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Economic Analysis of Soil-Cement Base Construction Compared with Crushed-Rock Base

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Cement stabilization involves some special equipment with a relatively high initial investment cost, such as a soil stabilizer; this equipment is generally more expensive than other conventional equipment. The economy of employing a soil-cement base to replace a crushed-rock base has been in doubt. An economic analysis is presented that accounts for the cost of renting and operating all equipment for soil-cement production, cost of the cement, and cost of the soil. Results of the analysis indicated that the soil-cement base will be cheaper than the crushed-rock base by about 35-46 percent when the hauling distance for crushed rock is 200-300 km from the job site. It is found that the most expensive item is the cost of the cement and the cheapest is that of the machinery. Cement cost accounts for 57 percent of the total cost; the cost of machinery is only 19 percent.

Soil-cement roads were introduced in Thailand in 1965 by the Siam Cement Company (1). At that time, a 5-km test road was constructed employing lateritic soil-cement as a base course. Lateritic soil and terrace gravel are local materials found in abundance in northeastern Thailand. Rock sources are deficient in this region. After 1965, there was a period of using soil-cement to replace crushed rock in road construction in northeastern Thailand for about five years (1967-1971). Some soil-cement roads, because of the traffic load, developed reflection cracks on the surface, which caused increased maintenance.

The quantity of reflection cracks tends to increase with time and number of heavy trucks. Reflection cracking is due both to the shrinkage of the soil-cement and to deflections from heavy trucks. Differentiation between both modes of crack formation could be made roughly by visual evaluation. For shrinkage cracks, orientation of the crack will be random and it might be longitudinal and transverse in direction. Sometimes it is considered as a surface crack or hair crack because it will form only on the top of the soil-cement road. Deflection cracks are formed because of overloaded trucks or too much flexibility in the lower layer. Again, the crack might be both transverse and longitudinal. However, if the raw soil is well graded, the cracked slab will interlock with the coarse fraction of the soil aggregates. The ones most available in northeastern Thailand are lateritic soil and terrace gravel.

Routine maintenance work to repair the reflection cracks is to seal them with liquefied asphalt or premix. However, it was found that the liquefied asphalt tends to fill the upper part of the crack only, due to the fact that the crack is too small or that viscosity of the liquefied asphalt is too high to penetrate into the lower layer. As a result, reflection cracks will be partly sealed and water penetration through the crack is not completely prevented. The incomplete reflection-crack sealing made the Department of Highways in Thailand doubtful

about the performance of the soil-cement road. As a result, soil-cement road construction in Thailand has been terminated, probably since 1972. During 1967-1971, there were about 1400 km of soil-cement road being constructed.

Even though reflection cracks in soil-cement were not properly sealed, it was found that most soil-cement roads exhibited good performance. Periodic maintenance applied on those soil-cement roads is sealing with a single surface treatment (seal coat) after the roads had been serving traffic for five to seven years. Consequently, major or plastic failure is not apparent in this type of road, except for two soil-cement roads that were seriously damaged after being open to traffic for more than 10 years. Now both of them have been partly reconstructed. During the reconstruction phase, one existing soil-cement road was excavated and a silty-clay layer 30-50 cm thick was found. For additional proof, it was apparent that the elevation of the soil-cement layer was nearly the same as that of the surrounding soil and the water table under the embankment was relatively high in the rainy season; this increased the flexibility of the soil-cement base. From this evidence, it might be expected that both the intervening clay layer and the high ground-water layer tend to induce reflection cracks and failure of the two soil-cement roads.

An oil crisis has caused the cost of transportation to increase considerably. Different types of construction materials and goods are loaded onto heavy-duty trucks (10-wheel trucks in Thailand) as much as possible so that the number of hauls could be reduced. The total load of truck and goods will usually be more than 21 tons, which is the legal load limit for this type of truck in Thailand. Evidence from traffic counts and checks along some selected highways showed that the number of heavy buses and trucks varies in the range of 25-40 percent of the average daily traffic, and their gross weight could be as high as 25-40 tons. It can be imagined how much the pavement will deteriorate from the overloaded trucks. The service life of the road pavement was determined from the repetitions of standard axle loads; overloaded trucks increased the deteriorating effect on the pavement many times more than did the lighter ones and shortened the life of the road. From the average gross weight and the traffic composition, repetitions of the equivalent standard load could be estimated by using equivalent factors developed by using data from the road test of the American Association of State Highway Officials (2).

The overloaded trucks transporting the construction material from the crushing plant to the job site tend to destroy the pavement and to shorten its

Figure 1. Physiographic regions of Thailand.

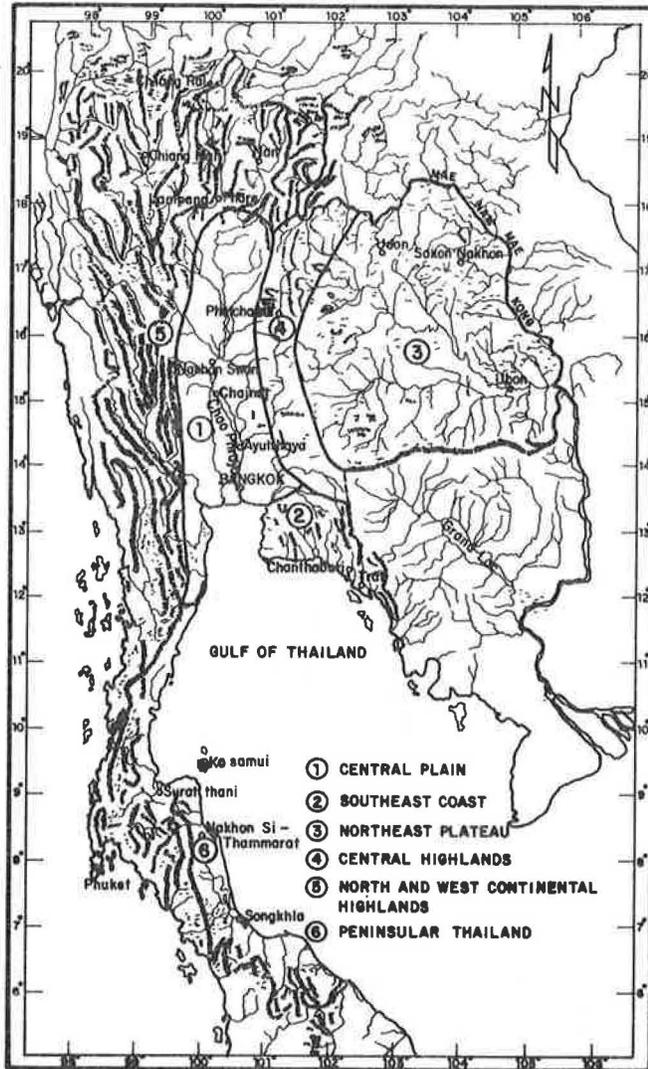
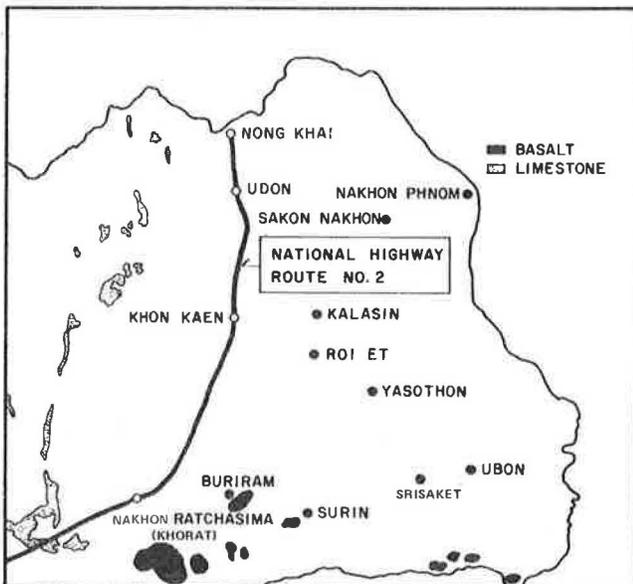


Figure 2. Rock sources in Northeast Plateau.



life. These trucks will also destroy the road pavement in all sections that they pass between the material source and the job site. From the analysis of the truck load it is usually found that life of the newly constructed highway is reduced by one to two years, depending on the trucks hauling the construction materials, the length of the highway, and distance from the material source.

SOME APPROACHES TO LENGTHEN ROAD LIFE

In order to avoid damaging road pavement by hauling construction materials, it is proposed to use local materials in road construction instead of those transported from distant sources. During the past 10 years, an attempt has been made by our Department of Highways to study the performance of soil-cement roads and how to reduce reflection cracks in them. It is hoped that specifications, design criteria, quality-control criteria, and construction techniques as modified from past experience will enable the Department of Highways to construct good soil-cement roads without the problem of reflection cracks. Some newly constructed test sections have proved this attempt.

In spite of eliminating the problem of reflection cracks, the cost of a soil-cement base as compared with that of a crushed-rock base, which is conventional for a standard pavement structure, was suspicious. It is the objective of this paper to make an economic analysis of a soil-cement base as compared with a crushed-rock base to serve as a guideline for deciding when the base course should be soil-cement. Since the Department of Highways has many mixed-in-place soil stabilizers, the cost of soil-cement construction being analyzed here will be based on the operation of the soil stabilizers.

FACTORS TO BE CONSIDERED IN ANALYSIS

Many factors affecting the construction cost and performance of the roads in northeastern Thailand need to be considered in the economic analysis. Some factors directly affect the construction cost and performance but some might influence the indirect mean. In this section, some important factors will be discussed briefly.

Sources of Rock and Crushing Plant

The physiographic regions in Thailand could be divided as shown in Figure 1 (3). The geologic map of the Northeast Plateau is shown in Figure 2 (3).

From Figure 2, it will be seen that the basaltic rock sources in the Northeast Plateau are in the southern part of Changwats Surin, Srisaket, and Buriram, near the Cambodian border. Limestone is found in the western part close to the Central Highland. If road construction is in the vicinity of the central portion, the north, or the east of the plateau in Changwats Khon Kaen, Kalasin, Sakon Nakhon, Nakhon Phanom, Ubon, Yasothon, and Nong Khai, crushed rock has to be hauled from various rock sources for a distance of 150-300 km. The problem of overloaded trucks since the oil crisis has become critical; road sections between the crushing plants and the project site are being destroyed by the load repetitions of very heavy trucks. This has shortened the service life of the road, and road rehabilitation must be made very soon before excessive repairs and reconstruction are necessary.

Hauling Distance

The hauling distance of 150-300 km from the rock sources to the project site definitely increases the

cost of fuel consumption, depreciation, time, and construction material. So the hauling distance seems to be one of the most important factors to be considered in the economic analysis.

Local Materials

Lateritic soil, terrace gravel, and silty sand are the three most abundant types of soil in the Northeast Plateau. Generally, the hauling distance from the material borrow pit to the project area varies from a few to more than 50 km. If the hauling distance is farther than 50 km, that pit will be considered uneconomical and new ones will be tried. Lateritic soil and terrace gravel have been used as the subbase course for roadways in the Northeast Plateau for many decades.

Effect of Load Repetitions on Road Performance

Repetition of wheel load on the pavement is another factor to be considered in this analysis. The National Highway Route 2, which links Bangkok to some main cities in the Northeast Plateau, serves the heaviest traffic volume in the country. As the number of heavy trucks and their wheel loads increase, the degree of pavement deterioration goes up accordingly. This effect will be apparent from the rut depth found near the wheel path. Once in a while, the existing pavement has to be overlaid to eliminate the rutting and to lengthen the service life of the road. If not, after a few years the damage will extend downward and finally there will be complete failure. As a result, the road has to be reconstructed.

Subsoil Condition and Drainage

The major parent rock of the Northeast Plateau is sandstone interbedded with shale and other stratified rocks. Both physical and chemical weathering processes of the region result in layers of silty and sandy surficial soil overlying the original sandstone parent rock. Since the soil is more or less cohesionless, the foundation is expected to be strong. Thus compressibility and flexibility of the lower layer, after it has been subjected to surface loads, seem to be low compared with the soft clay foundation in the Central Plain. Drainage conditions in most areas of the Northeast Plateau are good, so the groundwater table is low. Floods might occur in some depressed areas, but water will be drained away rapidly. The possibility that the pavement structure may be soaked under the flood water for a long time is not common in this region. Both the good foundation and the drainage of the subsoil tend to promote construction of the road by employing local materials.

COST ANALYSIS OF CRUSHED-ROCK BASE

The cost of compacted crushed-rock base construction varies with the type of rock, distance of hauling, cost of compaction, and other factors. According to bidding in Thailand, the cost of a compacted crushed-rock base will vary from \$10.90 to \$26.10 (U.S. dollars)/m³. In this analysis, it might be practical to calculate the cost of compacted crushed rock per kilometer of the road and to compare that with the cost of the soil-cement base per kilometer. For a long-term construction period, the basic cost of crushed-rock production and the cost of hauling may fluctuate. In this case, the probable escalation factor for adjusting the basic cost will be applied.

COST ANALYSIS OF SOIL-CEMENT BASE

There are many components to be considered in estimating the cost of soil-cement base construction. The three most important items are construction machinery, cement cost, and cost of the soil to be stabilized. All of them will be described in more or less detail in the following sections.

Cost of Construction Machinery

The units of machinery required for soil-cement construction are as follows:

Machine	No. of Units
Soil stabilizer	1
Motor grader	1
Water sprinkler	3
Rubber-tired roller	3
Steel roller	1
Cement box spreader	2
Flat-bed truck	2

The cost of each type of machine consists of rent, operation, and fuel consumption. All expenses for each machine are given in Table 1. Data and procedure used in the calculation are from the Office of Equipment Revolving Funds of the Department of Highways of Thailand. The method of calculation is shown below in U.S. dollars for the case of the soil stabilizer. For other pieces of equipment, the cost of renting and operation will be determined by the same procedure.

Capital Costs

Estimated 1981 price (\$173 913) less replacement cost of tires (\$870) less residual value (5 percent, \$8652) = depreciation value (\$164 391).

Life of machine = 12 years,
 Working days/year = 180 days,
 Working hours/day = 3 h,
 Annual working hours = 540 h,
 Life hours planned = 6480 h.
 Avg investment = $1/2[(\text{life} + 1)/\text{life}]$ (equipment price) = $1/2(13/12)$ (\$173 043) = \$93.732.

Hire Rate Calculation

The hire rate includes the cost of operation, servicing, and maintenance.

Ownership:

Depreciation = (depreciation value)/(life hours) = \$25.40.
 Special reserve = (avg investment x 18 x 3/4 percent)/(hours/year) = \$23.40.
 Total = \$48.80.

Insurance:

Insurance = (avg investment x 3 percent)/(hours/year) = \$5.20.

Operation:

Spare parts = (depreciation value x 78 percent)/(life hours) = \$19.80.
 Filters, oils, lubricants = (15 percent of fuel) = \$1.00.
 Tires [two sets x cost (given above)]/(life hours) = \$0.30.
 Overhead (other costs x 30 percent) = \$22.50.

Total = \$43.60.
 Total hire rate/hour = \$48.80 + \$5.20 + \$43.60
 = \$97.60/h.

Fuel Consumption

20 L/h of diesel fuel at \$0.32/L = \$6.40/h.
 Cost of renting + cost of fuel consumption = \$97.60
 + \$6.40/h = \$104.00/h.
 Daily rental rate, excluding fuel consumption
 = \$97.60 x 3 = \$292.80/day.

According to Table 1, the cost of machinery rental and operation to construct a soil-cement base 500 m long is found to be \$1212.50 (U.S. dollars), which is \$2425/km.

From Table 1, the most expensive equipment in soil-cement road construction is the soil stabilizer, and the one manufactured by Brothers in the United States is used in this analysis. This is a single-pass soil stabilizer used in many soil-cement road construction projects in this region. It has proved to be the most efficient soil stabilizer for the Department of Highways in Thailand, which has about 10 stabilizers of different models. The compacted soil-cement after mixing will be about 15 cm thick, which is a minimum requirement for the soil-cement base in Thailand. Since disc and harrow mixing machines only provide a thickness of 5-8 cm, which is not adequate to sustain heavy trucks in Thailand, these machines will not be employed for soil-cement roads of the Department of Highways in

Thailand, even though the cost of renting them is less.

Cost of Soil-Aggregate Materials

The soil-aggregate materials suitable for soil-cement construction in this area are lateritic soil, terrace gravel, and silty sand. Most of them have a hauling distance of less than 50 km, generally of only a few kilometers. The cost of soil materials could be calculated as follows (in U.S. dollars):

Assuming cost of lateritic soil with hauling distance of 50 km = \$2.61/m³, maximum dry density = 2.3 tons/m³, compensating for loss during construction = 30 percent, and
 Assuming width of stabilized road base = 6 m, length of stabilizer section = 1000 m, and thickness of compacted soil-cement = 0.15 m, thus,
 Volume of soil for soil-cement base construction = 6 x 0.15 x 1000 = 900 m³,
 Volume of soil being excavated = 900 x 1.3 = 1170 m³.
 Therefore, cost of soil = 1170 x \$2.61 = \$3053.70.

Cost of Cement and Soil-Cement Base Construction

Assuming cement used = 5 percent by weight and volume of compacted soil = 900 m³, thus,
 Weight of compacted soil = 2.3 x 900 tons = 2070 tons,
 Weight of cement used per kilometer of soil-cement

Table 1. Cost of machine rental and operation for soil-cement construction.

Machine	No. of Units	Cost (U. S. \$)			
		Daily Rental ^a	Daily Fuel	Rental and Fuel	Total ^b
Soil stabilizer (Brothers, United States)	1	292.8	43.5	336.3	336.3
Motor grader (Caterpillar Tractor Co., United States)	1	111.1	21.7	132.8	132.8
Water sprinkler (Hino, Japan)	3	58.3	21.7	80.0	240.0
Rubber-tired roller (Chamberlain, Australia)	3	47.1	21.7	68.8	206.4
Steel roller (Ruthmayer, Germany)	1	112.4	21.7	134.1	134.1
Cement spreader (Panquip, Thailand)	2	11.9	10.9	22.8	45.6
Flat-bed truck (Nissan, Japan)	2	36.9	21.7	58.6	117.2
Total					1212.5

^aQuoted from Office of Equipment Revolving Funds, Department of Highways, Thailand.
^bAll expenses include cost of operator and overhead.

Table 2. Cost comparison between soil-cement base and crushed-rock base.

Crushed Rock (\$/m ³)	Crushed-Rock Base (\$/km)	Soil-Cement Base (\$/km)	Constructed by Department of Highways ^a		Constructed by Contractor ^b		
			Difference		Soil-Cement Base (\$/km)	Difference	
			Dollars per Kilometer	Percent			Dollars per Kilometer
10.9	9 810	12 677	-2867	-23	15 213	-5403	-36
13.0	11 700	12 677	-977	-7	15 213	-3513	-23
15.2	13 680	12 677	+1003	+7	15 213	-1533	-10
17.4	15 660	12 677	+2983	+19	15 213	+447	+3
19.6	17 640	12 677	+4963	+28	15 213	+2427	+14
21.7	19 530	12 677	+6853	+35	15 213	+4317	+22
23.9	21 510	12 677	+8833	+41	15 213	+6297	+29
26.1	23 490	12 677	+1081	+46	15 213	+8277	+35

Notes: (-) means soil-cement base is more expensive than crushed-rock base.
 (+) means soil-cement base is cheaper than crushed-rock base.
^aNo profit included in cost.
^b20 percent profit included in cost.

Figure 3. Difference between cost of crushed-rock and soil-cement bases versus cost of crushed rock in U.S. dollars per kilometer.

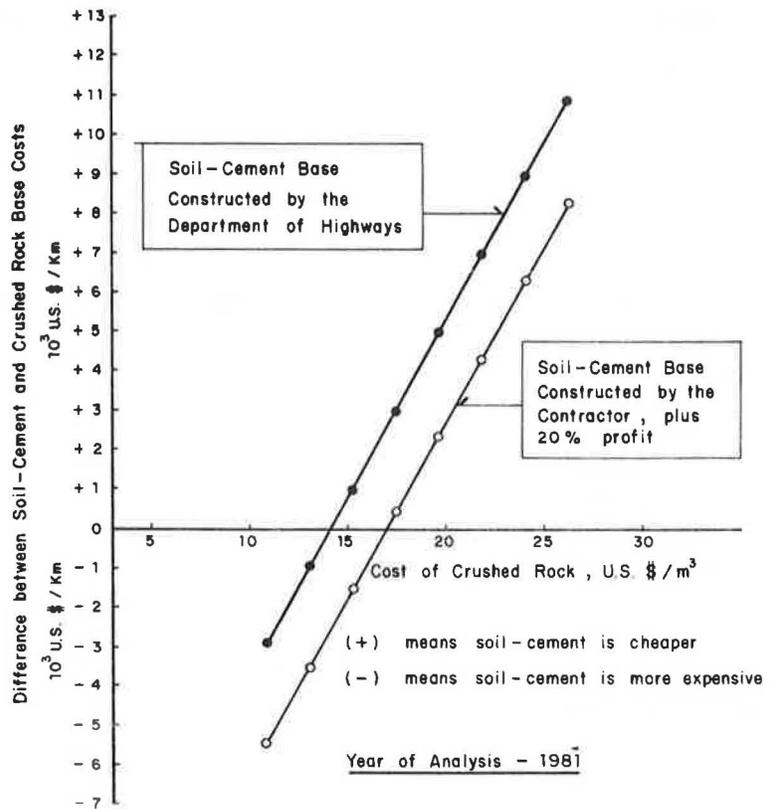
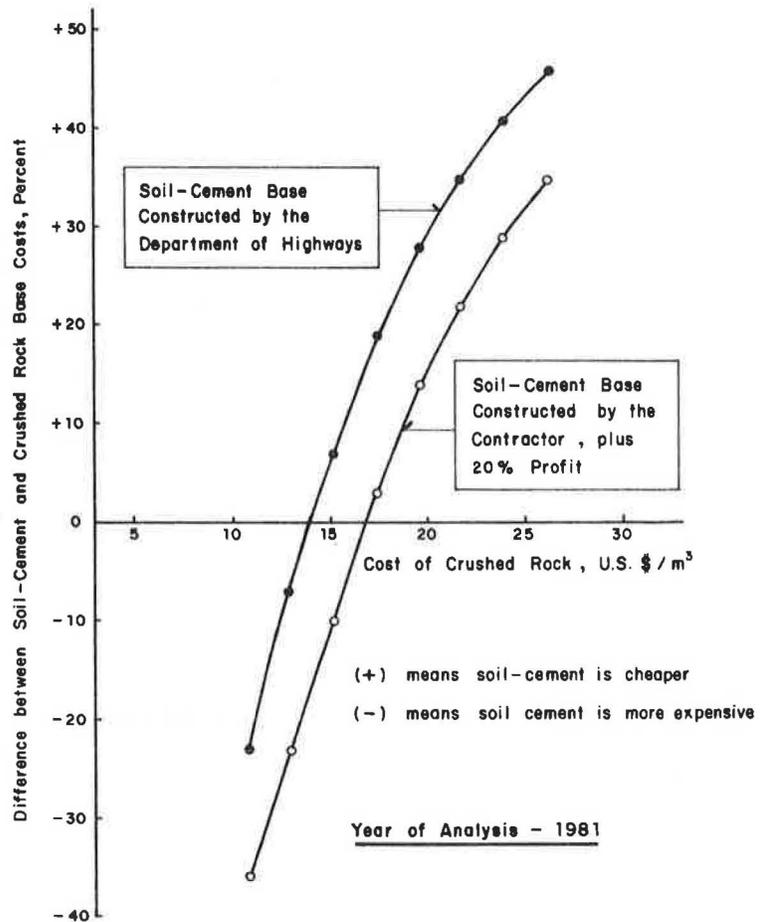


Figure 4. Difference between cost of crushed-rock and soil-cement bases versus cost of crushed rock in percent.



road construction = $(5 \times 2070)/100$ tons = 103.5 tons,
 Cost of cement (local price) = \$69.60 (U.S. dollars)/ton,
 Therefore, cost of cement per kilometer of soil-cement base = $\$103.50 \times \$69.60 = \$7200$.
 Cost of soil-cement base construction = cost of machinery + cost of soil + cost of cement = $\$2425 + \$3053.70 + 7200 = \$12\ 678.70$.

From the above analysis, it will be seen that the costs of machinery and local soil are 19 and 24 percent, respectively, of the total soil-cement base construction. The highest cost is cement, which comprises about 57 percent of the whole. Therefore, the economics of soil-cement construction depends mainly on the costs of cement and soil, which in turn vary with the hauling distance. If the hauling distance of the soil is less than 50 km, the soil-cement base will be more economical.

Since reflection cracks are believed to be essentially due to the excessively high strength of the soil-cement base, it is proposed to limit the strength of the soil-cement in the appropriate range to cut down reflection cracks (4,5). Thus, the amount of cement has to be lessened. As a result, the cost of soil-cement road construction could be reduced.

Lime is another additive that can be used to improve the strength of the local soil in northeastern Thailand. It is expected that soil-lime might develop less cracking than soil-cement. However, in Thailand the cost of lime is slightly higher than that of cement, and its quality is not consistent because lime production is the cottage industry in that area. In addition, hydrated lime tends to harden due to moisture absorption, so lime cannot be effectively used to stabilize the soil. And finally, it was found that the strength of soil-lime develops very slowly, and it takes about 28 days to reach the strength criterion required for stabilized bases. For the conditions in Northeastern Thailand, cement is the cheapest additive for use in soil stabilization.

COMPARISON BETWEEN COST OF SOIL-CEMENT AND CRUSHED-ROCK BASES

According to the above analysis, the construction cost of a soil-cement base could be accurately estimated by considering all the important factors mentioned above. Variations might be possible, but only in a narrow range. For the crushed-rock base, the construction cost varies greatly; it depends primarily on the hauling distance from the quarry or crushing plant to the project site. After a survey of the projects in the Northeast Plateau, it was found that the construction cost of a crushed-rock base varied in a range of \$10.90-\$26.10 (U.S. dollars)/m³. In order to compare the construction cost of the soil-cement base and the crushed-rock base graphically, it is assumed that the cost of the crushed-rock base is \$10.90, \$13.00, \$15.20, \$17.40, \$19.60, \$21.70, \$23.90, and \$26.10/m³. This unit price is for compacted volume. For each value of the unit price, the cost of crushed-rock base construction could be calculated and compared with that of the soil-cement base, which will be shown later.

If it is assumed that the width of the road is 6 m, the thickness of the compacted base course is 0.15 m, and the length of the road section is 1000

m, the volume of the compacted crushed-rock base is calculated as follows:

$$6 \times 0.15 \times 1000 = 900 \text{ m}^3.$$

After the quantity of crushed rock being employed in the construction as well as the different unit prices are known, the cost of the crushed-rock base could be calculated and is given in Table 2. The tabulated cost included the cost of material, hauling, compaction, and profit as well as compensation for loss during construction.

Difference in construction cost between soil-cement and crushed-rock bases with respect to the volumetric cost of crushed rock is shown in Figure 3 in U.S. dollars per kilometer and in Figure 4 in percent of difference. For soil aggregates with other basic costs, the procedure for analysis will be the same. From the results of the analysis shown in Figures 3 and 4, it can be seen that the soil-cement base could be 35-46 percent cheaper than the crushed-rock base. The saving in cost for only 10 km of soil-cement road would more than equal the cost of a soil stabilizer. From Figures 3 and 4, the engineer could make the decision about the selection of the type of base on the basis of economy.

In addition to the saving in cost, employing the soil-cement base will reduce the deterioration of the existing road that links the quarry and the project site because of overloaded trucks.

CONCLUSIONS AND RECOMMENDATIONS

The soil-cement base is apparently cheaper than the crushed-rock base, especially for a hauling distance that makes the cost of the crushed-rock base in the range of \$17.50-\$26.10/m³.

The saving could be as high as \$10 000/km if the cost of crushed rock is \$26.10/m³. This corresponds to a hauling distance of 200-300 km.

Replacement of crushed-rock base with soil-cement base will save a great amount of money as well as lessen the effect of the overloaded trucks used to haul the crushed rock from the distant crushing plants.

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