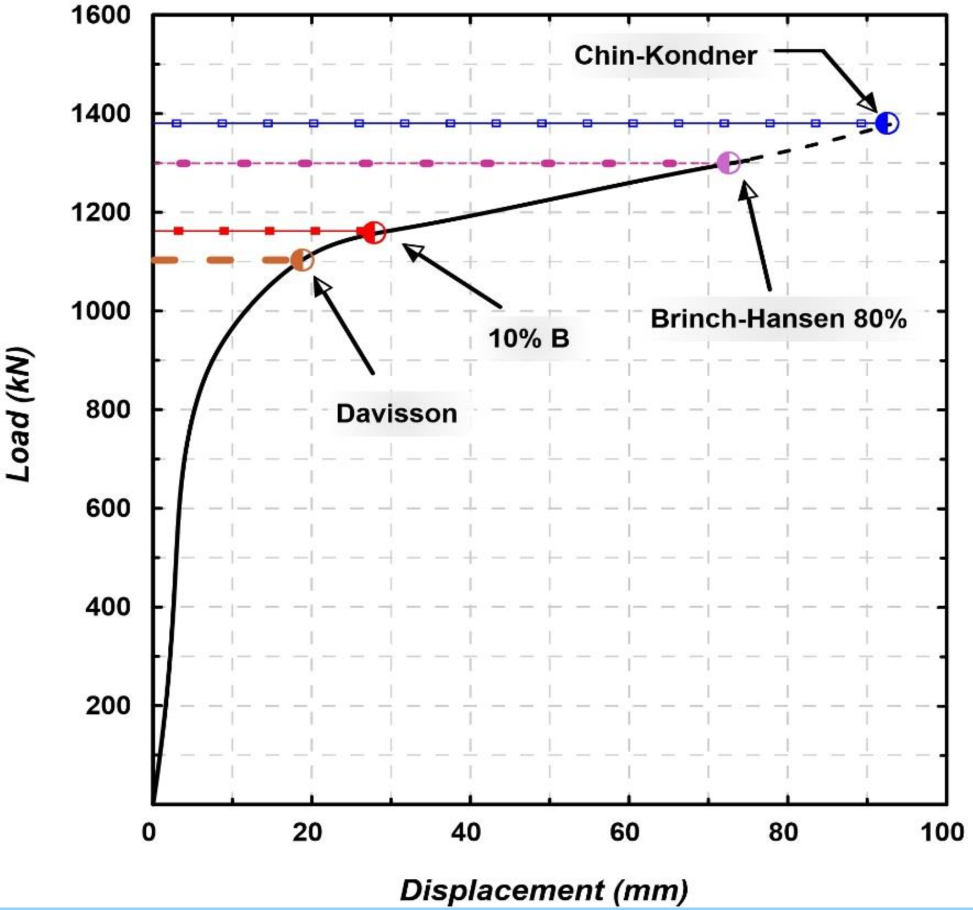
Sara Moshfeghi and Abolfazl Eslami*

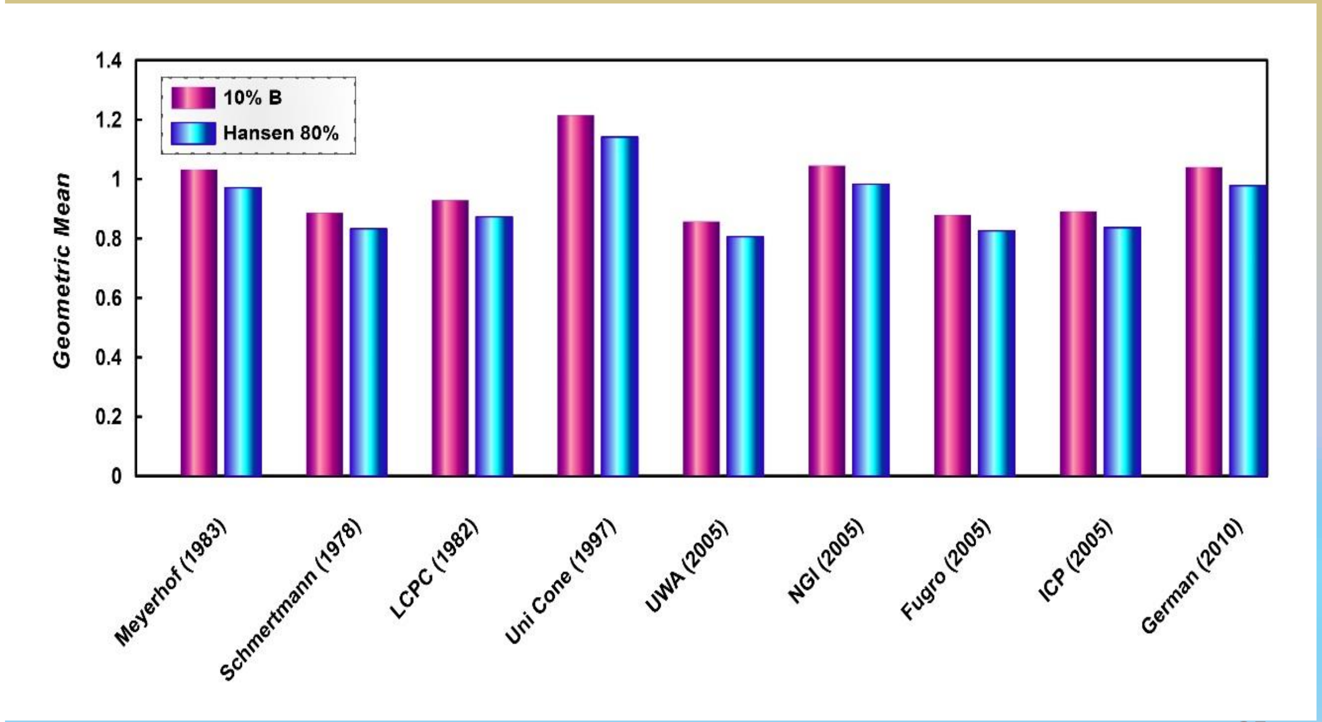
Due to the variety of current Cone Penetration Test (CPT)-based methods of estimating the pile bearing capacity, for optimum design, it is necessary to evaluate the performance of such methods in various geotechnical conditions. Geotechnical databases including piling and *in situ* testing records have been recognised as useful tools for analysis, design and economical construction. In order to evaluate current CPT-based pile bearing capacity methods, AUT-CPT and Pile database has been compiled including 450 full scale pile load tests and CPT sounding records. This database consists of different pile types with a relatively wide range of geometries and various soil conditions. Forty-three records of piles driven in sand deposits were then employed to evaluate effects of ultimate capacity interpretation criteria from load displacement diagrams. The Brinch Hansen 80% criterion and the load at the displacement of 10% of the pile diameter were compared to estimated capacities from 10 CPT-based design methods currently used in practice. The Brinch Hansen 80% criterion and the load at the displacement of 10% of the pile diameter lead to reasonable results, the Brinch Hansen 80% criterion showed less scatter. For evaluating the accuracy and the precision of CPT-based methods, the results were compared to estimated capacities. Methods with the best performance are introduced. Generally, comparisons indicate that the CPT-based methods mainly predict the pile capacity with reasonable accuracy.

Keywords: Ultimate pile bearing capacity, Direct CPT method, Load test, Failure criterion, Database

2-CPT and Pile Databases

Moshfeghi & Eslami (2015-2019)





2-CPT and Pile Databases

Moshfeghi & Eslami (2015-2019)

MARINE GEORESOURCES & GEOTECHNOLOGY
https://doi.org/10.1080/1064119X.2018.1448493

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Reliability-based assessment of drilled displacement piles bearing capacity using CPT records

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ABSTRACT
Drilled displacement piles (DDPs) are known as an alternative to conventional foundations in coastal areas, given the elimination of environmental impacts and difficulties caused by installation process of driven piles and more consistency with environment. Despite increasing employment of these piles, the extent of research works does not yet suffice the requisites to reach a routine design. This paper aims to analyze six cone penetration test (CPT)-based methods of determining the bearing capacity of DDP. The statistical and reliability-based approaches were used in two parts of assessing performance of the methods with respect to soil–pile characteristics followed by evaluating reliability of the prediction outcome. A database is compiled including 65 DDP load tests with adjacent CPT profiles. Performance of the methods are analyzed. Finally, a reliability parameter, i.e., confidence interval, is introduced to demonstrate a more realistic insight into the evaluations by expressing performance of the methods in terms of a range for possible average values of the predictions ratios, rather than simply an arithmetic mean. The study reveals that the commonly used CPT-based methods which have not been specifically developed for DDP show great potential for design. The results indicate that the investigated methods can have promising performance if some modifications are applied.

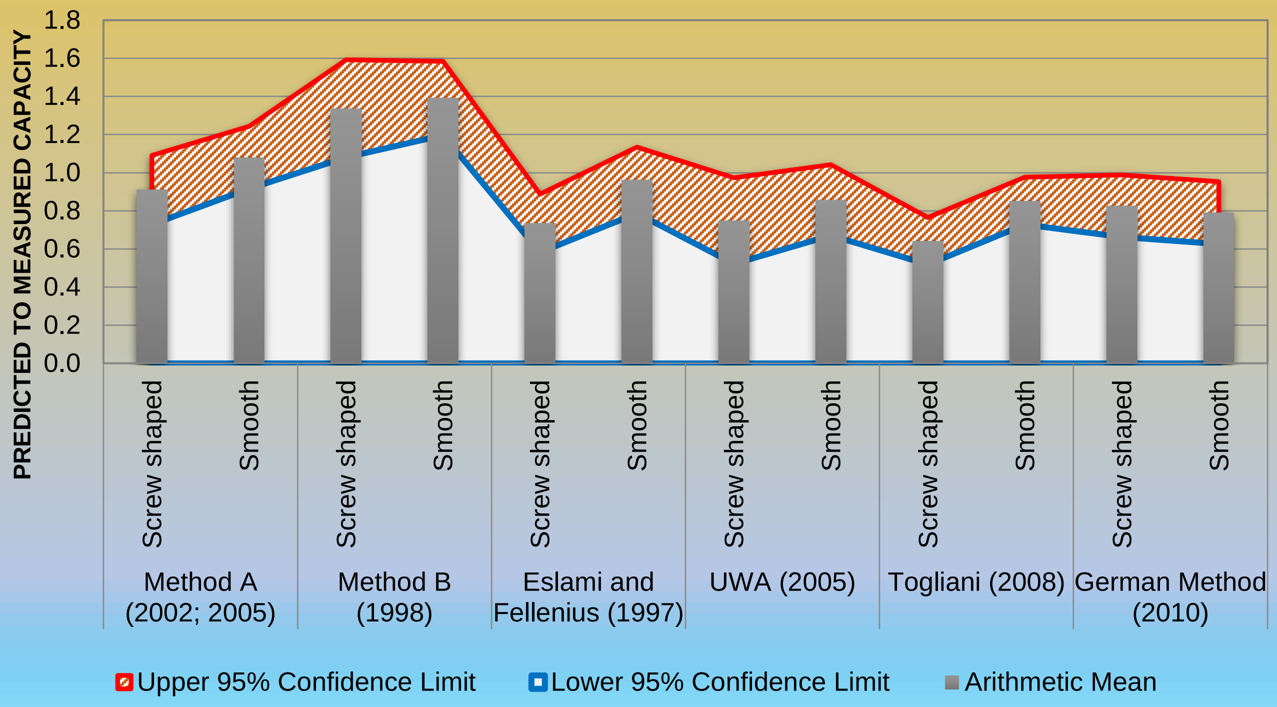
ARTICLE HISTORY
Received 10 November 2017
Accepted 1 March 2018

KEYWORDS
Bearing capacity; confidence interval; CPT methods; drilled displacement pile (DDP); reliability-based evaluation

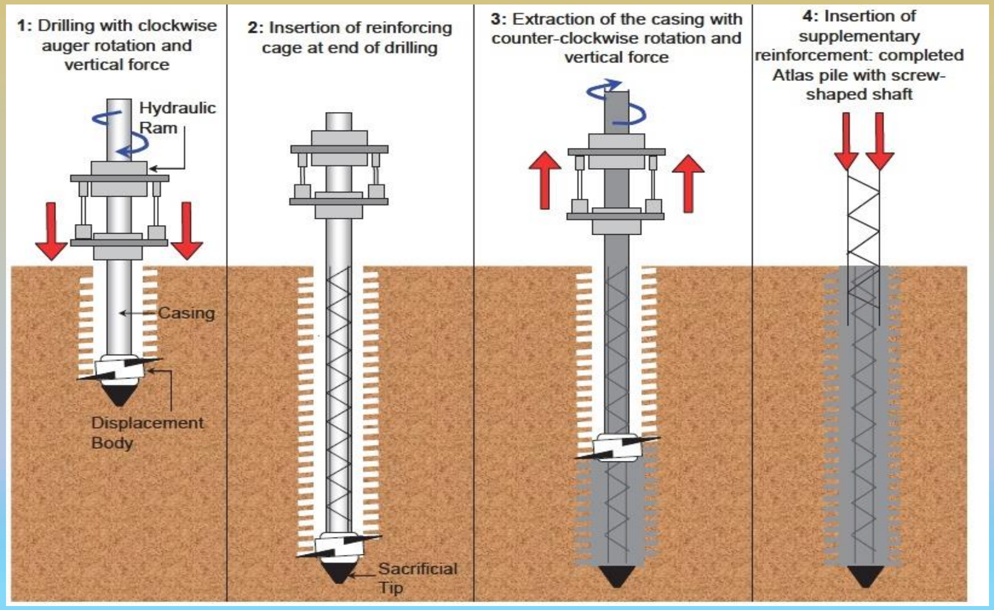
2-CPT and Pile Databases

Moshfeghi & Eslami (2015-2019)

Reliability-based Assessment of Drilled Displacement Piles Bearing Capacity Using CPT Records



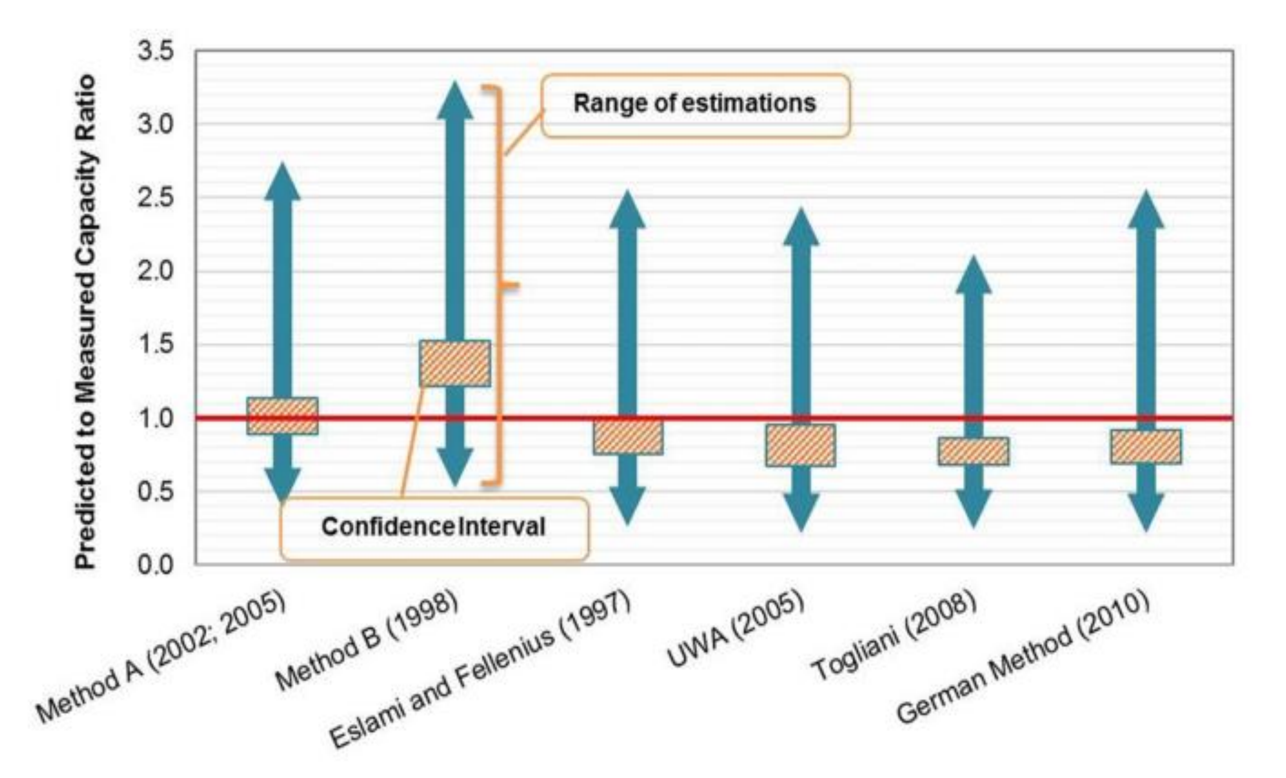
Evaluation results of CPT-based methods based on shaft shapes

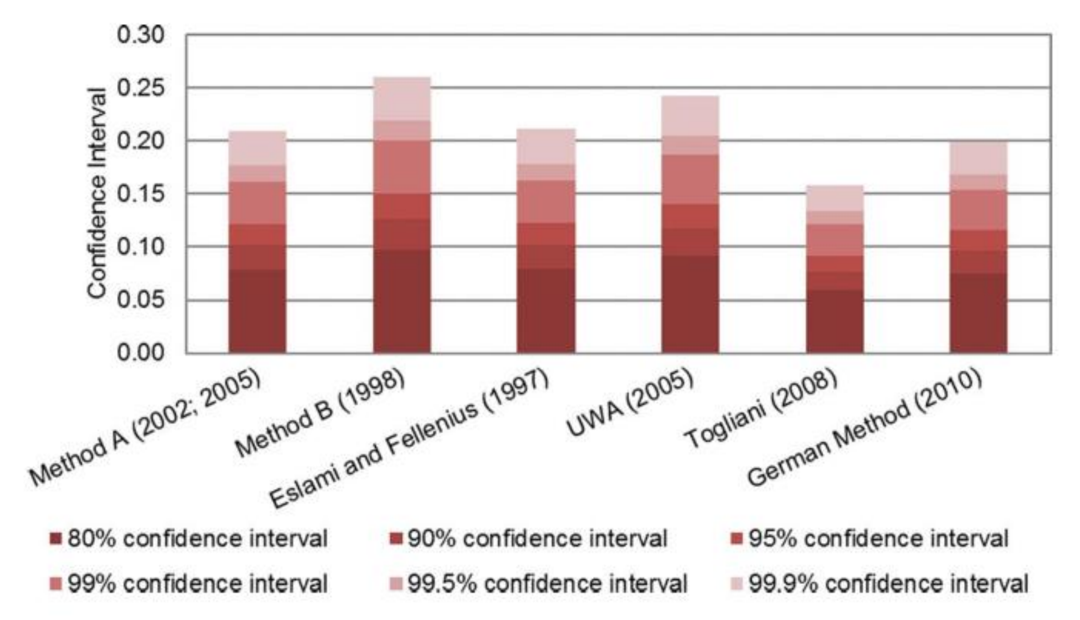


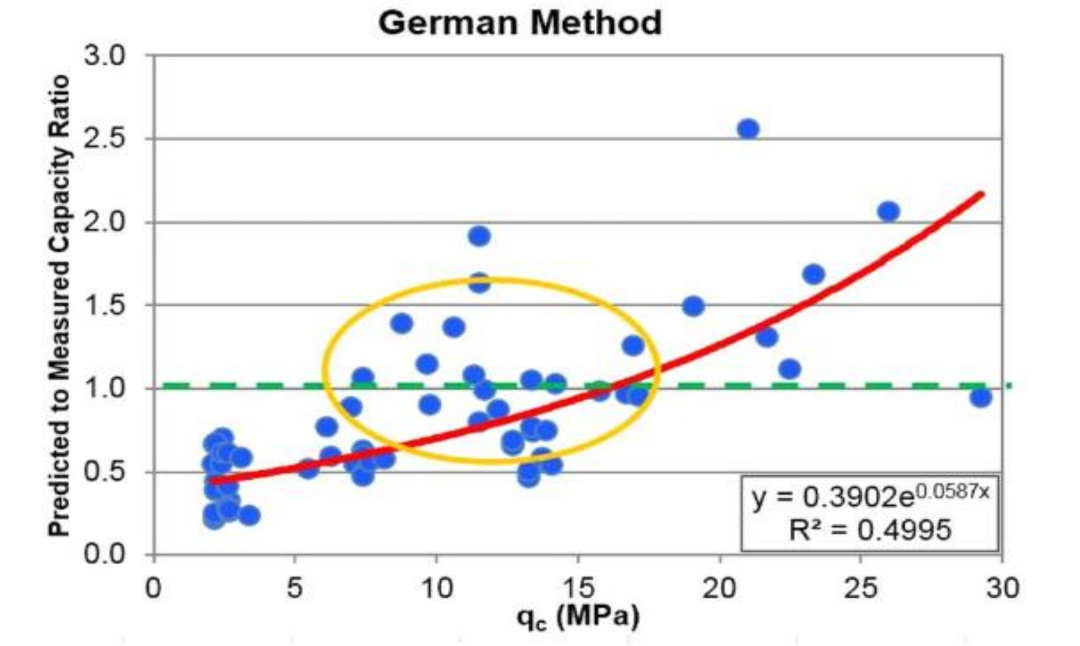
Drilling displacement procedure of Atlas piles (Basu et al., 2010)

2-CPT and Pile Databases

Moshfeghi & Eslami (2015-2019)







2-CPT and Pile Databases

Eslami, Moshfeghi, Heidari, Valikhah (2019)- Fellenius Issue

Geotechnical Engineering Journal of the SEAGS & AGSSEA Vol. 50 No. 2 June 2019 ISSN 0046-5828

AUT: Geo-CPT&Pile Database
Updates and Implementations for Pile Geotechnical Design

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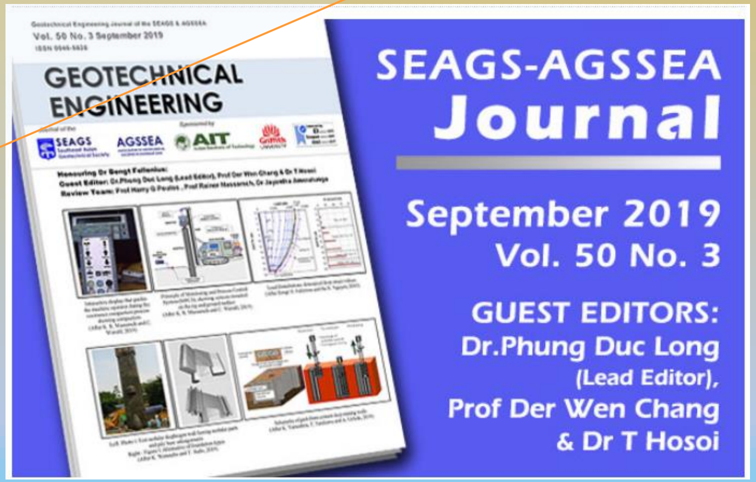
ABSTRACT: Due to uncertainties in geomaterial properties and modelling, a detailed and precise data source can significantly improve reliability indices. Accordingly, to facilitate quantifying the uncertainties, there are currently several databases in the realm of piling and CPT. AUT (Amirkabir University of Technology): Geo-CPT&Pile Database was initially developed in 2015 by 466 case records including pile and CPT records. At present, it is updated to the total number of 600 case records which is partly accessible online. Aiming at pile performance-based design, risk analyses and evaluation of optimum safety factor have been examined based on value engineering by Wasted Capacity Index (WCI). Subsequently, the performance of direct and indirect CPT methods for pile bearing capacity estimation has been assessed focusing on reliability-based approaches. In addition, a methodology was employed to predict the load-displacement and bearing capacity of driven piles interactively. Finally, an algorithm is implemented for pile geotechnical performance-based design through a selected database considering probabilistic, reliability and risk assessments.

KEYWORDS: AUT: Geo-CPT & Pile Database, Pile Capacity, CPT-based Methods, Performance-Based Design (PBD)

B. H. Fellenius ISSUE

SEAGS Southeast Asian Geotechnical Society



2-CPT and Pile Databases

Eslami, Lotfi, Infante, Moshfeghi & Eslami (2019)

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Pile Shaft Capacity from Cone Penetration Test Records Considering Scale Effects

Abolfazl Eslami[1]; Sepide Lotfi[2]; Julio Angel Infante[3]; Sara Moshfeghi[4]; and Mohammad M. Eslami A.M.ASCE[5]

Abstract: The cone penetration test (CPT) is used as a complementary approach for determining the bearing capacity of piles. Via direct CPT methods for pile capacity prediction, correlation coefficients smaller than unity are used to relate cone tip resistance and sleeve friction to pile toe and shaft capacities, respectively. For correlating CPT data to pile capacity, specific factors must be considered, such as diameter, penetration rate, partial embedment of pile toe into a hard layer, mechanism of plunging, failure zone, data processing, and stress–strain conditions. The aim of this paper is to investigate the role and significance of scale effects to establish a direct relation between CPT records and pile shaft capacity. A database has been compiled including 83 full-scale pile load tests and CPT records in order to calibrate and validate the proposed approach. The less-than-unity ratio of pile shaft capacity to cone sleeve friction (i.e., r_s/f_s) for most of the cases shows that shear stress in the soil surrounding the pile is smaller than in the soil around the cone. Therefore, the differences between pile and penetrometer penetration rate and geometry are considered as the major factors that cause lower shear strain in the soil around the pile. By considering the determinants, an analytical-practical procedure is proposed, from which the pile shaft capacity can be predicted using cone sleeve friction. This approach demonstrates better agreement with measured capacity by static loading test results (R_s) and less scatter than other current CPT methods, and it can be used as a complementary approach for determining pile shaft capacity. **DOI:** 10.1061/(ASCE)GM.1943-5622.0001652.

Author keywords: Pile; Shaft capacity; CPT; Sleeve friction; Scale effects.

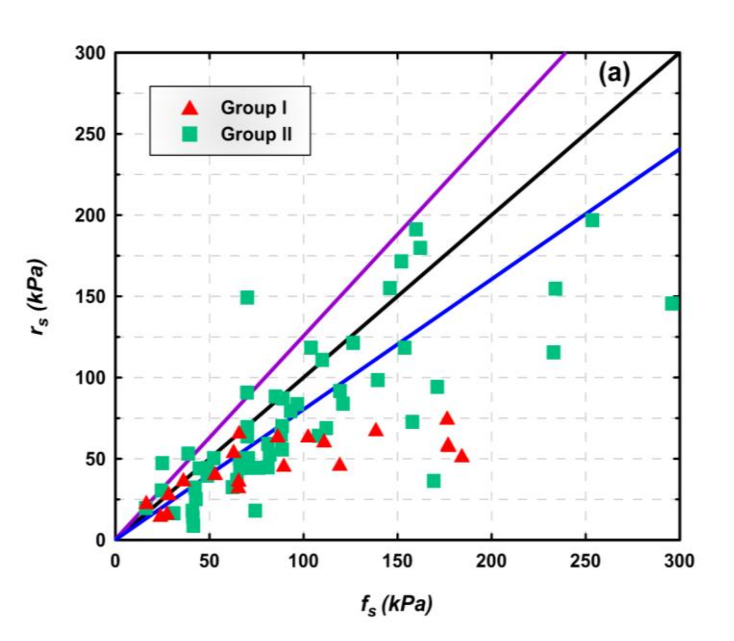
2-CPT and Pile Databases

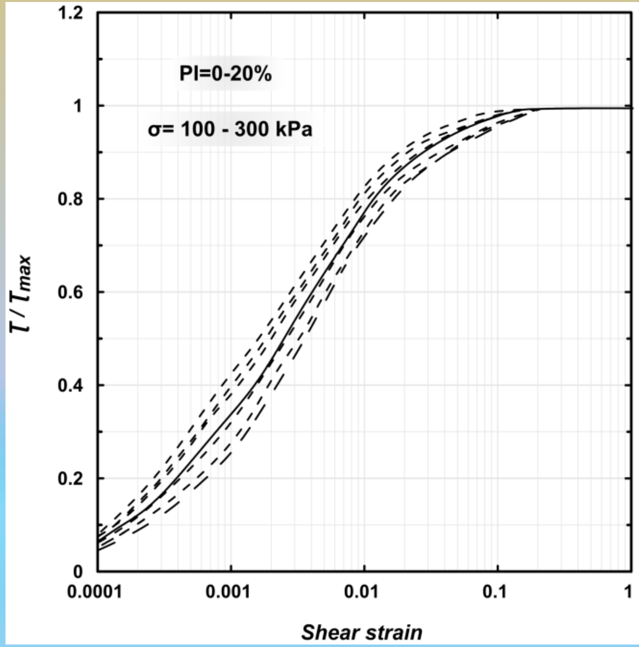
Eslami, Lotfi, Infante, Moshfeghi & Eslami (2019)

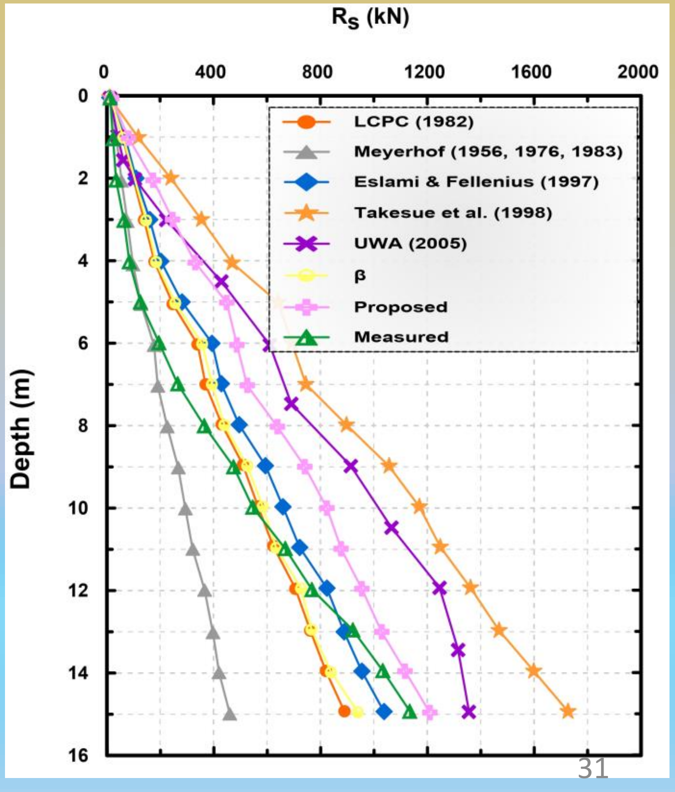
$$\gamma_{Pile} = 0.0255\,(V_{Pile})^{0.61}.(D_{Pile})^{0.5}$$

$$r_{s(z)} = k_z\,.k.\,f_{s(z)}$$

Shaft bearing capacity regarding Scale effect (f_s-r_s)







2-CPT and Pile Databases

Heidari, Eslami and Jamshidi (2019)

Geotech Geol Eng
https://doi.org/10.1007/s10706-020-01346-x

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ORIGINAL PAPER

Probabilistic Assessment of Model Uncertainty for Prediction of Pile Foundation Bearing Capacity; Static Analysis, SPT and CPT-Based Methods

Sara Heidarie Golafzani · Abolfazl Eslami · Reza Jamshidi Chenari

Received: 10 January 2019 / Accepted: 7 May 2020

Abstract Geotechnical designs, like other engineering disciplines, are always accompanied by uncertainties. Supplying continuous and reliable records and reducing the uncertainty associated with measurement errors, the cone penetration test (CPT) enhances the geotechnical designs to a more decent level. Deep foundation design, as an essential challenge of foundation engineering, is also involved with different sources of uncertainty. Moreover, the presence of various design methods, relying on different assumptions and requirements, introduces further complications to the selection of an appropriate method, which leads to the broad spectrum of the predictions. Hence, a database, including 60 driven pile load test results and CPT records in the vicinity of them, was compiled to investigate the model uncertainties embedded in various predictive approaches. Investigated approaches include two static analyses, five SPT, and five CPT-based methods, and were implemented to predict axial pile bearing capacity. The model parameters for these methods are investigated through seven statistical, probabilistic, and reliability-based criteria. Performance of the methods under these criteria is assessed by the use of radar charts. Moreover, the resistance factor, adopted in this study to estimate the efficiency ratio and actual factor of safety, is calibrated by four different prevailing methods. Eventually, among conventional available predictive methods, CPT-based methods perform better than others and result in cost-effective and optimized trends.

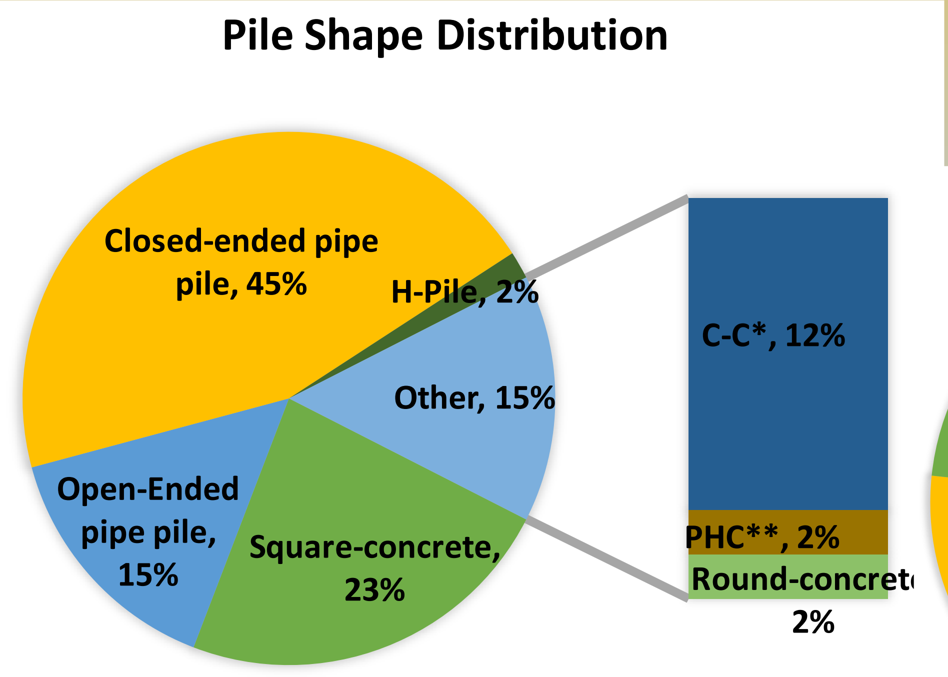
Keywords Uncertainty · Bearing capacity · CPT · LRFD · Reliability · Driven piles · SPT · Static analysis

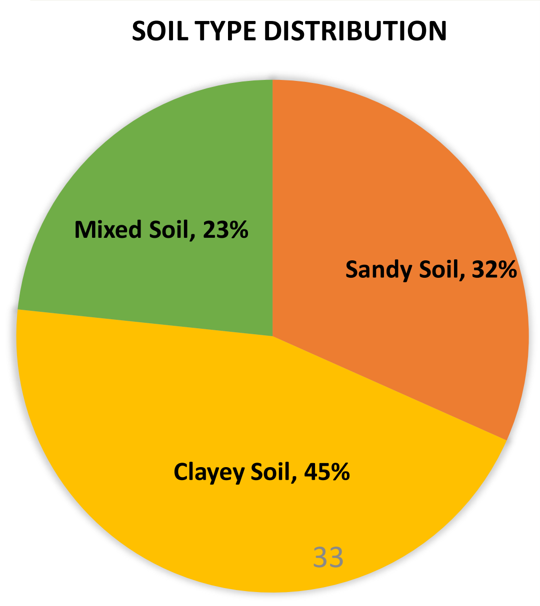
2-CPT and Pile Databases

Heidari, Jamshidi and Eslami (2020)

Assessment of different predictive methods for a database including 60 driven piles and their adjacent CPT records

- Static Analyses
  - CFEM
  - API
- SPT-based methods
  - Meyerhof (1976)
  - Shioi and Fukui (1982)
  - Bazaara and Kurkur (1986)
  - Briaud and Tucker (1988)
  - Decourt (1995)
- CPT-based methods
  - Schmertmann (1978)
  - DeRuiter and Beringen (1979)
  - Bustamante and Gianeselli (1982)
  - Meyerhof (1956, 1976, 1983)
  - UniCone (1997)

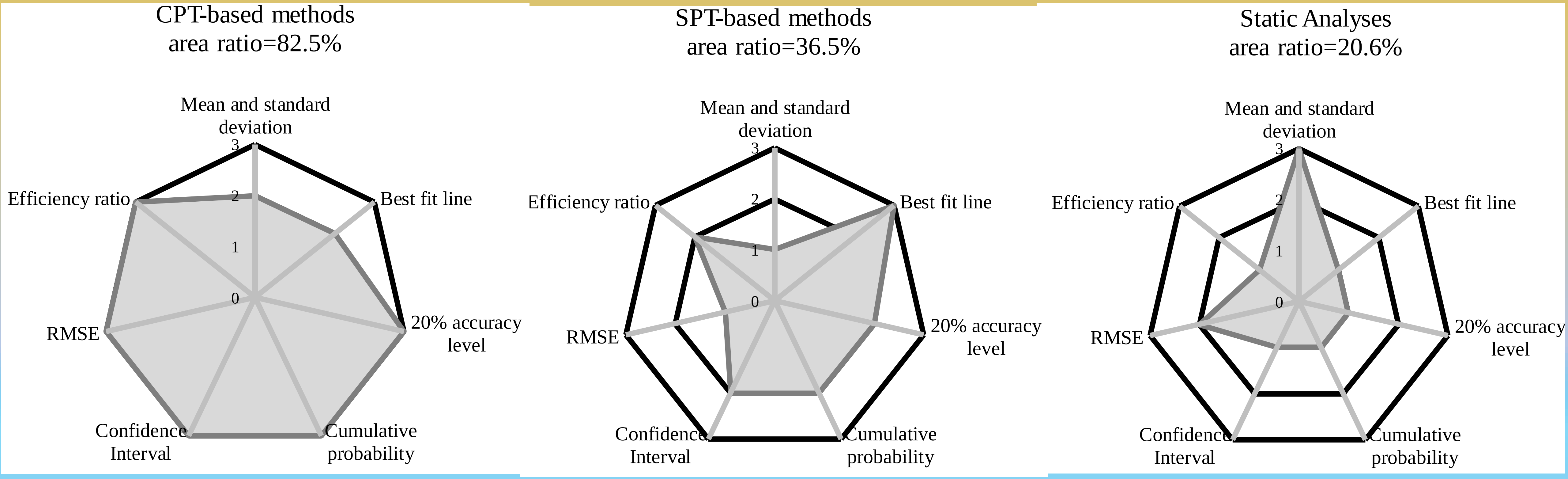




2-CPT and Pile Databases

Heidari, Jamshidi and Eslami (2019)

Probabilistic Assessment of Model Uncertainty for Predictive Methods



2-CPT and Pile Databases

Eslami and Heidari (2020)

MARINE GEORESOURCES & GEOTECHNOLOGY
https://doi.org/10.1080/1064119X.2020.1841861

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Relevant data-based approach upon reliable safety factor for pile axial capacity

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ABSTRACT

Pile foundations are one of the significant marine substructure systems for a variety of offshore and onshore facilities. Thus, optimum and reliable design during their lifetime and under inherent uncertainties is noteworthy. Among various methods for predicting axial pile bearing capacity, cone penetration test (CPT)-based methods enhance geotechnical design to a more satisfying level due to continuous and reliable CPT records and their suitable performance in offshore environments. This article aims to reveal the importance of CPT and pile databases, especially in deltaic deposits. A new relevant CPT and pile data-based approach is introduced by assessing a few elaborated works on typical CPT and pile case studies. The proposed procedure assists in comparing the characteristics and conditions of a given pile with similar database cases through screening and, consequently, deciding on the design methods' priority. It is depicted that superior methods result in a more reliable design and higher resistance factors and efficiency ratios in load and resistance factor design (LRFD). Accordingly, it is engaged with lowered safety factors in the allowable stress design (ASD) approach. Eventually, upon various assessment criteria, the optimum site-specific methods are proposed leading to a performance-based design that can be realized in geotechnical practice.

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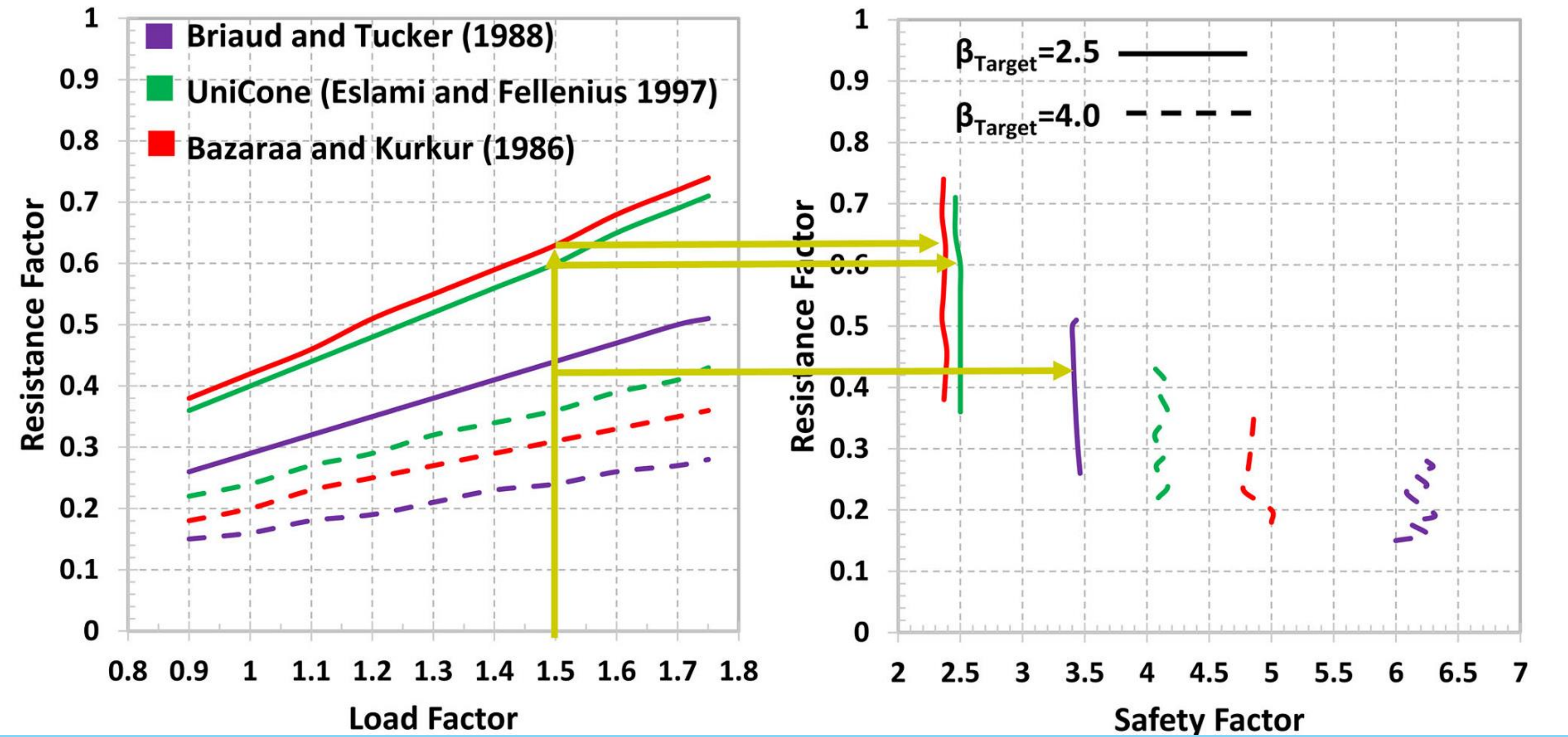
KEYWORDS
CPT; deltaic deposit; pile axial capacity; relevant database; safety factor

2-CPT and Pile Databases



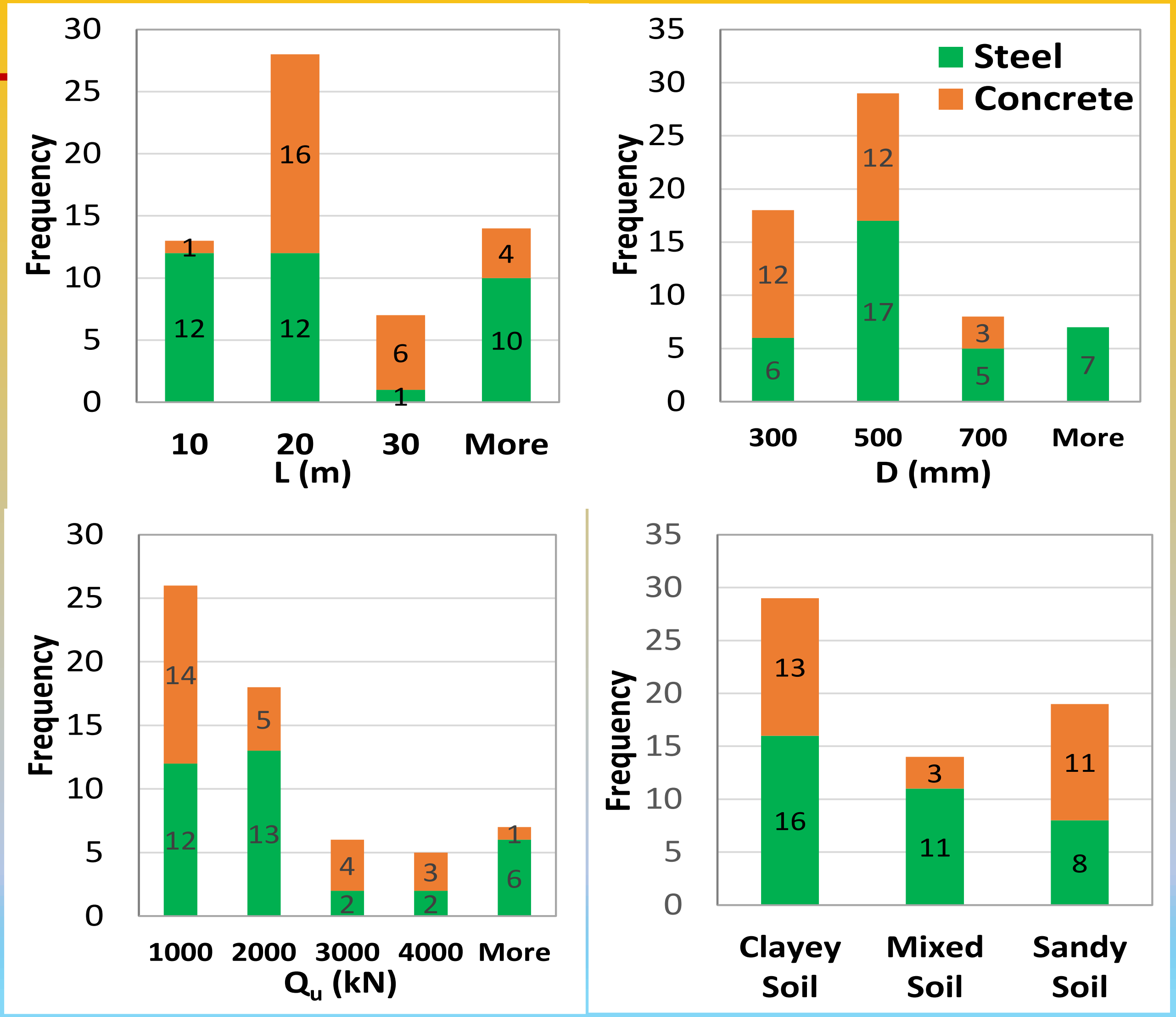
Outline

1	Generals
2	CPT and Pile Databases
3	**Statistics and Probabilistic Criteria**
4	Reliability-Based Approach
5	Discussions and Assessment
6	Remarks and Conclusions

3-Statistics and Probabilistic Criteria

In this study to access the performance of CPT-based methods

- A database of 62 piles with their adjacent CPT records from AUT:GEO-CPT&Pile database was gathered.
- These records belong to different continents:
    - Asia (31%),
    - Europe (24%),
    - North America (42%), and
    - Australia (3%).
- About 47%, 23%, and 30% of site soils are clayey soil, mixed soil, and sandy soil, respectively.

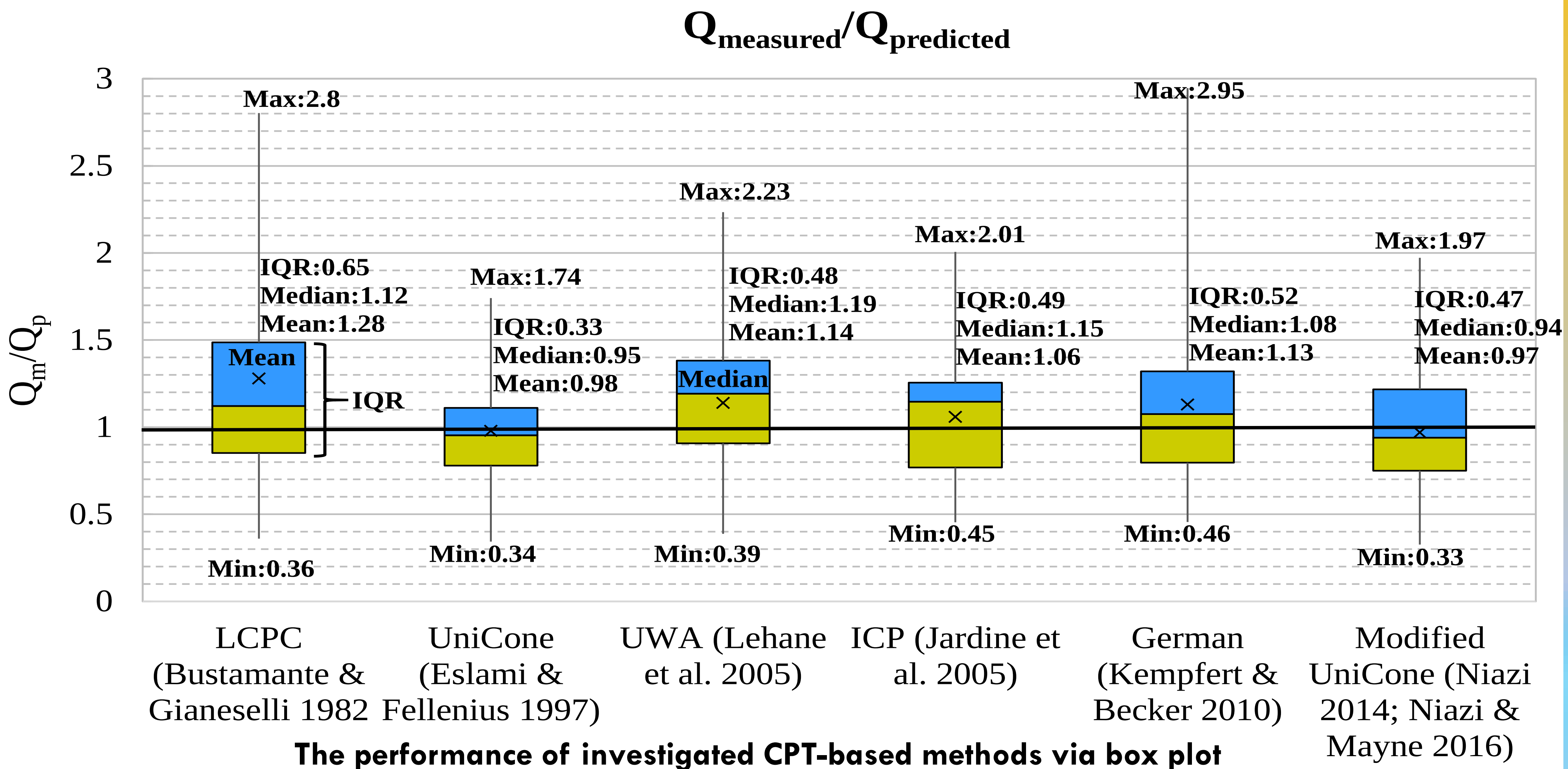


Characteristics of studied piles according to their material; (a) Length, (b) dimension, (c) ultimate bearing capacity and (d) soil type

3-Statistics and Probabilistic Criteria

- CPT-based methods outperforms other approaches in prediction of piles' bearing capacity for the investigated database.
- Six CPT-based methods were selected
  - LCPC (Bustamante and Gianeselli 1982)
  - UniCone (Eslami and Fellenius 1997)
  - UWA (Lehane et al. 2005)
  - ICP (Jardine et al. 2005)
  - German (Kempfert and Becker 2010)
  - Modified UniCone (Niazi 2014 & Niazi and Mayne 2016)
- The probabilistic and statistical criteria include
  - Mean and coefficient of variation
  - Best fitted line
  - 20% accuracy level
  - Cumulative probability (P_{50}, P_{90})
  - Root mean square error (RMSE)

3-Statistics and Probabilistic Criteria



The performance of investigated CPT-based methods via box plot

3-Statistics and Probabilistic Criteria

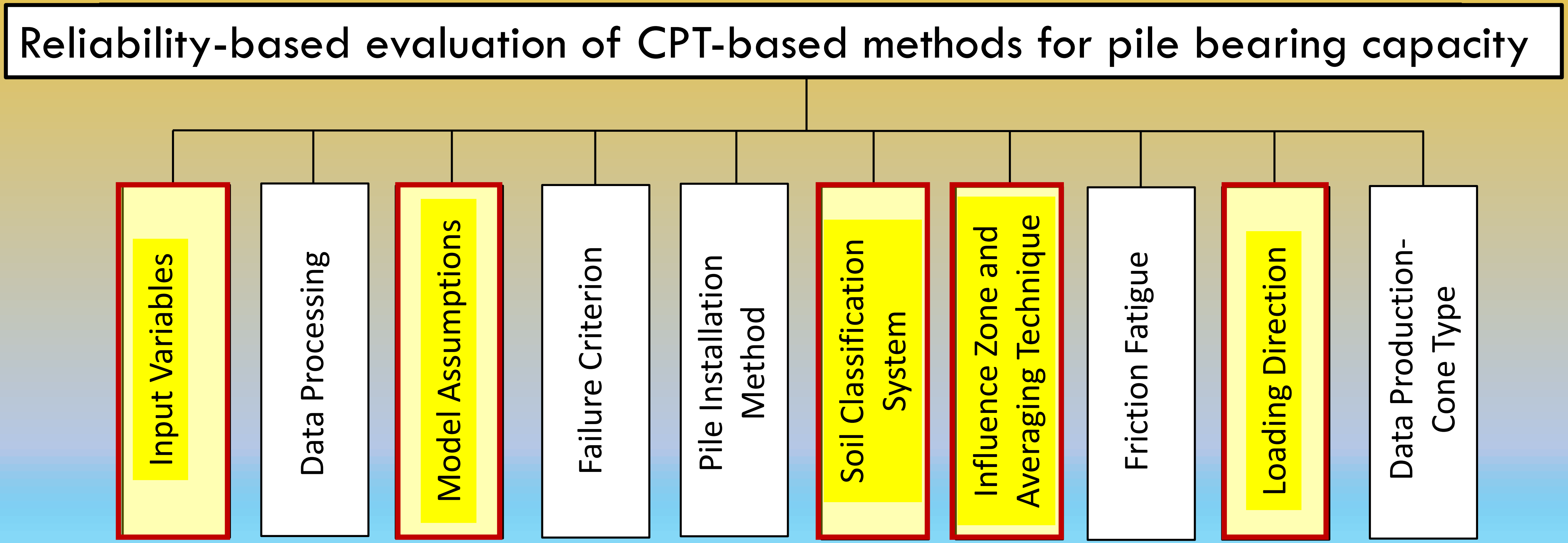
Performance of the methods via statistical and probabilistic criteria

Methods	C_1			C_2			C_3		C_4			C_5	
	μ	COV	R_1	Q_{fit}/Q_m	R^2	R_2	20% AL*	R_3	P_{50}	P_{90}	R_4	‡RMSE	R_5
LCPC (Bustamante & Gianeselli 1982)	1.28	0.44	1	0.83	0.78	2	0.34	1	1.12	2.16	3	3346	3
UniCone (Eslami & Fellenius 1997)	0.98	0.33	6	1.05	0.8	6	0.46	6	0.95	1.45	6	1836	5
UWA (Lehane et al. 2005)	1.14	0.35	2	1.12	0.62	3	0.4	3	1.19	1.71	1	3461	2
ICP (Jardine et al. 2005)	1.06	0.34	4	1.09	0.69	4	0.43	4	1.15	1.49	2	4136	1
German (Kempfert & Becker 2010)	1.13	0.42	3	1.04	0.69	5	0.39	2	1.08	1.69	4	964	6
Modified UniCone (Niazi 2014; Niazi &Mayne 2016)	0.97	0.33	5	1.32	0.66	1	0.43	5	0.94	1.30	5	2570	4

*AL: Acceptance Level; ‡RMSE: Root Mean Square Error

Outline

4-Reliability-based criteria

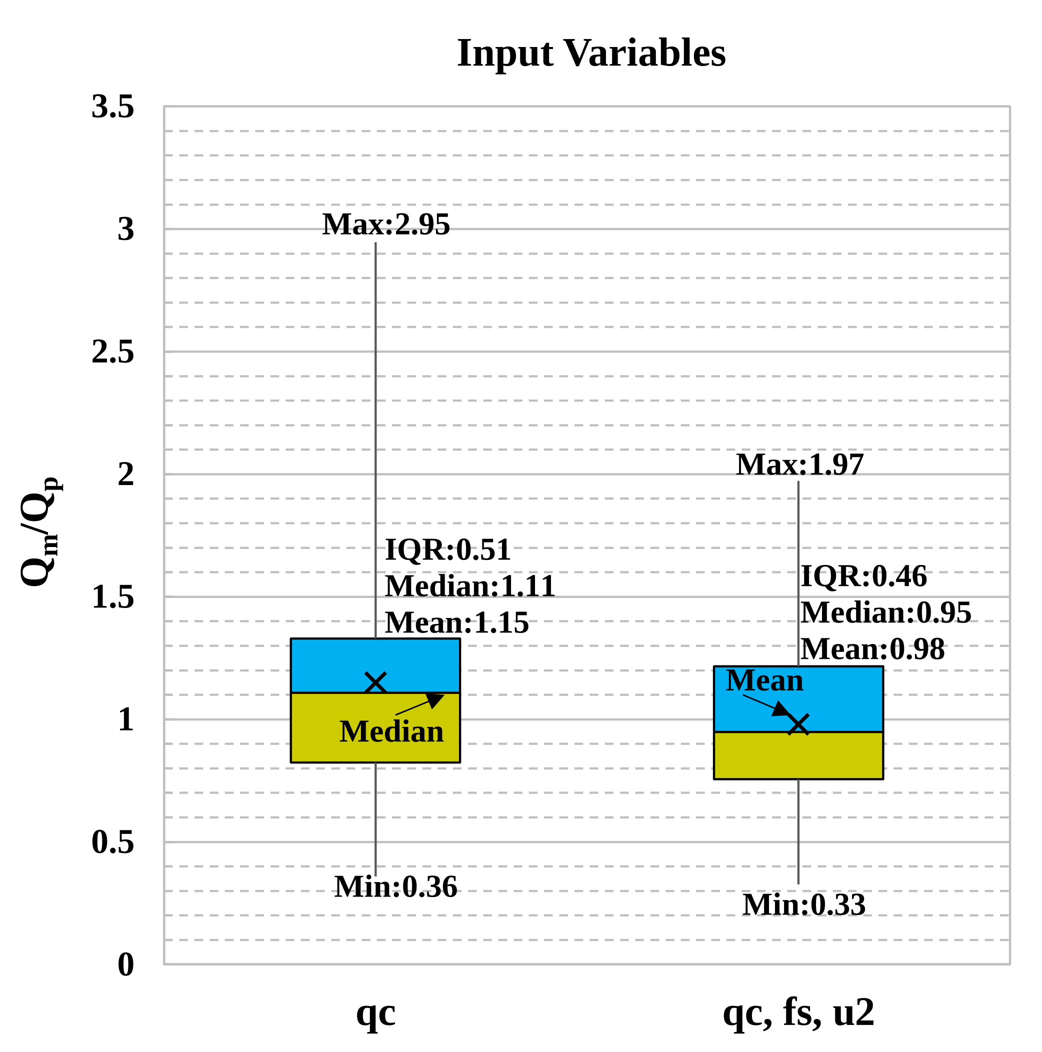


Reliability based assessment criteria (Eslami et al. 2019)

4-Reliability-based Approach

Characteristics of classified groups according to "input variables" criterion; β_{Target}=2.33, Q_D/Q_L=3

		$\mu_{Qm/Qp}$	$COV\mu_{Qm/Qp}$	Range	$\varphi^{\dagger}$	$ER^{\ddagger}$
Input Variables	1 Variable	1.15	0.4	2.59	0.53	**0.48**
	3 Variables	0.98	0.33	1.65	0.53	**0.54**
	$\varphi^{\dagger}$: Resistance factor; $ER^{\ddagger}$: Efficiency Ratio					

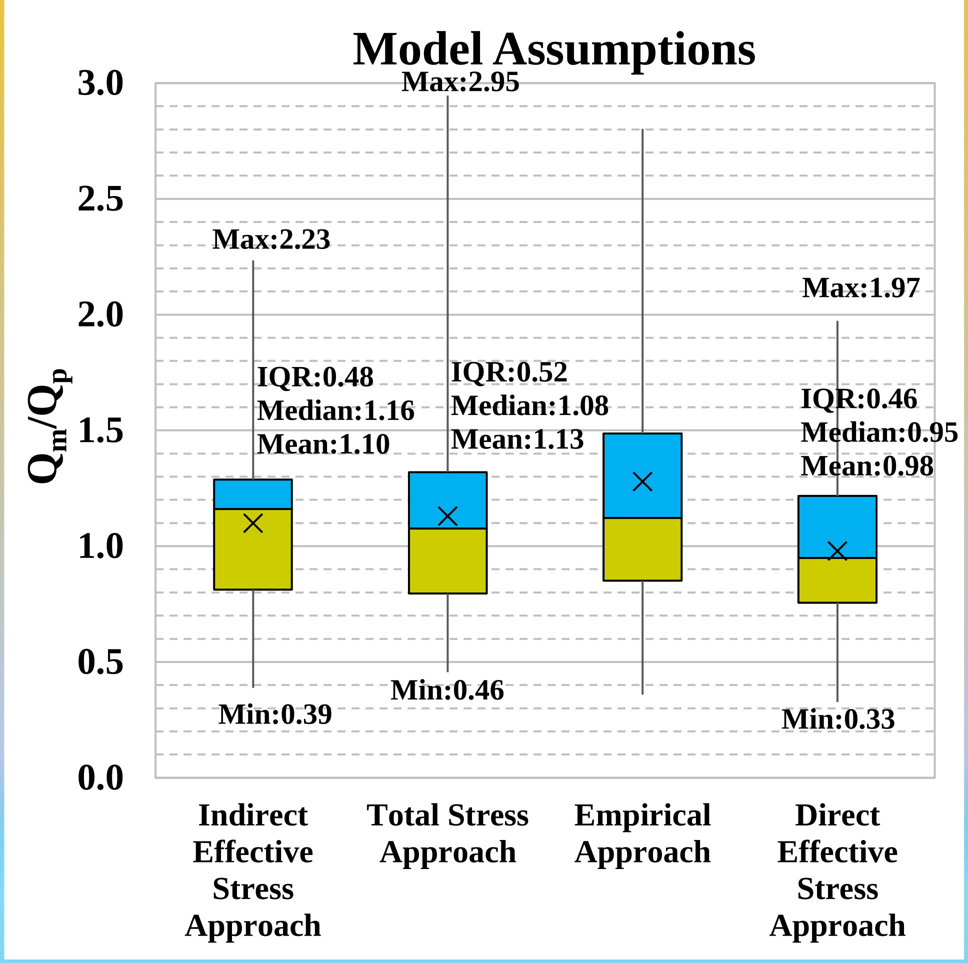


The efficiency ratio for CPT-Based methods classified according to "Input Variables"

4-Reliability-based Approach

Characteristics of classified groups according to "Model Assumptions" criterion; β_{Target}=2.33, Q_D/Q_L=3

		$\mu_{Qm/Qp}$	$COV_{\mu_{Qm/Qp}}$	Range	$\varphi^{\dagger}$	$ER^{\ddagger}$
Model Assumptions	Indirect Effective Stress Approach	1.10	0.35	1.85	0.57	0.52
	Total Stress Approach	1.13	0.42	2.49	0.5	0.44
	Empirical Approach	1.28	0.44	2.44	0.54	0.42
	Direct Effective Stress Approach	0.98	0.33	1.65	0.53	0.54
	$\varphi^{\dagger}$: Resistance factor; $ER^{\ddagger}$: Efficiency Ratio					

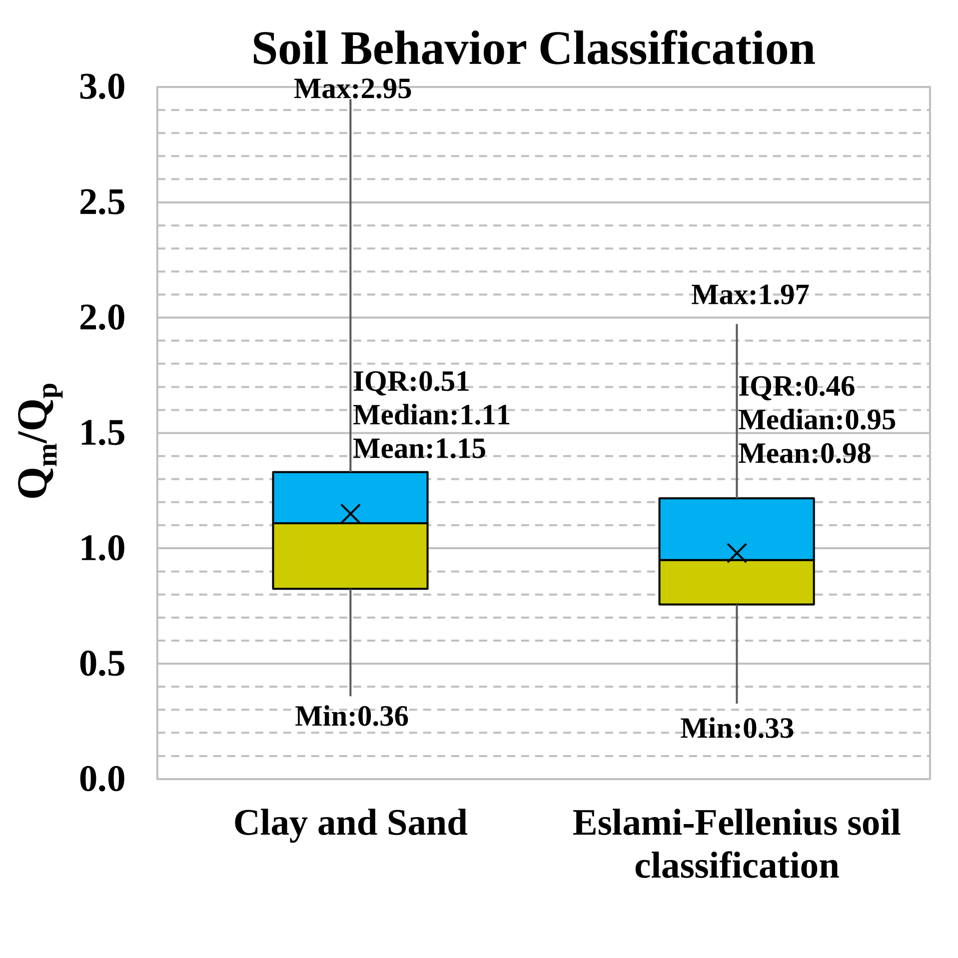


The efficiency ratio for CPT-Based methods classified according to "Model Assumptions"

4-Reliability-based Approach

Characteristics of classified groups according to "Soil Behavior Classification" criterion; β_{Target}=2.33, Q_D/Q_L=3

		$\mu_{Qm/Qp}$	$COV\mu_{Qm/Qp}$	Range	$\varphi^{\dagger}$	$ER^{\ddagger}$
Soil Behavior Classification	Clay and Sand	1.15	0.4	2.59	0.53	**0.46**
	Eslami-Fellenius Classification	0.98	0.33	1.65	0.53	**0.54**
	$\varphi^{\dagger}$: Resistance factor; $ER^{\ddagger}$: Efficiency Ratio					

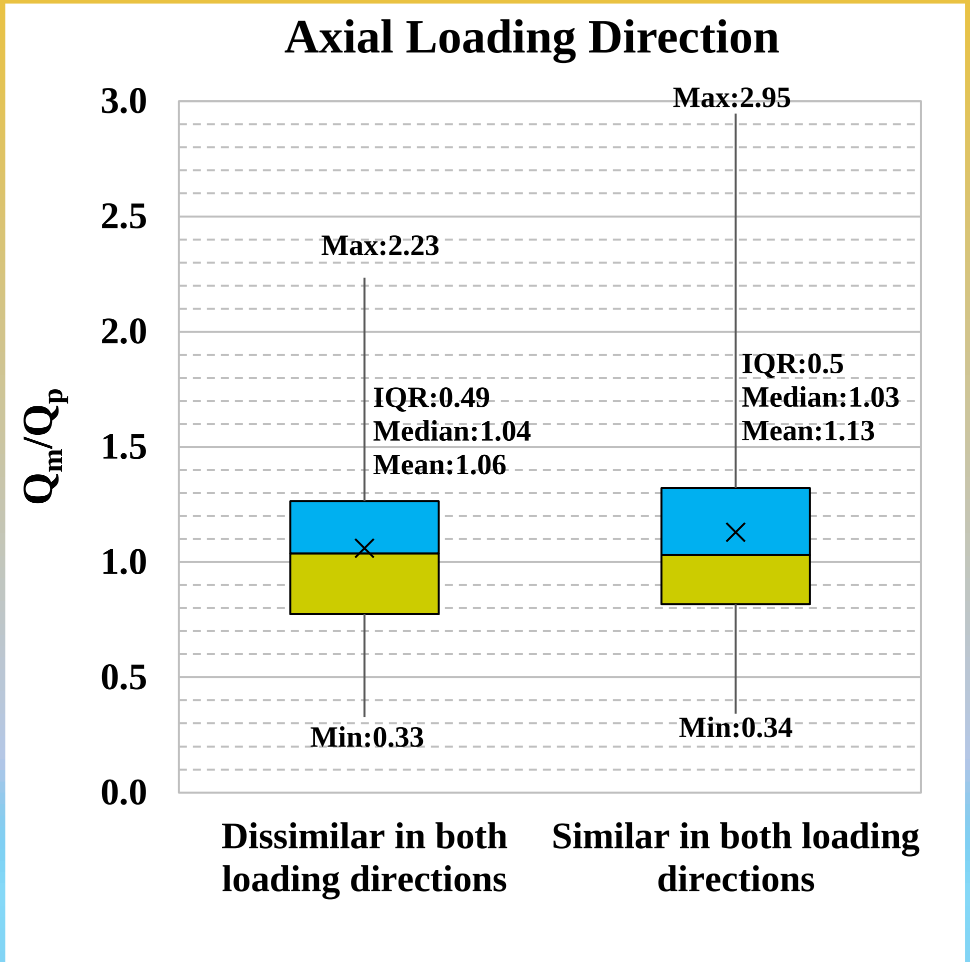


The efficiency ratio for CPT-Based methods classified according to "Soil Behavior Classification"

4-Reliability-based Approach

Characteristics of classified groups according to "input variables" criterion; β_{Target}=2.33, Q_D/Q_L=3

		$\mu_{Qm/Qp}$	$COV_{\mu Qm/Qp}$	Range	$\varphi^{\dagger}$	ER‡
Axial Loading Direction	Distinction between axial loading directions	1.06	0.35	1.91	0.55	**0.46**
	No distinction between axial loading directions	1.13	0.42	2.60	0.5	**0.44**
	φ†: Resistance factor; ER‡: Efficiency Ratio					

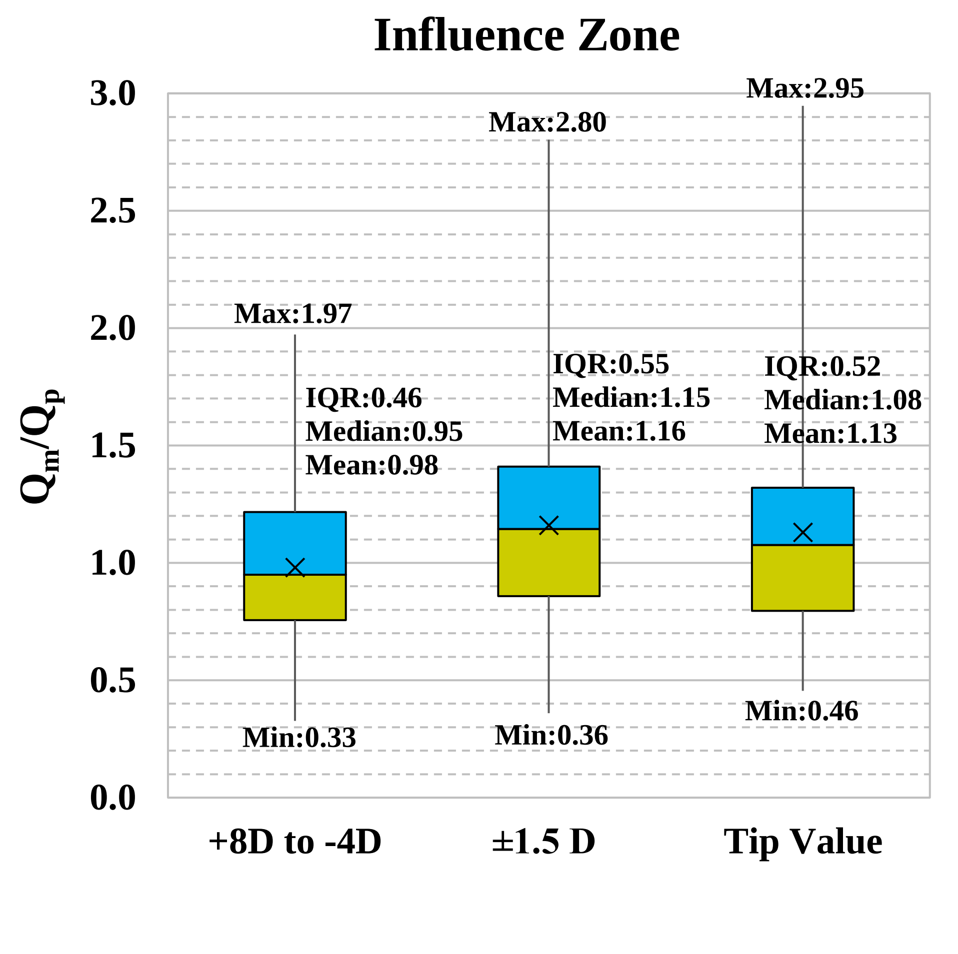


The efficiency ratio for CPT-Based methods classified according to "Axial Loading Direction"

4-Reliability-based Approach

Characteristics of classified groups according to "Influence Zone" criterion; β_{Target}=2.33, Q_D/Q_L=3

		$\mu_{Qm/Qp}$	$COV_{\mu Qm/Qp}$	Range	φ[†]	ER[‡]
Influence Zone	+8D to -4D (geometric mean)	0.98	0.33	1.65	0.53	**0.54**
	±1.5D	1.16	0.4	2.44	0.53	**0.46**
	Tip value	1.13	0.42	2.49	0.5	**0.44**
	φ[†]: Resistance factor; ER[‡]: Efficiency Ratio					



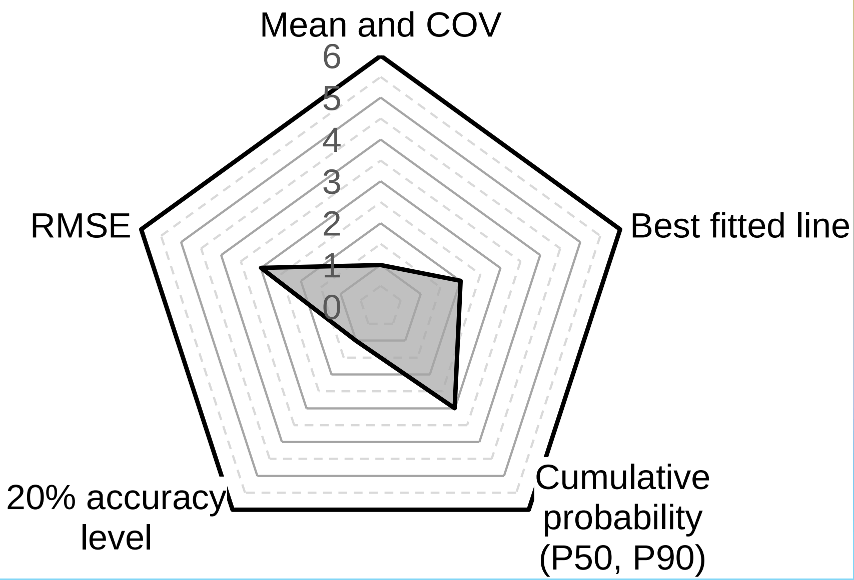
The efficiency ratio for CPT-Based methods classified according to "Influence Zone"

Outline

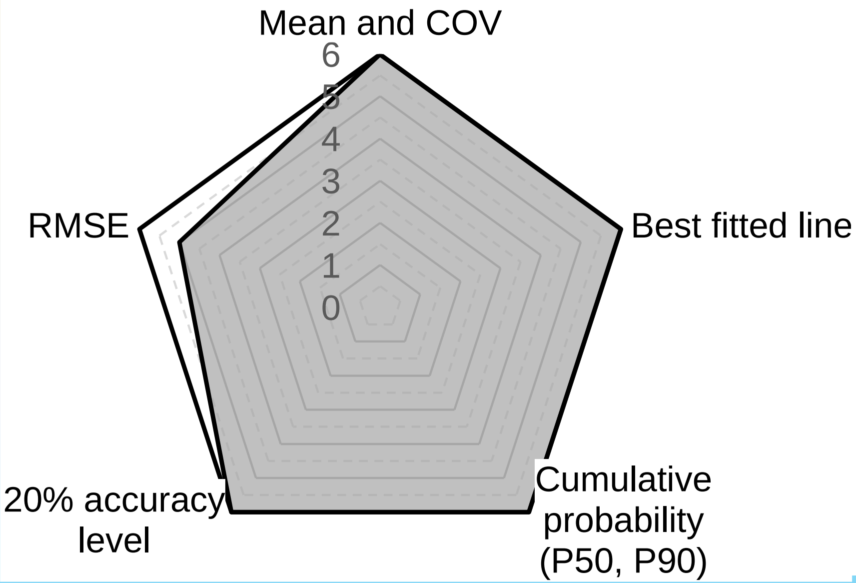
5-Discussions and Assessments

The performance of CPT-based methods according to statistical and probabilistic criteria

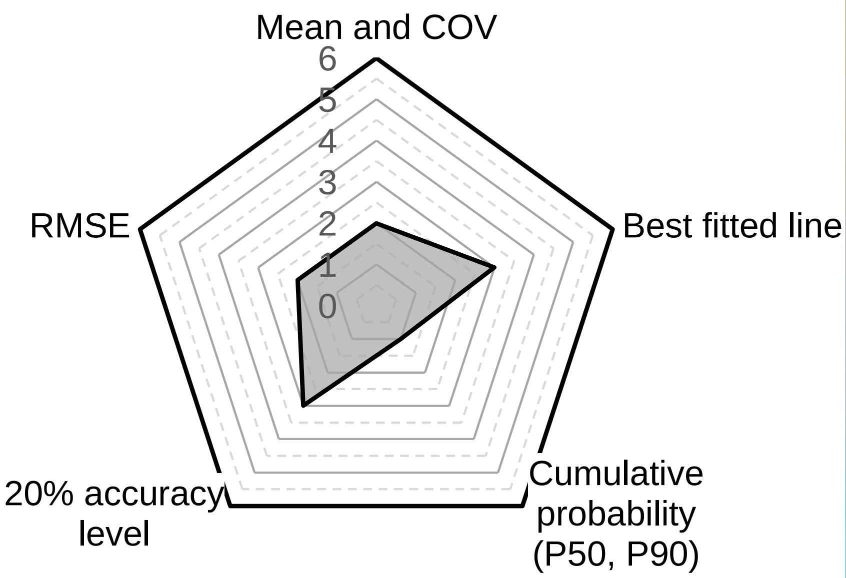
LCPC (Bustamante and Gianeselli 1982)
Area Ratio=9%



UniCone (Esalmi and Fellenius 1997)
Area Ratio=93%



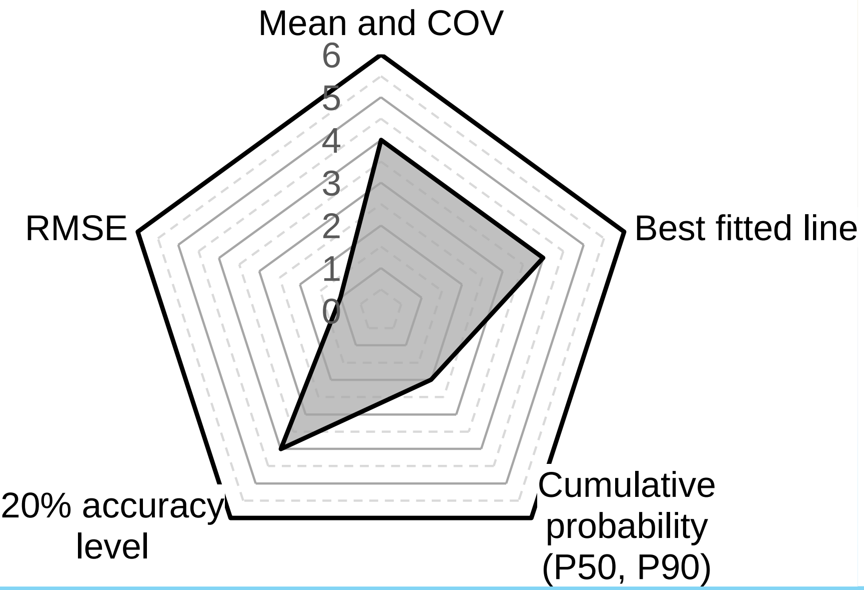
UWA (Lehane et al. 2005)
Area Ratio=12%



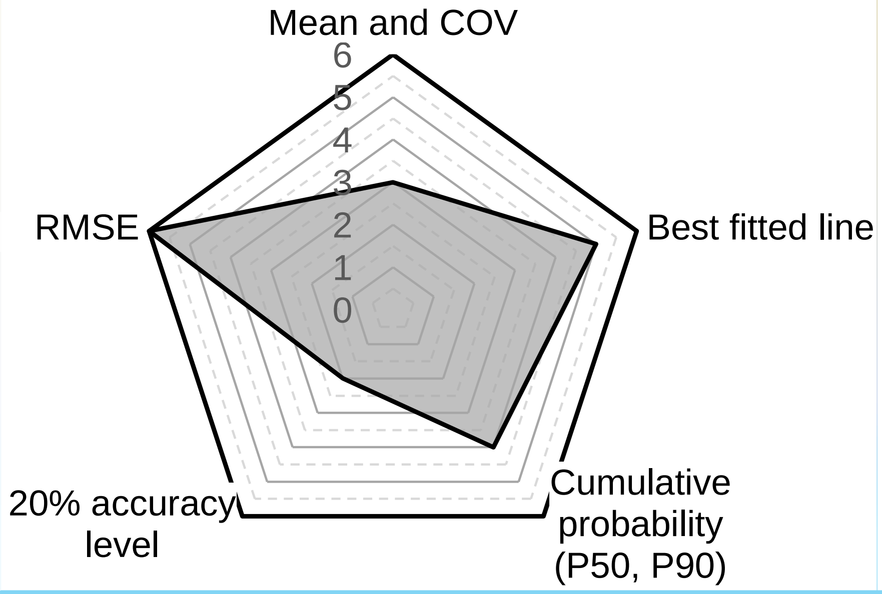
5-Discussions and Assessments

The performance of CPT-based methods according to statistical and probabilistic criteria

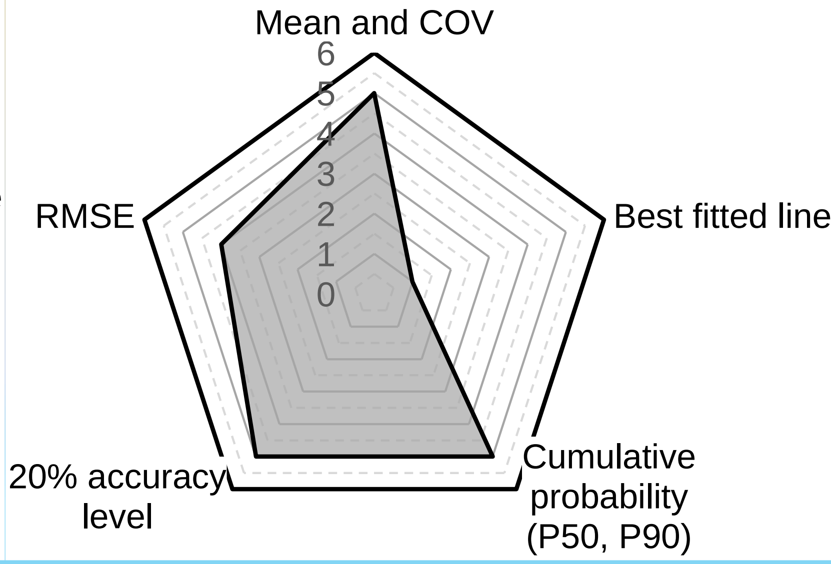
ICP (Jardine et al. 2005)
Area Ratio=22%



German (Kempfert and Becker 2010)
Area Ratio=41%



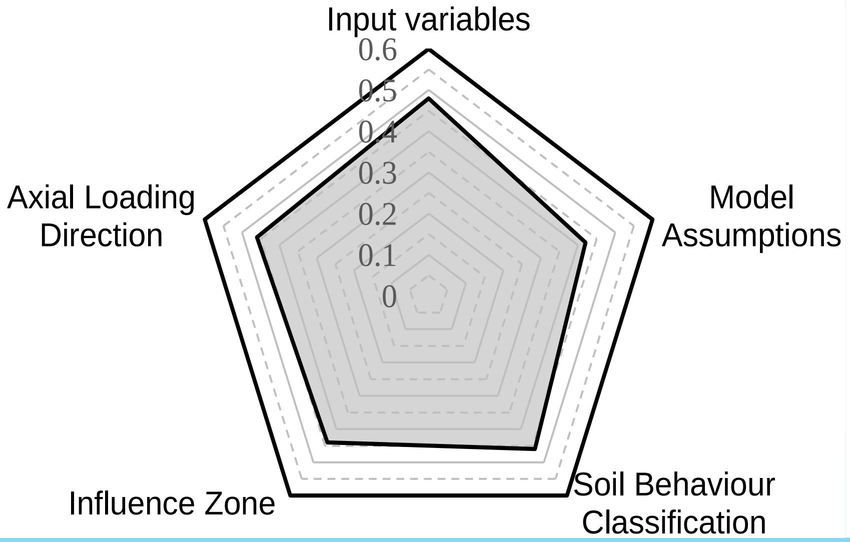
Modified UniCone
(Niazi 2014; Niazi and Mayne 2016)
Area Ratio=42%



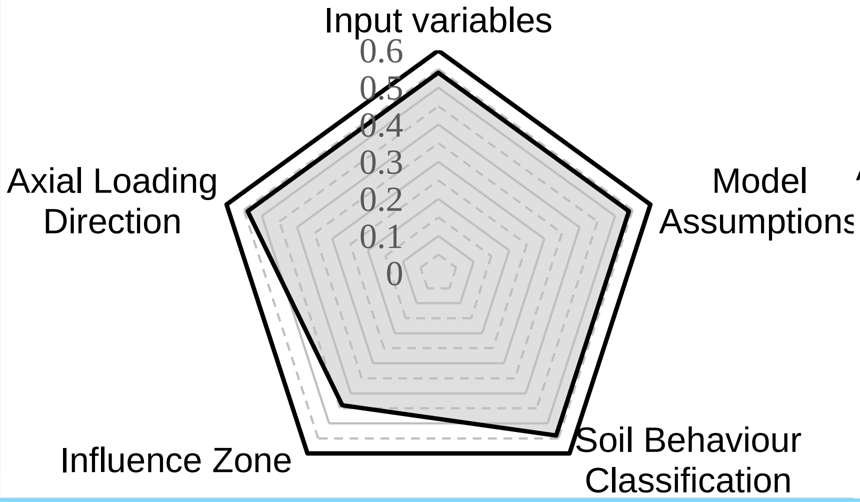
5-Discussions and Assessments

The performance of CPT-based methods according to reliability-based criteria

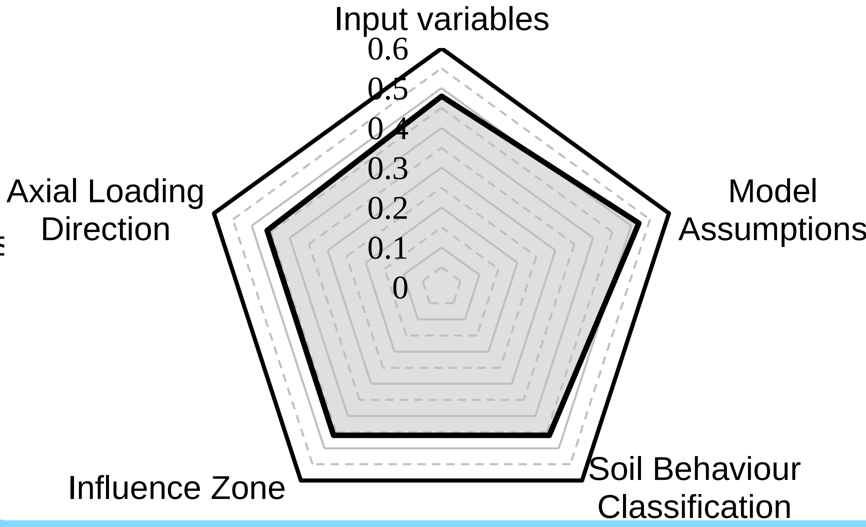
LCPC (Bustamante and Gianeselli 1982)
Area Ratio=57%



UniCone (Eslami and Fellenius 1997)
Area Ratio=75%



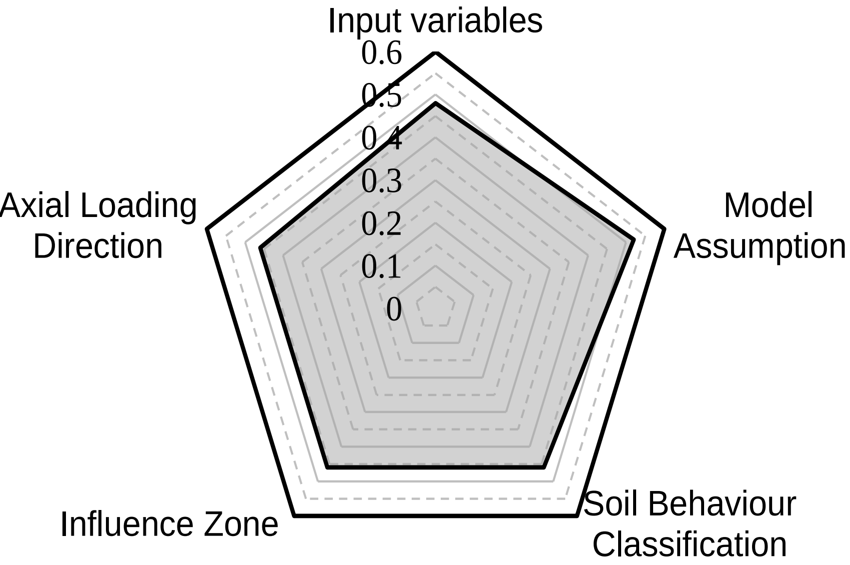
ICP (Jardine et al. 2005)
Area Ratio=63%



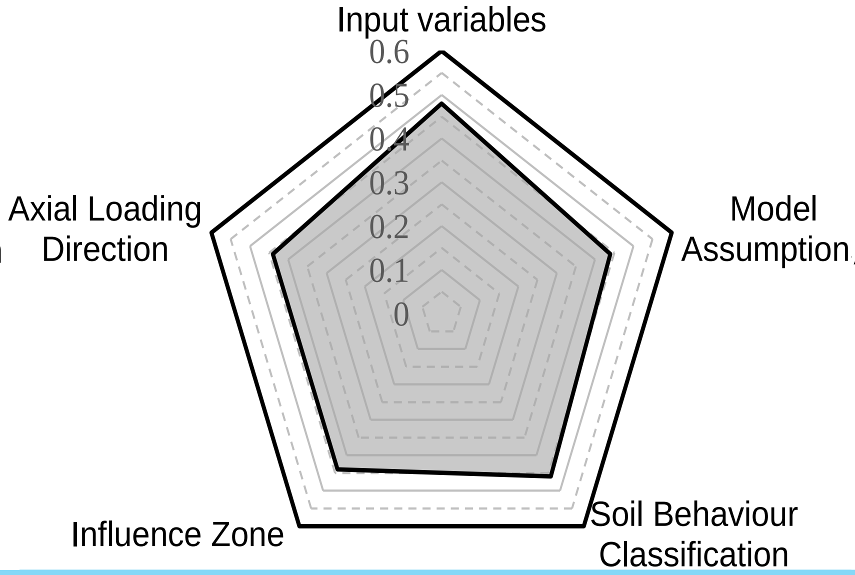
5-Discussions and Assessments

The performance of CPT-based methods according to reliability-based criteria

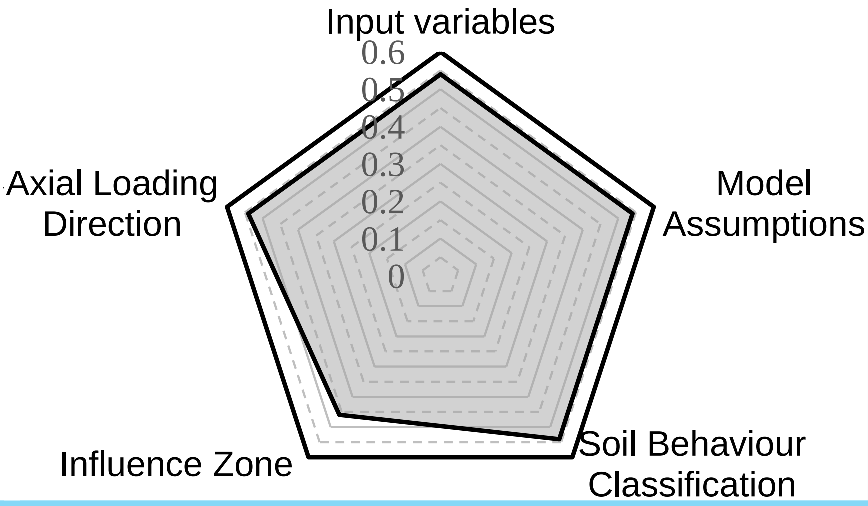
UWA (Lehane et al. 2005)
Area Ratio=63%



German (Kempfert and Becker 2010)
Area Ratio=57%

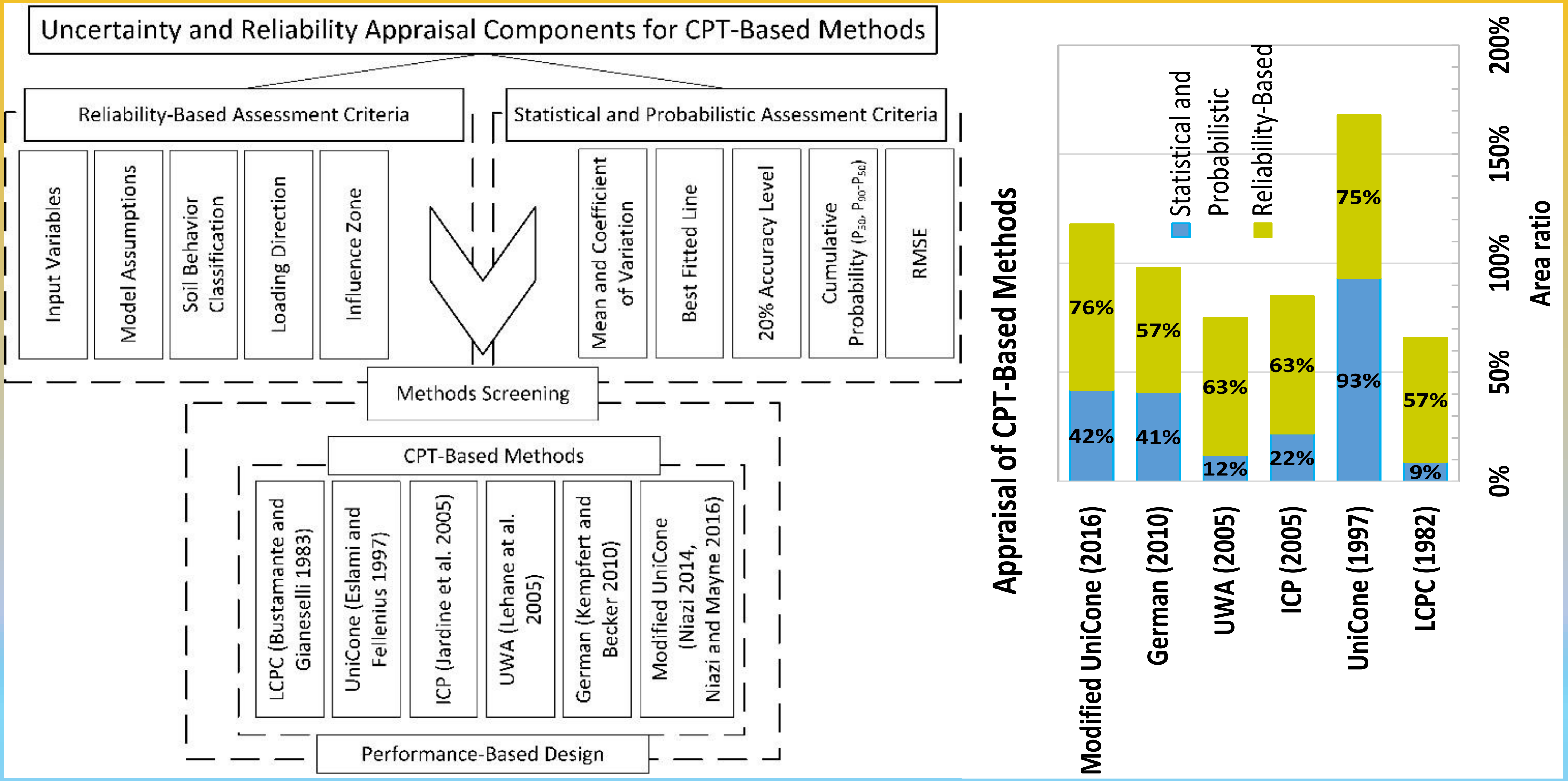


Modified UniCone
(Niazi 2014, Niazi and Mayne 2016)
Area Ratio=76%



5-Discussions and Assessments

Methods screening (a) appraisal components (b) the performance of CPT-based methods via investigated criteria

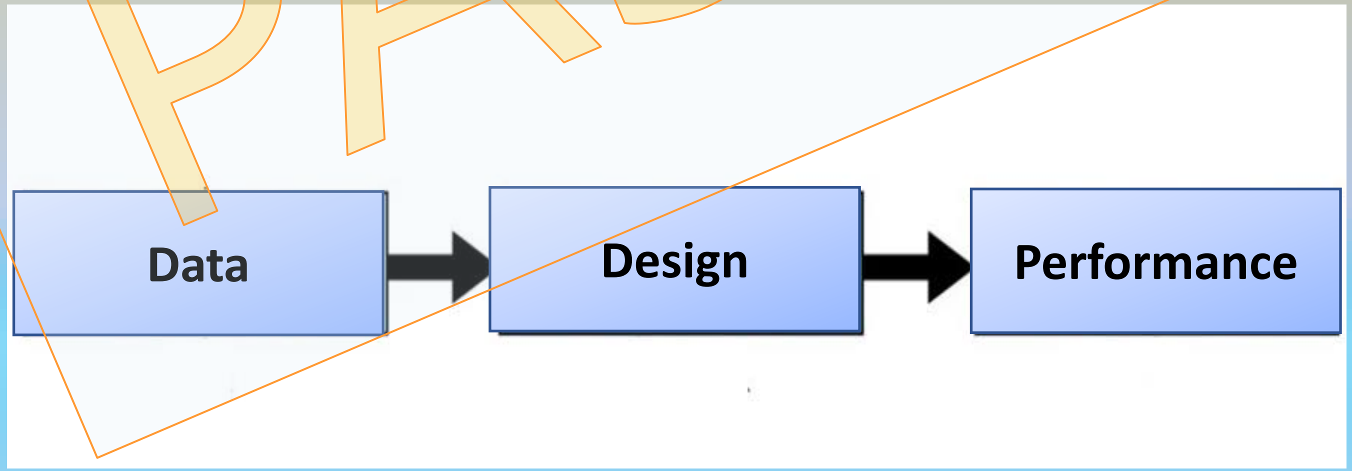


Outline

6-Remarks and Conclusions

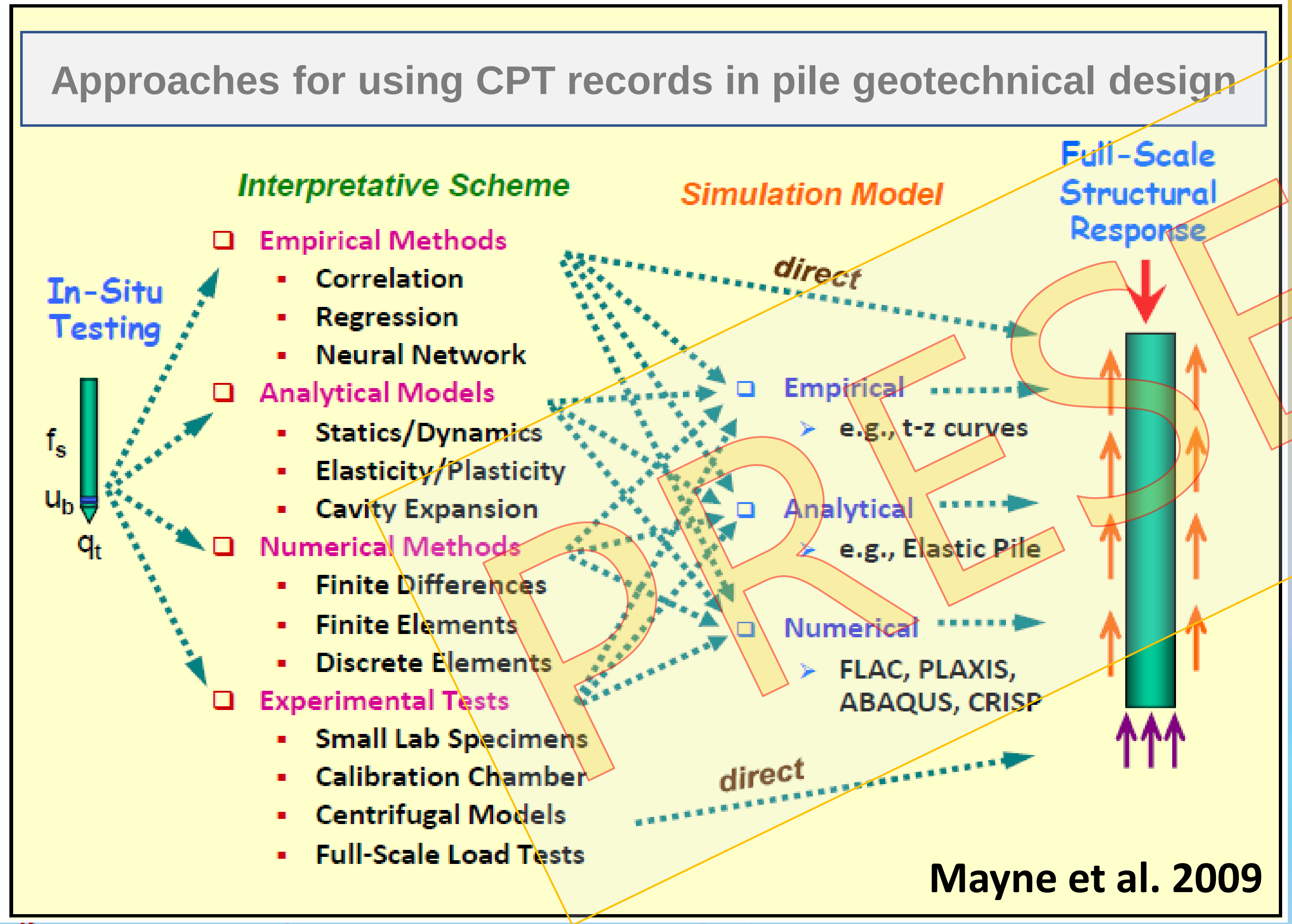
1. CPT and Pile (Past):

- Provides continuous records with depth
- Cone penetrometer is considered as a model pile
- Direct and indirect approaches for bearing capacity
- Bearing capacity methods: more than 28 currently used

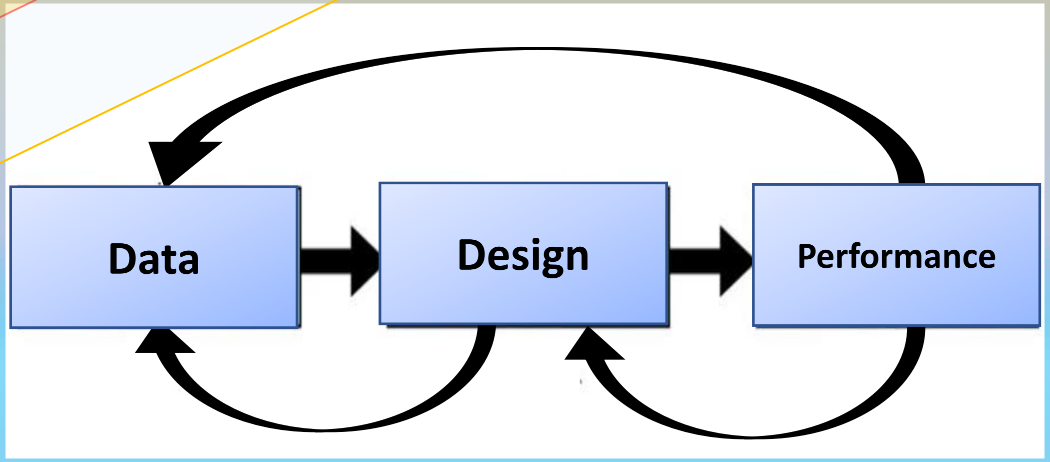


6-Remarks and Conclusions

2. CPT & CPTu: Pile Geotechnical Design (Present):

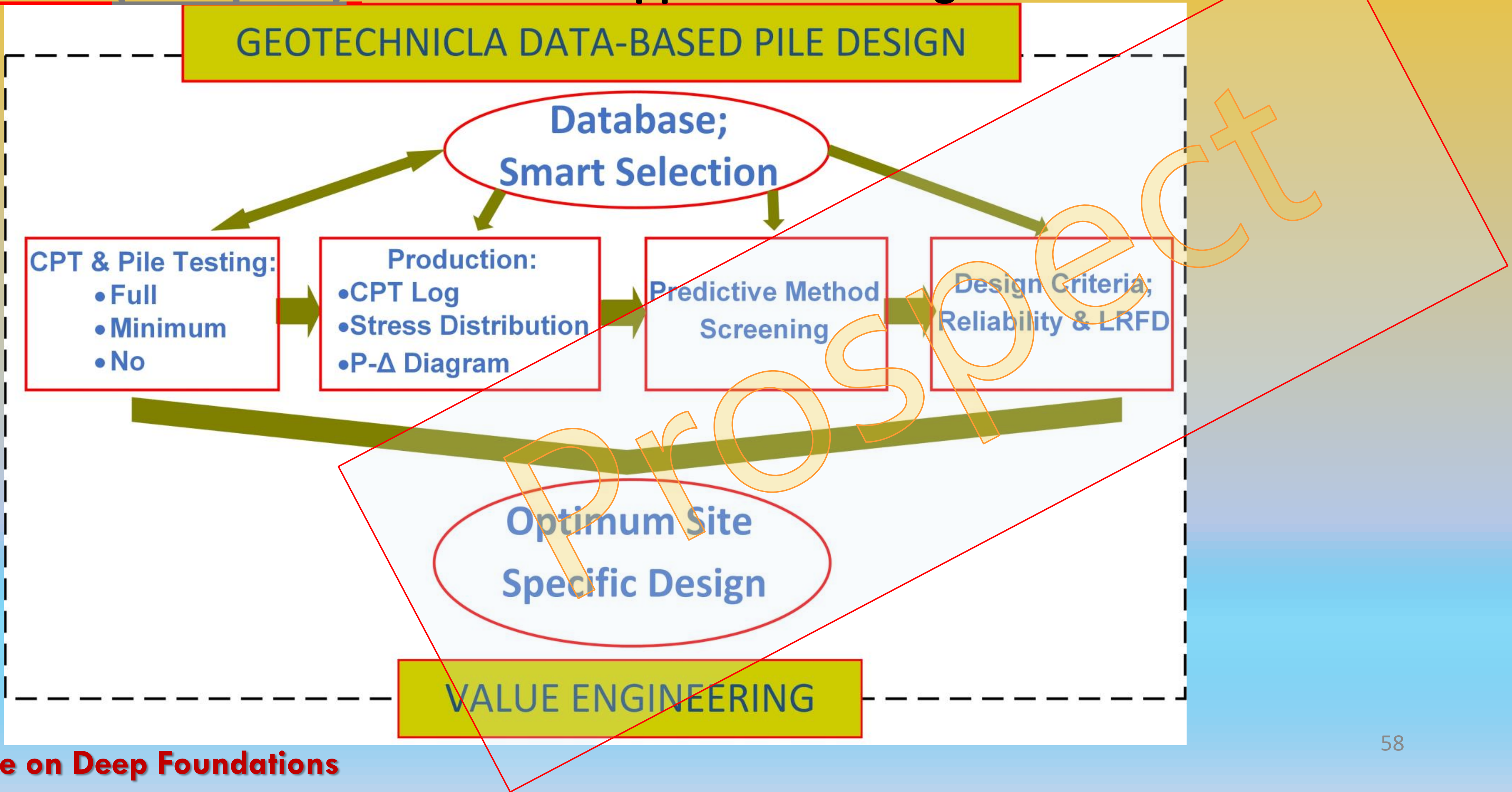


Mayne et al. 2009



6-Remarks and Conclusions

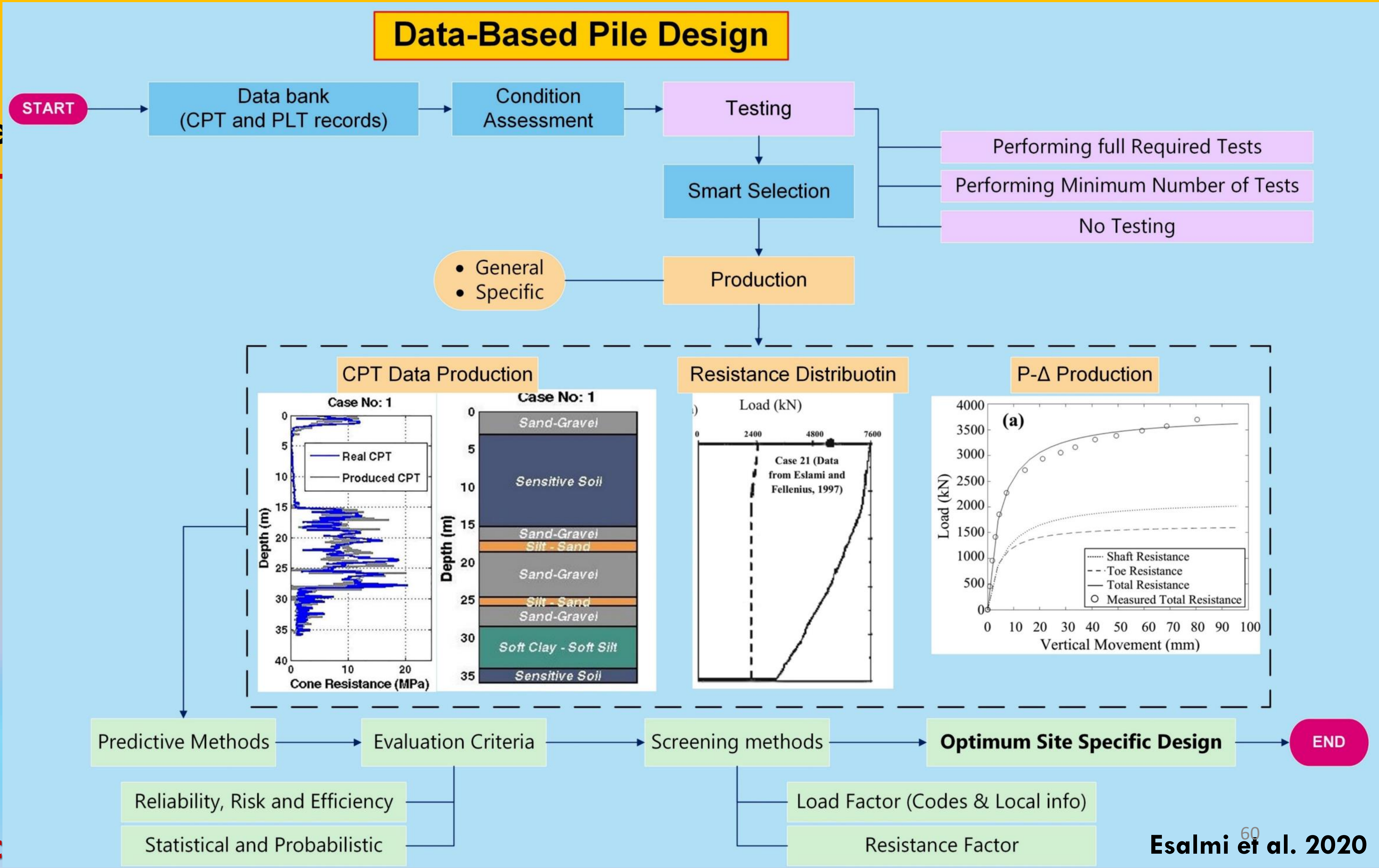
3. New trends (Prospect): Data-based approach in design



6-Remarks and Conclusions

- **Reliability-based criteria include**
  - Input variables,
  - Model assumptions,
  - Soil behavior classification
  - Loading direction and
  - Influence zone and averaging technique
  - Data processing
  - Pile installation method
  - Friction Fatigue
  - Failure Criterion
  - Data production-cone type
- **The statistic and probabilistic criteria include**
  - Mean and coefficient of variation,
  - Best-fitted line,
  - Cumulative probability,
  - 20% accuracy level, and
  - RMSE
  - Efficiency ratio

6-Re



Data-Based Pile Design
START
Data bank (CPT and PLT records)
Condition Assessment
Testing
Performing full Required Tests
Performing Minimum Number of Tests
No Testing
Smart Selection
Production
• General
• Specific
CPT Data Production
Resistance Distribuotin
P-Δ Production
Case No: 1
Real CPT
Produced CPT
Depth (m)
Cone Resistance (MPa)
Sand-Gravel
Sensitive Soil
Silt - Sand
Soft Clay - Soft Silt
Load (kN)
Case 21 (Data from Eslami and Fellenius, 1997)
(a)
Shaft Resistance
Toe Resistance
Total Resistance
Measured Total Resistance
Vertical Movement (mm)
Predictive Methods
Evaluation Criteria
Screening methods
Optimum Site Specific Design
END
Reliability, Risk and Efficiency
Statistical and Probabilistic
Load Factor (Codes & Local info)
Resistance Factor
Esalmi et al. 2020

THANKS FOR YOUR ATTENTION

https://edudotiran.com/wp-content/uploads/2020/09/amirkabir-university-of-technology.jpg

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