Undrained Shear Behavior of Cemented Clayey Sand-Recycled Asphalt Pavement Blends for Pavement and Railway Applications

Jirayut Suebsuk[1, a] and Komkorn Chaidachatorn[1, b]

[1]Department of Civil Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhon Ratchasima, Thailand, 30000

[a]< jirayut.su@rmuti.ac.th >, [b]< komkorn2003@yahoo.com >

Abstract

This paper presents the mechanical and chemical improvements of clayey sand by recycled asphalt pavement (RAP) and cement for soil-cement embankment in pavement and railway applications. The engineering behavior of clayey sand improved by RAP and cement have been presented; those are gradation, compaction, compressibility, and shearing. The variation of RAP replacement has been studied for improving the compaction and compressibility of clayey sand. The increasing RAP replacement improves the gradations of clayey sand. The dry unit weight increases with increasing in RAP replacement due to the better gradation. The cement stabilization was used to increase the cementation bonding for resisting the shearing during low confining pressure. Excess pore-water pressures were investigated during shearing, while pre-shear effective stress varies between 50 to 200 kPa. The uncemented sample shows the hardening behavior with a positive excess pore water pressure while the cemented sample shows the softening behavior with a negative pore water pressure. The RAP replacement and cement stabilization have played a significant role in an increase in strength and stiffness of blended materials.

Keywords: *Clayey sand, Recycled asphalt pavement, Gradation, Undrained shear behavior*

1. Introduction

Many research study about the renewable civil engineering materials uses due to the increase in infrastructure development, which required high quality of natural materials, especially pavement and railway applications. Cut slope and embankment structure required an excellent quality coarse grain material to meet the minimum standard requirements (i.e., gradation and internal friction angle). Recycled materials from the rehabilitation of civil engineering structure can be used instead of the natural aggregate in many engineering applications. The reduction of environmental problem is a significant advantage of recycled material use. Recycled asphalt pavement (RAP) has been used extensively in geotechnical applications such as embankment fill, base, and subbase materials [1-2]. RAP is a removed and reprocessed pavement material containing asphalt binder and aggregates. RAP consists of high-quality, graded aggregates coated with asphalt binder [3]. Although the in-situ pavement recycling has been widely used in many developed countries to carry out the new

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base course by milling the damaged pavement and base course layers before the re-compaction process to build a new base layer. However, RAP aggregate remains in the stockpile, and the process for disposal of unused RAP should be explored. Previous studies have investigated the utilization of RAP in road base materials [4]. The stabilization of RAP blended with the base course by a chemical such as Portland cement or cement kind dust (CKD) has been used. Most studies indicated that the increase in RAP content affects the increase in resilient modulus [5-8]. However, the unconfined compressive (UC) strength, CBR, and durability decrease with the increasing RAP replacement. Chemical stabilization has played a significant role in strength development. The UC strength tends to increase with a curing time [4-8]. Many researchers have studied to assess the strength to meet the standard requirement of pavement base and subbase course materials.

The requirements of embankment materials are gradation, internal friction angle, critical state strength parameters, and stress-strain behavior during shear for predicting the deformation of the geotechnical structure. The shear behaviors under drained and undrained conditions are significantly for modeling the deformation of the geotechnical structure during loading. The excess pore pressure and volumetric deformation during loading have affected on the stress state of embamkment material. Rahman et al. [10] have investigated the suitability of recycled construction and demolition materials as alternative pipe backfilling materials for stormwater and sewer pipes. Triaxial consolidation drained (CD) test, and direct shear test (DST) were performed on RAP to assess the shear strength parameters. The gradation of RAP is recognized as well-graded gravel with high permeability. Thus the drained condition was investigated for the triaxial test. The internal friction angle of RAP tested under DST and CD tests are 45 and 58 degrees, respectively. Arulrajah et al. [11] have also reported the triaxial and direct shear test results on RAP. They presented that particles of RAP have high energy absorption capacity due to the presence of asphalt binder. According to the result from Viyanant et al. [12] indicated that the residual asphalt binder in the RAP affects internal friction angle. Cosentino et al. [13] have investigated the RAP admixed with soil under CD test. The result indicated that the 100% RAP shows the highest internal friction angle when compared to those of soil/RAP blend. The internal friction angle decreases with an increase in the percentage of fine sand. The increase in fine sand has reduced the grain-to-grain contact causing the large particles to float within the soil matrix. The cohesion bonding observed from RAP sample may be an effect of asphalt binder that would cause the particles attaches by asphalt/soils bonding.

The limit of high-quality fill material is a problem of the developing country included Thailand. A good quality fill material is expensive due to the transportation cost. The clayey sand, which is a natural soil of Thailand, can be found out as embankment materials. However, the clayey sand has a poorly graded with a high percentage of fine particle and high plasticity index. It is usually classified as marginal material with high compressibility, low permeability, and low shear strength. This paper attains to use the RAP to improve gradation of marginal clayey sand for using in soil-cement embankment materials in pavement and railway applications. This work investigates the shear behavior of soil/RAP blends improved by cement under isotropic consolidated undrained triaxial compression

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(CIU) test. The deviator stress and excess pore pressure during shear as well as an effect of RAP and cement contents were reported and discussed.

2. Research Methodology

The marginal clayey sand was corrected from a borrow pit in Nakhon Ratchasima, Thailand. The RAP was corrected from the rehabilitation of asphalt pavement road in Buriram, Thailand. The particle size of clayey sand and RAP have presented in Fig. 1. More than 80% of clayey sand has passed the 4.75mm-sieve while 50% of RAP has retained on 4.75mm-sieve. Basic properties of clayey sand and RAP are shown in Table 1.

The clayey sand has improved by replacing with RAP under various blended proportion. The modified Proctor compaction has performed on marginal clayey sand, RAP and soil/RAP blends according to ASTM D1557 to investigate the variation in dry unit weight ($\square_{dmax}$) and water content relationships. For the triaxial shearing test, the splitting steel mold was used to prepare the sample under compression molding. The sample after molding has a 50mm diameter and 100mm height.

Samples were prepared at a specific optimum water content and maximum dry unit weight obtained from the compaction curve. The RAP replacement was varied for 0 and 50% by weight of dry soil while the cement content was varied as 0, 1, and 3% by weight of dry soil. The cylindrical samples were molded at a particular moisture content and dry unit weight and then wrapped in vinyl bags. The isotropic compression tests of clayey sand improved by cement and RAP performed under various cement and RAP content. The selected samples tested under isotropic consolidated undrained compression after 28 days of curing. The pre-shear effective stress varies from 50 to 200 kPa.

Table 1 Engineering properties of Soil and RAP

Properties	Soil	RAP
Liquid limit, *LL* [%]	32	-
Plastic index, *PI* [%]	16	-
Coarse contnt [%]	77	99
Fine content [%]	23	1
Specific gravity, G_s	2.58	2.60
Asphalt binder content, *AS* [%]	-	7

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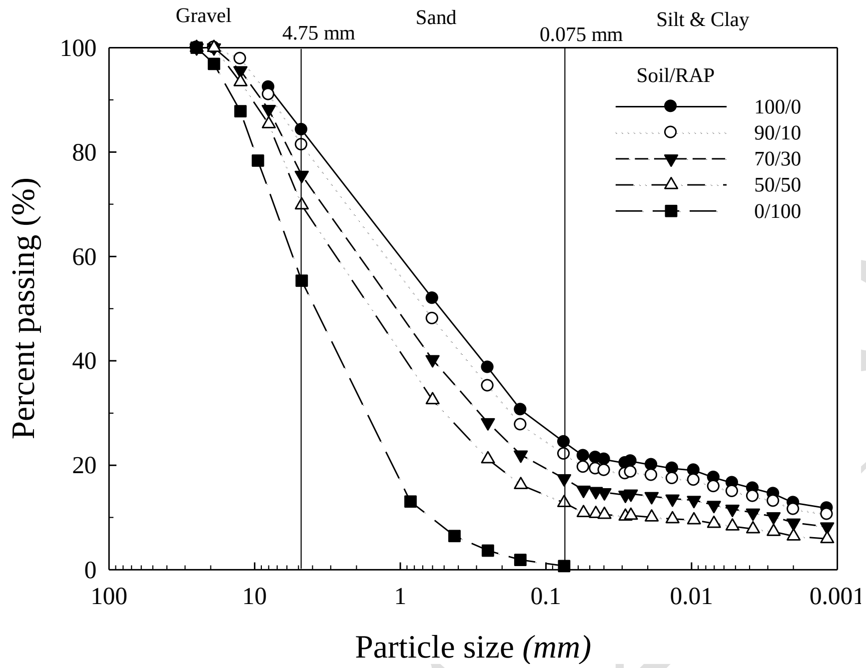

Figure 1 Particle size of soil, RAP and soil/RAP blends

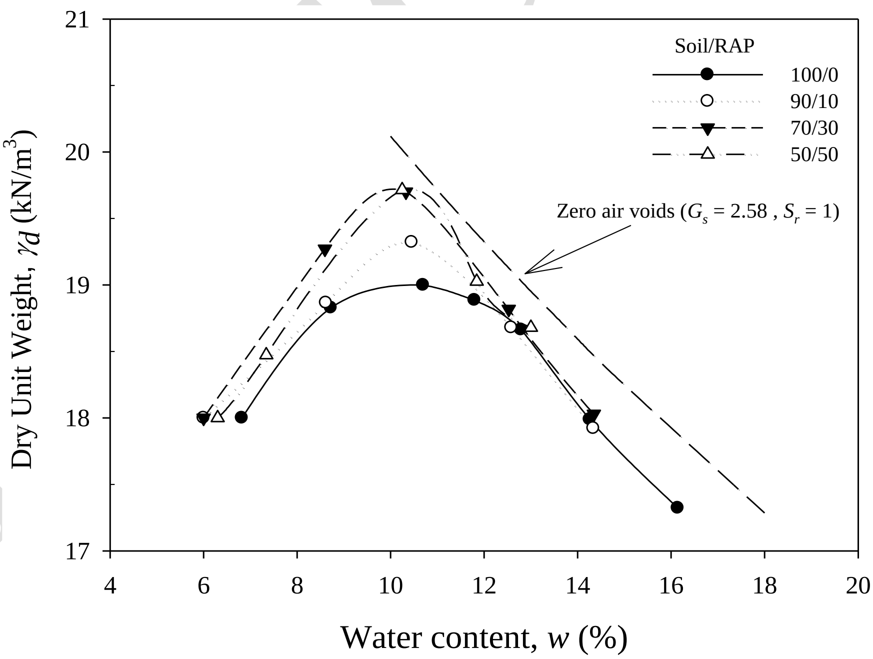

Figure 2 Compaction characteristic of soil/RAP blends

3 Result and Discussion

3.1 Compaction Behaviors

The compaction curve of materials has presented in Fig. 2. The 100% clayey sand have shown the low dry unit weight when compared to those of blended materials. It is because of the poorly graded and high fines particle. However, compaction behavior can be improved by mixing with RAP, which has a high coarse particle. A fines particle of clayey sand can fill the void of RAP, which enhances the dry unit weight of blended material. An increasing in RAP content increases maximum dry unit weight up to 19.7 kN/m^3 for 50% RAP replacement. The void ratio decreases with an increase in dry unit weight. However, all mix proportions have classified as A-2-6 according to ASSHTO standard and clayey sand (SC) according to USCS.

3.2 Compressibility Behaviors

Fig. 3 presents the relationship between the void ratio (*e*) and effective vertical stress (σ'_v) for uncemented soil-RAP blends under various proportions. After the consolidation stage at any loading path, it was found that the void ratio decrease with an increase in effective vertical stress as linear relation in e-logσ'_v space up to the yield stress (σ'_y). An increasing in RAP replacement tend to increase the magnitude of yielding stress, which varied between 580-1000 kPa.

3.3 Shearing Behaviors

The deviator stress vs. axial strain relationships obtained from the triaxial compression tests of 100% clayey sand and 50/50 soil/RAP blend were illustrated in Figs. 4 and 5, respectively. The cement content and pre-shear effective stress were varied. For uncemented sample (C = 0%) the deviator stress increases with increasing in pre shear effective stress. The deviator stress increase with axial strain up to peak strength state, then the strain-softening was observed. The deviator stress depends on RAP content. The 50/50 of soil/RAP blends show higher deviator stress when compared to those of 100% clayey sand.

Deviator stress-strain curve and development of excess pore pressure of uncemented and cemented samples have presented in Figs. 4 and 5. For the 1% cement sample, deviator stress increases with increasing in pre-shear effective stress, and the peak strength and strain softening cannot be observed. The shape of the deviator stress-strain curve of cement = 1% is similar to those of uncemented samples. However, the strain-softening behavior was observed for highly cemented sample with 50 kPa of pre-shear effective stress (heavily overconsolidated state). For soil/RAP blended sample, the final deviator stress increases with the RAP content while the strain at peak strength increases with RAP replacement. The strain softening, which is a general problem of cemented soil, have been solved by RAP

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replacement. The strength and stiffness of clayey sand blended with 50% RAP and 3% Cement tend to decrease due to the crushing of cementation bond between clayey sand particle and RAP particle after the stress state reached the peak strength state.

Developments of excess pore pressure during shear of the uncemented sample were presented in Figs. 4 and 5. The excess pore pressure increases with increasing in pre-shear effective stress. The excess pore pressure increases before it reaches a maximum value, then decline until remains constant. The strain corresponding to peak excess pore pressure is lower than those of strain corresponding to maximum deviator stress.

Moreover, RAP content does not effect on the development of excess pore pressure. Although deviator stress for all mix proportion for 1% cement sample is similar to uncemented samples, the excess pore water pressure is different. For cemented samples (C = 1 and 3%), positive excess pore pressure was observed before it reaches a maximum value after that the negative pore pressure takes place. For undrained cemented sample, volume change has prevented, the breakdown of cementation bond and aggregate crushing generate negative pore water pressure. The excess pore pressure of cemented sample depends on pre-shear effective stress and cement content. The strain at peak excess pore pressure occurs before the strain at maximum deviator stress.

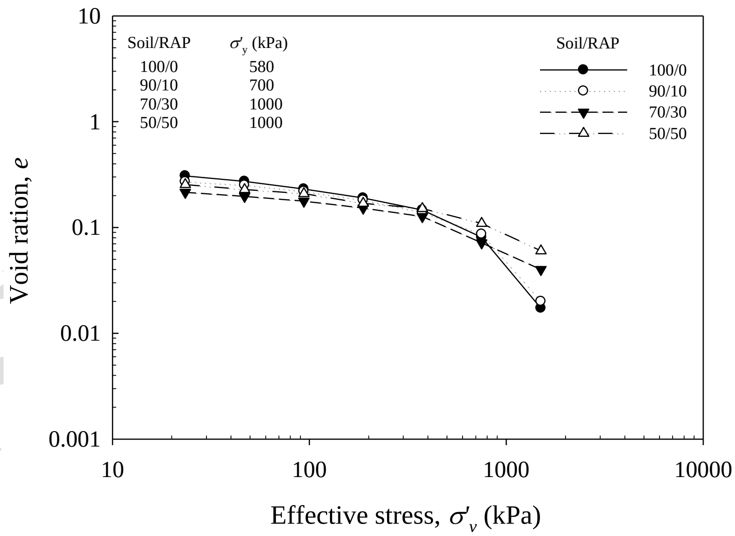

Figure 3 Compressibility behavior of soil/RAP blends

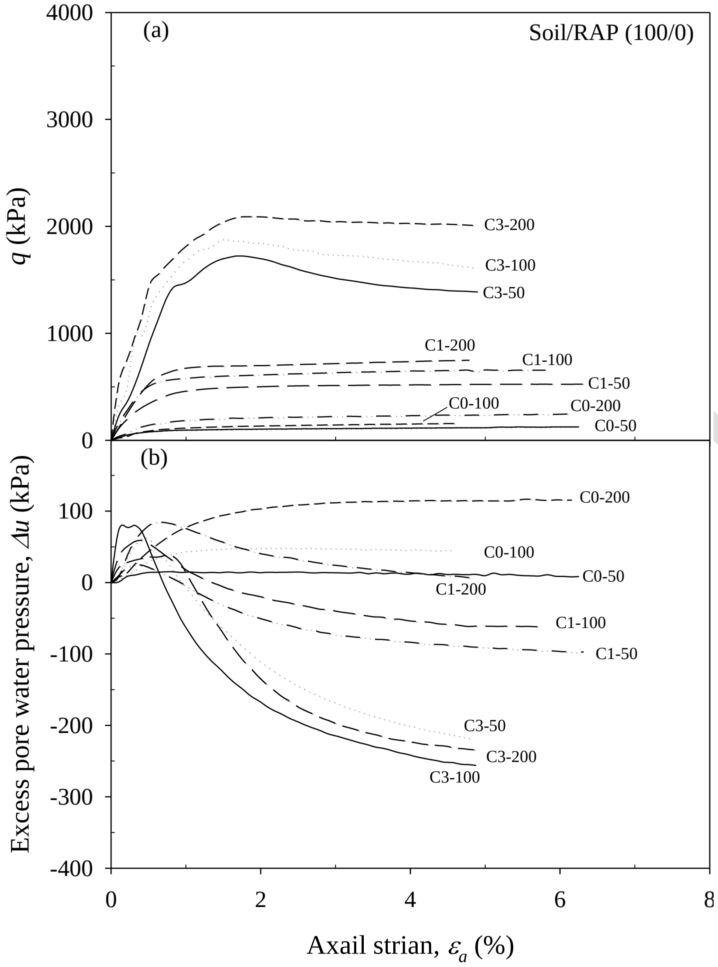

Figure 4 Deviator stress and excess pore pressure vs. axial strain for cemented and uncemented 100% clayey sand

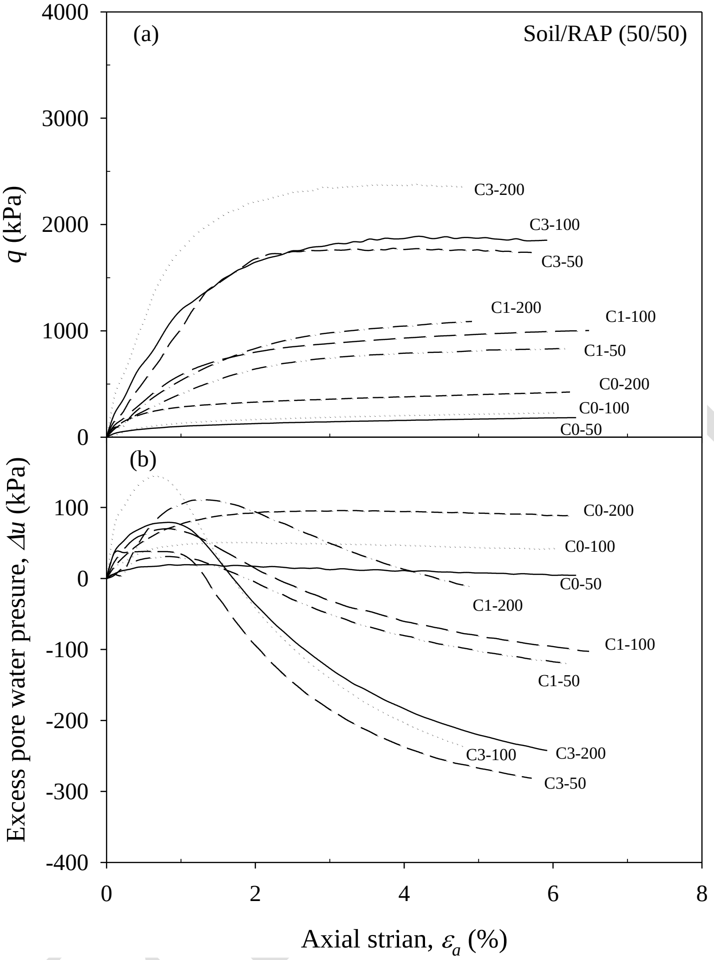

Figure 5 Deviator stress and excess pore pressure vs. axial strain for cemented and uncemented 50/50 soil/RAP blend

4. Conclusions

This paper discussed the undrained behavior of marginal clayey sand improved by recycled asphalt pavement (RAP) and cement for soil-cement embankment. The compressibility of clayey sand decreases with the increase in RAP replacement. The deviator stress increase with RAP replacement under the same condition of uncemented and cemented samples. Asphalt binder in RAP obstructs the cementation bonding to reduce strength development of cemented soil/RAP blends but do not affect the variation in the internal friction angle. Negative excess pore pressure depends on cement content and pre-shear effective stress and RAP replacement. Strength and stiffness increase with pre-sheer effective stress and cement content. Stiffness of 50/50 of soil/RAP blend tend to decrease slightly when compared with those of 100% clayey sand but strain softening have been improved. The RAP replacement significantly effects on strength and stiffness of improved soil-cement material.

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Assistant Professor Jirayut Suebsuk, Ph.D. (Civil Engineering), Geotechnical Innovation for Transportation Infrastructures Research Unit, Department of Civil Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, 744 Suranarai Rd., Nai Maung Subdistrict, Maung District, Nakhon Ratchasima, Thailand, 30000, Tel. 044-233-000 (ext. 3210), e-mail: jirayut.su@rmuti.ac.th, Research area: Geotechnical Innovation for Transport Infrastructures

Mr. Komkorn Chaidachatorn, M.Eng. (Civil Engineering), Department of Civil Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, 744 Suranarai Rd., Nai Maung Subdistrict, Maung District, Nakhon Ratchasima, Thailand, 30000, Tel. 044-233-000 (ext. 3210), e-mail: komkorn2003@yahoo.com, Research area: Recycled construction materials

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