

Experimental and analytical studies of the parameters influencing the action of TBM disc tools in tunnelling

*Original*

Experimental and analytical studies of the parameters influencing the action of TBM disc tools in tunnelling / Cardu, Marilena; Iabichino, Giorgio; Oreste, Pierpaolo; Rispoli, Andrea. - In: ACTA GEOTECHNICA. - ISSN 1861-1125. - STAMPA. - 12:(2017), pp. 293-304. [10.1007/s11440-016-0453-9]

*Availability:*

This version is available at: 11583/2640244 since: 2017-10-09T19:28:31Z

*Publisher:*

Springer-Verlag Berlin Heidelberg

*Published*

DOI:10.1007/s11440-016-0453-9

*Terms of use:*

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

*Publisher copyright*

Springer postprint/Author's Accepted Manuscript

This version of the article has been accepted for publication, after peer review (when applicable) and is subject to Springer Nature's AM terms of use, but is not the Version of Record and does not reflect post-acceptance improvements, or any corrections. The Version of Record is available online at: <http://dx.doi.org/10.1007/s11440-016-0453-9>

(Article begins on next page)

## Tables

Table 1. Rock properties of samples used in the ILCM tests.

<b>PRALI WHITE MARBLE</b>					
Density [kg/m <sup>3</sup> ]	C <sub>0</sub> [MPa]	$\sigma_{t, fle}$ [MPa]	E <sub>t</sub> [GPa]	Knoop Hardness[MPa]	DRI
2790	120	19.8	35	1286	90
<b>LUSERNA STONE</b>					
Density [kg/m <sup>3</sup> ]	C <sub>0</sub> [MPa]	$\sigma_{t, fle}$ [MPa]	E <sub>t</sub> [GPa]	Knoop hardness[MPa]	DRI
2620	124	21.3	63	4261	33

Table 2. Conditions and results of the tests. p: penetration; s: spacing between the grooves;  $F_N$  and  $F_R$ : average of the normal and rolling forces in the peak zones.

Rock type	ref.	p [mm]	s [mm]	s/p	$F_N$ [kN]	$F_R$ [kN]
Prali White Marble	M1	3.0	21.9	7.3	89.3	7.0
	M2	2.9	25.7	9.0	86.6	8.1
	M3	2.9	31.4	11.0	95.2	9.0
	M4	2.8	33.3	11.9	99.1	10.0
	M5	2.9	38.5	13.5	96.9	9.8
	M6	3.0	45.1	15.3	102.9	9.7
	M7	3.0	47.8	16.2	104.9	9.8
Luserna Stone	P1	3.9	29.6	7.6	144.7	11.8
	P2	4.2	39.1	9.3	149.9	12.6
	P3	3.8	41.0	10.8	149.5	13.3
	P4	4.1	45.2	11.1	144.7	12.3
	P5	4.4	54.0	12.3	157.9	14.1

Table 3. Analytical formulations proposed by the CSM model (Rostami et al., 2002).

$F_N = T \cdot R \cdot \phi \cdot P' \cdot \cos\left(\frac{\phi}{2}\right)$		$\phi = \arccos\left(\frac{R - p}{R}\right)$		$P' = C \cdot \sqrt[3]{\frac{\sigma_c^2 \cdot \sigma_t \cdot S}{\phi \cdot \sqrt{R \cdot T}}}$	
$F_N$	normal cutting force [N]	$p$	penetration [mm]		
$T$	cutter tip width [mm]	$C$	constant equal to 2.12		
$R$	cutter radius [mm]	$\sigma_c$	uniaxial compressive strength of rock [MPa]		
$\phi$	angle of the contact area	$\sigma_t$	tensile Brazilian strength of rock [MPa]		
$P'$	average pressure in the contact area	$S$	spacing between the cuts [mm]		

Table 4. Normal forces in the peak zones, obtained from tests through ILCM and estimated thanks to the CSM model, NTNU model and NTNU model with the correction factor proposed ( $k_d=2.17$ ).

Rock type	ref.	p [mm]	s [mm]	s/p	ILCM	CSM	NTNU	NTNU correct
					$F_N$ [kN]	$F_N$ [kN]	$F_N$ [kN]	$F_N$ [kN]
Prali White Marble	M1	3.0	21.9	7.3	89.3	51.7	103.8	91.4
	M2	2.9	25.7	9.0	86.6	53.5	103.1	90.7
	M3	2.9	31.4	11.0	95.2	57.2	105.3	92.7
	M4	2.8	33.3	11.9	99.1	58.0	105.4	92.7
	M5	2.9	38.5	13.5	96.9	61.2	108.3	95.4
	M6	3.0	45.1	15.3	102.9	65.4	112.9	99.4
	M7	3.0	47.8	16.2	104.9	66.6	114.2	100.5
Luserna Stone	P1	3.9	29.6	7.6	144.7	65.9	161.6	142.2
	P2	4.2	39.1	9.3	149.9	74.3	172.5	151.8
	P3	3.8	41.0	10.8	149.5	72.7	167.4	147.3
	P4	4.1	45.2	11.1	144.7	77.0	174.7	153.8
	P5	4.4	54.0	12.3	157.9	84.2	186.7	164.3

Table 5. Factors conditioning the penetration per revolution following the NTNU model.

	<b>FACTOR</b>	<b>PARAMETER</b>
<b>INTACT ROCK CHARACTERISTICS</b>	Drilling Rate Index (DRI)	$k_{DRI}$
<b>ROCK-MASS CONDITION</b>	Joints frequency	$k_{s-tot}$
	Joints orientation	
	Joints condition	
<b>DISCS</b>	Spacing	$k_a$
	Diameter	$k_d$
	Mean normal force	$M_B$

Table 6. Input parameters of the NTNU model referring to the Ceppo Morelli Tunnel (Italy).  
 Key: DRI – Drilling Rate Index;  $k_{DRI}$  – correction factor for DRI value;  $k_s$  – fracturing factor for each joint set and for the rock mass;  $k_d$  – correction factor for disc diameter;  $k_{ekv}$  – equivalent fracturing factor;  $M_B$  – gross average thrust per disc ( $F_N$ );  $\phi_{disc}$  – disc diameter.

<b>INTACT ROCK CHARACTERISTICS</b>			DRI	47
			$k_{DRI}$	0.98
<b>ROCK-MASS CONDITION</b>			$k_{s1}$	0.75
			$k_{s2}$	1
			$k_{s3}$	0.8
			$k_{s-tot}$	1.83
			$k_{ekv}$	1.79
			<b>DISCS</b>	$\phi_{disc}$ [in]
$k_d$	2.38			
$\phi_{disc}$ [in]	<b>17</b>	$M_B$ [kN]		200
		$k_d$		2.25
$\phi_{disc}$ [in]	<b>19</b>	$M_B$ [kN]		250
		$k_d$		2.20

Table 7. Parameters obtained through the NTNU model referred to in the Ceppo Morelli Tunnel (Italy).

$\phi_{\text{disc}}$ [in]	$F_N$ [kN]	s/p	p [mm/rev]	n. discs	P [kW]
15	150	10	5.4	33	595
		14	5.0	26	448
		18	4.6	22	366
		22	4.3	19	304
17	200	10	6.4	28	686
		14	5.8	22	511
		18	5.3	19	421
		22	4.8	17	361
19	250	10	7.0	26	785
		14	6.2	21	596
		18	5.6	18	485
		22	5.1	16	413



Table 8. Comparison between the results obtained through NTNU model and the on-site measured parameters at the Ceppo Morelli Tunnel (Italy).

	$\phi_{disc}$ [in]	$F_N$ [kN]	s/p	p [mm/rev]	n. discs	P [kW]
<b>NTNU</b>	16¼	200	14	5.97	22	532.9
<b>REAL</b>	16¼	200	14	5.2	23	596.4