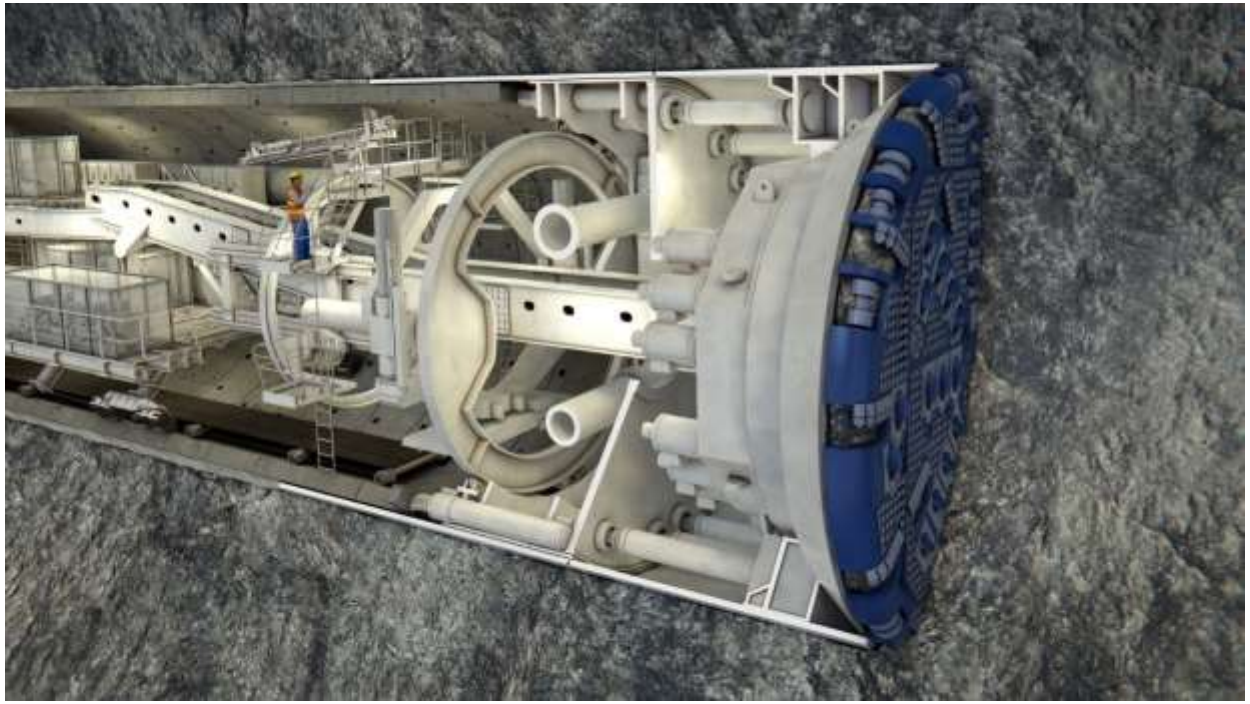
BACK ANALYSED OF MAXIMUM SURFACE SETTLEMENT USING ARTIFICIAL NEURAL NETWORK (ANN) TO EARTH PRESSURE BALANCE MACHINE FOR KVMRT LINE 1 IN KENNY HILL FORMATION



CIVILCORE
CONFERENCE ON RESEARCH IN ENGINEERING
2020

Presented by:
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15th September 2020

بسم الله الرحمن الرحيم

<u>PRESENTATION FRAMEWORK</u>

1) QUICK FACT FOR INTRODUCTION OF KVMRT PROJECT, SOIL GEOLOGY, TBM DRIVE
2) OBJECTIVES-RESEARCH SCOPES-METHODOLGY
3) SOIL CHARACTERIZATION
4) RESULTS FOR BACK ANALYSED TUNNEL SMAX & VOLUME LOSS
5) RESULTS FOR ANN TUNNEL SMAX & VOLUME LOSS
6) EPB PERFORMANCES
7) CONCLUSIONS-Findings & Scientific Contributions

MASS RAPID TRANSIT (MRT) - system is a rail system transporting passengers in urban areas.

SYNONYMS - mass transit, subway, underground railway or metro.

ABILITY - carry large numbers of people efficiently and form a city's public transport system.

TRACKS - typically in underground tunnels (city center) or on elevated viaducts above street level (suburbs of a city).

URBAN TUNNELLING - **shallow depth tunnelling**

- **Work in Limited Spaces**
- **Potential damages to surfaces and building deformations**

GEOTECHNICAL ASPECTS - maintaining stability during excavation

- minimize ground movement
- minimize impacts on existing structures

TUNNELLING & UNDERGROUND SPACE TECHNOLOGY

- **TUNNEL BORING MACHINES (TBM) :**
  CLOSED FACE TUNNELLING – EPB OR VD (SLURRY) MACHINE
- **PARAMETERS AFFECTING TBM WORKS**

Tunnel Boring Machine

EARTH PRESSURE BALANCE (EPB)

Geology :

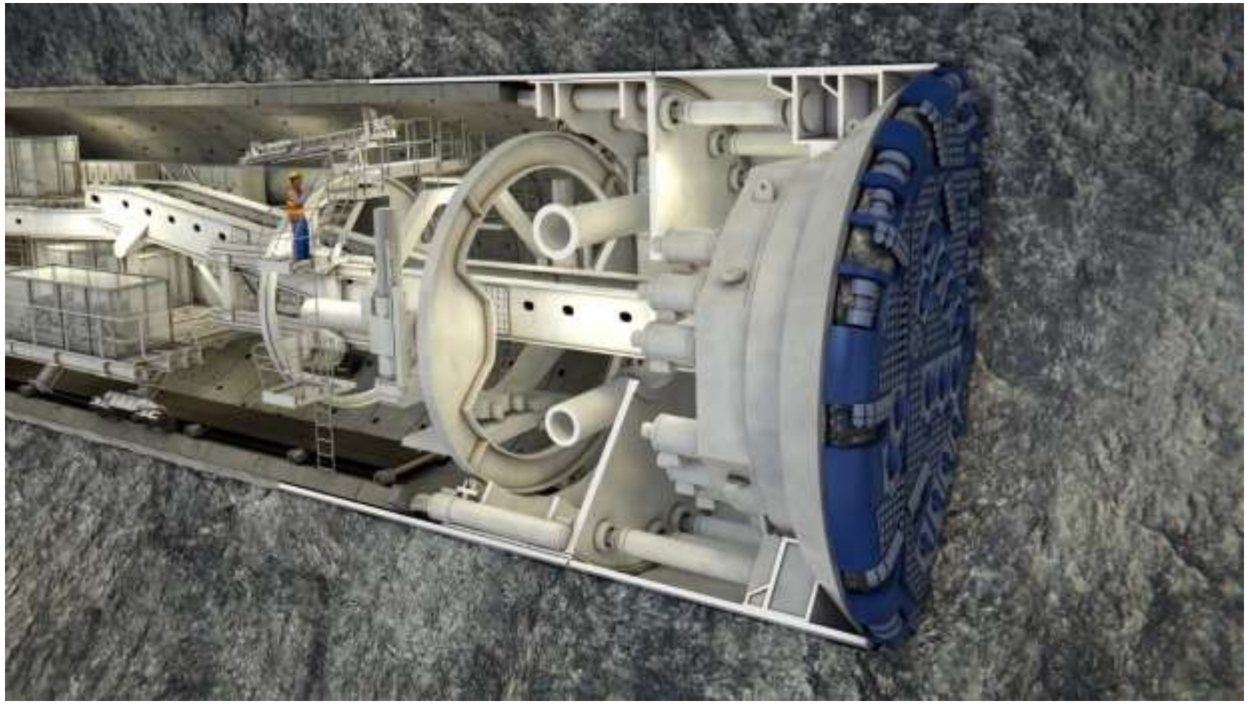
Soft Ground with low water permeability (clay, Silt & Loam)

Methods:

Excavated material into a soil paste that is used as pliable, plastic support medium

OPERATING PRINCLE AT GLANCE

1) EXCAVATION-uses cutting knives , disc cutters remove the soil
2) TUNNEL FACE SUPPORT- plastic soil produces active support pressure in the excavation chamber
3) REMOVAL- A screw conveyor transports the excavated material to the logistics systems at the back
4) THRUST - Hydraulic thrust cylinders in the shield or a jacking frame in the launch shaft push the machine forward
5) TUNNEL LINING- Segmental lining

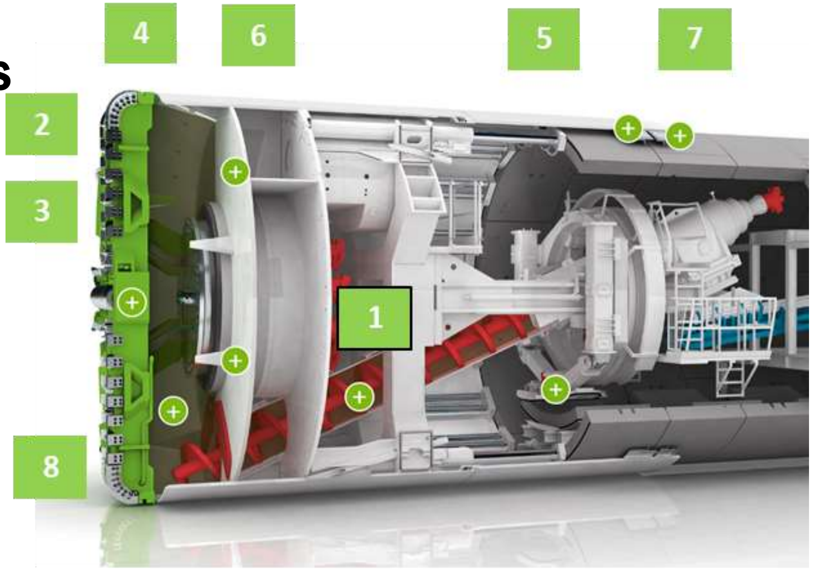


TBM Parameters Affecting Ground Catastrophic

1) Human Errors

3) Geo-Mechanical Components

- ❖ Cutter head & Cutters
- ❖ Spoil Conditioning
- ❖ Screw Conveyors
- ❖ TBM Articulations
- ❖ Seal Systems
- ❖ Torque & Thrust
- ❖ Filling the shield annulus
- ❖ Rate of tunnel penetration
- ❖ Frictional Forces
- ❖ Stress at TBM Head



1	Screw Conveyor	5	Tail Sealing
2	Foam Injection	6	Thrust Speed
3	Earth Pressure	7	Total Grouting
4	Cutter Head	8	Soil Conditioning

4) Tunnel Rings Segment

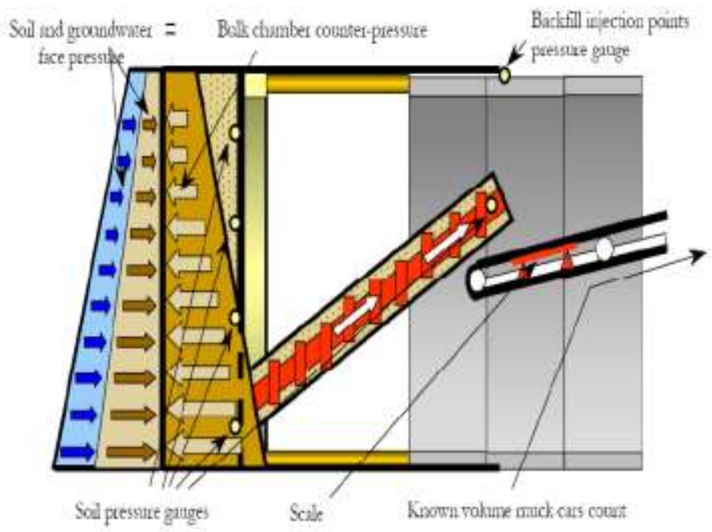
- ❖ Annular Grouting

5) Alignment Deviation

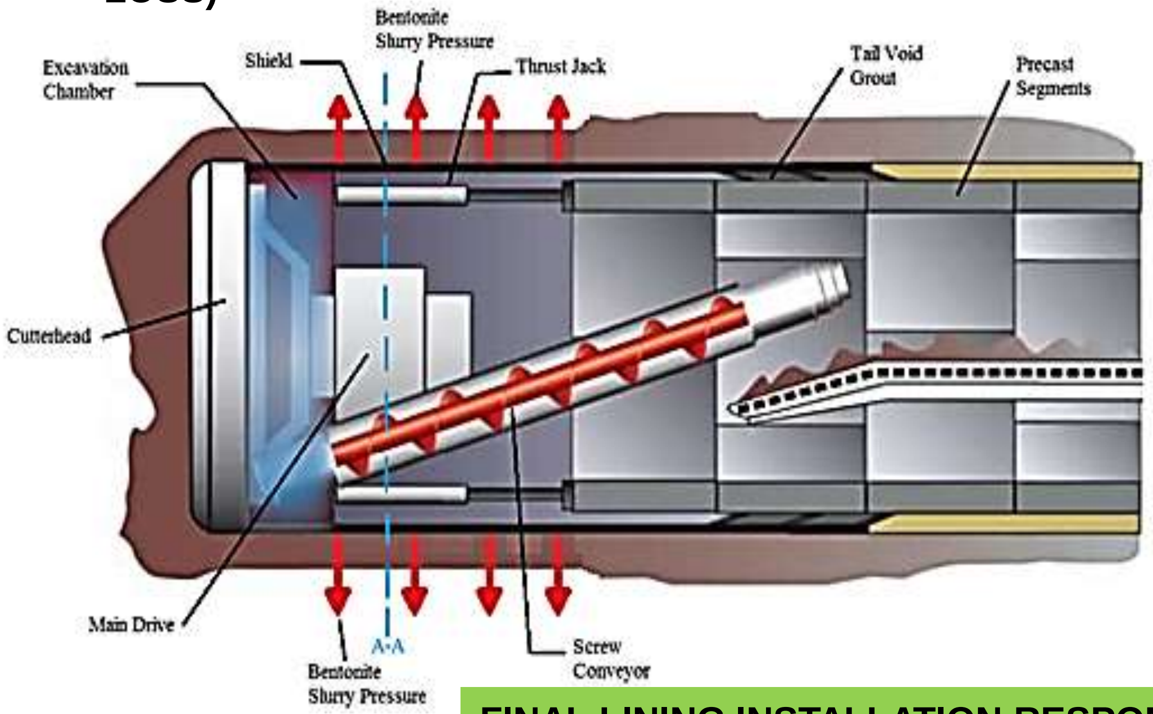
- ❖ Dimension & Shape

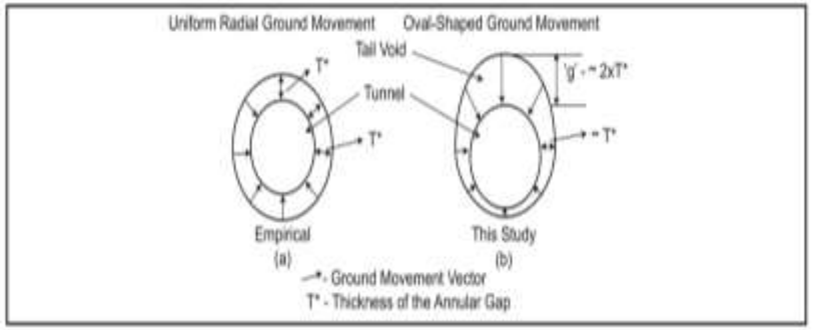
Tunnel Ground Settlement Attributes

STABILITY OF TUNNEL FACE PRESSURE (FACE LOSS)

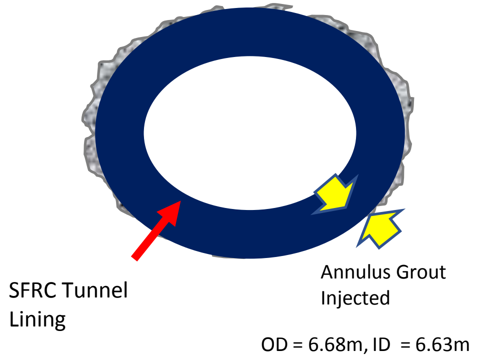


CROSS SECTIONAL STAGING OF EXCAVATION WORK (SHIELD LOSS)





FINAL LINING INSTALLATION RESPONSE (TAIL LOSS)



The sequential TBM variables contributed to subsurface deformation identified by (Loganathan, 2011) and (Leca & New, 2007)

Catastrophic to Ground Surface Deformation by TUNNELLING

TUNNELLING POSSESS HIGHEST RISK OF ALL CONSTRUCTION TYPE !!!!!!

Ground Settlement @ Jln Bukit Bintang April 2014

INTRODUCTION/ CASE STUDY

Semantan North Portal, 2019

<u>Tunnel Facts:</u>

1) First Metro Line in Kuala Lumpur, Malaysia
2) The biggest Metro Project In KL, SBK & on going SSP
3) A total 9.4km underground tunnel in two geological profile: KH & KL Limestone
4) Kenny Hill Formation, Tunnel dia. 6.65m(OD), Both EPB from CREC, China
5) 2 Tunnel driven from Semantan North Portal to Muzium Negara
6) Parallel Tunnel configuration
7) Average segment operation R8/day
8) Tunnel intervals apart each 1month
9) A series of settlement arrays placed on ground (monitored data by Maxwell Geosystem)
10) AAA I&M established
11) Designed VL=1%, K=0.5
12) Average tunnel depth >15m, tunnel apart 1D

Objectives of Study

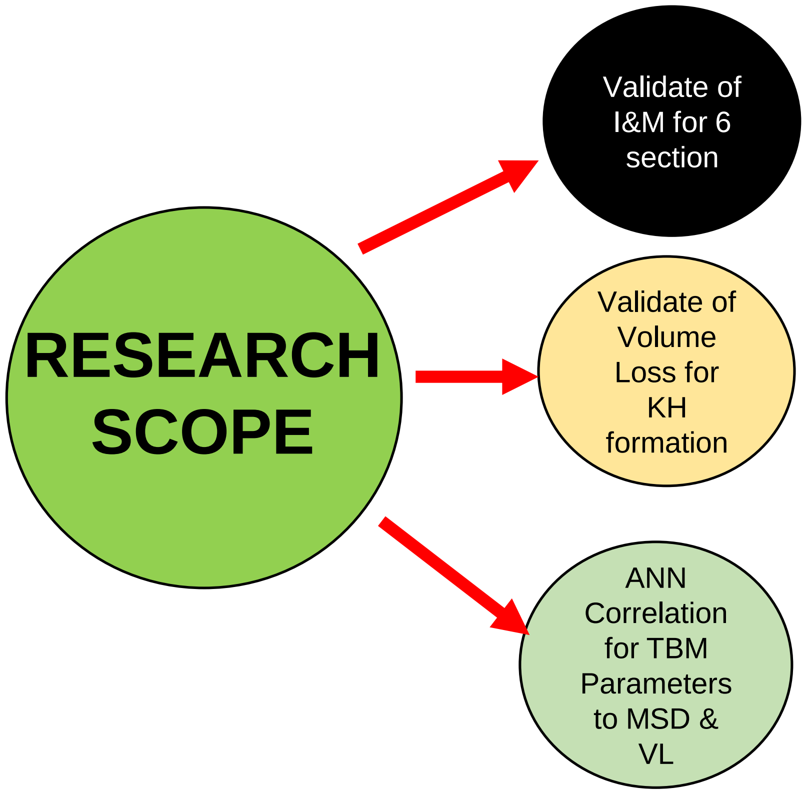
Ground settlement responses vital for tunnelling works, this research objectives embarks:

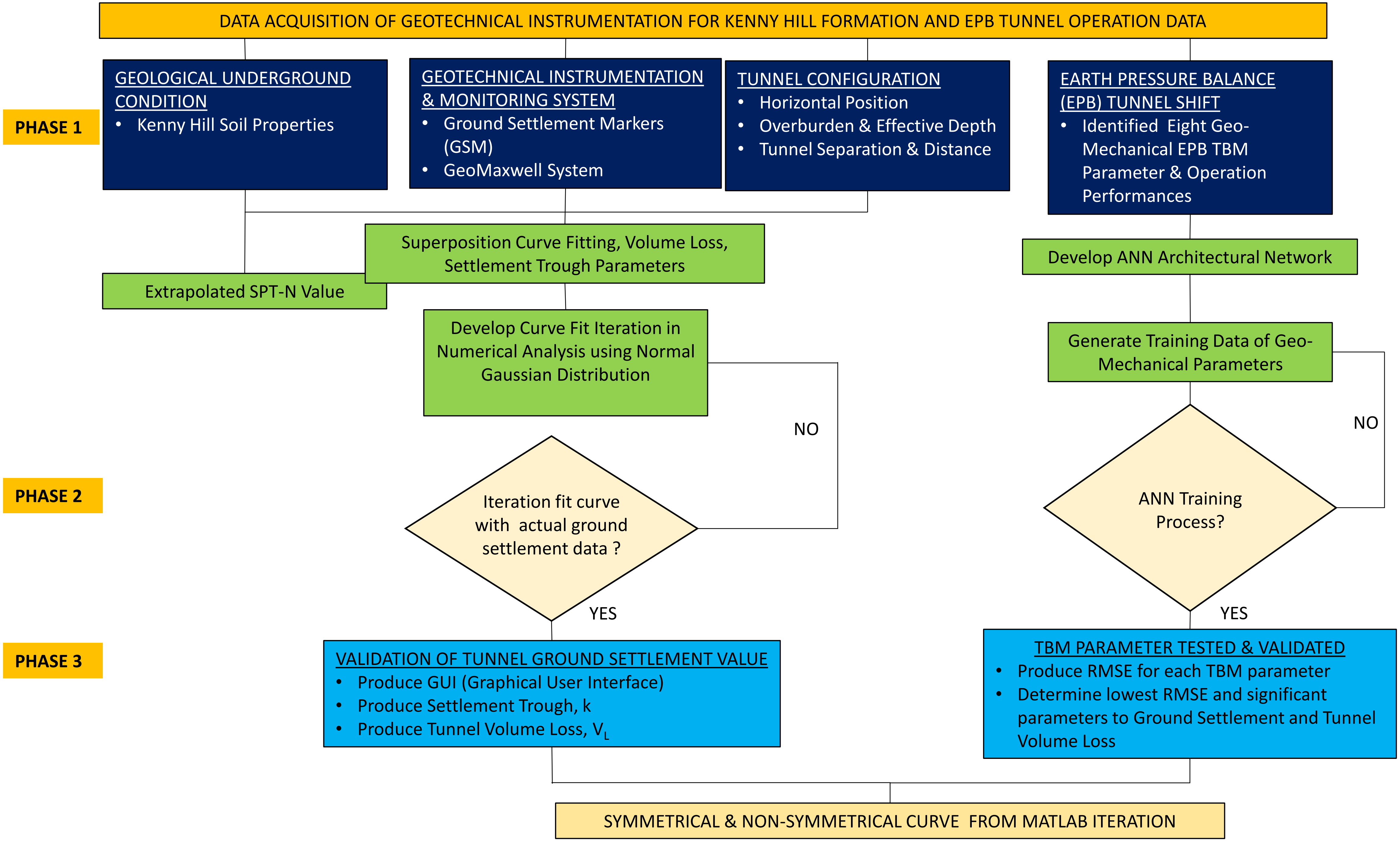
1. To determine and characterize the **subsurface ground deformation & Tunnel Volume Loss of Earth Pressure Balance (EPB) in KHF** by utilization of **best fit iteration** in empirical Gaussian Distribution (single & superposition tunnel configuration) by correlation to Maximum Surface Deformation and Volume Loss in Kenny Hill Formation.

2. To Correlation factors of EPB TBM parameters by **Artificial Neural Network (ANN) Model** for MSD Maximum Surface Deformation & Tunnel Volume Loss of EPB Tunnel Data Mining along the KHF

3. To **digitalize eight TBM** operational from the EPB tunnel shift report in order to perform data mining and tunnel analysis.

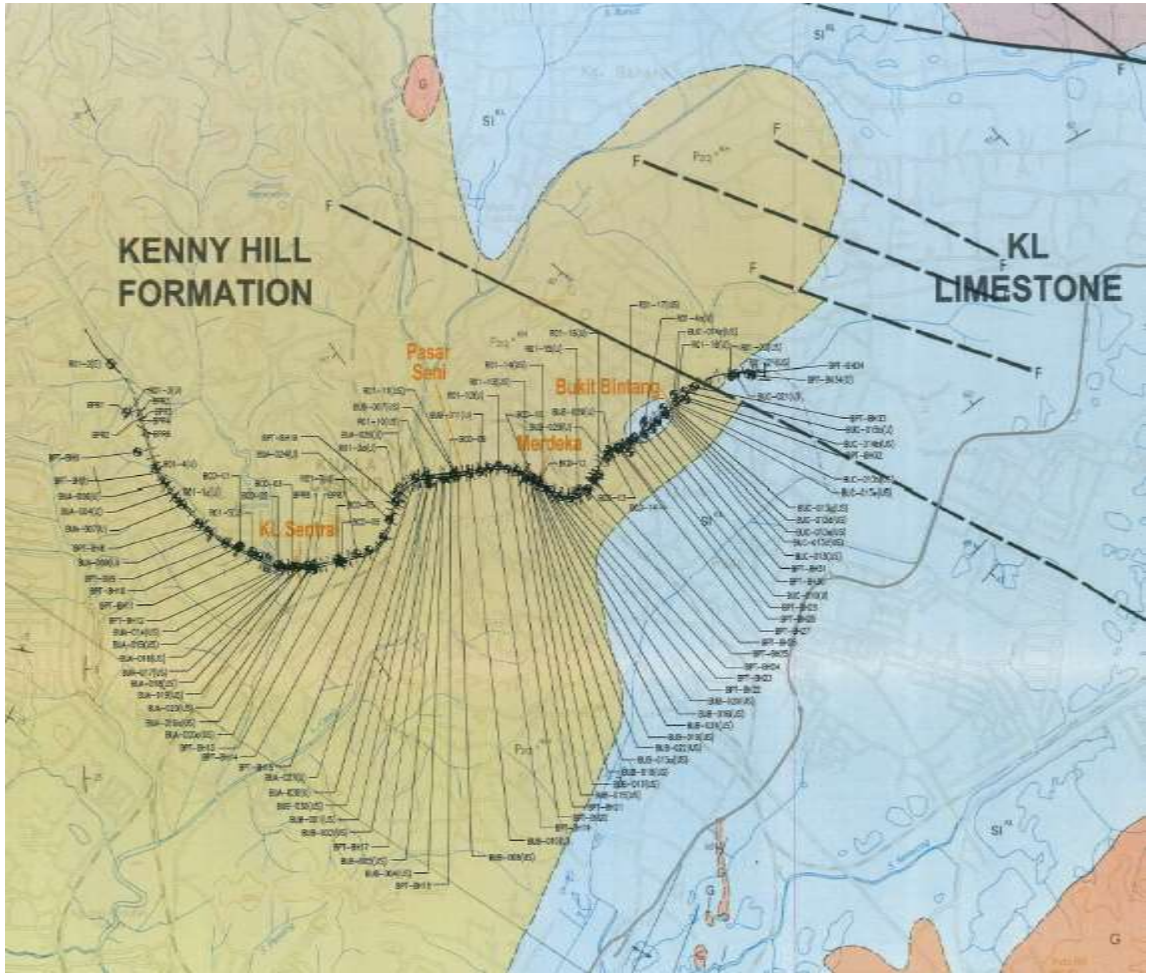
Research Scope





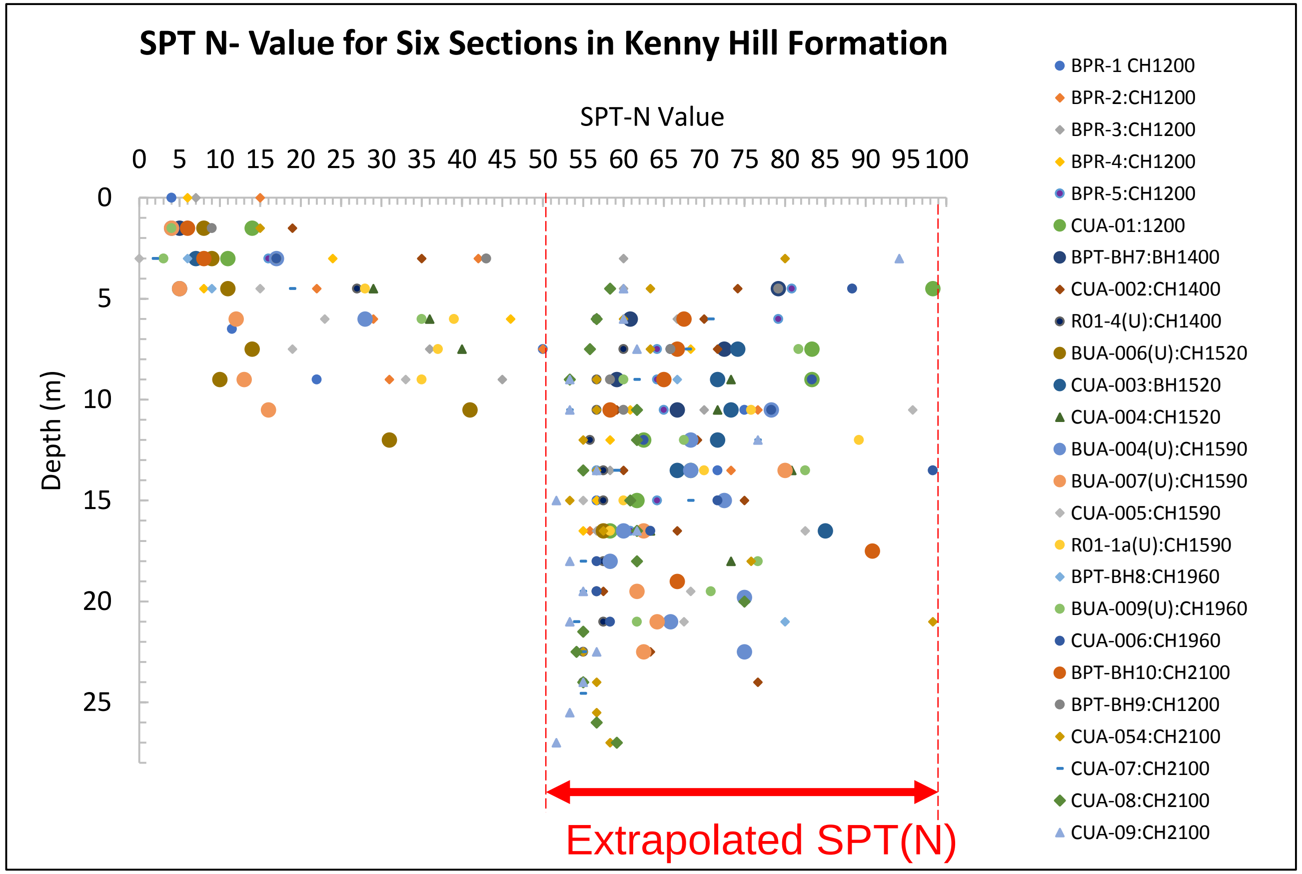
DATA ACQUISITION OF GEOTECHNICAL INSTRUMENTATION FOR KENNY HILL FORMATION AND EPB TUNNEL OPERATION DATA
PHASE 1
GEOLOGICAL UNDERGROUND CONDITION
• Kenny Hill Soil Properties
GEOTECHNICAL INSTRUMENTATION & MONITORING SYSTEM
• Ground Settlement Markers (GSM)
• GeoMaxwell System
TUNNEL CONFIGURATION
• Horizontal Position
• Overburden & Effective Depth
• Tunnel Separation & Distance
EARTH PRESSURE BALANCE (EPB) TUNNEL SHIFT
• Identified Eight Geo-Mechanical EPB TBM Parameter & Operation Performances
Superposition Curve Fitting, Volume Loss, Settlement Trough Parameters
Extrapolated SPT-N Value
Develop ANN Architectural Network
Develop Curve Fit Iteration in Numerical Analysis using Normal Gaussian Distribution
Generate Training Data of Geo-Mechanical Parameters
NO
NO
PHASE 2
Iteration fit curve with actual ground settlement data ?
ANN Training Process?
YES
YES
PHASE 3
VALIDATION OF TUNNEL GROUND SETTLEMENT VALUE
• Produce GUI (Graphical User Interface)
• Produce Settlement Trough, k
• Produce Tunnel Volume Loss, V_L
TBM PARAMETER TESTED & VALIDATED
• Produce RMSE for each TBM parameter
• Determine lowest RMSE and significant parameters to Ground Settlement and Tunnel Volume Loss
SYMMETRICAL & NON-SYMMETRICAL CURVE FROM MATLAB ITERATION

Kenny Hill Geological Profile & Tunnel Parameter



- **Residual Soil**
- Weathered rock with complete decomposed rock
- **Consistent Clay Silt Soil**
- Approximate 10m below GL, surficial layer (sandy silts & silty sand)
- **Below 10m SPT>50 and GWT <5m from GL**
- Bulk density 19KN/m3 to 22KN/m3
- PL 15% to 30%

Geotechnical Characterization of Kenny Hill Formation



- EPB=closed face tunnelling method
- Excavated material as soil paste as support medium
- **Earth Pressure Stabilized = Soil Paste Pressure + Pressure soil + Pressure Groundwater**
- **To control tunnel face + avoid uncontrolled inflow soil + minimum settlement + Tunnel Volume Loss**
- Choosing the Tunnel Machines are based on Soil Particle Distribution

Fundamental Curve Fitting Gaussian Distribution

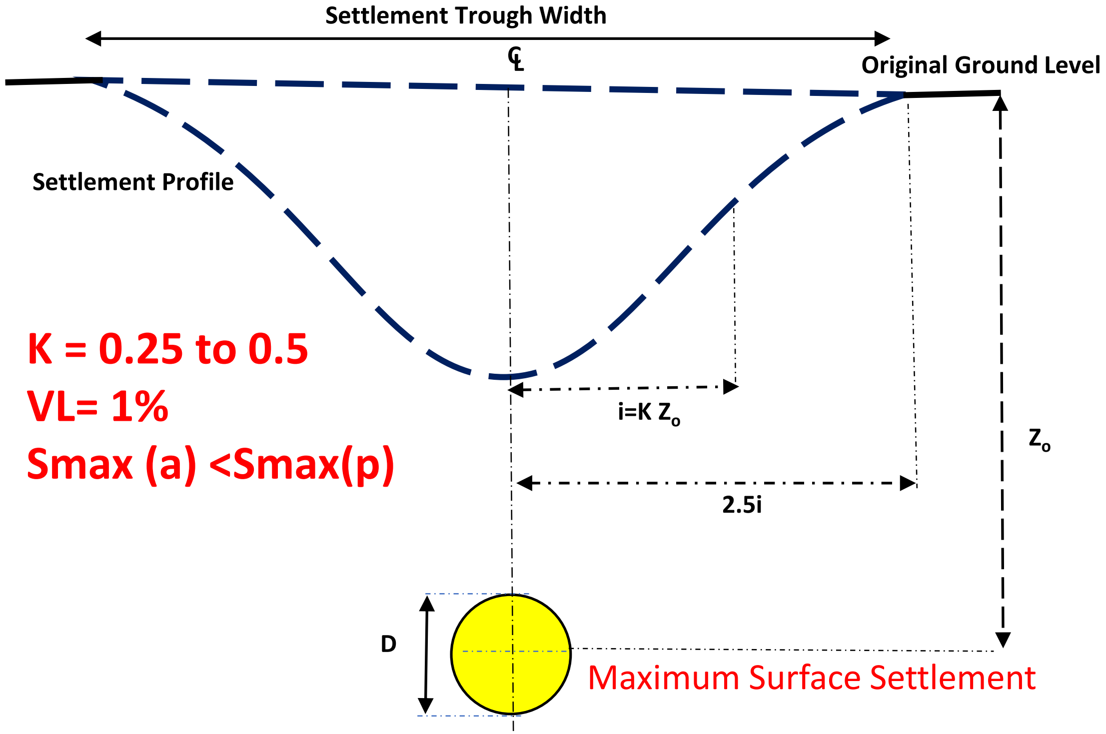
Allows for Maximum Surface Settlement and Tunnel Volume Loss comparison:

- different location
- soil profiles
- tunnel machines
- relevant parameters

Empirical Surface Settlement by Peck(1969), Mair (1993)

Hypothesis:

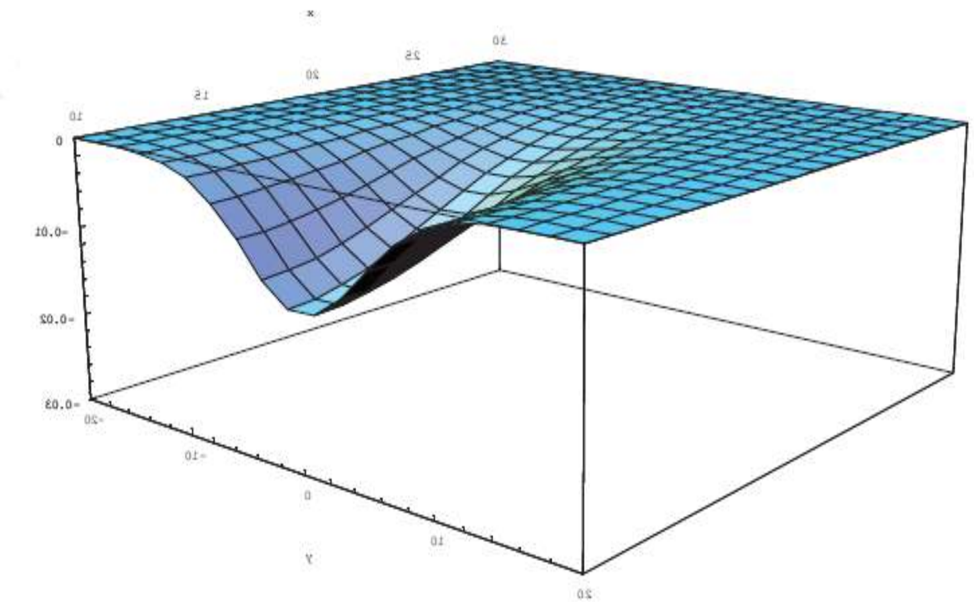
- Narrower settlement, higher S_{max} & V_L : higher gradients & curvatures
- KVMRT1, settlement trough consistently lower design values depends to K & Z_o
- 3 major identified settlement contributors tested by ANN method



Settlement trough

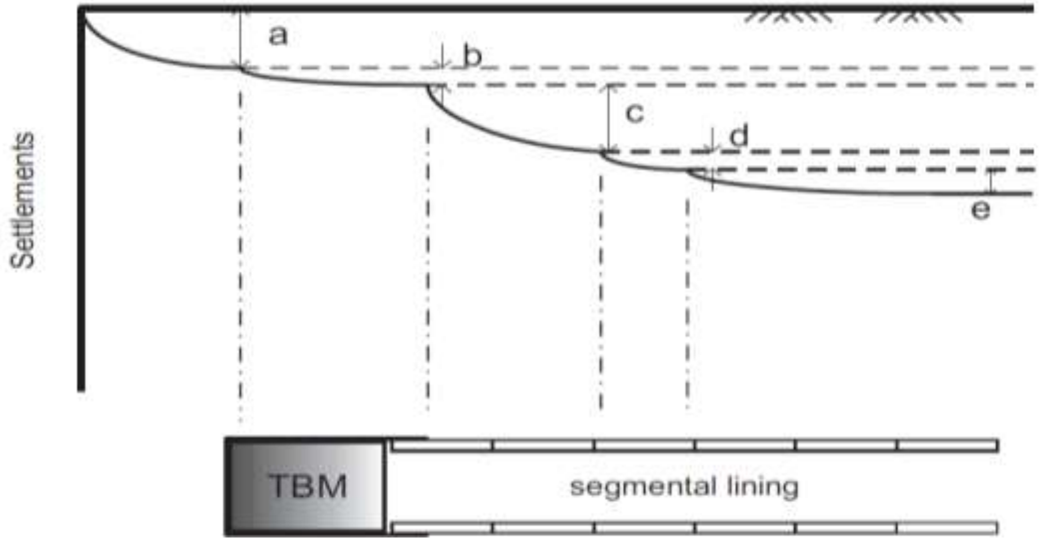
Equations		Descriptions
$S_v = S_{max}$ exp $(-y^2/2i^2)$	**(1)**	**S_v = SETTLEMENT** S_{max} = the maximum settlement directly above the tunnel centreline y = the transverse horizontal distance from the tunnel centreline of the trough i = the horizontal distance from tunnel centreline to the point of inflexion on the settlement trough
i= K Z_o	**(2)**	**K = tunnel soil parameter (approximately ranging from 0.5 to 0.25) depending on soil geological type e.g.; clay and sand 0.5 and**
$V_s=V_L$ π $D^2/4$	**(3)**	**V_s = VOLUME OF THE SURFACE SETTLEMENT TROUGH** V_L = excavated tunnel, m^3 D = tunnel diameter
S_{max} = 0.31$V_L D^2$/ K_z	**(4)**	Combined equations (2) and (3)

Ground Movement Induced by Tunnelling



Settlement trough in 3D

Sequencing for Ground Settlement by Tunnelling

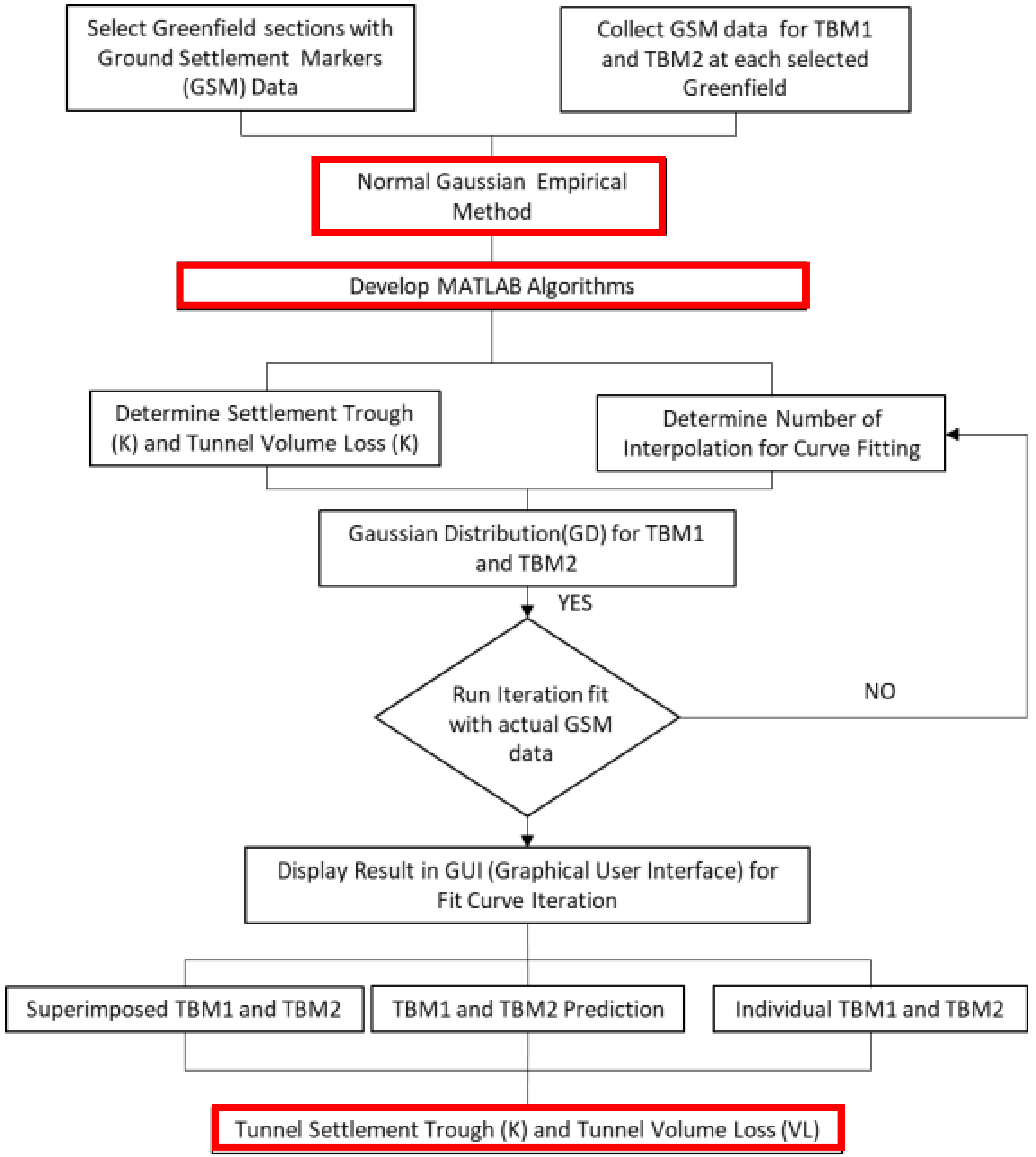


a. Ahead & above TBM Cutterhead
b. Along the TBM excavation
c. Induced at Tail Loss
d. Induced by Lining deflection
e. Induced by long term settlement

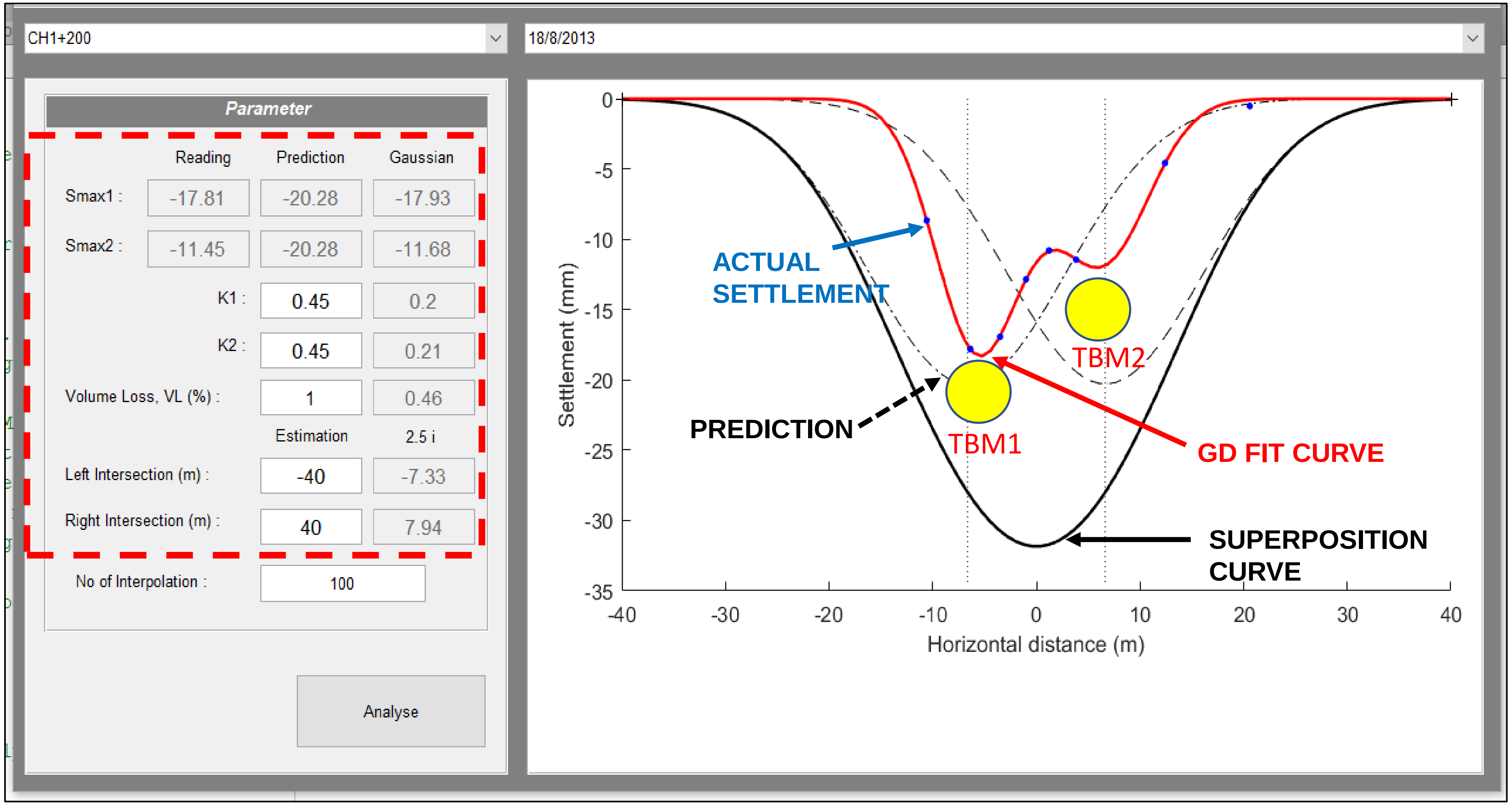
GD Curve Fitting & MATLAB

Curve fittings to real monitoring data methods applied (Jones & Clayton, 2012):

- Direct Calculation (DCJ)
- Direct Calculation S_{max} (DCSMAX)
- Non-Linear Regression Sum of absolute error (NRSAE)
- Non-Linear Least Squares (NRLS)
- Visual Fit By Eye



Fundamental Result of Curve Fitting GD



- Common research only single tunnel
- Combined and superposition **TWO** tunnel parallel
- Actual Smax settlement on 1st and 2nd TBM for NB & SB intervals.
- Highly depends of i (settlement trough) and z (tunnel overburden depth).
- Best fit the Gaussian distribution shape, iterations tunnel parameters to simulate ground settlement effects caused by the TBMs.
- Each sections have different fitting GD

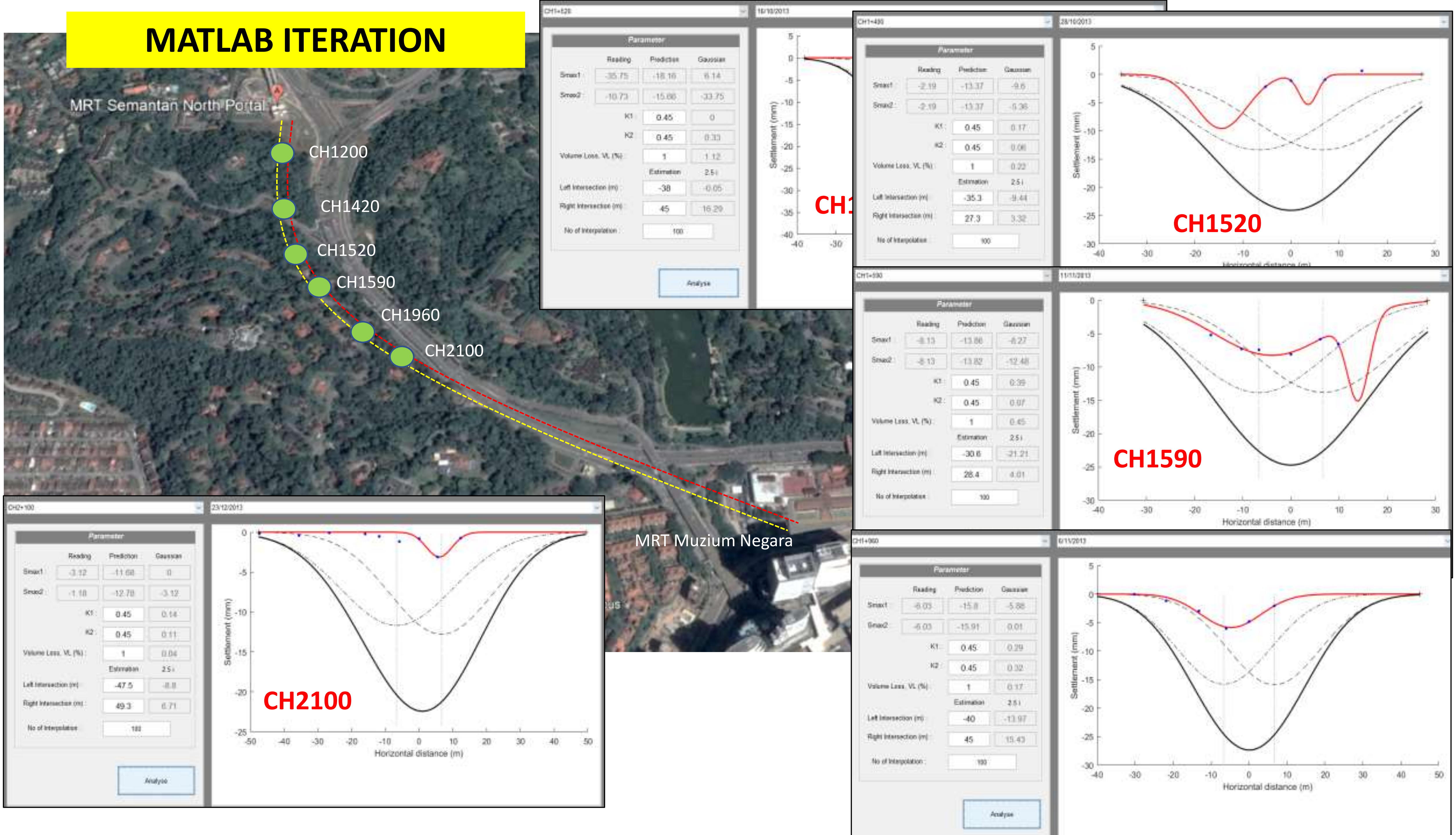
Results:

1) S_{max} (Actual) < S_{max} (Prediction) ground settlement
2) Tunnel, K (design) < K(actual)
3) V_L(design) < V_L(actual)

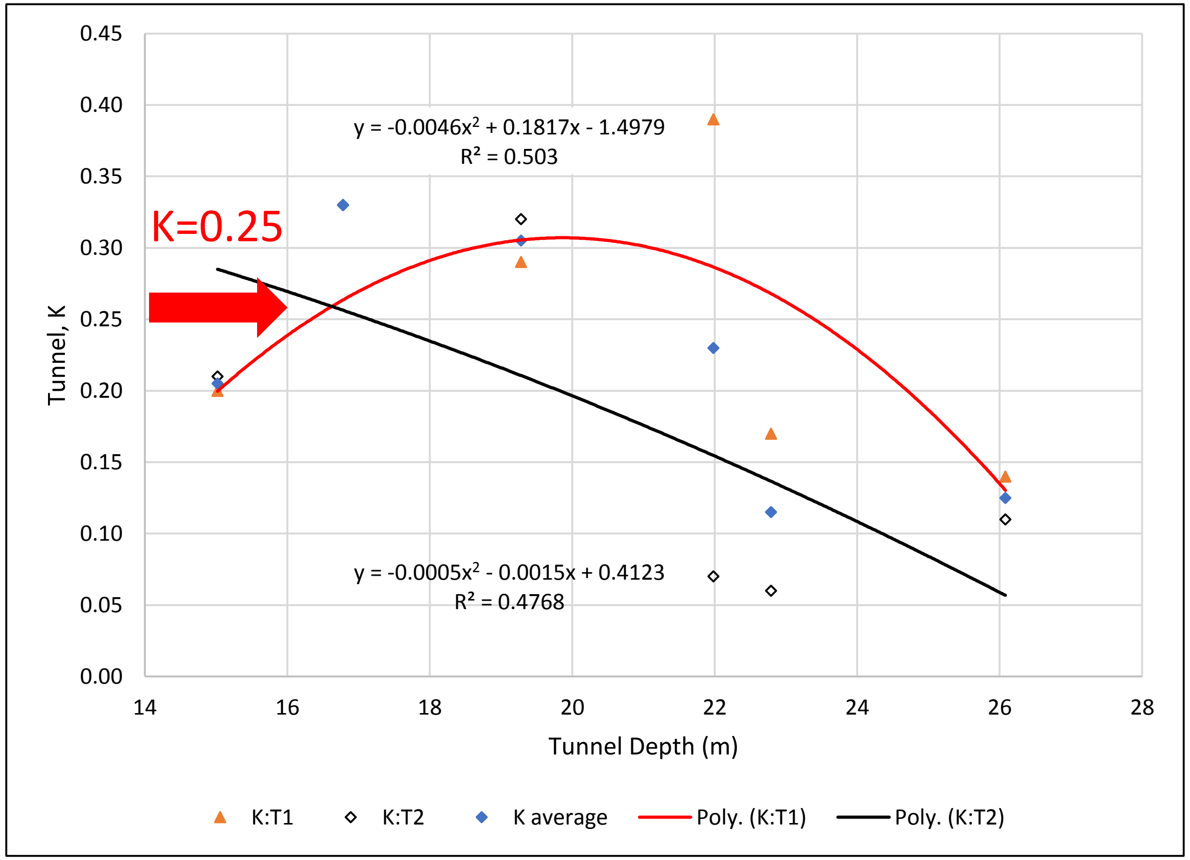
Other circumstances:

1) Depends to Tunnel depth/overburden
2) Tunnel Operation by the operator

MATLAB ITERATION



Results of Tunnel Parameters (K)



Chainage	Tunnel Depth	Before		During		After	
		Tunnel (TBM1)	Tunnel (TBM2)	Tunnel (TBM1)	Tunnel (TBM2)	Tunnel (TBM1)	Tunnel (TBM2)
CH1200	15.02	0.24	0.32	0.2	0.21	0.15	0.41
CH1400	22.79	0.51	0.21	0.17	0.06		
CH1520	16.78		0.05		0.33	0.09	0.5
CH1590	21.98	0.02	0.18	0.39	0.07		
CH1960	19.28	0.29	0.32	0.29	0.32	0.07	0.54
CH2100	26.08	1.02	0.09	0.14	0.11	0.135	0.113

Chainage	Tunnel Height (m)	Actual Volume Loss (V_L) %
1+200	15.02	0.46
1+420	22.79	1.12
1+520	16.78	0.22
1+590	21.98	0.45
1+960	19.28	0.17
2+100	26.08	0.04

Theoretical (K) : 0.45 vs 0.25
(VL) : 1% vs 0.41%

Curve Fitting Gaussian Distribution

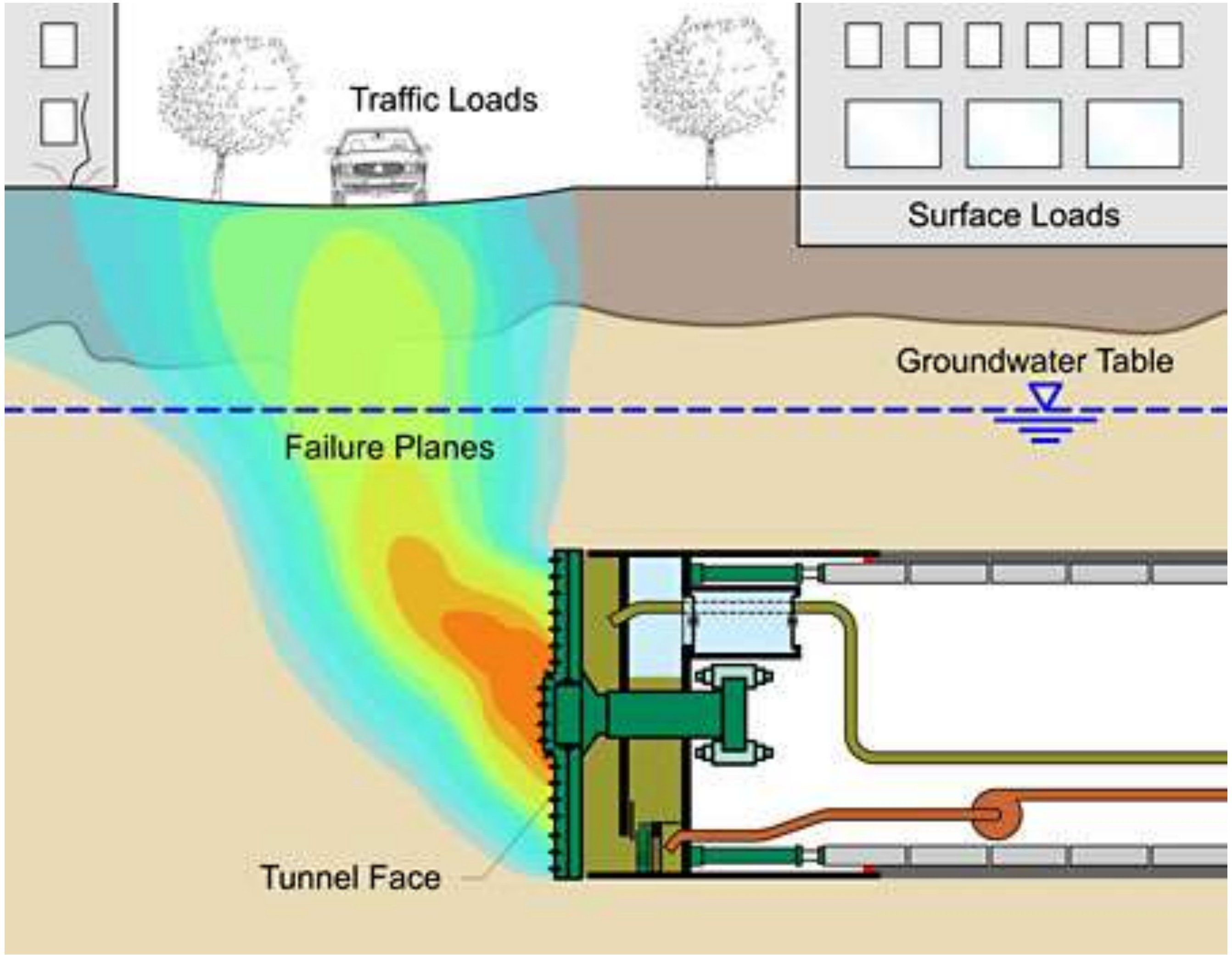
Formation	Weathering grade/material	Tunnelling method	K
Jurong Formation	S(V)/S(VI)	Greathead shield	0.45
	S(V)/S(VI)	Greathead shield in compressed air	0.45
	S(II)/S(III)	EPB shield	0.45
	S(II)/S(III)	NATM	0.45
	FCBB	NATM	0.45 – 0.50
	FCBB	Greathead shield	0.50
Bukit Timah Granite	G(V)/G(VI)	Greathead shield	0.45
	G(V)/G(VI)	Greathead shield in compressed air	0.45
	G(V)/G(VI)	TBM in compressed air	0.45
	G(V)/G(VI)	NATM in compressed air	0.45
	G(V)/G(VI)	EPB shield	0.45
Old Alluvium	-	EPB shield	0.45
Kallang Formation	Marine Clay	Semi-blind/semi-mechanical shield	0.50
	Marine Clay	Great head shield with ground treatment and compressed air	0.50
	Marine Clay	TBM in compressed air	0.50
	Marine Clay	EPB shield	0.50

Formation	Weathering grade/material	K
Jurong Formation	All grades	0.50
	FCBB	0.45
Bukit Timah Granite	G(VI)	0.45
	G(I) to G(V)	0.50
Old Alluvium	-	0.50
Kallang Formation	-	0.30

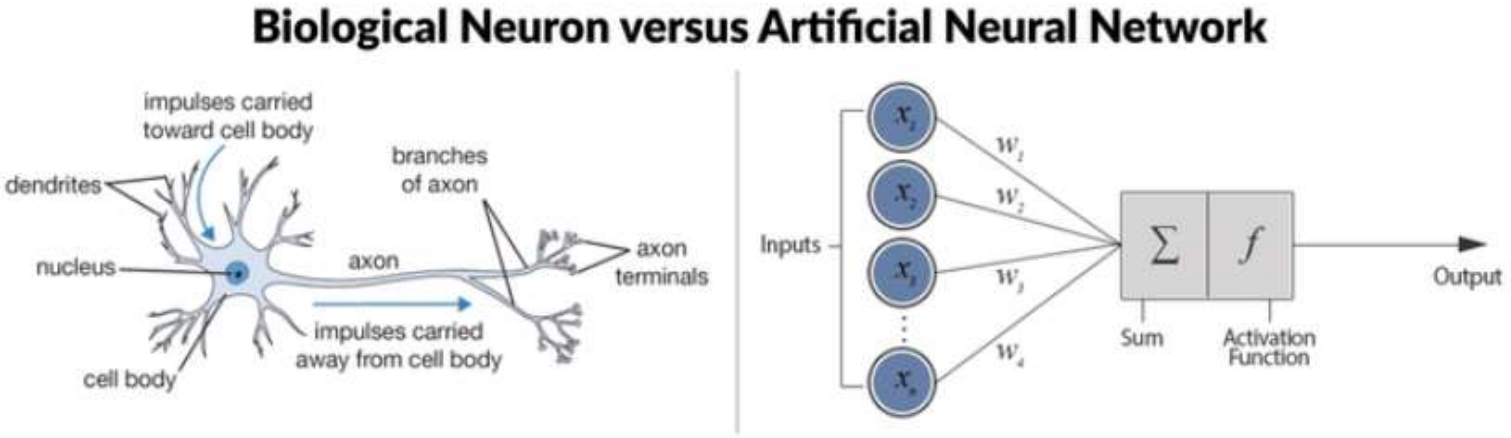
Referencing to Singapore's experience & enhancement from MY MRT Project

Empirical values of Volume Loss (Zhu & Li, 2017)

ANN & TBM PARAMETERS



ANN INTRODUCTIONS



<u>The design of optimum network</u>

Realistic Model with 3 layers:

1) Input
2) Hidden Layer
3) Output

Also includes:

1) Training and testing of ANN using the available subset data
2) These data trained to convergence to the training samples
3) Network will measure the performance with the validation set

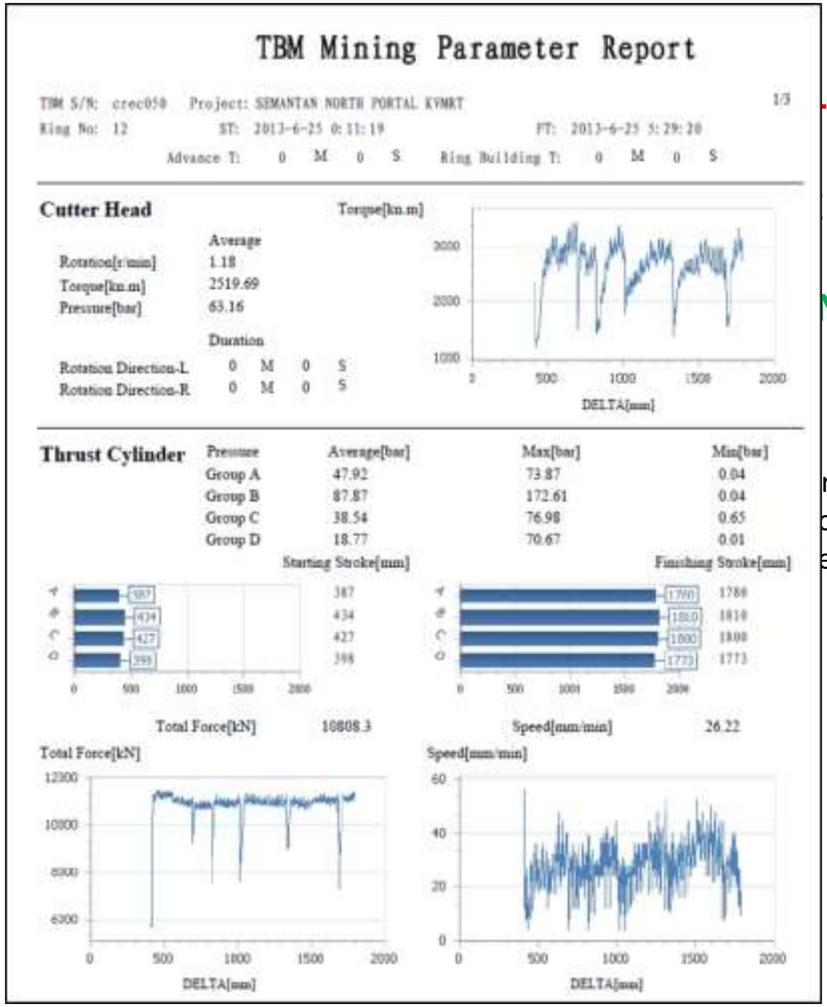
ANN Concept

- A neural network is computing algorithm method -layered structures - similar of neurons in the brain- layers of connected nodes.
- ANN can learn from data—trained -recognize patterns-classify data- forecast future events.

https://towardsdatascience.com/from-fiction-to-reality-a-beginners-guide-to-artificial-neural-networks-d0411777571b

ANN IN EPB TUNNEL

EXTRACTION WITH MANUALLY INPUT OF 43,000 DATA FROM EPB TBM



TBM Mining Parameter Report

TBM S/N: crec050 Project: SEMANTAN NORTH PORTAL KVMRT 1/3

Ring No: 12 ST: 2013-6-25 0:11:19 FT: 2013-6-25 5:29:20

Advance T: 0 M 0 S Ring Building T: 0 M 0 S

Cutter Head

	Average
Rotation[r/min]	1.18
Torque[kn.m]	2519.69
Pressure[bar]	63.16

	Duration
Rotation Direction-L	0 M 0 S
Rotation Direction-R	0 M 0 S

Thrust Cylinder

Pressure	Average[bar]	Max[bar]	Min[bar]
Group A	47.92	73.87	0.04
Group B	87.87	172.61	0.04
Group C	38.54	76.98	0.65
Group D	18.77	70.67	0.01

	Starting Stroke[mm]	Finishing Stroke[mm]
A	387	1780
B	434	1810
C	427	1800
D	398	1773

Total Force[kN] 10808.3 Speed[mm/min] 26.22

Gap Analysis for ANN

REFERENCE	MSS METHOD	REMARKS	PROS & CONS
1) Martos, 1958 2) Peck, 1969 3) O'reilly and New, 1982 4) Mair,1993	Empirical	▪ Gaussian or normal distribution ▪ Fitted the GD Curve and relationship of relative depth of a tunnel - inflection point of transverse settlement trough for various soil types.	▪ Fails to consider all TBM components for MSS ▪ Limited to only region developed
1) Sagaseta, 1987 2) Bobet, 2001 3) Yang,2004 4) Verruijt, 1997	Analytical	▪ Virtual Image Technique ▪ Form Stress Function In Polar Coordinate ▪ Stochastic Medium Theory ▪ Complex Variable Method	
1) Melis ,2002 2) Sun & Liu, 2002 3) De Farias ,2004 4) Kasper & Meschke, 2004 5) Chakeri ,2013 6) Yasitli, 2013	Numerical	▪ FEM and FDM (Finite Element /Finite Difference Method) ▪ Empirical, Analytical & FDM ▪ 3D FDM, FLAC^{3D}	▪ Only approximate result ▪ Time consuming with large data ▪ Data need to discretized in FEM or FDM ▪ Requires TBM mechanisms & model physical involved, experience
1) Suwansawat & Einstein, 2006 2) Ocak & Seker, 2013 3) Neaupane & Adhikari, 2006 4) Pourtaghi Lotfollahi-Yaghin, 2012 5) Samui, 2008 6) Jiang ,2011 7) Ding,2012 8) Hasanipanah ,2016 9) Moghaddasi & Noorian-Bidgoli, 2018	Artificial Intelligence	▪ MSS by EPB tunnel ▪ NATM & sequential excavation ▪ Support Vector Machines (SVM) ▪ ANN & Heuristic Algorithms Called Hybrid Methods ▪ ICA-ANN, Multiple Regression	▪ Large data ▪ Faster for data result ▪ More data Input ▪ Better result obtained

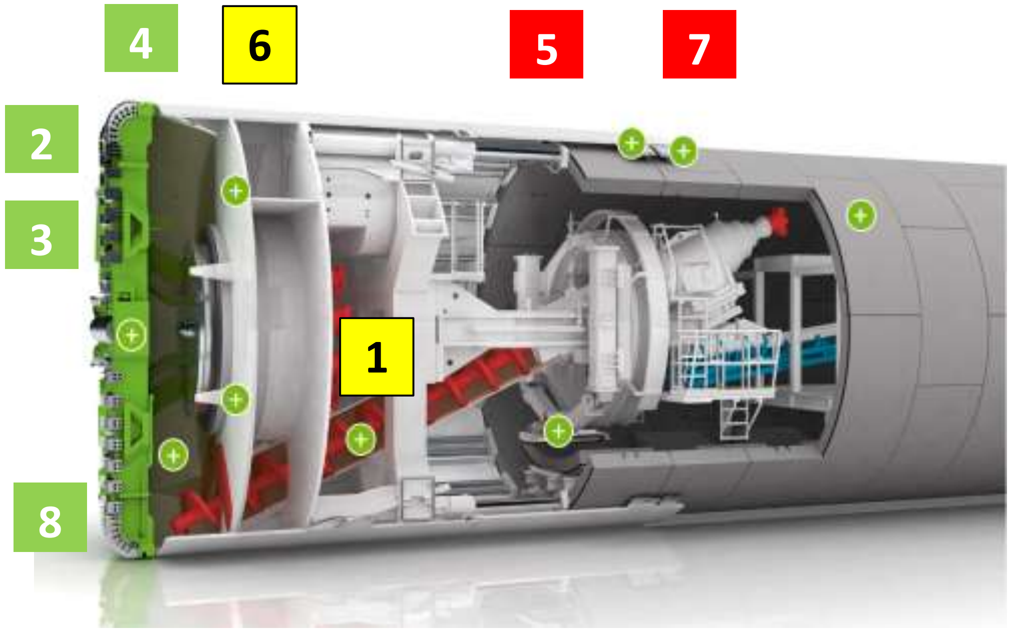
Most studied on MSS, VL not yet

Comparisons & Current PhD Research

CATEGORY	FACTORS RESEARCH *	FACTORS RESEARCH
Tunnel geometry	1. Tunnel depth (m) 2. Distance from launching station (m)	1. Initial finding less significant due to small settlement magnitude and overall tunnel depth
Geological conditions	1. Geology at tunnel crown 2. Geology at tunnel invert 3. Ground water level from tunnel invert (m)	1. Not in scope
Shield operation factors	1. Face pressure (KPa) 2. Penetration rate (mm/min) 3. Pitching angle (°) 4. Tail void grouting pressure (bar) 5. Percent tail void grout filling	1. Cutter Head (1) Rotation (r/min) (2) Torque (KN/m) (3) Pressure (bar) 2. Screw Conveyor (1) Rotation (r/min) (2) Torque (KN/m) 3.Earth Pressure (bar) 4.Total Grouting (m3) 5.Tail Sealing – Front and back(bar) 6.Foam Injection (1) Average (m3) (2) Foam Additive (m3) (3) Water Per Ring (m3) (4) Solution Per Ring (m3) 7. Soil Conditioning (1) Bentonite/Ring (m3) (2) Cutter Head Flushing Water/Ring (m3)

S. Suwansawat and H. H. Einstein, "Artificial neural networks for predicting the maximum surface settlement caused by EPB shield tunneling," *Tunn. Undergr. Sp. Technol.*, vol. 21, no. 2, pp. 133–150, 2006.

ANN Architectural



Infront TBM

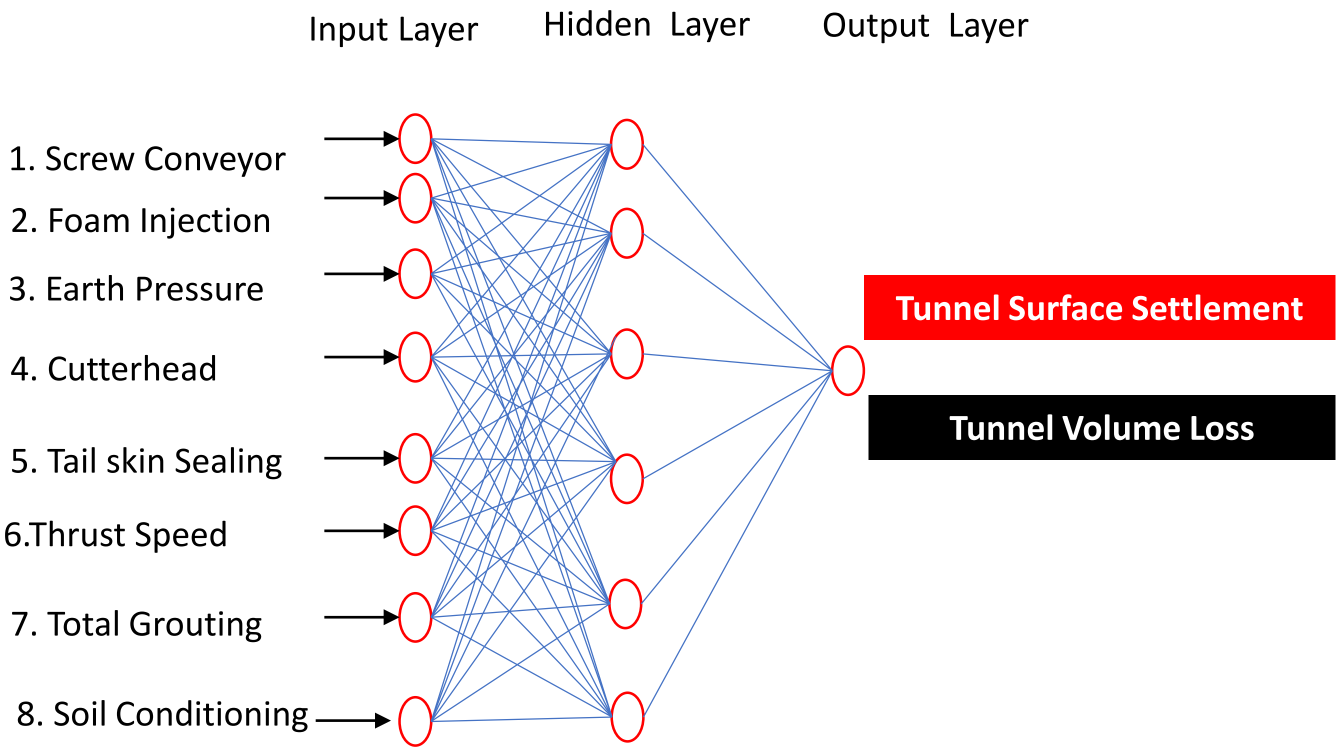
- 2 Foam Injection
- 3 Earth Pressure
- 8 Soil Conditioning
- 4 Cutter Head

Inside TBM

- 1 Screw Conveyor
- 6 Thrust Speed

Outer TBM

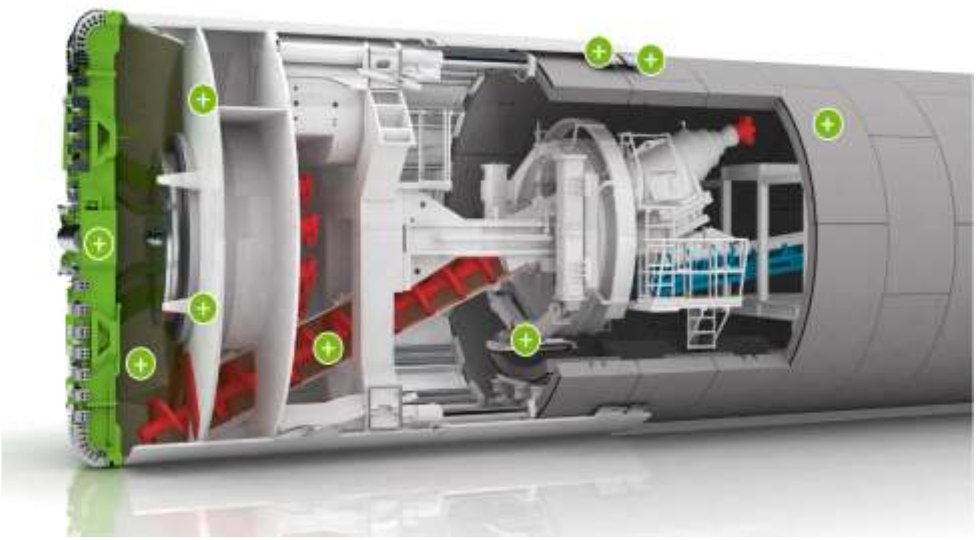
- 5 Tail Sealing
- 7 Total Grouting



Structure of one layer neural network model for predicting tunnel surface settlement & volume loss

Two EPB TBM studied in both directions (NB and SB) and 8 parameters analysed using Matlab. All results are reorganised by **RMSE** and **Regression** using **Feedforward back-propagation method**.

EPB Geomechanical Components



FACE LOSS

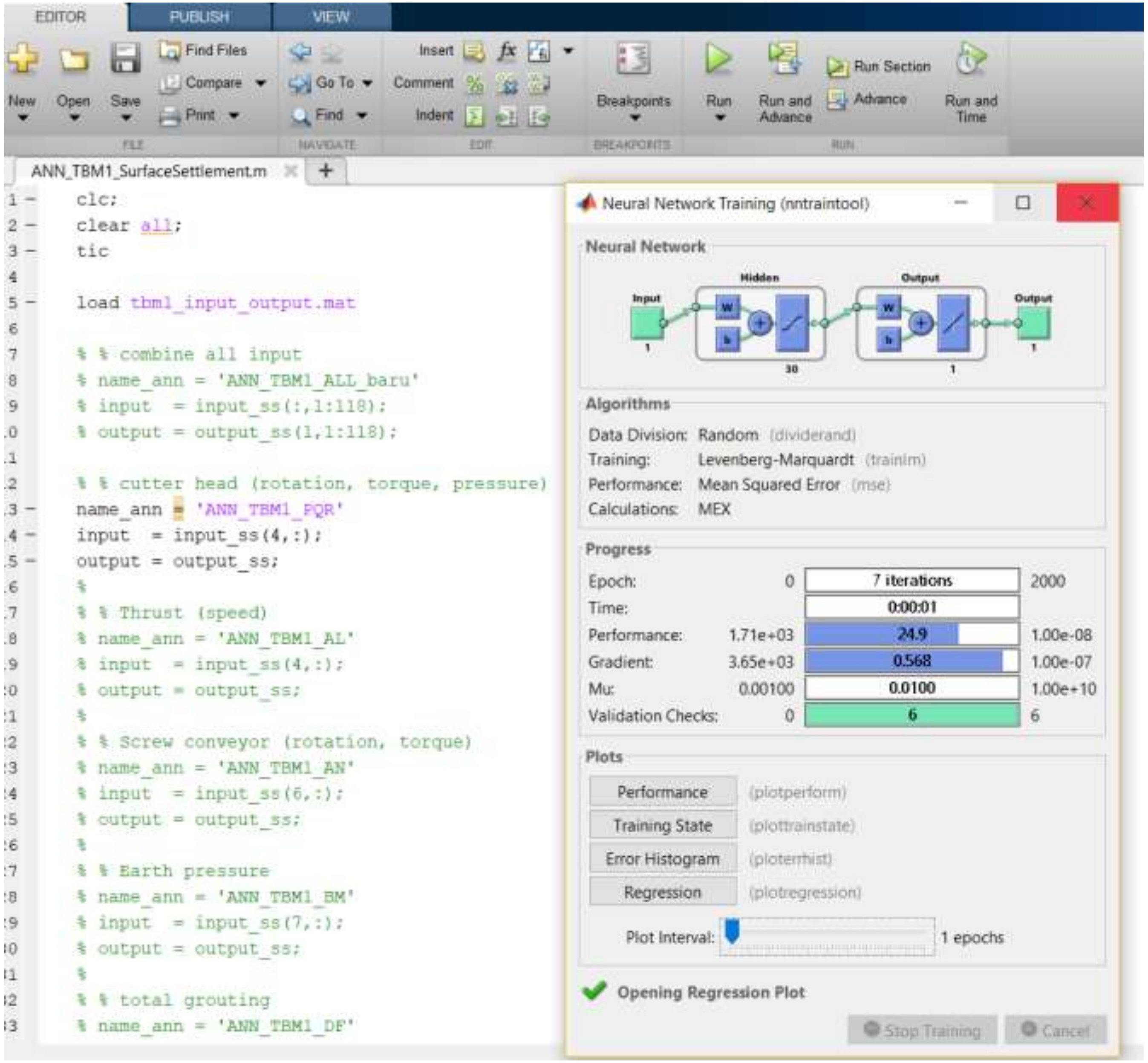
SHIELD LOSS

TAIL LOSS

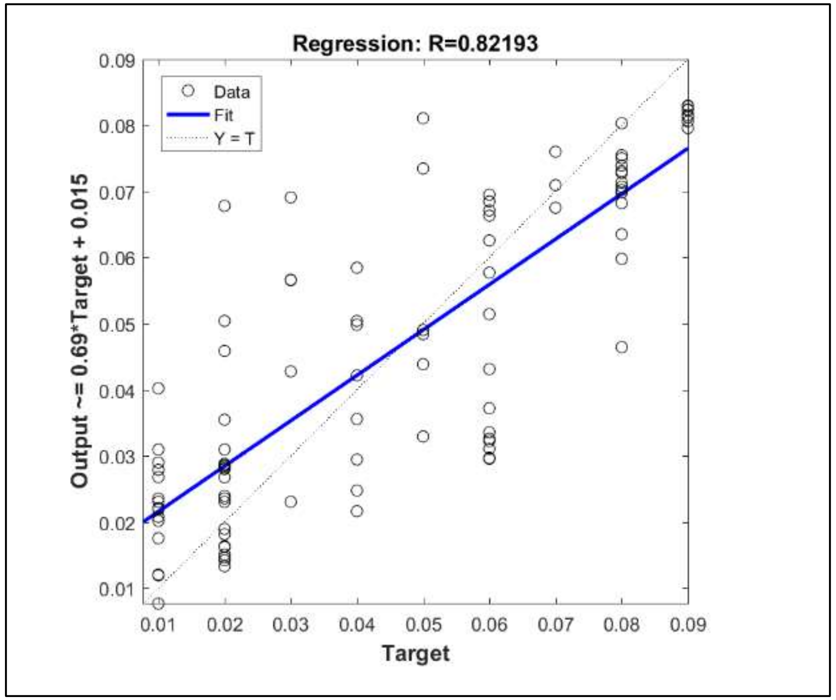
Major TBM Group	EPB Tunnel Parameter
Cutter Head	Cutter Head Rotation
	Cutter Head Torque
	Cutter Head Pressure
Thrust Speed	Thrust Speed
Screw Conveyor	Screw Conveyor Rotation
	Screw Conveyor Torque
Earth Pressure	Earth Pressure
Total Grouting	Total Grouting
Tail Skin	Tail Skin (Front)
	Tail Skin (Back)
Foam Injection	Foam Injection
	Foam Injection (Additive)
	Foam Injection (Water)
	Foam Injection (Solution)
Soil Conditioning	Soil Conditioning (Bentonite)
	Soil Conditioning (Cutter Head Flushing/Water)
	Soil Conditioning (Shield Bentonite)
	Soil Conditioning (Polymer)

Two EPB TBM studied in both directions (NB and SB) and 21parameters analysed using Matlab. All results are reorganised by **RMSE** and **Regression** using **Feedforward back-propagation method**.

ANN USING MATLAB



All results are reorganised by **RMSE** and **Regression** using **Feedforward back-propagation method**.



<u>ANN Facts:</u>

- 6 Greenfield with 12 TBM sections
- 8 Major TBM Parametric with 12 minor TBM component tested
- Total 252 data for both tunnels (126 sections x 2 TBMs)
- Total 32,338 TBM data matrix mining (703 rings x 23TBM parameters x 2 TBMs)

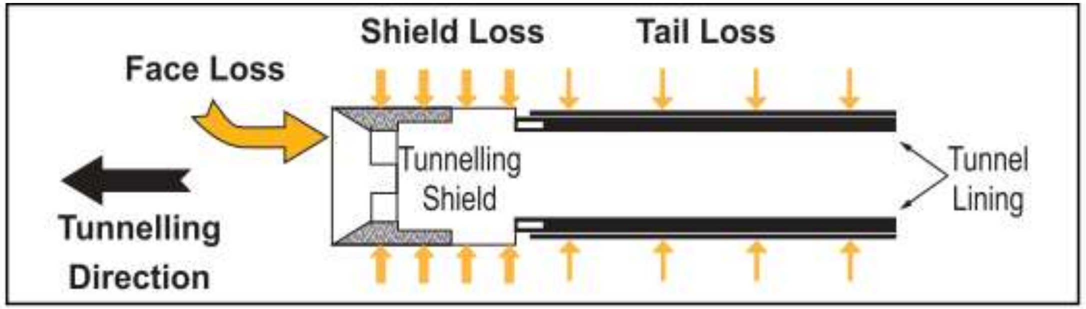
ANN & Overall EPB 21 Parameters: S_{max} & V_L

21 Parameters (Smax)	Lowest RMSE
Tail Sealing Front	0.0551
Sealing Grease Injection	0.0749
Foam Injection	0.1052
SC Bentonite/Ring	0.1154
SC Torque	0.1196
SC Rotation	0.1371
Screw Conveyor	0.1463
CH Torque	0.1596
CH Rotation	0.1665
Total Grouting	0.1671
Earth Pressure	0.1717
CH Pressure	0.1807
Thrust Speed	0.1883
Tail Sealing Back	0.1905
FI Water/Ring	0.1916
FI Foam Addictive	0.1933
FI Average	0.2038
Soil Conditioning	0.2044
Cutterhead	0.2537
FI Solution/Ring	0.2607
SI Cutter Head Flushing Water/ Ring	0.4264

21 Parameters (VL)	Lowest RMSE
SC Torque	0.0080
Cutterhead	0.0102
Thrust Speed	0.0108
Foam Injection	0.0113
Earth Pressure	0.0122
SC Bentonite/Ring	0.0129
Screw Conveyor	0.0133
SI Cutter Head Flushing Water/ Ring	0.0134
CH Torque	0.0138
Total Grouting	0.0141
Tail Sealing Back	0.0142
Tail Sealing Front	0.0143
Soil Conditioning	0.0143
FI Foam Addictive	0.0146
CH Rotation	0.0153
SC Rotation	0.0155
FI Water/Ring	0.0163
FI Solution/Ring	0.0165
CH Pressure	0.0170
FI Average	0.0180
Sealing Grease Injection	0.0183

- Lower RMSE is better than the higher
- RMSE measure accuracy, to compare forecasting errors of different models of particular dataset (scale-dependent).
- Higher values of R^2 and lower value of RMSE, indicates the superiority of the predictive model.

Results of Specific TBM Components Contributors in S_{max} & V_L



21 Parameters (Smax)	Lowest RMSE
Tail Sealing Front	0.0551
Sealing Grease Injection	0.0749
Foam Injection	0.1052
SC Bentonite/Ring	0.1154
SC Torque	0.1196

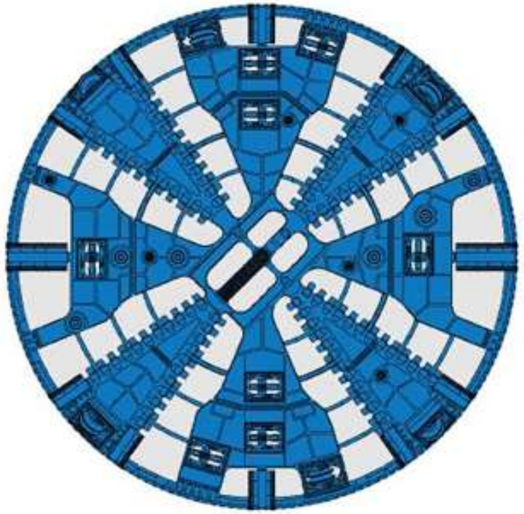
FACE LOSS
change in ground stress at TBM face resulting longitudinal ground movement

SHIELD LOSS
ground moves radially during TBM into gap created by TBM shield overcut.

TAIL LOSS
shrinkage/ incomplete grout filling to tail gap after segmental lining leaves TBM shield

21 Parameters (VL)	Lowest RMSE
SC Torque	0.0080
Cutterhead	0.0102
Thrust Speed	0.0108
Foam Injection	0.0113
Earth Pressure	0.0122

GEOMECHANICAL COMPONENTS =RANKING + PRECISE LOWEST RMSE



SUMMARY EPB TUNNEL PERFORMANCE

Major TBM Group	EPB Tunnel Parameter	Average Performance
Cutter Head	Cutter Head Rotation	1.56 r/min
	Cutter Head Torque	2977.11 kN/m
	Cutter Head Pressure	83.76 Bar
	Thrust Speed	32.06 mm/min
Screw Conveyor	Screw Conveyor Rotation	6.67 r/min
	Screw Conveyor Torque	44.21 kN/m
Earth Pressure	Earth Pressure	1.49 Bar
Total Grouting	Total Grouting	4.66 m^3
Tail Skin	Tail Skin (Front)	10.10 Bar
	Tail Skin (Back)	11.48 Bar
Foam Injection	Foam Injection	1.35 Bar
	Foam Injection (Additive)	0.08 ring/m^3
	Foam Injection (Water)	3.53 ring/m^3
	Foam Injection (Solution)	5.47 ring/m^3
Soil Conditioning	Soil Conditioning (Bentonite)	5.89 ring/m^3
	Soil Conditioning (Cutter Head Flushing/Water)	6.71 m^3
	Soil Conditioning (Shield Bentonite)	0.35 ring/m^3
	Soil Conditioning (Polymer)	27.14 ring/m^3

Shows the EPB efficiency & controlling the MSD in KHF

Conclusions

MAIN FINDINGS

1 **Absolute value of tunnel parameters, K and V_L** by comparing empirical values used by tunnel designers

2 **ANN** for EPB geo-mechanical tunnel correlations to ground surface settlement, S_{max} & tunnel, V_L

SCIENTIFIC CONTRIBUTIONS

1 K substitutions of **0.25 from 0.5** for clay type soil in tunnelling design by precise back analysed Gaussian Distribution

2 Proves the **efficiency of EPB tunnel** in Kenny Hill Formation and design inputs can be used for **current/future Malaysian Tunnelling Guidelines**. Current standard of SIRIM 2363:2010 has limited geotechnical tunnel input.

3 **Developing ANN** and significant results to EPB Geo-mechanical parameters in Civil Engineering.

SUCCESSFULLY DIGGING!!!

Special Dedications to:

- JKR CDPK
- JKR Teammates 2013-2016
- MRT Corp especially Tunnel Department