Aug 11th - Aug 16th

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6th International Conference on
Case Histories in Geotechnical Engineering, Arlington, VA, August 11-16, 2008

COMPRESSIVE STRENGTH OF REPAIRED ROAD BY RECYCLING TECHNIQUE OF PAVEMENT MATERIALS

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ABSTRACT

The Department of Highways, Thailand, has used the pavement recycling technique to restore damaged pavement since 1965. This technique is economical because cement is readily available at reasonable cost in Thailand. From this study, it is found that the field roller-compacted strength, q_{ufr} is lower than the laboratory strength, q_{ul} under the same dry unit weight, soil-water/cement ratio and curing time due to several field factors. The ratio q_{ufr}/q_{ul} varies from 50 to 100%. Non-uniformity in mixing soil with cement is realized by the ratio of field hand-compacted strength to laboratory strength, q_{ufh}/q_{ul} ranging from 0.75 to 1.2. For most data, the field roller-compacted strength is 55 to 100% the field hand-compacted strength. This might be caused by the difference in compaction method and curing condition between laboratory and field stabilization. From this field observation and the proposed model, a practical procedure for repairing damaged roads using the pavement recycling technique is introduced. The procedure consists of the determination of cement content, the execution of the field stabilization and the examination of the field strength. It can save on sampling and laboratory testing and hence cost.

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 compact the in-situ soil mixed with 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. In addition, the Department of Highways, Thailand, has used this method of cementation to restore damaged pavement since 1965. This method is designated as the pavement recycling technique. The damaged pavement would be dug up and mixed with cement. The soil-cement mixture would be immediately field compacted by rollers as illustrated in Fig.1. 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.

Recently, the effects of water content, cement content and compaction energy on the laboratory strength development of cement stabilized coarse-grained material have been researched by Horpibulsuk et al. (2006a and b). They reveal that the strength development at a specific curing time is dependent upon soil-water/cement ratio, w/C, which is defined as the ratio of soil water content to cement content (both reckoned in percentage). They have also proposed a phenomenological model for predicting strength development in terms of w/C, and curing time. The proposed model is useful for assessing the strength development wherein water content, cement content and compaction energy vary over a wide range. Only the test result of a single laboratory trial is needed.

In addition to laboratory study, field observations are also necessary to investigate the field strength development. This leads to the understanding of the difference between field and laboratory strengths and consequently, the estimate of the optimal input of cement to achieve the target field strength. The strength difference between laboratory and field stabilization has been investigated by Horpibulsuk et al. (2004). They have concluded that one of the main factors controlling the field strength development is non-uniformity in mixing soil with cement. For a specific volume of soil stabilized by cement, the strength of the whole stabilized material is not uniform due to the variation in amount of cement during mixing.

At the service time, the field strength must meet the designed strength. To facilitate the determination of proper quantity of cement to be stabilized, which compensates for strength reduction in the field, the engineer needs to understand the field strength development. A stepwise procedure for repairing damaged roads is introduced in this paper. It consists of determination of cement content, execution of field stabilization and examination of field strength.

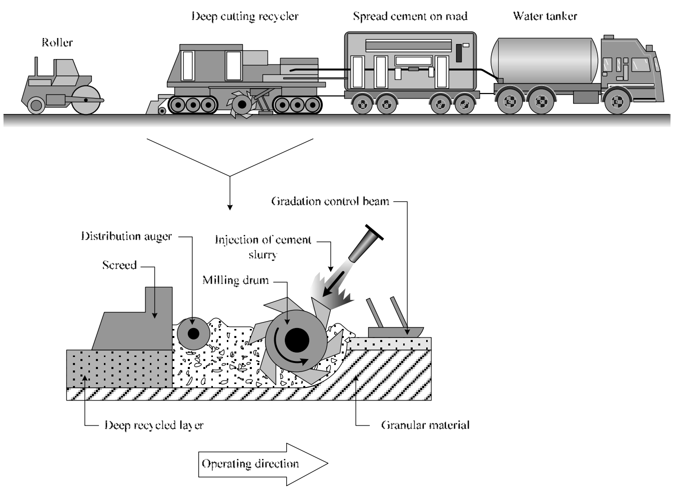

Fig.1 Typical characteristics of pavement recycling technique.

FIELD INVESTIGATION

The field study investigates the strength reduction due to several field factors such as non-uniformity in mixing soil with cement, and difference in compaction method and curing condition between laboratory and field stabilization. The pavement recycling was performed in Phetchabun (3 sites) and Utaradid (1 site) provinces, Thailand. The input of cement for each site was obtained from trial modified proctor tests at the optimum water content to attain a 7-day strength of 2750 kPa for Phetchabun 1, Phetchabun 3 and Utaradid, and of 3500 kPa for Phetchabun 2 as shown in Table 1. About 20-cm thickness of the damaged pavement was dug up and mixed with cement and water. At each station 150 meters apart, soil-cement mixture was collected, thoroughly mixed by hand and passed through a 19-mm sieve to manually compact in the laboratory. These samples are herein referred to as field hand-compacted samples. The water content (w_{fh}) and the dry unit weight (γ_{dfh}) of the field hand-compacted samples were controlled to be within 2% of the optimum water content (OWC) and higher than 95% maximum dry unit weight (γ_{dmax}), respectively as shown in Fig. 2 to Fig. 5. The OWC and γ_{dmax} are 6.4% and 23.05 kN/m^3 for Phetchabun 1, 6.3% and 22.63 kN/m^3 for Phetchabun 2, 5.7% and 22.61 kN/m^3 for Phetchabun 3, and 5.9% and 22.54 kN/m^3 for Utaradid. Immediately after mixing, the soil-cement mixture was 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 kN/m^2. The smooth wheel roller employs two smooth metal rollers with ground contact pressure of about 350 kN/m^2. The vibratory and pneumatic rollers are effective in compacting granular material containing a small amount of fines whereas the smooth wheel roller is used to provide a smooth finished grade. 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 (presented in Figs. 2 to 5). This ratio at various stations from the four sites is presented in Fig. 6. It is seen that this ratio ranges from 95 to 105% for most samples showing the effectiveness of the field compaction.

Table 1 7-day trial mix for determination of input of cement for the tested sites.

Site	OWC (%)	C (%)	q_{ul} (kPa)	Fitting curve	Designed C (%)
A	6.4	1	1700		
	6.4	2	2355		
	6.4	3	3300	$q_u = 835.57C + 796.33$	2.3
	6.4	4	4100	$R^2 = 0.994$	
	6.4	5	5170		
	6.4	6	5700		
B	6.3	1	1650		
	6.3	2	2400		
	6.3	3	3700	$q_u = 884.86C + 809.33$	3.0
	6.3	4	4375	$R^2 = 0.987$	
	6.3	5	5410		
	6.3	6	5903		
C	5.7	1	1742		
	5.7	2	2538		
	5.7	3	3145	$q_u = 612.46C + 1260.40$	2.4
	5.7	4	3846	$R^2 = 0.991$	
	5.7	5	4353		
	5.7	6	4800		
D	5.9	1	1730		
	5.9	2	2480		
	5.9	3	3500	$q_u = 754.57C + 1044.00$	2.3
	5.9	4	4000	$R^2 = 0.989$	
	5.9	5	5000		
	5.9	6	5400		

Remarks: Site A= Phetchabun 1
Site B= Phetchabun 2
Site C= Phetchabun 3
Site D= Utaradid

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 referred to 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. The field roller-compacted strength would be compared with laboratory and field hand-compacted strengths to investigate the factors controlling strength reduction.

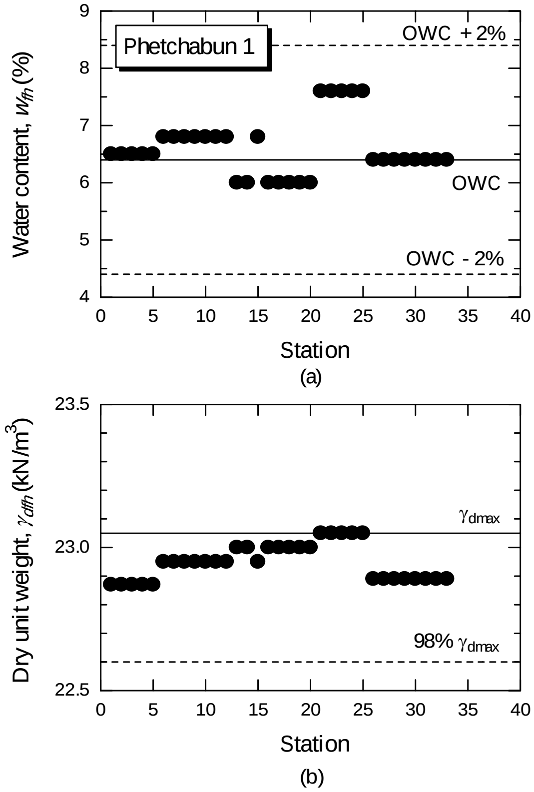

Fig. 2 Dry unit weight and water content of the field-hand compacted samples at various stations for Phetchabun 1.

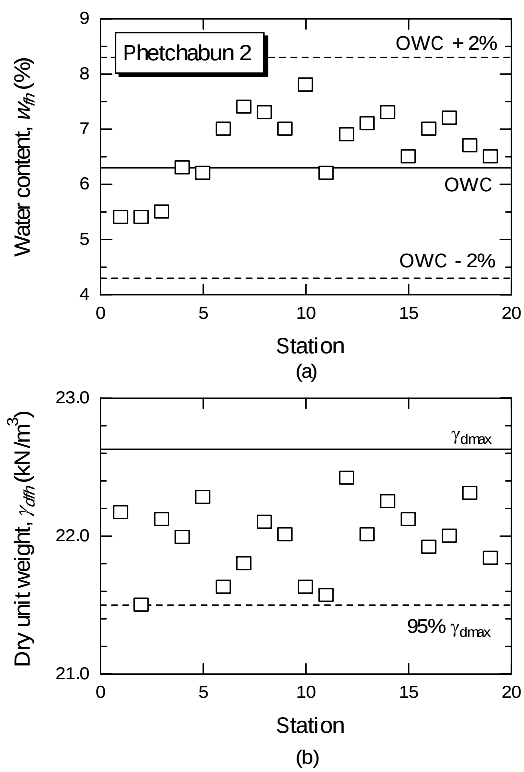

Fig. 3 Dry unit weight and water content of the field-hand compacted samples at various stations for Phetchabun 2.

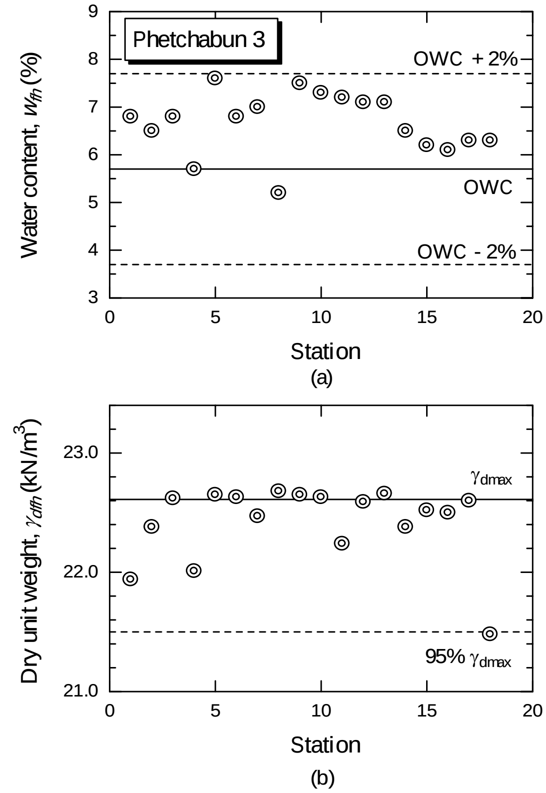

Fig. 4 Dry unit weight and water content of the field-hand compacted samples at various stations for Phetchabun 3.

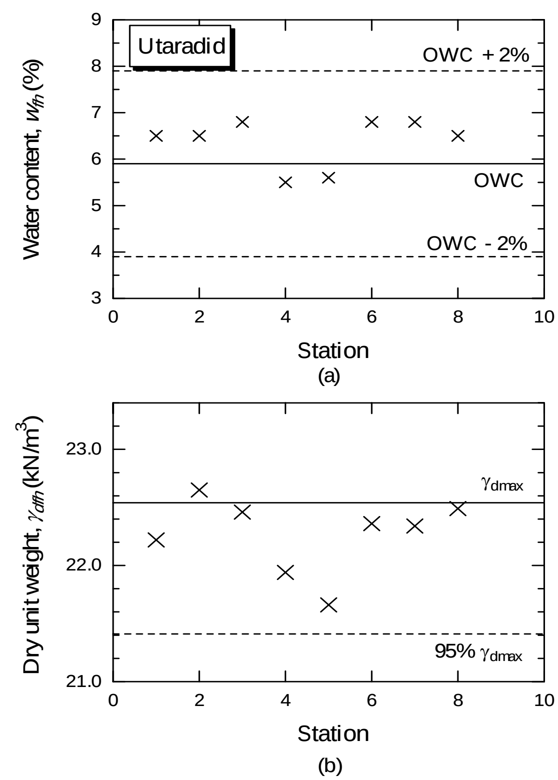

Fig. 5 Dry unit weight and water content of the field-hand compacted samples at various stations for Utaradid.

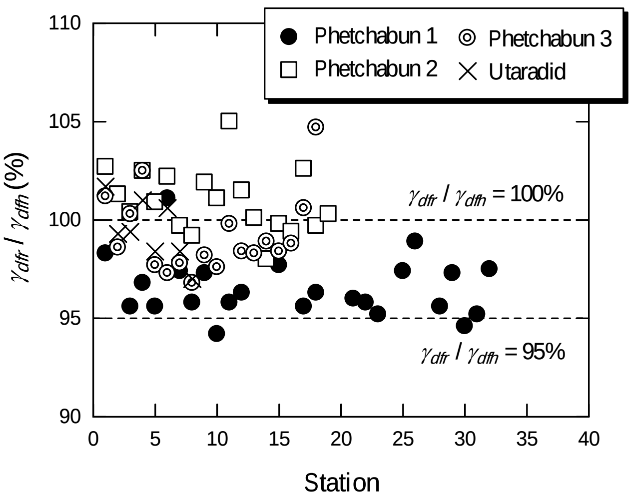

Fig. 6 Ratio of dry unit weight at various stations.

TEST RESULT

Fig. 7 through 10 shows the field hand-compacted strength (q_{ufh}) and field roller-compacted strength (q_{ufr}) compared with the laboratory strength (q_{ul}) for the four sites. Both field hand-compacted and laboratory samples were compacted under the same energy and cement content with practically the same water content and dry unit weight (*vide* Figs. 2-5). It is however revealed that the field hand-compacted strength (q_{ufh}) is between 0.75 and 1.2 times laboratory strength (q_{ul}). The variation in strength (q_{ufh}/q_{ul}) is probably attributed to the non-uniformity in mixing soil with cement. Although effectiveness of the compaction is generally high enough ($\gamma_{dfr}/\gamma_{dfh}$ > 95%), test result (Figs. 7-10) shows large difference between field roller-compacted and field hand-compacted strengths. For most data points, the field roller-compacted strength ranges from 0.55 to 1.0 times field hand-compacted strength as shown in Fig. 11. The field hand-compacted samples are mixed by the machine at the location where the field roller-compacted samples are cored. Thus both samples have the same water content and cement content, and practically the same dry unit weight (95% < $\gamma_{dfr}/\gamma_{dfh}$ < 105%) but different compaction method and curing condition. The different compaction method causes the difference in soil structure as explained by Day and Daniel (1985) and Prapaharan *et al.* (1991). The field curing causes more loss of water than laboratory curing due to higher field temperature. The loss of water during field curing might result in incomplete hydration and minor cracks in the field roller-compacted samples. These two factors result in the field-roller compacted strength being lower than the field-hand compacted strength. To conclude, the field strength reduction is caused by the non-uniformity in mixing soil with cement, and the difference in compaction method and curing condition between the laboratory and the field. Due to these factors, the ratio q_{ufr}/q_{ul} ranges from 50-100% as also shown in Figs. 7-10. Since the study is at the optimum water content, this finding might not be valid for other conditions of water content.

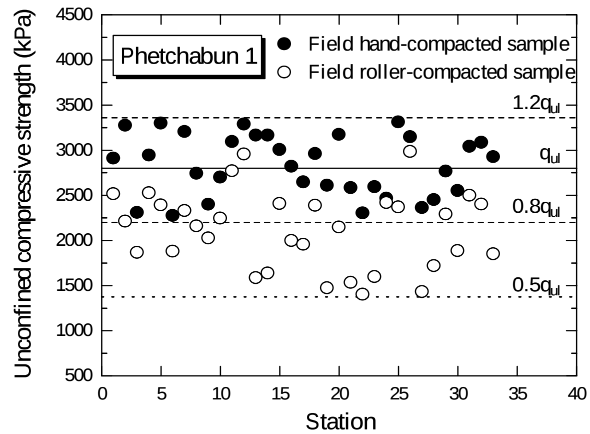

Fig. 7 Field roller-compacted and field hand-compacted strengths at 7 days of curing for Phetchabun 1.

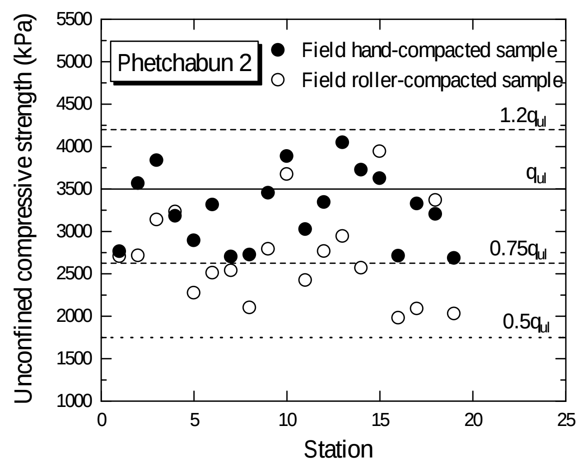

Fig. 8 Field roller-compacted and field hand-compacted strengths at 7 days of curing for Phetchabun 2.

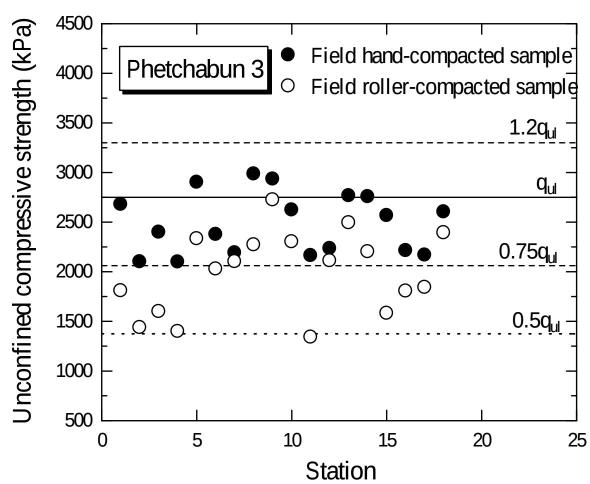

Fig. 9 Field roller-compacted and field hand-compacted strengths at 7 days of curing for Phetchabun 3.

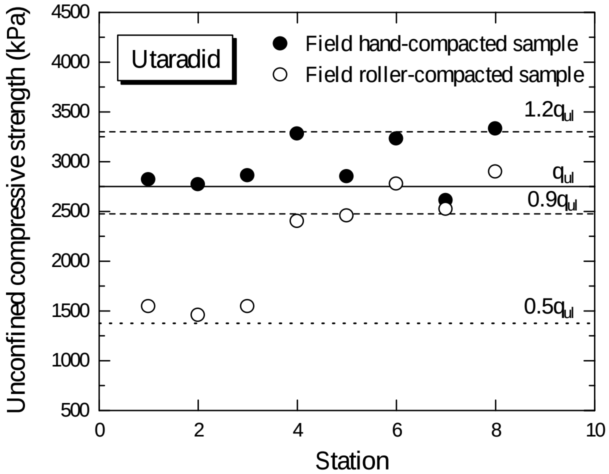

Fig. 10 Field roller-compacted and field hand-compacted strengths at 7 days of curing.

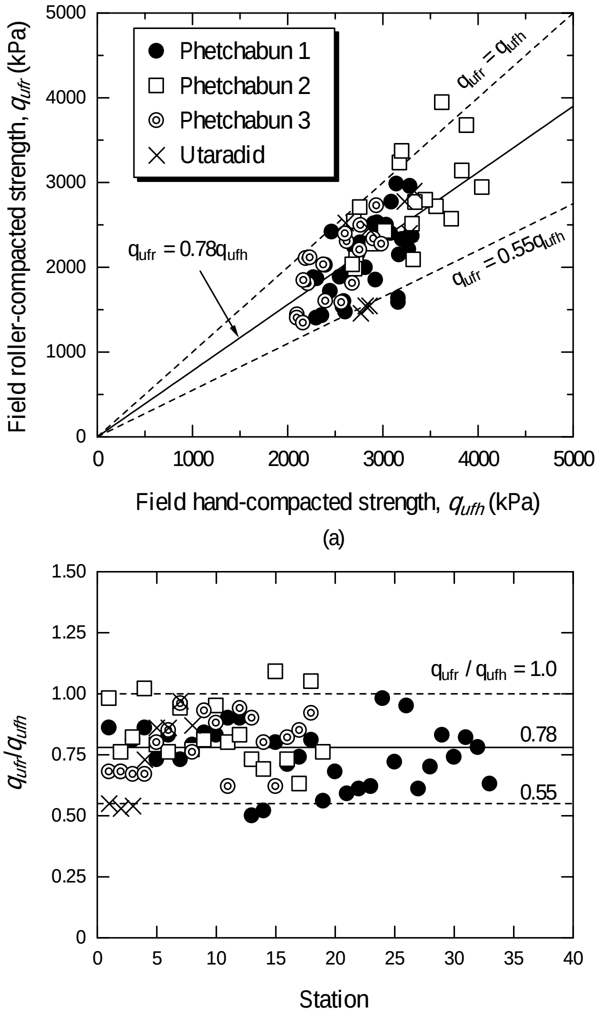

Fig. 11 Relationships between field roller-compacted, field hand-compacted and laboratory strengths.

SUGGESTED PROCEDURE FOR PAVEMENT RECYCLING TECHNIQUE

Based on the laboratory and field study, the suggested procedure of repairing damaged roads by the pavement recycling technique is summarized in Fig. 12 and presented as follows.

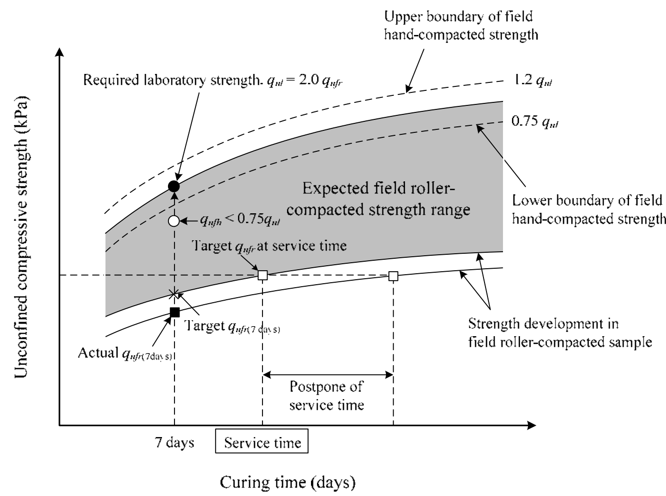

Fig. 12 Suggested procedure for pavement recycling technique.

<u>Determination of input of cement compensating for field factors</u>

1. From the target field strength at service time (open square symbol), estimate the target field strength at 7 days of curing (Target $q_{ufr(7\ days)}$) (cross symbol) which can be approximated using strength equation proposed by Horpibulsuk *et al.* (2006a and b).
2. Determine the laboratory strength at 7 days of curing ($q_{ul(7days)}$), using the field strength reduction of 2.0 (q_{ufr}/q_{ul} = 0.5) (black circle symbol).
3. Determine the cement content to attain the laboratory strength at 7 days of curing ($q_{ul(7days)}$) and service time at optimum water content and designed compaction energy. This task can simply be done by using the strength equation.

<u>Field execution and examination of field strength</u>

4. Take field soil-cement mixture to conduct the laboratory compaction test (field hand-compacted sample). The water content of the field hand-compacted samples must be within 2% of OWC.
5. Compact the field soil-cement mixture by rollers to achieve the ratio of dry unit weight higher than 95%.
6. Determine the field hand-compacted strength ($q_{ufh(7days)}$) of samples obtained from step 4 at 7 days of curing.
7. If the $q_{ufh(7days)} > 0.75q_{ul(7days)}$, it is concluded that the q_{ufr} meets the requirement.
8. If the $q_{ufh(7days)} < 0.75q_{ul(7days)}$, take cored sample to determine actual $q_{ufr(7days)}$.
   8.1 If the actual $q_{ufr(7days)}$ is higher than the target field strength (target $q_{ufr(7days)}$), the requirement is met.

8.2 If the actual $q_{ufr(7days)}$ is slightly lower than the target $q_{ufr(7days)}$ (black square), the service time of the station should be postponed to increase curing time.

8.3 If the actual $q_{ufr(7days)}$ is much lower than target $q_{ufr(7days)}$, this station must be re-improved.

CONCLUSION

A practical procedure for repairing the damaged road by the pavement recycling technique is introduced in this paper. The following conclusions can be drawn:

1. The field strength is lower than laboratory strength resulted from the non-uniformity in mixing soil with cement, and the difference in compaction method and curing condition between the laboratory and field stabilization. Due to these factors, the field roller-compacted strength is 0.5-1.0 times the laboratory strength for the same cement content, water content and dry unit weight.
2. The suggested procedure for repairing damaged roads by the pavement recycling technique is useful in terms of engineering and economical viewpoints. The procedure can save on sampling and laboratory testing and hence cost.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support provided to them by Thailand Research Fund and Siam City Cement Public Company Limited.

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