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Effect of Curing Time on the Velocity of Ultrasonic Wave of Granular Soil Stabilized with Cement

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Abstract

This study shows the relation between P-wave velocity and curing time for granular soil (Tekala Nahree) extracted from Hleela district in Mosul city to the north of Iraq stabilized with cement. Cure samples for 7, 14 and 28 day and do the nondestructive Laboratory ultrasonic experiments test were made on stabilization soil samples, in order to observe the effects of this curing on compression (longitudinal) wave velocity, then do the destructive of compressive strength test second. After reach 2.94 MPa (29.4 Kgf/cm²) by compressive strength test in 7 day curing, this value represent the middle value which range (14-56 Kgf/cm²) in recommendation (below table that use in Base for heavy traffic building blocks) and fix 5% by dry weigh the design percentage of cement. This value represented the dry side (ds) of compaction curve then taken the opposite side of compaction curve that represent the wet side (ws).

Keywords: Cement stabilization soil; P-wave velocity (Vc); Dry side of compaction curve (ds); Wet side of compaction curve (ws).

Introduction

Chemical soil stabilization is used in various civil engineering applications to improve engineering properties and behavior of soils. The most common stabilizing agents are cement and lime, with fly ash also used as an agent [1]. Soil-cement first used application in North America was in 1935 by South Carolina state DOT used cement modified soils to improve the roadbed for State Highway 41 near Johnsonville. Since that time, portland cement and blended cements have been used to stabilize soils and aggregates for pavement applications on thousands of kilometers of roadway all over the world. After almost 80 years of use, experience has demonstrated that different kinds of engineered soil-cement mixtures can be tailored to specific pavement applications [2]. The soil-cement mixture design procedure consists of preparation of various mixtures of the soil with varying amounts of cement and testing the mixtures. Tests are conducted on these mixtures to determine the compaction characteristics of the soils and also to determine the specific property of the soil to be improved, such as water content, dry density and compressive strength. In addition, tests can be conducted to determine the specific property of the soil to be improved such as the compressive strength. Extensive literature is available on soil stabilization including materials, testing, and design procedures [1]. However, the basic always remain the same: soil-cement is the simple product of Portland cement blended with soil and/or aggregate, and water and compacted for use in pavement structure.

KATTAB, 1986 [3] studied the effect of (0, 10, 15, 22) % of gypsum on granular soil (gravel, sand and fine material) treated with (3, 6, 9) % cement. He notice an increase in the unconfined compressive strength, splitting tensile strength and CBR for soil stabilized with cement without and with gypsum content.

Jaro, 2000 [4] discussed the effect of addition of fine material (< 0.074 mm) on the properties of soil known as Tekala Jabele by (6, 14, 22, 30) percent by weight, and stabilized with Portland cement by (4, 8, 12) percent of weight. He found that the tensile and compressive strength of stabilized soil with 4 percent cement increase as fine material content increase up to 14 percent and then decrease. Also, he concluded that the tensile strength of stabilized soil equal to (3.9-17.6) percent of the compressive strength. Ultrasonic pulse velocity testing is a nondestructive testing technique. Ultrasonic testing was a simple and fast and there is significant experience in the use of this method for evaluating concrete for structural applications [1]. which sends sound waves ranging in frequency from 20 kHz to 1 GHz through the specimen. By measuring the travel time through the specimen, the p-compressional (longitudinal) wave or shear wave velocity and related dynamic properties of the material can be determined [5].

Yesiller et al., 2000 [6] observed that the velocity of ultrasonic wave increased with the increasing of dry and total density of the soils. The velocity of wave-propagation increases as the amount of solids in a soil mass increases while decrease with the increase of voids amount especially when filled with water.

Ismaiel, 2013 [7] Show the effect of kiln dust cement on the ultrasonic velocity values including both longitudinal (Vp) and shear (Vs). The addition of the optimum cement kiln dust to the soil led to an increase in both Vp- and Vs-values from. He concluded that the increment of the curing time from 7 to 28 days led to an increment of both Vp- and Vs-values.

Yesiller et al., [1] and **TIRUPAN MANDAL, 2012** [5] Deduced that the velocity of P-waves increased with increasing strength and modulus of the soils. The increase in velocity with modulus was more pronounced than the increase in velocity with strength. They added that the velocity of the soils also increased as the total and dry densities of the soils increased for the measurements conducted immediately after compaction of the samples. This is because wave transmission through solids is faster than through voids (filled with either air or water).

ABBECHE et al., 2010 [8] resulted that ultrasonic speed varies, depending on the variation of the energy of compaction and/or moisture content. For the same value of the energy of compaction, whatever the soil, the ultrasonic speed is increasing with the growth of the moisture content.

Materials and Methods

The soil used in extracted from Hleela district in Mosul city to the north of Iraq. A mixture of gravel, sand and fine materials, locally known as Tekala Nahree it could be described as. It found approximately in both sides of Tigris River. The soil was excavated, placed in plastic bags for keeping on cleanness, and transported to the laboratory for testing. Laboratory tests were carried out to classify soil. The index properties of soil are presented in table 1.

Cement: Ordinary Portland cement obtained from Badoosh manufacture to the northwestern of Mosul city has been used with an amount of (3, 5, 7 and 9) % of dry weight of the soil.

Table 1: Show the properties of the used soil in the study

Property		Hleela Soil
Atterberg Limits	Liquid Limit L.L.%	24
	Plastic Limit P.L.%	NP
	Plasticity Index P.I.%	NP (< 6%)
Weighted Specific Gravity G.s.		2.64
a-Bulk Specific Gravity of coarse Material		2.58
b-Specific Gravity of Material Pass No.4 Sieve		2.69
Total Soluble Salts T.S.S %		3.8
Organic Content %		1.91
Wearing Percentage (Los Angeles Test) %		25
Granular Gradation	Gravel %	41
	Sand %	53
	Silt %	4
	Clay % (≤ 0.002 mm)	2
Coefficient of uniformity Cu		16.5
Soil Classification	Unified Soil Classification System USCS Symbol	A-1-a
	AASHTO Soil Classification Symbol	SW

Table 2: Physical characteristics and chemical composition of Ordinary Portland cement

Property	**Test Results**	**IQS : 5/1984** [9]
Physical test		
Initial setting time(minute)	210	Min. 45 minute
Final setting time (minute)	330	Max. 600 minute
Fineness (Blain m2/kg)	263	Min. 230 m^2/kg
Compressive strength of 50 mm cubic mortar specimen (MPa)		
3 days	23	Min. 15 MPa
7 days	30	Min. 23 MPa
Chemical Test		
1- Oxide Composition		
SiO2	21.31	-----
Al2O3	5.89	-----
Fe2O3	2.67	-----
CaO	62.2	-----
MgO	3.62	$\leq$ 5%
SO3	2.6	$\leq$ 2.8%
Loss of ignition	1.59	$\leq$ 4%
Insoluble residue Free CaO	0.24	$\leq$ 0.75%
Free Cao	1.74	-----
L.S.F.	0.8818	0.66-1.02
2- Compound Composition		
C3S	33.37	-----
C2S	35.92	-----
C3A	11.09	-----
C4AF	8.12	-----

Sample Preparation for Compaction

Procedure of ASTM D 1632-96 [**10**] has been followed to preparation the soil. Sufficient amount of soil has been dried in air or drying by oven such that the temperature of the sample does not exceed 60°C until it becomes friable under a trowel. Sieve a sufficient quantity of soil on the 2 inch (50 mm), 3⁄4 inch (19.0 mm), and No.4 (4.75-mm) sieves. Remove aggregate passing the 2 inch (50 mm) sieve and retained on the 3⁄4 inch (19.0 mm) sieve, and replace it with an equal mass of aggregate passing the 3⁄4 inch (19.0 mm) sieve and retained on the No. 4 (4.75 mm) sieve. Obtain aggregate for replacement from the original sample. The portion retained on 4.75 mm (No.4) sieve has been saturated by soaking in water. The saturated, surface-dry aggregate was obtained. The preparation could be summarized by the mixing of the soil that passing 4.75 mm (No.4) sieve thoroughly with cement to a uniform color, using either in suitable laboratory (Blakeslee) mixer or by hand. An appropriate amount of water was add to the soil-cement mixture and mixed again in the same mixer. The saturated, surface-dry aggregate was add to the mixture and mixed thoroughly [11].

Samples Compaction

Cubical molds with dimensions 152 mm (6 inches) x 152 mm (6 inches) x 152 mm (6 inches) have been used to compact the soil-cement mixture. The treated soil placed thoroughly in 5 equal layers, each layer was compacted by 93 blows from 4.5 kg (10 Ib) hammer having a square face of 44 mm (1 ¾ inches) x 44 mm (1 ¾ inches) falling from 457 mm (18 inches) height, the hammer manufactured to apply compactive effort equivalent to the modified compactive effort of **AASHO**. During the compaction process at least 500 gm. of material was taken for the moisture content determination [11].

Curing Operation

The compacted specimens in its mold was covered by metal plate, to prevent the loss of moisture, and left for 24 hours at the laboratory for curing. After passing of curing time (24 hours) in mold, the specimen was removed from its mold and wrapped several times by wax paper and followed by 6 days curing at the laboratory oven at 25°C. The weight of specimen was recorded after finishing the compaction and also after every 24 hours of curing time, no significant variation in weight was found.

Cement Design Percentage

In order to determine the cement design percentage for heavy traffic subbase [12], the cement-soil block samples have been submitted to compressive strength test by using The uniaxial testing machine with 2000 kN capacity was used and loading rate 0.02 (mm/Min)

Nondestructive (Ultrasonic) Test

The ultrasonic test have been conducted on cement-soil block samples treated with cement design percentage and cured for (7, 14, 28) days and for two side dry and wet side (ds and ws) of cement design percentage compaction curve. After end of period curing, the nondestructive test ultrasonic plus apparatuses' on the specimens is started. Performance using electronic equipment which generate longitudinal (compression) waves in specimens. The sample between two transducers (transmitter and receiver) then the time (T) required to move the wave between the both transducers through the sample (L) has been record as shown in Fig .1 The following equation (1) is used to calculate the P-wave velocity type compression wave (Vc) ASTM Designation C 597-02 [13].

$$Vc = \frac{L}{T} \quad \ldots\ldots\ldots (1)$$

Where:
Vc = Velocity of waves (m/s)
L = Length of specimen(m)
T = Time require for traveling in second (s)

The dynamic Young's modulus then can be calculated from equation (2).

$$Vc = \sqrt{\frac{E}{\rho}} \quad \Longrightarrow \quad E = \frac{\rho}{Vc^2} = \frac{\rho L^2}{T^2} \quad \ldots\ldots\ldots (2)$$

Where:
E = Dynamic Modulus of Elasticity, (MPa).
ρ = Density of the specimen, (Kg/m^3).

Braja M. Das [14]

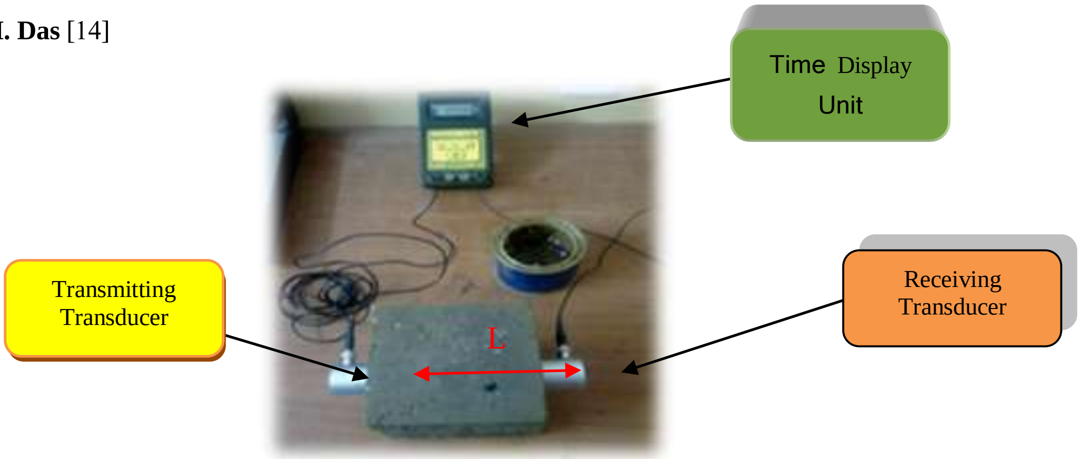

Figure 1. Parts and procedure type of measuring velocity of ultrasonic wave test

Then compressive strength test has been performed on the specimens [A20] as show in figure 5 to know the suitable design percent of cement that meet with criteria of **Ingles & Metcalf 1972** [12] requirements.

Fig .2(A) show the relation between moisture content and compressive strength for stabilized compaction samples with different percent of cement take the optimum point of the 5% cement curve and which have value 2.94 MPa (29.4 Kgf/cm^2) in 7 day curing, this value represent the middle value which range (14-56 Kgf/cm^2) according to **Ingles & Metcalf 1972** [12] criteria requirements. Increase in compressive strength for treated soil with increase of different ratio of cement at different moisture contents. Great value for compressive strength at optimum moisture content for treated soil specimens.

Fig .2(B) that show the relation between moisture content and dry density with different percent of cement, observe increase in dry density with increase of the amount of cement percent, this increase return to the high specific gravity of cement which tends to produce a higher density the explanation of this behavior as similar to mention by [4]. The increase in moisture content increase as increase in cement content is return to the water required for the cement hydration and this behavior as clarification by [4, 15]. Figure 2(B) shows the both condition (ds and ws) which had been adepted in the tests.

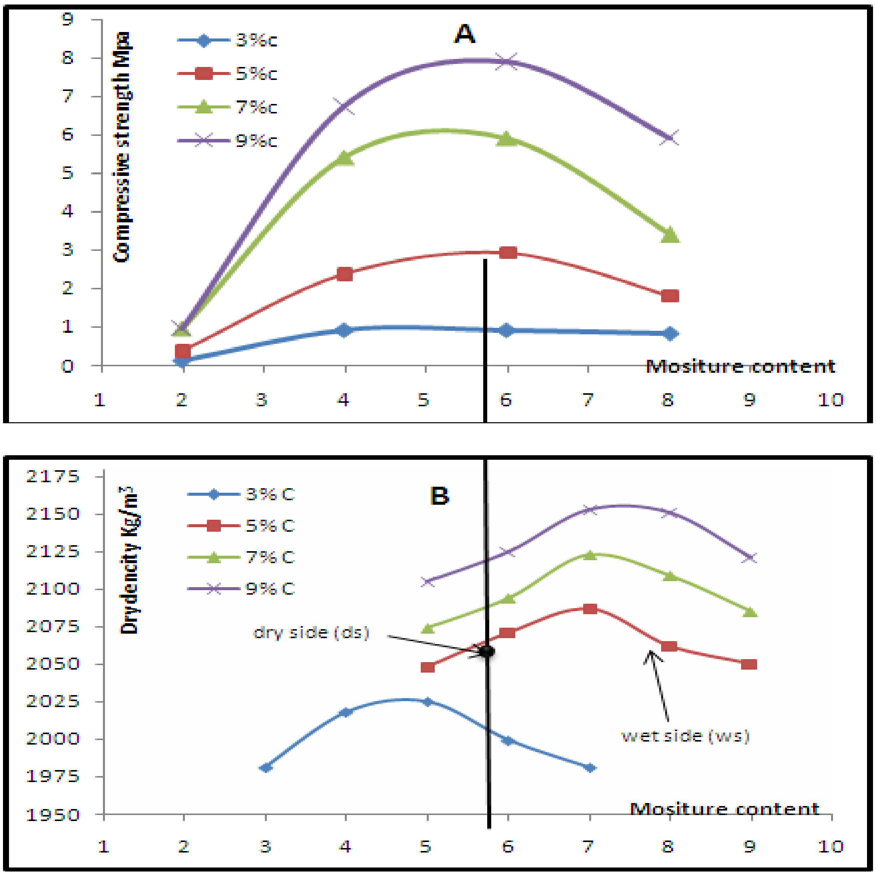

Figure 2. A: The relation between compressive strength and moisture content for different cement

B: The relation between compaction curves with water content for different percent of cement.

Fig .3 show the relation between P-wave velocity and curing period, the P-wave velocity of the stabilized soils increased with curing time for two side of compaction curve dry and wet side (ds & ws) same as reach each of [1, 16, 17, 18 and 19].

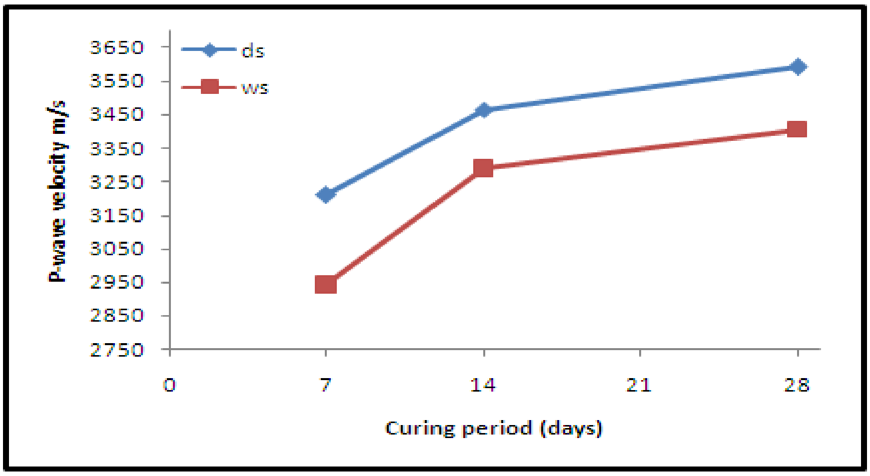

Figure 3: The relation between P-wave velocity and curing period

In general, there is a direct proportion between the Wave velocity and compressive strength, that increased in Wave velocity with increasing strength for two side of compaction curve (ds & ws) and as shown in Fig .4 and same [1] reach.

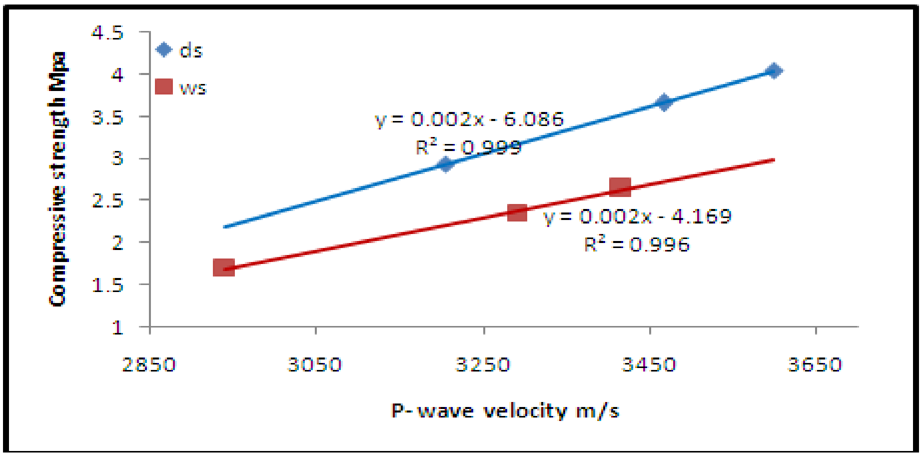

Figure 4: The relation between P-wave velocity and compressive strength

Also increased in Wave velocity as the total and dry densities of the soils increased of the compaction samples. The reason of this increase in velocity due to the wave transmission through solids is faster than through voids (filled with either air or water) [1]. Also, find dynamic modulus of elasticity Ed and that have a direct proportion .
With ultrasonic wave Wave velocity through the relation that reach to it **Braja M. Das** [14] and the relation with curing period as shown in Fig .5.

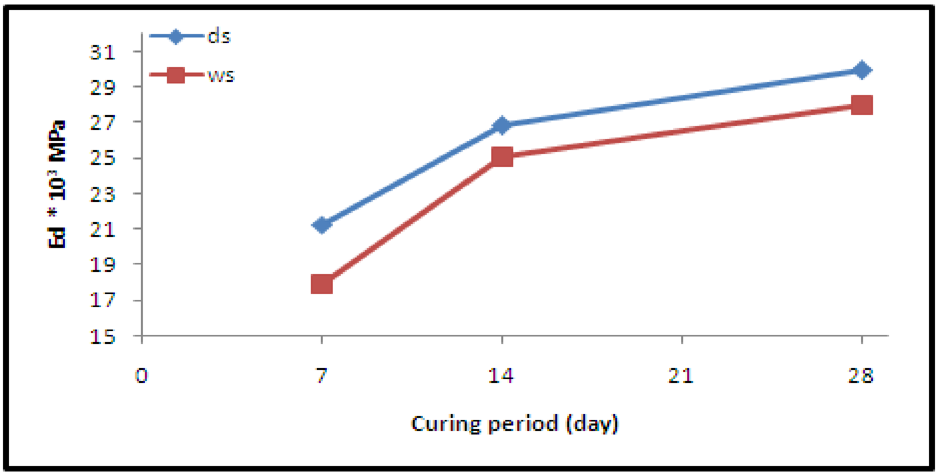

Figure 5: Effect of curing period on Ed

And from this, find the clarification relation between Ed and compressive strength as that appear through Fig .6, the Ed increase with increment of compressive strength and for two sides of compaction curve (ds & ws).

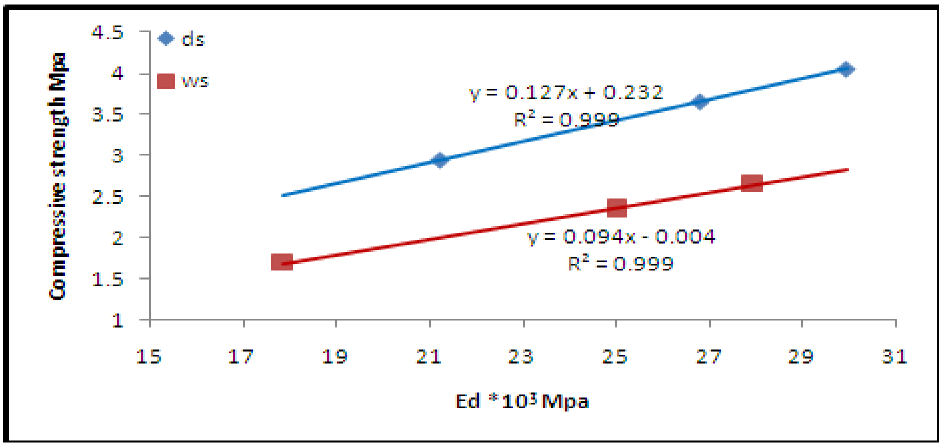

Figure 6: The direct proportion between compressive strength and Ed

Conclusion

Influence the amount of cement that treated soil on density and strength, increase in density and compressive strength respectively with increase cement content. The curing period also affect on strength of stabilizes soil with cement and for ds and ws of compaction curve, observe that increase in compressive strength with increase curing period from 7 days to 14 until 28 days for samples. Ultrasonic pulse velocity tests showed that influence with curing period of the stabilized soil specimens with cement, P-wave velocity increase, with increase curing time for specimens in two sides of compaction curve ds and ws. The ultrasonic pulse velocity tests showed a clear trend of increasing with increasing strength for two side of compaction curve ds and ws. There is a direct relation between compressive strength and P-wave velocity and that lead to also to anther direct relation between compressive strength and dynamic modulus of elasticity Ed.

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