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

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Tables

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

PRALI WHITE MARBLE					
Density [kg/m^3]	C_0 [MPa]	$\sigma_{t,fle}$ [MPa]	E_t [GPa]	Knoop Hardness[MPa]	DRI
2790	120	19.8	35	1286	90
LUSERNA STONE					
Density [kg/m^3]	C_0 [MPa]	$\sigma_{t,fle}$ [MPa]	E_t [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]
	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
Prali White Marble	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
	P1	3.9	29.6	7.6	144.7	11.8
	P2	4.2	39.1	9.3	149.9	12.6
Luserna Stone	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).

$$F_N = T \cdot R \cdot \emptyset \cdot P' \cdot \cos\left(\frac{\emptyset}{2}\right) \qquad \emptyset = \arccos\left(\frac{R - p}{R}\right) \qquad P' = C \cdot \sqrt[3]{\frac{\sigma_c^2 \cdot \sigma_t \cdot S}{\emptyset \cdot \sqrt{R \cdot T}}}$$

F_N	normal cutting force [N]	p	penetration [mm]
T	cutter tip width [mm]	C	constant equal to 2.12
R	cutter radius [mm]	σ_c	uniaxial compressive strength of rock [MPa]
$\emptyset$	angle of the contact area	σ_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 F_N [kN]	CSM F_N [kN]	NTNU F_N [kN]	NTNU correct 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.

	FACTOR	PARAMETER
INTACT ROCK CHARACTERISTICS	Drilling Rate Index (DRI)	k_{DRI}
ROCK-MASS CONDITION	Joints frequency Joints orientation Joints condition	$k_{s\text{-}tot}$
DISCS	Spacing Diameter Mean normal force	k_a k_d 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); Φ_{disc} – disc diameter.

INTACT ROCK CHARACTERISTICS			DRI	47
			k_{DRI}	0.98
ROCK-MASS CONDITION			k_{s1}	0.75
			k_{s2}	1
			k_{s3}	0.8
			k_{s-tot}	1.83
			k_{ekv}	1.79
DISCS	ϕ_{disc} [in]	15	M_B [kN]	150
			k_d	2.38
	ϕ_{disc} [in]	17	M_B [kN]	200
			k_d	2.25
	ϕ_{disc} [in]	19	M_B [kN]	250
			k_d	2.20

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

ϕ_{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).

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