Tunnelling Asia 2023
International Conference on Underground Space

SUSTAINABILITY IN UNDERGROUND PLANNING, DESIGN, CONSTRUCTION, AND OPERATION OF TUNNELS AND UNDERGROUND PROJECTS

(I)-TM's Output in T01 of USBRLP

An Efficient and Safe Hybrid Tunnelling Method

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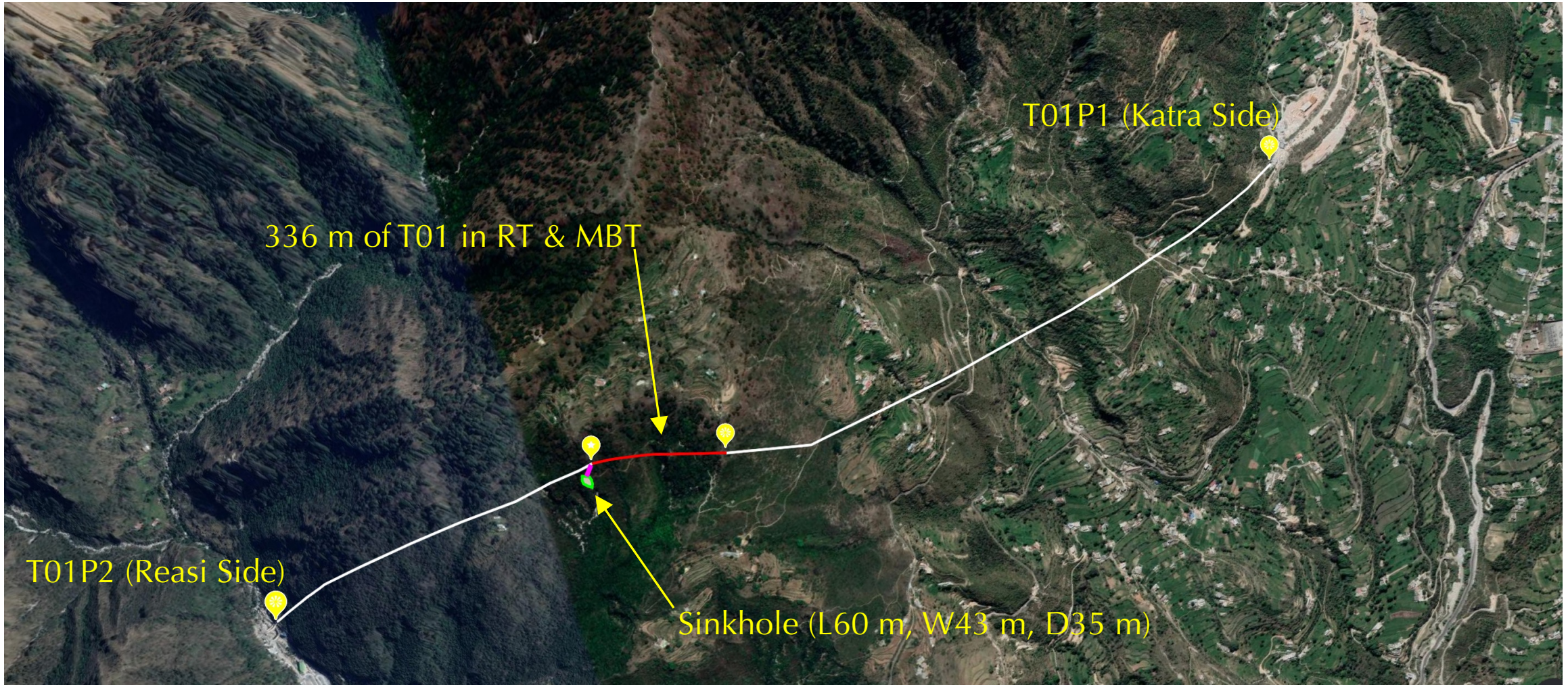
Suru
Zulidok

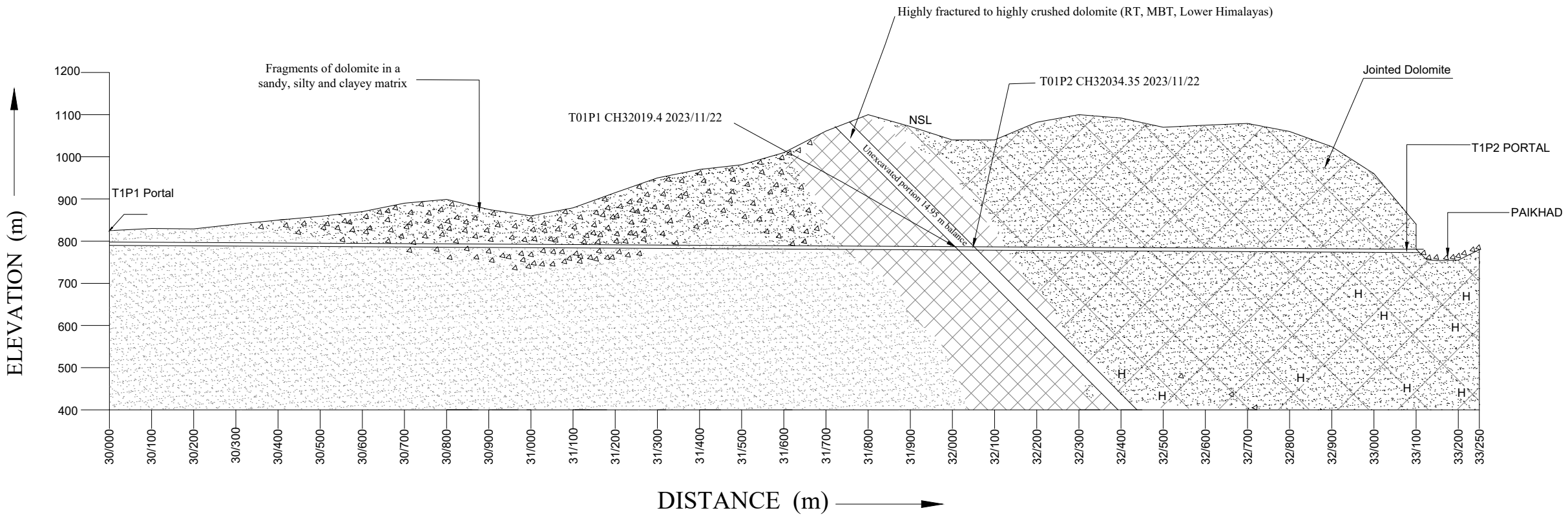
T01: Salient Features

Total Length	3209 m
(I)-TM (Bineshian, 2022)	336 m; successfully employed in problematic portion due to failure of Conventional and NATM
Conventional Tunnelling Method	1082 m; unsuccessful in problematic portion
NATM	1791 m; unsuccessful in problematic portion
Wetness	Moist, Leak, Wet, Drip, Shower, Flow, Gush, Burst
Lithology	Alluvium, Claystone, Colluvium, Dolomite, Limestone, Mudstone, Sandstone, Scree, Shale, Siltstone
Identified Mechanical Behaviour of Ground	Fully Plastic, Gravity Driven, Liquefaction, Squeezing, Visco-elasto Plastic
Geo-structure	Highly Jointed, Highly Sheared, Highly Tectonised

T01: Alignment in RT within MBT



T01: Geological L-Profile



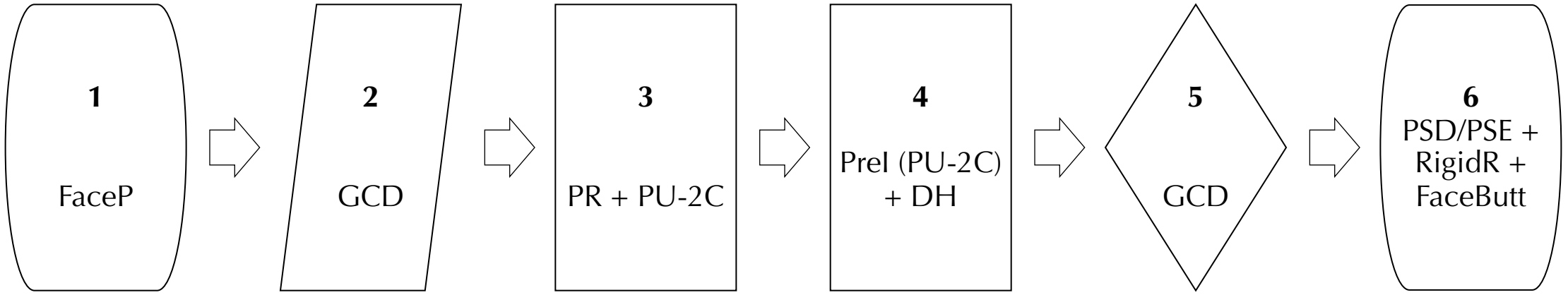
T01: Chronology of Failures

Failure Code	Date of Failure	Discharge (m^3)	Failure Location	Chainage
01	2016/08/28	5,000	T01P2	CH32140
02	2016/09/29	10,000	T01P2	CH32145
03	2017/02/23	150	T01P2	CH32145
04	2017/03/12	100	T01P1	CH31804
05	2017/03/18	250	T01P1	CH31804
06	2017/03/24	150	T01P1	CH31804
07	2017/03/29	250	T01P1	CH31804
08	2017/05/05	6,000	T01P2	CH32137
09	2017/09/21	100	T01P1	CH31818
10	2017/09/26	150	T01P1	CH31820
11	2017/10/03	350	T01P1	CH31820
12	2017/10/14	20,000	T01P2	CH32140
13	2017/11/02	350	T01P1	CH31820
14	2017/11/22	3,000	T01P2	CH32145
15	2018/01/25	300	T01P1	CH31820
16	2021/11/17	300	T01P2	CH32140

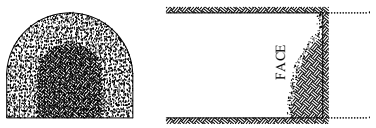
T01: Overview of Physical Progress in MBT

TM Employed	Classification Employed	Progress (mm/day)	From	To	Duration (days)	Total Advance (m)
NATM	Q	Nil	2016/08/28	2019/08/31	1098	Nil
NATM	RMR	**2.03**	2019/05/23	2022/01/31	984	**2**
(I)-TM	I-System	**512.28**	2022/05/01	2023/11/22	570	**292**

T01: Advancement Flowchart

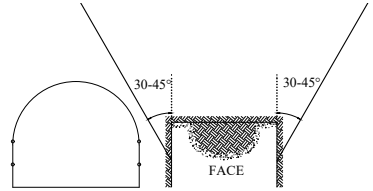


T01: Execution Details

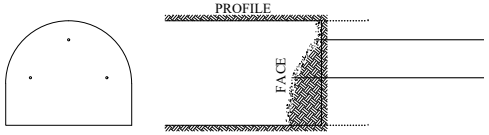


a. FaceP and FaceButt

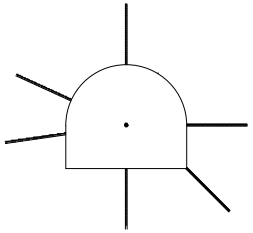
b. Axial Drainage Hole/s (ADH)



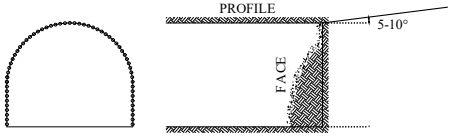
c. Wing Drainage Hole/s (WDH)



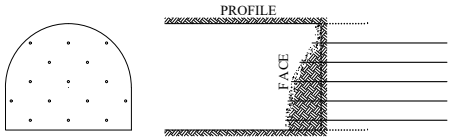
d. GCD Holes



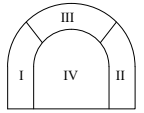
e. Examples of drilling location and orientation



f. Pipe Roofing (PR)

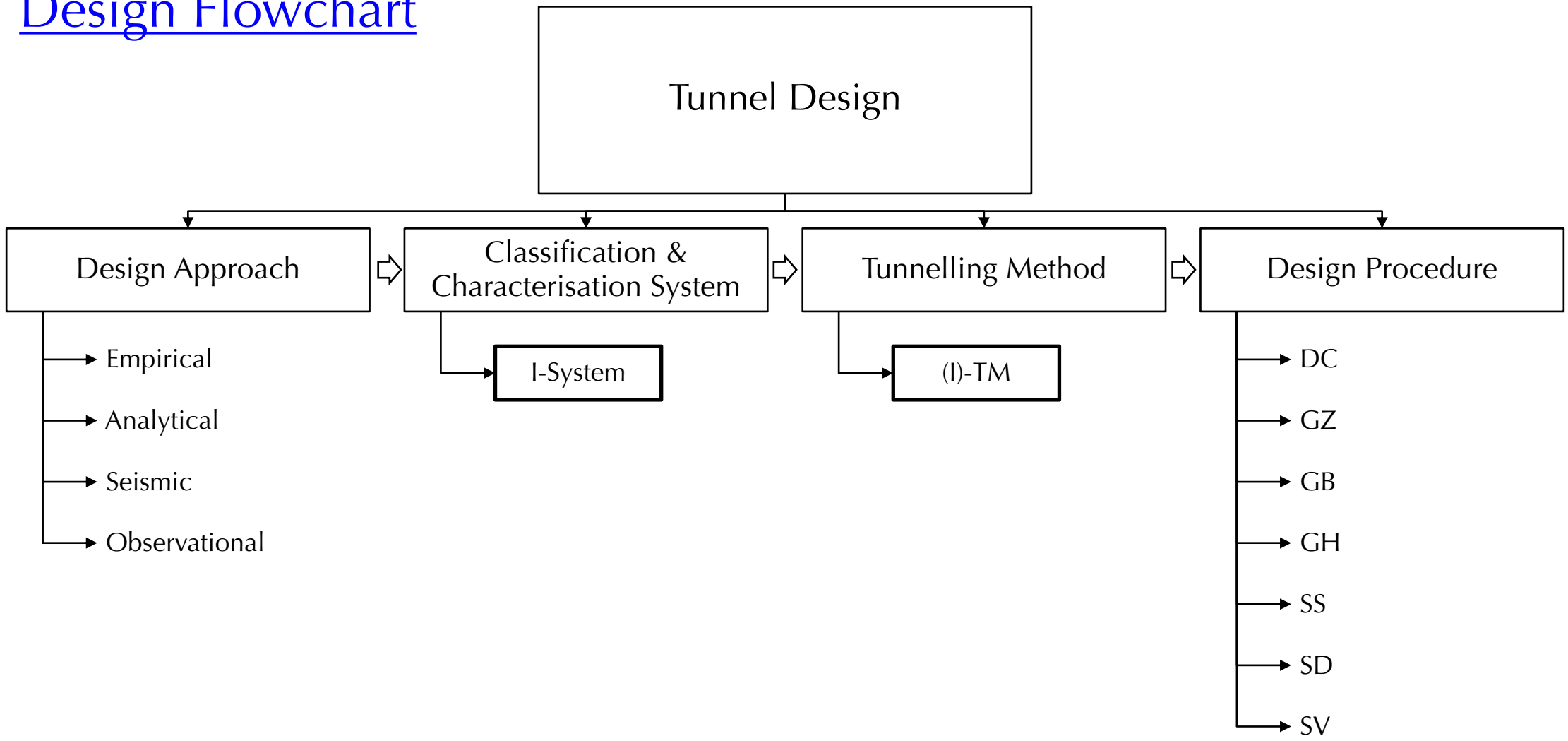


g. Pre-excavation Injection (PreI)



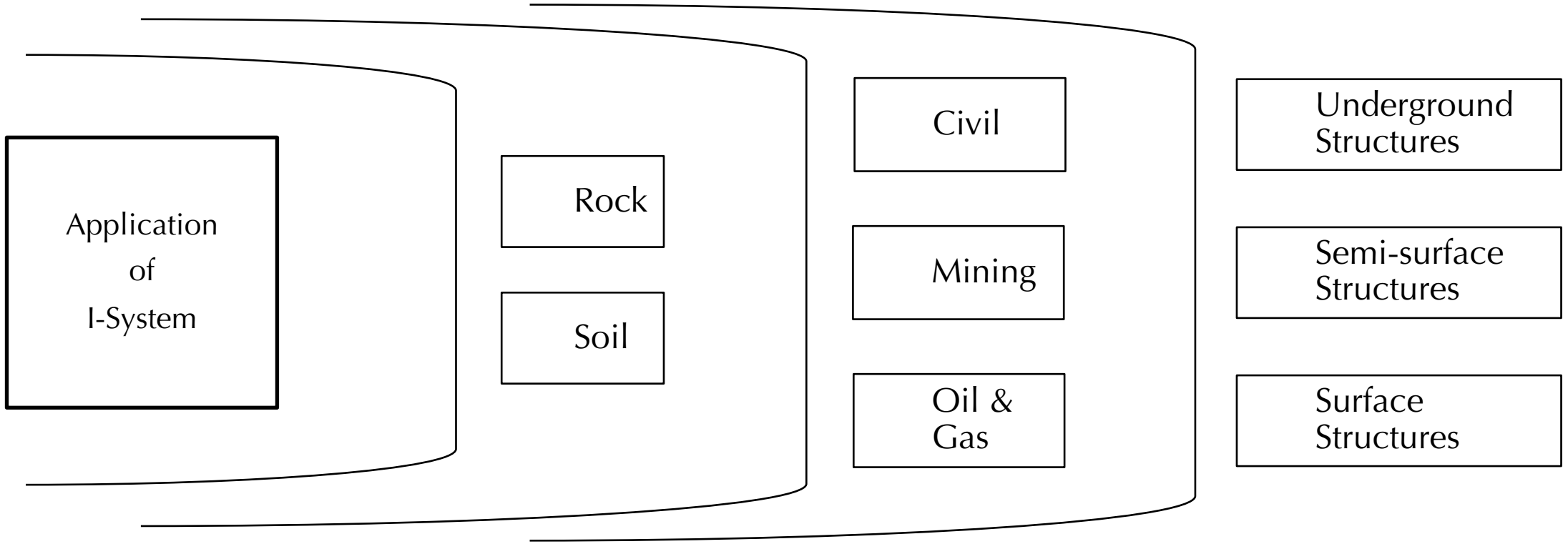
h. Partial Sequential Digging/Excavation (PSD/PSE)

Design Flowchart



I-System: Application

Accurate in Prediction of GB After 24 Years Scrutinization in Practice



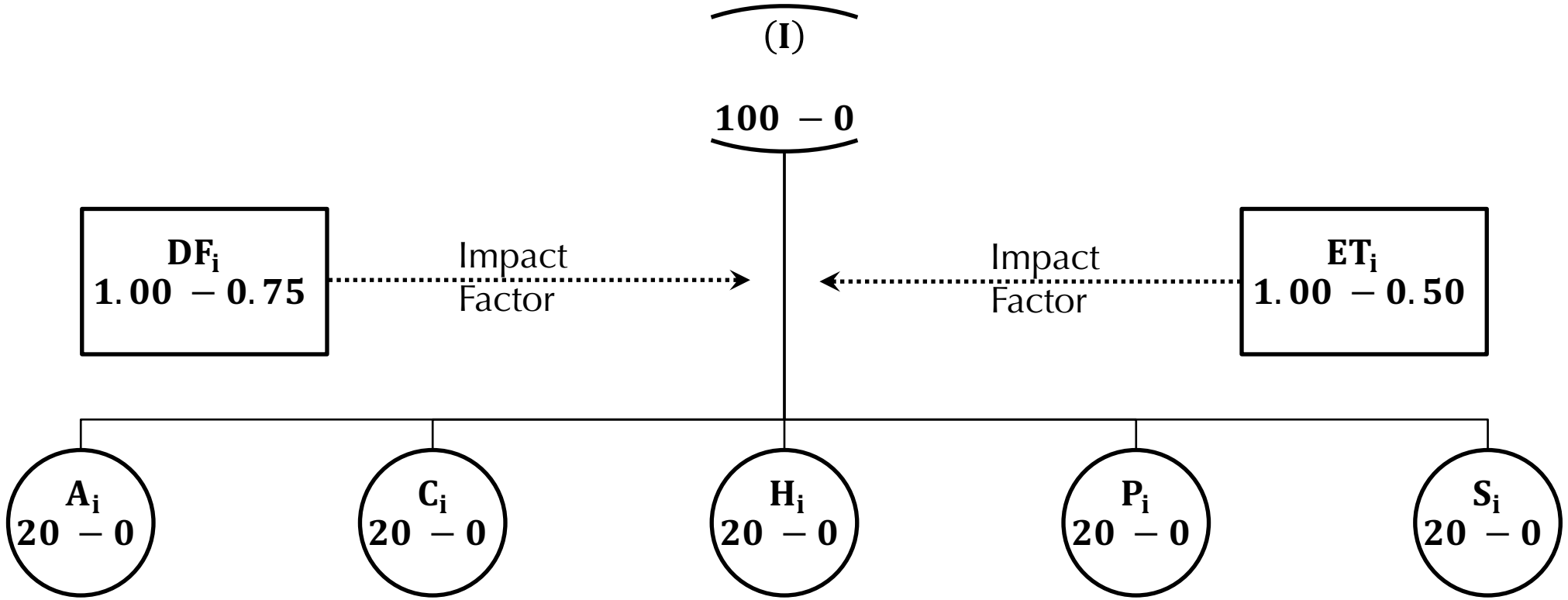
I-System: Features

First Ever Classification That Considers

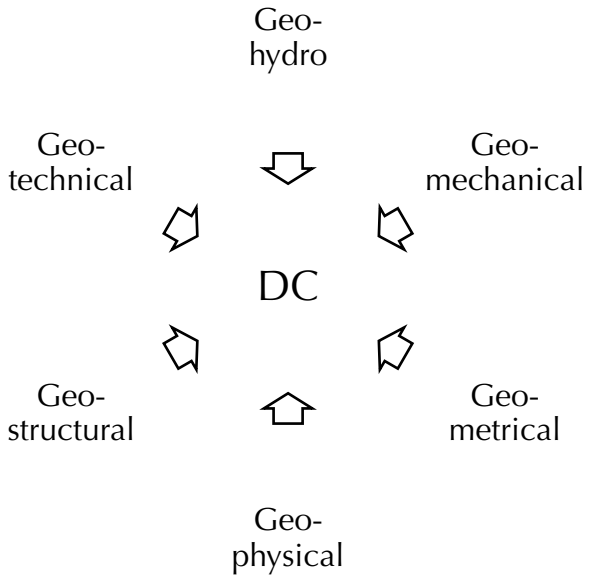
Problematical Configuration	Structural Configuration	Scale Effect	Earthquake Effect	Excavation Method Impact
Squeezing/Swelling/ Heaving	VEP Behaviour	Fully Plastic Behaviour	Time Dependent Behaviour	Burst Prone Ground Condition

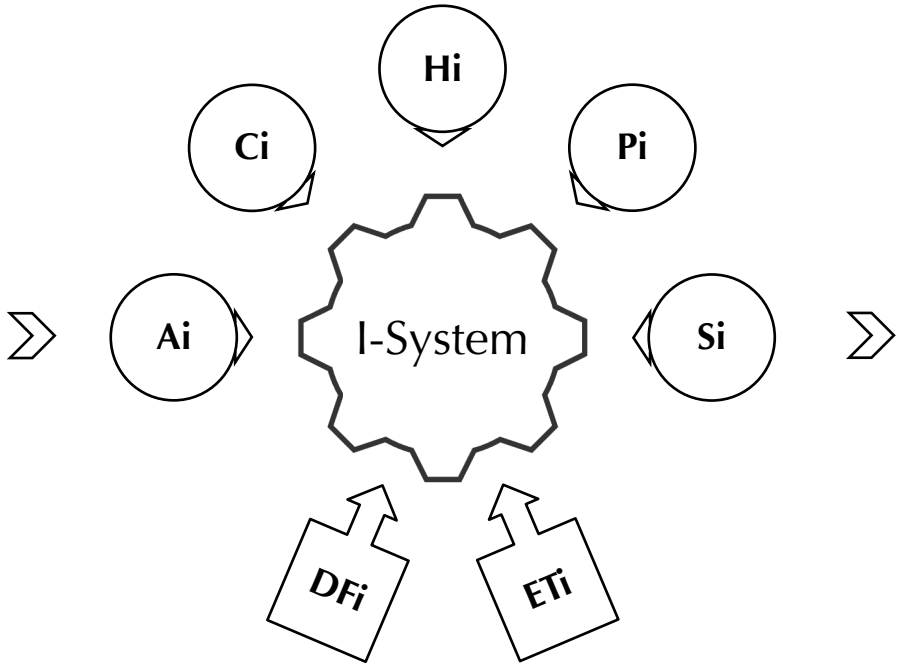
I-System: Scoring Diagram

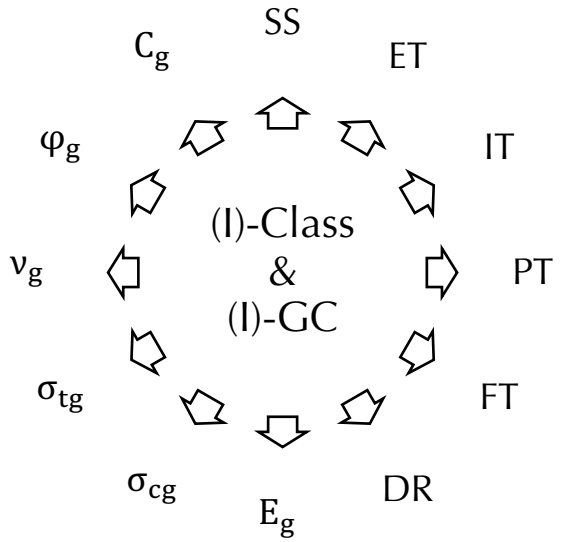
$$(I) = (A_i + C_i + H_i + P_i + S_i) \times DF_i \times ET_i$$



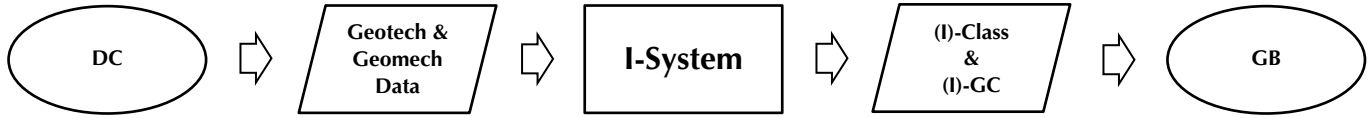
I-System: Summary





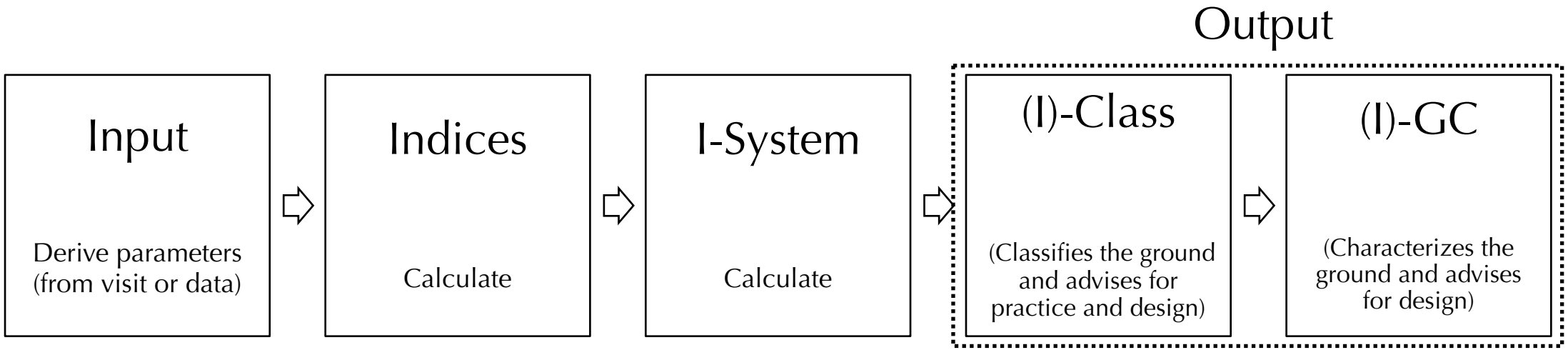


(I)	(I)-Class	(I)-GC	Value
100-91	(I)-01	E_g	
90-81	(I)-02		
80-71	(I)-03	ν_g	
70-61	(I)-04		
60-51	(I)-05	σ_{cg}	✓
50-41	(I)-06		
40-31	(I)-07	σ_{tg}	
30-21	(I)-08		
20-11	(I)-09	C_g	
10-00	(I)-10		
		φ_g	



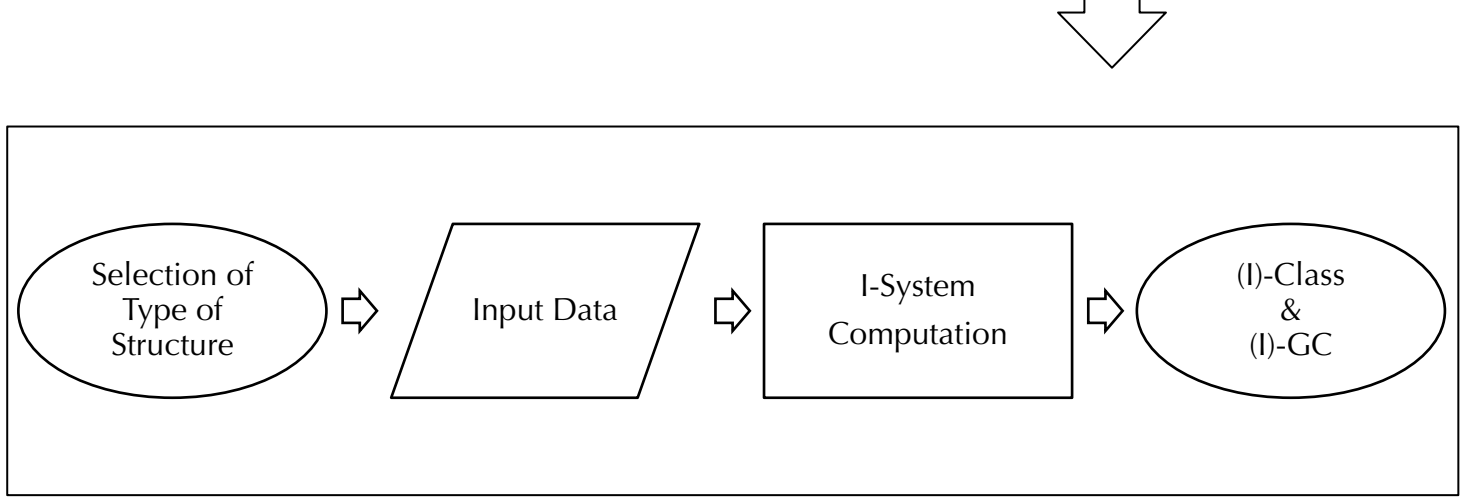
I-System: Utilisation Diagram

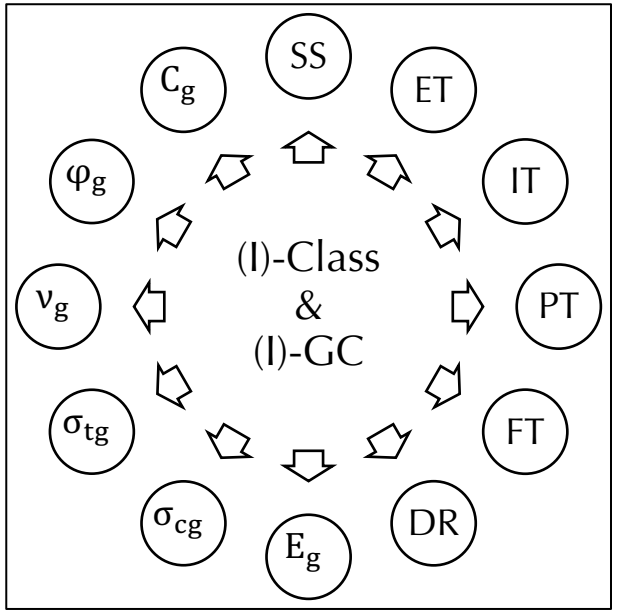
$$(I) = (A_i + C_i + H_i + P_i + S_i) \times DF_i \times ET_i$$



I-System Software

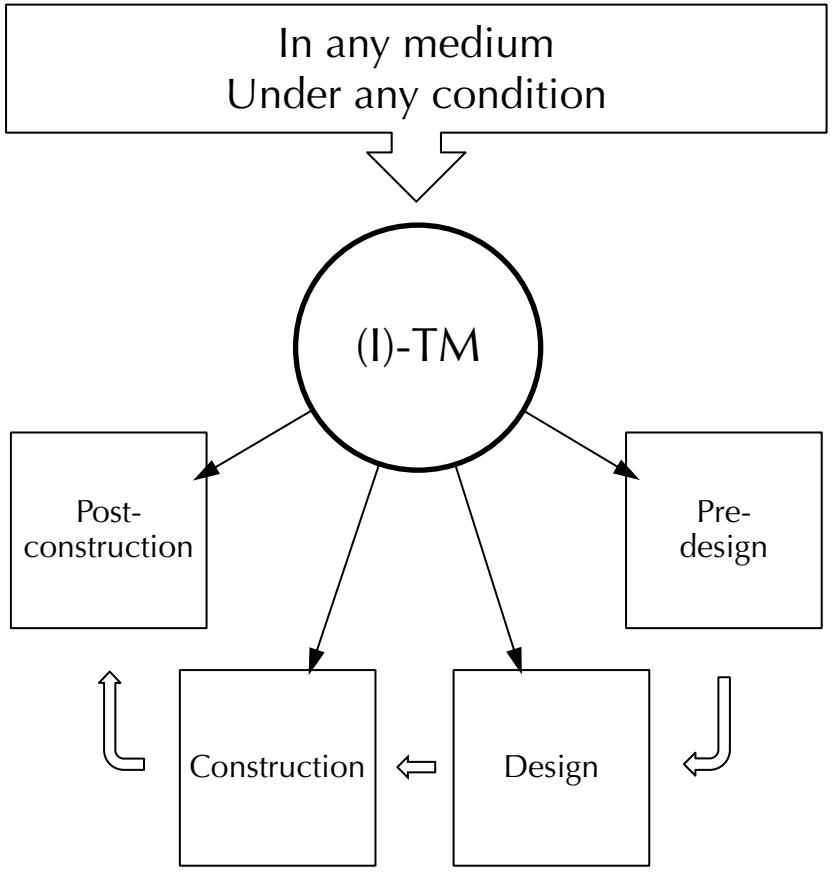
$$(I) = (A_i + C_i + H_i + P_i + S_i) \times DF_i \times ET_i$$



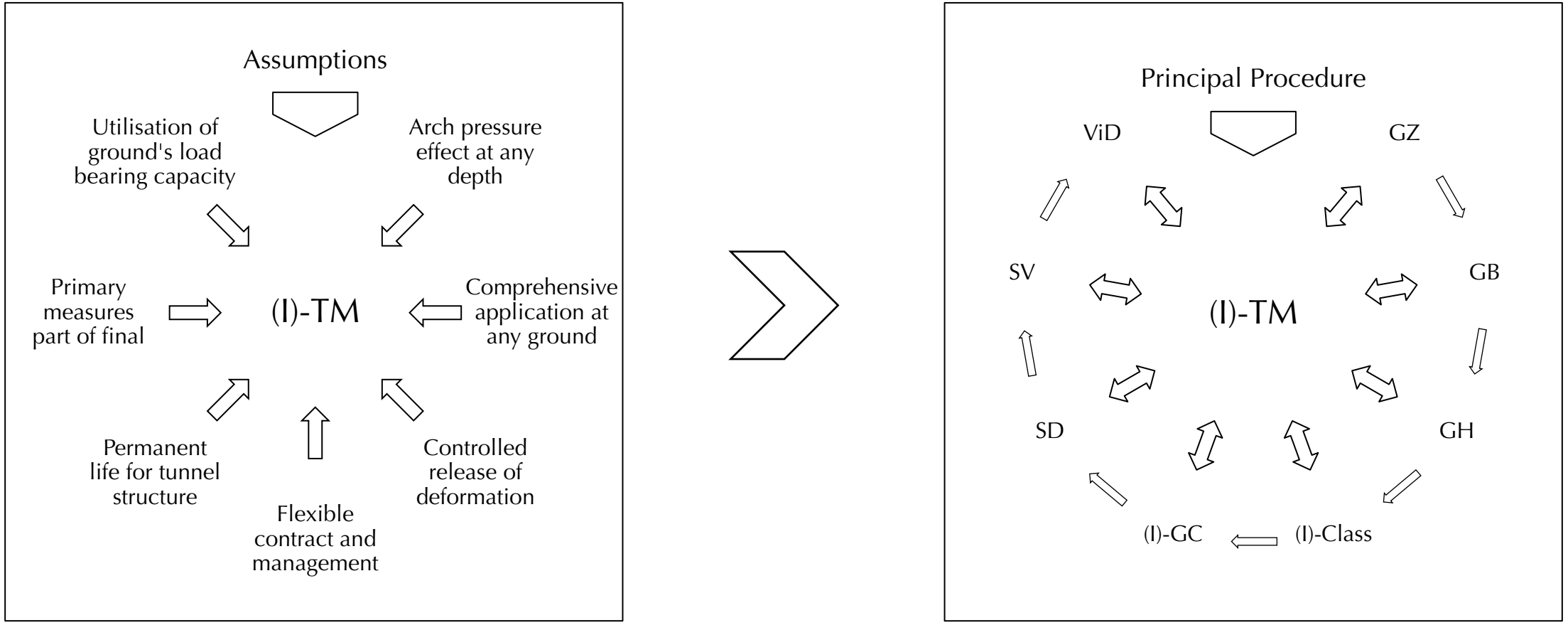


- (I)-Class: I-System's Ground Classification (Bineshian, 2021)
- (I)-GC: I-System's Ground Characterisation (Bineshian, 2021)
- (I)-TM: I-System's Tunnelling Method (Bineshian, 2021)
- GCD Calculator: Ground Conductivity Designation (Bineshian, 2020)
- PL Advisor: Pull Length Advisor (Bineshian, 2021)
- PPV Predictor: Peak Particle Velocity Predictor (McKown, 1986)
- SSH Identifier: Squeezing, Swelling, and Heaving Identifier (Bineshian, 2020)
- SysB Configurator: Systematic Bolting Configurator (Bineshian, 2021)
- ViD Assessor: Vibration-induced Damage Assessor (Bineshian, 2021)

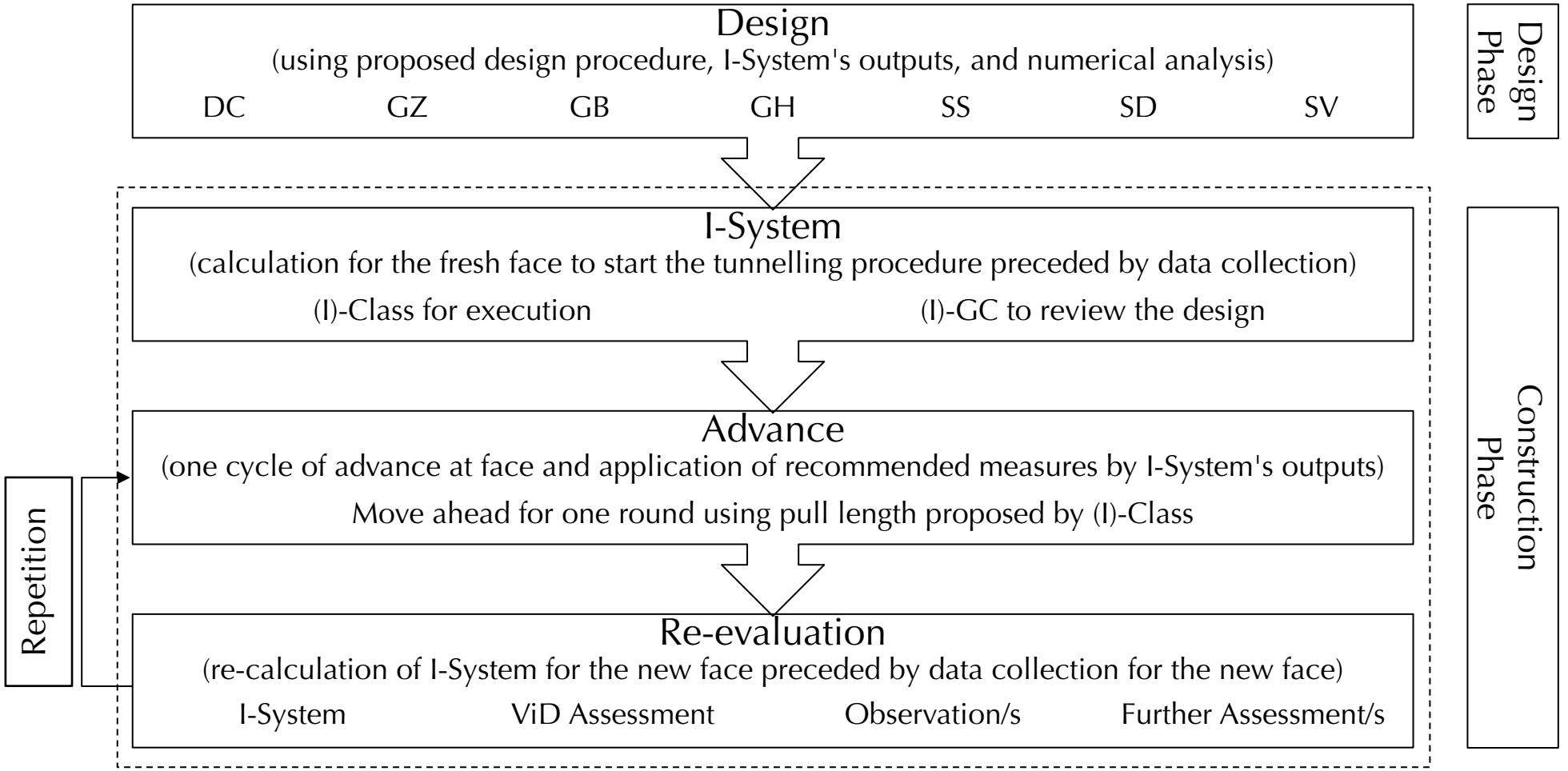
(I)-TM: Application



(I)-TM: Principles and Concept



(I)-TM: Utilisation Diagram



(I)-TM vs Other Existing Tunnelling Methods

Tunnelling Method	Application							Employing (Conceptual)					
	In Phases				In Media		Under Special Conditions*	Permanent Life Expectancy for Tunnel Structure	Flexibility of Contract for Execution	Surrounding Ground's Load Bearing Capacity	Arch Pressure at Any Depth	Controlled Release of Deformation in Plastic Ground	Primary Measures as Part of Final Measures
	Pre-design	Design	Construction	Post-construction	Rock	Soil							
Conventional	N/A	N/A	A	N/A	A	A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
CnC	N/A	N/A	A	N/A	A	A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NATM	N/A	N/A	A	N/A	A	N/A	N/A	N/A	N/A	A	C/A	C/A	N/A
NMT	N/A	N/A	A	N/A	C/A	N/A	N/A	N/A	N/A	A	N/A	N/A	A
Pipe/box Jacking	N/A	N/A	A	N/A	N/A	A	N/A	N/A	N/A	N/A	A	N/A	N/A
SCL	N/A	N/A	A	N/A	C/A	N/A	N/A	N/A	N/A	A	C/A	N/A	N/A
(I)-TM	A	A	A	A	A	A	A	A	A	A	A	A	A

A Applicable **C/A** Conditionally Applicable **N/A** Not Applicable

(I)-TM vs Other Existing Tunnelling Methods

Tunnelling Method	Recommendations in Construction Procedure						Embedded Classification	Embedded Characterisation	Post-excavation Damage Assessment
	Support System	Excavation Technique/s	Instrumentation Technique/s	Prevention Technique/s	Forecast Technique/s	Stages in Construction			
Conventional	N/I	N/I	N/I	N/I	N/I	N/I	N/I	N/I	N/I
CnC	N/I	N/I	N/I	N/I	N/I	N/I	N/I	N/I	N/I
NATM	N/I	N/I	N/I	N/I	N/I	N/I	N/I	N/I	N/I
NMT	P/I	N/I	N/I	N/I	I	N/I	I	N/I	N/I
Pipe/box Jacking	N/I	N/I	N/I	N/I	N/I	N/I	N/I	N/I	N/I
SCL	P/I	N/I	N/I	N/I	N/I	N/I	N/I	N/I	N/I
(I)-TM	I	I	I	I	I	I	I	I	I

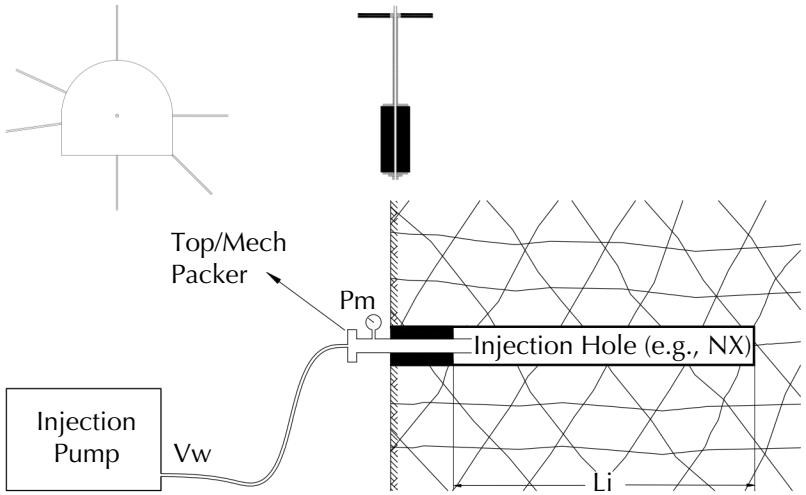
N/I Not Included in the method **I** Included in the method **P/I** Partially Included in the method

Ground Conductivity Designation

$$GCD = \frac{V_w}{T_i(P_m + L_i)}$$ Bineshian (2017, 2022)

GCD	Ground Conductivity Designation (dimensionless)
L_i	Length of water injected portion (packed length) of hole (or perforated SDA) in m (length of the hole to be equal or lesser than the grouted/injected length if GCD is used for post-grouting/injection assessment)
P_m	Peak head (MPa) during T_i (the measured water pressure before the first drop in peak; the first peak)
T_i	Injection period (min) for injecting V_w water (the period from initial raise in pressure till the first drop in peak)
V_w	Injected quantity of water (lit) during T_i (measured from the initial raise in pressure till the first drop in peak)

GCD Range	GCD-Class	Technical Description		
		Ground Hydraulic Conductivity	Ground Solidification Quality	
≤ 0.99	GCD-01	Considerably Low (CL)	Considerably Good (CG)	Judgement as per design requirement
1 - 1.99	GCD-02	Extremely Low (EL)	Extremely Good (EG)	
2 - 2.99	GCD-03	Very Low (VL)	Very Good (VG)	
3 - 4.99	GCD-04	Low (L)	Good (G)	
5 - 6.99	GCD-05	Moderate (M^-)	Fair$^+$ (F^+)	
7 - 9.99	GCD-06	Medium (M^+)	Fair$^-$ (F^-)	
10 - 14	GCD-07	High (H)	Poor (P)	
15 - 24	GCD-08	Very High (VH)	Very Poor (VP)	
25 - 49	GCD-09	Extremely High (EH)	Extremely Poor (EP)	
50 -100	GCD-10	Considerably High (CH)	Considerably Poor (CP)	



Disclaimer

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