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Contact Mechanics and its Normalized Indices for Trenchless Cutting Associated with Machine Learning

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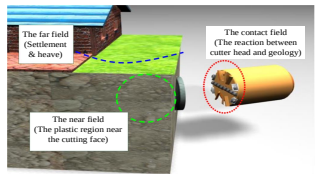
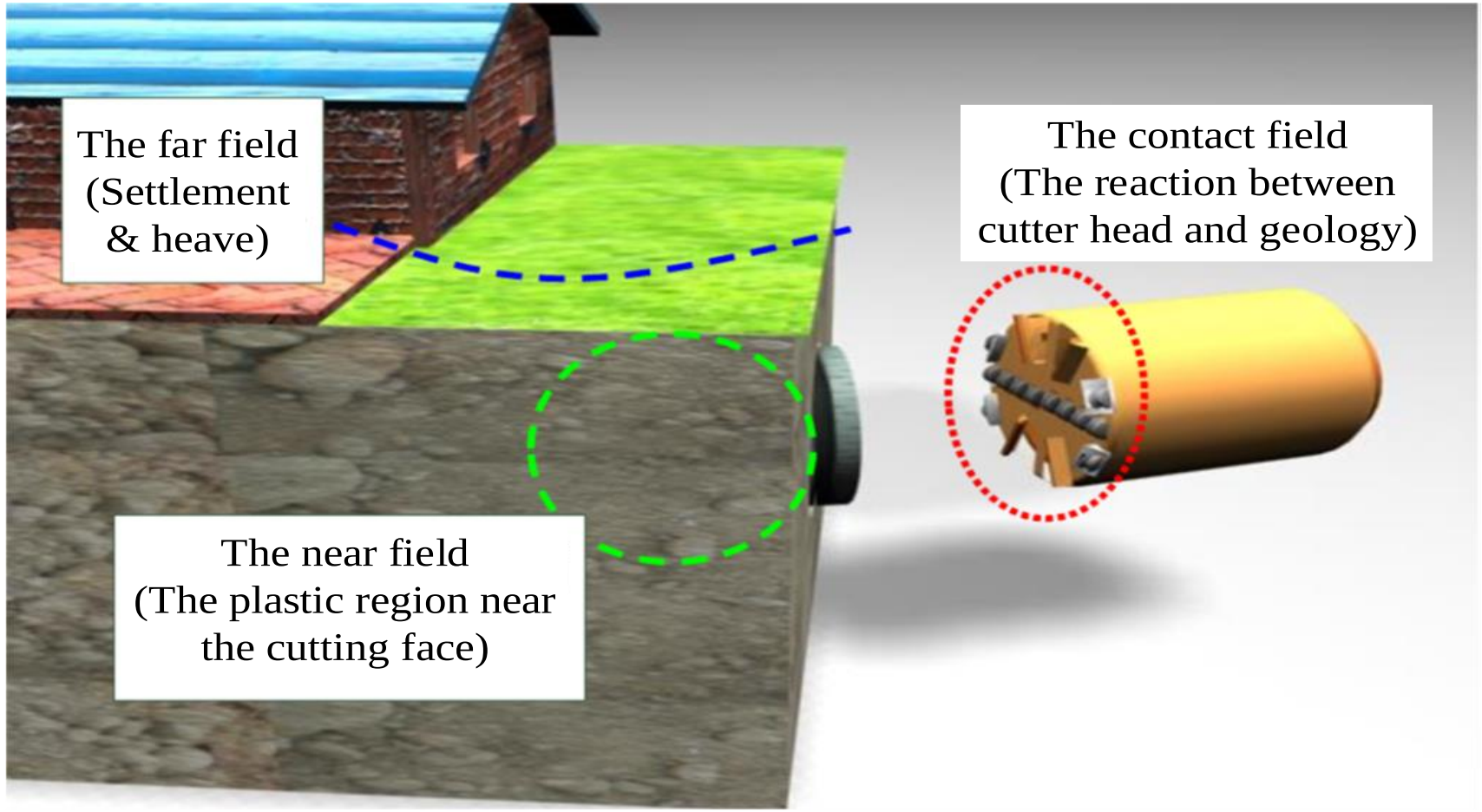
Contact Mechanics and its Normalized Indices for Trenchless Cutting Associated with Machine Learning

Motivation:

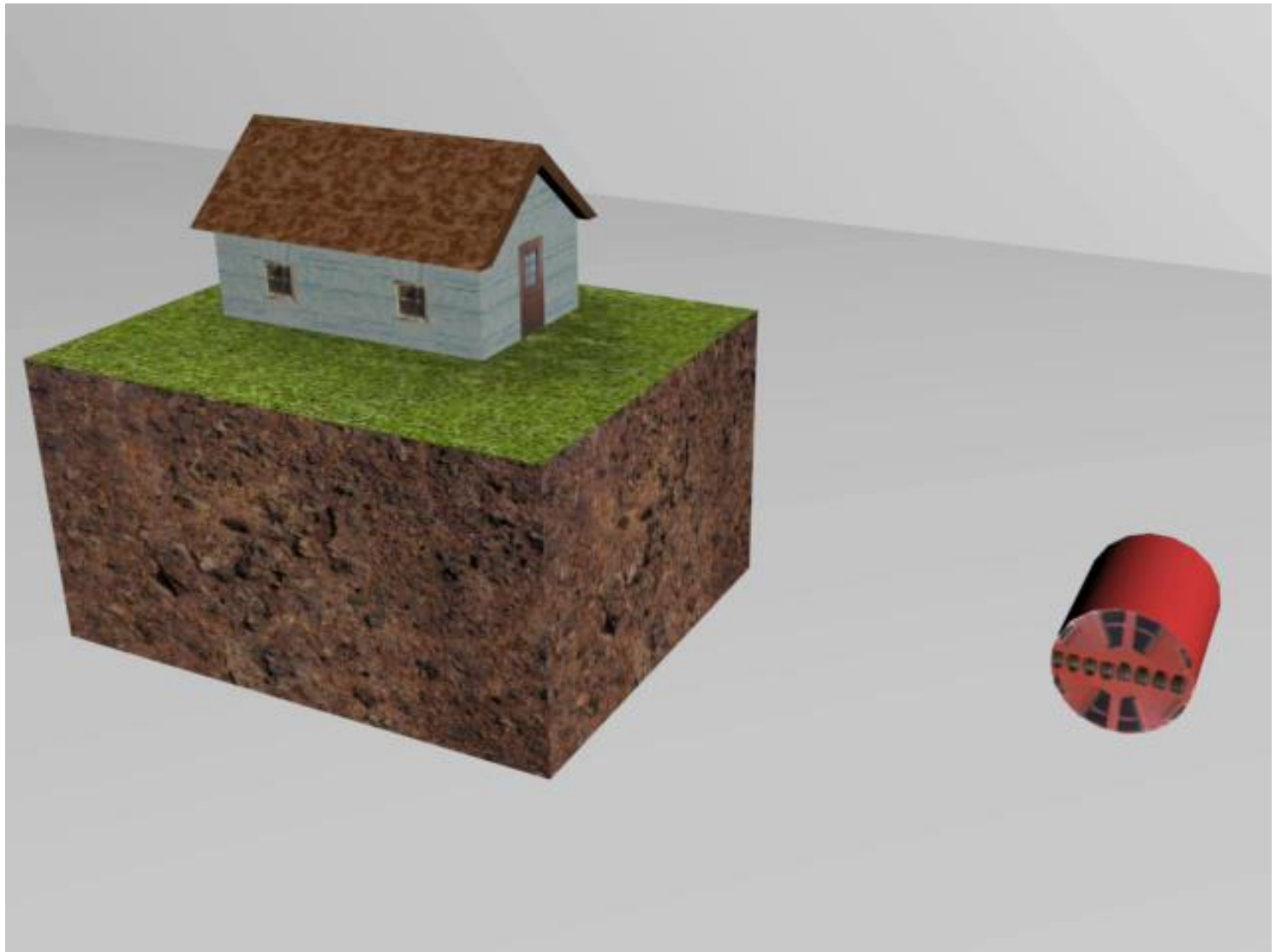
Make More Clear about Physical field:

1. Contact- ;
2. Near- ;
3. Far-field





Mechanism of Trenchless Cutting



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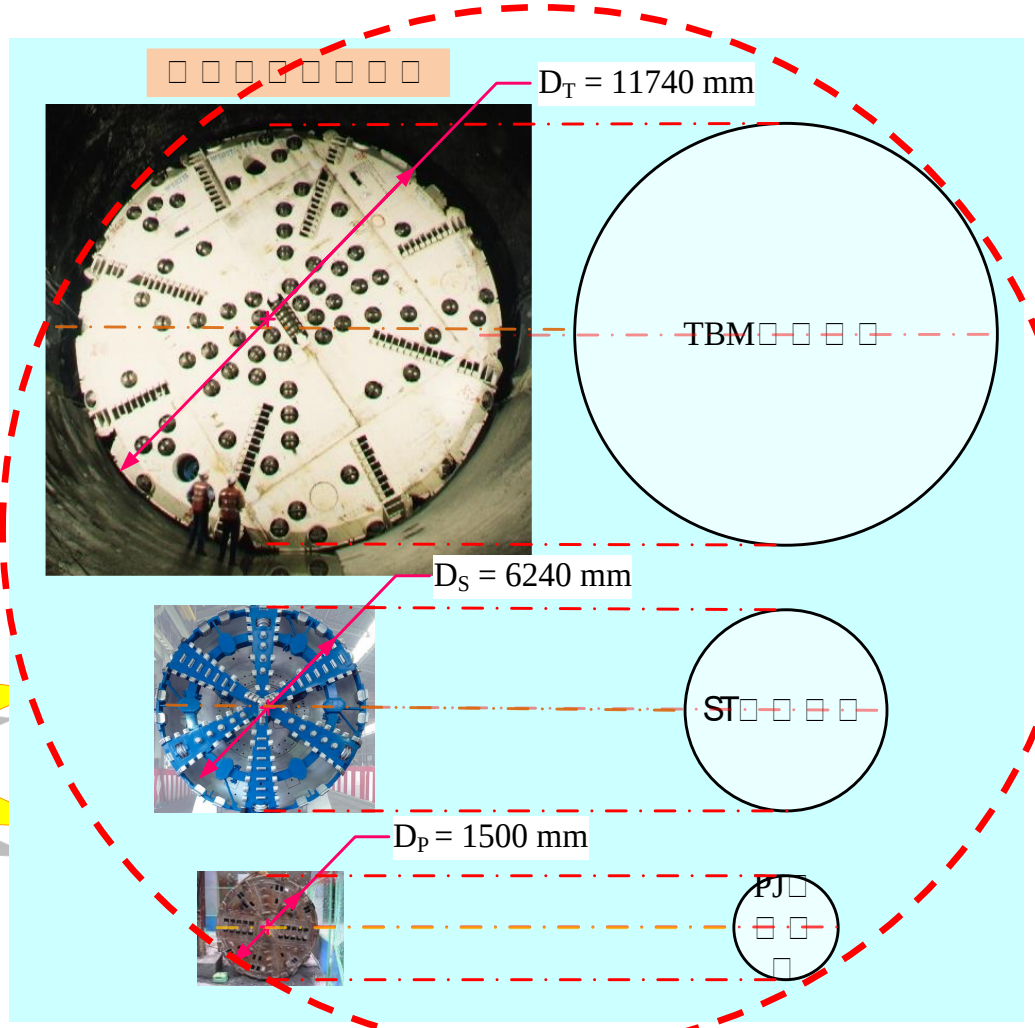
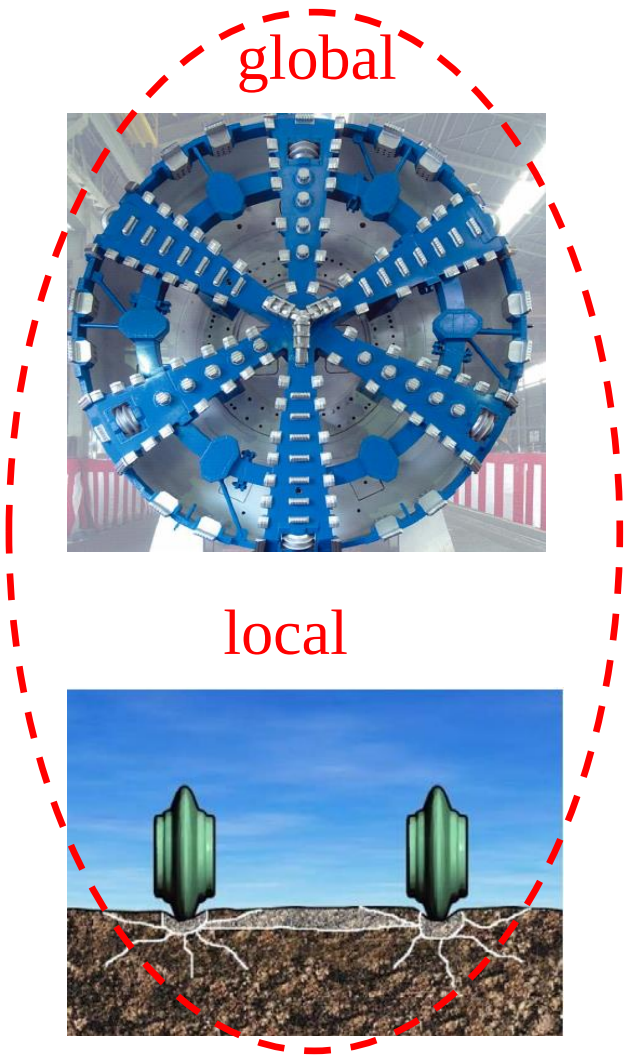
Motivation:

Possible to Generalize?





1. Rule-based Method: Mechanical generalized thrust system

- Classical Contact Mechanics
- Normalized Indices

2. Data-driven Approach: Machine Learning

- Identification: Cutting Process & Indices above
- Prediction: Geo-conditions ahead of Cutting Face

1. Rule-based Method: Mechanical generalized thrust system

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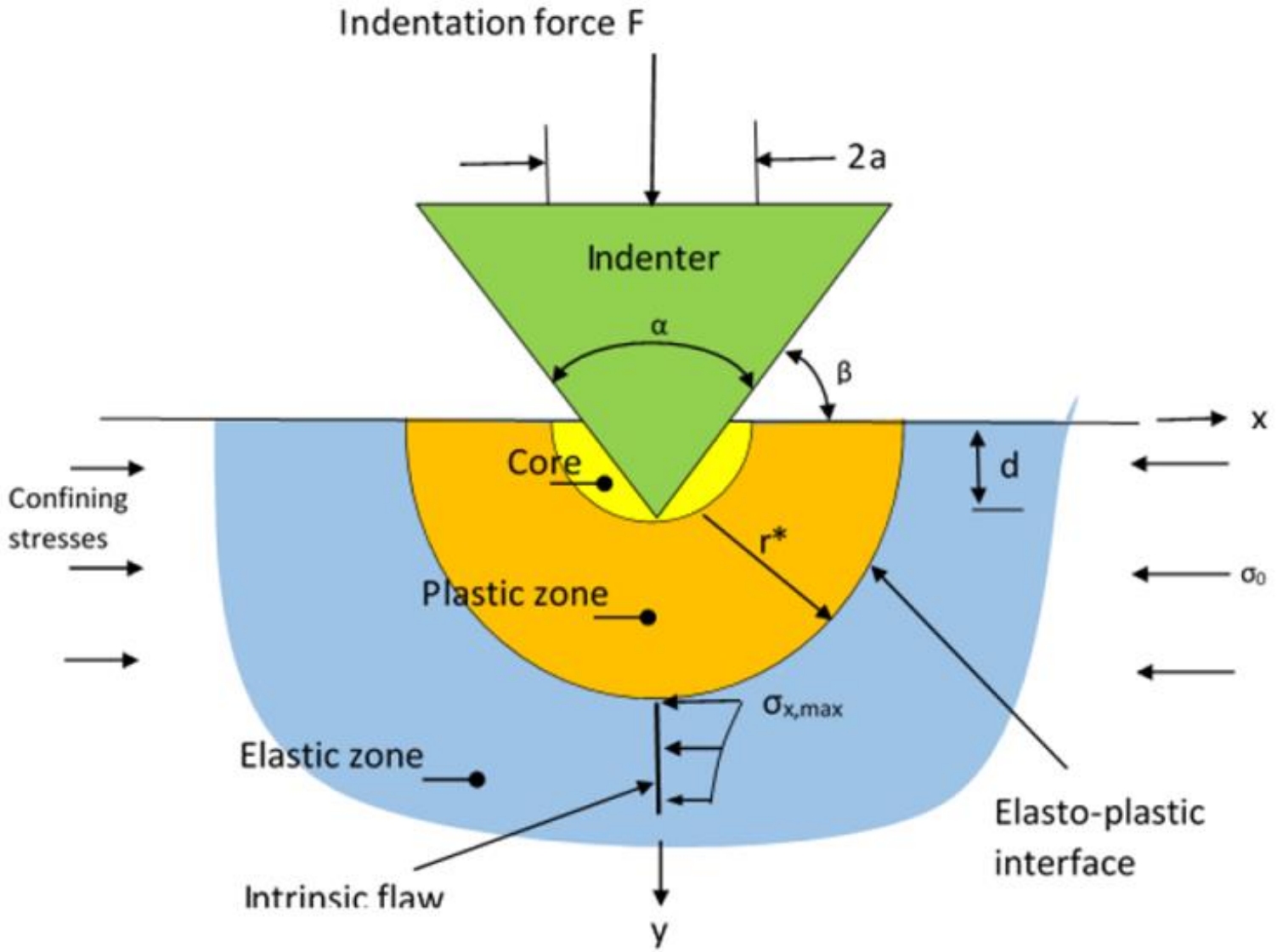
Governing Eqn.:

Cutting Breakage occurred on…

Critical Elasto-Plastic Interface ξ^*

(Huang,2000; Chen, 2002)



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Governing Eqn.:

Cutting Breakage occurred on…

Critical Elasto-Plastic Interface ξ^*

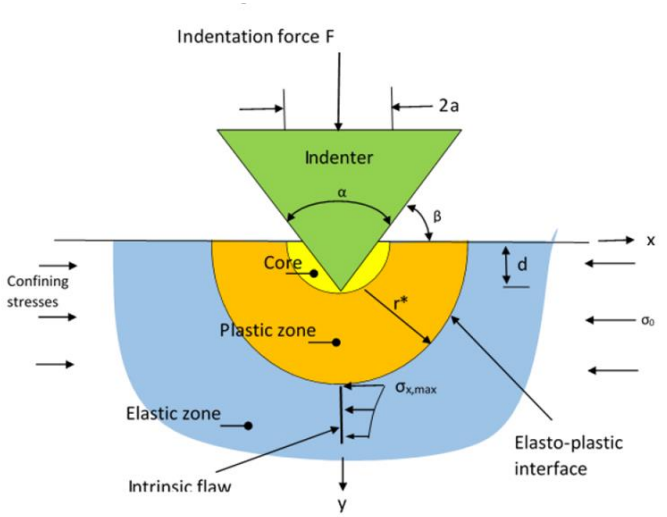
(Huang,2000; Chen, 2002)

$$(1+\mu)\xi^{*(k_d+n)/k_d} - \mu\xi_*^{n(k_p-1)/k_p} = \gamma$$

$$\xi_* = \xi_*\left(E, \upsilon(or\ G), q_u, \phi, \phi^*, \beta_i, \sigma_c\right)$$

$$\frac{P}{q} = \frac{1}{K_p - 1}\left\{\frac{(n+1)\cdot K_p}{K_p + n}\cdot \xi_*^{n\cdot(K_p-1)/K_p}\cdot -1\right\}$$

$$F_i = (3-n)\cdot\pi^{n-1}\cdot P\left(\frac{d}{\tan\beta}\right)$$



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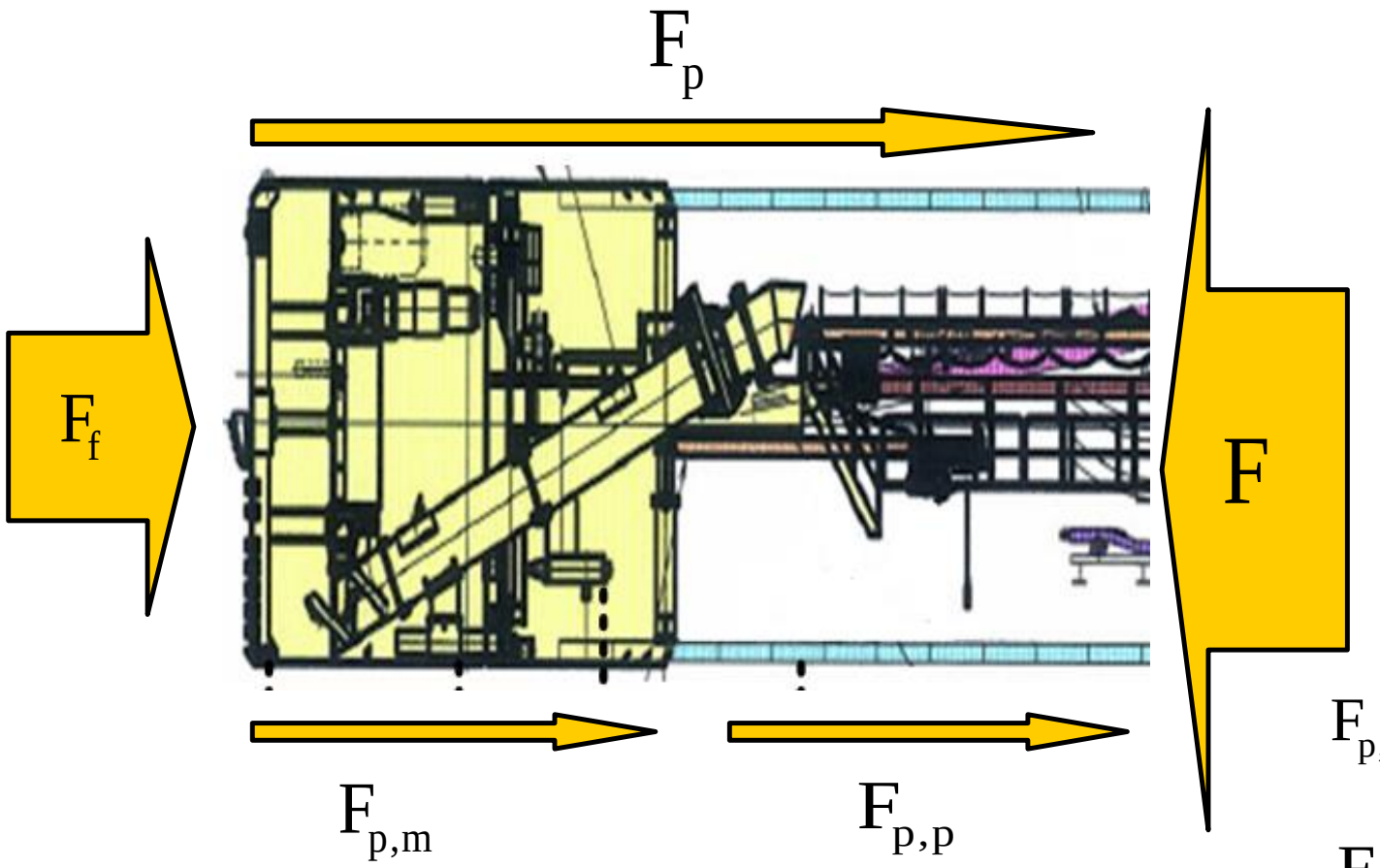

Equilibrium Balance + Breakage Force = F : Resistances during Trenchless Excavation

$$F = F_f + F_{p,m} + F_{p,p}$$

$$F_f = \sum_{j=1}^{m} n_j \cdot f_j + P_s \cdot A$$

$$F_{p,m} = (W_m' + W_s)\left[2(\cos\beta)(\sin\theta_m)\mu_m + \sin\beta\right]$$

$$F_{p,p} = W_p'\left[2(\cos\beta)(\sin\theta_p)\mu_p + \cdot\sin\beta\right]L_p$$

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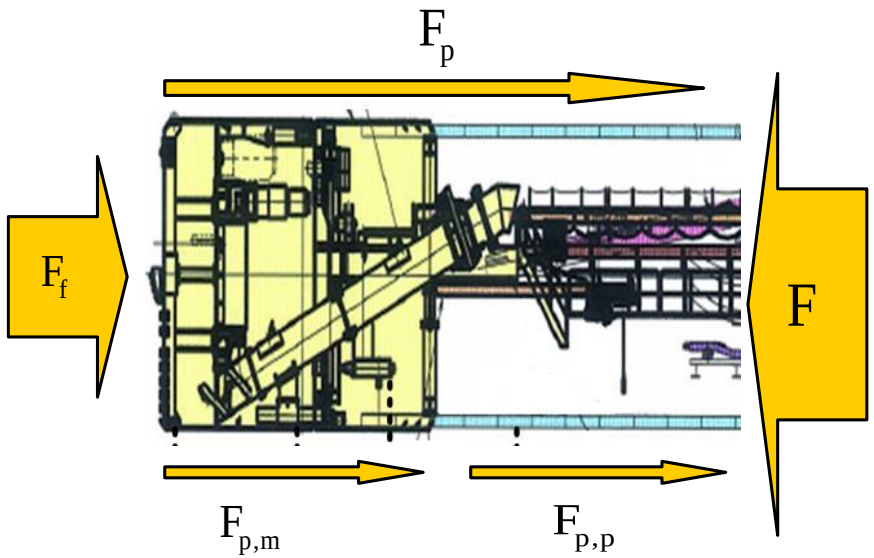
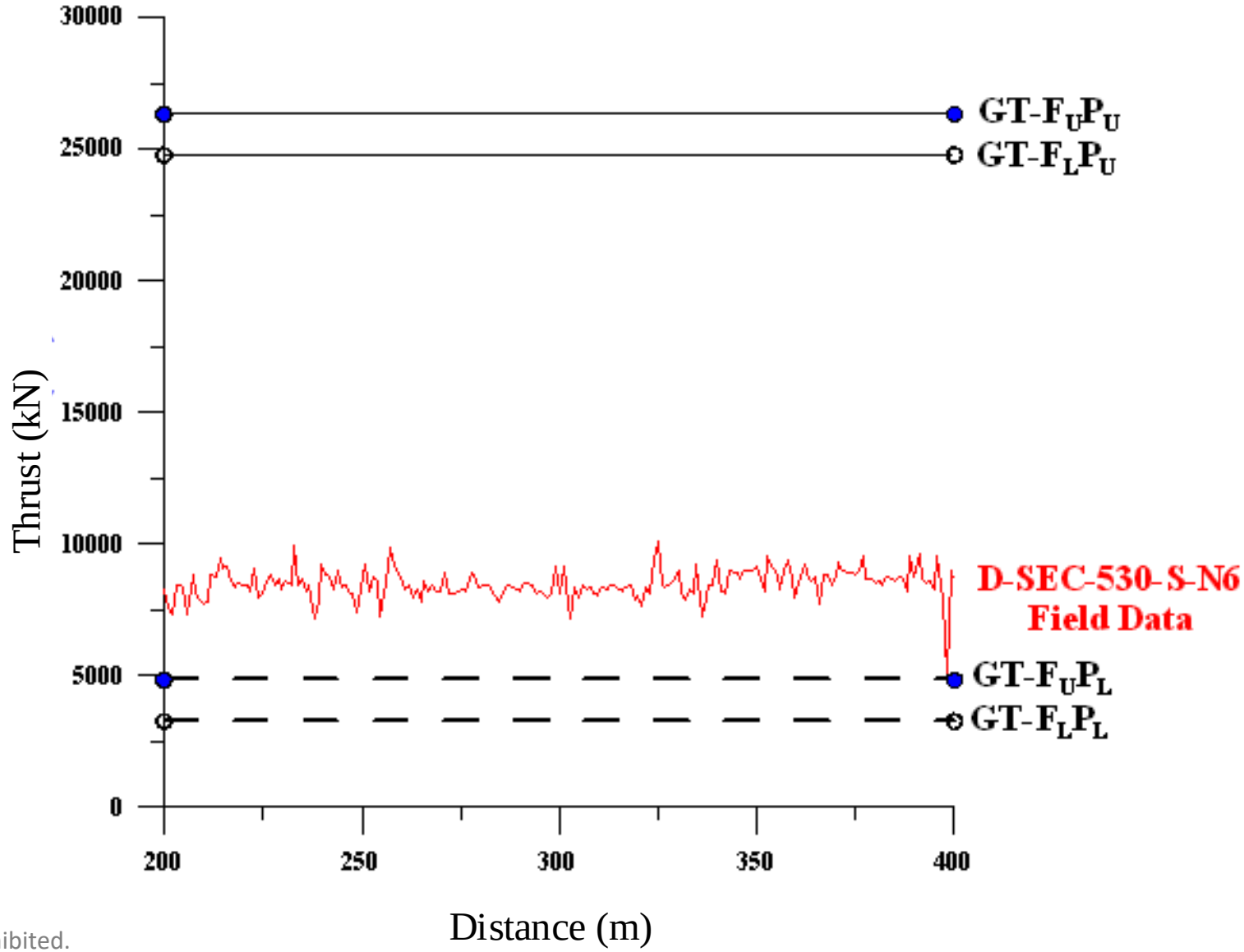
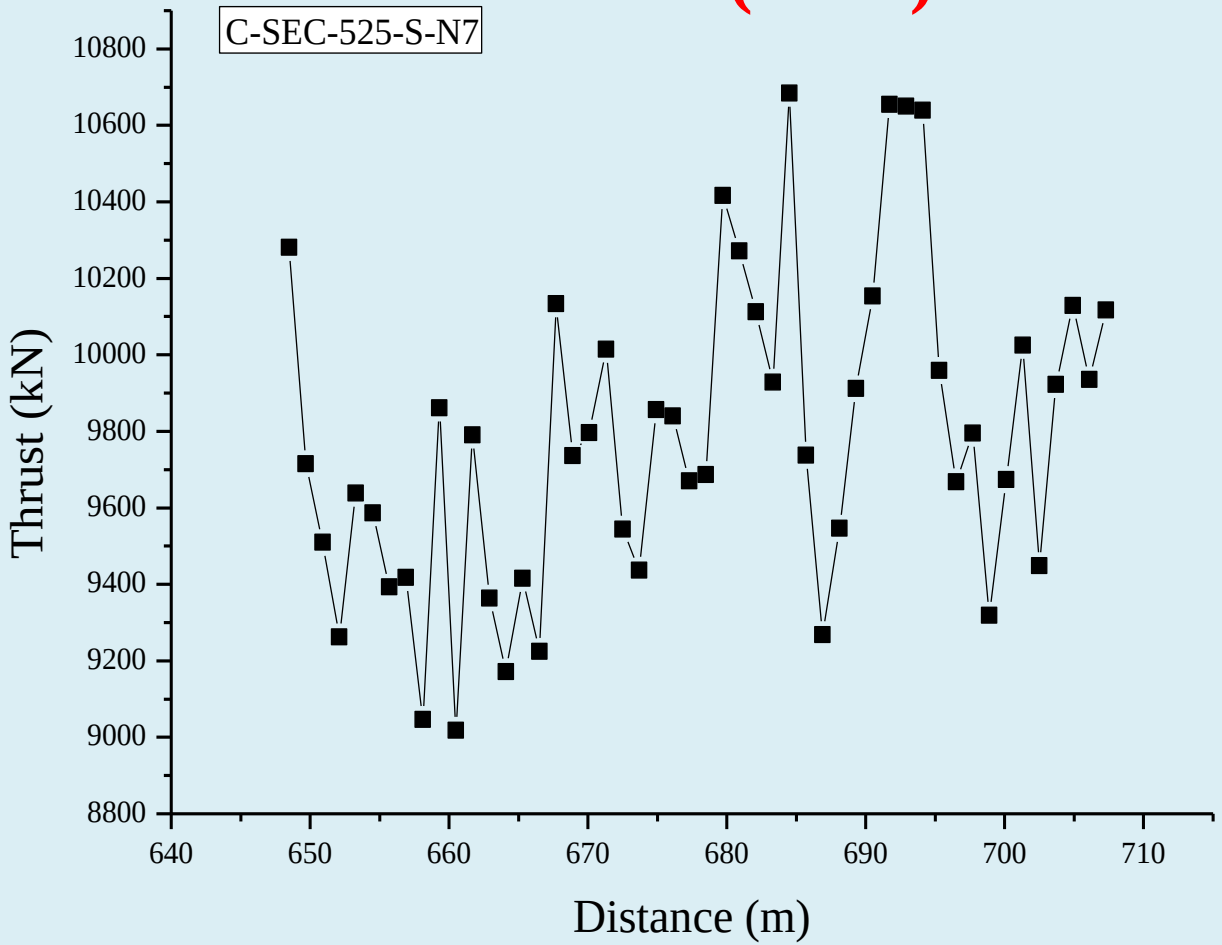
$$F = F_f + F_{p,m} + F_{p,p}$$



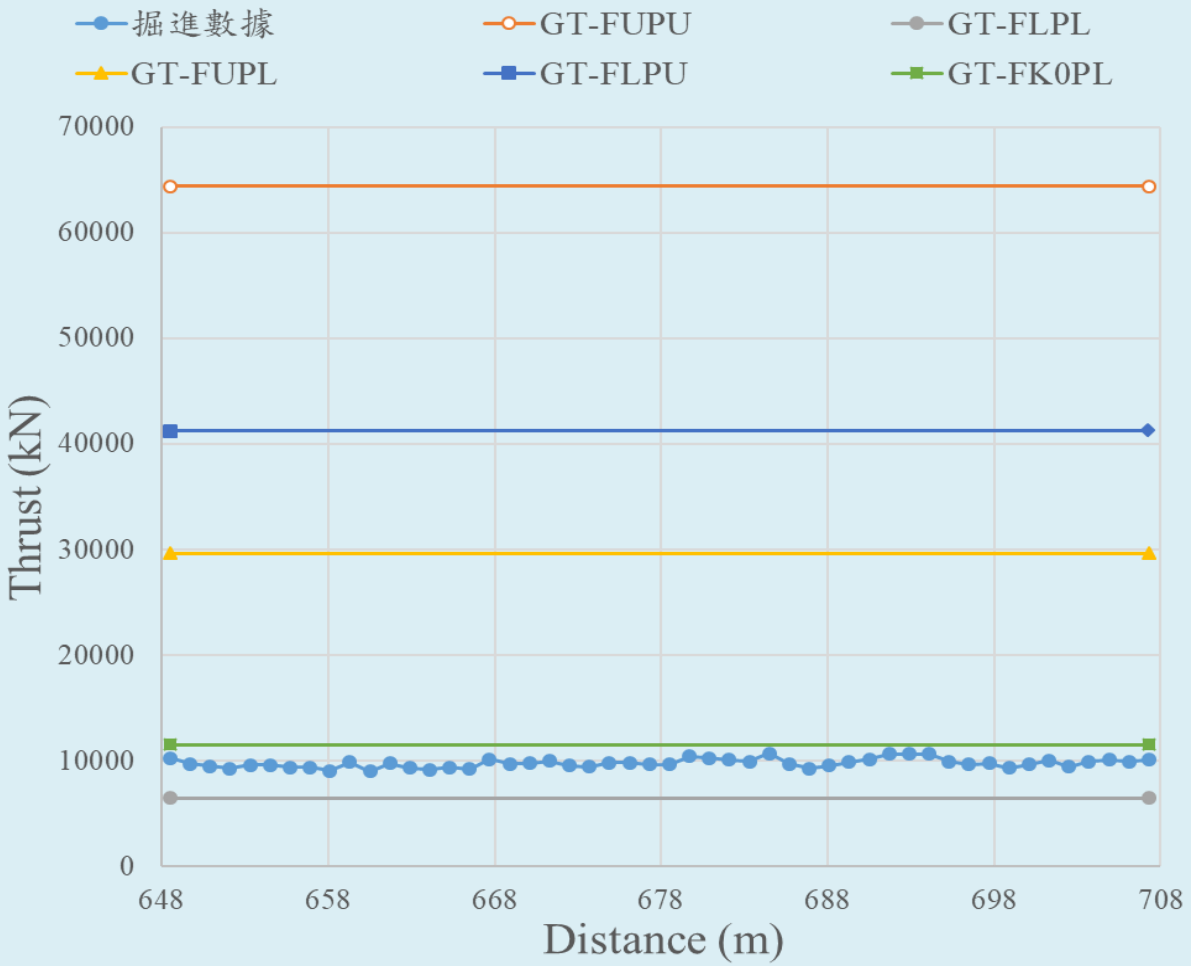


Contact Mechanics -- Trust w/ Upper & Lower Bounds for the Design Stage: Case of Gravel

Conventional Expression of Trust w/ Distance (ROP)



Trust w/ Upper & Lower Bounds



Dimensional analysis　Π Theory

$$I_{cut} = f(E, \nu, \gamma, c, \phi, \sigma_c, \sigma_t, \sigma_0, r, Th, Tq, W)$$

n = 12 ; k = 3　　F , L , T (基本因次)

$[E]=FL^{-2}$	$[\nu]=1$	$[\gamma]=FL^{-3}$
$[c]=FL^{-2}$	$[\varphi]=1$	$[\sigma_c]=FL^{-2}$
$[\sigma_t]=FL^{-2}$	$[\sigma_0]=FL^{-2}$	$[r]=L$
$[Th]=F$	$[Tq]=FL$	$[W]=FL^{-1}T^2$

$[\nu]$, $[\varphi]=1$
(dimensionless)

$[r]=L$
(length)

$[Th]=F$
(force)

$[E]$, $[c]$, $[\sigma_c]$, $[\sigma_t]$, $[\sigma_0]=FL^{-2}$
$[Tq]=FL$　$[\gamma]=FL^{-3}$
(force & length)

$[W]=FL^{-1}T^2$
(force or length & time)

Dimensional analysis

$$\Pi_{10} = Th\ r^a\ \sigma_c^{\ b}\ W^c$$
$$F^0L^0T^0 = (F)\ (L)^a\ (FL^{-2})^b\ (FL^{-1}T^2)^c$$

$$\Pi_{11} = Tq\ r^a\ \sigma_c^{\ b}\ W^c$$
$$F^0L^0T^0 = (FL)\ (L)^a\ (FL^{-2})^b\ (FL^{-1}T^2)^c$$

1 + b+ c = 0 (F, Force)
a - 2b - c = 0 (L, Length)
2c = 0 (T, Time)

Obtain: a =-2、b=-1、c=0

1 + b+ c = 0 (F)
1+ a -2b- c = 0 (L)
2c = 0 (T)

Obtain: a = -3、b=-1、c=0

Trust

$$\Pi_{10} = Th^* = \frac{Th}{r^2\sigma_c}$$

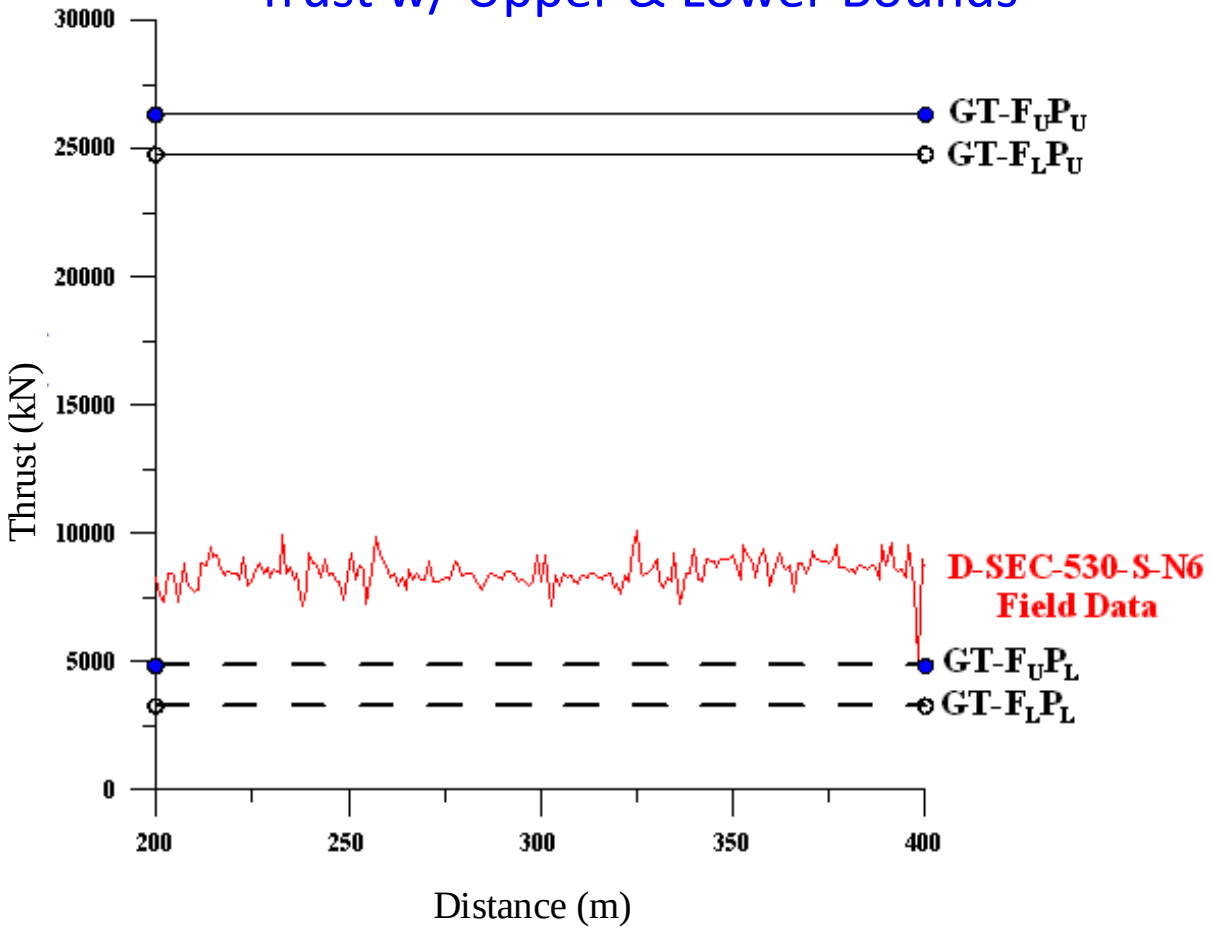
Torque

$$\Pi_{11} = Tq^* = \frac{Tq}{r^3\sigma_c}$$

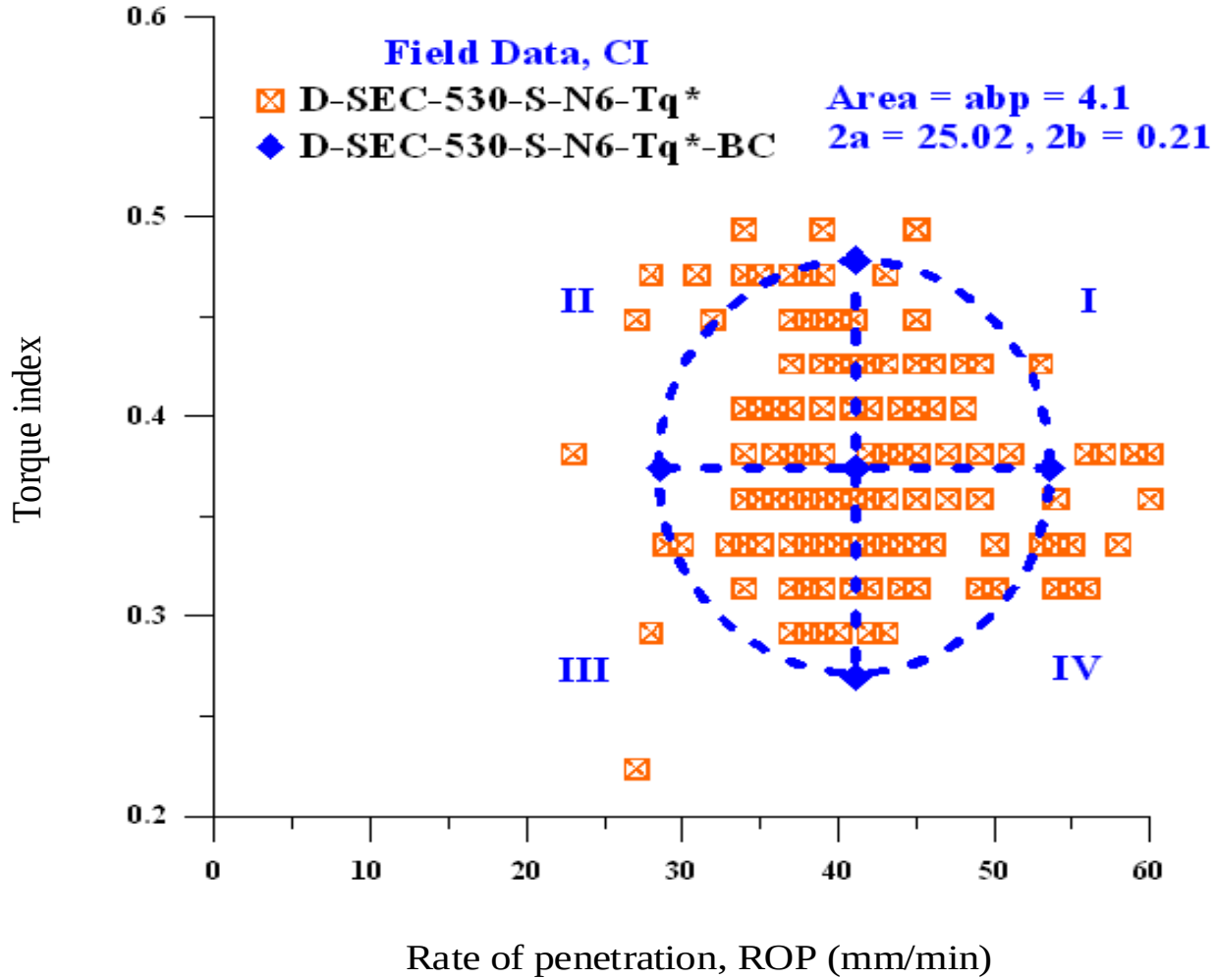
Note that: * meansNormalized

Contact Mechanics & its Normalized Indices: Proposed 2 Cutting Diagrams for both Design & Construction Stages…

1. Design Stage: Trust w/ Upper & Lower Bounds

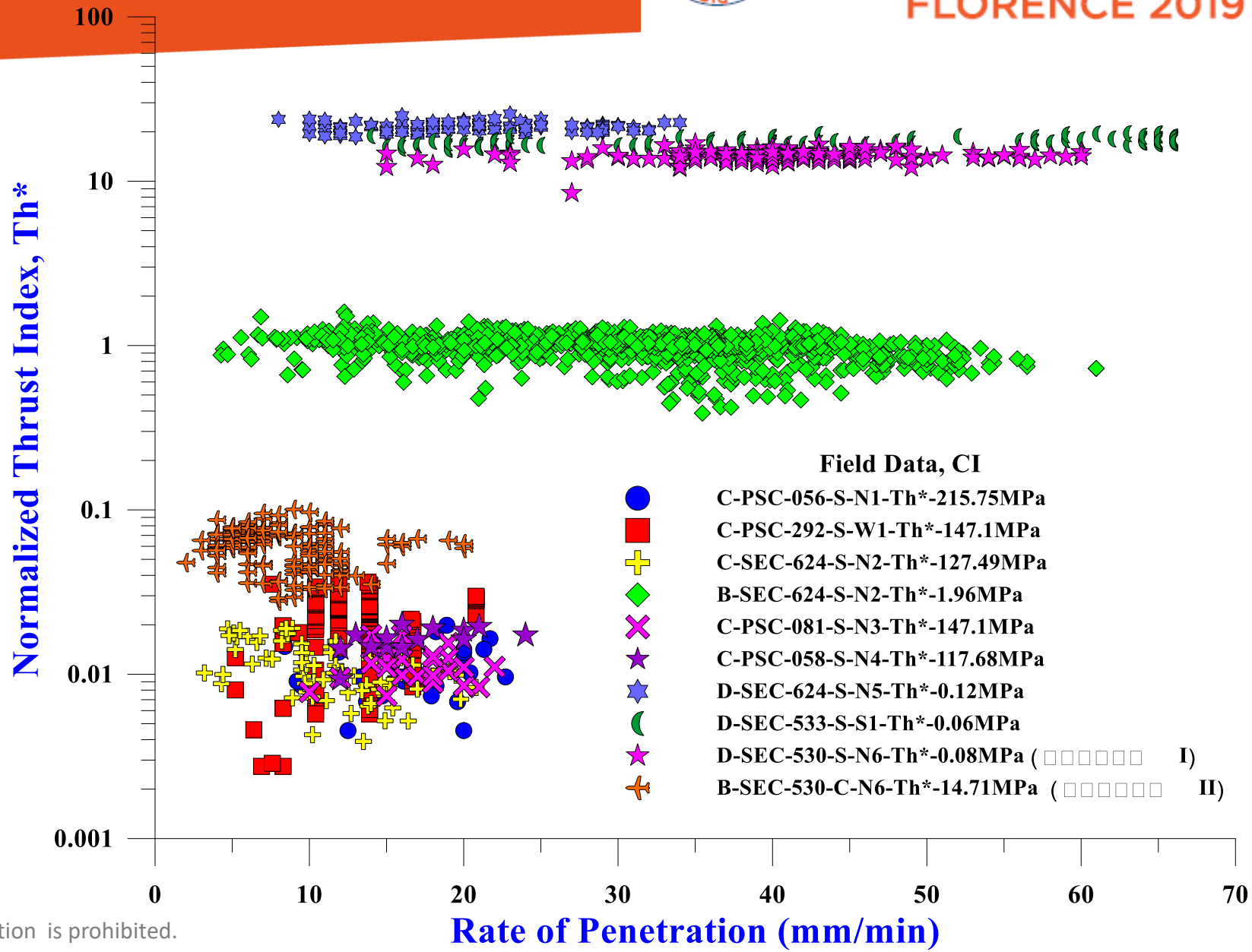


2. Construction Stage: Ellipse-shape Excavation Diagram



Proposed Clustering Excavation Diagram during construction period…

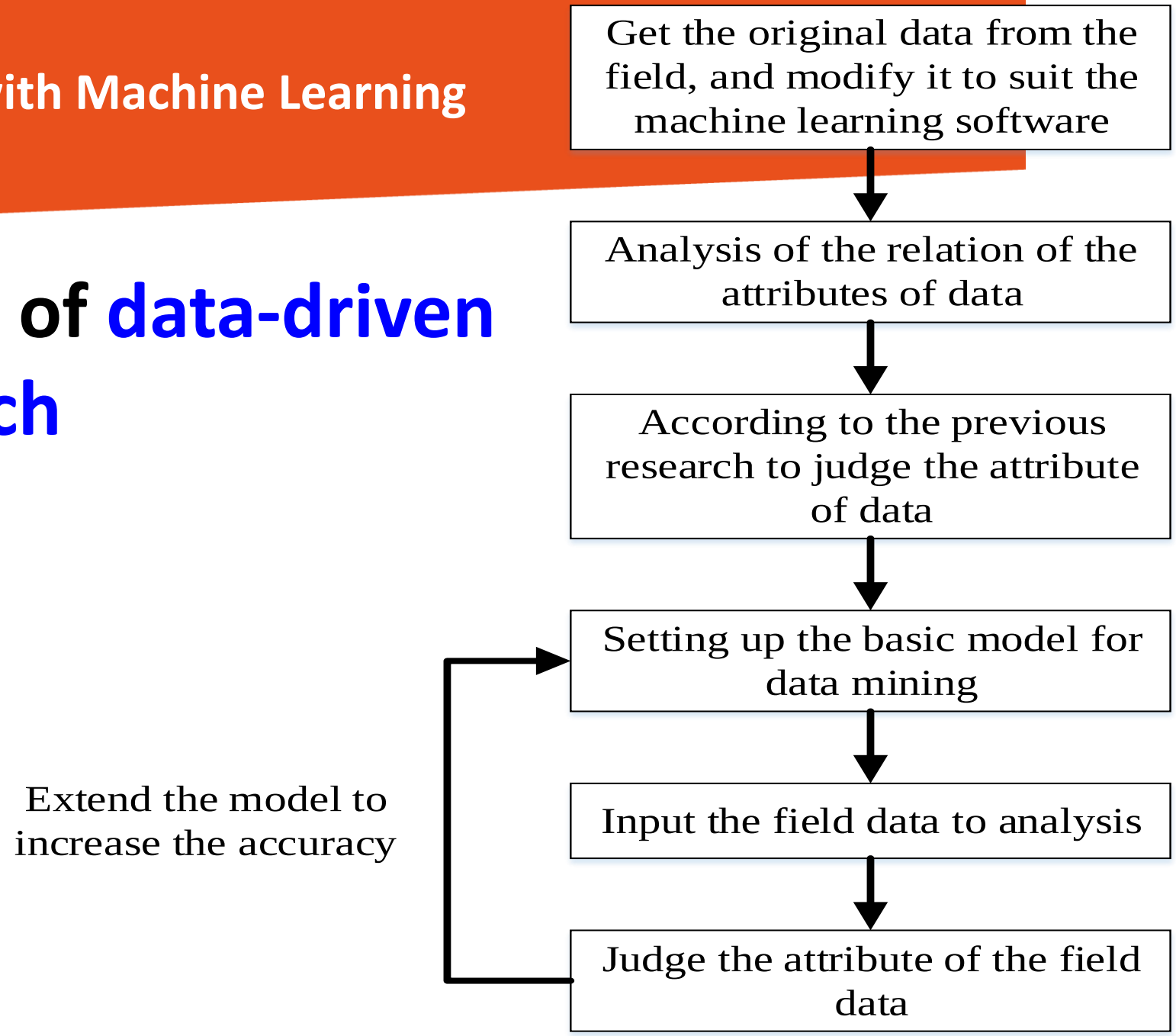
Proposed Clustering Diagram w.r.t. Different Geo-Materials



2. Data-driven Approach: Machine Learning

- Identification: Cutting Process & Indices above
- Prediction: Geo-conditions ahead of Cutting Face

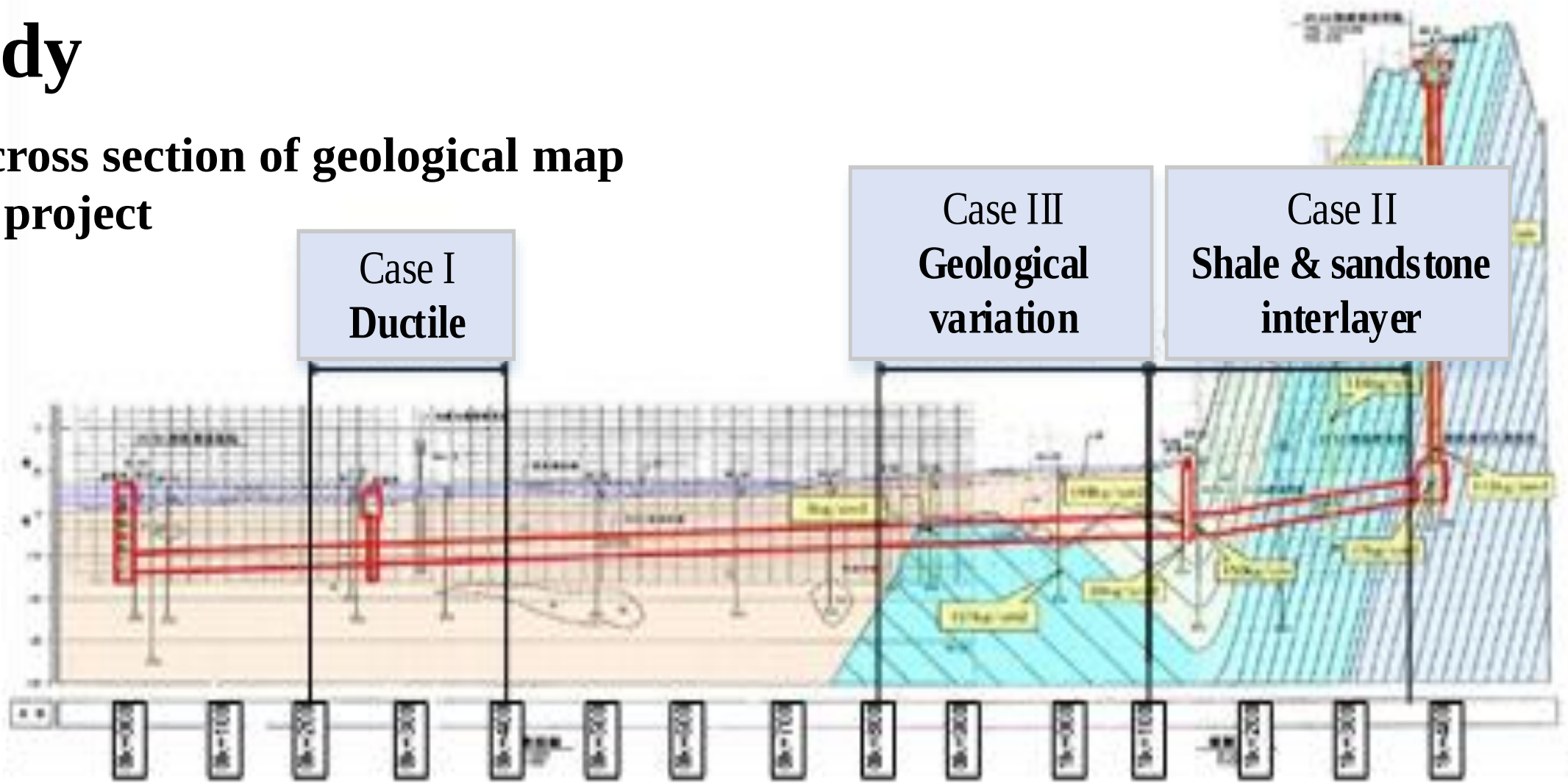
Process of data-driven approach



Case study (Taipei, Taiwan)

Case study

longitudinal cross section of geological map for tunneling project



Principal Component Analysis:

K-means Clustering

Coefficient correlation	The attribute
0.9871	Thrust index
0.9181	Torque index
0.8439	Torque ratio
0.8439	Torque
0.8222	Rate of penetration
0.7635	Earth pressure
0.5419	The amount of conveyed soil
0.1427	The rotation speed of screw conveyor
0.0823	Thrust
0.0257	The pressure of screw conveyor

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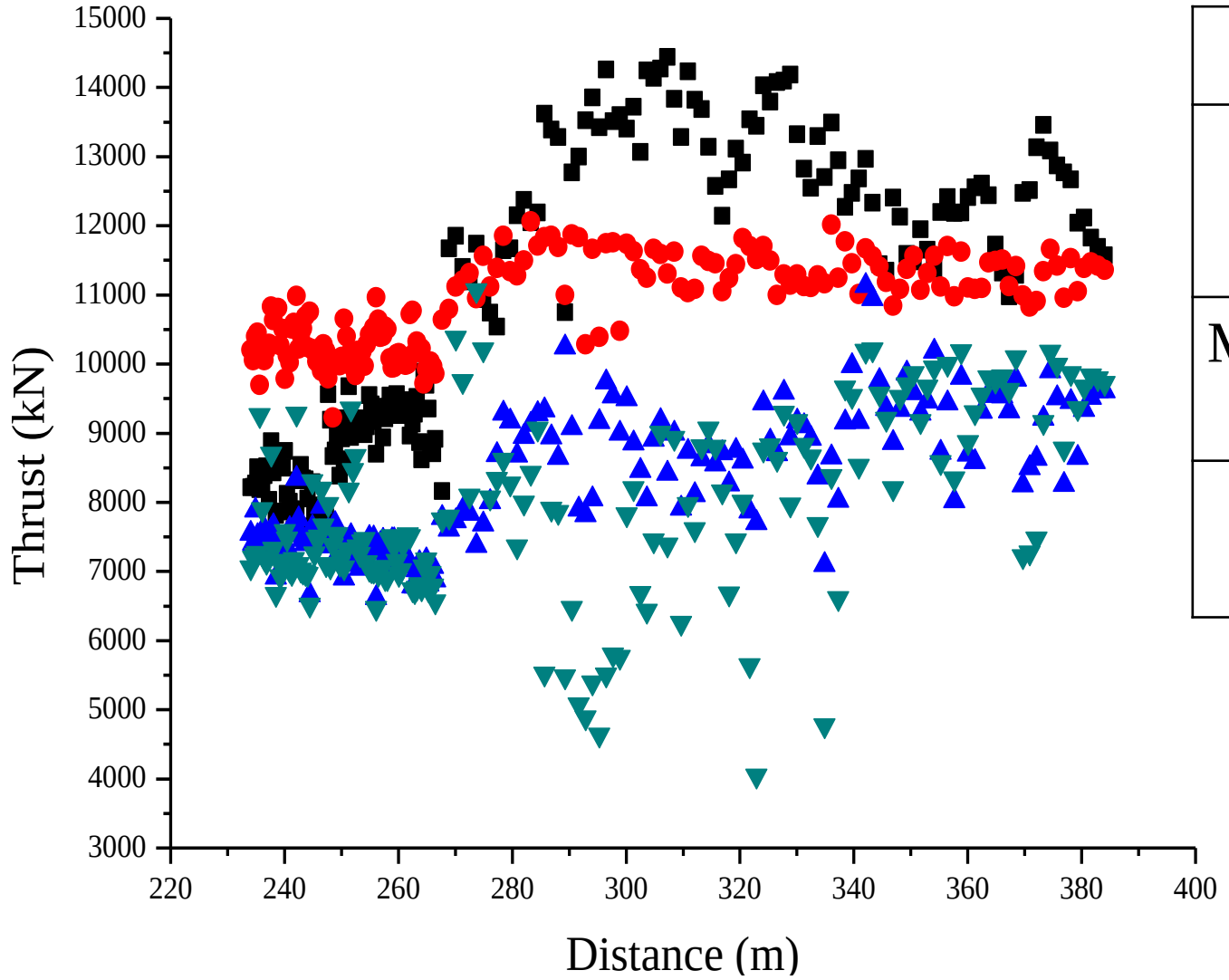
Weight	Top 5 attribute
0.73	**Torque ratio, Torque, Thrust, Rate of penetration, Thrust index**
0.56	Thrust index, Torque index, Torque ratio, Torque, Thrust
0.40	The rotation speed of screw conveyor, The amount of conveyed soil, Earth pressure, Rate of penetration, Torque
0.27	Torque, Thrust, Rate of penetration, Earth pressure, The amount of conveyed soil
0.18	The pressure of screw conveyor, The amount of conveyed soil, Thrust, Torque ratio, Torque
0.11	Earth pressure, The amount of conveyed soil, The pressure of screw conveyor, Rate of penetration, The rotation speed of screw conveyor
0.05	Thrust, Rate of penetration, Earth pressure, The pressure of screw conveyor, Torque index

Trenchless Cutting w/ Machine Learning: 3 Argorithms show Error(s) as Signals to Predict the Change in Geo-Materials



"Error" as Signals	M5P	LR	MP
Root Mean Square Error, RMSE	1645.1	3085.0	3718.3
Mean Absolute Error, MAE	1427.0	2663.3	3022.6
Correlation Coefficient, CC	0.79	0.71	0.22

- Real Data
- M5P (Decision tree)
- Linear Regression
- MultilayerPerceptron (Neural Network)

THANKS