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TBM machines and guidelines for their selection

L. Cornejo
Agromán, Madrid, Spain
J.M. Serrano
Secegsa, Madrid, Spain

ABSTRACT: Frequently the successful construction of tunnels depends mainly on the adequate selection of machinery, refering specifically to excavation machinery and bearing in mind the actual proliferation of these machines on the world market, it is necesary to have basic general criteria to help in the correct selection of these machines.

This paper presents a machinery classification proposing criteria for its selection considering the characteristics of rocks or of the ground to be excavated and the conditions of the surroundings where the underground excavations wil take place. Recomendations are also given for auxiliary preliminary treatment techniques.

1.- INTRODUCTION

The mechanical excavation of tunnels and, therefore, the construction of tunneling machines has undergone outstanding development since 1960 and above all in recent years. The outlook for the coming years includes the incorporation of new technological advances and new ideas in machine design.

The international competition among the leading machinery manufacturers resuts in the appearance of new generations of machines. On the horizon there are glimpses of robotized multi-purpose mechines capable of being effectively used in very diverse situations, ranging from the excavation of hard rock to that of soft ground below the water table.

These are some examples of the current generation of machines:

a) Multi-purpose TBM machines for hard rock with articulated double shield; these machines are capable of excavating highly fractured formations and even of crossing fault zones and soft ground.

b) Multi-purpose shields, which can operate as conventional or pressurized shields.

c) Multi-purpose pressurized shields capable of being easily converted, inside the tunnel, into any of these units: slurry shield, compressed air shield and earth shield.

2.- PROPOSED CLASSIFICATION OF SHIELDS

Considering the proliferation of machines, and in the aim of easing their choice, the folowing classification is proposed (TABLES 1-4).

3.- GUIDELINES FOR SELECTING SHIELD MACHINES

The selection of the most suitable type of excavation machine is a choice that often has a decisive infuence on the success of the job. To ensure the correct choice, a few points should be kept in mind.

a) Hardness of the ground.
b) Presence and height water table above tunnel.
c) Permeability of the ground.

d) Adaptability of the machine to the various conditions imposed by the ground traversed.

e) Conditioning factors imposed by the medium through which the tunnel passes.

f) Presence of gases.

Tables 5-8 give the most suitable types of shield machines according to the type of ground to be excavated and the presence or absence of water table.
Table 9 is a guide for selecting shield machines according to the characteristics of the ground and the presence or absence of water table; recommendations are also given for auxiliary preliminary treatment techniques.

4.- CONCLUSION

The choice of a shield machine decisively influences the success or failure of tunnel construction and it should be made after meticulously evaluating such aspects as hardness of the ground, presence of water, permeability of the ground and adaptability of the machine to the various types of ground crossed.

5.- REFERENCE

- Stack, Barbara; handbook of mining and tunneling machinery (1982).
- L.Cornejo, la excavacion mecánica de túneles, ediciones rueda Madrid 1988.
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Table 1.- General clasification of shields type a.

	TIPE	DEFINITION	MODALITY	PECULIARITY	VARIANT
Conventional Shields	A	No Mechanized Shields Rigid Shields	A-1 Open Type	A-1-M Hand Excavation Type.	A-1-M-S Simple Shield
					A-1-M-C Blade Shield
					A-1-M-B Mesh Shield
				A-1-H Jet Shild	
			A-2 Blind Type		

Table 2.- General clasification of shields type b

	TIPE	DEFINITION	MODALITY	PECULIARITY	VARIANT - TOOL
Conventional Shields	B	Semi-Mechanical Schield Digger Shields Hybrid Class	B-1 Open Type	B-1-S No Blade Shiel	ackhoe
					Impactor
					Roadheader
					Rotary Boom
					Screw
				B-1-C Blade Shiel	Backhoe
					Impactor
					Roadheader
					Rotary Boom
					Screw
			B-2 Half Close Type	B-2-S No Blade Shiel	Backhoe
					Impactor
					Roadheader
					Screw
				B-2-C Blade Shiel	Backhoe
					Impactor
					Roadheader

Table 3. General clasification of shields type c

	TIPE	DEFINITION	MODALITY	PECULIARITY	VARIANT
Mechanical Shields	C	Mechanical Shields	C-1 Oscillator Type	C-1-R Spoked Wheel Type	C-1-R-O Oscillator-Type
					C-1-R-C Rotary Head
			C-2 Drum Digger		C-2-O Oscillator Type
					C-2-C Rotary Head
			C-3 Shielded-TBM	Full Face Hybrid Machine	KTB-S-B KAWASAKI;ROBBINS 188-227
					KTB-S-J KAWASAKI;ROBBINS 151-191
					KTB-M KAWASAKI

Table 4. General clasification of shields type d

	TIPE	DEFINITION	MODALITY	PECULIARITY	VARIANT
Pressuriced Shields	D	Pressuriced Shields	D-1 Open Type Shield Compresed Air		
			D-2 Close Head Type	D-2-LB Slurry Pressuriced Shield	KTBM
					MBM
					Hydroshild
					Thixschild
				D-2-T Earth Pressure Balanced Shield	D-2-T-T
					D-2-T-AP Earth Pressure Balanced Shield Water Pressure
					D-2-T-AB Mud Pressure Shield
				D-2-AP Compresed Air System	
				D-2-MU Universal Boring Machine	

Table 5. Selection criteria shields type a

SHIELD CLASS		GROUND TYPE		
		SURROUNDING CONDITIONS		
TYPE	VARIANT	NO WATER TABLE	WATER TABLE	
			AUXILIARY TECHNIQUES	
			NO	YES
A	A-1-M-S	COHESIVE GROUND BUT SOFT STABLE FACE COMPACT SOIL CLAY STONE CEMENTED SAND		
	A-1-M-C	SOFT ROCK AND WEATHERED ROCK PARTIALY CONSOLIDATED SANDSTONE MUDSTONE		
	A-1-M-B	GROUNDS WITH UNSTABLE FACE COHESIONLESS GROUNDS OR LITTLE COHESIVE		
	A-2	LITTLE COHESIVE GROUNDS WITH PLASTIC OR SEMI FLUID CONSISTENCY GROUNS BEHAVIOUR SIMILAR TOOTHPASTE		

Table 7.- Selection criteria shields type c

SHIELD CLASS		GROUND TYPE		
		SURROUNDING CONDITIONS		
TYPE	VARIANT	NO WATER TABLE	WATER TABLE	
			AUXILIARY TECHNIQUES	
			NO	YES
C	C-1-R-0	ADECUATE WHERE THE FACE STABILIZATION IS PRECARIOUS		
	C-1-R-C	CLAY AND SAND WITH WATER SOFT AND RAVELING GROUNDS		
	C-2-0	SAND AND CLAY CLAY SAND WITH GRAVEL		
	C-2-C	WET SHALE RUNNING GROUNDS		
	C-3	FROM SOFT GROUNDS TO HARD ROCK (150 Mpa) MIXED GROUNDS		* +

Table 6.- Selection criteria shields type b

SHIELD CLASS		GROUND TYPE		
		SURROUNDING CONDITIONS		
TYPE	VARIANT	NO WATER TABLE	WATER TABLE	
			AUXILIARY TECHNIQUES	
			NO	YES
B	B-1-S-1	SOFT AND COHESIVE GROUND STABLE FACE COMPACT GROUND CLAY STONE CEMENTATED SAND SOFT AND WEATHERED ROCK LITTLE CONSOLIDATED SANDSTONE MUDSTONE		
	B-1-S-2	SIMILAR TO PREVIOUS GROUNDS BUT MORE HARD	+	
	B-1-S-3	SIMILAR TO PREVIOUS GROUNDS BUT MORE HARD	+	
	B-1-S-4	COHESIVE AND SOFT GROUND STABLE FACE COMPACT SOIL CLAY STONE CEMENTED SAND SOFT AND WEATHERED ROCK PARTIALY CONSOLIDATED SANDSTONE MUDSTONE	+	
	B-1-S-5	SIMILAR TO PREVIONS GROUNS		
	B-1-C	SIMILAR GROUNDS TO MARQUED FOR B-1-S MACHINES	+	
	B-2-S	GROUNDS THAT OCCASIONALY NEED PARTIAL STABILIZATION FACE		
	B-2-C	SOFT FRACTURED AND/OR WEATHERED ROCK		

Table 8.1.- Selection criteria shields type d

SHIELD CLASS		GROUND TYPE		
		SURROUNDING CONDITIONS		
TYPE	VARIANT	NO WATER TABLE	WATER TABLE	
			AUXILIARY TECHNIQUES	
			NO	YES
D	D-2-L-B	SAND,GRAVEL AND SILT PERMEABLE ALLUVIAL DEPOSITS	SAND,GRAVEL AND SILT PERMEABLE ALLUVIAL DEPOSITS	SAND,GRAVEL SILT AND PERMEABLE ALLUVIAL DEPOSITS HIGH WATER TABLE. +
	D-1		LITTLE COHESIVE AND - LITTLE PERMEABLE,SOILS CLAY, SILT, CLAY SILTY.	SOFT GROUNDS SILT,SAND AND GRAVEL WITH WATER PRESSURE (MAX.3,5bar)
	KTBM (F.C.B/KAWASAKI)	MIXED GROUND	COLLABSIBLE SOILS UNDER WATER TABLE	COLLABSIBLE SOILS UNDER WATER TABLE ‡ +
	MBM (F.C.B/KAWASAKI)	LOAM, GYPSM, CHALK, MARL, CLAYSTONE, WEATHERED SAND STONE	COLLABSIBLE SOILS UNDER WATER TABLE	‡ +
	HIDROESCUDO		GRANULAR SOILS,SAND, GRAVEL,UNDER WATER TABLE. HIGH PERMEABILITY SOILS	SOILS UNDER HIGH WATER TABLE
	HIDROVET	SANDY SOILS. SILTS AND SOFT CLAY	SANDY SOILS, SILTS AND SOFT CLAY.	SOILS UNDER HIGH WATER TABLE.

Table 8.2.- Selection criteria shields type d

SHIELD CLASS		GROUND TYPE		
		SURROUNDING CONDITIONS		
TYPE	VARIANT	NO WATER TABLE	WATER TABLE	
			AUXILIARY TECHNIQUES	
			NO	YES
D	THIXSCHILD		SANDY SOILS, SILT AND SOFT CLAY.	SOILS UNDER HIGH WATER TABLE
	MIXSCHIELD		SANDY SOILS, SILT AND SOFT CLAY	SOILS UNDER HIGH WATER TABLE
	D-2-T-T		CLAY,SILT, SILTY SAND SOILS WITH SHORT COHE-SION. SILTY SAND SMALL PERMEABLE	SOILS UNDER HIGH WATER TABLE.
	D-2-T-AP		SANDS VERY LITTLE SILTY NO COHESIVE SOILLS SANDS AN GRAVELS WITH SILTY MATE-RIAL(10%).	SOILS UNDER HIGH WATER TABLE.
	D-2-T-AB		VERY PERMEA BLE AND COHESIONLESS SOILS.SANDS AND GRAVELS WITHOUT CLAY O SILT.	UNDER HIGH WATER - TABLE.
	D-2-AP		ALL KIND OF GROUNDS, SOILS AND WEATHERED ROCK.	SOILS UNDER HIGH WATER TABLE.

TABLE 9 SELECTION SHIELDS GUIDANCE

○ ADECUATE SELECTION

△ ACCEPTABLE SELECTION

K PERMEABILITY COEFFICIENT

W % OF WATER (WEIGHT D.S)

\+ GROUTING

● FREEZING

WATER TABLE DOWN

SOIL TYPE		N VALUE	PERMEABILITY K cm / seg WATER CONTENT W %	AUXILIARY TECHNIQUES WATER TABLE DOWN	FREEZING	GROUTING	SHIELD TYPE: NO MECHANIZED FACE OPEN	NO MECHANIZED FACE CLOSE	HALF MECHANIZED	MECHANICED FACE OPEN	MECHANICED FACE HALF OPEN	MECHANICED FACE CLOSE	SLURRY SHIELD	EART PRESSURE SHIELD E.P.S.	E.P.S. + WATER RE	E.P.S. + MUD RE	AIR PRESSURE FACE
SOFT ROCK $10 > \sigma_c > 0.3$ Mpa		≥ 50				+	—	—	○	○	○	△	—	—	—	—	—
BOULDERS D > 200 m.m.		≥ 50	$K \fallingdotseq 10^{-1}$	↓	✱	+	↓	+△	—	↓	+△	—	—	—	—	—	—	—	—
COBBLES 60 < D < 200 m.m.		≥ 50	$K \fallingdotseq 10^{-1}$	↓	✱	+	↓	+△	—	↓	+△	—	—	—	—	—	△	—
SAND AND GRAVEL $\varphi \begin{cases} 25° \\ 45° \end{cases}$ $60 > D > 2$ m.m.	SAND AND GRAVEL + COBLES	> 40	$K \fallingdotseq 10^{-2}$	↓	✱	+	↓	+△	—	↓	+△	↓	+△	↓	+△	—	↓ +○	△	○	—
	SAND AND GRAVEL + COBLES	> 30	$K \fallingdotseq 10^{-2}$	↓	✱	+	↓	+○	—	↓	+○	↓	+△	↓	+△	↓ +○	+△	↓ +○	△	○	—
	SAND AND GRAVEL	> 30	$K \fallingdotseq 10^{-2}$	↓	✱	+	↓	+○	—	↓	+○	↓	+△	↓	+△	↓ +○	△/ +○	↓ +○	○	○	+ ○
C $\begin{cases} 0 \\ 0.02 \end{cases}$ $\varphi \begin{cases} 30° \\ 36° \end{cases}$ SAND $2 > D > 0.06$ mm	SAND WITH WATER TABLE	10-40	$K \fallingdotseq 10^{-2}$	↓	✱	+	↓	+△	—	↓	+△	↓	+△	↓	+△	↓ +○	+ ○	↓ +△	○	○	+ ○
	SAND - COARSE	20-40	$K \fallingdotseq 10^{-3}$	↓	✱	+	↓	+○	—	↓	+○	↓	+△	↓	+△	↓ +○	△/ + ○	↓ +○	○	○	+ ○
	SAND - MEDIUM	20-40	$10^{-3} \sim 10^{-4}$	↓	✱	+	↓	✱ +○	—	↓	✱ +○	↓	✱ +△	↓	✱ +△	↓ ✱ +○	△/ + ○	↓ +○	○	○	+ ○
	SAND - FINE	15-30	$10^{-3} \sim 10^{-4}$	↓	✱	+	↓	✱ +○	—	↓	✱ +○	↓	✱ +△	↓	✱ +△	↓ ✱ +○	△/ + ○	↓ +○	○	○	○
	FINE SAND SILTY	10-15	$K < 10^{-4}$	↓	✱	+	↓	✱ +○	—	△/	✱ +○	↓	✱ +△	↓	✱ +△	↓ ✱ +○	○	○	○	○	○
HARD SOIL	HARD-PAN	> 50	W < 30				△	—	△	○		○	△	○		○	○
	SILT SANDY CLAY.	35-50	W < 30				○	—	○	○		○	△	○		○	○
	SILT SANDY CLAY	20-35	W < 30				○	—	○	○		○	△	○		○	○
MEDIUM SOIL $D < 0.06$ mm	LOAN	10-25	W < 40				○	—	○	△		○	○	○		○	○
	SILT SANDY CLAY	5-10	W > 50				△ /+○	—	△/ +○	△		+○	○	○		○	○
POOR	SANDY SILT	2-5	100 > W > 80				+○	○	+○	△			○	○		○	○
SUB SOIL	SILT	0-5	200 > W > 100				+△	○	+△	△			○	○		○	○
	PEAT	0	W > 300										△	△		○	○