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Modulus of resilience under road and runway stresses for base soil modified with cement and lime

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ABSTRACT: This paper examines the behavior of untreated and treated soil with cement and lime, as well as the relationship between the design parameters of the base layer such as uniaxial compressive strength (UCS), CBR with resilient modulus. The specimen selection for the triaxial test was based on the results of UCS, indirect tensile strength (INTS), wetting-drying, and freezing-thawing cycles tests. In general, the addition of lime along with cement causes the tensile strength to be halved compared to the addition of cement alone, but it eliminates the volume reduction problems caused by modification with cement. Also, a large-scale dynamic triaxial test was performed on the untreated base and C7L2 specimens. In all confining pressures, the values of elasticity modulus and damping ratio of C7L2 are higher and lower, respectively, compared to the untreated soil. The data points of the ratio of modulus of the elasticity-axial strain of specimen C7L2 are above the corresponding curves for sand and even higher than the rock ones, and its damping ratio data points are above the corresponding curve for rock specimens. The average values of the modulus of elasticity increase with the increase of confining pressure and initial axial stress. Increasing the loading frequency increases the Yang modulus, shear modulus, and damping ratio, but decreases the induced shear strain on the specimen.

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1- Introduction

According to the current code of practice, soil stabilization with lime or cement alone is questionable for soil with a fine grain percentage of less than 25% and PI ≥ 10, and treating with both materials simultaneously is recommended in different layers of the pavement, especially the base materials [1]. One of the main features of in-situ chemical stabilization and modification of soil, whether as a base, sub-base, or modified subgrade, is to improve its engineering characteristics to meet minimum design and operation requirements and reduce costs [2]. The most widely used chemicals for traditional stabilization are lime and cement [3]. The mechanism of chemical stabilization mainly depends on the type of soil, the type of additive, the mixing method, and even the purpose of stabilization [4]. In general, although the addition of cement increases the strength and resilient modulus, but it reduces the ductility with higher shrinkage percentages and the specimen reaches its maximum strength at lower strains [5].

2- Methodology

Soil stabilization tests with cement-lime and Nicoflock admixture include determination of soil-lime proportion requirements (ASTM D6276), dry-wet durability (ASTM D559), freezing-thawing evaluation (ASTM D560), the California bearing ratio-CBR (ASTM D1883), the uniaxial compressive strength,UCS (ASTM D1633/D5102) and indirect (Splitting) tensile strength, INTS (ASTM C496). Three curing conditions including normal, thaw-freeze, and wet-dry were employed. Dynamic tests include triaxial tests to determine shear modulus and damping ratio (ASTM D3999) and resilient modulus (AASHTO T307) as well as the determination of permanent settlement. The soil used in these experiments has with maximum grain size is about 25 mm and fine grain of 23 percent. The average liquid limit, plastic limit, and plasticity index of natural soil are 23%, 11%, and 12, respectively, and its G_s is 2.65. The soil is GM-SM according to the unified classification system and according to ASSHTO is classified as A-2. A soundness of aggregates test (ASTM C88/C88M-18) was performed and the weight loss of the treated soil specimen was 11% (1% for the coarse grain part with the size of 4.75-25 mm and 10% for the fine grain part with the grain size of 0.3-9.5 mm) was acquired. All the specimens were compacted with a dry density of 22 kN/m^3 (ASTM D1557), initial moisture content of 8%, and 6% in 3 layers with the same thickness. The specimens were cured for 3, 7, 28, 56 and 90 days in the humidity room, and then they were tested.

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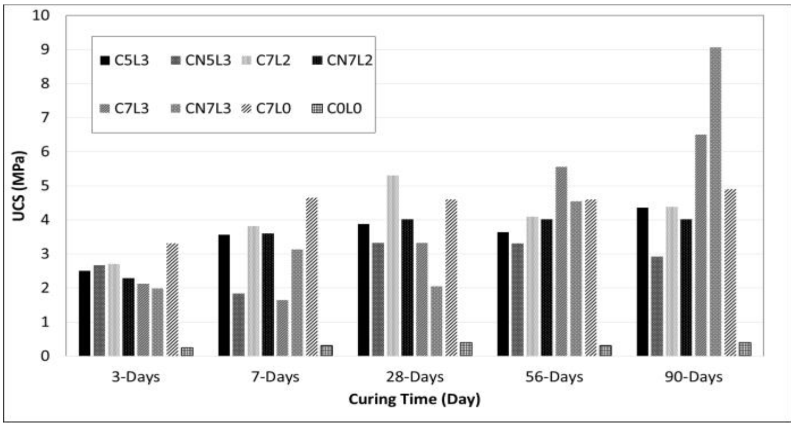

Fig. 1. Results of uniaxial compressive strength

Table 1.Results of resilient modulus and shear modulus, damping ratio and shear strain according to AASHTO T307 and isotropic stress state and untreated (UTS) and treated (TS) soils for the base and sub-base of the road and runway

	Frequency (Hz)	M_r (kPa)		G (kPa)		D (%)		Shear Strain (%)	
		UTS	TS	UTS	TS	UTS	TS	UTS	TS
Isotropic Confining Pressure (A)	10	219.1	867.4	87.0	377.2	19.7	13.2	0.0114	0.0037
	5	159.2	760.7	64.7	330.7	13.3	6.6	0.0250	0.0056
	2	147.8	750.3	59.9	326.2	7.0	2.2	0.0276	0.0056
AASHTO T307 (B)	10	301.3	944.6	120.4	410.7	19.7	14.6	0.0121	0.0049
	5	228.4	885.0	90.6	384.8	12.5	7.4	0.0217	0.0067
	2	203.1	871.4	80.6	378.9	6.3	2.1	0.0286	0.0074
Modified AASHTO T307 (C)	10	519.8	1489.4	194.5	647.6	18.5	14.7	0.0133	0.0052
	5	393.8	1411.4	164.4	613.6	12.2	8.9	0.0313	0.0130
	2	324.9	1286.7	135.7	559.4	7.2	3.1	0.0622	0.0277

3- Results and Discussion

Figure 1 presents the results of uniaxial compressive strength (UCS) of tested materials. According to the design requirements for the road and runway base, C7L2 specimen (containing 7% cement and 2% lime) has the best performance in terms of UCS. Moreover, UCS value for CN7L2, specimen containing the Nicoflock [6] as well is almost constant after 7 days of

curing. The UCS of C7L2 and C7L3 specimens in the un-brushed freezing-thawing test are half of those of the brushed one. The secant modulus of C7L2 specimen with increasing curing time is higher than for the curing times of 56 and 90 days. The secant modulus of C7L0 specimen is increased up to a curing time of 28 days of and then almost constant. The addition of Nicoflock for the CN7L2 specimen causes a decrease in the values of the secant modulus over time. The increase of moisture from 6% to 8% in the melting-freezing test causes a slight decrease in uniaxial compressive strength and secant modulus. The uniaxial compressive strength of specimens in the wet-dry test is higher than the values such as freezing-thawing and increases with increasing moisture content during the construction stage. Based on the results of freezing-thawing and wet-dry conditions, specimen C7L2 is more suitable for the base layer in hot-dry conditions. The tensile strength of CN7L2 specimen is lower than C7L2 and both of them are lower than C7L0 values.

The CBR values of the dry C7L2 specimen are about 5 times the values of the untreated dry specimen, which is higher than the minimum values required for the road base and sub-base with values of 80 and 25, respectively.

The weight loss of the specimen after treated specimen with cement-lime in freezing-thawing and wet-dry tests was 10.85 and 8.5%, respectively, which is less than the allowed value of 14%.

The highest percentage of volume change of freezing-thawing and wet-dry tests for brushed specimen CN7L2 and 8% moisture is 1.89% and 1.457%, respectively, which is less than the allowed values of 2%. The percentage of volume changes of the specimen treated with cement only in the freezing-thawing test for moisture percentage between 6 and 8% is -2 and -4.1%, respectively.

Table 1 shows the results of resilient modulus and shear modulus, damping ratio, and shear strain according to AASHTO T307 under isotropic stress state for untreated (UTS) and treated (TS) soils for the base and sub-base of the road and runway. The average values of maximum elasticity modulus under the frequency of 10 Hz, 5 Hz, and 2 Hz for treated and untreated dry soil are 1018.6, 964.3, 961.1, and 404.7, 351.1 and 324.7 MPa, respectively. Therefore, soil modification for frequencies of 10 Hz, 5 Hz, and 2 Hz causes an increase of 2.5, 2.75, and 3 times the average maximum modulus of elasticity compared to untreated soil. The maximum damping ratio for the frequency of Hz 2, Hz 5, and Hz 10 for the treated specimen is 4%, 11%, and 17% respectively, and for the untreated specimen is 10%, 15%, and 22% respectively.

The results show that untreated materials are more dependent on anisotropicity than treated materials. With the increase of anisotropicity, for the treated specimen, the effect of other factors on the damping ratio is insignificant compared to the frequency, while for the untreated specimen, the effect of other factors on the damping ratio compared to the frequency is slightly higher than the other treated specimen before cracking.

The average values of the resilient modulus for all test conditions in the treated state are more than 3.5 times the same values in the untreated state (328.5 MPa compared to 1148.1 MPa). The ratio of similar values for shear modulus values is about 3.8 times. The ratio of average damping ratio and shear strain of untreated to treated specimens are equal to 1.5 and 2.6.

The post-cyclic monotonic strength of specimen C7L2 is equal to 5.8 MPa for 15 days of curing time, which is comparable to the UCS values of wet-drying and freezing-thawing, and also untreated natural soil with the values of 7.18 MPa, 3.37 MPa, 5.3 MPa respectively for 28-day curing.

The secant modulus of the C7L2 specimen obtained from the UCS test is approximately one-fourth to one-fifth of the values of the post cyclic monotonic test under the confining pressure of 34.5 kPa.

4- Conclusion

In this research, a soil specimen with a fine percentage of 23% and PI of more than 12%, which is not suitable for use as a base for roads and runways in unmodified form, was subjected to various tests in treated and untreated form. The results show that soil modification by combining an optimal percentage of cement and lime under suitable curing conditions improves soil behavior in cyclic loadings. Also, the increase in the loading frequency causes an increase in the resilient modulus, shear modulus, and damping ratio, and a decrease in the applied shear strain on the specimen. The resilient modulus (in MPa) for dry untreated soil is equal to 10*CBR and for C7L2 is approximately equal to 20*UCS or 3*CBR in soaked state or 2.5*CBR in the dry state for 1.25 mm penetration.

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