Cement Stabilization for Pavement Material in Thailand

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ABSTRACT: Highway pavement generally consists of base and sub-base, which are constructed from suitable materials. When no suitable materials are available and it is expensive to bring the materials from distant sources, an alternative way which is widely practiced in Thailand is to stabilize the in-situ soil by cement. This method is economical and the engineering properties of the soil-cement mixture can be controlled. The strength and resistance to deformation increase with time. Two types of pavement material, widely used in Thailand, are lightweight cemented clay and pavement recycled material. The effects of water content, cement content, air content and curing time on engineering properties (unit weight, strength and compressibility) of lightweight cemented clay are illustrated. The equations to assess the engineering properties are presented. The equations facilitate the determination of cement content and air foam content to attain the target strength, unit weight and compressibility characteristics using a few trial data. The statistical analysis result of the field strength development of the pavement recycled materials is presented. Mixing process in this technique plays a minor role on the field strength reduction. Curing condition is a major role controlling the field strength development. For engineering and economic viewpoints, the satisfactory curing water is required after pavement stabilization.

Keywords: lightweight cemented soil, pavement recycled material, cement stabilization, pavement material

1. INTRODUCTION

Highway pavement generally consists of base and sub-base, which are constructed from suitable materials. When no suitable materials are available and it is expensive to bring the materials from distant sources, an alternative way which is widely practiced in Thailand is to mix the in-situ soil with cement. This method is economical and the engineering properties of the soil-cement mixture can be controlled. Two types of pavement material, widely used in Thailand, are lightweight cemented clay and pavement recycled materail.

Lightweight materials, with unit weight of 8 to 12 kN/m^3 and moderate to high strength, can be used as bridge abutments to reduce the earth pressure behind the wall and the foundation settlement and as a fill for construction of embankments on soft soil to reduce overburden pressure. The advantage of the lightweight cemented clay is cost-effective in terms of construction time, material and transportation. Following is the process of manufacturing lightweight cemented clay (*vide* Figure 1). Soft clay is mixed with water to obtain a clay slurry. The clay slurry is pumped into a mixing chamber and mixed with Portland cement. The cement-clay mixture is then transferred to air foam mixing plant and mixed with air foam to have a high workability (high flow value) and low density. The air-cement-clay mixture is then pumped into the construction site. This material does not require compaction and saves the transportation cost of the suitable granular backfill material from distant sources. With time, strength, stiffness and Poisson’s ratio of lightweight cemented clay increase; hence, the resistance to lateral movement. The lightweight cemented clay has been extensively used for highway and port construction in many countries such as Japan and Thailand (Tsuchida et al., 2001; Satoh et al., 2001; Hayashi et al., 2002; Otani et al., 2002; Jamnongpipatkul, et al., 2009; Kikuchi and Nagatome, 2010; and Kikuchi et al., 2011).

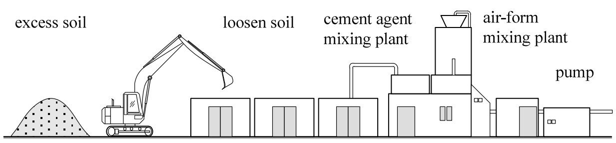

Figure 1 Schematic diagram illustrating the production of lightweight cemented clay

The pavement recycled material is generally used to restore damaged pavement. The Department of Highways, Thailand, has used this method of cementation since 1965. This method is designated as the pavement recycling technique. The damaged pavement is milled and mixed with cement. The soil-cement mixture is immediately field compacted by rollers as illustrated in Figure 2. This technique is economical because cement is readily available at reasonable cost in Thailand. Moreover, adequate strength can be achieved in a short time and the pavement is ready for use after about 24 hours.

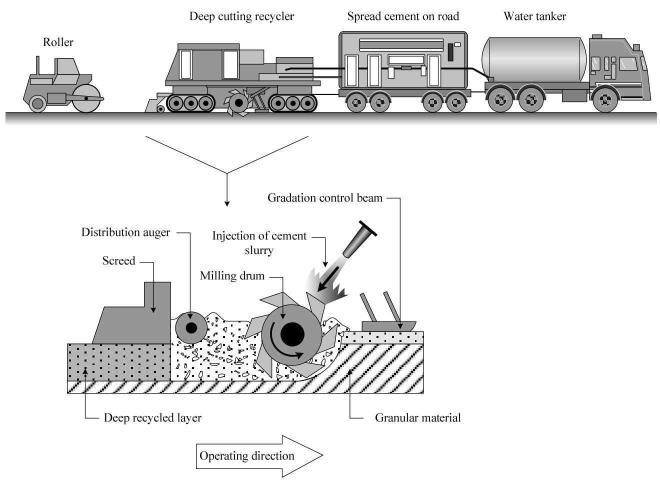

Figure 2 Typical characteristics of pavement recycling technique

The effects of water content and cement content on the engineering characteristics of cement stabilized soils have been extensively researched (Terashi et al., 1979; Kawasaki et al., 1981; Clough et al., 1981; Tatsuoka and Kobayashi, 1983; Kamon and Bergado, 1992; Nagaraj et al., 1997; Consoli et al., 2000; Kasama et al., 2000; Horpibulsuk et al., 2003 and 2004a and b). These studies considered cement content, either as the ratio of cement to soil by weight or in kgs of cement per cubic meter of soil along with its water content. Horpibulsuk et al. (2005) and Miura et al. (2001) have demonstrated that it would be advantageous to have a parameter to reflect the combined effects of clay, cement and water in the analysis of strength and deformation of cement admixed clays. Clay-water/cement ratio which is the ratio of clay water content to cement content (both reckoned in percentage) has been found to meet the above need. Miura et al. (2001) and Horpibulsuk and Miura (2001) have introduced the clay-water/cement ratio hypothesis based on the critical state and state boundary surface concepts. It is a fundamental in analyzing and assessing the laboratory strength development of cement admixed clay. In practice, the laboratory strength must be high enough to compensate for conditions which are uncontrollable in the field. The understanding of factors controlling the field strength development is thus vital for determination of the laboratory strength.

This paper attempts to present the recent research works on the engineering properties of lightweight cemented clay and pavement recycled material in Thailand. The application of clay-water/cement ratio to analyze and assess the laboratory strength development in lightweight cemented clays is illustrated. In addition to strength, unit weight and compressibility characteristics, which are the required parameters for pavement design, are also presented. Last but not least, the field strength development in pavement recycled material is presented based on the test data at four sites of roadway. The statistical analysis of the field strength data is depicted to understand the field parameter controlling the strength development.

2. LIGHTWEIGHT CEMENTED CLAY

2.1 Unit weight

Liquid limits of clays have the same order of pore water suction (5 – 6 kPa) (Russell and Mickle, 1970; Wroth and Wood, 1978; and Whyte, 1982). Under this state, most clays exhibit hydraulic conductivity of the same order of 10^{-7} cm/sec (Nagaraj et al., 1993 and Horpibulsuk et al., 2007) and the undrained shear strength of about 1.7 – 2.5 kPa (Wroth and Wood, 1978; and Whyte, 1982) although few clays exhibit larger undrained shear strength up to 5.6 kPa (Wasti and Bezirci, 1986). As such, liquid limit, w_L, is generally used as a state parameter for analyzing engineering properties of clay. Horpibulsuk et al. (2012c) used the liquid limit to determine the suitable water content to make lightweight cemented clay.

Figure 3 shows the typical relationship between unit weight and generalized stress state, w/w_L, of the lightweight cemented kaolin, Bangkok clay and bentonite at different air contents. The unit weights insignificantly change with air content at low water content. The unit weights decrease with air contents when water contents are greater than a particular water content identified herein as the transitional water content. This transitional water content varies from 1.5 to 1.9 times w_L. It is about $1.5w_L$ for bentonite, $1.6w_L$ for Bangkok clay and $1.9w_L$ for kaolin. This transitional water content increases with decreasing the free swell ratio, FSR. The slight variation of the transitional water content is affected by the clay fabric. The contribution of diffuse double layer to the shear behavior dominates for montmorillonitic or swelling soils (Sridharan et al., 1986). But for low swelling clay (kaolin), the particles associate with each other in an edge-to-face manner (van Olphen, 1963); i.e. the clay exhibits an open flocculated fabric with greater shear strength. Even at the same stress state (w/w_L), the kaolin slightly possesses higher viscosity than the swelling clays and hence more water in kaolin is required to have the same viscosity.

Besides the addition of the air bubble, the unit weight can be reduced by adding fly ash (FA). Figure 4 shows the relationships between unit weight and FA replacement of the lightweight cemented clay at the same w/w_L of 3 and cement content of 15%. The unit weight decreases with increasing the FA replacement. This means that the low specific gravity of FA plays greater role on the reduction in unit weight.

Based on the phase diagram, the unit weight (in kN/m^3) was proposed in terms of water content, cement content and void/cement ratio by the following equation:

$$\gamma = \frac{\left(\dfrac{G_c G_s \gamma_w^2 (1+w)}{C} + G_c \gamma_w\right)}{\left(\dfrac{G_c \gamma_w}{C} + 1\right)} - (V/C)\left(\frac{G_s \gamma_w (1+w)}{\dfrac{G_c \gamma_w}{C} + 1}\right) \qquad (1)$$

where w is water content (decimal), G_c, G_s are the specific gravity of cement and soil, respectively, γ_w is unit weight of water (kN/m^3), C is cement content (kg/m^3) and V/C is the void/cement ratio, which is the volume of void to the volume of cement in the mix. The theoretical derivation of the equation is referred to Horpibulsuk et al. (2012c). The equation was developed based on the assumption that all air bubbles (air foam) enter into the pore space when mixed with cement and clay.

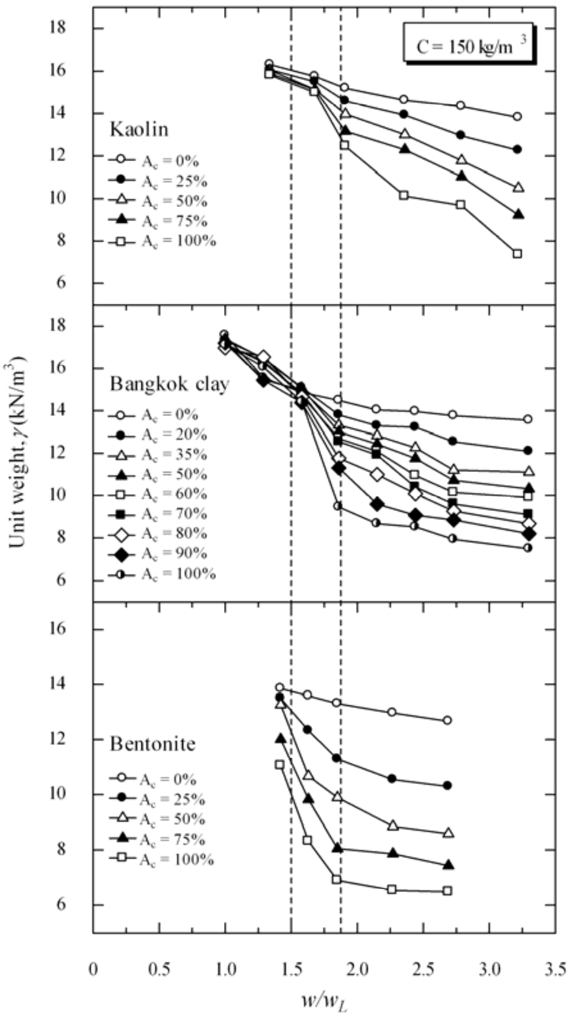

Figure 3 Effect of air foam on unit weight of air-cement-admixed clays at different water contents (Horpibulsuk et al., 2012c)

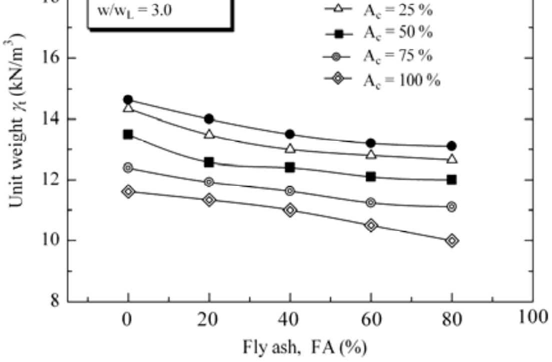

Figure 4 Effect of FA replacement on unit weight of air-cemented clays at different water contents (Horpibulsuk et al., 2013c).

Figure 5 shows the comparison between the predicted and measured unit weight of lightweight cemented Bangkok clay at different water contents and air contents for high and low cement contents (C = 400 and 150 kg/m^3). The predicted unit weights are generally lower than the measured ones because all the air foams cannot enter into the pore space due to the viscosity of the clay. Because the viscosity decreases as the clay-water content increases, the prediction error decreases with increasing water content.

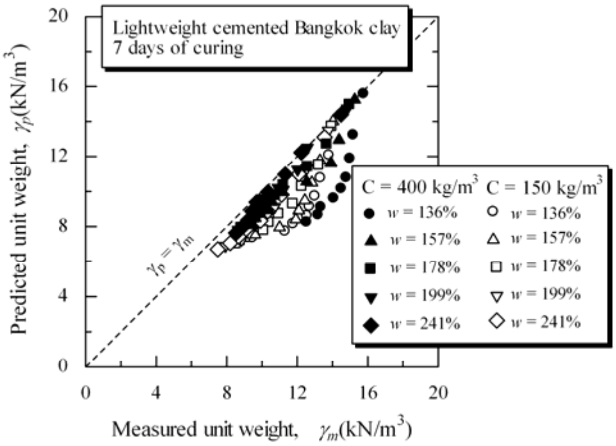

Figure 5 Predicted and measured unit weight of lightweight cemented Bangkok clay (Horpibulsuk et al., 2012c)

2.2 Strength

For soft clay admixed with cement, the clay-water/cement ratio, w_c/C was proved as the prime parameter governing engineering properties (Miura et al., 2001; Horpibulsuk and Miura, 2001 and Horpibulsuk et al., 2005). Horpibulsuk et al. (2003; 2011a, b and 2012b) successfully employed this parameter to develop a generalized strength equation based on Abrams' law (Abrams, 1918). Consoli et al. (2007) extended the clay-water/cement ratio hypothesis to analyze the strength development in compacted (unsaturated) cement-stabilized sand. They proved that the V/C is the key parameter controlling the strength development in cement-stabilized sand. This parameter was then successfully adopted to analyze the strength development in lightweight cemented clays (Horpibulsuk et al. 2012c and 2013a).

Figures 6 to 8 show the stress~strain relationships in unconfined compression tests of samples with different air contents and cement contents but with the same V/C values of 30 and 10, at 14 days of curing. Figure 6 is for the lightweight cemented kaolin at water content of 88%. Figure 7 is for the lightweight cemented Bangkok clay at water contents of 136%. Figure 8 is for the lightweight cemented bentonite at water contents of 170%. It is noted that as V/C decreases, the compressive strength increases. The lightweight cemented samples with the same V/C exhibit the similar stress-strain behavior. To conclude, the V/C controls compressive strength for a particular water content, while the unit weight does not, which is different from natural clays. The fabric (arrangement of clay particles, clusters and pore spaces) reflected from both air foam content and water content is taken into consideration by the void volume while the inter-particle forces (levels of cementation bond) are governed by the input of cement (cement volume).

The reduction in unit weight by both increasing water content and air content is generally associated with the reduction in strength. The advantage of adding air foam over adding water to make the lightweight cemented clay in terms of strength development is illustrated in Figure 9. It shows the relationships between strength and unit weight of lightweight cemented samples for different water contents and air contents but the same input of cement. For a same range of unit weight, the lightweight cemented samples with lower water content but higher air content have higher strength than those with higher water content but lower air content. For example, at unit weight of 15 kN/m^3, the strengths are 25 kPa, 50 kPa and 210 kPa for 198%, 132 and 99%, respectively.

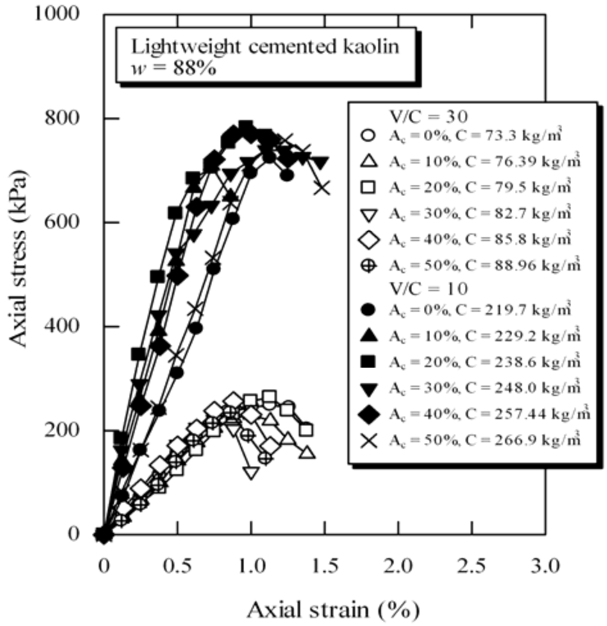

Figure 6 Stress-strain relationship of air-cement-admixed kaolin at w = 88% (Horpibulsuk et al., 2013a)

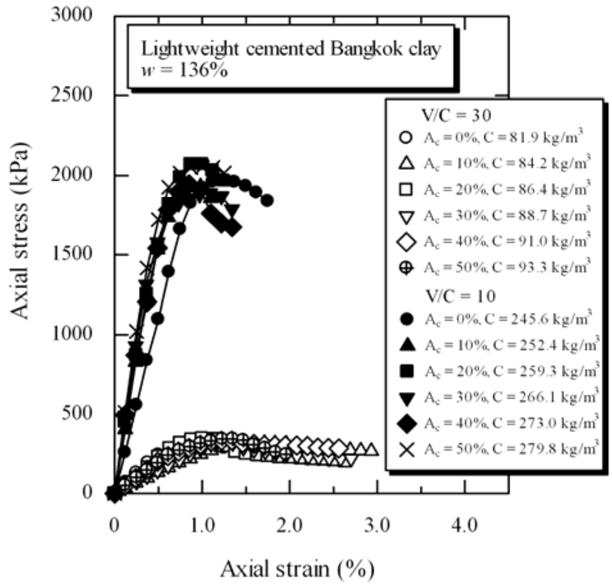

Figure 7 Stress-strain relationship of air-cement-admixed Bangkok clay at w = 136% (Horpibulsuk et al., 2013a)

Because the V/C is the prime parameter governing the engineering properties in elastic range (at low effective confining stress), it is possible to develop a relationship between strength and V/C for a particular curing time. Figure 10 shows the relationship between strength and V/C at 7 days of curing of the lightweight cemented Bangkok clay as an example to guarantee the applicability of the V/C. The unique relationship between strength and V/C can be found for a given initial water content at different cement contents and air contents.

For a mix design purpose, the relationship between strength and V/C at a certain water content is advanced on the basis of Abrams' law (1918):

$$q_u = \frac{A}{(V/C)^B} \qquad (2)$$

where q_u is the unconfined compressive strength, *V/C* is the void/cement ratio, and *A* and *B* are constants. This equation when A_c = 0 yields the same equation proposed by Horpibulsuk et al. (2011a, b and 2012b). The *A*-value is dependent upon the clay type, curing time and air content. As the water content increases, the *A*-value decreases. The *B*-value is practically constant and equal to 1.26 to 1.29, which is the typical values for cemented non- to low-swelling clays (Horpibulsuk et al., 2011b). It was suggested to take the *B*-value as 1.27 for the cemented non- to low-swelling clays (Horpibulsuk et al., 2011a, b and 2012b). To employ Eq. (2) for assessing the strength of any lightweight cemented clay at different void/cement ratios (air content and cement content), the parameters *A* and *B* must be predetermined. This task can be achieved by a back-calculation of at least two trial strength data.

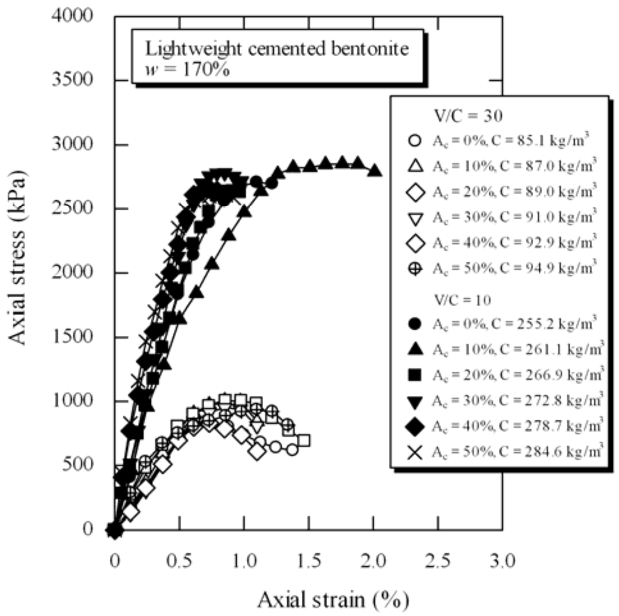

Figure 8 Stress-strain relationship of air-cement-admixed bentonite at w = 170% (Horpibulsuk et al., 2013a)

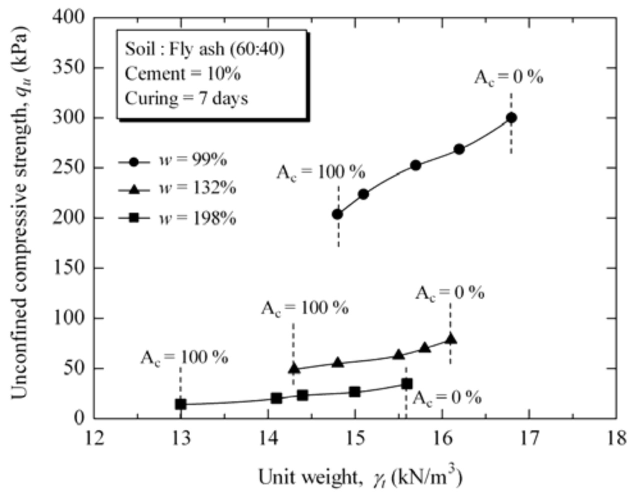

Figure 9 Relationship between strength and unit weight of lightweight cemented clay samples with different water contents for the same cement content (Horpibulsuk et al., 2013c)

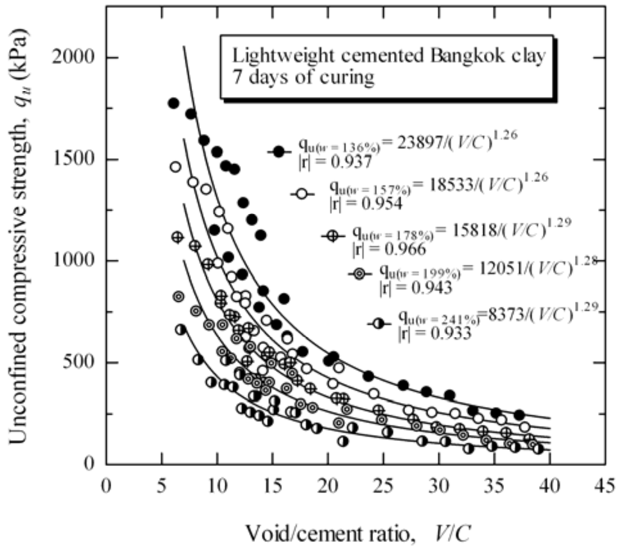

Figure 10 Analysis of strength development in lightweight cemented Bangkok clay using *V/C* (Horpibulsuk et al., 2013a)

2.3 Compressibility

Figure 11 shows the typical compression curves of 20% cement Bangkok clay at different water contents and air contents. The water content and air content affect significantly the fabric (pore space among the clay particles). The higher the water content and the air content, the greater the void ratio. The samples with larger void ratio possess lower yield stress and undergo higher rate of destructuring. The compression strain is low (about 0.05) up to the yield stress, σ'_y, due to the contribution of structure (Horpibulsuk et al., 2012c). Beyond the yield stress, there is sudden compression of relative high magnitude, which is indicated by the steep slope and attributed to the destructuring.

The void ratio at post-yield state can be expressed as follows.

$$e = e_R + e_s \qquad (3)$$

where e represents the void ratio for a lightweight cemented clay, e_R is the void ratio for the corresponding destructured clay and e_s is the additional void ratio attributed to soil structure. e_R is the void ratio supported by the intrinsic soil fabric of destructured (completely remolded) sample. The additional void ratio is expressed in the form (Liu and Carter, 1999 and 2000 and Horpibulsuk et al., 2013b):

$$e_s = e_{sy}\left(\frac{\sigma'_y}{\sigma'_v}\right)^b + e_{sr} \qquad (4)$$

where e_{sy} is the additional void ratio corresponding to the yield stress and e_{sr} is the residual additional void ratio sustained by soil structure that cannot be eliminated by an increase in effective vertical stress (when σ'_v approaches infinity, $e_s = e_{sr}$). Because the soil structure remains even at very high effective vertical stress beyond yield (Horpibulsuk et al., 2004b), e_{sr} is never null. e_{sy} is determined by considering that when $\sigma'_v = \sigma'_y$:

$$e_{sy} + e_{sr} = e_y - e_{Ry} \qquad (5)$$

where e_y and e_{Ry} are the void ratios of cemented and destructrured curves corresponding to the yield stress, respectively.

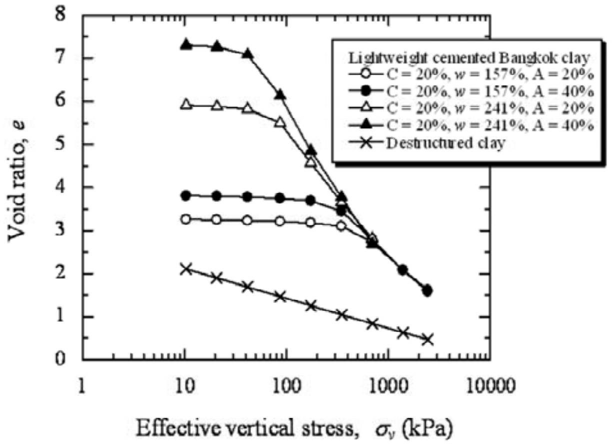

Figure 11 Influence of water content and air content on the compressibility (Horpibulsuk et al., 2013b)

Figure 12 shows the applicability of the destructuring framework to the prediction of the compression curves of lightweight cemented clays with a wide range of swelling potential: kaolin, Bangkok clay and bentonite. The virgin compression curves can be well defined by the two main parameters, b and e_{sr}. Overall, the predicted and measured compression curves are in very good agreement. The void ratio, yield stress and swelling potential are the influential factors, which govern the b and e_{sr} values. The role of water content, air content and yield stress on the parameters b and e_{sr} can be referred to Horpibulsuk et al. (2013b).

3. PAVEMENT RECYCLED MATERIAL

Laboratory strength development in pavement recycled material has been investigated based on the clay-water/cement ratio hypothesis (Horpibulsuk et al., 2006 and Chinkulkijniwat and Horpibulsuk, 2012). The analysis is similar to that presented in the previous section for lightweight cemented clay. This section will then focus on the field strength development. Understanding of field strength development is useful for construction control and pavement design. The field strength data of stabilized pavement materials were gathered from 4 sites of roadway (3 sites in Phetchabun province and 1 site in Utaradit province) remedied by the pavement recycling technique. The input cement for each site was obtained from trial modified Proctor tests at the OWC to attain a 7-days strength of 2750 kPa for Phetchabun 1, Phetchabun 3 and Utaradit, and of 3500 kPa for Phetchabun 2. About 20 cm thickness of damaged pavement was dug up and mixed with cement and water by the recycling machine. At each station 150 meters apart, soil-cement mixture was collected from the machine and manually compacted in the laboratory. These samples are herein referred to as field hand-compacted samples. Immediately after mixing, the soil-cement mixture was field compacted by a vibratory roller, going back and forth for 3 passes and followed by a pneumatic roller for 5 passes and a smooth wheel roller for 3 passes. The vibratory roller supplies frequency of 1500 cycles per minute. The pneumatic roller consists of 6 rubber tires with contact pressure under the tires of about 600 kPa. The smooth wheel roller employs 2 smooth metal rollers with ground contact pressure of about 350 kPa. This field compaction results in the ratio of dry unit weight ($\gamma_{dfr}/\gamma_{dfh}$) at each station higher than 95%. The γ_{dfr} is the dry unit weight of field-mixed and roller-compacted samples, which is obtained from sand cone test within 1 hour after field compaction. The γ_{dfh} is the dry unit weight of field hand-compacted sample at each station. This high $\gamma_{dfr}/\gamma_{dfh}$ indicates the high field quality controls. For each station, the field-mixed and roller-compacted samples were taken by a coring cutter from the improved pavement after 7, 14 and 28 days of curing to conduct the unconfined compression test. These samples were trimmed to a ratio of diameter to height of 1.0 which is the same as those prepared in the laboratory. They are herein further referred as field roller-compacted samples. Since the samples are hard and carefully cored and trimmed, the effect of sample disturbance on the strength can be neglected.

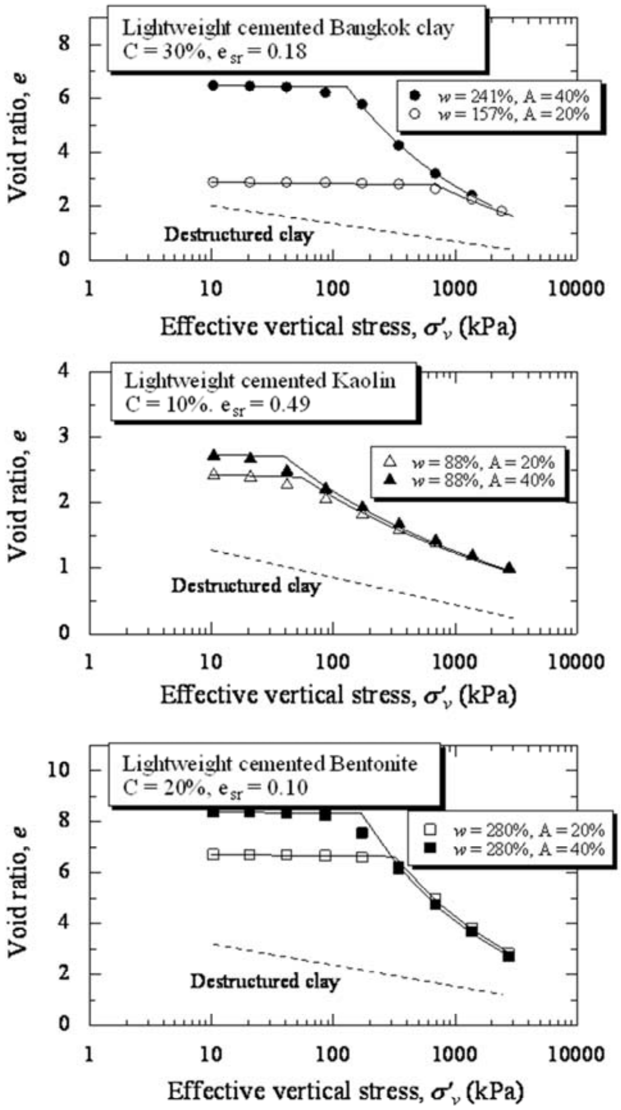

Figure 12 Measured and predicted compression curves (Horpibulsuk et al., 2013b)

Unconfined compressive strengths from the three different cement-stabilized samples, field hand-compacted strength (q_{ufh}), field roller-compacted strength (q_{ufr}) and laboratory strength (q_{ul}), were statistically analyzed to evaluate the mechanism influencing the field strength development. The SPSS software was applied for this objective. Variation of these three strengths along the test sites is illustrated in Figure 13. The diversity of the field hand-compacted from the laboratory strengths is probably attributed to the non-uniformity in mixing cement with the dug pavement materials in the mixing machine while the diversity of the field roller-compacted from field hand-compacted strengths is due to the differences in compaction method and curing condition. The dashed line represents the laboratory design strength (q_{ul}). Table 1 summarizes descriptive statistics of q_{ufh} and q_{ufr} . The Kolmogorov-Smirnov test for normal distribution for both q_{ufh} and q_{ufr} is also presented in Table 1. None of q_{ufh} and q_{ufr} differs significantly from the normal distribution. The t-test was performed to compare the mean values of q_{ufh} with q_{ufr} (Table 2). Results indicate that the variances between q_{ufh} and q_{ufr} were homogeneous at a significant level of 0.123 based on the Levene's test. Thus, the t-value with equal variance was used. The significant level of 0.000 was found for 2-tailed test, indicating that the field hand-compacted strengths (mean value = 2872.43 kPa) are significantly higher than the field roller-compacted strengths (mean value = 2243.22 kPa).

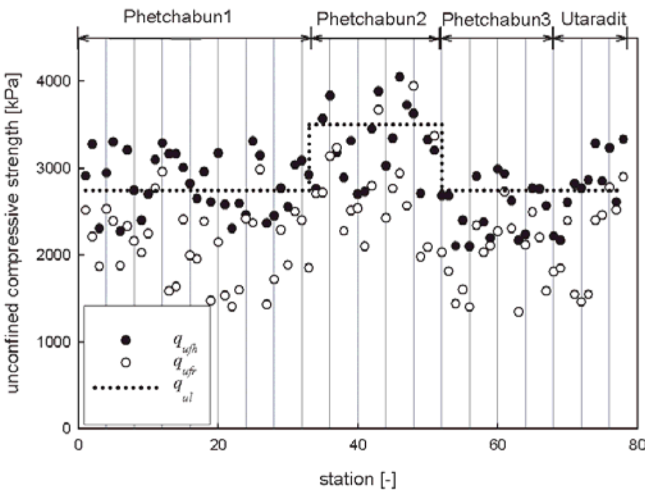

Figure 13 Field roller-compacted and field hand-compacted strength after 7 days of curing.

Table 1 Descriptive statistic and Kolmogorov-Smirnov tests for the q_{ufh} and q_{ufr}

	q_{ufh} Statistic	q_{ufr} Statistic
Mean	2872.43	2243.22
5% Trimmed Mean	2857.76	2217.29
Median	2835.00	2273.00
Std. Deviation	438.90	543.74
Minimum	2100.00	1342.50
Maximum	4045.20	3941.30
Range	1945.20	2598.80
Skewness	.351	.534
Kurtosis	-.152	.459
Kolmogorov-Smirnov Z	.588	.678
Asymp. Sig. (2-tailed)	0.879	.748

Table 2 Independent samples test to compare means of the q_{ufh} and q_{ufr}

	Levene's test for equality of variances		t-test for equality of means		
	F	Sig.	t	df	Sig. (2 tailed)
Equal variances assumed	2.404	.123	7.952	154	.000
Equal variances not assumed			7.952	147.2	.000

A variation of the q_{ufh} compared with the q_{ul} for each site was studied. The t-test result (Table 3) shows that the significant (2-tailed) levels are greater than 0.05 at most construction sites. This result indicates the equality between q_{ul} and q_{ufh} . It is thus concluded that the mixing process plays a minor role on the field strength reduction in pavement recycling technique. In other words, the in-situ mixing by the machine is practically uniform and acceptable. This conclusion contradicts to that of Horpibuksuk et al. (2004c, 2011b and 2012c) and Larsson et al. (2005) in case of deep mixing columns. In fact, the uniformity of deep mixing is rarely achieved due to the viscosity of clay and very high in-situ effective overburden stress. The flow ability of the recycled material (cement stabilized coarse-grained soil) is much higher than that of fine-grained soil. As such, the shallow stabilization of the recycled pavement material is more uniform.

Table 3 Equality test between q_{ul} and q_{ufh} at each studied sites

Sites	Mean (q_{ufh})	Std. deviation	Test value (q_{ul})	t	df	Sig. (2-tailed)
Phetchabun1	3834.170	332.629	2750	1.454	32	0.156
Phetchabun2	3294.484	431.120	3500	-2.023	17	0.059
Phetchabun3	2498.558	310.580	2750	-3.634	18	0.002
Utaradit	2968.750	270.420	2750	2.288	7	0.056

The large difference between q_{ufh} and q_{ufr} (Table 2) indicates that the compaction and curing conditions play a great role on the field strength development. Regarding the compaction condition, the compaction method and the compaction effort might affect the field strength. However, the compaction was performed by the vibratory and pneumatic rollers, which is a widely used method for highway and pavement works. These rollers are known as effective in compacting granular material and generally utilized in field compaction process. Moreover, the compaction was well controlled as indicated by very high relative density of over 95%. Hence, the compaction condition is nothing to whine about. In practice, the curing condition is only the major factor that can be taken care. Field curing condition is currently done by spraying water on to the recycled pavement twice a day. This seems not enough for Thailand, a tropical country. The curing water must be satisfactorily provided to attain higher field strength.

For the field curing condition as currently done, the difference between the laboratory and field strengths was investigated via q_{ufr} to q_{ul} ratios to recommend the appropriate factor of safety (field strength reduction). Distribution of the strength ratios along the test sites is illustrated in Figure 14. Descriptive statistic and Kolmogorov-Smirnov goodness-of-fit q_{ufr} / q_{ul} ratios are presented in Table 4. The Kolmogorov-Smirnov test result indicates that the normal distribution of q_{ufr} / q_{ul} is acceptable with probability of 95%. The 95th percentile is 1.05 indicating the magnitude of q_{ufr} is less than the magnitude of q_{ul} for the most of the population. The 5th percentile is 0.52 meaning that 95% of the population has q_{ufr} greater than 0.52 q_{ul} . Hence, factor of safety of 2.0 is recommended.

In mix design process, many laboratory trial mixes are carried out to acquire the laboratory strength that compensates for the field strength reduction. For the current practice in Thailand, the safety factor of 2.0 is recommended. No consideration of the field strength reduction (factor of safety) in mix design might result in the pavement deterioration. Proper water content and input of cement obtained from the laboratory mix design are then assigned to field stabilization. The higher field strength of pavement recycling technique can be achieved by satisfactory curing water.

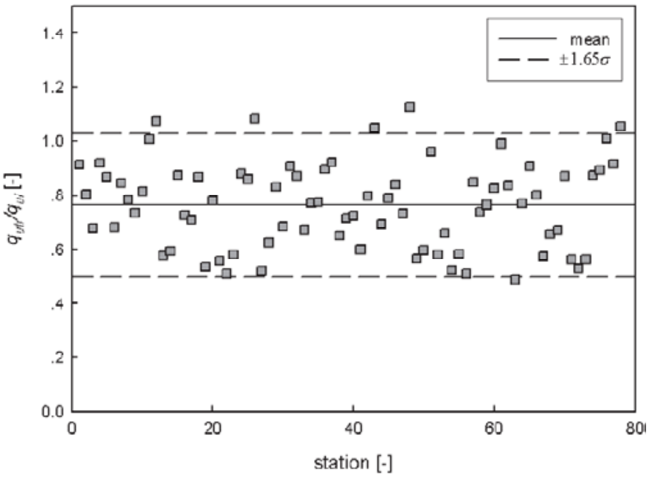

Figure 14 Distribution of the strength ratio q_{ufr} / q_{ul}

Table 4 Descriptive statistics and Kolmogorov-Smirnov goodness-of-fit for q_{ufr} / q_{ul}

Statistics	Values
N	78
Mean	.7640
Std. Deviation	.1599
Kolmogorov-Smirnov Z	.805
Asymp. Sig. (2-tailed)	.536
5th Percentile	0.5194
95th percentile	1.0547

4. CONCLUSIONS

Research on lightweight cemented clay and recycled pavement material, which are commonly used in Thailand, is reviewed in this paper. The presented test results are mainly unconfined compressive strength and compressibility. The durability characteristic, which is one of the vital parameters for long term design, is thus an interesting topic for further research. The following conclusions can be drawn.

1. The clay viscosity prevents the air entry into the clay slurry. The water content of about 1.5 to 1.9 times the liquid limit is proved as the optimum water content for producing the lightweight cemented clay.
2. For a given soft clay at a particular water content, the compressive strength of lightweight cemented clays increases with the decrement of *V*/*C*. The stress-strain response is practically the same as long as the *V/C* value is identical.
3. Based on the void/cement ratio and Abram's law, a relationship between strength and void/cement ratio for a particular water content and curing time of lightweight cemented clays is proposed. The relationship is useful in estimating the laboratory strength wherein air content and cement content vary over a wide range by a few trial tests. It also facilitates the determination of proper quantity of cement to be admixed for different air contents to attain the target strength. The formulation of the proposed relationship is on sound principle and developed from distinct clays (non- to high swelling clays). The *A* and *B* values can be determined by a back-analysis of at least two trial strength data. It is thus possibly applicable for various clays.
4. The destructuring framework is capable of predicting the compression curve of lightweight cemented clays with various swelling potentials under different conditions of water content, air content and cement content. This framework is simple and only two parameters with physical meaning are required for its definition i.e., *b* and e_{sr}.
5. The field strength of the pavement recycled material is significantly lower than the laboratory strength. A ratio between field and laboratory strengths is normally distributed. The curing condition is the major factor controlling the field strength development. Based on this study (current curing practice in Thailand), the 5th percentile of the field to laboratory strength ratio is 0.52. Hence, it is logical to assign a factor of safety of 2.0 for determining the input of cement. For engineering and economic viewpoints, the satisfactory curing water is required after pavement stabilization.

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