EVALUATION OF STIFFNESS OF CEMENT STABILIZED GRANULAR LATERITIC SOILS USING ULTRASONIC PULSE VELOCITY (UPV) TEST

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ABSTRACT

Modulus of pavement materials is an important input parameter for mechanistic design of pavements. The cement bound pavement layers usually fail in flexure and therefore flexural modulus (FM) should be the appropriate stiffness parameter for analysis of pavements. FM is generally determined using a four point bending test subjected to cyclic loading, but this process is a time consuming exercise and therefore nondestructive methods such as ultrasonic pulse velocity test (UPV) test may be employed for rapid determination of stiffness of these materials. In this study, the constrained moduli values determined using ultrasonic pulse velocity were correlated with Indirect Tensile Strength (IDT) flexural strength (FS) and FM of cement stabilized granular lateritic soil (CLS). Strong relationships were observed between these parameters, which indicates the suitability of employing UPV test for determination FM of CLS samples.

Keywords: Ultrasonic pulse velocity test, constrained modulus, Flexural strength, Flexural modulus, Cement stabilised granular lateritic soil

1. INTRODUCTION

Sources of good quality aggregates are depleting day by day and the transportation of crushed stones from long distances results in substantial hike in project costs. Therefore, use of marginal aggregates or locally available granular soil has become necessary for construction of base and subbase layers of road pavements. Granular lateritic soils (GLS) are available in plenty in many parts of world including India and presently being used as a sub-base material for low volume road projects. However, GLS from various sources do not satisfy the strength and plasticity requirement of sub base layer (Biswal *et al.,* 2016). It is well established that stabilization results in increase of strength, stiffness and reduction of plasticity (Portelinha *et al.,* 2012; Joel and Agbede, 2010). Therefore, stabilization is necessary to use these marginal materials in bound form in structural layers of road pavements.

Modulus is an intrinsic property of an elastic material in terms of design of any structure involving the material. For mechanistic design of pavements, different stiffness values are used for different materials under given test conditions. As the cement bound layers usually fail in flexure, FM is usually used to represent the stiffness of CLS for pavement design. This simulates the stress strain development in stabilized layers of any pavement (Jameson 2008).Fatigue analysis of stabilized layers also require flexural strength or modulus of rupture that is determined from flexure test. Various destructive tests such as the unconfined compressive strength test, flexural strength test, indirect tensile strength test for stabilized samples are employed to determine desired pavement design parameters. But, unlike destructive tests, nondestructive tests such as UPV test, are very fast and rapid methods of determining the modulus of a materials. Modulus of the bound materials are measured by passing of ultrasonic waves through the material and by measuring the velocity. Rebound hammer tests and seismic modulus tests are also other nondestructive test methods which can be employed to study the strengths or modulus properties of cement stabilized materials (Breysse, 2012; Yesiller, 2001).

1.1 Ultrasonic Pulse Velocity Test

UPV test is a small strain elastic wave based nondestructive testing method which has also been employed for in-situ characterization of cement bound materials (Breysse 2012). This technique is based on the measurement of wave velocities through material in direct, indirect or semi-direct transmission mode (Figure 1). As shown in the figure, the ultrasonic pulse is generated and transmitted by a transmitting transducer (T) and received at other end by a receiving transducer (R) after travelling through the sample. The receiving transducer detects the arrival of fastest wave (longitudinal wave or P-wave).

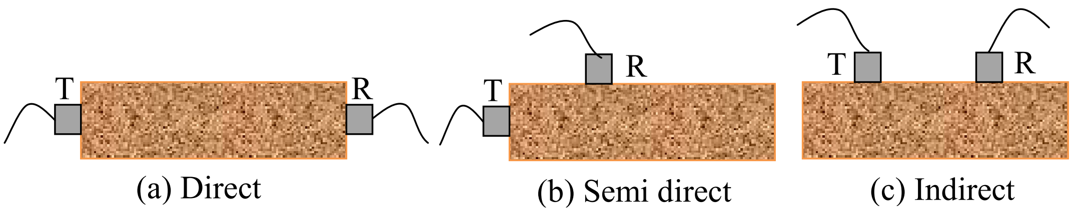


Figure 1: Transmission modes of ultrasonic pulse velocity

Constrained modulus (*CM*) of the samples are calculated by using Eq (1) as per IS 13311 (1992).

$$CM = \frac{\rho(1+\mu)(1-2\mu)}{(1-2\mu)} V_p^{\ 2} \qquad (1)$$

Where, V_p is ultrasonic pulse velocity in m/s , t is the transmission time in sec and l is the transmission distance in meter, ρ density kg/m^3, μ is dynamic Poisson's ratio.

1.2 Review of Literature

There have been numerous studies on assessment of properties of concrete using ultrasonic pulse velocity as this test provides a highly repeatable measurement in case of homogeneous concrete (Barisic *et al.*. 2016). A detailed literature survey by Breysse shows that the magnitude of variability of V_p results for cemented materials are very low (Breysse

2012). The velocity of ultrasonic pulses travelling in a solid depends on the density and elastic properties of the material (Breysse 2012, Panzera *et al*. 2008, Yim *et al*. 2014).This has given enough confidence to believe that ultrasonic pulse velocity can be used to assess the strength of cement stabilized soils. A number of researchers have developed relationships between pulse velocity and physico-mechanical properties of concrete (Yesiller *et al*. 2001,Panzera *et al*., 2011, Rio *et al*. 2004). UPV test can also be employed for performance study of constructed stabilized pavements as it is a rapid method of determining the in-situ modulus. Various correlations developed through past studies between compressive strength and V_p of cement concretes and cement stabilized soils are presented in Table 1. However, some discrepancies were observed by Panzera *et al.*(2011)and they concluded that there is no significant correlation between compressive strength and ultrasonic pulse velocity. Many researchers have found good correlations between UPV and density (Panzera *et al*. 2011, Su *et al*. 2013).

Yesiller *et al.* (2001) assessed the viability of using UPV test for stabilized materials for pavement application. They studied the change in UPV measurements with increase in curing time of the samples and observed that, velocity increases with amount of stabilizer and curing time. Good correlations were observed between velocity and strength and velocity with modulus value of the mixture. Stephenson (1978) reported that elastic modulus and shear modulus increases or decreases with the increase or decrease of ultrasonic velocity respectively within the material.

Table 1. Relationships between Flexural strength and ultrasonic pulse velocity

Correlations	Variables	Material	References
$FS = 0.005{V_p}^{1.48}$ $FS = 0.92CM^{0.67}$	*FS* (flexural strength) in kPa, V_p in m/s, *CM* (constrained modulus) in MPa	Cement stabilized soil	Mandal *et al*. (2016)

Very few studies are available related on UPV testing of cement stabilized soils or more specifically on granular lateritic soils. Therefore in this paper, UPV tests were conducted on cement stabilized granular lateritic soils and relationships were established for prediction of various strength and stiffness parameters (such as compressive strength, flexural strength, indirect tensile strength test and flexural modulus) from ultrasonic pulse velocity and/or constrained modulus. As pulse velocity method provides a reliable, easy to conduct, quick and inexpensive way to estimate the quality of cement bound materials, this study research work has been taken up to check its effectiveness in predicting the strength and modulus of cement stabilized granular lateritic soils (CLS).

2. MATERIALS AND METHODS

2.1 Materials

Tests were carried out on a locally available granular lateritic soil collected from the eastern part of the India. Various geotechnical properties of studied granular lateritic soil are presented in Table 2.

Table 2: Engineering properties of lateritic soil

Gravel (%)	Sand (%)	Silt and caly (%)	Classification (as per USCS)	Specific Gravity	Liquid limit	Plasticity index	OMC	MDD (kN/m^3)
40.8	50.1	9.1	SW	2.71	48.25	16.67	12.7	19.15

2.2 Methods

Collected granular lateritic soils were air dried prior to testing and mixed with various cement percentages of 2%, 3%, 4%, 6% and 8%. All the stabilized samples were prepared at optimum moisture content and maximum dry density at respective dosed state for the strength and stiffness studies.Unconfined compressive strength tests were conducted on cement stabilized lateritic soil samples of cylindrical shape (100mm in diameter and 115mm in height) prepared as per ASTM D1633 (2007).Indirect tensile strength tests were conducted as per suggestions given by Yeo (2008). Cement stabilized beam samples of size 75mmx75mmx285mm were prepared for 3 point flexure test, which was used for determination of flexural strength or modulus of rupture. Flexural modulus (FM) was determined by applying haver-sine cyclic loads with frequency 1 Hz on beam samples as per the procedure given by Yeo (2008). The flexural modulus test arrangement is shown in Figure 2. The cyclic load test was conducted at a stress ratio of 0.3 and the modulus determined at that stress ratio was considered as flexural modulus of this stabilized material (Yeo 2008). Linear variable differential transducers (LVDTs) were used for measuring deflection of the beam at the centre. Eq (2) and (3) were used to estimate the flexural strength and flexural modulus of CLS beam samples.

$$FS = \frac{Pl^3}{bd^2} \quad (2)$$

$$FM = \frac{23Pl^3}{108bd^3\delta d} \quad (3)$$

Where,

FS is in MPa; FM is in MPa; *P* = Cyclic load in kN; *b* = Width of beam in mm; *d* = Thickness of beam in mm; *l* = Span from centre to centre of support in mm; δ_d =Elastic vertical deformation at midpoint in mm.

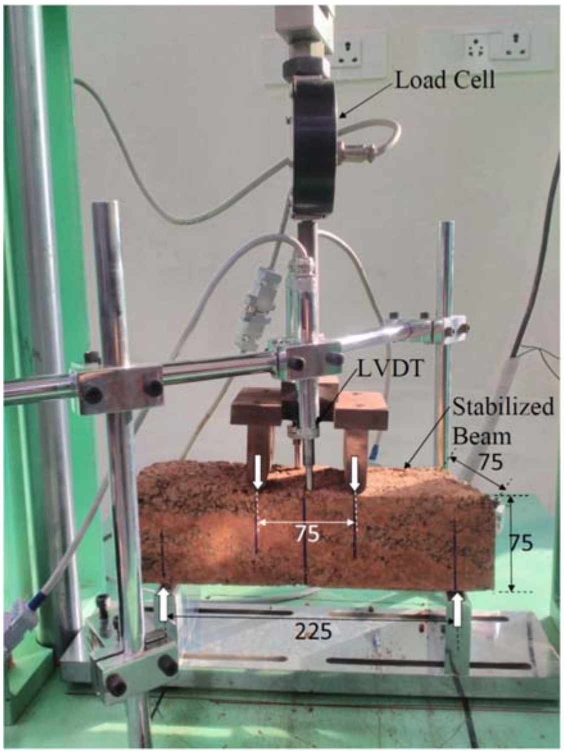


Figure 2: Flexural modulus test on CLS sample

Cement stabilized beam samples were prepared at various cement percentages of 2, 4, 6 and 8 at respective optimum moisture content and dry density and cured for 28 days for UPV test. UPV tests were conducted by connecting the transducer and receiver at two parallel ends of the specimens for direct transmission of the ultrasonic pulse. Transducers used are of 50mm in diameter and maximum resonant frequency of 50 kHz. Three replicate tests were conducted for each specimen in longitudinal direction and the average value was taken. Travel time of P-wave velocity in direct transmission mode through the length of specimens are noted along with the length of specimens, which are used to estimate the velocity of ultrasonic pulses (Figure 3).

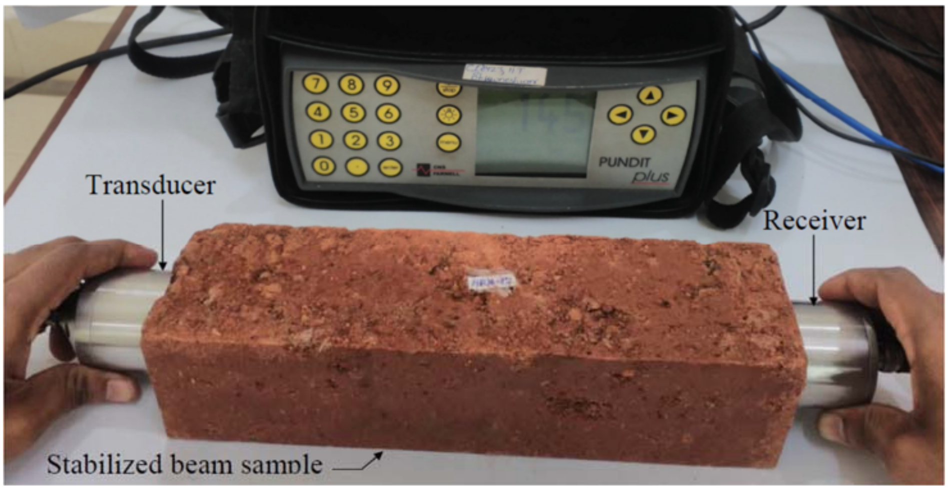


Figure 3: Ultrasonic pulse velocity test of CLS sample

3. RESULTS AND DISCUSSION

Strength parameters such as compressive strength (*UCS*), indirect tensile strength (*IDT*) and flexural strength (*FS*) and stiffness parameters in terms of flexural modulus are presented in this section. Tensile strength of CLS (after 28-days of curing) were determined in terms of *FS* and *IDT* with various dosage of cement. The correlation between ultrasonic pulse velocity and the mechanical properties of cement stabilized granular lateritic soil sample are presented in the following sections.

Effect of cement content on ultrasonic pulse velocity has been presented in Figure 4. The pulse velocity varies from 1180 m/s to 2000 m/s for granular lateritic soils stabilized with cement in the range of 2% to 10%.A strong correlation was observed between cement content and pulse velocity. It is observed that ultrasonic pulse velocity increases with increase in cement content, almost linearly, which is in tune with the previous studies on cemented materials (Barisic *et al.* 2016 and Breysse, 2012).

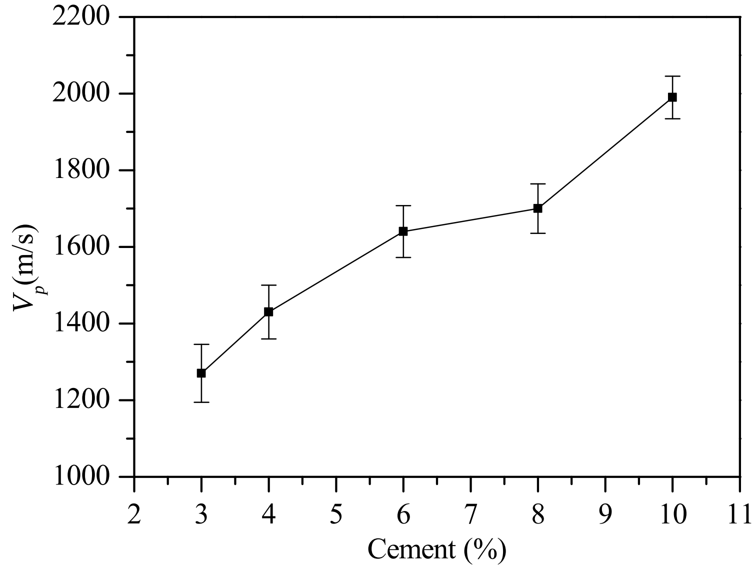
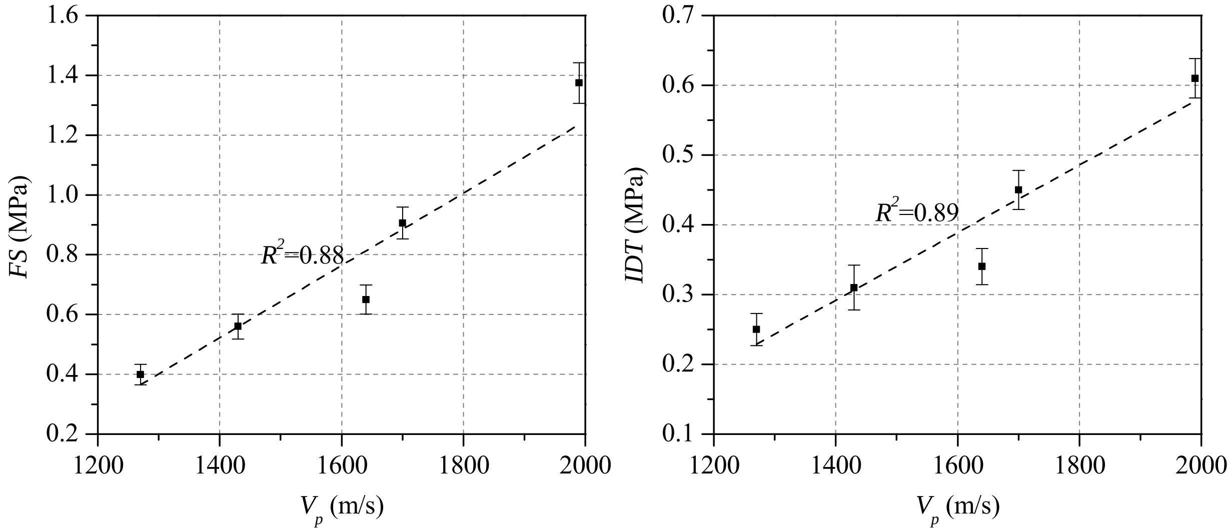


Figure 4: Plot between UPV and cement content of CLS

Theoretical background supports a direct link between elastic modulus and pulse velocity in an elastic media (Yesiller 2001). Relationships between flexural strengths vsV_p and indirect tensile strengths *vs.* V_p are presented in Figures 5(a) and (b) respectively. High value of coefficient of determination ensures that, UPV can also be used for assessment of strength properties of cement stabilised granular lateritic soil. In the present study, it has been observed that with increase in V_p results corresponds to increased value of *FS* and *IDT*, which has also been observed by Mandal *et al.*, (2016).

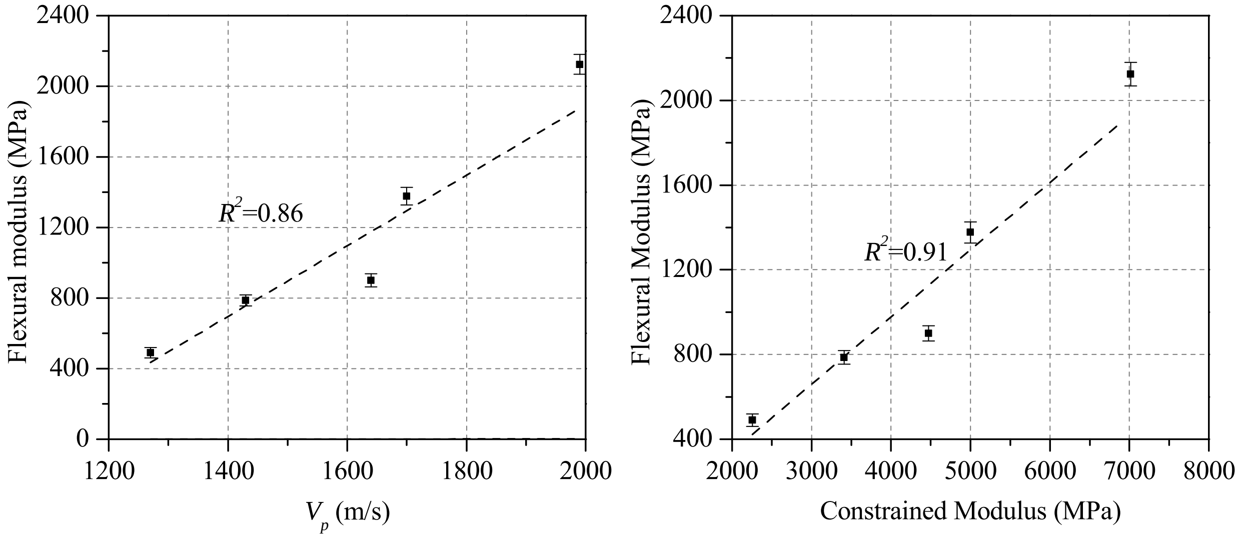


(a) **(b)**

Figure 5: (a) Relationship between *FS* and V_p (b) Relationship between *IDT* and V_p

Mechanistic design of pavements requires elastic modulus as an input parameter: For pavements having stabilised base layers, flexural modulus is used as design modulus (Jameson, 2008). Therefore, an attempt has been made to correlate the flexural modulus with indirect estimation of constrained modulus from ultrasonic pulse velocity test of the CLS. The constrained modulus is estimated using the Eq (1) as provided in IS13311 (1992).

UPV tests were conducted on stabilised beam samples prior to flexural modulus testing. The relationships of flexural modulus with V_p and estimated constrained modulus have been presented in Figures 6 (a) and (b) respectively. A strong correlation was obtained between both flexural modulus with ultrasonic pulse velocity and flexural modulus with constrained modulus. Similar observation has also been made by past researchers (Yesiller, 2001; Su *et al.*, 2013). It is observed that UPV and constrained modulus increases with increase in flexural modulus, exponentially.



(a) **(b)**

Figure 6: (a) Relationship between flexural modulus and UPV (b) Relationship between flexural modulus and constrained modulus

4. CONCLUSIONS

From the present experimental investigation and analysis, it was found that there lies a very good correlation between V_p and various strength and stiffness properties of cement treated lateritic soils. It can be highlighted that the ultrasonic pulse velocity tests can ideally be used to assess the strength and stiffness parameters of the CLS used in subbase and base layers of any pavement. The results indicate that, increase in cement content results in increase in V_p and constrained modulus values. The charts presented here will help to determine compressive strength, flexural strength and indirect tensile strength of stabilized lateritic soils from ultrasonic pulse velocity measurements.

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