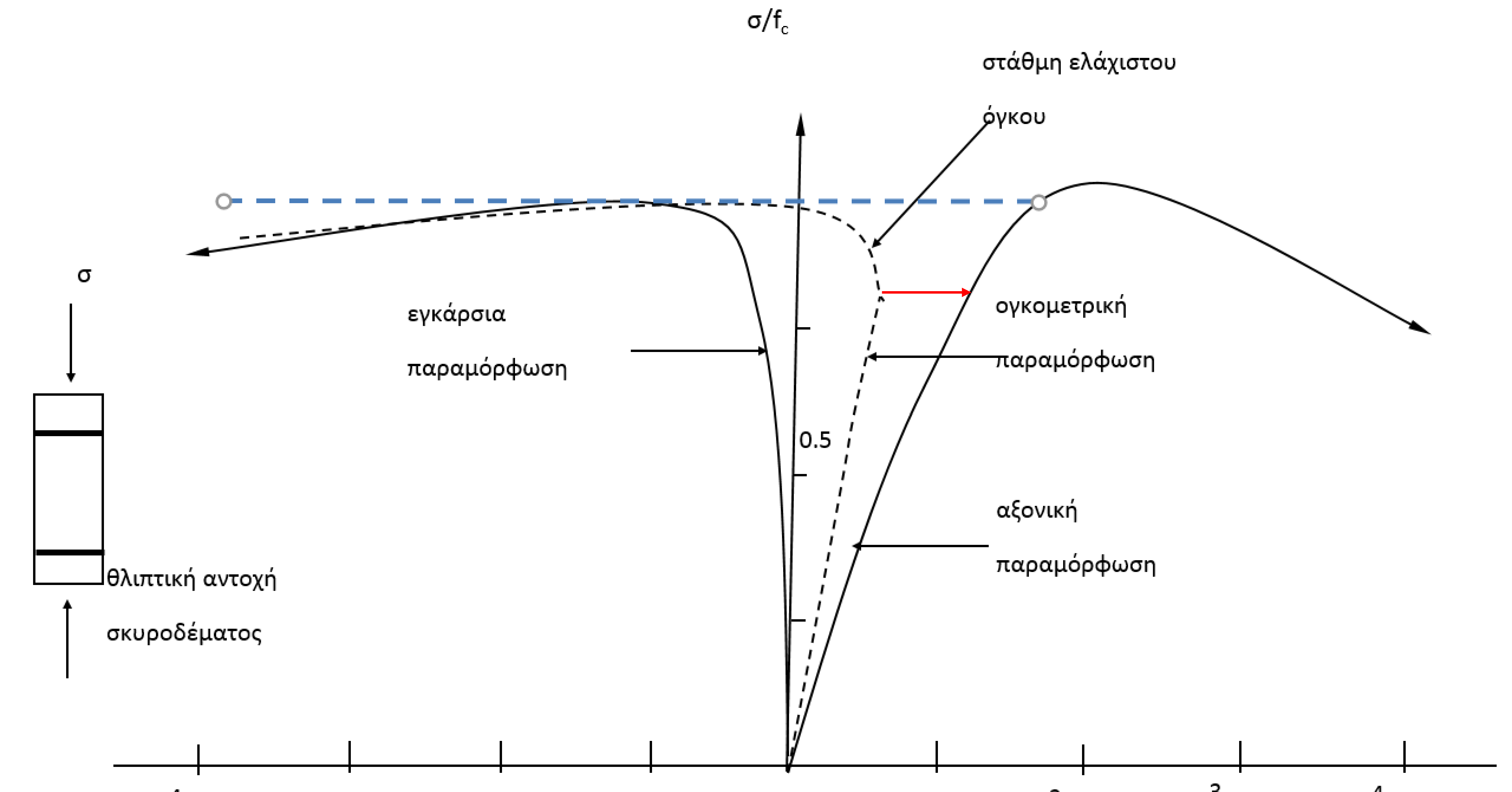
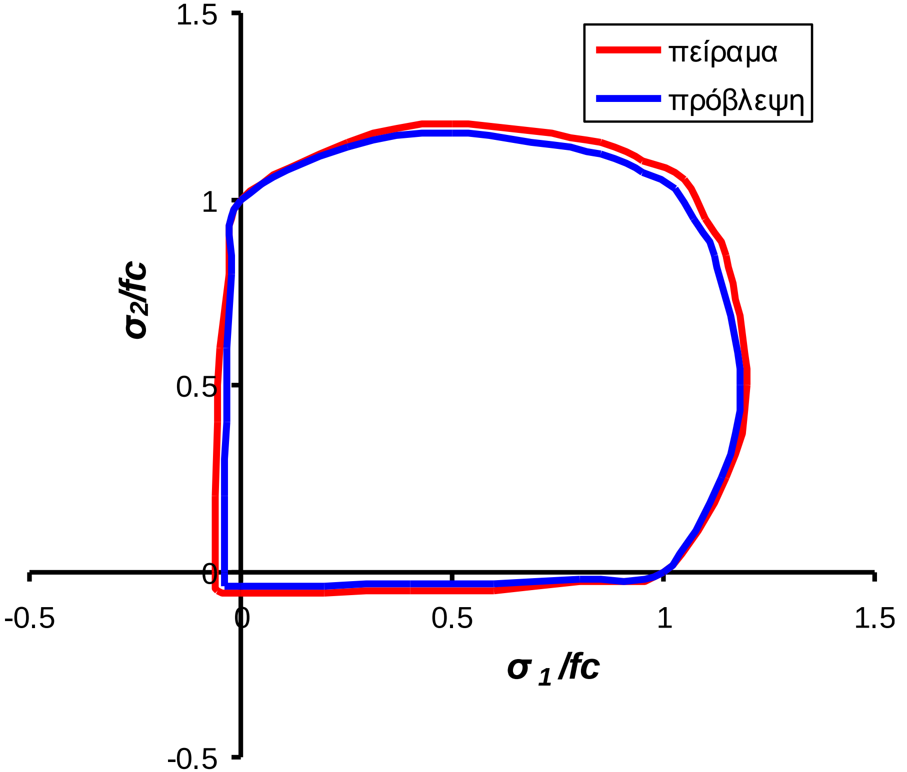
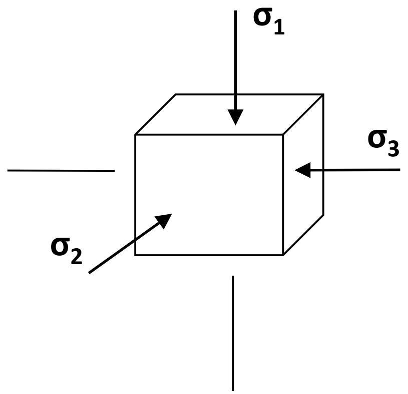


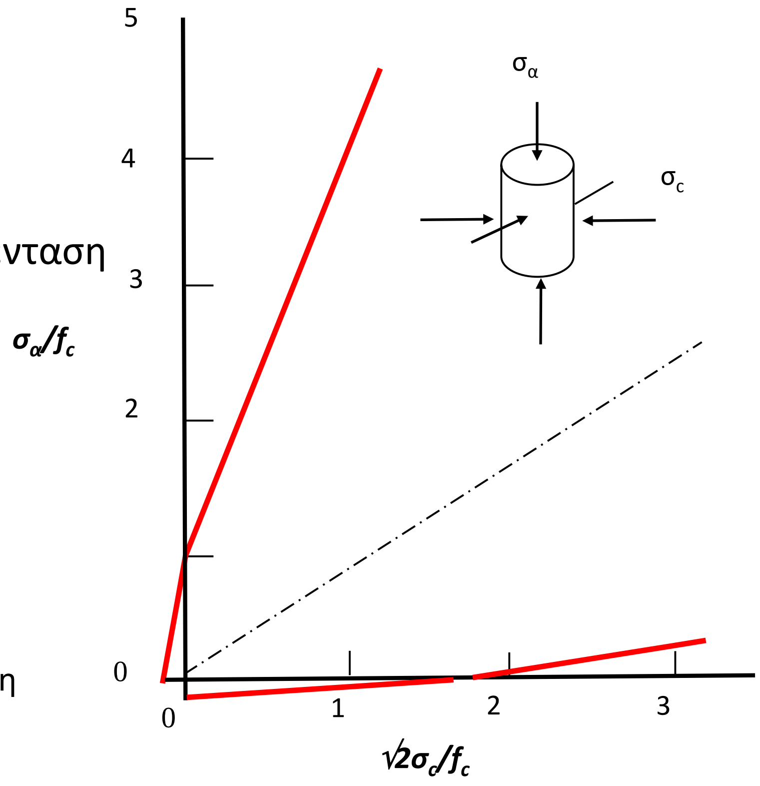
σ/f_c
στάθμη ελάχιστου
όγκου
σ
εγκάρσια
παραμόρφωση
ογκομετρική
παραμόρφωση
0.5
αξονική
παραμόρφωση
θλιπτική αντοχή
σκυροδέματος



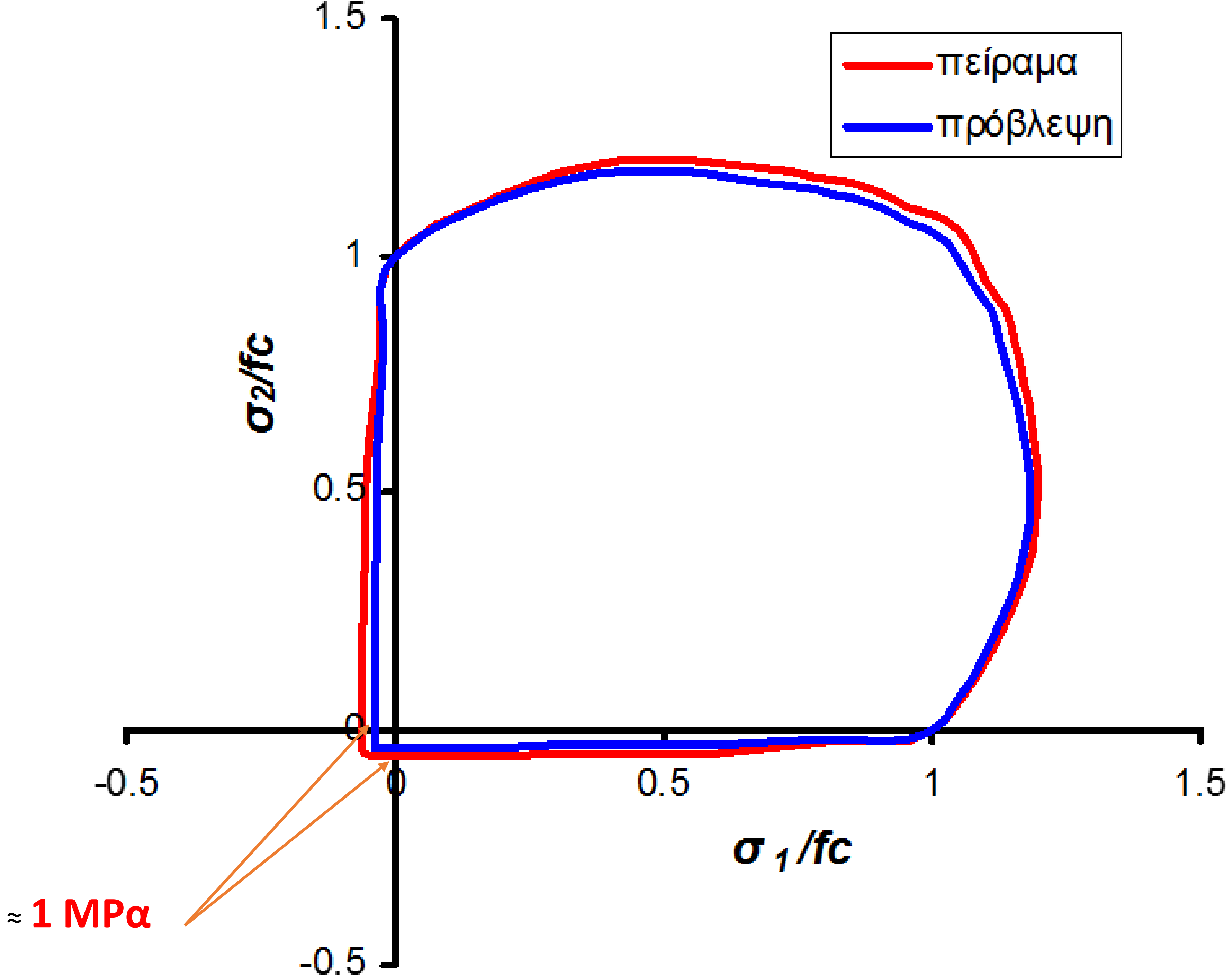
Καμπύλη αντοχής σκυροδέματος υπό διαξονική ένταση



Στοιχειώδης κύβος υπό τριαξονική ένταση.



Αντοχή σκυροδέματος υπό αξονοσυμμετρική ένταση



πείραμα
πρόβλεψη
σ2/fc
σ 1 /fc
1.5
1
0.5
0
-0.5
-0.5
0
0.5
1
1.5
≈ 1 MPα

Differential Settlement and Induced Structural Damage in a Cut-and-Cover Subway Tunnel in a Soft Deposit

Shunhua Zhou[1]; Honggui Di[2]; Junhua Xiao[3]; and Peixin Wang[4]

Abstract: This study investigated the differential settlement and induced structural damage in the west extension of Nanjing Metro Line 1. The minimum and maximum cumulative settlements measured over the course of four years of operation were 1 mm and 122 mm, respectively. Four settlement troughs in the longitudinal direction of the line, as well as a periodic variation of differential settlement between the stations and the tunnel, were observed. Approximately 10% of the vertical radius of curvature of the line violates the safety limit of 15,000 m, and three typical kinds of cracks (i.e., transverse cracks in the tunnel roof and in the track bed, and inclined cracks in the outer wall) and leakage have occurred. The differential settlement of the line was mainly caused by the nonuniform distribution of underlying soft soil. The periodic variation of differential settlement between the stations and tunnel was attributed to the structural characteristics and the seasonal variation in the groundwater level. The findings presented in this paper can provide a reference for controlling the differential settlement of tunnels constructed in soft deposits. **DOI:** 10.1061/(ASCE)CF.1943-5509.0000880.

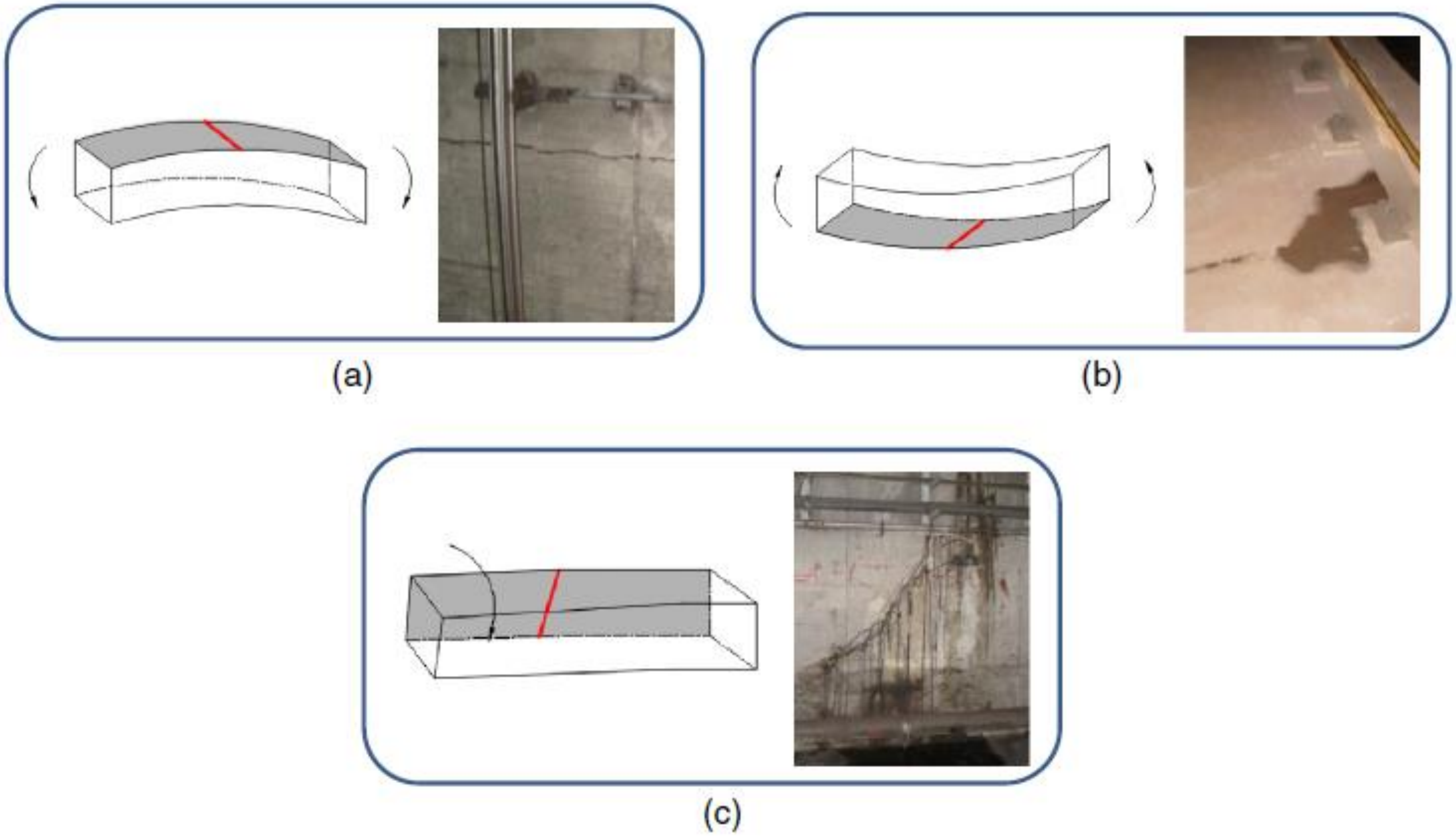
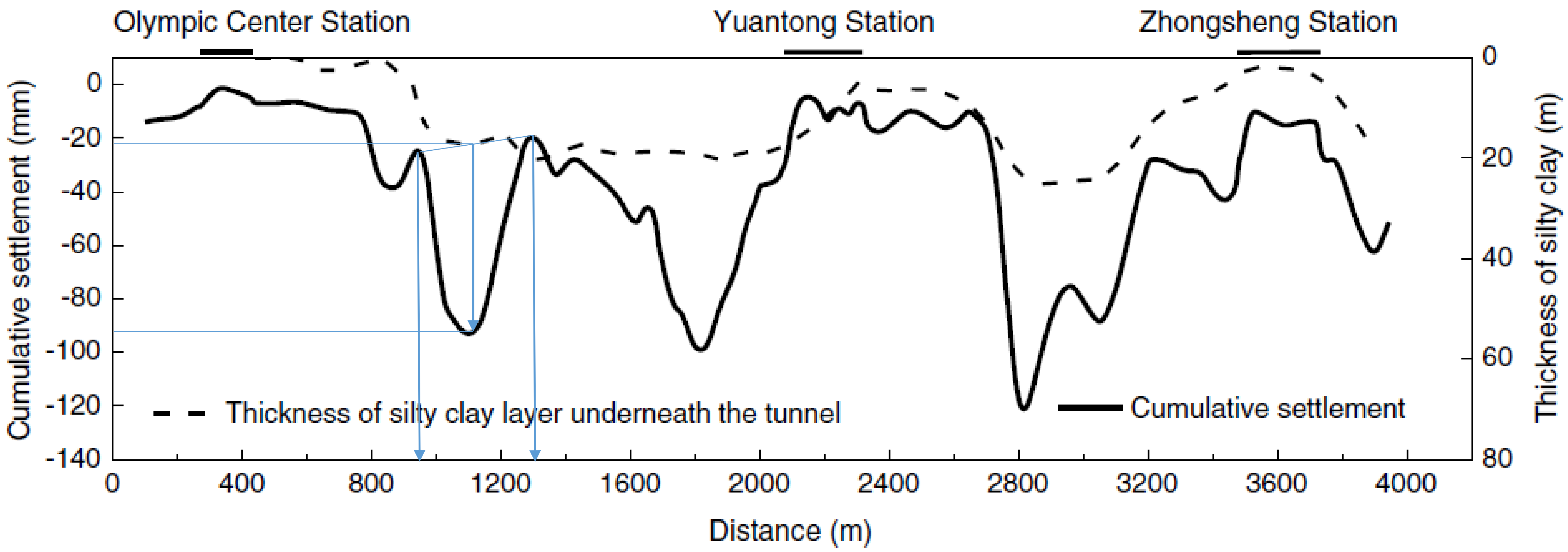
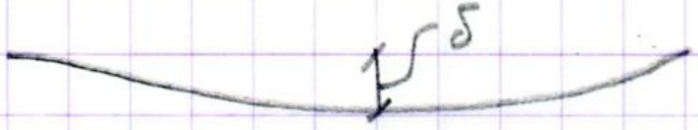


Fig. 11. Structural damage in the line: (a) transverse cracks in the tunnel roof; (b) transverse cracks in the tunnel floor and track bed; (c) incli
cracks in the outer wall


Olympic Center Station
Yuantong Station
Zhongsheng Station
Cumulative settlement (mm)
0
-20
-40
-60
-80
-100
-120
-140
Thickness of silty clay (m)
0
20
40
60
80
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
Distance (m)
Thickness of silty clay layer underneath the tunnel
Cumulative settlement

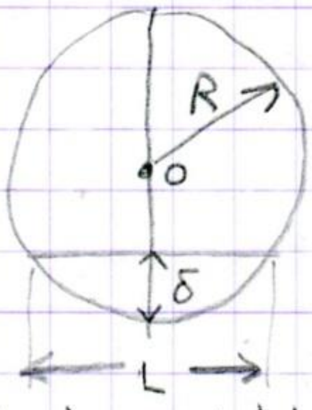
Εφαρμογή: Πόσο μειώνεται η φέρουσα ικανότητα της σήραγγας λόγω της σχετικής υποχώρησης κατά δ σε μήκος L;

Η επιβαλλόμενη καμπυλότητα στη σήραγγα, προκύπτει ως:



$L = 1320 - 880 = 440$ (m)

$\delta = 94 - 22 = 72$ mm



(α) Υπολογισμός καμπυλότητας σήραγγας:

$$(2R - 0{,}072)\cdot 0{,}072 = \left(\frac{440}{2}\right)^2$$

$$\rightarrow 2R - \cancel{0{,}072} = \frac{220^2}{0{,}072}$$

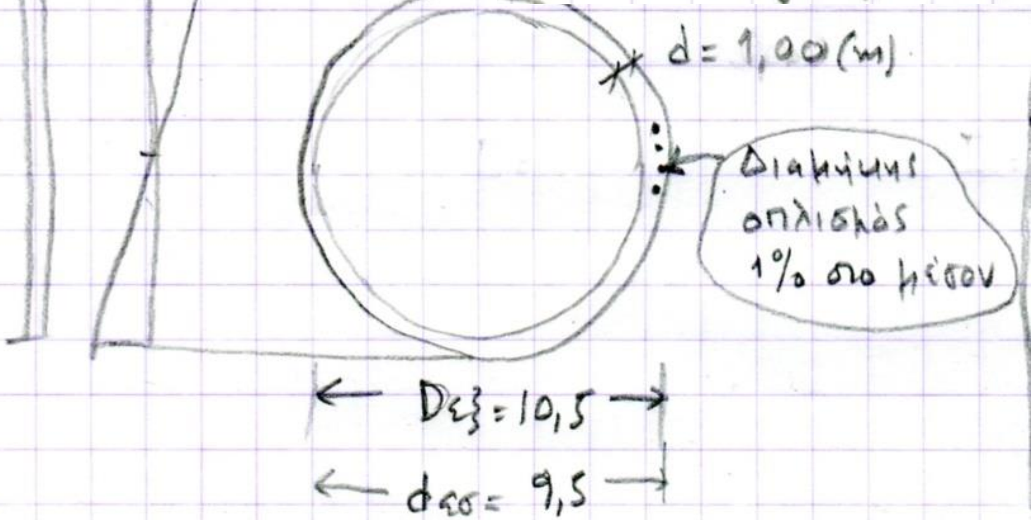
$$\rightarrow 2R \simeq 672\cdot 10^3 \text{ m}$$

$$\rightarrow R \simeq 336\cdot 10^3 \text{ m}$$

$$\rightarrow \frac{1}{R} \simeq 3\cdot 10^{-6} \text{ m}^{-1}$$

Πόσο επηρεάζει η κατάσταση αυτή τη φέρουσα ικανότητα της σήραγγας "εντός επιπέδου";

(β) Υπολογισμός αν η σήραγγα ρηγματώθηκε:



C40/50

$$\frac{1}{R_{crack}} = \frac{\varepsilon_{c1} + \varepsilon_{c2}}{d} = \frac{2 \cdot 8,33 \cdot 10^{-6}}{10,5}$$

$$= 1,59 \cdot 10^{-6} \ m^{-1} < 3 \cdot 10^{-6} \ m^{-1}$$

Άρα η διατομή έχει ρηγματωθεί στην εφελκυόμενη περιοχή, λόγω κάμψης.

(γ) Υπολογισμός Mcr

$$I_c = \pi \frac{(D_{εξ}^4 - d_{εσ}^4)}{64}$$

$$I_c = \pi \frac{10,5^4 - 9,5^4}{64}$$

$$= 196,8 \ m^4$$

Ισοδύναμη διατομή
$1\% \cdot a_e \cdot 500 \cong 28 \ mm$

$$a_e = \frac{200}{35} = 5,7$$ (λόγος μέτρων ελαστικότητας στην αρηγμάτωτη κατάσταση)

$$\frac{528 - 500}{500} = 5,6\ \%$$

$$I = 196,8 \cdot 1,056 = 207,8 \ m^4$$

$E = 35$ GPa

Κατά τον Ευρωκώδικα 2, μέρος 1, παρ. 5.8.9, η διαξονική κάμψη λαμβάνεται υπόψη με το παρακάτω απλοποιητικό κριτήριο:

$$\left(\frac{M_{Edz}}{M_{Rdz}}\right)^{a} + \left(\frac{M_{Edy}}{M_{Rdy}}\right)^{a} \leq 1{,}0$$

όπου:

$M_{Edz/y}$ είναι η ροπή σχεδιασμού ως προς τον αντίστοιχο άξονα, συμπεριλαμβανομένης μιας ονομαστικής ροπής 2ας τάξης.

$M_{Rdz/y}$ είναι η καμπτική αντοχή σχεδιασμού στη αντίστοιχη διεύθυνση

a είναι εκθέτης

- για κυκλικές, δακτυλιοειδείς και ελλειψοειδείς διατομές: $a = 2$
- για ορθογωνικές διατομές:

N_{ed}/N_{Rd}	0,1	0,7	1,0
$a =$	1,0	1,5	2,0

οι ενδιάμεσες τιμές υπολογίζονται με γραμμική παρεμβολή

N_{Ed} είναι η τιμή σχεδιασμού της αξονικής δύναμης

N_{Rd} $= A_c f_{cd} + A_s f_{yd}$, το αξονικό φορτίο αντοχής σχεδιασμού της διατομής

$f_{ctm,0,05} = 2,5$ MPa

$f_{ct,d,0,05} = \frac{2,5}{1,5} = 1,67$ MPa

$e_t = \frac{1,67}{200.000} = 8,33 \cdot 10^{-6}$

$M_{cr} = f_{ctd} \cdot \left(\frac{I}{R}\right) = 1,67 \text{ MPa} \cdot \frac{207,4}{5} \frac{m^4}{m}$

$= 1,67 \cdot 10^3 \frac{kN}{m^2} \cdot \frac{207,4}{5} \frac{m^4}{m}$

$= 68,3 \cdot 10^3$ kNm

(δ) Για λεπτές κυλινδρικές διατομές

Η $M_{cr} \simeq 20\% \, M_R$

Άρα $M_2 = \frac{3}{1,59} \cdot 20\% = 37\% \, M_{R,2}$

$M_{R,1} = \left(\sqrt{1 - 0,37^2}\right) M_1 = 0,93 \, M_1$

Άρα η διατομή διατηρεί το 93% της φέρουσας ικανότητάς της.

Tunnelling and Underground Space Technology 107 (2021) 103652

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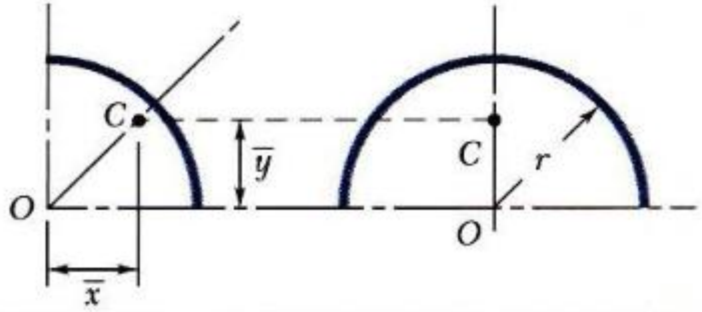
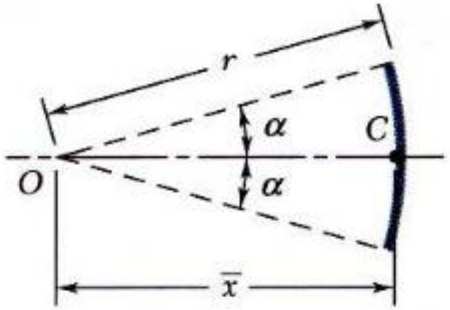
General solutions for the longitudinal deformation of shield tunnels with multiple discontinuities in strata

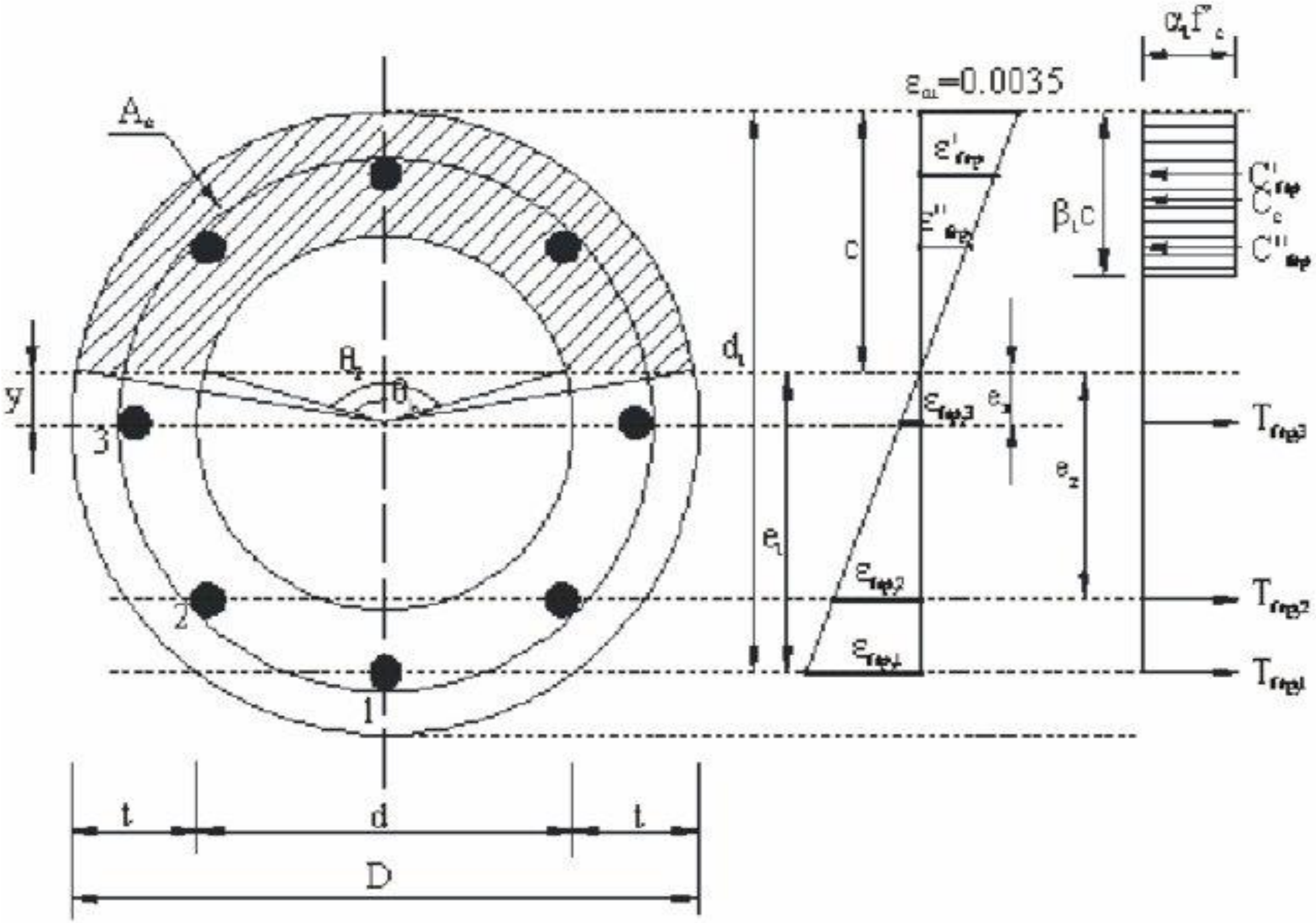
Hongzhan Cheng [a,d], Renpeng Chen [a,b,c,*], Huaina Wu [a,b,c], Fanyan Meng [a], Yaolin Yi [d]

Table 1
Summarize of the existing tunnel accidents caused by unfavorable circumstances.

Unfavorable circumstances	Name of the existing tunnel	Case description	Tunnel outer diameter	Tunnel buried depth	Deformation of the existing tunnel		Tunnel defects
					Displacement	Convergence	
Nearby excavation	Taipei Rapid Transit System, China (Chang et al., 2001)	Distance from the excavation 6.9 m	6240 mm	17.5 m	27 mm (Horizontal) 33 mm (Settlement)	24 mm (Horizontal) 46 mm (Vertical)	i. Separation of the track bed with the tunnel segments with a gap of 20 mm ii. Cracks varied from 0.05 to 0.25 mm in width
	Ningbo Metro Line 1, China (Chen et al., 2016)	Distance from the excavation 7.2–13 m	6200 mm	12.1–18.1 m	33.5[a] mm (Horizontal) 25.3[a] mm (Settlement)	21.9[a] mm (Horizontal) 16[a] mm (Vertical)	i. Leakages ii. Cracks
	Guangzhou Metro Line 1, China (Liu, 2008)	Distance from the excavation 6 m	6000 mm	10 m	7.8 mm (Horizontal) 12.3 mm (Settlement)	/	i. Leakages ii. Cracks iii. The ditch mud lowering
Surface surcharge	Shanghai Metro, China (Shao et al., 2016)	Surcharge 7 m in height	6200 mm	17.9–19.6 m	/	214 mm (Horizontal)	i. Break of the bolt ii. Leakages iii. Concrete spalling between segments
	Shanghai Metro, China (Huang and Zhang, 2016)	Surcharge 4.1 m in height	6200 mm	/	15 mm (Settlement)	128 mm (Horizontal)	i. Leakages ii. Concrete spalling between segments
Groundwater lowering	Shanghai Metro Line No. 1, China (Shen et al., 2014)	A long-term monitoring period of 12.5 years	6200 mm	12.1–18.1 m	111 mm[b] (Settlement)	/	i. Separation of the track bed with the tunnel segments ii. Leakages
Cyclic train load	Nanjing Metro Line 1, China (Zhou et al., 2016)	A long-term monitoring period of 4 years	Internal width and height of 4.4 m and 5.16 m	/	1–122 mm (Settlement)	/	i. Leakages ii. Cracks in the segment and the track bed

Positive horizontal displacement value represents displacements toward the excavation.
Positive convergence value represents the tunnel horizontally or vertically elongated.
[a] means the increment of tunnel deformations during the 3rd excavation step.
[b] means the average settlement of Shanghai Metro Line No. 1, China.

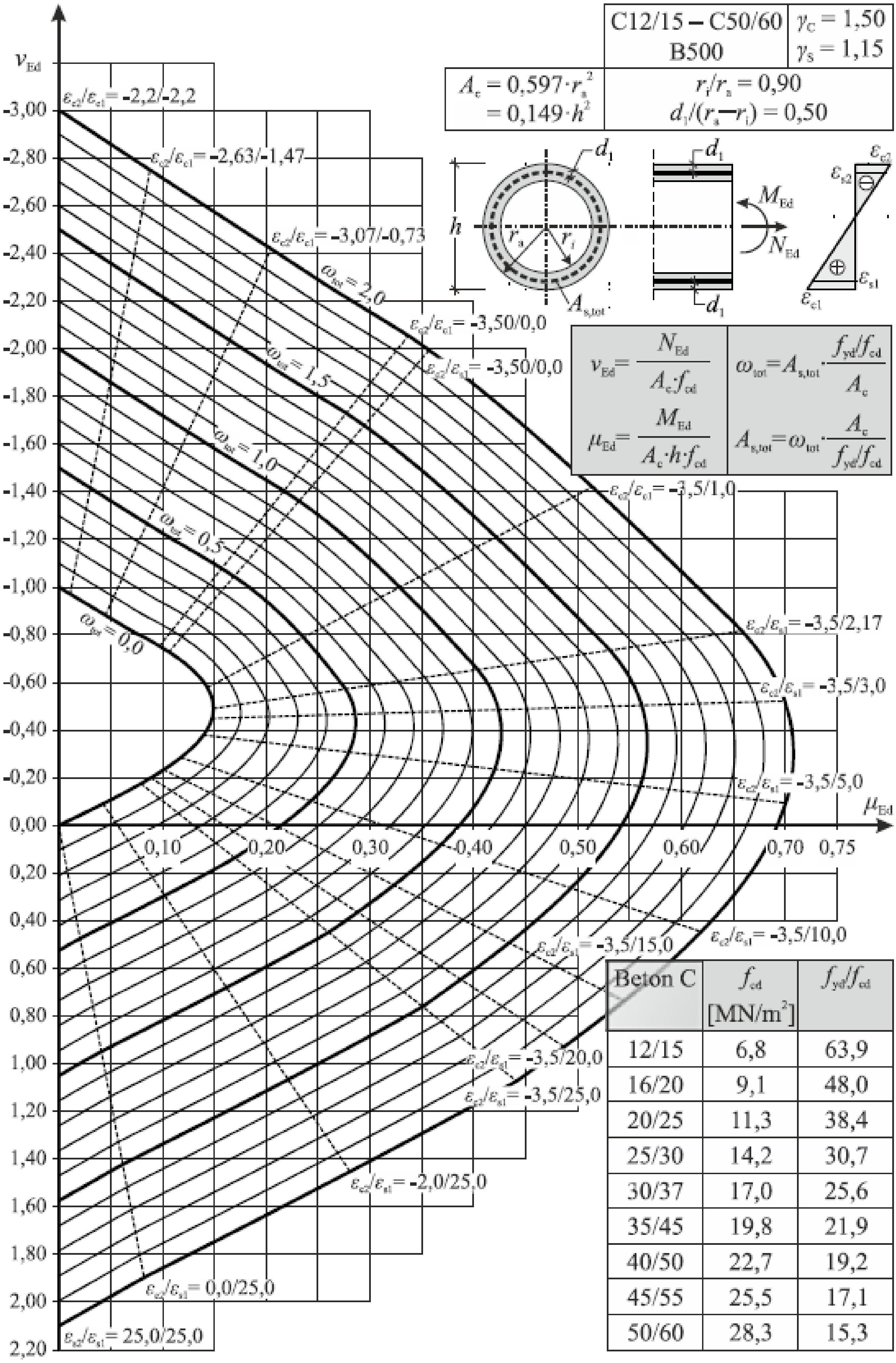
Shape		$\bar{x}$	$\bar{y}$	Length
Quarter-circular arc		$\frac{2r}{\pi}$	$\frac{2r}{\pi}$	$\frac{\pi r}{2}$
Semicircular arc		0	$\frac{2r}{\pi}$	πr
Arc of circle		$\frac{r \sin \alpha}{\alpha}$	0	$2\alpha r$



A_c
θ_1
θ_2
y
3
2
1
t
d
t
D
d_1
c
e_1
ε_{cu}=0.0035
ε'_{frp}
ε''_{frp}
ε_{frp3}
ε_{frp2}
ε_{frp1}
e_3
e_2
$\alpha_1 f'_c$
$\beta_1 c$
C'_{frp}
C_c
C''_{frp}
T_{frp3}
T_{frp2}
T_{frp1}

C12/15 – C50/60 B500	$\gamma_C = 1{,}50$ $\gamma_S = 1{,}15$
$A_c = 0{,}597 \cdot r_a^2 = 0{,}149 \cdot h^2$	$r_i/r_a = 0{,}90$ $d_1/(r_a - r_i) = 0{,}50$

$\nu_{Ed} = \dfrac{N_{Ed}}{A_c \cdot f_{cd}}$	$\omega_{tot} = A_{s,tot} \cdot \dfrac{f_{yd}/f_{cd}}{A_c}$
$\mu_{Ed} = \dfrac{M_{Ed}}{A_c \cdot h \cdot f_{cd}}$	$A_{s,tot} = \omega_{tot} \cdot \dfrac{A_c}{f_{yd}/f_{cd}}$



Beton C	f_{cd} [MN/m²]	f_{yd}/f_{cd}
12/15	6,8	63,9
16/20	9,1	48,0
20/25	11,3	38,4
25/30	14,2	30,7
30/37	17,0	25,6
35/45	19,8	21,9
40/50	22,7	19,2
45/55	25,5	17,1
50/60	28,3	15,3