

Introduction to Tunnel Construction, Second Edition

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and Alfred Stark**



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Dedication

This book is dedicated to Professor Reinhard Rokahr, who provided the inspiration and first introduced some of us to the El Dorado of tunnelling. It is also dedicated to our families.

Abbreviations

2D	two-dimensional
3D	three-dimensional
ADS	anti-drag system
BSI	British Standards Institute
BTS	British Tunnelling Society
CDM	cement deep mixing
Ch	Chainage
CPT	cone penetration test
CTRL	Channel Tunnel Rail Link
EL	Enlargement
EPBM	earth pressure balance machine
EPDM	ethylene-propylene-diene monomer
ESR	excavation support ratio
FER	foam expansion ratio
FIR	foam injection ratio
FoS	Factor of Safety
FSTT	French Society for Trenchless Technology
GBR	Geotechnical Baseline Report
GFR	Geotechnical Factual Report
GIR	Geotechnical Interpretive Report
GSL	ground surface level
GWL	groundwater level (table)
HDD	horizontal directional drilling
HDPE	high density polyethylene
HME	Hypothetical Modulus of Elasticity model
HSE	Health and Safety Executive, UK
ICE	Institution of Civil Engineers, UK
ISRM	International Society for Rock Mechanics
ITA	International Tunnelling Association
ITIG	International Tunnelling Insurance Group
LF	load factor ($=N/N_c$)
LHS	left-hand side
LVDT	linear variable differential transformer
NATM	New Austrian Tunnelling Method
NTM	Norwegian Tunnelling Method
ÖBV	Österreichischer Beton Verein
PFA	pulverised fuel ash
PicEx	Piccadilly Line Extension
PJA	Pipe Jacking Association

PT	Platform Tunnel, Pilot Tunnel
PTW-E	Platform Tunnel Westbound – East Heading
RHS	right-hand side
RMR	rock mass rating
RQD	Rock quality designation
SCL	sprayed concrete lining
SCR	solid core recovery
SGI	spheroidal graphite (cast) iron
SISG	Site Investigation Steering Group, ICE, UK
SPT	standard penetration test
SRF	stress reduction factor
SSP	seismic soft-ground probing
STBM	slurry tunnel boring machine
STM	slurry tunnelling machine
SWOT	Storm Water Outfall Tunnel
TAM	tube-a-manchette
TBM	tunnel boring machine
TCR	total core recovery
TSG	tail shield grease
UK	United Kingdom
VSP	vertical seismic profiling

Symbols

α	parameter associated with the yield–density curve (m)
γ	(bulk) unit weight of ground (kN/m ³)
γ_d	(bulk) unit weight for ground above the groundwater table (kN/m ³)
γ_{sat}	(bulk) unit weight for ground below the groundwater table (kN/m ³)
γ_w	unit weight of water (kN/m ³)
$\Delta\epsilon$	change in strain
$\Delta\sigma$	change in stress (MN/m ²)
$\Delta\sigma_m$	average normal stress on the load plates (MN/m ²)
$\Delta S_{Z,R}$	average settlements of the centre and the edge of the load plate (mm)
ΔV	potential difference
$\dot{\epsilon}$	strain rate
ϵ	strain (‰)
ϵ_u	ultimate strain at failure
ϵ_{horiz}	horizontal strain
ϵ_{pl}	plastic strain
ϵ_R	failure stain from test results (‰)
ϵ'_v	strain rate, viscous (‰/d)
ϵ_{vert}	vertical strain
η	stress-intensity-index, Utilisation value (%)
λ	parameter to describe the proportion of unloading in the convergence– confinement method
λ_d	predetermined value of the parameter λ
μ	Poisson's ratio
σ	total stress (kN/m ²)
σ'	effective stress (kN/m ²)
$\sigma_1, \sigma_2, (\sigma_3)$	principal stresses (kN/m ²)
$\sigma_3, (\sigma_2)$	confining stress for triaxial test (kN/m ²)
σ_v	total vertical stress (kN/m ²)
σ'_v	effective vertical stress (kN/m ²)
σ_h	total horizontal stress (kN/m ²)
σ'_h	effective horizontal stress (kN/m ²)
σ_s	surcharge acting on the ground surface (kN/m ²)
σ_T	tunnel face support pressure (kN/m ²)
σ_u	ultimate stress at failure (MN/m ²)
$\sigma_{u,adj}$	adjusted σ_u for uniaxial test (MN/m ²)
ϕ	internal friction angle (°)
ϕ'	effective internal friction angle = angle of shearing resistance (°)
ϕ_u	undrained internal friction angle (°)
ψ	diminution factor

ω	constant for the type of loading plate
b	parameter associated with the yield–density curve
c	apparent cohesion (kN/m^2)
c'	effective apparent cohesion (kN/m^2)
C	overburden to tunnel crown (or cover depth) (m)
c_u, s_u	undrained shear strength (kN/m^2)
c_v	coefficient of consolidation (mm^2/min)
d	sample diameter for uniaxial test and point load index test (mm)
D	diameter of tunnel (m)
D_e	equivalent dimension of the excavation (m)
D_r	relative density of coarse grained soils
E	Young's modulus (kN/m^2)
E'	drained deformation modulus (kN/m^2)
E_d	deformation modulus (kN/m^2)
E_s	stiffness modulus (kN/m^2)
E'_v	vertical drained deformation modulus from oedometer test (kN/m^2)
f_c	ultimate cylinder strength (MN/m^2)
f_1	factor to allow for the plasticity index
f_s	sleeve friction for CPT (MN/m^2)
G_{\max}	shear stiffness/modulus (kN/m^2)
G_s	specific gravity (kN/m^3)
H	depth from the ground surface to tunnel axis ($C + D/2$) (m)
h	sample height for a uniaxial test (mm)
h	horizontal displacement of footing (mm)
I	current (A)
i	trough width parameter (m)
I_c	consistency index
I_L	liquidity index
I_p	plasticity index
I_s	point load index strength (MN/m^2)
J_a	joint alteration number for Q-method
J_n	joint set number for Q-method
J_r	joint roughness number for Q-method
J_v	sum of the number of joints per unit length for the RQD index
J_w	joint water reduction factor for Q-method
k	hydraulic conductivity (permeability) (m/s)
k_1	calibration parameter Lubby2
k_2	calibration parameter Lubby2
K	trough width factor
K_a	active coefficient of lateral earth pressure
K_p	passive coefficient of lateral earth pressure
K_0	coefficient of lateral earth pressure at rest
L	failure load in point load index test (MN)
L_1	interface between two strata
m_v	coefficient of volume compressibility (m^2/MN)
n_1	calibration parameter Lubby2
n_2	calibration parameter Lubby2
N_{SPT}	standard penetration test blow count
N	stability ratio
N_c	critical stability ratio or stability ratio at collapse
P	length of unsupported tunnel ahead of tunnel shield or lining (m)

P_T	support resistance (kN/m^2)
p_h	horizontal pressure (kN/m^2)
p_v	vertical pressure (kN/m^2)
Q	Q-value for rock mass quality rating method
q_c	cone tip resistance for CPT (MN/m^2)
Q_c	normalised Q-value
Q_{TBM}	Q-value for TBM tunnelling
r	radius of the load plate (m)
R_f	friction ratio for CPT (%)
s_1	spring rigidity, stress dependent (MN/m^2)
s_1^*	spring rigidity, constant (MN/m^2)
s_2	viscosity, stress dependent (dMN/m^2)
s_2^*	viscosity, constant (dMN/m^2)
S	surface settlement (mm)
S_h	horizontal ground displacement (mm)
S_{max}	maximum surface settlement directly above the tunnel centreline (mm)
S_v	vertical ground displacement (mm)
t	Time (d or h)
t_a	age of sprayed concrete (d or h)
t_0	time at start (of test) (d or h)
T_y	tunnel stability number for the soil load
T_s	tunnel stability number for surface surcharge
u	pore water pressure (kN/m^2)
UCS, q_u	unconfined compressive strength (MN/m^2)
V_l	volume loss per metre length of tunnel (m^3/m)
V_o	excavated volume of the tunnel per metre length of tunnel (m^3/m)
V_p	seismic velocity (m/s)
V_s	volume of the surface settlement trough per metre length of tunnel (m^3/m)
V_t	estimated volume loss per metre length of tunnel (m^3/m)
v	vertical displacement of footing (mm)
w	water (moisture) content (%)
w	settlement of the tunnel crown (mm)
w_{crit}	critical settlement of the tunnel crown (mm)
w_L	liquid limit (%)
w_p	plastic limit (%)
x, y, z	coordinate axes
y	transverse horizontal distance from tunnel centreline (m)
z	depth from the ground surface (m)
z_w	depth below groundwater table (m)

Note that all logarithmic terms are \log_{10} in this book.

