The Use of Lime Stabilization for Rural Road Rehabilitation in Cambodia

AUTHOR: **Stephen Eagle (**BSc., MSc)

Director
Fraser Thomas Partners
152 Kolmar Road
Papatoetoe
Auckland 2055
Tel 09 278 7078
Email: seagle@ftl.co.nz

Co-authors: **Christopher Tolley** (BSc, MBA, MIPENZ, MICE, MIHT, CPEng, IntPE)

Technical Director
Maunsell AECOM
47 George St
Auckland 1140
Tel 09 379 1299
Email: chris.tolley@maunsell.com

Presenter: **Stephen Eagle**

Abstract:

Since the signing of the Paris Accord in 1991 there has been intense investment and effort in road rehabilitation, of primary, district and rural roads throughout Cambodia. All too often, pavements have failed in the space of a year or two. In the case of rural roads, which amount to over 40,000 km in total, the cost of sealing is rarely justified and the norm is to use laterite, which can be distant and expensive, and always requires intensive maintenance and re-grading after each rainy season. The laterite soil is subject to wind erosion and the extra dust caused from this material is causing a major health problem. Lime is available in Cambodia and the authors have secured New Zealand Government funding to establish and demonstrate its value for rural roads, prepare standards and training manuals, and train a cadre of professionals to lead its wider adoption in the country. Potential benefits include greatly reduced road life cycle costs, ability to use more locally available materials, and reductions in dust emissions. This paper will present the background, findings from the trials, and outlook for the greater use of lime in the Cambodia road sector in general.

1. The Context: Rural Road Construction and Maintenance in Cambodia

Reliable rural transport is a high priority for Cambodia's socio-economic development. The roads sector in Cambodia suffered severe damage over three decades of civil strife until peace was fully restored in 1999, when most of the road network was rendered impassable. In the past 10 years, efforts to rehabilitate Cambodia's core transport infrastructure have received emphasis to restore national cohesion and create the foundations for economic growth. While much of the road network is in better condition, some 8,000 km of secondary national and provincial roads, as well as a vast remaining network of rural roads are still in need of rehabilitation. Rural roads are of particular concern because, given current predicted resource allocations, there are very limited prospects of providing them with a sealed surface. Most provincial and rural roads await rehabilitation and are seasonably impassable to motorized traffic. Infrastructure improvement is mostly donor financed and its subsequent operation and maintenance is hindered by a shortage of funds and the lack of efficient and transparent mechanisms for maintenance planning, disbursement and execution (ADB, 2006). Transport services are expensive, partly because of this poor infrastructure. At the same time, improved roads are key to sustained economic growth and poverty reduction. Most rural areas and many provincial towns are still without dependable access to the mainstream economy and this isolation perpetuates poverty in rural areas where the majority of the Cambodian population that exists below the poverty line lives. The role of improved rural roads in enabling access to markets for cash crops is a pre-requisite for the growth of the rural economy. In order to sustain these improvements, more cost effective maintenance is required to prevent loss of road assets.

Considerable investment has been made in the rehabilitation of the country's rural road network of some 44,000km over the last two decades. In nearly all cases, unsealed pavements are being constructed, utilizing laterites (for the purposes of this paper, "laterite" refers to high grade concretionary and generally red coloured soils common in parts of Cambodia). These unsealed pavements are prone to the ravages of high rainfall and flooding, have a heavy maintenance demand and short service lives, often requiring reconstruction within two to three years of rehabilitation. In practice, they are seldom passable during the rainy season. Further, the roads are dependent on declining reserves of high grade laterite deposits which are becoming increasingly depleted in some areas with the result that material needs to be hauled from further and further away. Apart from the high costs associated with the long haulage distances the effect of the generally overloaded trucks also causes significant damage to the existing roads en-route. Other concerns associated with the use of laterite include high susceptibility to steady deterioration from wind and traffic use under normal conditions plus rapid deterioration during rains or when subject to high axle loads. Windblown material causes extensive dust deposition and this is linked to a high occurrence of respiratory and eye problems among roadside populations.

While improved maintenance and vehicle policing regimes are necessary for more cost effective and reliable rural road network upkeep, a move away from dependence on high quality laterite with long haulage distances and the use of locally available soils for more durable pavement construction offer extremely high benefits for the nation's rural population.

The authors represent two New Zealand companies that have worked widely in Cambodia since the United Nations intervention there in 1992. For many years they have held a conviction that Cambodia has both a need and the means to employ lime base stabilization techniques to substantially overcome shortcomings associated with traditional laterite based construction methods and to produce longer lasting roads with considerably reduced whole life cycle costs. Investigations undertaken by the two firms confirmed that manufactured lime products suitable for road stabilization are available in Cambodia and that typical soils in much of the country are "reactive" and suitable for such stabilization. While engaged by the Ministry of Rural Development as engineers and management consultants on the Asian Development Bank funded Northwestern Rural Development Project (NRDP), which included the rehabilitation of some 700km of rural roads, the firms also undertook a special initiative funded by NZAID entitled "Local Resources for Local Roads" (LRLR). This consisted of technical advice and support needed to establish and demonstrate the applicability of lime and lime/cement stabilization methods and to provide the training and reference material necessary for its wider application.

Work on LRLR took place on 20km of rural road which provides a crucial link for village communities to daily goods and services at their provincial centre. The location is shown in **Error! Reference source not found.**.

1.1. Lime Stabilization

Stabilization is a construction process that improves or corrects a deficiency in a pavement material and makes it more suitable to perform its function within the pavement. The process is either mechanical or chemical and there are often a number of options available to the Pavement Engineer. Lime and lime/cement stabilization are a subset of these.

The treatment of a local material to improve its engineering properties has always been an attractive proposition compared with removing the materials and importing a better quality material. Lime is commonly used world-wide to improve the engineering properties of certain appropriate in situ or imported soil materials with high plasticity. In the broadest context hydrated lime improvement or stabilization of local soils for road-base, sub-base or shoulder construction is used as a viable alternative to the importation of higher-grade road building materials. Lime and lime/cement stabilization is practiced widely and successfully throughout the world, including in New Zealand and Australia.

The process of lime base stabilization involves a reaction between calcium from lime with aluminates and silicates from suitable soils – usually soils with significant clay content. The calcium from the lime forms calcium silicate hydrates and calcium aluminate hydrates which are stable and, if they form in the correct proportions, lead to a stabilized soil with higher resilient modulus values, greatly improved shear strengths and long term durability. Lime can be applied in two forms, burned lime or quick lime, which is Calcium Oxide (CaO), usually manufactured by heating limestone; or hydrated, or slaked lime, Calcium Hydroxide ($CaOH_2$), formed when burned lime reacts with water.

When lime is added to a plastic material, it first flocculates the clay component and substantially reduces the plasticity. The removal of water and the increase in the Plastic Limit causes a substantial and rapid increase in the strength and traffickability of the material.

Typically, with the soils encountered thus far in Cambodia, two to four percent of hydrated lime (calcium hydroxide) stabilizer by Maximum Dry Density is sufficient to gain a significant increase in the compressive and tensile strengths. The gain in strength with lime stabilizer is slower than that for cement so providing a much longer time (generally 4 hours) for mixing and compaction as compared to stabilizer where cement is an additive (generally 2 hours working time). The reduction of plasticity and increase in strength is time dependent during the initial weeks and the production of cementitious compounds can continue for one or more years, with the strength developed being influenced by the materials and the environment. The elastic modulus varies similarly to the strength and continues to increase over time.

In view of the difficulties associated with current construction practice for rural roads, Cambodian engineers and their advisers have long sought methods of stabilizing lower quality laterite with the use of an additive or agent to attain the desired properties. Yet, with the loss of technical skills and related knowledge during the civil war that forced turmoil on the country in the latter part of the last century, there has been some reluctance to adopt technologies which are new to Cambodia and Cambodian engineers, despite the successful use of these technologies elsewhere.

Compounding the problem is the general lack of suitable equipment for the mixing of the soils and the lime stabilizer. On the other hand Cambodia has substantial limestone deposits and prior to the 1960s had cement and lime production facilities. The processing of natural limestone into hydrated lime, or calcium hydroxide has continued over the years as a village based activity for the production of additives for local paints and lime washes. Some village kilns operating in groups or cooperatives at village and district level have the capacity to produce the calcium hydroxide of the quality required for lime stabilization of roadworks.

2. The Initiative: Trials, Demonstrations and Training

2.1. Synopsis

Construction activities on the project road were planned surveyed and designed by national engineers within the Provincial Department of Rural Development (PDRD) working on the NRDP. Technical assistance was provided by the Project Management Consultants (PMC) for NRDP and the LRLR team, the latter providing advisory input particularly in relation to construction standards for placement of fill, compaction of the road shoulders and widening of road embankments on which the stabilized pavement is to be constructed.

Stabilization specifications developed in New Zealand were reviewed and adapted to local circumstances, and then translated into the Khmer language and included in contract documentation.

The planning and design phase by NRDP involved full topographical and cadastral survey, geotechnical investigation and testing and the preparation of full contract (construction) drawings and specifications, as well as the standard review and appraisal process carried out for all NRDP subprojects. Two contract packages were tendered, and following a bidding process, two contractors were appointed in February 2007, each responsible for pavements works on a 5km length of road. The main earthworks then proceeded, with substantial stabilization works beginning in November 2007 and completion in May 2008.

2.2. Methods

2.2.1. Adaptation of Specifications

In New Zealand, burned lime (calcium oxide) is usually applied directly to the target material. This facilitates rapid bonding with graded material and incurs lower transportation costs, but requires a high level of efficiency, and raises potential hazards unless operators are well trained and appropriate delivery trucks and mixers (stabilizing plant) are used. Hydrated lime (calcium hydroxide) is an effective and safer alternative for use in developing countries such as Cambodia, although a higher volume is required to achieve the same effect and transport costs are higher. Hydrated lime far less hazardous to handle than burned lime and the laying operation is less critical.

2.2.2. Equipment

The appropriate choice of equipment is important both for the success of the technique and for its replication. In this sense Cambodia is very much at the pioneering stage New Zealand was in during the 1960s where stabilization was introduced and developed using tractor powered agricultural cultivators and rotary hoes adapted for the purpose. While good basic construction equipment is becoming more available throughout Cambodia there is still a general shortage of specialised rollers and compaction equipment. Water tankers are largely manually controlled with elementary and coarse delivery; graders have limited tine lengths and no indicators to allow the drivers to control the depth of scarification. Equipment available for the mixing of the soil and lime stabilizer is confined to a limited number of second hand rotary hoes imported from Japan,

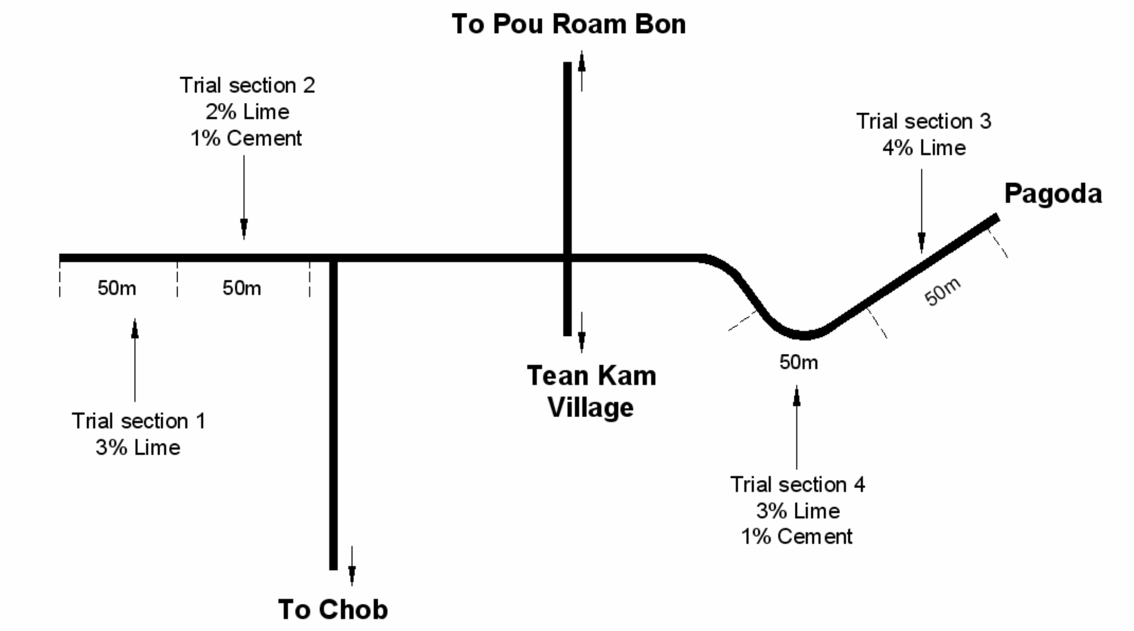
The LRLR engineers advised the Contractors on suitable modifications of equipment already widely used for road construction in Cambodia. These included the use of longer grader tines for full depth scarification of the base material, and the design of more efficient cutting and mixing blades for tractor drawn rotary hoes, as well as more suitable compaction equipment. The LRLR consultants have called upon the earlier experiences of their professional careers where they participated in these pioneering activities in New Zealand, when equipment of a similar rudimentary nature was used.

2.2.3. Construction Process

Trial sections consisted of two road lengths of around 100m. These were divided into four 50m sections to test different treatments as follows:

- i. lime @3% to a depth of 200mm;
- ii. lime @2% and cement @1%, again to a depth of 200mm;
- iii. lime @4% to a depth of 200mm; and,
- iv. lime @3% and cement @1% again to a depth of 200mm.

Figure 1: Locations of test sections in Northwest Cambodia



Stabilization work was preceded by shaping of the existing laterite surface, fixing a grid for the spreading of the stabilizing agent, installing lift pegs for checking crossfall and pavement depth and organising traffic control and site management. Bags containing the lime were then placed, and the material was spread with hand rakes, under close supervision. A grader was then used to scarify the pavement, along with the stabilizing agent. The depth of the tine penetration was determined by carrying out small scarification trials following which an indication mark was placed on the grader's frame to ensure the correct depth of 190mm.

Following scarification, water was applied to the surface from a cart (the water cart had no gauge and the rate of application was therefore approximate). The wetted surface was then mixed using a tractor drawn rotary hoe. A minimum of three passes were necessary for thorough mixing. Finally, the moisture content was checked to establish the relationship to OMC and when judged correct the mixture was compacted using a large dynamic roller.

2.2.4. Pre-Construction Testing

Several local quarries with lower grade laterite were investigated as suitable borrow areas. The source chosen was a quarry within 1 km of the demonstration road. Quick reactivity tests for the lime / cement mixtures showed strong and positive reaction with indications of considerable gains in strength. On the basis of these indications full laboratory testing proceeded, using recommended testing methods provided in the publication "Lime Stabilization for New Zealand Roads" – Section 4.3.2 and involved the following testing in order to determine the most effective percentages of lime and cement to be mixed with the laterite:

1. Hydrated lime mixed with laterite in the percentages of 2%, 3%, 4% and 5%
2. Hydrated lime and cement mixed with laterite in the following percentages

   Lime 2%, 3%, 4% and 5% mixed with 1% cement
   Lime 2%, 3%, 4% and 5% mixed with 2% cement
   Lime 2%, 3%, 4% and 5% mixed with 3% cement

A control sample of plain laterite was also tested for the main parameters and CBR. The results are summarized in the table below.

Binder and Soil Mixtures		CBR at 90% of specified dry weight density	CBR at 95% of specified dry weight density	Maximum Dry Density g/cc	Optimum Moisture Content	PI – Plasticity index
Hydrated Lime	Hydrated lime 2%	62.50	87.0	2.110	9.1%	8.40
	Hydrated lime 3%	55.0	95.0	2.120	9.1%	10.25
	Hydrated lime 4%	75.0	125.0	2.102	9.0%	9.04
	Hydrated lime 5%	65.0	145.0	2.094	9.9%	8.78
Hydrated Lime 2%	+ 1% cement	64.0	108.0	2.138	9.1%	8.45
	+ 2% cement	75.0	125.0	2.152	8.0%	10.71
	+ 3% cement	89.0	140.0	2.148	8.3%	10.03
Hydrated Lime 3%	+ 1% cement	86.0	115.0	2.128	8.95%	8.87
	+ 2% cement	95.0	160.0	2.138	9.0%	9.02
	+ 3% cement	98.0	185.0	2.150	9.0%	11.46
Hydrated Lime 4%	+ 1% cement	105.0	153.0	2.110	9.4%	9.54
	+ 2% cement	107.0	165.0	2.116	9.2%	10.05
	+ 3% cement	115.0	190.0	2.134	9.4%	9.66
Hydrated Lime 5%	+ 1% cement	112.0	180.0	2.104	10.0%	9.65
	+ 2% cement	115.0	205.0	2.112	10.2%	9.56
	+ 3% cement	175.0	250.0	2,124	10.4%	9.38
Nil	Laterite Control Sample	22.0	50.0	2,200	8.0%	11.64

The laboratory results show that mixtures of straight hydrated lime at 3% and 4% of the dry weight of the soil and hydrated lime at 2% + cement 1%, and hydrated lime at 3% + cement 1% gave good gains in strength suitable for the pavement design.

Following construction of the road embankments and pavements further laboratory tests were conducted to ensure the uniformity of the laterite and lateritic soils used in the pavement construction, and their similarity with the soils originally tested, and upon which the pavement design was based.

2.3. Post Construction Testing of Trial Stabilization Sections

To give confidence for the stabilization of the more substantial lengths of pavement core samples were taken from each of the four trial lengths and cured, prepared and tested in a local soils laboratory for unconfined compression strength (UCS). The results, summarised in the following table, confirm that the pavements have achieved a heavily bound condition, and therefore an adequate strength.

COMPRESSIVE STRENGTH OF SOIL – LIME STABILIZED SPECIMENS											
Project Name: Chob – Tean Kam Ponley Road, B.M.C.							Location: Chob - Tean Kam, Preah Netr Preah District, B.M.C.				
Lab No. 117M/07			Sample No. 017SLS07				Stabilized Date: 27/04/07			Tested Date: 06/06/07	
Client: Fraser Thomas Ltd.			Curing Lab/Field: DPWT				Trial Section: Section 1, 2 (26/04/07), 3, 4 (27/04/07)				
Sample ID No.	Testing date	L/D Proportion	Dimensions in cm				Area (cm^2)	Load KN	UCS (MPa)	Mix Proportion %	
			I	D_1	D_2	Av D					
A (1)	6/6/07	0.70	5.30	9.00	9.00	9.00	63.617	40.12	4.50	3% Lime + 0% Cement	
B (2)	6/6/07	0.59	5.30	9.00	9.00	9.00	63.617	41.8	4.29	2% Lime + 1% Cement	
C (3)	6/6/07	1.28	11.50	9.00	9.00	9.00	63.617	30.5	4.55	4% Lime + 0% Cement	
D (4)	6/6/07	0.61	5.50	9.00	9.00	9.00	63.617	42.6	4.44	3% Lime + 1% Cement	
								Average	4.44		
Test Method: AASHTO – T-106											

2.4. Review of Trial Sections

2.4.1. Community Acceptance

The trial sites were inspected regularly following the original work. These inspections showed that the pavements were standing up well under traffic and the conditions of the wet season. Comments from the villagers at Tean Kam reflect the following typical views:

- "there is no dust, a big improvement on the existing laterite surfaces"
- "the trial pavements shed water quickly after rain and dry out quicker than the nearby laterite surfaced roads following rain"
- "the trial pavements are not muddy and difficult to ride and walk over following rain"
- "the surface is not slippery after rain and is safer to ride over"
- "The pavements are an improvement. We [the villagers] want all pavements to be constructed the same"

While some wear was apparent after use, particularly loss of fines in the lime plus cement stabilized section, the larger gravel and stones were not dislodging. Overall the road surface on all trial sections was seen to be holding up well.

2.4.2. Observations

Overall the trials were a success and very worthwhile. As expected however they were not perfect. Plant and machinery had to be adapted for the task. The contractors and their teams also faced a steep learning curve regarding the importance of organization, productivity and quality control. The most positive outcome was the immediate response of the contractors in adopting the right approach and methods. The enthusiasm to do a good job and learn could not be faulted. The lessons learned from the trials emphasised the importance of using the right machinery or at least making improvements and adjustments in the contractor's own workshops to the machinery that was available.

The other positive outcome of the trials and testing was the scope for the LRLR consultant to indicate, and demonstrate where improvements could, and should be made. The discussions with the contractors concentrated on the need for these improvements plus the modification of equipment for the main stabilization activities.

2.4.3. Concerns

The main concern at the time was the limited financial capacity of the local contractors and the restrictions this might place on their ability to upgrade their plant and equipment, and acquire backup units and parts for the critical units, e.g. rotary hoes and extra blades for the hoes. This concern has subsequently proved groundless as the contractors, like their counterparts in developed countries, have either manufactured the parts and acquired backup units, exhibiting considerable resourcefulness.

2.4.4. Positives

The NRDP and PDRD Engineers, the contractors and their staff were willing and keen to learn, especially after seeing the results from the completed trials. The contractors also showed considerable initiative in adapting and modifying plant and equipment to meet the job requirements. Overall the trials achieved good results including positive feedback from the local community who were able to form a opinion on stabilization before the main upgrading works began.

3. Next Steps: Realising the Benefits

3.1. Technical Capacity

The soils, traffic conditions and economic setting in the Northwest of Cambodia, where the trials have been taking place, are similar to those in much of the country, where rural roads are built largely on low embankments, suitable for the flat and often wet terrain. The potential to apply lime base stabilization is therefore vast, applicable to nearly the entire 44,000km rural road network.

The lack of skilled labour, technicians and engineers is a potential limiting factor, as supervisors, contractors and plant operators need to understand the process of lime application if the technique is to be applied successfully in any situation. In particular, knowledge and experience is required of appropriate testing methods for reaction to stabilizing agents; mix design to determine the quantity of stabiliser required; an appreciation of the limits of stabilization; and correct construction methodologies to achieve the correct mixing depths, mix proportions of soil and moisture content for successful pavement construction. Attempts to apply lime stabilization in the absence adequate technical capacity may lead to failure, potentially influencing opinion and making the technique appear unsuitable for wider adoption.

Technical capacity is a key aspect of sustainability, of the lime stabilization technique itself as well as the impacts of its use. The LRLR project therefore had a substantial training component, which is designed to train trainers, and therefore “seed” the spread of technical capacity. This was customized to the training needs of Ministry staff and contractors, as identified during the trial work and by formal assessment. The team prepared reference material and training guidelines for “on-the-job” training, and provided training, utilizing this material, in order to test its appropriateness and uptake. The material was then improved accordingly, and incorporated into a comprehensive training manual, which was translated into Khmer. In order to facilitate the effectiveness of subsequent training, a “training of trainers” approach was used, ensuring that a group of competent and confident trainers, familiar with the techniques, is available to provide further training. This has enabled the Ministry of Rural Development to organize subsequent training on suitable sites in Cambodia.

4. Conclusions

Trials to date, using lime sourced from within Cambodia, locally available equipment and materials representative of rural road situations in much of the country, have established that lime stabilization is a viable means of improving road pavement durability and decreasing whole life cycle costs. Local contractors have also shown the ability to be able to apply the technique on rural road rehabilitation contracts. The wider adoption of this technique carries vast potential in terms of cost effectiveness and economic benefits associated with reliable year round transport. However, for the benefit of the technique to be realised to its full potential several challenges remain. These are the proliferation of capabilities to apply the technique successfully (including sound technical knowledge and ability to ensure quality of construction) and management of the road sector to ensure regular and adequate road maintenance.