Effect of loading rate on the properties of lightly stabilized granular materials by using flexural beam testing

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ABSTRACT
An experimental study has been undertaken to investigate the effect of loading rate on the flexural properties of lightly stabilized granular materials. The flexural beam samples were prepared from a typical granular material stabilized lightly with 1.5% cement-flyash and moisture at optimum moisture content (OMC). Then the samples were cured for 7 days and tested by monotonic third-point load testing at different loading rates ranging from 0.01 to 1.2 mm/min. However, an improved testing setup was used to measure the mid-depth vertical deflection internally for characterizing the lightly stabilized materials more reliably. The experimental results show that the loading rate has a significant influence on the modulus of rupture and flexural modulus of lightly stabilized material. Details of the newly improved experimental arrangement and rate sensitivity on the flexural properties of lightly stabilized materials are presented in this paper.

RÉSUMÉ
Une étude expérimentale a été entrepris pour étudier l'effet du taux de charge sur les propriétés de flexion de la légère stabilisation des matériaux granulaires. Les échantillons ont été préparés à la flexion du faisceau à partir d'un matériau typique granulaire stabilisé légèrement avec du ciment-cendres volantes de 1,5% et d'humidité à teneur en humidité optimale. Ensuite, les échantillons ont été mûris pendant 7 jours et testés par les tests de charge monotone troisième point au taux de charge différents, allant de 0,01 à 1,2 mm / min. Toutefois, une installation d'essai améliorée a été utilisée pour mesurer la flèche à mi-profondeur verticale interne pour caractériser les matériaux légèrement stabilisée de manière plus fiable. Les résultats expérimentaux montrent que le taux de chargement a une influence significative sur la résistance à la flexion et module de flexion du matériau légèrement stabilisée. Détails de l'accord récemment améliorée et la sensibilité aux taux d'expérimentation sur les propriétés de flexion des matériaux légèrement stabilisée sont présentés dans le présent document.

1 INTRODUCTION

The base layer of a pavement structure is regarded as the principal structural layer and hence it plays an important role in a flexible pavement system. The base layer is usually constructed with unbound granular materials. However, cementitious binders are often incorporated to enhance the mechanical properties of the base layer. Improving the strength, stiffness and durability by adding small amount of binders, referred as light stabilization, is becoming popular these days mainly because of being a cost-effective technique. However, proper characterization of the materials is essential for the successful mechanistic design of pavements.

There are different testing methods adopted by the researchers and pavement engineers for the characterization of stabilized materials. Flexural beam testing is one of them and believed to be the most practical testing method because it resembles the similar loading/stress condition to that in the real pavement. In fatigue testing, stress ratio, which is the ratio of applied flexural stress to the static flexural strength, plays an important role in defining the fatigue life of the bound material. Hence one needs to carry out monotonic load flexural beam testing to determine the flexural strength of the material. Moreover, static stiffness modulus determined from the monotonic load flexural beam testing is often used for characterizing lightly stabilized granular materials which is dependent on the loading rate.

Loading rate is a key test variable that should be controlled within prescribed limits. It is known that the behaviour of fine soils is strain rate dependent. Literature reveals some studies on clay materials evaluating the effect of loading rate on its mechanical properties. Both the strength and stiffness properties have been found to be increased with the increase in loading rate (Casagrande and Wilson 1951; Berre and Bjerrum 1973; Zhu and Yin 2000; Diaz-Rodriguez et al. 2009). Similar trend has also been observed for materials other than soils such as concrete (Bischoff and Perry 1986; Malvar and Ross 1998) and composite materials (Suaris and Shah 1982; Malej et al 2005). However there is no literature found, according to the best knowledge of the authors, on the rate sensitivity of soil-cement mixture.

In this study, a laboratory investigation was carried out to evaluate the rate sensitivity of lightly stabilized granular material by using monotonic third-point loading flexural beam test. Three different loading rates ranging from 0.01 mm/min to 1.2 mm/min were used to assess the effect of loading rate on the flexural properties of lightly stabilized materials. The details of the materials used, sample preparation, curing technique, testing setup and test results are presented in this paper.

2 EXPERIMENTAL PROGRAM

In this experimental program, a typical lightly stabilized granular material with a small percentage (i.e. 1.5%) of binder content was chosen. The dry density-moisture content relationships were established in accordance to ASTM D 698 (2007) as shown in Figure 1. Then all the samples were prepared at OMC (i.e. 9%) and tested to characterize and also to investigate the rate sensitivity of lightly stabilized granular materials.

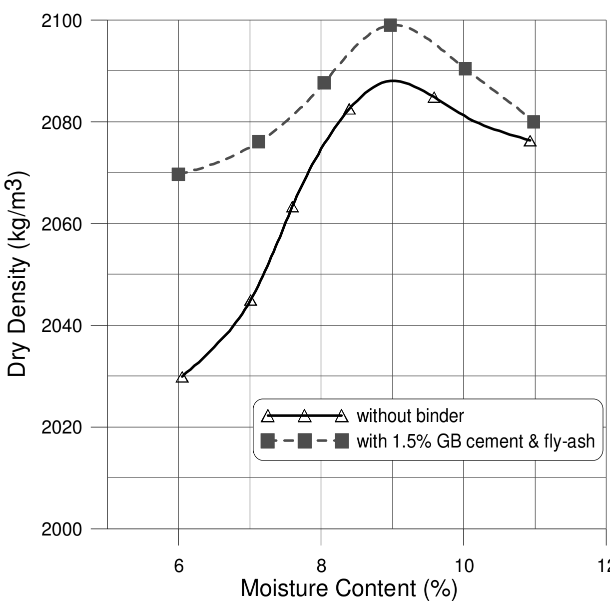

Figure 1. Dry density-moisture content relationship

2.1 Parent Material and Stabilizer

A typical freshly quarried crushed rock was chosen in this study which was obtained from the quarries located in Canberra, Australia. It was classified as well graded sandy gravel with some fines according to Unified Soil Classification System. However, to get consistent samples from such a crushed rock materials is very difficult and unreliable proportions of particle in the samples are common. To overcome this potential inconsistency, reconstituted material with an unchanged (or consistent) material grading shown in Figure 2, were adopted. This reconstituted material, of consistent grading for the entire test regime, has been achieved by sieving a large batch of parent material, separating them into different particle series and then remixing them at suitable weight proportions. Therefore the adopted grading for the reconstituted sample, hereafter referred as the 'parent material', was essentially the same for all the samples that were tested in this experimental investigation.

As indicated earlier, the stabilizers used in this experimental study were general blend (GB) cement and flyash. The GB cement and flyash were used in the ratio of 75% to 25% by dry weight. The parent material was stabilized with 1.5% GB cement–flyash for this laboratory investigation.

2.2 Sample Preparation and Curing

Flexural beam specimens of dimension 285 mm x 76 mm x 76 mm were prepared according to ASTM D 1632-07 (2007). These specimens were compacted in compression machine by applying static load. It is noted that all the prepared samples achieved 99.5% Standard Proctor maximum dry density at the OMC. The prepared specimens, wrapped with polythene, were cured 7 days in a fog room at 23±2 ℃ and 95±5 % humidity. Then specimens were taken away from the fog room and tested immediately in flexure.

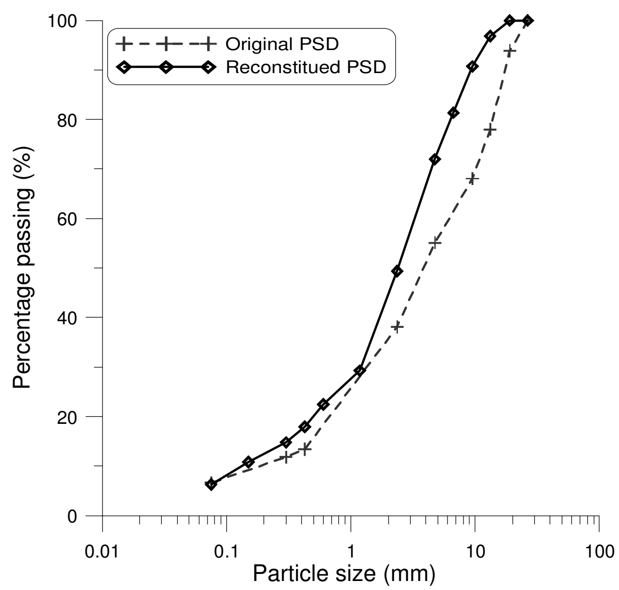

Figure 2. Particle size distribution curves of parent material

2.3 Flexural Beam Testing Setup

In this investigation, a monotonic load flexural testing program has been carried out to determine the mechanical properties of the lightly stabilized material by means of improved experimental setup. In conventional flexural testing, mid-span vertical deformation is generally measured externally which may include some extraneous deformation. As a result, the load-deformation curve obtained may not be representative.

To eliminate these erroneous vertical movements, several researchers (Kim et al 2008; Chang et al 2011) adopted special measurement technique to measure the vertical deflection of composite beams.

In this study, an improved vertical deflection measurement was used to monitor the mid-span vertical deflection of the beam. A pair of video extensometer was used to measure the mid-span vertical deflection of the beam. This device computed the net deflection by tracking two gauge marks attached to the specimen. The vertical deflection measurement setup used is shown in Figure 3.

2.4 Flexural strength and static modulus

The flexural strength or modulus of rupture, MOR of soil-cement beam is determined by using Equation 1 provided that the fractures occurred within the middle third of the beam span length. It is noted that fractures were observed within the middle third for all the specimens but one (specimen # 2 – loading rate 0.01 mm/min). Equation 2 was used for the case when the fracture was found outside of the middle third by not more than 5% of span length.

$$MOR = \frac{PL}{bd^2} \qquad [1]$$

$$MOR = \frac{3Pa}{bd^2} \qquad [2]$$

Where MOR = modulus of rupture in MPa, P = maximum applied load in N, L = span length in mm, b = average width of specimen in mm, d = average depth of specimen in mm and a = distance between line of fracture and the nearest support.

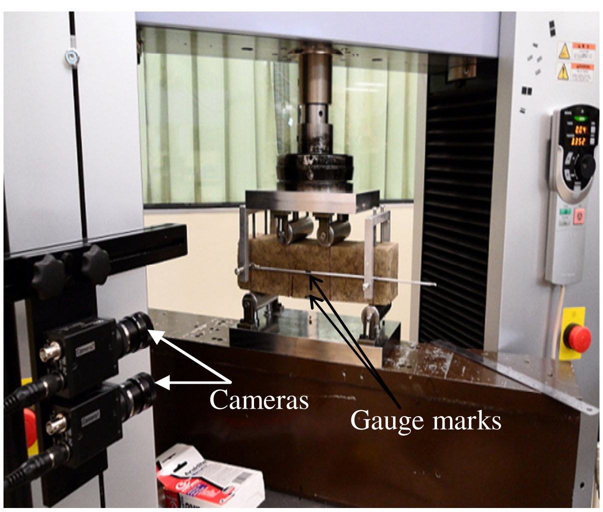

Figure 3. Pictorial view of flexural beam testing setup

The stiffness modulus was calculated using the following formulae for a selected point on the linear portion of the load-deformation (*P, δ*) curve.

$$S_m = \frac{23PL^3}{108bd^3\delta}\left[1 + \frac{216d^2(1+\nu)}{115L^2}\right] \qquad [3]$$

Where S_m = Stiffness modulus in MPa and P = load in N corresponding to deflection δ in mm and ν = Poisson's ratio of the lightly stabilised material. The value of Poisson's ratio was assumed to be 0.2 as per AUSTROADS (2004) recommendation.

3 RESULTS AND DISCUSSIONS

Initially the samples were tested in displacement control mode at the rate of 1.2 mm per minute as recommended by ASTM guideline. However the samples failed suddenly within few seconds (~ 3 seconds) from the beginning of the test. This indicates that the testing speed suggested in ASTM guideline, which was mainly developed for normally bound materials, may not be suitable for lightly stabilized materials. Hence an attempt has been made to evaluate the effect of loading rate on the flexural properties.

A total of 9 samples (i.e., 3 samples for each batch) were tested at three different testing speeds – 0.01 mm/min, 0.1 mm/min and 1.2 mm/min. Figure 4 shows the load-deformation curve of lightly stabilized material obtained from the flexural beam testing performed at 0.1 mm/min displacement rate.

3.1 Effect of loading rate on flexural strength and static stiffness modulus

The average modulus of rupture and static stiffness modulus calculated by using Equations [1] – [3] from the experimental data are summarised in Table 1. It could be noted that the loading rate has a significantly effect on the properties of lightly stabilized granular material. The flexural strength, MOR was found increasing considerably with the increase in displacement rate. The MOR raised to 0.151 MPa from just 0.106 MPa for the rise in loading rate from 0.01 mm/min to 1.2 mm/min.

Table 1. Rate sensitivity of lightly stabilized materials

Loading rate mm/min	Flexural strength, MOR MPa	Static modulus, S_m MPa
0.01	0.106	344
0.1	0.139	602
1.2	0.151	850

Similarly, higher value of static modulus was obtained for faster testing speed. The static stiffness modulus, S_m increased from 344 MPa to 850 MPa when the loading rate increased from 0.01 to 1.2 mm/min. Moreover the

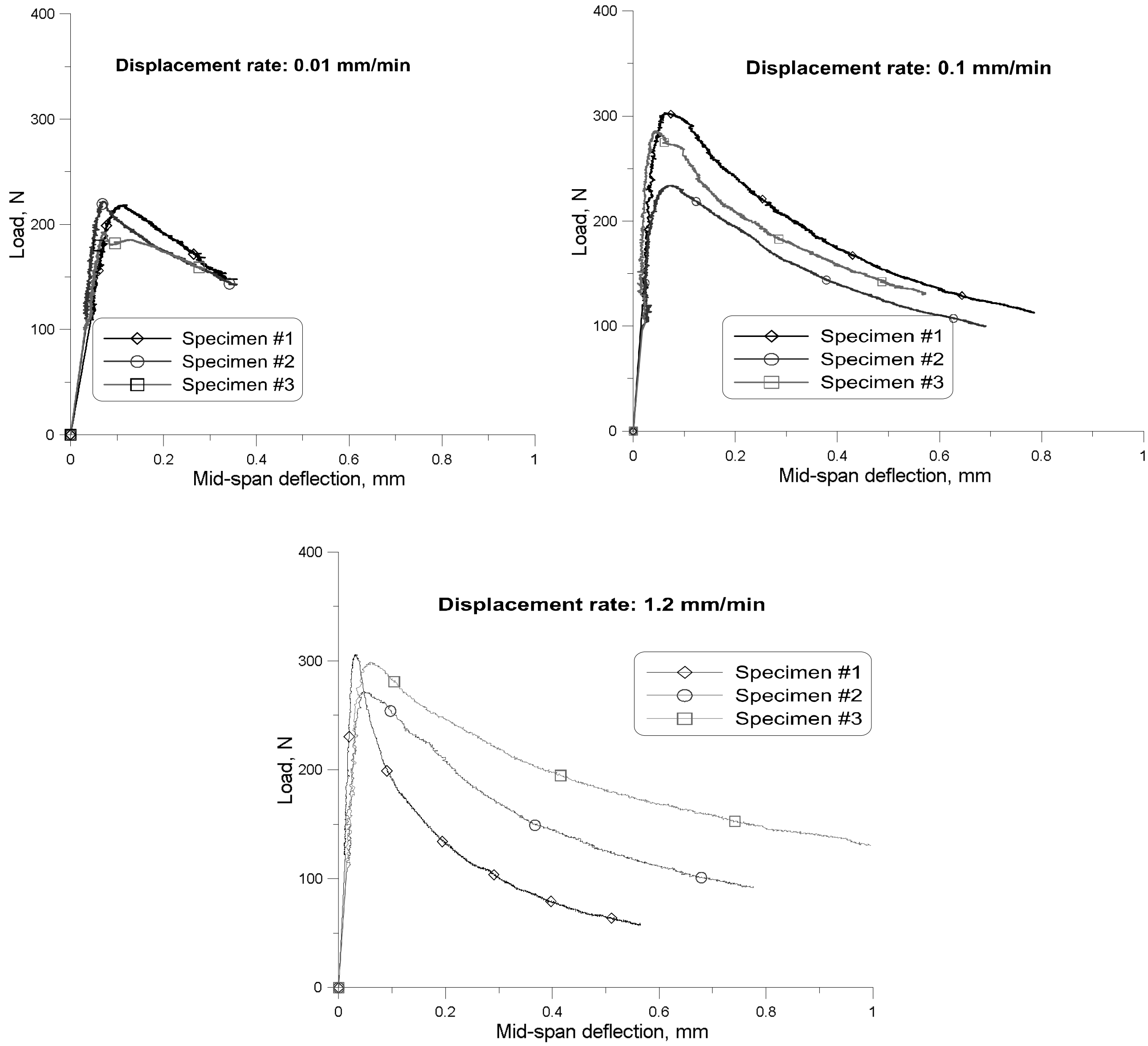

Figure 4. Load-deformation curve of lightly stabilized material at different displacement rates

static modulus was correlated and found to be 4400 times the MOR for lightly stabilized material investigated in this paper.

4 CONCLUSIONS

Flexural beam testing with internal displacement measurement has been carried out in this study to evaluate the effect of loading rate in terms of flexural strength and static modulus in this study. Three different loading rates were used to characterize a typical granular material stabilized lightly with 1.5% cement – flyash. The samples were cured for 7 days and tested with an improved testing arrangement for measuring the mid-span vertical deflection more reliably. The loading rate, which is the major test variables for laboratory testing, was found to be very sensitive and has a significant upshot on the properties of a lightly stabilized material. Therefore one should choose the appropriate testing speed which represents the quasi-static or monotonic testing criteria for the characterization of lightly stabilized granular materials.

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