GEOTECHNICAL ASPECTS OF LOW VOLUME ROAD DESIGN AND CONSTRUCTION IN NORTHEASTERN THAILAND

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Northeastern Thailand occupies about one-third of the total area of the kingdom, and this region is physiographically called the Khorat Plateau. The most available local materials in this area are lateritic soil, gravel and silty sand. Road construction in this vicinity encounters with the problem of material deficiency, especially crushed rock for base and surface courses. As the traffic volume of most routes is rather low, in order to help accelerating development in this region the approach of low cost road should be introduced to construct the road network in the Khorat Plateau. In order to satisfy this approach, the uses of the local material as base course are recommended. The method of cement stabilization with local materials are strongly emphasized to replace crushed rock. Examples of cement stabilized roads in Thailand with their performance are shown.

Introduction

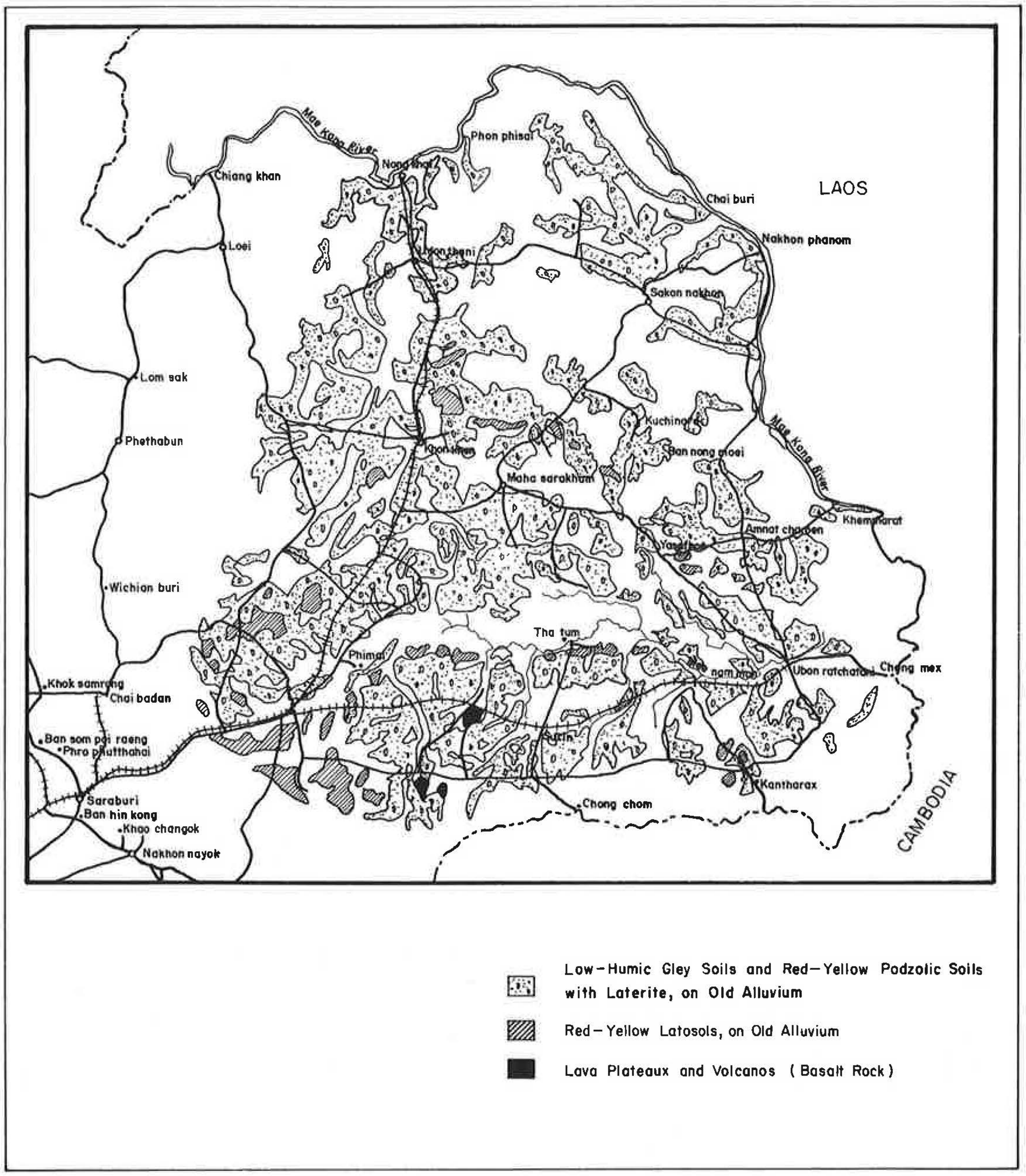
Northeastern Thailand occupies about one-third of the total area of the kingdom, and this region is physiographically called the Khorat Plateau or the Northeast Plateau for the relatively flat elevated plain. There are about 80,000 km of unpaved road in Thailand. Out of this, there are about 5,000 km under the responsibility of the Department of Highways, and more than 50 percent is in this plateau. Every year the mileages of the unpaved road under the responsibility of the Department of Highways increase. Traffic volume of these routes is generally low to medium, and most of them are less than 500 vpd. It is the policy of the Thai Government to build up the road network linking the nearby villages to induce communication between the local people and to raise the standard of living of the dwellers in the remoted areas. Many routes are built because of the political and military influences. So it is hoping that in the near future quite a few mileages of road are going to be constructed in this region. It is interesting to analyze how these roads are built, and what pavement type will be suitable for the developing countries that most of them have the financial problem, and they have to spend money in other phases of development too, not only to construct the road. Northeast Plateau has encountered the problem of material deficiency for years, especially crushed rock for base and surface courses. Since the time of an oil crisis the long haul distance of crushed rock from the remoted quarries has made the cost of material go up considerably. For the relatively low traffic volume of most routes and for the problem of material shortage associated with the financial status of the country, the approach of low cost road and staged construction could be significantly applied to the disign and construction of the road network in this vicinity. According to this approach, the local available material and manpower must be utilized as much as possible. The most abundant local materials are lateritic soils, silty and sandy soils and terrace gravel which easily found everywhere in the Khorat Plateau. This paper describes about some geotechnical aspects such as some properties and the suitability of employing such materials in low volume road design and construction. The most suitable method of stabilization is also suggested. Conclusions and recommendations are drawn on the basis of the local experience, research conducted in this region, and the results of regional international seminars in Southeast Asia.

Geology, Parent Rock and Climate

Rocks in the Northeast Plateau are mainly arenaceous rocks (clastic sediments of sand grain size) which are either subhorizontal or very gently folded. Igneous rocks are relatively rare. The modified geologic sketchmap is shown in Figure 1 (1). Sandstone is an important parent rock associated with sparsely formed basalt plugs, alluvial deposits and limestone. The surficial materials of the Northeast Plateau are silty and sandy soils of about 7 meters in thickness. The surface drainage of the area is dominant. Thus, even though flooding commonly occurs in some places in the rainy season, the soil is dried out rapidly because water will seep through the surficial soil of relatively high permeability.

Thailand has a savana-typed climate influenced by seasonal monsoons. There are three major seasons as the dry, the hot and the rainy seasons. The annual rainfall in most of the Northeast varies from 1,100 to 1,500 mm with the average of about 1,300 mm. Rainfall increases to 2,000 mm annually near the borders between Thailand and Laos, and Thailand and Cambodia. The average temperature is about 27° C.

Figure 1 Geologic Map of Northeastern Thailand (1)



Local Highway Materials and Material Improvement

Various local highway materials available in the Northeast Plateau are laterites, lateritic soil, silty and sandy soils, terrace gravel, basalt and limestone. Lateritic soil and terrace gravel from some borrow pits oould be directly employed as base course of the paved feeder road. However, some sources have to be stabilized with cement to attain the proper strength for serving the mentioned purpose. Distribution, properties and utilization of the abovementioned materials are going to be described in more or less detail in the following sections.

Laterites and Lateritic Soils

General Characteristics. Laterites and lateritic soils are extensively used in road construction in Thailand for many decades. Sources of these types of soil are found widely in the Northeast Plateau. This is due to the suitability of the climatic conditions, the good drainage of the area, and other environmental factors inducing the formation of lateritic soils. Literatures concerning the occurrence of lateritic soils could be found out elsewhere (2,3). The modified geologic map showing the probable areas of lateritic soil formation in the Northeast Plateau is illustrated in Figure 1.

Lateritic soil is generally used as subbase material for the primary and secondary highways. However, lateritic soils from some particular sources have low plasticity, durable particles, and high CBR

Figure 2. Relationships Between Compressive Strength and Carifornia Bearing Ratio for Soil-Cement Specimens (11)

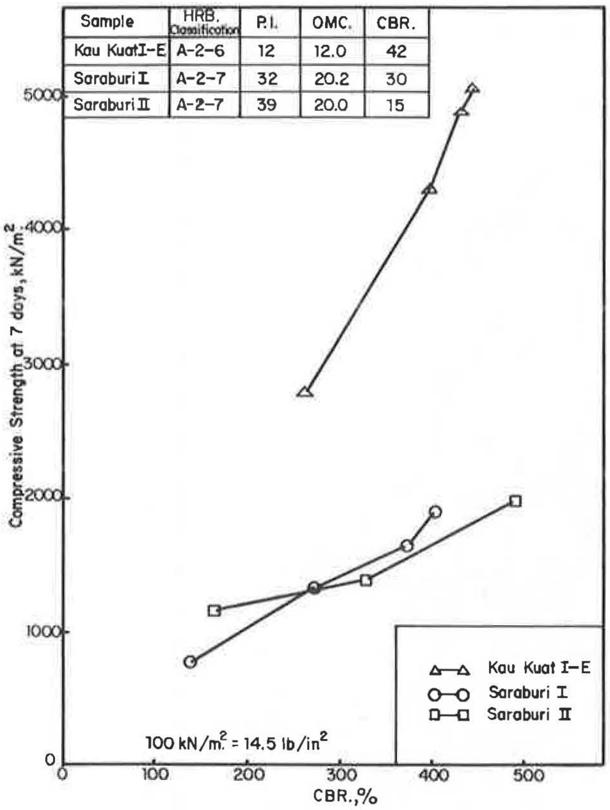
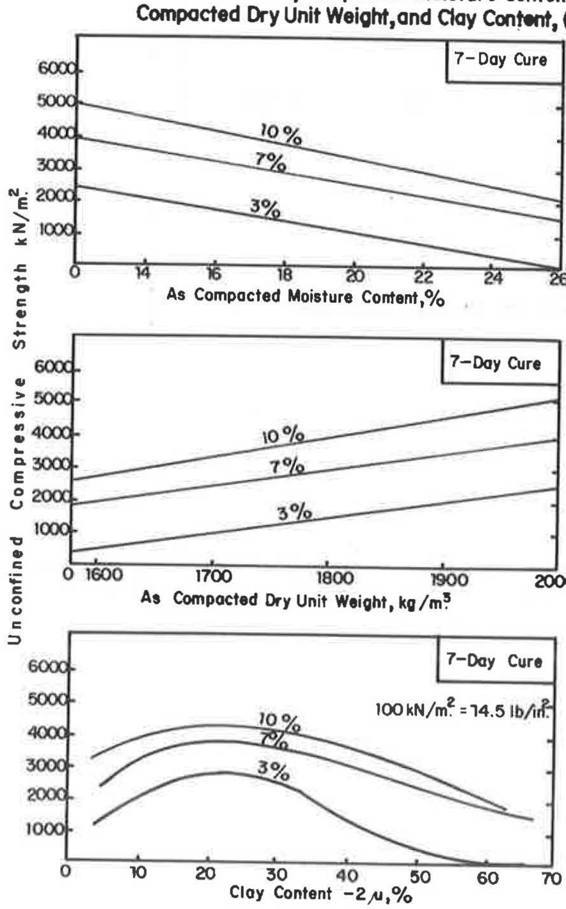


Figure 3. Variations of Unconfined Compressive Strength with Cement Content, Compacted Moisture Content Compacted Dry Unit Weight, and Clay Content, (13)



value, so they could be employed as base course of the paved low volume road. In many feeder or access roads, they are also used as soil-aggregate typed surface properly. Laterites forming as a massive structure are not suitable for employing in the pavement structure, even though their bearing value is very high. They can be properly used as the riprap instead of rock which is deficient in this area. According to researches conducted at the Thai Highway Department, most lateritic soils in Thailand have wide variations in CBR from 7 to 60, depending on grain size distribution, plasticity, durability, and irregularity of the grains. The experience of the Thai Highway Department Laboratory showed that unconfined compressive strength of lateritic soil specimen compacted at optimum moisture content in the Proctor mold varies from 275 to 1000 kN/m^2 (40 to 150 lb/in^2) which is not considered to be low (4).

Data on the triaxial compression test for the strength parameters C and Ø are very limited. MAHMOOD and MOH (5), reported the effective strength parameters of lateritic soil with PI of 11 and compacted at optimum moisture content are as C=48 kN/m^2 (7 lb/in^2) and Ø = 34°. REMILLON (6) recommended a minimum cohesion of 48 kN/m^2 (7 lb/in^2) as a limiting value and over 70 kN/m^2 (10 lb/in^2) for acceptable lateritic soil.

Classification of Lateritic Soil. Quite a few classification systems have been specifically developed for lateritic soils (2, 3). These systems are generally based on agricultural, chemical and mineralogical factors for which the parameter determination is rather complicated and time consuming. Systems of engineering soil calssification such as AASHO, Unified Soil, and U.S.Bureau of Soils, all based on the data of grain size distribution and Atterberg limits. However, these index properties changed with treatment during the test and methods of preparation as demonstrated by many investigators (7, 8, 9, 10). Described properties affecting the soil classification systems which have proved so successful for soilfrom temperate regions are not readily applicable to lateritic soils.

VALLERGA, VAN TIL and RANANAND (10) tried to modify the existing soil classification system by introducing some parameters that reflect the nature of lateritic soils other than grain size distribution and Atterberg limits. After conducting research on lateritic soils in Thailand,VALLERGA, VAN TIL, and RANANAND (10) proposed the Extended Unified Soil Classification System to incorporate the durability characteristics of gravel and sand to the original system.

Stabilization of Lateritic Soil. Stabilization of Thailand lateritic soils was studied in the past by many investigators (11, 12, 13, 14). JONES and YIMSIRIKUL (11) made an experiment on cement stabilization of lateritic soils with PI in the range of 12 to 39. It was reported that CBR value increased considerably to more than 100 after adding 3 percent cement. Both unconfined compressive strength and CBR values will be higher for greater compactive effort. The relationship between unconfined compressive stength and CBR was shown in Figure 2.

Satisfactory results were reported from the laboratory investigation by MOH, CHIN, and NG (12) on samples with PI range from 11 to 19, while textural composition is extremely variable. It is found that after stabilizing with 4 to 7 percent cement all the samples have unconfined compressive strength more than 1725 kN/m^2 (250 lb/in^2) which is

Table 1 Some Soil-Cement Roads in Thailand

Route No.	Km.	Year Constructed	Age Years	Pavement Structure, mm.			Performance
				Subbase	Base[2]	Surface	
23	120-187	1969	9	150 SA[3]	150	DBST[4]	Good riding quality, low deflection
	187-212	1968	10	470 SA	180	DBST	" " "
24	4-9	1966	12	100 L[5]	150	DBST	Slightly rolling, patching
201	0-64	1967	11	150 SA	150	DBST	—
202[6]	12-66	1969	9	150 L	150	40 AC[8]	—
	66-85	1970	8	150 SA	150	PM[9]	—
202[7]	0-53	1970	8	150 SA	150	DBST	Reflected crack, good riding quality, and low deflection
	53-125	1970	8	150 SA	150	50 AC	
205	244-321	1970	8	150 SA	150	DBST	—
	321-340	1968	10	150 L	150	DBST	—
	340-403	1967	11	150 SA	150	DBST	—
212	57-138	1969	9	100 SA	150	DBST	Good riding quality, mostly uncracked
213	0-84	1968	10	100 SA	150	DBST	
214	0-55	1969	9	150 SA	150	40 AC	Good pavement condition, some cracks and rutting
	55-74	1967	11	100 SA	150	40 AC	
217	5-59	1969	9	150 SA	150	40 AC	Good condition, low deflection, much cracked
221	0-64	1970	8	150 L	150	DBST	Good condition, rutting and crack

1. Data from Maintenance Division
2. Base is soil - cement
3. SA is soil-aggregate
4. DBST is double surface treatment
5. L is lateritic soil
6. Route Chaiyaphum - Bua Yai
7. Route Amnatchareon-Kemmarat
8. AC is asphaltic concrete
9. PM is penetration macadam

the criterion suggested by the British Road Research Laboratory from his experience in Africa (15). The importance of proper compaction is strongly emphasized by the fact that a small decrease in percent compaction resulted in considerable reduction of compressive strength.

WOO (13) made a detailed investigation on cement stabilization of lateritic soils extensively sampling from Thailand. The samples employed in this investigation varied from sandy loam (A-2-4) to clay (A-7) with the plasticity indices of 9 to 35. After interpreting the Woo's data, the variations in unconfined compressive strength with molded water content, compacted dry unit weight, and percentage amount of clay content are shown in Figure 3. The unconfined compressive strength increases with cement content for all values of compacted dry unit weight, molded water content and clay content.

Most lateritic soils usable for soil-cement base course construction have dry density generally not less than 2000 kg/m^3 (125 lb/ft^3). According to Figure 3, at the value of dry density of 2000 kg/m^3 (125 lb/ft^3) and cement content of 3 percent, the unconfined compressive strength will be about 2500 kN/m^2 which is higher than the criterion suggested by the British Road Research Laboratory, that is 1725 kN/m^2 (250 lb/in^2). After making an extensive investigation as reported by WOO (13) and interpreting his data in Figure 3, it is clearly seen that cement requirements for lateritic soil in Thailand could be ranged from 3 to 7 percent, with an average of 5 percent. This tends to substantiate the past investigations (11, 12). However, the actual construction projects in Thailand indicated that lateritic soil in Thailand requires only 3 to 5 percent cement to attain the unconfined compressive strength not less than 1725 kN/m^2 (250 lb/in^2).

Another interesting finding interpreted from WOO's data is that the critical clay content for maximum unconfined compressive strength varying from 20 to 25 percent for the same type of clay mineral in all samples. Any lateritic soils having clay content greater or lower than this critical range the unconfined compressive strength will drop as evidenced by Figure 3.

The Siam Cement Company introduced a soil-cement road to Thailand for the first time in 1966 by constructing a test road of 5 km long using cement stabilized lateritic soil as base course. He recommended the CBR value of the soil-cement base of 120 be a criterion for low volume road with low typed surface in the Northeast. The criterion for unconfined compressive strength is the same as that suggested by the British ROAD RESEARCH LABORATORY (15), that is 1725 kN/m^2 (250 lb/in^2).

The Thai Highway Department adopted a criterion of minimum unconfined compressive strength of cement stabilized soil of not less than 1725 kN/m^2 (250 lb/in^2) like the British Road Research Laboratory. From the experience of more than 1400 km of lateritic soil-cement road constructed in the Northeast Plateau, it was found that 3 to 5 percent cement is enough to satisfy the unconfined compressive strength requirement for the soil with PI of less than 18. For highly plastic lateritic soil, 2 percent of lime was added and mixed with the soil to cut down its plasticity before applying cement. At this range of cement content, the unconfined com-

Figure 4. Map Showing Soil–Cement Routes in Northeastern Thailand

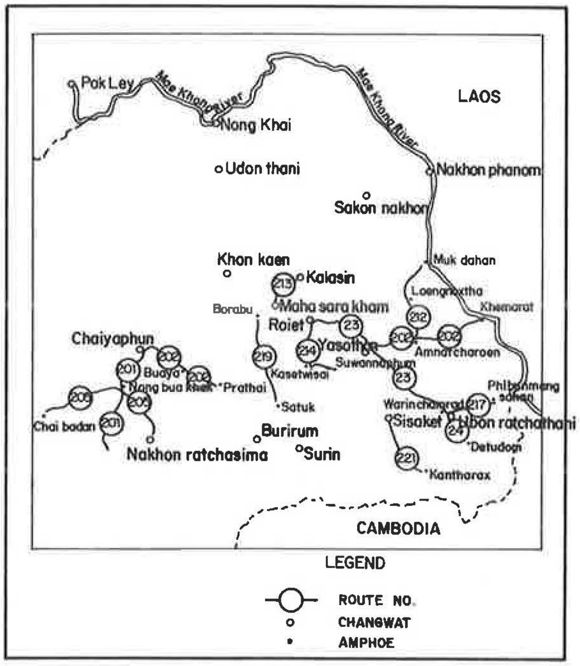
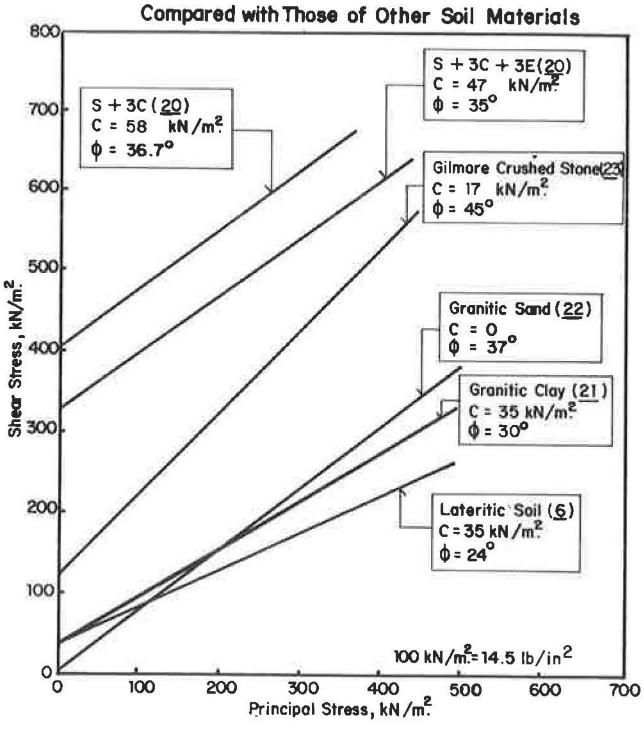


Figure 5. Strength Parameters of Stabilized Silty Sand Compared with Those of Other Soil Materials



pressive strength varied from 1725 to 2760 kN/m^2 (250 to 400 lb/in^2).

WOO and MOH (14) studied lime stabilization of eight lateritic soil samples from the Northeast Plateau. The PI are in the range of 9 to 35. It was found that most soil samples stabilized with 7 to 10 percent of hydrated lime developed more than 1725 kN/m^2 (250 lb/in^2) compressive strength after 28 days curing and one day immersion. Lime stabilization is not recommended to use in this region for its slower rate of strength development than cement. Its cost is also slightly higher than cement. Lime is generally employed as a secondary additive for cement stabilization to reduce the plasticity of highly plastic lateritic soil as stated before.

Pavement Design and Performance of Lateritic Soil - Cement Roads. In Northeastern Thailand there are about 1400 km of soil-cement roads with varying ages of 8 to 12 years. Table 1 shows the pavement structure of individual route including other data concerned such as age of service, type of surface, and etc. The route map is also shown in Figure 4. The thickness of the cement stabilized base is limited to 150 mm for every route.

The surface type of soil-cement road may be penetration macadam, double surface treatment, or asphaltic concrete. Performance of soil-cement road varied with the type of surface. The performance is evaluated on the basis of the Benkelman Beam deflection, riding quality rut depth, and roughness of road surface. After such evaluation it is found that performance of most soil-cement roads in this region is satisfactory. The plastic failure is not significant. In the future when the traffic volume increases, only additional few centimeters of high typed surface will be enough to strengthen the pavement. This is corresponding to the modified PIARC definition of low cost - low volume road that will be described in the Discussion section. So it is clear that soil-cement could replace crushed rock, and the road could serve low to medium traffic (ADT less than 500 vpd) in Northeastern Thailand. Even though the performance of soil-cement roads tends to be acceptable, but they usually encounter with a serious problem, that is the shown up reflected crack on the surface which increased much work in the maintenance program. The causes of crack were due to shrinkage of the soil-cement slab itself associated with many other factors (16). RANANAND (16) stated, on the basis of his investigation on some test roads, that reflected crack could be minimized if the surface is made penetration macadam because this type of surface could sustain larger deflection without crack than asphaltic concrete and double surface treatment.

According to the ECAFE's Report of the Seminar on Low Cost Roads and Soil Stabilization (17), it was urged to make use of the local materials in low volume road construction as much as possible in order to reduce the cost. Applying the concept of employing the local materials, staged construction approach and appropriate technique of soil stabilization together, cement stabilized lateritic soil is a suitable material to serve as base course of low volume road in Northeastern Thailand. From experience of soil-cement design and construction in this region associated with researches conducted, it is expected that the problems of reflected crack, the field control and compaction could be eliminated.

Silty and Sandy Soils

Silty and sandy soils are earth materials covering an extensive area of Thailand. Both of them are surficial soil in the Northeast Plateau. As the most available materials, they are expected to be employed as parts of the pavement structure for low volume road.

Table 2. Recommended Pavement Thickness for Low Volume Road in Thailand (25)

Unsoaked CBR. of Subgrade Compacted at OMC.	Buses and Trucks Less Than 25 Vpd.*			Buses and Trucks 26–60 Vpd.*			CBR. of Subgrade Compacted at OMC.	Buses and Trucks 61 – 120 Vpd.			Buses and Trucks 121 – 200 Vpd.		
	Surface Type – Single Surface Treatment.			Surface Type – Double Surface Treatment				Surface Type – Double Surface Treatment			Surface Type – Double Surface Treatment		
	Base CBR ≮ 60 (mm)	Subbase CBR ≮ 25 (mm.)	Selected Materials CBR ≮ 8 (mm.)	Base CBR ≮ 80 (mm.)	Subbase CBR ≮ 25 (mm.)	Selected Materials CBR ≮ 8 (mm.)		Base CBR ≮ 80 (mm.)	Subbase CBR ≮ 25 (mm.)	Selected Materials CBR ≮ 8 (mm.)	Base CBR ≮ 80 (mm.)	Subbase CBR ≮ 25 (mm)	Selected Materials CBR ≮ 8 (mm)
2	100	120	140	120	120	150	2	140	120	180	150	130	200
4	100	120	120	120	120	120	4	140	120	140	150	150	150
6	100	150	–	120	150	–	6	140	150	–	150	130	–
8	100	120	–	120	120	–	8	140	120	–	150	–	–

*In both directions

Silty sand, a fine grained soil with well gradation, has been used as subbase of many roads in Northeastern Thailand. As the problem of material deficiency is so critical, a pilot project was conducted using silty sand stabilized with cement and emulsified asphalt for hoping that it may be strong enough to be employed as base course of low volume road. From the result of the laboratory test it was found that the molded specimen of silty sand mixed with 5 percent emulsified asphalt, or 3 percent cement and 3 percent emulsified asphalt, had high stability enough to serve this purpose (18). The performance of the test road was found to be satisfactory (19).

RUENKRAIRERGSA and DEOPANICH (20) made a further investigation on strength characteristics of silty sand stabilized with cement, emulsified asphalt or both additives with the same proportions as in the past studies (18). The strength of stabilized material was evaluated in terms of strength parameters C and Ø by conducting the undrained triaxial compression test on the specimens after curing for 7 days. The result is shown Figure 5. Also included in the same figure are strength parameters of some other soils obtained from the past studies namely decomposed granite, crushed gravel, and lateritic soil (5, 21, 22, 23)

From Figure 5 it is obviously seen that silty sand stabilized with cement or cement and emulsified asphalt has very high strength as evaluated from the strength parameters C and Ø. The strength of stabilized silty sand is higher than compacted lateritic soil (5), granitic clay (21), and granitic sand (22). In the case of crushed stone, cohesion of stabilized silty sand is higher, while the angle of internal friction is lower than the Gilmore crushed stone (23). This indicated that for low pressure range (low traffic volume) stabilized silty sand could be suitably used as base course, but for higher pressure (or high traffic volume) it is better to employ crushed stone base for longer life.

Terrace Gravel

Terrace gravel is one of the most important highway materials that easily found in the Northeast Plateau. Sometimes it is formed as lateritic gravel which has thin layer of iron oxide coating around the gravel particles. Terrace gravel, like lateritic soil, is a well graded material with some quantities of fines. The plasticity index is generally lower than lateritic soil. After blending with tractor in the borrow pit, it can be directly used for subbase or base courses of low to medium traffic road. Good terrace gravel from some sources in this region may have CBR as high as 80.

Design of Pavement Structure for Low Volume Road in Thailand

The design of road pavement in Thailand is based on the CBR of subgrade and number of heavy truck of that particular route, following the method of THE ASPHALT INSTITUTE (24). As there are so many low volume roads, both paved and unpaved, in Thailand. Sometimes the division engineer has to design the pavement structure of some roads or some sections of road in his area by himself. In order to standardize the typical pavement structure for any particular soil bearing value and traffic volume in all divisions, the Department of Highways appointed a Working Group for Drafting the Most Probable Pavement Design for Low Volume Road. This Working Group has to compromise between the theoretical design following the method of THE ASPHALT INSTITUTE (24) and the local experience for the individual regional traffic and climatic condition in Thailand to set up the most probable pavement structure. Table 2 shows some pavement designs of low volume road for different subgrade soil bearing values in Thailand as compiled by POMTYEN and THUM-UMNAUYSUK (25). According to Table 2 CBR of the base required is 60 to 80. Good lateritic soil and terrace gravel in some localities have CBR values fall in this range and they can satisfy the design criterion for low volume road.

Discussion

In 1958 ECAFE organized the Seminar on Low Cost Roads and Soil Stabilization in New Delhi, India(17). The Seminar emphasized the use of local materials in road construction in order to cut down the cost of the road. In case the available material is not suitable, some methods of soil stabilization should be tried. However, during the past time, the meaning of the word "low cost" had changed dramatically. During the Sixth World Highway Conference held in Montreal, Canada, in 1970, BENNETT (26) stated that staged construction could provide a minimum standard facility which could be improved as the need increases. BENNETT also pointed out that current economic analysis methods will seldom provide justification for a low cost road. In many international seminars there are some controversies about the real meaning of the words "low cost". Many suggested to use "low volume" instead. However, the Permanent International Association of Road Congress (PIARC) compromised the argument and use the terms "low cost - low trafficked road" to satisfy both ideas. In 1976 the Indonesian Road Research Institute organized the Regional Seminar on Low Cost Roads in Bandung, Indonesia. A modified PIARC definition of low - cost roads by VANCE (27) seemed to be generally accepted by the Seminar as:

> "A low cost road is one which, having regard to conditions of climate and traffic, has been located and built to geometrical standards commensurate with future requirements, but has been constructed down to a price rather than up to a standard. It is, however, one which should be so designed, constructed and maintained that it allows for stage construction when improvement in economic conditions permits."

The objective of organizing this Seminar is to promote the low cost - low volumed road construction and the technical cooperation in road engineering to develop the Southeast Asian countries. Some conclusions pertaining to the use of local materials are reached as follows (28):

> "The need for more information about the distribution, properties and road performance of naturally occurring materials was stressed. Some possible practical steps to overcome this was spelled out as follows:
> a) identification of those materials of widespread occurrence and identification of greatest problem to be faced in recording national inventories of material;
> b) undertaking studies of these materials, such as full-scale trials, to evaluate their usage in low-cost road construction; and
> c) creation of more realistic specifications for low cost road application as the final step in the abovementioned process.
> In this way more effective use be made of local resource , perhaps the most important constideration in lowering the cost of construction."

From the conclusions above it will be clearly seen that the effective utilization of the local materials plays a great role in cost reduction of road construction in many developing countries such as those in Southeast Asia. The regional highway materials must be investigated associated with determining their properties. Lateritic soil, silty and sandy soils, and terrace gravel are major types of soil most available in the Northeast Plateau. The appropriate specifications for each must be set up specially for use with low volume roads and for local application. Today the specifications of highway materials adopted by the Department of Highways are slightly modified from those of AASHO. The modified specifications are found to limit the effective employment of local materials in the tropical areas. The modes of formation of lateritic soil and other tropical soils are not comparable to the materials in the temperate regions. So their nature will be different and then should their specifications. Realizing about this fact, the Department of Highways conducted many research projects studying about the properties and stabilization of some local materials in Thailand. These are lateritic soils, silty and sandy soils in the Northeast Plateau, granitic soil in the North and the South. The research programs of the Department of Highways tend to substantiate the conslusion of the Bandung Regional Seminar in 1976 that research needs in various phases of planning, design, and construction of low cost roads are important for the countries in the tropical region in which most of them are developing.

From the above discussion it will be seen that the effective employment of local materials, the future planning for upgrading the road to satisfy the future traffic volume, the appropriate techniques of soil stabilization and staged construction must be considered harmoniously in design and construction of low cost-low volume roads. This type of road is not designed for the present situation alone, but also for the future expansion. If not, the word "low cost" will have no meaning. So, why the UNESCO's experts emphasized in the book entitle "Low Cost Roads" that

> "----- the disign and construction of roads in developing countries have a special character." (29).

Conclusions

1. Geotechnical aspects concerning the low cost - low volume road design and construction are the effective employment of local materials, the appropriate methods of soil stabilization, and the technique of staged construction. All of these should be kept in mind when dealing with low volume road.

2. Specifications adapted from experience in the temperate countries are found to limit the effective use of local materials in the Northeast Plateau and other parts of Thailand.

3. Researches on materials and their stabilization are needed in Thailand in order that the more suitable specifications are developed on the basis of data from the local resources.

4. Major soil materials employable for base course of low volume road in Northeastern Thailand are lateritic soil, terrace gravel, and stabilized silty and sandy soils.

5. On the basis of the CBR value, lateritic soil and terrace gravel which are abundant in Northeastern Thailand could be directly employed as base course

of low volume road.

6. For fine grained or high plasticity lateritic soil, about 3 to 5 percent of cement is required to get the unconfined compressive strength of 1725 kN/m^2 (250 lb/in^2) which is adopted as a criterion for soil-cement base in Thailand. At this range of cement content the CBR will increase to more than 100.

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