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PENETRATION MACADAM AS A SURFACE TO MINIMIZE THE REFLECTED CRACKS FROM SOIL CEMENT BASE

By

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PREFACE

Stabilization is a method to improve available unsuitable materials to meet the requirement . It is necessary for developing countries to apply this method in their practice in order to make use of their limited fund to cope with needed mileage of national highways. In Thailand there are quite a number of kilometers of road stabilized by cement and lime and cracks are one of the main maintenance problems for us to spend money on.

With this study we can confidently apply this type of surface on the cement stabilized base without fear of spending more fund on continuing maintenance.

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Director - General

PENETRATION MACADAM AS A SURFACE TO MINIMIZE THE REFLECTED CRACKS FROM SOIL CEMENT BASE *

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SYNOPSIS

This report covers stabilization to improve inferior materials for road base. Cement and lime stabilization are used as stabilizers. Several types of surface are introduced in the test section. Penetration macadam is proved as a surface that can minimize reflected cracks from soil cement base, in Thailand.

1. INTRODUCTION

Stabilization to improve inferior materials for road base is widely used in developing countries. Cement is one of the chemical agents used for stabilization. Experience indicates that soil-cement mix always cracks and can cause reflected cracks in the surface. This type of cracking always causes trouble to road engineers, because moisture can easily seep through the surface and base and soak the sub-base. So it is indeed necessary for the road engineer to find a method to minimize those reflected cracks.

Several hundred kilometres of soil-cement base were built in some areas in Thailand where aggregates and stone are not available within economical haul distances. The Highway Department engineers seem to agree that we can not really eliminate cracking in soil-cement bases, so the best approach is to study whether any type of surface can help minimizing the reflected cracking that is likely to occur.

In order to explain the behaviour of the penetration macadam that can minimize reflected cracks from soil-cement, a test section on the Highway No.213 from the town of Mahasarakam to the district of Nong Wang was studied.

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2. DESIGN CRITERIA

Our laboratory tests showed that some plastic lateritic soils with a PI less than 14 after mixing with cement to obtain 250 psi unconfined compressive strength after 7 days curing in moist room showed signs of surface spalling when dry. If two percent of lime was added with the percentage of cement needed to obtain 250 psi unconfined compressive strength of the mix at 7 days, we found that we could easily overcome the spalling problem. This method was introduced in the Thai Department of Highways practice.

Materials specifications and design details are given below:

2.1 Soil. Soil shall be free from vegetation or other objectionable matter and may be either the existing soil in the roadbed, borrowed soil, or a combination of both, approved by the engineer. Soil for the base course materials shall all pass a 3-inch sieve and not more than 45 percent shall be retained on the No.4 sieve.

2.2 Lime. Lime shall be a good quality hydrated lime with a minimum calcium hydroxide content of 90%. A 100% of lime shall pass No.40 sieve and at least 90% shall pass sieve No.200.

2.3 Cement. The Portland cement shall meet the requirements of the AASHO Standard Specification M 85, Type I.

2.4 Water. The water used in the construction of the soil-cement base course shall be reasonably free from salt, oil, acid, alkali, organic matter or other deleterious substance, or it shall pass the test in accordance with AASHO T-26.

2.5 Soil-cement mix samples of the size of Proctor mold must have at least 250 psi unconfined compressive strength at 7 days of age and CBR of at least 95%. The compaction of soil-cement sample is done by Modified Proctor and the sample has to be soaked in the water for 2 hours before testing. Samples must be cured, before testing, by keeping in plastic bags for 7 days.

2.6 Trial mixes shall be made by adding 2% of lime with successive increasing percentages of cement to the soil. A curve of unconfined compressive strength is plotted against cement content and from this curve a cement content is selected to meet the specification after allowing a margin for inefficient workmanship. This margin may be reduced when cored samples show that the specification is being exceeded.

As soon as the soil-cement base has been laid and compacted up to 95% Modified Proctor and shaped to required grade and elevation, curing should be done by either rapid curing cutback or quick setting emulsion. Traffic is permitted to run on the soil-cement after 24 hours.

2.7 Penetration macadam. Materials specification requirements for penetration macadam can be explained briefly as follow:-

2.7.1 Stone must be crushed rock or aggregate of cubical shape with percentage of wear less than 40% perferably less than 25%. Gradation must meet the requirements of Table I.

TABLE I

PENETRATION MACADAM GRADATION

Nominal size	$2\frac{1}{2}$"	2"	$1\frac{1}{2}$"	1"	3/4"	1/2"	3/8"	#4	#8	#16
2" - 1"	100	90-100	30-70	0-15	-	0-5				
3/4 - 3/8	-	-	-	100	90-100	20-60	0-15	0-5		
1/2 - #4					100	90-100	40-70	0-15	0-5	
3/8 - #8						100	80-100	10-30	0-10	0-5

TABLE II

QUANTITIES OF MATERIALS

Materials requirements according to construction steps	Quantities of materials for surface thickness 7 cm.
<u>First step</u>	
Spread 2" - 1" crushed stone	116 - 145 kg.
Spray AC 80 - 100	4.5 - 6.5 litres
<u>Second step</u>	
Spread $\frac{3}{4}$" - $\frac{3}{8}$" crushed stone	12 - 20 kg,
Spray AC 80 - 100	2.3 - 3.1 litres
<u>Third step</u>	
Spread $\frac{1}{2}$" - #4 crushed stone	9 - 12 kg.
Spray AC 80 - 100	0.9 - 1.1 litres
Finished by spreading	
coarse sand or $\frac{3}{8}$" - #8 stone	9 - 12 kg.

Note: Quantities of bitumen in each layer vary inversely with number of traffic. First length of test section should be done before making any decision.

2.7.2 Bituminous material. Asphalt cement 80-100 penetration that meets the Department of Highways specifications (Asphalt Institute specifications) must be used.

2.7.3 Quantities of materials to be used for penetration macadam are shown in Table II.

2.8 Surface treatment. During the period of construction we are considering, i.e. between the year 1966 and 1968, the surface treatment specifications did not require a single sized chipping as the present specifications do.

Quantities of materials to be used for surface treatment are shown in Table III.

TABLE III

QUANTITIES OF MATERIALS OF DOUBLE SURFACE TREATMENT

Materials requirements according to construction steps	Quantities of materials for surface per sq. meter
First step	
Spray bituminous materials (cut back or emulsion)	1.7 - 2.1 litres
Spread first layer of stone $\frac{3}{4}$" size	18 - 22 kilograms
Second step	
Spray bituminous materials (cut back or emulsion)	0.65 - 0.9 litres
Spread second layer of stone $\frac{3}{8}$" size	8 - 10 kilograms
Seal coat	
Spray bituminous materials (cut back or emulsion)	0.45 - 0.65 litres
Spread third layer of stone or coarse sand	4 - 7 kilograms

2.9 Asphaltic concrete. All specifications for asphaltic concrete are specified as Type IVb in the "Specifications and construction methods for asphalt concrete, the Asphalt Institute."

2.10 Pavement was designed as a flexible pavement by CBR Method corresponding to CBR values of materials in each layer.

3. CONSTRUCTION METHOD

The author does not intend to explain the construction method in full detail, but a brief statement is made in order to make known our method of construction:

3.1 Prepare the subgrade and sub-base to meet required grade, profile and compaction specifications.

3.2 Either plant mix or single pass stabilization road mix should be utilized as the construction equipments.

3.3 Maximum thickness of soil-cement layer should be justified by the capability of rolling equipments, but it should not be thicker than 20 cm. or thinner than 15 cm.

3.4 Cement shall be applied only to areas such that all operations can be continuous and completed in daylight. No cement shall be applied when the moisture content of the pulverized soil, at the time of cement application, exceeds the optimum moisture content for soil-cement by more than 2 percentage points.

3.5 Lime shall be applied to an area at the same time as the application of cement.

3.6 When central plant mix is used, soil, lime, cement and water shall be mixed in a pugmill. Mixing shall continue until a uniform, intimate and homogeneous mixture is obtained. Not more than 30 minutes shall elapse between the placement of soil-cement in adjacent lanes except at longitudinal centre joint.

Not more than 60 minutes shall elapse between the start of moist mixing and the start of compaction of soil-cement.

3.7 When single-pass stabilization is used, cement, lime and soil shall be dry mixed with a single-pass travelling mixing plant. Add the required quantity of water uniformly and at such rate as to obtain the specified optimum moisture for the mixture. Mix them thoroughly and spread the complete mixture evenly over the machine process width and leave it in a loose condition ready for immediate compaction.

3.8 Compaction. The complete soil-cement mixture shall be compacted immediately after the mixing operations to 95% Modified Proctor density. Any portion which has a density of 5 lb or more below that specified shall be removed. Compaction shall begin within 30 minutes after the last increment of water has been added and uniformly incorporated to fulldepth of the mixture.

.9 **Finishing.** Finishing operation shall be completed within 3 hours after mpletion of mixing operations.

.0 Curing. After the soil-cement base has been finished, its surface shall be otected by applying rapid-curing cutback or quick setting bituminous emulsion. d should be spread after the bituminous materials have set and then the base be opened to traffic.

.11 Surfacing. Surfacing should be put on the complete soil-cement base as on as possible in order to protect the base from deterioration. Quantities of rushed rock and bituminous materials in the case of penetration macadam and uble surface treatment should be done as specified. Roller is needed for comction as a usual practice as specified in the standard specification for conruction of the Thai Department of Highways. Asphaltic concrete may be constructed specified following the aforementioned standard specifications or by the method construction specified by the Asphalt Institute.

.. THE TEST SECTION

highway was built in the year 1966 and completed in the year 1968 using soilment base on well-graded sand mixed lateritic soil sub-base and with double rface treatment.

flected cracks both longitudinal and transverse appeared on the surface from weeks to 2 months after the completion of a particular section. Most cracks re hair cracks but some were up to 0.15 cm. Crack spacing was uneven about 1-3 tres transversely and from 1-2 metres distant from the centre line longitudinally. e traffic lane width of this two-lane highway is three metres.

e traffic on this road is plotted in Figure I.

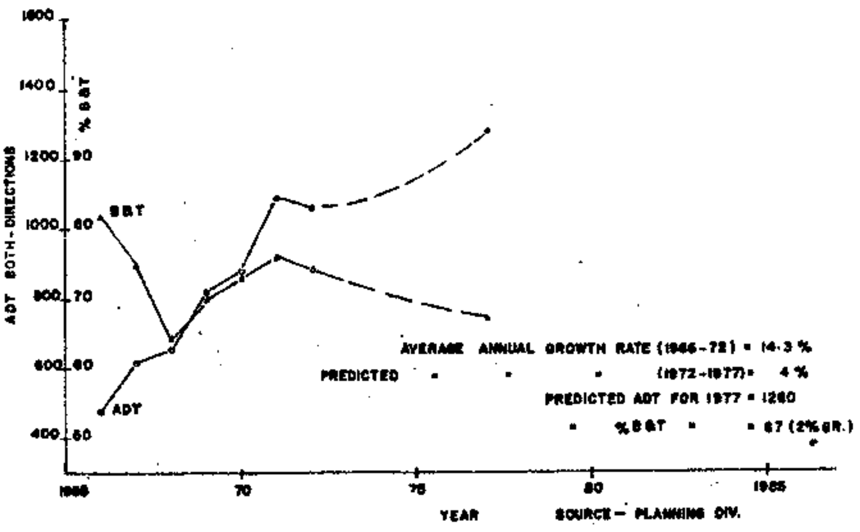

Fig. I Traffic on Route No. 213

maintenance crew was assigned to seal all cracks but this was effective only in the t season; the cracks appeared again in the iny season.

this highway was designed for stage construction, and it would be necessary to strengthen the pavement at about 7 years after the completion of the project then the test section was introduced in order to make sound selection of the right type of the surface.

In the meantime several hundred kilometres of other highways had been constructed using the same method with surface treatment or asphaltic concrete surfacing and, in one project, a penetration macadam surfacing was introduced. The penetration macadam surface exhibited less cracking than the other two types, only single longitudinal cracks appeared and these were filled with bitumen pumped up by the traffic.

In view of the above, a test section, divided into 2 parts each of 500 metres, was selected in tember 1971. Figure II shows a typical ttern of cracks on the proposed test section efore new surfacing was applied. On the first metres a 5 cms. thick asphaltic concrete urface was laid; on the second 500 metres 7 cms. of penetration macadam.

Typical deflections on the proposed test section, tested by Benkelman beam deflection devices are shown in Figure III.

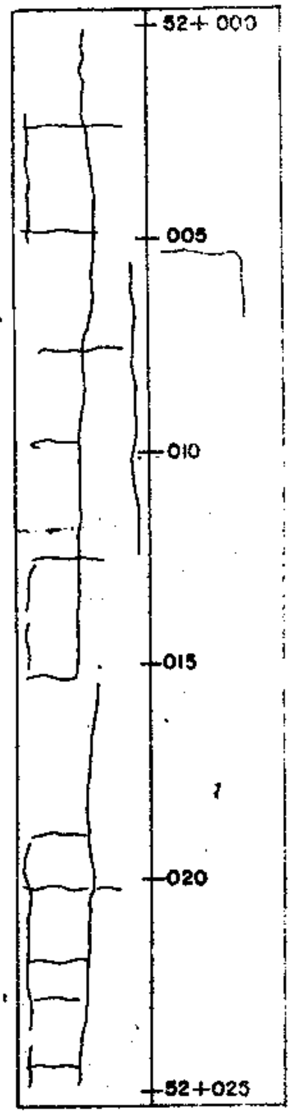

Fig. II Pattern of Cracks on the Proposed Test Section.

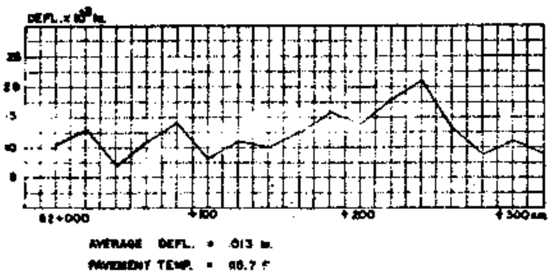

Fig III Typical Deflection for 300 Metres of Proposed Test Section

In Figure III, we can see that the deflection fluctuates which means that the pavement of this section is not uniformly strong. In fact, this soil-cement base was constructed by plant mix which should have obtained uniformity.

By Benkelman beam deflection devices, we also measured the differential deflections across the cracks as shown in Figure IV at one crack in the proposed test section.

5. PRESENT PERFORMANCE OF THE TEST SECTION

A close visual survey was performed at the test section recently and on adjacent sections and it was found that:

5.1 Quite a number of both lognitudinal and transverse cracks could easily be seen on surface treatment surfacing along this route even though another layer of seal coat was done in 1971.

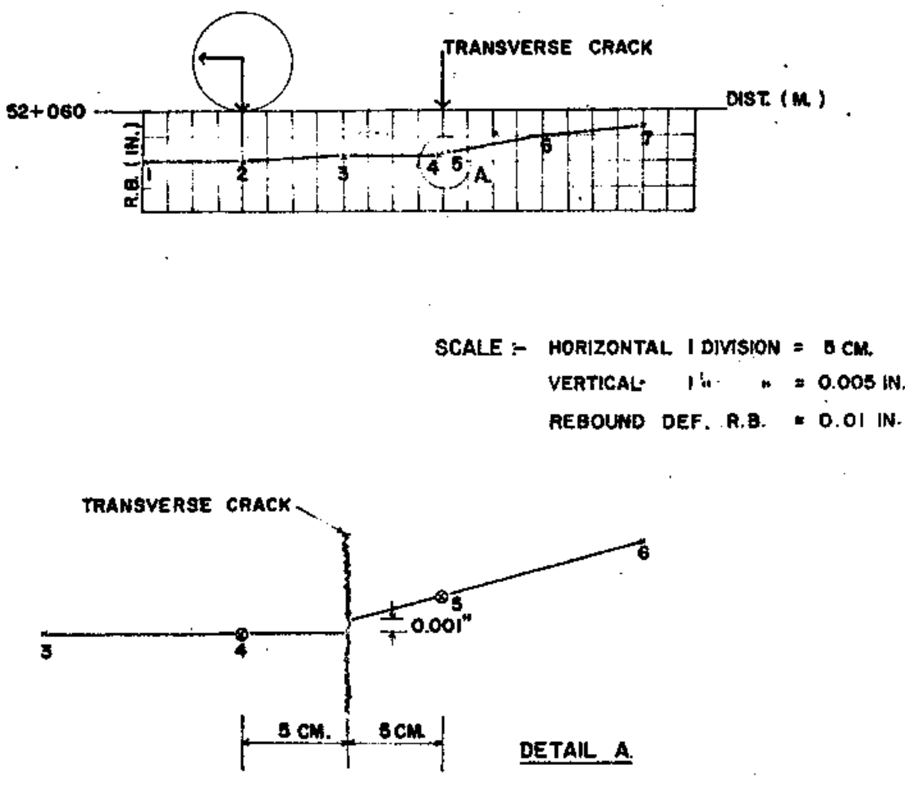

Fig. IV Typical Differential Deflection Across a Crack.

5.2 On asphaltic concrete surface section, hair size longitudinal cracks about 1.5-1.8 metre from the centre line of the surface showed and extended all along the length of the test section.

5.3 No sign of cracking could be seen on penetration macadam section.

6. CAUSES OF CRACKS IN SOIL-CEMENT BASE

As was mentioned before on all highways that were built using soil-cement base with asphaltic concrete or double surface treatment surfacing, cracks can be seen all over the surface. On the contrary, few cracks have appeared in penetration macadam sections.

It is accepted that causes of soil-cement base cracking come from many factors such as:-

- Shrinkage of the soil-cement itself.
- Loads from the traffic.
- Differences of moisture through the depth of soil-cement.
- amount of cement.
- mixing water content and degree of compaction.
- method and time of curing.
- distortion of the slab after cracking.

7. HOW PENETRATION MACADAM CAN MINIMIZE REFLECTED CRACKS

Penetration macadam or as it is sometimes called, grouting, consists basically of a compacted layer of single size coarse stone to which a bituminous binder is applied to bind the stone together. A layer of key stone is added and is then grouted. The whole is then sealed.

7.1 The cracks reflected up by the shrinkage of the soil-cement mix, are minimized for these reasons:-

7.1.I As the stones of the penetration macadam are crushed rock of uniform size, after rolling until no movement of stone can be noticed, then these stones must be interlocked. The overlapping or interlocking area, as shown in Figure V, in that particular place is wider than the shrinkage crack. The horizontal movements among stones caused by shrinkage in the base is less than the interlocking distance. Moreover, key stones also assist in controlling the movement of shrinkage cracks, by causing more overlapping to the first layer. So the horizontal movement due to shrinking of soil-cement mix will not cause movements in the surface to such an extent that macadam stone will become separated enough to show the crack.

7.1.2 Penetration bitumen that is applied to the coarse single size stone, will fill about 1/3 to 1/2 of the total voids. This will cause quite a thick film on the soil-cement base. As penetration bitumen is a viscous ductile material, the horizontal movement due to shrinkage cracks is not sufficient to cause any cracks through this thickness of bitumen film as shown in Figure VI.

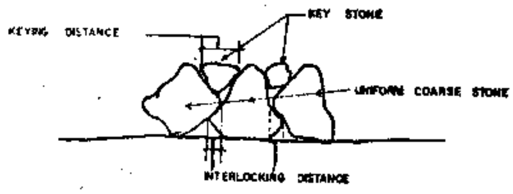

Fig. V Interlocking & Keying of Stone in Penetration Macadam.

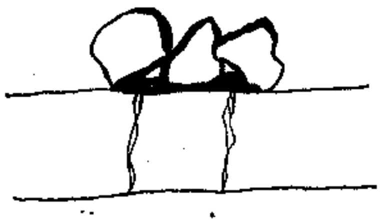

Fig. VI Thick Film of Bitumen in Penetration Macadam.

7.2 Because the crack size is reduced to narrow limits due to traffic loads put on the soil-cement mix at an early age, the penetration macadam can bridge these cracks more easily. Lateritic soil used are usually composed of some percentage of aggregates, and have an initial stability in themselves. Basing on the concept that cracks are formed when the tensile stresses, set up in soil-cement base slabs due to the restraint resulting from the friction between the slab and sub-grade, exceed the tensile strength of the material (George 1969); then, if traffic loads are allowed on the soil-cement base after 24 hours of the mix, it is expected the crack spacing will be reduced to 10-100 cm. as the friction between base and sub-base was greatly increased due to traffic loads. So the crack size varies from hair crack to the maximum size of 1.5 mm. With the benefit of penetration macadam as mentioned in 7.1, they are well covered.

7.3 The thicker film of bitumen that is applied and contained in the voids can reduce the difference of moisture through the depth of soil-cement. This bitumen will also seal the surface of the base.

7.4 The penetration macadam surface can tolerate more deflection than asphaltic concrete. According to the Department of Highways study it has been found that the pavement with penetration macadam surface can tolerate as high as 0.375 cm. (0.150")

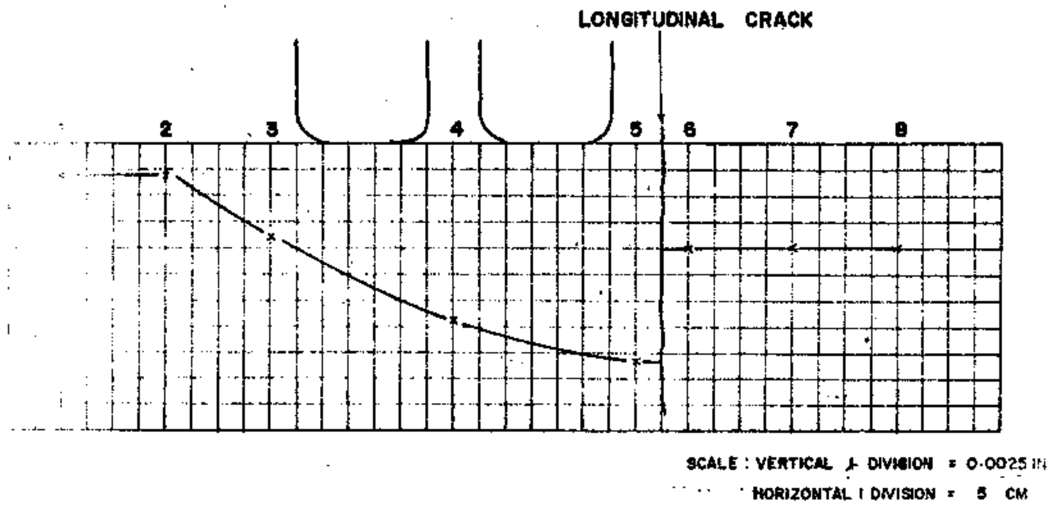

Fig. VII Differential Displacement Across the Longitudinal Hair Crack on Penetration Macadam Surface at Km. 48 + 840 on Bua Yai – Ban Si Da – Pratai Highway

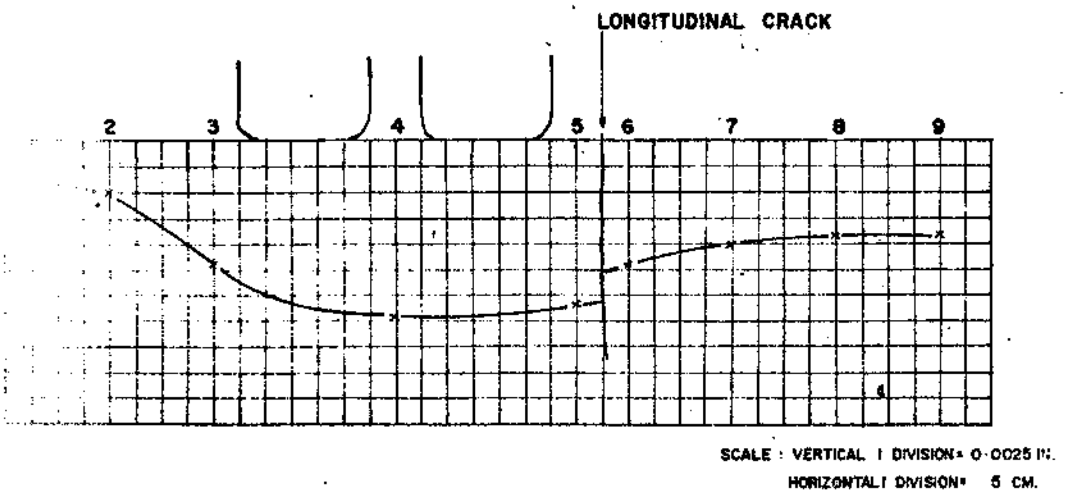

Fig. VIII Differential Displacement Across Longitudinal Crack in Soil-Cement Base which did not appear on the Surface at Km. 49 + 150 on the same Highway where accidentally found on coring.

Even though penetration macadam surface is able to take higher deflection than asphaltic concrete (0.062 cm. or about 0.025"), the soil-cement base itself cannot tolerate deflection more than 0.037 cm. (0.015"), so this is no real merit of the penetration macadam on the soil-cement base over the asphaltic concrete.

The author is confident that asphalt concrete and surface treatment type of surface cannot take much differential displacement across the crack without itself cracking. Penetration macadam proved that it can take a higher differential displacement across the crack as shown in the Figures VII and VIII.

The author thinks that the differential displacement across the crack should also be a guide line to determine the surface thickness. The problem in setting criteria for this differential displacement is very difficult, as we cannot easily specify the early stage of cracking in the base before the crack appears on the surface. Also it is extremely difficult to measure the differential displacement across the crack on the surface before reflected crack shows.

Differential displacement can be reduced, if the cracks are controlled to be as fine as possible. Some percentage of coarse aggregate should be present in the soil as it will cause the crack surface to be as irregular as possible, and will be able to transfer some percentage of load across the crack.

Besides causing cracks, the differential displacement across the crack can also cause pumping action at the crack plane.

Penetration macadam with a low percentage of bitumen always shows its permeability, as water can seep through the stone surface to the base. By the benefit of less deflection on the soil-cement, then higher percentages of bitumen can be spread on the crushed rock. Bitumen pumping within the voids of coarse stone after being subjected to traffic load can be reduced by this method. If any cracks are found in the penetration macadam, the pumping action behaviour of this type of surface can produce some self-sealing to protect the cracks.

8. CONCLUSION

By the experiences and test sections of the Thai Department of Highways, penetration macadam surface can minimize reflected cracks that may show on the surface. With this benefit, it can also protect the failure at the crack plane due to slab pumping action. With the right amount of applied bitumen, self-sealing can also be expected.

9. ACKNOWLEDGEMENT

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