Deriving design parameters for structures in ground using I-System

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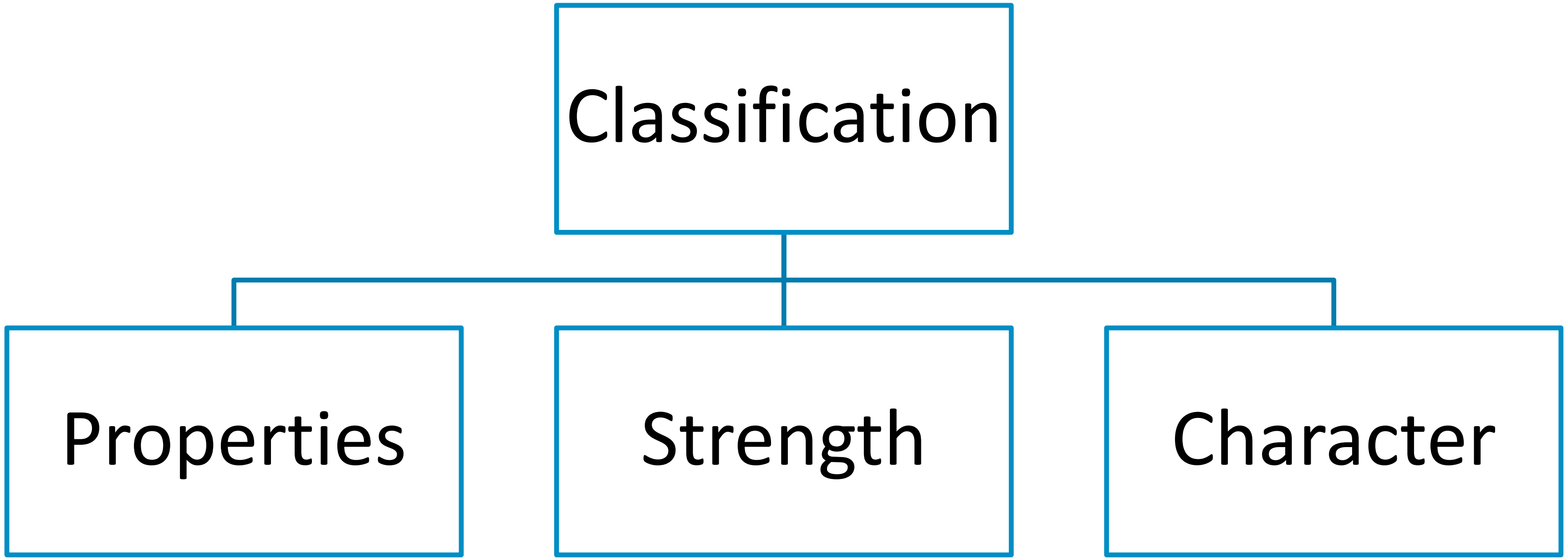
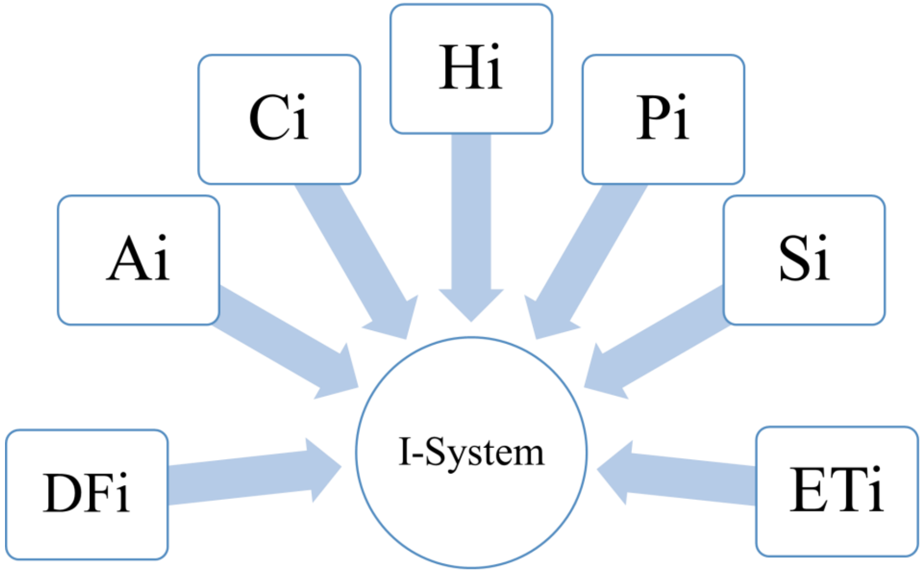
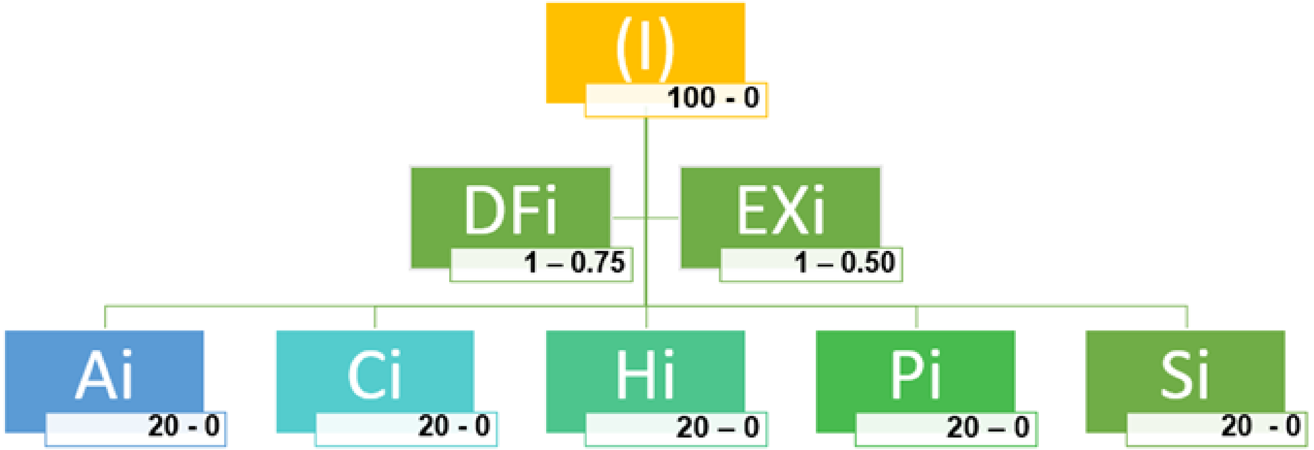

Classification
Properties
Strength
Character

- The design process of underground structures especially tunnels are based on Engineering Classifications which is significant part of the Empirical and Observational Approach.
- Every System/Technique/Method has a specific scope and limitations owing to the vast complexity of the Nature.
- The I-system is a Comprehensive way for Classification and Characterization of ground. It provides two outputs (I)-Class & (I)-GC.
- The USBRL T01 project has been selected for the Data collection for the investigation of the Geo-mechanical properties.
- Statistical Methods have been adopted for data processing and Regression analysis have been performed to obtain accurate results



Hi
Ci
Pi
Ai
Si
I-System
DFi
ETi



(I)
100 - 0
DFi
1 – 0.75
EXi
1 – 0.50
Ai
20 - 0
Ci
20 - 0
Hi
20 – 0
Pi
20 – 0
Si
20 - 0

I-System

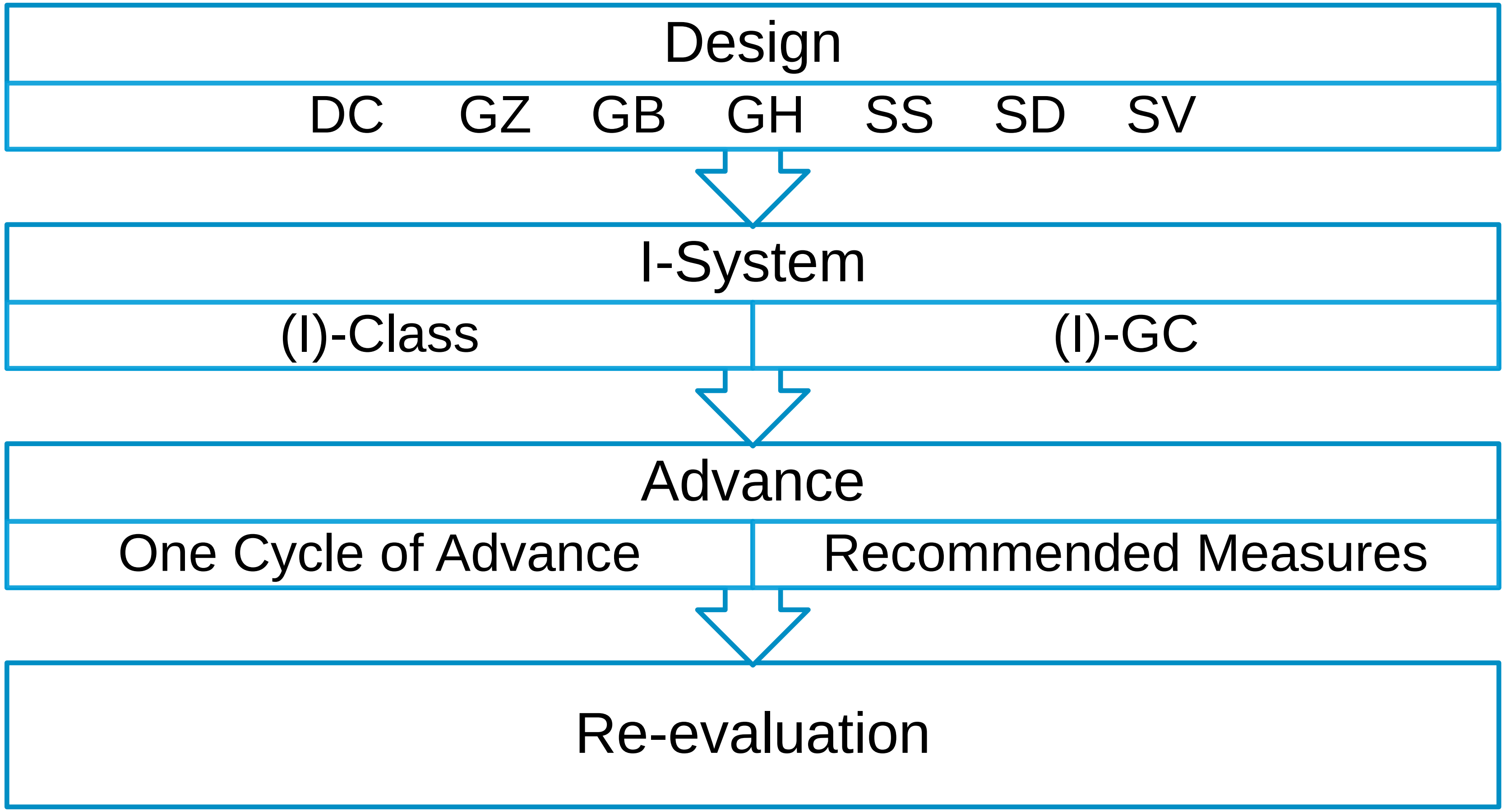
OUTPUTS

(I)-Class

1. Support System/s (SS)
2. Excavation Technique/s (ET)
3. Instrumentation Technique/s (IT)
4. Prevention Technique/s (PT)
5. Forecast Technique/s (FT)
6. Design Remark/s (DR)

(I)-GC

1. Modulus of Deformation (Eg)
2. Poisson's Ratio (vg)
3. Unconfined Compressive Strength (σcg)
4. Uniaxial Tensile Strength (σtg)
5. Cohesion (Cg)
6. Internal Friction Angle (φg)


Design
DC
GZ
GB
GH
SS
SD
SV
I-System
(I)-Class
(I)-GC
Advance
One Cycle of Advance
Recommended Measures
Re-evaluation

(I)	(I)-Class	Recommended Measure/s		
		SS	ET	IT
100-91	(I)-01	Scaling	FF, ME/DnB, PL	Nil
90-81	(I)-02	Scaling, IndiB25	FF, ME/DnB, PL	Nil
80-71	(I)-03	Scaling, SpotB25	FF, ME/DnB, PL	Nil
70-61	(I)-04	Scaling, SpotB25, PatchPS50	FF, ME/DnB, PL	3DMS@400m
60-51	(I)-05	Scalinng, SpotB32/SysHB25.L.S, PS50, PSFS50, RDH54.L	FF, ME/DnB, PL	3DMS@200m
50-41	(I)-06	Scaling, SysB32.L.S/SysHB32.L.S, FRS100, FRFS50, RDH54.L	HnB/(FF if ≤ 45 m^2),ME/DnB, PL	3DMS@100m, StrainM@300m
40-31	(I)-07	Scaling,CPS32.L.S/FP32.250.L.X1, SysB32.L.S/SysHB32.L.S,LG25.20.150.1000-, FRS200, FRFS150, RDH54.L	HnB/(FF if ≤ 35 m^2), ME/NonExBreak/ DnB, PL	3DMS@75m, StrainM@250m, PressC/LoadC@300m
30-21	(I)-08	FP32.200.L.X1/FP76.250.L.X1/PR100.300.L.X1, SysLB32.L.S, LG32.25.180.1000/ RigidR150UC23.1000- ,FRS225/FRC225,FaceButt.L,FRFS200, RDH54.L+CF	PSE, ME/NonExBreak, PL	3DMS@50m, StrainM@200m, PressC/LoadC@250m, SingleRodE@400m
20-11	(I)-09	PR100.250.L.X1/FP76.200.L.X1/FP32.200.L.X2, FaceB25.L.S/FaceP300- ,FaceButt.L,PreG/I,RigidR150UC23.750+RingC, SysN32.L.S,FRS225/FRC225, FRFS200, RDH54.L+CF	PSD, ME, PL	3DMS@25m, StrainM@150m, PressC/LoadC@200m, MultiRodE@400m, StrainG@500m
10-0	(I)-10	PR100.200.L.X1/FP76.200.L.X2, PreG/I,PostG/I,FaceB32.L.S/FaceP300- ,FaceButt.L,RigidR200UC46.500+RingC, SysN32.L.S, FRS250/FRC250, FRFS225, (RDH54.L, WDH54.L)+CF	PSD, ME, PL	3DMS@25m, StrainM@150m, PressC/LoadC@200m, MultiRodE@400m, StrainG@500m

(I)	(I)-Class	Recommended Measure/s		
		PT	FT	DR
100-91	(I)-01	Avoid: ‘UnCtldBlast’	TSP/PH100.BH.L	Active load configuration, SPL and/or SFL not required
90-81	(I)-02	Avoid: ‘UnCtldBlast’	TSP/PH100.BH.L	Active load configuration, SPL and/or SFL not required
80-71	(I)-03	Avoid: ‘UnCtldBlast’	TSP/PH100.BH.L	Active load configuration, SPL and/or SFL not required
70-61	(I)-04	Avoid: ‘ProdBlast / UnCtldBlast’	TSP/PH100.BH.L	Active load configuration, SPL and/or SFL not required
60-51	(I)-05	Avoid: ‘ProdBlast / UnCtldBlast’	TSP/PH100.BH.L/ PH54.EC.L	Load configuration to be maintained as active, SFL not required
50-41	(I)-06	Avoid: ‘ProdBlast / UnCtldBlast’	TSP/PH100.BH.L/ PH54.EC.L	Load configuration to be maintained as active
40-31	(I)-07	Apply: ‘CPS’ Avoid: ‘MineBlast / ProdBlast / UnCtldBlast’	TSP/PH100.BH.L/ PH54.EC.L	Critical load bearing capacity
30-21	(I)-08	Apply: ‘FP / PR, Maintainn Buttress’ Avoid: ‘FF & DnB’	TSP/PH54.EC.L	Passive load configuration, Sensitive to: ‘Scale, unsupported span, & stand-up time
20-11	(I)-09	Apply: ‘PreG/I & FP / PR, Maintainn Buttress’ Avoid: ‘FF, NonExBreak / DnB & ductile SS’	TSP/PH54.EC.L	Passive load configuration, Sensitive to: ‘Scale, unsupported span, & stand-up time
10-0	(I)-10	Apply: ‘PreG/I & PR, Maintainn Buttress’ Avoid: ‘FF, NonExBreak / DnB & ductile SS’	TSP/PH54.EC.L	Passive load configuration, Sensitive to: ‘Scale, unsupported span, & stand-up time

(I)-Class	Recommended Measure/s					
	SS	ET	IT	PT	FT	DR
(I)-BP	Scaling, SysDB25.L.S/ ConeB25.L.S/ YieldB25.L.S, FRS150, SRH100.L.S.X1, HEAM/CableL+ WeldM, FRFS50	HnB, ME/ DnB, PL	3DMS@25m, StrainM@100m, PressC/LoadC@ 300m, MultiRodE@ 600m	Avoid: 'ProdBlast/ UnCtldBlast, rigid SS, & naked faces'	TSP/ PH100. BH.L	Bursting initiation time and depth of plastic zone around periphery to be measured
(I)-TD	**Mild-Severe SSH:** YieldR1000+RingC, SRH100+ .L.S.X2, YieldFRS200/ YieldFRC200, LSC, SysDB25.L.S **Minor SSH:** RigidR200UC46.1000 - +RingC, FRS200/FRC200+ SRH100.L.S.X1+ SysLB32.L.S	HnB, ME, PL	3DMS@10m, StrainM@100m, PressC/LoadC@ 150m, MultiRodE@ 300m, StrainG@400m, DIC@25m	Apply: 'SRH, SysLB for Minor SSH' Avoid: 'FF, DnB, rigid SS, & SysLB for Mild-Severe SSH'	TSP/ PH100. BH.L	Nonuniform deformation, load relaxation, scale sensitive
(I)-VP	BulkH300+, FaceP300-, PR100.150.L.X1, PreI/JetG/PreF, PostG/I, RigidR200UC46.500- +RingC, FRS300/FRC300, FRFS275, (RDH54.L, WDH54.L, ADH54.L)+CF	PSD, ME, PL	3DMS@10m, StrainM@100m, PressC/LoadC@ 150m, MultiRodE@ 400m, StrainG@400m, DIC@25m	Apply: 'PreG/I & PR, maintain buttress' Strictly Avoid: 'FF, NonExBreak/ DnB, ductile SS, & build-up of hydrostatic pressure/thrust at face'	TSP/ PH54. EC.L	Passive load configuration, Sensitive to: 'scale, unsupported span, & stand-up time

I-GC Ground Characterization Parameters

$$\mathbf{Eg} = \boldsymbol{e}^{\mathbf{0.05\times(I)}} - \mathbf{1} \quad \mathbf{(1)}$$

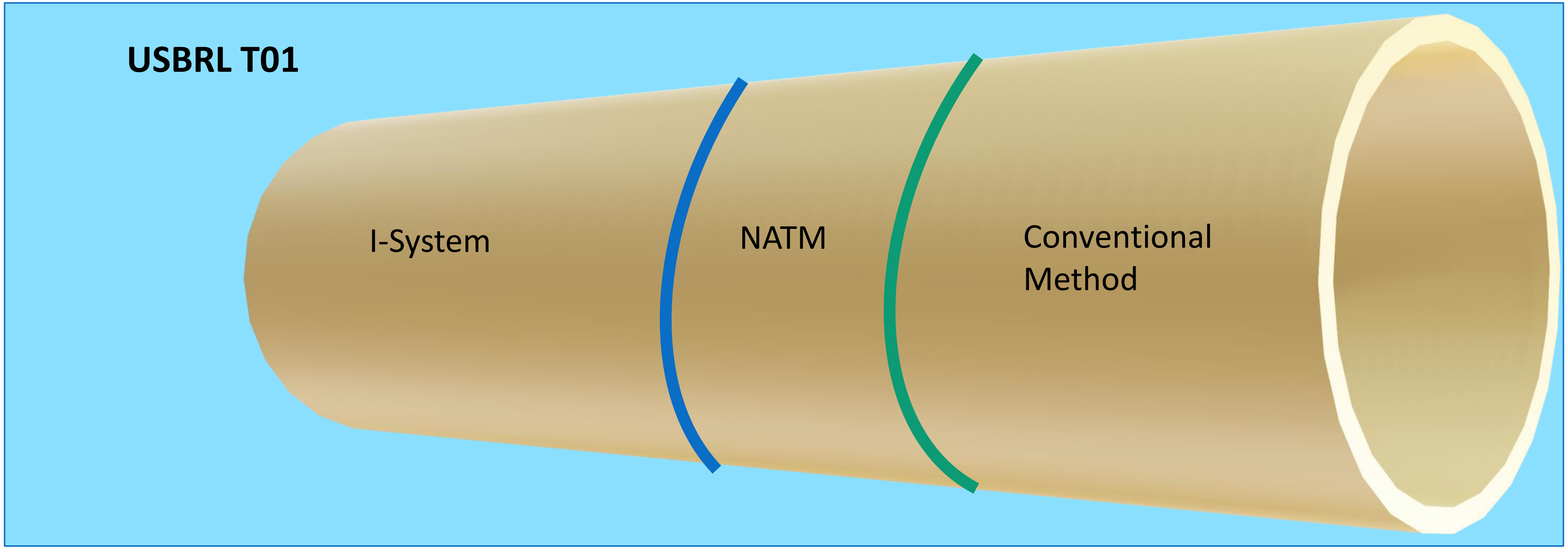
$$\nu g = 0.5 - 0.004 \times (I) \quad (2)$$

$$\sigma cg = 0.007 \times \sigma c \times e^{0.05\times(I)} \quad (3)$$

$$\sigma tg = -\sigma cg \times e^{(0.04\times(I)-4)} \quad (4)$$

$$\mathbf{Cg} = \mathbf{0.002} \times \boldsymbol{\sigma}\mathbf{cg} \times \boldsymbol{e}^{\mathbf{0.05\times(I)}} \quad \mathbf{(5)}$$

$$\boldsymbol{\phi}\mathbf{g} = \mathbf{15 + 0.55} \times \mathbf{(I)} \quad \mathbf{(6)}$$


USBRL T01
I-System
NATM
Conventional Method

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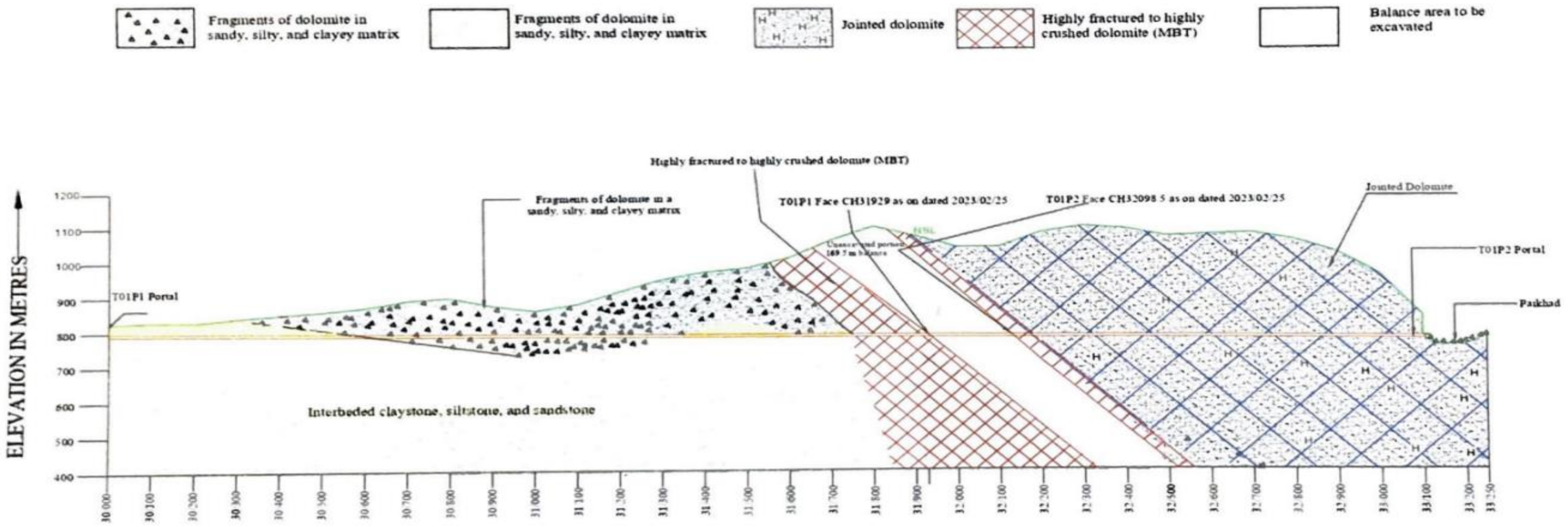
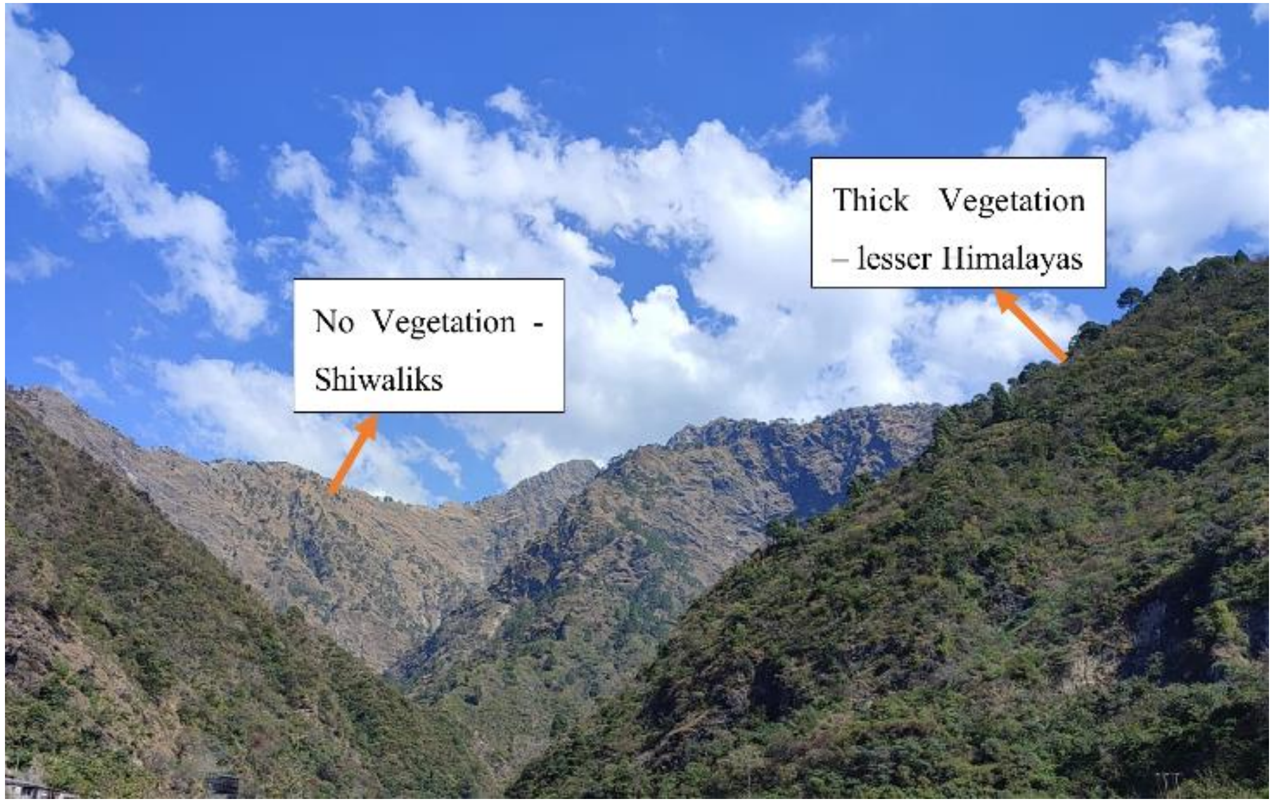


- The Tunnel T-01 passes through Main Boundary Thrust.
- Successful Implementation of I-System.

Face Butt at T01 P1 Tunnel Face



USBRL T01 Regional Topography

T01 P2 Tunnel Face

Crushed Dolomite mixed with PU-2C grout

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Indices	References
Armature Index (A_i)	Geological Face Maps
Configuration Index (C_i)	Geological Face Maps / Consultancy Report
Hydro Index (H_i)	Geological Face Maps
Properties Index (P_i)	Physical Ground Inspection / Geophysical Investigation Report / Standard References
Strength Index (S_i)	Geological Face Maps & Tunnel Cross Section Drawings
Impacting Factors	References
Excavation Technique Impact (ET_i)	Geological Face Maps / Refer Table
Dynamic Forces Impact (DF_i)	IS 1893-1 (2002) / Refer Table

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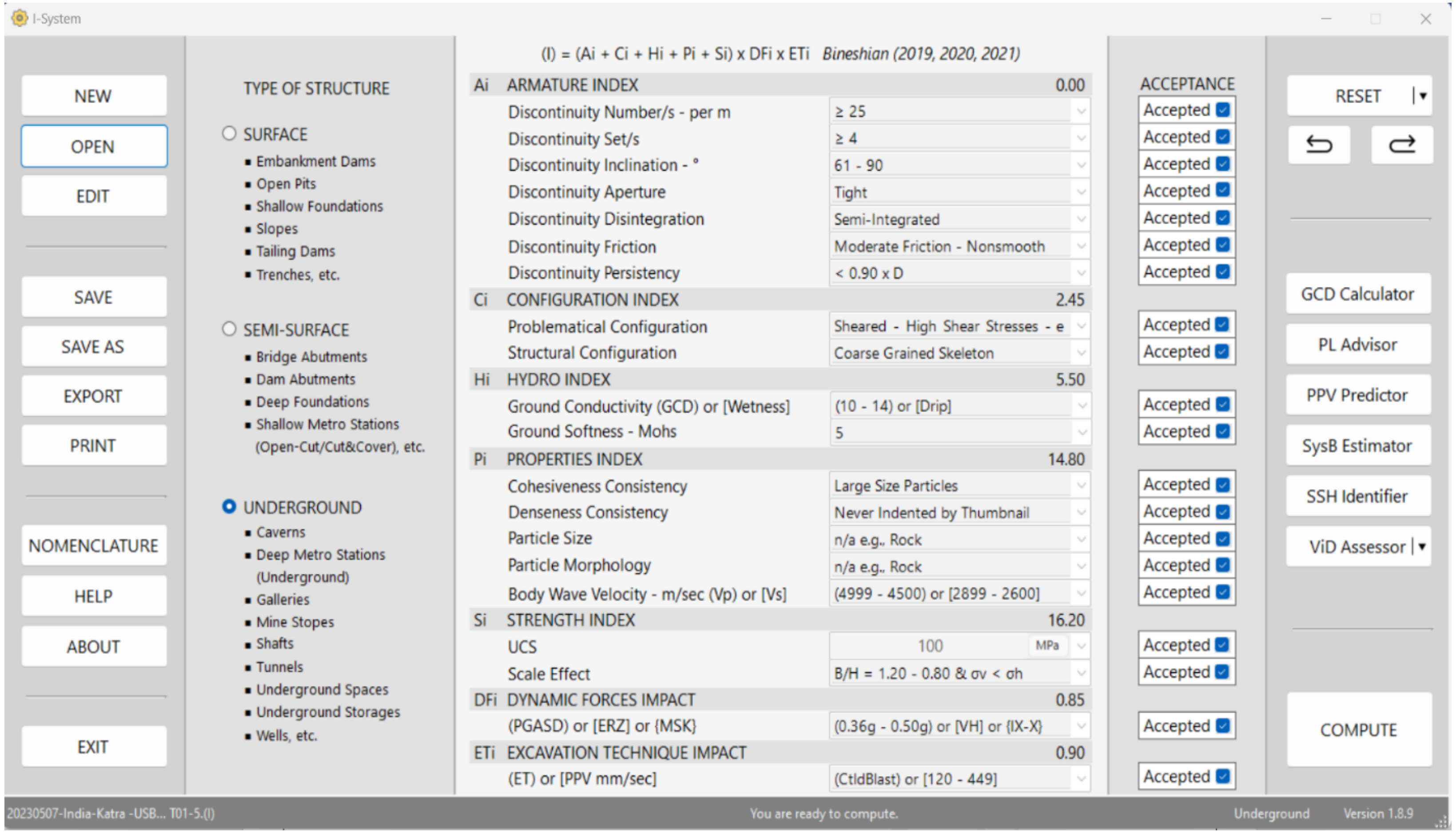
Evaluation of data pairs for Modulus of Deformation of the Ground (E_g)

Step I – Computation of (I)-Value for 100 cases using I-System's Software.



Step II – Derivation of (I)-GC properties from (I)-Value using I-System's Software

I-System - Index of Ground-Structure *Bineshian (2019, 2020, 2021)*

(I)-GC; I-System's Ground Characterization

(I) = 27
Selected UCS range is 74 - 50 MPa.
Specified σ_c Value = 50 MPa

Modulus of Deformation
E_g = 2.857 GPa

Poisson's Ratio
ν_g = 0.392

Unconfined Compressive Strength
σ_{cg} = 1.350 MPa

Uniaxial Tensile Strength
σ_{tg} = -0.073 MPa

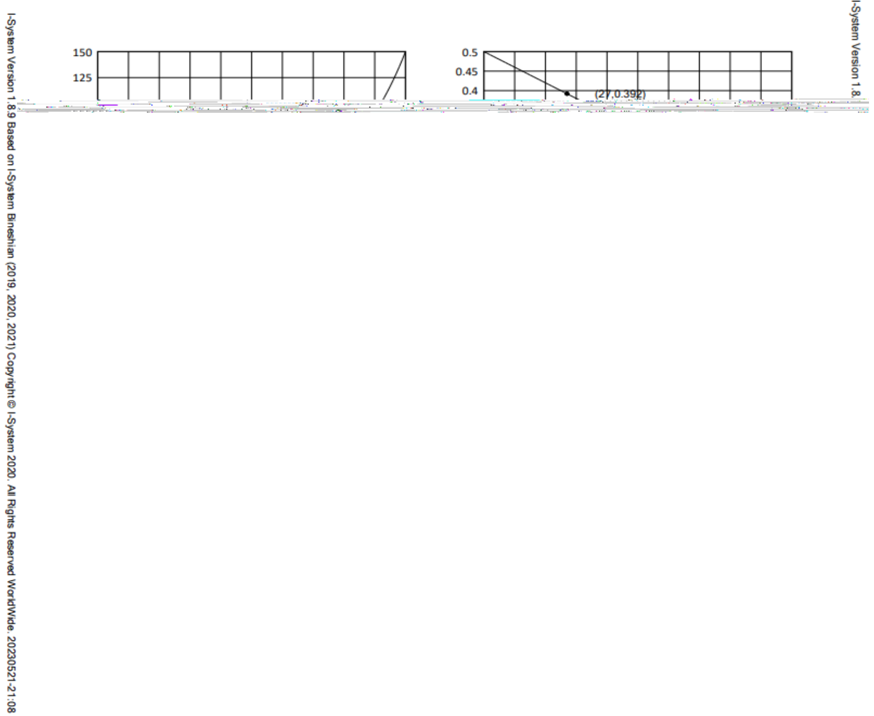
Cohesion
C_g = 10.416 KPa

Internal Friction Angle
ϕ_g = 29.850°

(I)-GC characterizes the ground based on (I); however, it is recommended to scrutinise it by deriving the mechanical properties of ground by standardised in-situ testing methods.

I-System - Index of Ground-Structure *Bineshian (2019, 2020, 2021)*

(I)-GC Chart



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TAI

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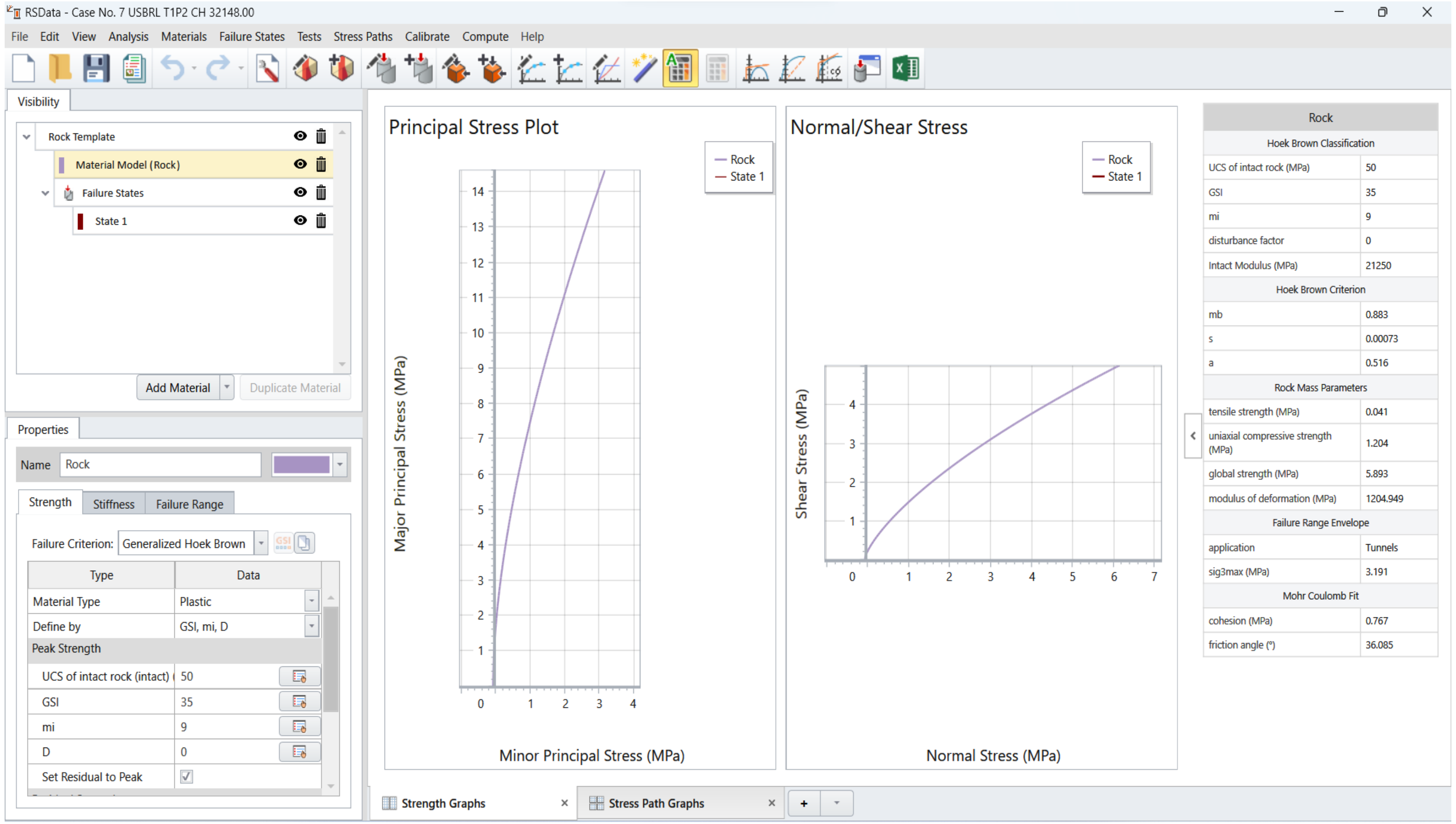
Step III – Derivation of Rockmass Properties using RSData Software



Purification of the Data Pairs

A total of 100 cases of TDP data pairs were plotted in a scatter plot between (I)-Value vs Geo-mechanical property. The plot highlighted the data pairs not following the trend. As per the principles of rock mechanics the value of Geo-mechanical property included in this study that are (Eg, Cg, ϕg) shall always increase with increase in strength of the ground. This means that the values of these Geo-mechanical properties should increase/decrease with increase/decrease in (I)-Value. Based on such conditions a purification technique was applied to eliminate the data pairs.

i. The data pairs representing lower value than the previous data pair were eliminated in an increasing trend and vice versa if necessary.

ii. The data pairs far away from the trend were eliminated.

iii. For the data pairs showing different Y values for same X values, the Data pairs obtaining better Coefficient of Multiple Determination (R^2) value were selected.

Step IV – Sorting of TDP (T-01 Data Pairs) as per ascending I-Value:

- The data pairs are in the form of (X, Y) where X represents the (I)-Value and Y represents Modulus of Deformation of the ground (E_g).
- The table. summarizes total case count of 100 cases for the Modulus of Deformation of the ground (E_g) based on the (I)-Value and sorted as purified and unpurified in black and red colour respectively. Out of 100 cases 39 cases were eliminated and 61 cases were selected for regression analysis with maximum coefficient of multiple determination value (R^2) as 0.999

Modulus of Deformation of the ground Eg TDP Summary			
(I)-Value	Eg (GPa) I-System	Eg (GPa) RS Data	Total Data Pairs
24	2.320	1.204	1
26	2.669	2.409	13
27	2.857	1.204	19
27	2.857	3.392	6
27	2.857	4.752	2
30	3.482	3.392	5
30	3.482	4.752	47
		Total Data Pairs	100

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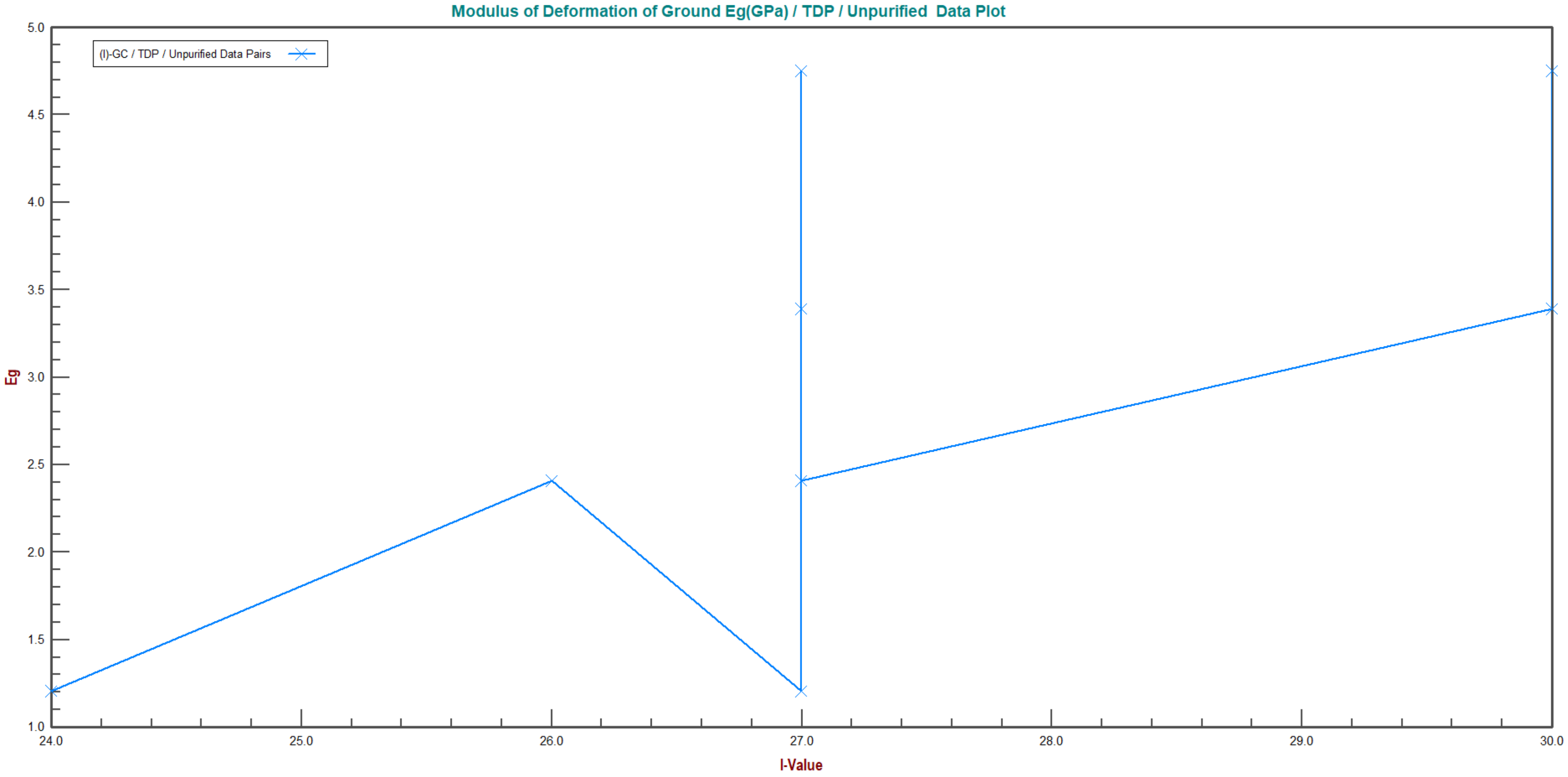
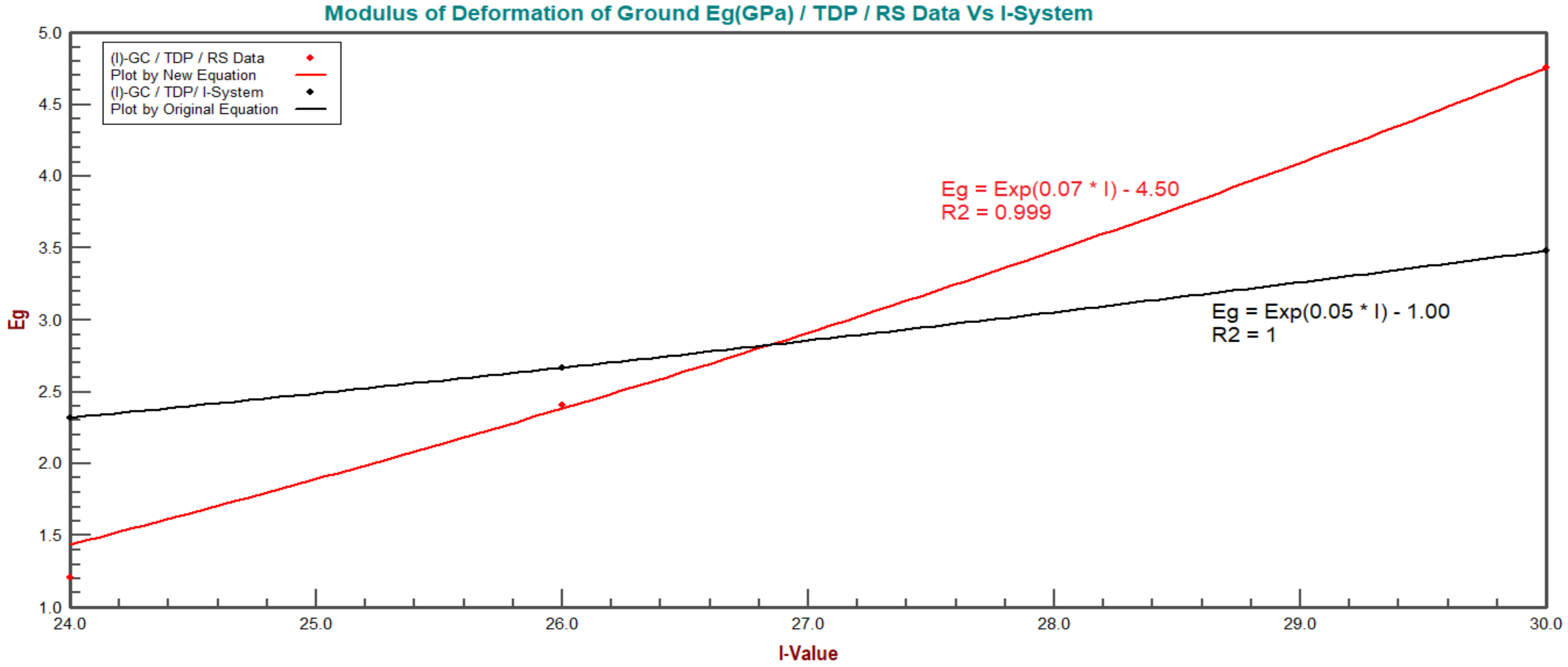
Data Analysis and Results

Plotting of Scatter Data using DataFit 9.1 Software



Regression Analysis of TDP data pairs for Modulus of Deformation of the Ground (E_g)

Eg-Modulus of the Deformation of the ground (GPa)							Y=Exp(a*x)-b
Sr. No.	Data Pair	Case Count	Original Constant		Proposed New Constant		R^2 Value
			a	b	a	b	
1	TDP	61	0.05	1.00	0.07	4.50	0.999



Evaluation of data pairs for Cohesion of the Ground (C_g)

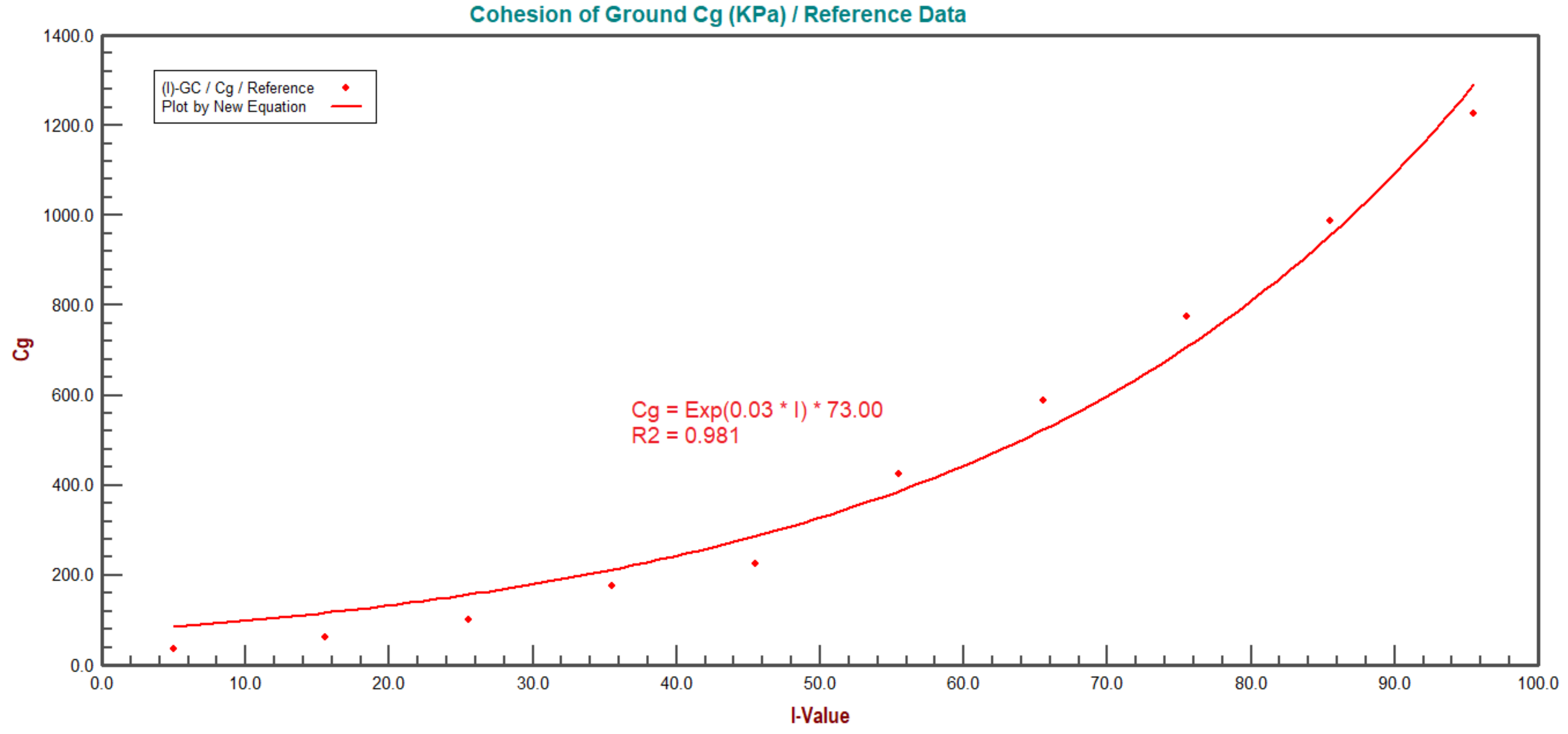
- The initial chainages of the USBRL project was constructed with conventional as well as NATM methods. Both the methods produced numerous failures and collapse for several times.
- Due to termination of various agencies, the project has insufficient data for evaluation of Cohesion of the ground from the site and hence a modification or correlation cannot be established using the TDP data pairs. Though the need to modify the original equation due to ultra conservative output by the (I)-GC for the Cohesion of the ground (C_g) is assessed.
- To propose the modification to improve the accuracy of the original equation of Cohesion of the ground (C_g) the source data presented in has been obtained from the standard reference notes and geotechnical references.

(I)-Value	(I)-Class	Cohesion C_g (KPa)
100 – 91	(I) - 01	1101 – 1350 or greater
90 – 81	(I) - 02	876 – 1100
80 – 71	(I) - 03	676 – 875
70 – 61	(I) - 04	501 – 675
60 – 51	(I) - 05	351 – 500
50 – 41	(I) - 06	226 – 350
40 – 31	(I) - 07	126 – 225
30 – 21	(I) - 08	76 – 125
20 – 11	(I) - 09	51 – 75
10 – 0	(I) - 10	25 – 50 or lesser

(I)-Value X	Cohesion of the ground C_g (KPa) Y
95.50	1225.50
85.50	988.00
75.50	775.50
65.50	588.00
55.50	425.50
45.50	225.50
35.50	175.50
25.50	100.50
15.50	63.00
5.00	37.50

Regression Analysis of data pairs for Cohesion of the Ground (C_g)

Cg-Cohesion of the ground (KPa)							Y=Exp(a*x)*b
Sr. No.	Data Pair	Case Count	Original Constant		Proposed New Constant		R^2 Value
			a	b	a	b	
1	Ref	10	0.05	0.002	0.03	73.0	0.981



Evaluation of data pairs for Friction Angle of the ground (°)

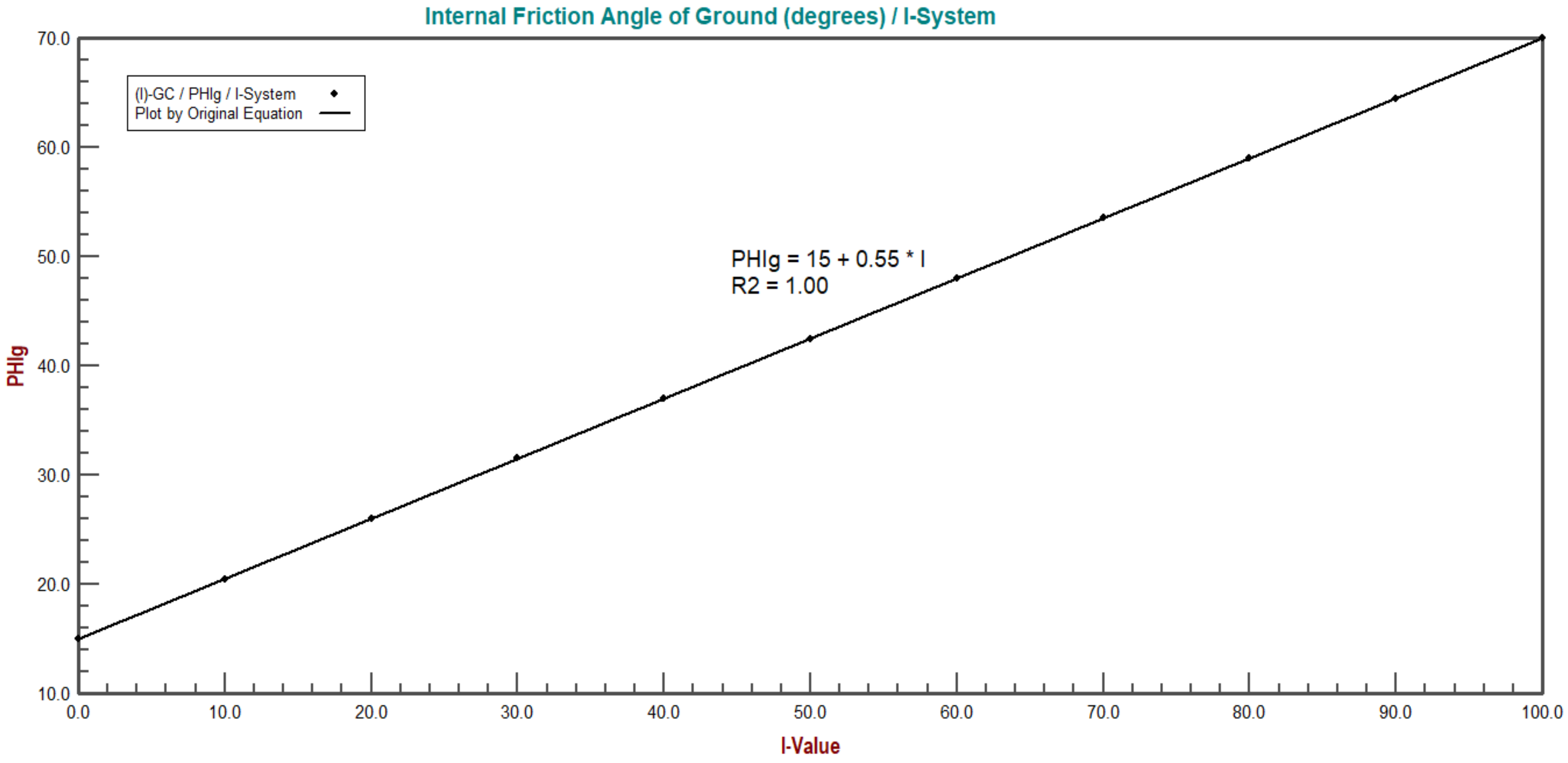
- The original Equation of the (I)-GC for the Friction angle of the ground has produced very accurate and precise results when compared with the actual value of the geotechnical references. Hence after the thorough assessment and the analysis of the results the original equation and the constants are kept same represented by the Eq.

$$\phi g = 15 + 0.55 \times (I)$$

(I)-Value X	Friction angle of the ground ϕ_g (°) Y
100	70.00
90	64.50
80	59.00
70	53.50
60	48.00
50	42.50
40	37.00
30	31.50
20	26.00
10	20.50
0	15.00

Regression Analysis of data pairs for Friction Angle of the ground (ϕg)

Cg-Cohesion of the ground (KPa)					Y=Exp(a*x)*b
Sr. No.	Data Pair	Case Count	Original Constant		R^2 Value
			a	b	
1	TDP	11	0.55	15.00	1.00



Statistical Analysis

Sr. No.	Properties	Constants		Coefficient of Multiple Determination (R^2)
		a	b	
1.	Modulus of Deformation of the ground (E_g)	0.07	4.50	0.999
2.	Cohesion of the ground (C_g)	0.03	73.00	0.981
3.	Friction angle of the ground (ϕ_g)	0.55	15.00	1.00

Concluding Remarks

- After the thorough analysis and its interpretation, the New Equation for the (I)-GC's Modulus of Deformation of the ground (E_g) proposed for the (I)-Value ranging between 20-40 is

$$\mathrm{Eg} = e^{0.07 \times (I)} - 4.50$$

- After the thorough analysis and its interpretation, the New Equation for the (I)-GC's Cohesion of the ground (C_g) proposed for the (I)-Value ranging between 20-40 is

$$\mathrm{Cg} = e^{0.03 \times (I)} \times 73.00$$

- After the thorough analysis and its interpretation, the Original Equation for the (I)-GC's Internal Friction Angle of the ground (ϕ_g) proposed to keep same for the (I)-Value ranging between 20-40 is

$$\phi g = 15 + 0.55 \times (I)$$

I thank TAI, TAIym and all the organizers, co-organizers and the industry experts for providing us the International Platform with such high standards and exposure.

Lastly, we would also thank our Head of Tunnel Engineering Department, MIT WPU, Dr. Sandeep Potnis and Dr. Bineshian Hoss for his continuous support and guidance.

Wishing all Safe and Happy Tunnelling!

Thank You