Hydromechanical Behavior of a Tuff/Bentonite Mixture Treated with Cement

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Abstract

Sandy soil-clay mixtures are commonly used as a liner/barrier material in various engineering applications, such as construction of hydraulic and waste containment. In this study, the hydromechanical characteristics of tuff-bentonite and tuff-bentonite/cement mixtures are investigated to propose a local barrier material. A series of free swelling, one-dimensional consolidation and falling head permeability tests for hydraulic characteristics as well as the direct shear test for mechanical characteristics were performed on four different tuff-bentonite mixtures and two different tuff-bentonite/cement mixtures. Test results show that the compressibility/swelling behavior of the mixtures increases with increasing bentonite content. The optimum amount of bentonite to achieve a permeability of less than 10-9 m/s, which is a liner/barrier design requirement, was found at 8% and 10%. The results of the strength tests indicate that the apparent cohesion increases with the bentonite content, while the apparent angle of friction decreases. Concerning the optimal mix treated with 3% and 5% cement, the test results show that the permeability and compressibility/swelling behavior decrease with the added cement content, while the angle of friction and cohesion increase. Finally, it was conclude that the 8% bentonite-92% tuff mixture treated with 3% cement is retained as a passive barrier material for landfill sites in arid and semi-arid regions..

Introduction

Compacted bentonite-soil mixtures have been preferred as suitable hydraulic barrier materials for landfill liners. A significant amount of data has been presented on landfill liner materials. Many engineers and writers recommend that locally available materials be used to construct landfill liners. As a general rule, the hydraulic conductivity of landfill liners must be less than or equal to 10^{-9} m/s [1].

In geotechnics, tuffs are said to be evolutionary. They have a high resistance in dry state but their behavior is different in contact with water; they may become swollen and not durable (collapsed), which limits their use as backfill material in civil engineering works and infra-structures. Schrefler and Delage [2] indicated that the presence of active clays will promote swelling, slowing and reducing the collapse of tuffs.

This study therefore aims to quantify the influence of bentonite content and cement content on the permeability, compressibility and shear strength of a tuffs soil, and to evaluate the use of a locally available material for landfill lining in arid regions.

Methodology

The proportion of bentonite added to the tuff was gradually increased until 4 different mixtures of bentonite and tuff (B:M)- 0:100, 3%-97% (named B3%), 6%-94% (named B6%), 8%-92% (named B8%) and 10%-90% (named B10%). After that, an optimal mix was chosen for their treatment with 2 proportions of cement: 3% and 5%.

Table 1. Physicochemical and hydromechanical properties of tuff, bentonite and mixtures

Parameter	Unit	Tuff	Bentonite	B3%	B6%	B8%	B10%	Standard used
C_U	-	28.6	-	27.33	26.89	26.45	25.96	NF P94-056 and NF P 94-057
C_c	-	0.41	-	0.39	0.383	0.368	0.360	
γ_s	g/cm³	2.70	2.75	2.72	2.72	2.72	2.72	
LL	%	29.00	141	39.32	43.19	46.35	50.26	NF P 94-051
LP	%	21.30	48	25.43	27.97	28.56	29.56	
IP	%	7.90	93	13.39	16.12	18.08	20.70	
VBS	%	1.4	22	/	/	/	/	NF P 94-068
S	m²/g	29.4	462	/	/	/	/	
$CaCO_3$	%	34.00	5	34	33	30	30	NF P 94-048
pH	-	9.00	10.30	9.20	9.56	9.88	9.90	ASTM D4972
w_n	%	8.00	/	/	/	/	/	
$\gamma_{d\,max}$	g/cm³	1.74	1.20	17.20	17.00	16.85	16.62	NF P 94-093
OWC	%	13.8	32.50	14.95	15.35	15.61	15.81	
Cc	/	0.099	/	0.129	0.136	0.146	0.162	XP P 94-090-1
Cg	/	0.042	/	0.096	0.0149	0.0161	0.0181	
e_0	/	0.521	1.20	0,541	0,559	0,577	0,595	
G	%	0.03	118.25	0.08	0.39	0.42	0.64	

Permeability Test: The falling head permeability test, based on the standard test method (AFNOR NFX 30-441 2008), was used to measure the hydraulic conductivity of soils when load reached each target consolidation stress (Equation (1)):

$$k_v = \frac{a.l}{A.T}.\ln(\frac{h_1}{h_2}) \qquad (1)$$

Consolidation Test : The oedometer test (AFNOR XP P 94-090-1, 1997) is used to determine the compressibility characteristics of soils (Compression Index, Cc and the coefficient of consolidation, Cv). The hydraulic conductivity (ksat) was obtained from both the CV (m2/s) evaluated by Taylor's approach and the coefficient of volume change mv (m2/kN) (Equation (2)).

$$k_{sat} = C_v \times m_v \times \gamma_w \qquad (2)$$

Shear Strength: The direct shear test in the box has used to determine the parameters of the shear resistance of cohesion and the angle of friction of bentonite/tuff mixtures according to NF P 94-071-1. Thus, the unconsolidated undrained (U.U) direct shear test is used. A deformation rate of 0.5 mm/min was ap-plied for the shearing of all samples.

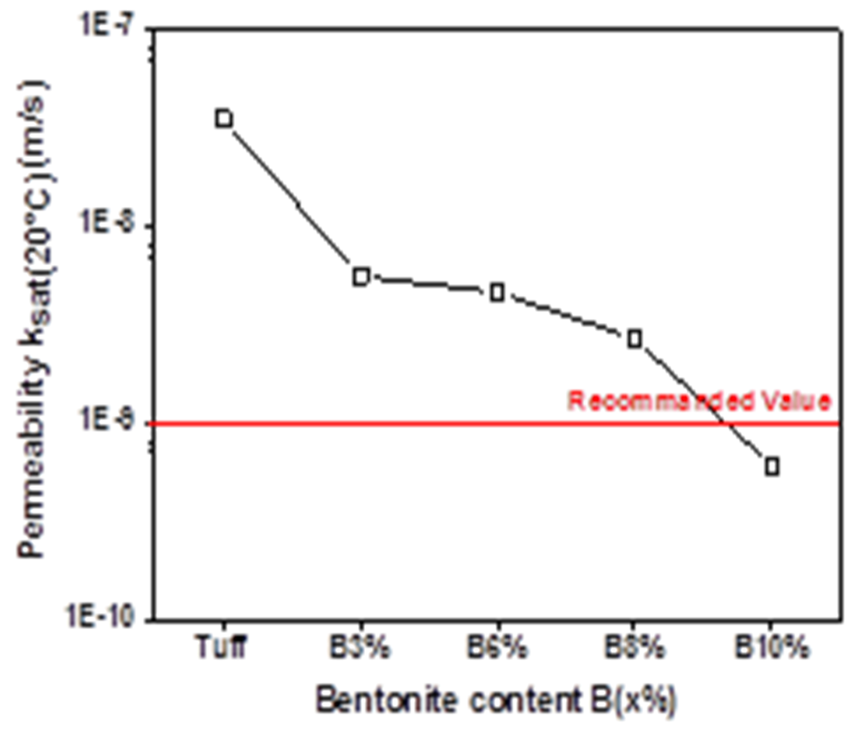

Fig. 1. Saturated hydraulic conductivity of Tuff-Bentonite mixtures (k_{sat})

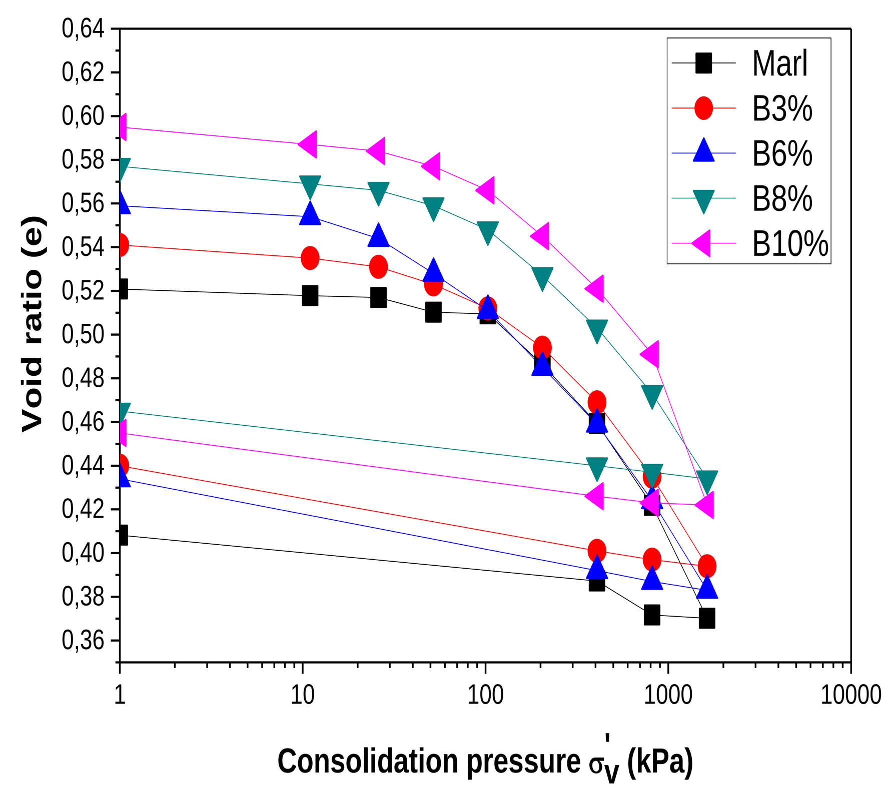

Fig. 2. Oedometric compressibility curves of Tuff-Bentonite mixtures

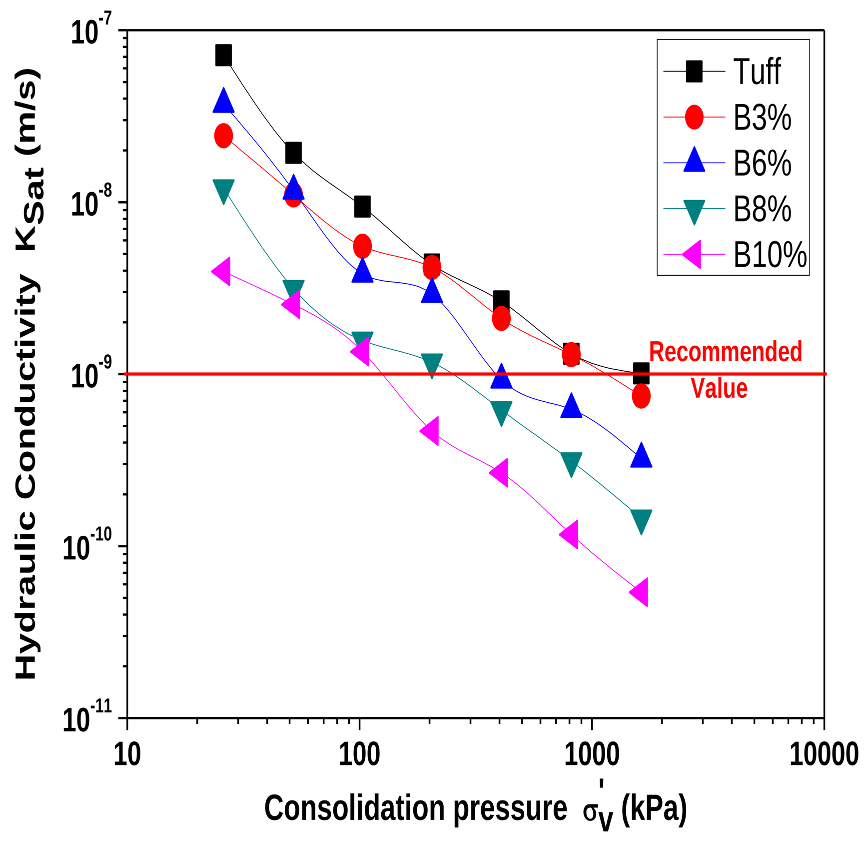

Fig. 3. Hydraulic conductivity versus the consolidation pressure of the Tuff-Bentonite mixtures

Table 4. Physico-mechanical characteristics

Parameter	B8% mixture	C3% B8% mixture	C5% B8% mixture
w_l (%)	46.35	36.52	34.00
w_p (%)	28.56	24.29	22.35
I_P	18.08	12.23	11.49
$\gamma_{d\,max}$ (KN/m³)	16.85	16	15.8
OWC	15.61	18.8	19.7
Cc	0.1462	0.0665	0.0632
Cg	0.0161	0.0057	0.0038
e_0	0.58	0.7	0.75
G (%)	0.64	0.40	0.04
C_{UU} (kPa)	44.4	53.41	90.54
Φ_{uu} (degre)	32°	38°	44°
k_{sat} (m/s)	2.65E-09	1E-11	5,50E -12

Results

***Permeability**

- The hydraulic conductivity decreases with increasing bentonite content in the bentonite-tuff mixtures (Fig. 1),
- The measured saturated hydraulic conductivities (K20° Sat) range from 5.50 10^{-9} m/s to 6.00 10^{-10} m/s for the 3.0 and 10.0% bentonite mixtures respectively.

***Consolidation**

Figure 2 shows the compressibility curves for the different mixtures. According to the soil classification with respect to compressibility (assessed from the ratio Cc /1+e_0; AFNOR XP P 94-090-1), the mixtures are classified as moderately compressible soil (0.05< (Cc /1+e_0) =0.156 <0.20) (Table 2).

Table 2. Coefficients of compressibility of Tuff-Bentonite mixtures

Mixture and tuff	C_C	C_g	σ_p (Bar)
Tuff	0.099	0.042	3.04
B3%	0.1297	0.096	2.51
B6%	0.1363	0.0149	2.42
B8%	0.1462	0.0161	2.15
B10%	0.162	0.0181	2.14

For consolidation pressures (<100kPa), the mixtures satisfying the landfill liner permeability criterion are B8% and B10%, which have hydraulic conductivities ranging from 1x10^{-8} to 3x10^{-10} m/s, respectively (Fig. 3).

Shear Strength

The angle of friction ϕ_{UU} of the mixtures decreases with the percentage of added bentonite, on the other hand, the cohesion increases (Table 3).

Table 3. Shear characteristics of the Tuff-Bentonite mixtures

Mixtures/Tuff	Tuff	B3%	B6%	B8%	B10%
Cohesion C_{UU} (KPa)	37,4	38,05	39,35	44,4	53,70
Angle of friction φ_{UU} (Degre)	35°	34°	33°	32°	30°

The Cement-Improved Mixture

The addition of cement led to a significant decrease in permeability due to the in-creased forces of attraction between the grains, on the one hand, and to the increase in fine particles, on the other hand. The forces of attraction mainly control the behavior of cement-treated soils [3].

Conclusion

Based on results and discussions, permeability and compressibility are strongly affected by the bentonite content in the tuff-bentonite mixture. The optimal amount of bentonite to achieve a permeability of less than 10^{-9} m/s, which is a landfill liners design requirement, was found at 10% bentonite.

The hydromechanical characterization tests carried out on the B8% mixture treated with cement have led to the following findings:

- The cement causes a significant reduction in the free swelling of the B8% mixture, especially in the 5% (almost 100%) cement content;
- The compressibility of the B8% mixture decreased by 50% with the addition of 3 and 5% cement;
- The determination of the hydraulic conductivity of cement-treated samples showed values below 1x10^{-9} m/s in the low consolidation pressure range;
- The value of the angle of friction of the B8% mixture treated with cement complying with the order of magnitude recommended for landfill liners of around 30° ±2° . Similarly, the adopted formulation B8% is satisfied with this condition.

Acknowledgements

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[3] Portland Cement Association (PCA) (1992), Soil-Cement laboratory handbook, Skokie, Ill.

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