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STRENGTH ASSESSMENT OF CEMENT TREATED SOIL-RECLAIMED ASPHALT PAVEMENT (RAP) MIXTURE

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ABSTRACT: The article attempts to present the influence of reclaimed asphalt pavement (RAP) content on the compaction behavior and unconfined compressive strength of cement treated soil-RAP mixture. The laboratory compaction and unconfined compression tests on cement treated soil-RAP mixture were carried out with various RAP and cement contents. The porosity was adopted as a state parameter for assessing the strength of the mixed materials. The results show that with an increase in RAP content, the OMC tends to decrease, up to the optimum of soil/RAP ratio of 50/50. The asphalt fixation point is designated as a transitional point where a small change in strength turns to a larger change. An asphalt content of 3.5% (50/50 soil/RAP ratio) is found to be the asphalt fixation point. The strengths, where the asphalt content is lower than the asphalt fixation point, can be predicted by the proposed generalized form of strength. This proposed equation can assess the laboratory strength of cement treated soil-RAP mixture under various mixed proportions, cement contents, water contents, and curing times.

Keywords: Reclaimed asphalt pavement, Lateritic soil, Unconfined compressive strength, Cement stabilization

1. INTRODUCTION

Reclaimed asphalt pavement (RAP) is defined as pavement materials containing asphalt and aggregates which have been removed and/or reprocessed [1]. Rehabilitation of asphalt concrete pavement includes the milling of asphalt concrete layer, which produces a great amount of RAP. Those RAP from the rehabilitation of asphalt road are a major problem for many countries. Fig. 1 shows the on-site RAP heap from the rehabilitation of asphalt pavement failure caused by flood in the Lopburi province, Thailand. RAP can be recycled by the following applications: cold in-place recycling, cold planning, hot recycling, hot in-place recycling, and full depth reclamation [2]. Although RAP can be recycled directly as a recycled proportion of new hot mix asphalt concrete, this is generally limited to 25% (or less) of the new material according to the standard. Some RAP remains and alternative methods for disposal would need to be developed.

When used as a total substitute for natural aggregates, most RAP materials do not often meet the minimum base material requirements set forth by the standard or local state guidelines [3]. The use of RAP as a granular base is one solution available for the disposal of RAP solid waste and provides good application where no suitable materials are available [4]. RAP can be used aggregate in pavement base or subbase if mixed with other natural aggregates [5]. However, the natural soils mixed with RAP exhibit low strength and collapse

Fig. 1 On-site RAP heap in the Lopburi province, Thailand (photo by Jirayut Suebsuk)

on wetting. These limitations have led to the new research efforts aimed at exploring novel stabilization methods to treat soil-RAP mixture before their use in pavement base or subbase construction [6]. The cost-effective method for stabilizing pavement material is a cold in-place mixed with cement. This method is economical and the engineering properties of materials can be controlled. The strength and resistance to deformation increase with curing time. The fundamental mechanical characteristics and some influential factors on the strength behavior (e.g., water content, cement content, curing conditions and compaction energy) of cement treated soils have been investigated extensively (e.g., [7] to [13], and others).

RAP is becoming increasingly popular as an alternative recycled solid waste material for pavement base applications over the last decade. Laboratory and field investigation on the use of RAP material in pavement base and subbase applications has been conducted by Rutgers University [14]. Other research works on the use of RAP have been reported in the most recent literature (e.g., [6], [15] to [17]). However, there are no methodologies based on rational criteria to assess the target strength for practical use; the conventional technique to design the mixed proportions of soil/RAP mixture is based on a trial batch.

This research therefore aims to study the influence of RAP content on the compaction behavior as well as to assess the unconfined compressive strength development with curing time of cement treated lateritic soil/RAP mixture, using porosity as a state parameter.

2. LABORATORY INVESTIGATION

2.1 Lateritic Soil

The natural lateritic soil used in this study is a local problematic soil from the Nakhon-Ratchsima province, Thailand. It contains high fine particle content over the maximum criteria according to the Department of Highways (DOH) standard. It was collected from a borrowed pit in the Nakhon-Ratchasima province, Thailand, at a depth 2 to 3 m. The fine particle accounts for the significant problems on the base course structure, especially the swelling, consolidation and collapse upon drying and wetting. The grain size distribution of the soil is presented in Fig. 2. The natural soil is composed of 2% gravel, 53% sand, 25% silt, and 20% clay. The specific gravity is 2.68. The liquid and plastic limits are approximately 23% and 5%, respectively. Based on the Unified Soil Classification System (USCS), the soil is classified as clayey sand (SC).

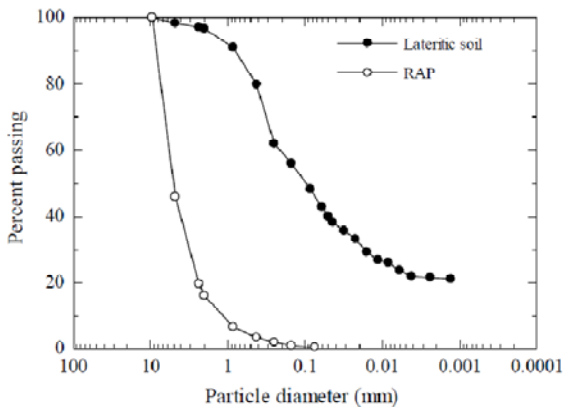

Fig. 2 The grain size distribution of lateritic soil and RAP

2.2 Reclaimed Asphalt Pavement (RAP)

The RAP material was obtained from the milling of asphalt pavement for resurfacing in the cold in-place recycling (CIR) process in the Nakhon-Ratchasima province, Thailand. This RAP contains primarily crushed limestone with 7% of asphalt content. The in-situ RAP were air-dried and then passed through a 10 mm sieve for removal of larger particles. The grain size distribution is also presented in Fig. 2. It indicated that approximately 100% of RAP was retained on the No. 200 sieve. The bulk specific gravity is 2.49.

2.3 Compaction and Unconfined Compression Tests

The compaction of lateritic soil, RAP and mixed materials was carried out using a 100-mm standard mold under modified Proctor energy (ASTM D 1557). The optimum moisture content (OMC) and maximum dry density ($\gamma_{d,max}$) of compacted lateritic soil under the modified Proctor are 8% and 21.2 kN/m^3, respectively; while the OMC and $\gamma_{d,max}$ of compacted RAP under the modified Proctor are 6.2% and 17.5 kN/m^3, respectively. The modified Proctor energy was performed on the untreated mixed materials to assess their OMC and $\gamma_{d,max}$.

The unconfined compressive tests were performed on the cylindrical samples, which were compacted on the OMC of untreated materials. The lateritic soil, mixed with RAP, was treated by various contents of Portland cement type I. The RAP content used in the mix proportions varied from 0 to 90% by weight of total material, while the cement content (*C*) varied from 0 to 5% by weight of solid. After 24 hours, the samples were dismantled from the mold, wrapped in vinyl bags, and stored in a humidity chamber with a constant temperature (25 ± 2 °*C*). Unconfined compression tests were conducted on the samples after 1, 7, 14, 28, and 60 days of curing. The rate of vertical displacement was constantly kept at 1 mm/min. After finishing the test, the moisture content of the samples was measured for evaluating the porosity.

For all mixtures at each curing time and combination of moisture content and cement content, at least five samples were tested under the same condition to check the consistency of the test. In the most cases, the results under the same testing condition were reproducible with a low mean standard deviation, SD (SD < 10%).

3. RESULTS AND DISCUSSIONS

Table 1. shows OMC and $\gamma_{d,max}$ of soil-RAP mixture for different soil/RAP ratios but with the same compaction energy. Fig. 3a shows the compaction curve of the lateritic soil and RAP. The various compaction curves of mixed materials were presented in Fig. 3b under various soil/RAP ratios. The OMC tends to decrease as the RAP content increases up to the optimum RAP content, which is 50/50 of soil/RAP ratios. At this point, the maximum dry density is 21.9 kN/m^3 and a moisture content is 6.4%. The reduction in the maximum dry density is associated with an increase in the RAP content, more than the optimum point. The reduction in the maximum dry density (increase in porosity) could be due to the larger particle size of RAP, where the soil-RAP mixture leads to a poorly graded material.

Table 1The OMC and maximum dry density of soil-RAP mixtures

Soil/RAP ratio	OMC (%)	$\gamma_{d,max}$(kN/m^3)
80/20	7.0	21.5
60/40	6.8	21.6
50/50	6.4	21.9
40/60	7.0	21.3
20/80	8.8	19.9

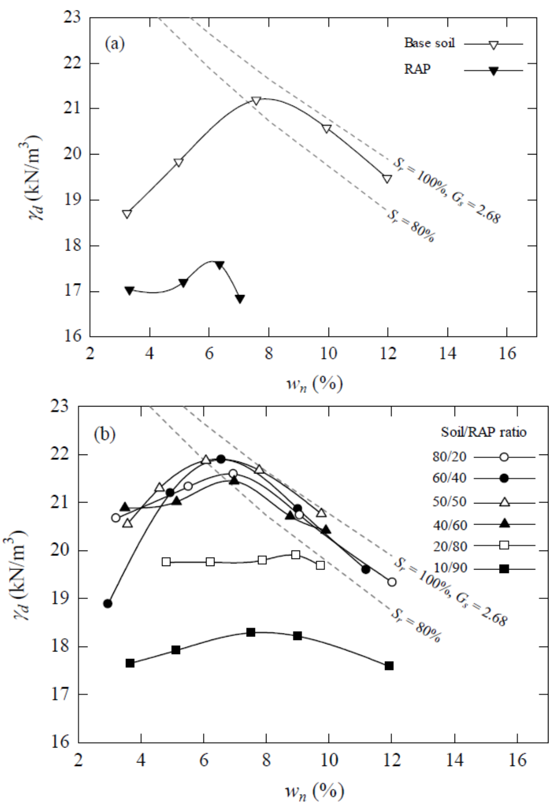

Fig. 3 Compaction curves of the lateritic soil, RAP, and mixed materials

Fig. 4 shows the typical stress-strain relationships in the unconfined compression tests of cement treated soil-RAP mixture for different RAP contents but with the same cement content and curing time. The RAP content in the mixed materials plays a significant role in the stress-strain-strength behavior under unconfined compression tests. The reduction in strength and stiffness of the mixed materials are associated with a decrease in dry density.

Fig. 5 shows the effect of RAP, as represented by the asphalt binder content *AS* (%), on the strength in unconfined compression tests of cement treated soil-RAP mixture. *AS* is calculated as follows:

$$AS = \frac{W_{as}}{W_s} \times 100 , \qquad (1)$$

where W_{as} is the weight of asphalt binder, and W_s is the weight of soil solid. As the asphalt content increases, the unconfined compressive strength significantly decreases. However, when the asphalt binder content is greater than 3.5% (50/50 of soil/RAP ratio), the change in strength is larger. The asphalt content of 3.5% can be designated as the "asphalt fixation point". The decrease in strength is due to a reduction in friction between the solid particles (soil and RAP aggregate), which is caused by the asphalt binder. The asphalt fixation point is a transitional point where a small change in strength turns to a larger change. The reduction in strength is minimal when the asphalt content is lower than the asphalt fixation point; this zone is called the inert zone. The zone is also called deterioration when the asphalt content is greater than the asphalt fixation point.

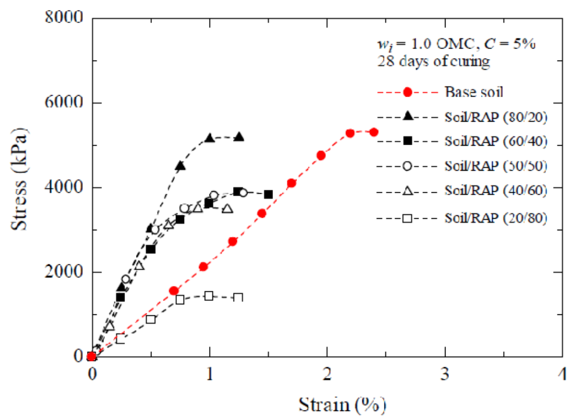

Fig. 4 Stress-strain relationships in unconfined compression test of lateritic soil and mixed materials

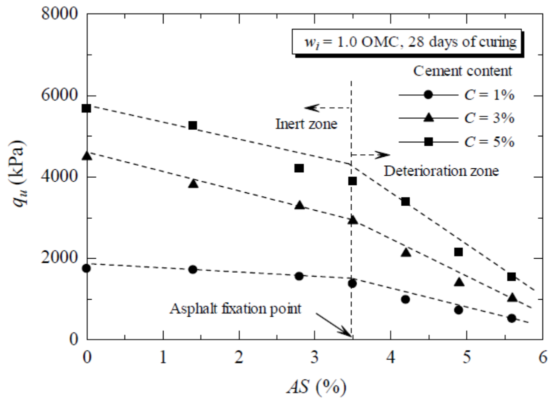

Fig. 5 Relationship between strength and asphalt content

Fig. 6 shows the porosity η of the cement treated soil-RAP mixture. The compacted 100% lateritic soil inherently exhibits 18.5% of porosity. The increase of asphalt content in the mixed material reduces the porosity. By adding 3.5% of asphalt content, the porosity is reduced by up to about 14%. However, when the asphalt content is greater than 3.5%, the porosity increases. The increase in the porosity could be due to the lower specific gravity of RAP and the compaction behavior of the mixed material.

Fig. 7 shows the strength development in cement treated soil-RAP mixture with various RAP contents but with the same cement content. As the asphalt content increases, the strength is lowered. The presence of asphalt binder reduces the bonding between RAP aggregate and soil. The asphalt binder is detrimental to cement treated soils. The typical strength development with curing time for cement treated soil-RAP mixtures under 20%, 40% and 50% of RAP content is shown in Figs. 8-10. The strength development with curing time (days) in a natural logarithmic scale can be expressed as a linear variation. The strength ratio plots after normalization are also shown in these figures. The normalized relation is presented in Eq. (2).

$$\frac{q_D}{q_{28}} = a + b \ln D , \qquad (2)$$

where q_D is the strength after D days of curing, q_{28} is the 28-day strength, a and b are constant.

From this investigation, the values of a and b are 0.248 and 0.225 for 80/20 of soil/RAP ratio, 0.297 and 0.197 for 60/40 of soil/RAP ratio, and 0.444 and 0.178 for 50/50 of soil/RAP ratio. The normalized strength development is comparable to that proposed for cement treated low plasticity and coarse grained soils [10]. It is found that these three sets of values depend on the variation of porosity and cement

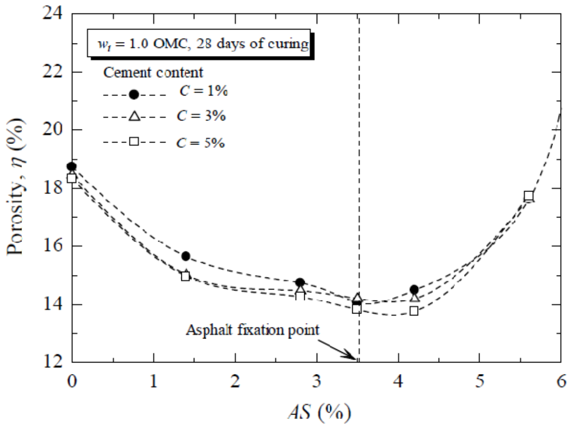

Fig. 6 Relationship between porosity and asphalt content

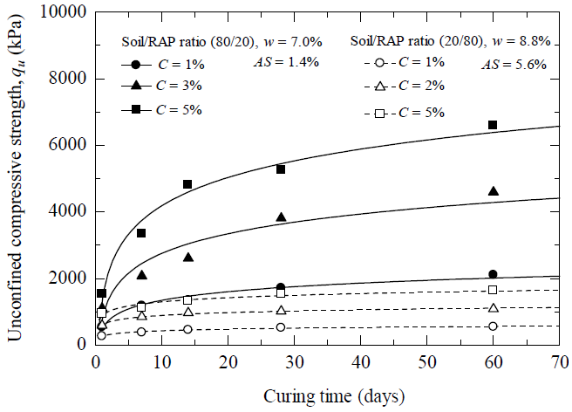

Fig. 7 The comparison of strength development in cement treated soil-RAP mixture under different RAP content

content for the range of curing time considered. The soil water/cement ratio and compaction behavior has play a significant role on the change in porosity of cement treated soil-RAP mixture. To account for the material type and the water-cement ratio, the porosity is incorporated into the Eq.(2):

$$\frac{q_D}{q_{28}} \eta = a^* + b^* \ln D \qquad (3)$$

where η is the porosity of treated specimens at each mixture, a^* and b^* are constant. Based on an analysis of test result in the inert zone, the generalization of strength development can be illustrated in Fig. 11. The linear regression analysis gives a^* = 0.028 and b^* = 0.046. This generalization accounts for the effect of the compaction behavior of different gradation. It is evident that the Eq.(3) is valid for asphalt content lower than the asphalt fixation point (3.5%) and for curing times between 1 and 60 days. For predicting the strength via Eq. (3), one laboratory test value of strength and porosity measured on the 28 days of curing at the same compaction energy, same cement content, and same soil/RAP ratio is needed. Using this generalization, the strength of cement treated soil-RAP (70/30 of soil/RAP ratio) mixture was predicted and compared with those of the laboratory test as shown in Fig. 12. There is some discrepancy between the predicted and laboratory strengths. However, the error from the prediction is acceptable in common engineering practice.

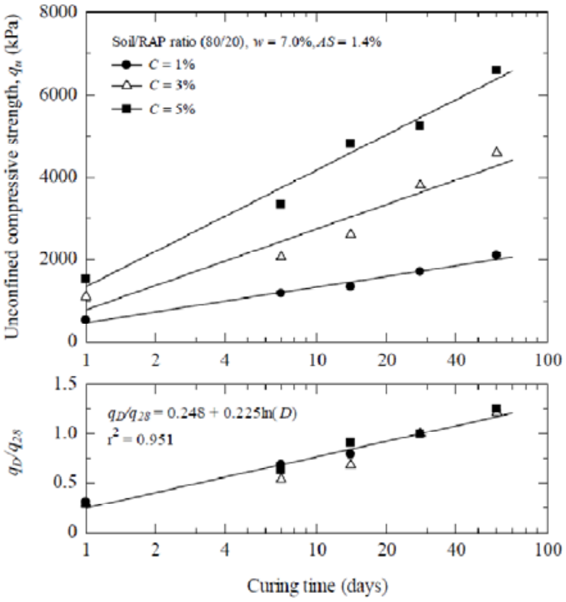

Fig. 8 Strength development in cement treated soil-RAP mixture (80/20) and its normalization

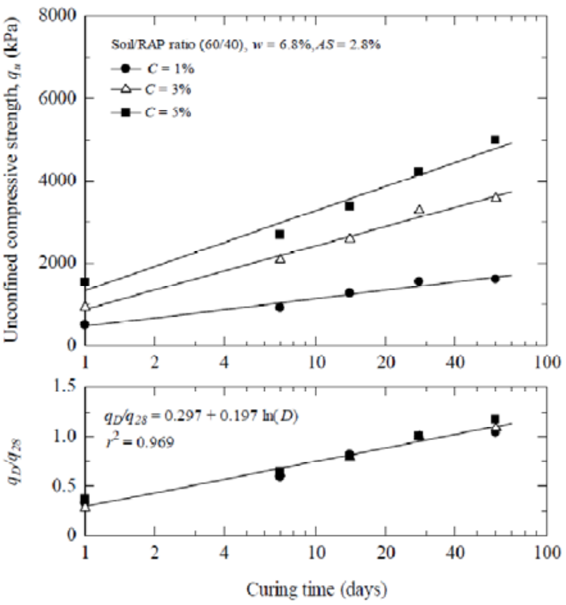

Fig. 9 Strength development in cement treated soil-RAP mixture (60/40) and its normalization

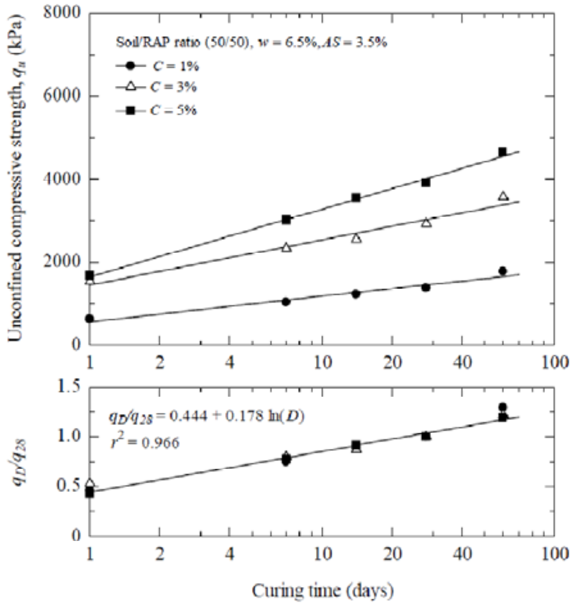

Fig. 10 Strength development in cement treated soil-RAP mixture (50/50) and its normalization

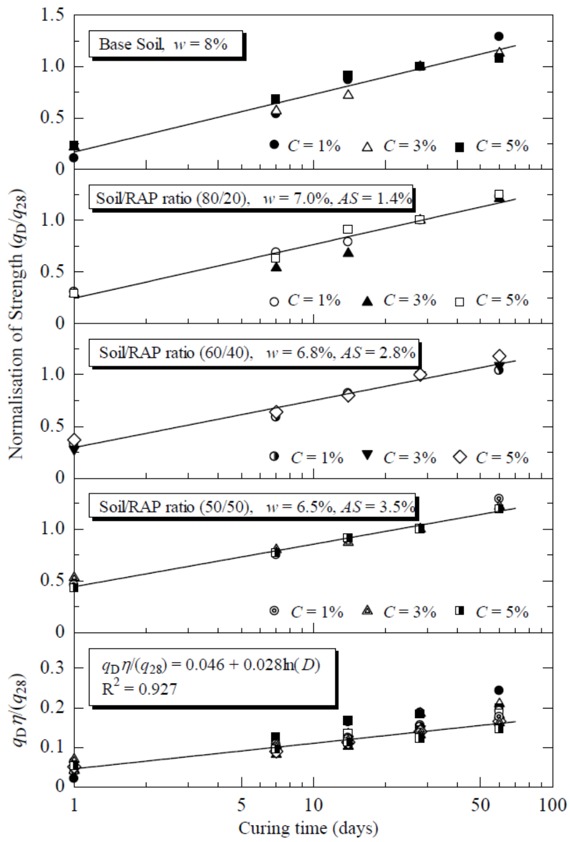

Fig. 11 Generalization of strength development in cement treated soil-RAP mixture

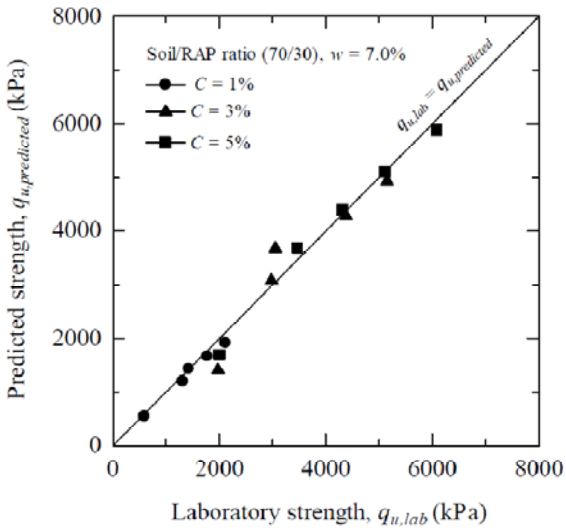

Fig. 12 Comparison between predicted and laboratory strengths

4. CONCLUSION

This article presents the unconfined compressive strength of a problematic lateritic soil mixed with RAP. The mixed materials were treated by cement to increase their strength and engineering properties. The influence of RAP content on the compaction and strength development with curing time was studied using porosity as a state parameter. The following conclusions can be drawn:

1) The OMC of mixed material is dependent directly on the mixed proportions. With anincrease in RAP content, the OMC tends to decrease, up to the optimum gradation with a soil/RAP ratio of 50/50.

2) As the asphalt content increases, the unconfined compressive strength decreases due to a reduction in friction between the solid particles (soil and RAP), which is caused by the asphalt binder. The unconfined compressive strength of mixed materials is associated with the variation in porosity. Asphalt fixation point is defined as the limit point of asphalt content that separates the inert from the deterioration zones. An asphalt content of 3.5% (50/50 of soil/RAP ratio)has become the asphalt fixation point of this investigation.

3) The target strength of cement treated soil-RAP mixture can be predicted by the generalized strength equation if and when the asphalt content is lower than the asphalt fixation point. This proposed equation can assess the laboratory strength of cement treated soil-RAP mixtures with various mixed proportion, cement content, water content, and curing time.

5. ACKNOWLEDGEMENTS

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