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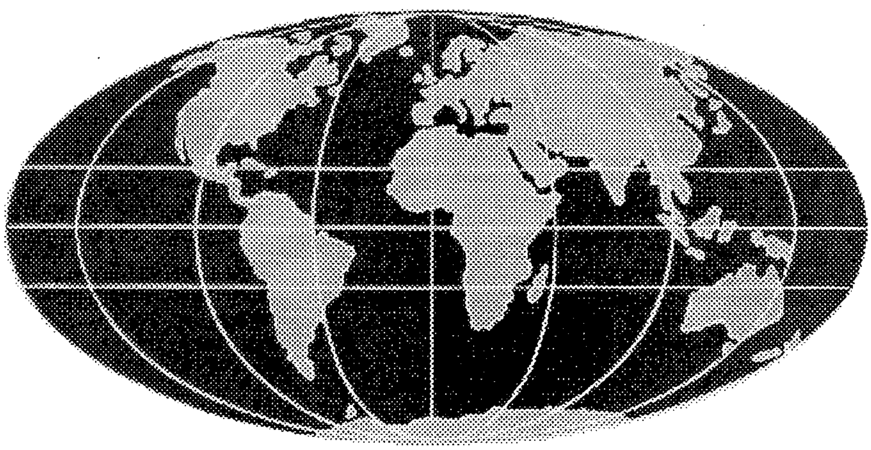

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Crowthorne
Berkshire RG45 6AU
United Kingdom

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MAINTENANCE OF UNPAVED ROADS IN WET CLIMATES

by

Dr T E Jones* and Y Promprasith**

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* Transport and Road Research Laboratory, UK
** Dept. for Accelerated Rural Development, Thailand

FIFTH INTERNATIONAL CONFERENCE ON LOW VOLUME ROADS

PAPER: MAINTENANCE STRATEGIES FOR MINOR ROADS IN WET CLIMATES

by

DR T E JONES* and Y PROMPRASITH**

ABSTRACT

In 1987, a research project on gravel roads was established in Thailand between the Thailand Office of Accelerated Rural Development (ARD) and the Overseas Unit of the UK Transport and Road Research Laboratory (TRRL). The principal objective was to compare the effects of alternative maintenance strategies for unpaved roads in wet regions. The project also studied the relative performances of motor graders and tractor-towed graders for maintaining roads carrying traffic volumes of 50 to 300 vehicles per day.

The potential benefits are the optimisation of grading frequencies for different levels of traffic. In addition, the opportunity was taken to evaluate the applicability of TRRL prediction models for gravel road deterioration produced from data obtained in dry and temperate regions to roads in wet climates.

Preliminary results from the study suggest that tractor-towed graders can achieve similar reductions in roughness to those obtained with the motor grader. Running costs of the tractor-towed grader units are less than half that of the motor graders. If investment and depreciation costs are considered then the savings in maintenance costs are substantially higher.

An additional problem in Thailand is that of maintaining rural roads built in hilly terrain with gradients up to 17 per cent. The ARD have investigated methods of reducing the high maintenance costs on such roads and found that the most cost effective solution was to surface the most vulnerable lengths of road with concrete blocks. After two years trafficking this treatment has proved to be highly cost effective, requiring no maintenance despite heavy rainfall.

* Head of Pavement Management Section, Overseas Unit, TRRL, UK

** Chief Maintenance Engineer - Office of Accelerated Development (ARD), Thailand

1. INTRODUCTION

Over the past 10 to 15 years, the Overseas Unit of the UK Transport and Road Research Laboratory (TRRL) has carried out extensive research on unpaved road deterioration and maintenance in several tropical countries. The results of these studies have led to the development of models for predicting the rate of various forms of deterioration and a means of optimising maintenance strategies (1).

However, the climate in the countries where research was undertaken has been predominantly dry or temperate. There has, therefore, been a need to validate the prediction models in more extreme climates, particularly in countries with annual rainfall above 2000mm.

In 1987 a collaborative research project was established in Thailand between the TRRL and the Office of Accelerated Rural Development (ARD) of the Ministry of Interior, Thailand. One of the principal aims of the ARD is to provide an all-weather road network in rural areas and to date it has constructed over 19,000 kilometres of gravel roads in some 73 provinces. The ARD is also responsible for the maintenance of these roads and looks to this research study to determine optimum grading frequencies and to evaluate appropriate equipment to achieve reductions in overall maintenance costs. Current progress on this work is reported in Part One.

The ARD is also currently undertaking a project to establish the costs and performance of precast concrete block paving. This technique is now well established in Europe and North America but its use as a surfacing for low-cost rural roads is unusual and if successful would provide an alternative maintenance strategy. This work is reported in Part Two.

2. PART ONE

2.1 Objectives of the ARD/TRRL Research Study

(1) To verify prediction models of gravel road deterioration produced from data obtained in dry and temperate regions under extreme conditions of climate. A minimum requirement is that the existing TRRL models are calibrated for wet climates but probably new prediction models will be developed.

(2) To study the relative merits of different maintenance strategies for unpaved roads in wet regions. This project would enable the TRRL to complete its studies on the performance of gravel roads over a wide range of climates. It has already been established that climate significantly influences the rate of deterioration but there is a lack of quantified data available on gravel road performance under very wet conditions.

Thailand provides an excellent environment for this research project. The rural development networks have roads carrying 50-400 vehicles per day and, in specific geographic areas, annual rainfall in the range 1700-2400mm. In addition, there is a well established road organisation responsible for maintenance.

2.2 Potential benefits to the ARD and other organisations.

The potential benefits of this research study are as follows:

(1) It should enable the maintenance organisation to determine optimum grading frequencies and this would result in more cost effective maintenance. This would reduce overall maintenance costs enabling additional funds to be spent on up-grading or construction projects. In addition, by quantifying the changes in surface condition, improved maintenance strategies could be obtained.

(2) ARD should be able to evaluate the merits of alternative equipment such as tractor-towed graders and drags to reduce maintenance costs on minor roads.

(3) It should enable the ARD to identify the effect of rates of change in surface condition on vehicle operating costs. This would be achieved by developing prediction models based on the field data and incorporating them in the TRRL micro-computer programme RTIM2 (2) which evaluates the costs and benefits of different maintenance strategies. This information would be invaluable to support requests for maintenance funds from Central Government.

2.3 Location of sites

Two provinces incorporating elements of the ARD road network are included in the research study. These are Hatyai in the southern region, where the study became operational in July 1987, and Nakhon Phanom in the north-east region where monitoring started in April 1988.

In both provinces there are 32 test sections each of which is 500 metres in length. All test sections are located on existing roads. The average annual rainfall based on 30 years of records is approximately 2400mm in each province. There are, however, specific differences in traffic volumes and loading and also in the materials available for gravel wearing courses.

At Hatyai the traffic varies from 50 to 300 vehicles a day with no heavy vehicles using the test roads, whilst at Nakhon Phanom the traffic varies from 25 to 250 vehicles a day with substantial volumes of heavy traffic on one of the test routes. Materials used for gravel wearing courses in the Hatyai region comprise sandstones, volcanic tuffs, laterites and limestones, whilst in the Nakhon Phanom region the gravels are derived predominantly from red sandstones of the Maha Sarakan formation together with terraced Mae Khong alluvial sandstones and siltstones.

2.4 Measurement of experimental variables

The principal experimental variables measured in the study are as follows:

(a) surface roughness

(b) rut depth

(c) traffic volume and loading

(d) climate

(e) gravel loss

(f) operating costs

(g) material properties measured both in the laboratory and in-situ

(h) grading frequency

Because of their geographic locations, the majority of the ARD road networks have large radii horizontal curves and vertical gradients of less than 2 per cent. Therefore, as the road alignment is similar in most cases, alignment was not included as a variable in this research project. The experimental framework used in the study is illustrated in Table 1.

This shows a basic framework of 24 experimental sections 500m long. In two provinces groups of eight test sections have been established on three different roads carrying the traffic levels illustrated in Table 1. Each road, therefore, includes three levels of maintenance utilising a towed or motor grader and two 'nil' maintenance sections. The resultant 48 test sections have been supplemented in both provinces by a further group of eight test sections incorporating a different gravel wearing course but utilising the same range of maintenance strategies and equipment resulting in an overall total of 64 test sections.

2.4.1 Surface roughness. Measurements of surface roughness were made using vehicle mounted bump integrators. These units are calibrated every six months against the Abay Calibration Beam (3) over roads in good structural condition but exhibiting a wide spectrum of roughness levels. In the study, three measurements of surface roughness are taken in each traffic lane. Frequency of measurement has been established at monthly intervals and immediately before and after grading operations.

2.4.2 Rut depth. The maximum rut depth is recorded in each wheeltrack in each lane utilising a two metre straight edge and a wedge calibrated in millimetres. Ten measurements are taken in each test section at one hundred metre intervals concurrently with the monthly roughness measurements.

2.4.3 Traffic volumes. The traffic volumes on each road incorporating the test sections are measured with automatic inductive loop counters. The counters, utilising loops buried beneath the gravel wearing course, are read manually each day. They also incorporate loggers which store data for periods of up to six months and have the facility to back-analyse. The counter readings are augmented by manual classified traffic counts taken at six monthly intervals.

2.4.4 Traffic loading. Axle load surveys are carried out at six month intervals utilising the TRRL portable weighbridge. Classified traffic counts are taken concurrently with the axle load surveys.

2.4.5 Climate. A volumetric raingauge and an automatic intensity rainfall recorder are located on each experimental road. The volumetric raingauges are read manually each morning whilst the automatic recorders incorporate data cassettes which are renewed each month for analysis by micro-computer.

2.4.6 Gravel loss. Gravel loss measurements in terms of remaining thickness of gravel wearing course are taken concurrently with the roughness and rut depth measurements. Additional measurements are taken when carrying out pavement strength evaluations using the Dynamic Cone Penetrometer (DCP)(4)(5).

2.4.7 Operating costs. During each maintenance activity the operating costs of the equipment are monitored. This includes the motor grader, tractor and towed-grader, compaction equipment and water tanker. As the study proceeds, data on vehicle operating costs for the traffic utilising the rural networks will be collected. This data will then be used to evaluate the vehicle operating costs relevant to different maintenance strategies and surface conditions.

2.4.8 Laboratory testing. At the beginning of the study, samples of gravel wearing course and subgrade were taken from each section and subjected to laboratory tests. The tests included the measurement of abrasion values, an important parameter in terms of gravel wearing course performance.

2.4.9 In-situ testing of materials. At six monthly intervals, before and after the rainy season in both provinces, in-situ measurements of material's strengths are carried out using the Dynamic Cone Penetrometer.

2.5 Results

Data from Hatyai Province now covers a 2 year period whilst 12 month's data has been collected from the Nakhon Phanom Province sites. The monitoring period will cover a period 3 years. The large quantity of data has not yet been fully analysed and this chapter summarises the more important results to date from both sites.

2.5.1 Roughness. All test sections were surface graded initially to enable measurements of deterioration to start from the same base. The initial roughness levels of the sections were in the range 2800-3200mm/km. The surface roughness measurements on the Hatyai test roads did not reach levels higher than 6000mm/km during the first twelve months. This is partly due to the good condition of the roads, including side drainage, prior to the onset of the study but also because the rainfall was below average. During the second twelve month period at Hatyai, levels of roughness were up to 20 per cent higher whilst the rainfall was very close to the 30 year average.

Another factor influencing the rate of change of roughness is traffic. Although there is an ADT of 290 on one of the roads, the traffic loading is relatively light. This was the reason for identifying a specific road carrying medium and heavy trucks in the Nakhon Phanom region for inclusion in the study.

Generally, both the towed and motor graders reduce surface roughness by about 30 per cent to a level of 3500mm/km, see Fig 1. However, the roads are still in moderately good condition and it remains to be seen whether, as the roads deteriorate, similar reductions in surface roughness can be achieved by both types of equipment.

The final prediction models for estimating changes in roughness will incorporate measurements of the physical properties of the materials inoluding abrasion and plasticity. These two latter variables must influence the development of roughness and laboratory tests are being carried out on each material type as the study proceeds.

2.5.2 Rut depth. The development of rutting on four consecutive sections in Hatyai is shown in Fig 2. The towed grader was used for maintaining these sections and it can be seen that rut depth after grading was reduced to 5-7mm. This is a very good standard for an unpaved road; however, each ARD maintenance operation involves the use of water distributor when necessary and always compacted with a roller which partly accounts for the low levels of rut depth achieved after maintenance had been carried out. Similar results were obtained when the motor grader was used. The rut depths reported are the average of ten measurements in each section remeasured every 6 weeks. On the nil maintained sections, rut depths have not been allowed to develop beyond 80mm because of the potential danger to traffic. When this level has been reached the section is graded and the progression of deterioration begins a new cycle.

2.5.3 Costs of operating maintenance equipment. One of the objectives of the research is to evaluate the potential saving using the towed grader instead of the motor grader. Table 2 gives the current costs to ARD of the equipment presently used for maintenance.

The costs are very much lower than found elsewhere (1). The low cost of investment and depreciation reflects the age of the fleet in which most of the motor graders are 15 years old and some are 22 years old. The low repair and maintenance costs reflect the high standard of expertise in the ARD workshops. It is too early to predict accurately what the running costs of the towed grader in Thailand will be. However, during each maintenance activity detailed records are kept of all expenditure and consumption, particularly of fuel, which is measured accurately with a calibrated pump. Currently where the maintenance activity involves a towed grader, the costs are less than half that of the same activity when the motor grader is used. The current ARD allocation for maintenance is 12,000 Baht or US $ 500 per kilometre.

2.5.4 Traffic. Table 3 gives the estimated ADT based on the automatic traffic counter results.

The maximum axle load found during the first survey was 9.1 tonnes but the average axle load for trucks using the ARD road are usually between 5 and 6 tonnes. The maximum traffic loading is expected to be not greater than 5000 standard axles per year for each road. Further surveys are carried out in the wet season to detect any changes in vehicle type, commodities, and axle loads.

2.5.5 Climate. The first twelve months rainfall was below the predicted average of 2300mm. From May 1987 to April 1988 only 1550mm was recorded although over 500mm of rain fell during December 1987. There have been some technical problems with the automatic rainfall recorders partly because of high temperature and humidity but this has now been resolved. The 1988/1989 rainfall period experienced levels of rainfall nearer the predicted average. Results in 1989/1990 indicate that the rainfall is higher than normal.

2.5.6 Gravel loss. Gravel loss has been measured in each section. The average losses for 1 year are given in Table 4.

2.5.7 Testing of materials. All sections were sampled at the start of the project and the tests have been repeated during the study. One of the objectives of these measurements is to identify any changes in the physical properties of the materials as a result of trafficking and climate. The initial laboratory results are given in Table 5.

2.5.8 In-situ strength tests. The effective strength of an unpaved road varies daily due to changes in the moisture content which is a function of permeability and rainfall. The US Waterway Experimental station has carried out considerable research on the traffickability of different soils (6). The results showed that if a road has a California Bearing Ratio (CBR) greater than 12 per cent it is capable of supporting 50,000 vehicle passes with tyre pressures not greater than 50 N/cm^2 and axle loads of 8.2 tonnes. The failure criteria for this analysis was a rut depth of 75mm. Therefore this level of bearing capacity should be adequate for most of the unpaved ARD rural roads in Thailand where tyre pressures and axle loads are likely to be less than the US values. The ARD specified gravel thickness for new construction is 200 mm for their standard road. Table 6 shows the in-situ CBR values based on Dynamic Cone Penetrometer (DCP) tests on the Hatyai sections which indicates that, on this basis, strengths are adequate. Further measurements were taken during the wet season to detect any changes that may occur, but preliminary analysis indicates that, apart from the top 50mm, changes of strength within the road are minimal.

3. PART TWO

3.1 Interlocking Concrete Block Pavement (ICB)

The maintenance of unpaved roads can, in some circumstances, become uneconomic, even when grading frequency and other maintenance tasks have been correctly optimised. This may be the case, for example, where very steep gradients are unavoidable or where particularly weak subgrades require large quantities of imported material to retain an acceptable running surface.

An unpaved road may also be unacceptable where it passes through a large village due to the accelerated deterioration caused by increased traffic movements and the nuisance created by dust in dry weather.

The usual remedy for these problems in the past has been the application of a double surface dressing. However, since 1986, ARD has experimented with interlocking concrete block (ICB) paving as a potentially more cost-effective solution.

3.1.1 Summary of benefits. The benefits of ICB pavements compared with bituminous surface treatment are:

(1) ICB pavements require minimised capital investment in heavy equipment.

(2) ICB pavements can eliminate the importation of expensive raw materials such as asphalt and fuel.

(3) Thailand has a surplus of locally-produced cement and ICB pavements provide alternative uses for this material.

(4) The discounted costs of an ICB surfacing over twenty years is about one third less than a double bituminous surface treatment.

(5) ICB pavements can be constructed by unskilled labourers under moderate supervision whereas bituminous pavements need to be constructed by skilled technicians with high levels of supervision.

(6) An ICB of 80mm web thickness can support wheel loads up to 5,000 kgs under the worst conditions, such as saturated and weak subgrades and

poorly drained materials. Tables 8-10 illustrate results from research done by the Engineering and Technology Faculty in Bangkok (7) under varying conditions of soil type and traffic.

(7) Lower labour costs through the use of relatively unskilled labour.

(8) The pavement surface can be removed and re-used elsewhere if required.

(9) Maintenance cost of ICB pavement is lower than bituminous surface treatment.

(10) ICB pavement provides employment opportunities for local villagers who quickly acquire the necessary skills. For ICB surfacing labour costs are typically 25 per cent of the total project cost. For a double bituminous surface treatment labour costs are typically 2 per cent of total project cost and this labour is imported.

Experience suggests, however, that ICB pavement is unsuitable where traffic speed regularly exceeds 60 km/h and also that construction is slower than for a double bituminous surface treatment.

3.1.2 Economic advantages of an ICB pavement. The economic benefits from substituting an ICB pavement for a double bituminous surface treatment were based on the following assumptions:

(a) a reduction in the initial construction cost of US $900/km.

(b) a reduction in the average annual maintenance cost of US $470/km.

(c) resealing the bituminous surface every seven years.

The first ICB pavement constructed in Thailand was near Chiang Mai. It was constructed in 1986 by the villagers under ARD supervision without the use of heavy equipment. The total length of the 3.5 metre wide pavement is 434 metres and the cost was US $11,100. This is equivalent to US $25,600 per km of which labour costs amounted to US $8,060 per km. A summary of the construction cost is shown in Table 7.

3.1.3 Performance of ICB pavements. The performance of interconnecting block pavements has been studied and the results are reported in Tables 8, 9 and 10.ARD currently use a concrete block 80mm thick which provides adequate performance when made with 1:2:4 concrete (by volume). Concrete blocks 50, 80 and 100mm thick were compared when subjected to repeated loading from a four wheel vehicle with a gross weight of 13,600 kg. The resultant rutting and cracking shown in Tables 8, 9 and 10 indicate that performance is directly related to the block thickness.

In Northern Thailand, the mountainous terrain, high rainfall and steep gradients of up to 17 per cent combine to cause severe erosion of the surface of unpaved roads. The problem is exacerbated by the poor cohesion and low plasticity of the materials available both in-situ and within reasonable haul distance. In some cases, road surfaces are damaged further by trucks using chains on their wheels. The erosion problem is illustrated in Plate 1 whilst a solution is shown in Plate 2 where a concrete block pavement has been successfully constructed on a road in hilly terrain and with a steep gradient. It is the intended policy of the ARD to continue using this technique to reduce the very high cost of maintenance on these roads in this type of terrain.

The ICB pavement can also solve the problem of serious differential settlement of rural roads in swampy areas because of the lower cost of maintenance and the capacity to support heavy loads. The first project constructed in a swampy area was at Petchaburi, Thailand. The total length of the ICB pavement was 1.20 kilometres, and cost US $38,700 or US $32,250/km.

A total of 215,040 blocks and 4,880 kerbs were used in the project. The road has an ADT of over 1,000 including 60 heavy trucks (20-25 tonnes gross weight) and 980 medium trucks, pick-ups and cars see Plate 3. During construction some sections exhibited large ruts caused by the heavy trucks but after recompaction of the subgrade and sub-base and relaying of the concrete blocks the road remains in good condition after two year's service, Plate 4.

3.1.4 Construction method. The method used to construct ICB paving was as follows:

(1) ARD manufactured and initially provided timber moulds for the projects. In current projects, steel moulds with 3 block capacity are used.

(2) ARD located the block manufacturing site and stockpile of materials near the construction site to minimise haulage costs.

(3) Demonstrations of construction and laying of concrete blocks were given by 10 skilled labourers of the ARD training centre.

(4) Labourers were organised into groups performing specific tasks. These consisted of:-

   (a) A concrete mixing group of 6 labourers.

   (b) A concrete pouring group of 20 labourers provided with 55 sets of timber moulds, each set with a capacity of 6 blocks. Each mould set could be used 3 times a day and the daily total production rate was approximately 1000 blocks.

(5) After pouring, each block was cured for 28 days. Twenty labourers were used to excavate and install concrete kerbs concurrently with the placement of the sand bed. Labourers were then used to lay the blocks, each individual labourer having an output of 10-30 square metres per day, whilst four labourers were normally used to fill the joints between blocks with sand. Final treatment was the compaction of the shoulders and the construction of drainage holes.

The manufacture of kerbs and blocks can be done using either timber or steel moulds. ARD use timber moulds for kerbs, which are larger than blocks, because they are lighter than steel, but only steel moulds are used for interlocking blocks. Cast-in-place kerbs give the best results in terms of quality and cost. The 1:2:4 concrete mix provides a specified cube strength for the concrete blocks of 240 kg/cm^2.

In all cases the ICB paving is laid on a subgrade of at least 6 per cent CBR with the natural material being improved to exceed this figure when necessary. A laterite sub-base at least 100mm thick is necessary although the actual thickness provided will be dependent upon the predicted wheel loads and ADT. Finally, a sand layer 50mm thick is provided on which the blocks are laid, Plate 5.

The joints between the blocks are filled with sand and dry cement proportioned 1:1 which is compacted using vibrating plate compactors to completely fill the joints and to ensure complete interlock and load transfer between adjacent blocks. A completed pavement is illustrated in Plate 6. Fig 3 illustrates the current block and mould design and Fig 4 shows typical construction details.

4. INITIAL CONCLUSIONS

The collaborative research study outlined in Part One of this Paper demonstrates the use of appropriate equipment for carrying out the surface maintenance of gravel roads. In many developing countries there is a scarcity of foreign exchange that would be required to purchase new or replacement machinery. It is far more appropriate to use machinery that is not over complex and can be maintained and repaired using local expertise and materials. The main criteria should be whether the equipment can achieve standards similar to those obtained by the more complex machinery with the same degree of reliability.

The most important finding so far from the study is the potential savings in maintenance costs by using the tractor-towed grader. If these savings are sustained then it will afford ARD the opportunity to increase maintenance on the higher trafficked roads to reduce road user costs. Results from this research will also help the ARD to optimise the frequency of grading for roads with different levels of traffic, materials and climate.

The use of concrete blocks to reduce maintenance costs in specific areas such as steep terrain and swampy ground has been reported in Part Two and is shown to provide a cost-effective alternative maintenance option.

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Table 1. Experimental framework

	Traffic			
	< 75 vehicles per day	75-150 vehicles per day	150-300 vehicles per day	
	Grading frequency per year			
Vertical gradients < 2 per cent	3 2 1 0	3 2 1 0	3 2 1 0	Annual rainfall 2400mm
No of sections	8	8	8	
	Duplicate sections are maintained either by motor grader or towed-grader			

Table 2. Operating Costs of Equipment

Plant type	Costs per hour US$							
	Investment	Dep.	Fuel	Maint.	Tyres	Repair	Operator	Total
140/160 hp motor grader	1.51	2.67	5.12	1.08	1.10	4.28	1.20	16.97
120/140 hp motor grader	1.07	1.88	4.27	0.90	1.10	3.05	1.20	13.48
10 ton roller	0.56	0.98	2.73	0.45	1.00	1.90	0.60	8.24
65/80 hp tractor	0.20	0.35	2.47	0.44	0.59	0.55	0.60	5.19
water tanker	0.31	0.54	4.52	0.48	0.60	1.07	0.60	8.12

Table 3. Estimated Average Daily Traffic on Experimental Sections in Hatyai

Road No.	Mean ADT (2 way)	Standard Deviation
11010 (site 1)	287	82
11004	150	46
11010 (site 2)	90	27
11011	40	16
11012	38	16

Table 4. Annual Gravel Loss

Road No.	Mean ADT (2 way)	Gravel Loss (mm)
11010	287	21
11012	38	8
11004	150	15
11011	40	12

Table 5. Results of Initial Laboratory Results on Surfacing Materials

Sieve size	Grading: Retained Material (%)							LL	PI
	1"	3/4"	3/8"	No 4	No 10	No 40	No 200		
Road 11010	-	97	77	51	35	29	14	34	10
Road 11004	-	-	99	92	69	47	23	33	11
Road 11012	-	93	74	59	48	43	21	30	10
Road 11011	-	88	67	42	31	29	21	32	9

The normal criteria used by ARD for PI is that it should be in the range 6-12.

Table 6. Calculated CBR Values Based on DCP Results

Road No	Average CBR (%)	Penetration depth (mm)
11010 (site 1)	46	0-192
	29	192-500
11004	37	0-242
	12	242-500
11010 (site 2)	41	0-200
	44	200-500
11011	17	0-300
	11	300-500
11012	19	0-165
	28	165-500

Table 7. Summary of construction costs of the first ICB pavement in Thailand

No.	Type of work	Unit	Quantity	Material cost US $	Labour cost US $
1	Scarify and compact existing laterite surface (>100mm depth)	M^2	1,953	970	16
2	Lay sand bedding	M^2	1,953	251	493
3	Lay ICBs and compact	M^2	1,432	84	678
4	Manufacture blocks				
	4.1 ICBs	No	42,960	4,438	1,696
	4.2 Kerbs	No	1,752	1,101	276
5	Timber moulds	M^3	70	553	118
6	Construct shoulders	M^3	46	197	158
7	Install sand drains	No	868	6	63
		Total Cost =		7,600	3,498
		Equivalent to US $25,578/km			

Note: Timber moulds were used only in the first ICB project. Steel moulds are currently used and cost US $3 each.

Table 8. Performance of ICB pavement, 50mm thick

Year 1988

No of vehicle passes	Maximum rut depth (mm)			Pavement area cracked (%)	Remarks
	Left Track	Average	Right Track		
25	24.20	17.15	10.10	16.09	
50	38.40	24.85	11.30	34.62	Average temp 32°C
100	46.30	29.20	12.10	47.79	Tyre pressure 80 psi
300	69.40	45.90	22.40	97.32	Average speed 7.2km/hr
400	90.10	59.25	28.40	100	Gross vehicle weight
500	82.50	61.75	41.00	100	= 13,600 kgs
800	131.50	95.85	60.20	100	(4 wheel truck)
1000	142.20	97.35	52.50	100	

Table 9. Performance of ICB pavement, 80mm thick

Year 1988

No of vehicle passes	Maximum rut depth (mm)			Pavement area cracked (%)	Remarks
	Left Track	Average	Right Track		
100	11.80	6.80	1.80	1.83	
200	8.51	5.86	3.20	2.85	
300	9.30	6.50	3.70	4.09	
400	14.60	10.06	5.51	6.62	
500	18.10	12.30	6.50	8.82	
600	23.51	15.56	7.61	9.43	Average temp 32°C
700	28.31	18.56	8.80	9.65	Tyre pressure 80 psi
800	29.10	19.10	9.10	10.23	Average speed 7.2km/hr
900	33.50	21.51	9.51	10.89	Gross vehicle weight
1000	34.00	22.85	11.70	11.40	= 13,600 kgs
1100	34.20	22.71	11.21	11.98	(4 wheel truck)
1200	55.00	33.26	11.51	12.50	
1300	60.01	35.91	11.80	13.15	
1400	62.00	37.00	12.00	13.60	
1500	55.40	34.25	13.10	14.33	
1600	51.51	32.36	13.21	14.84	
1800	76.70	45.05	13.40	15.78	

Table 10. Performance of ICB pavement, 100mm thick

Year 1988

No of vehicle passes	Maximum rut depth (mm)			Pavement area cracked (%)	Remarks
	Left Track	Average	Right Track		
100	3.00	2.20	1.40	0.00	
200	9.31	5.76	2.20	0.00	
300	9.50	5.85	2.20	0.00	
400	9.61	6.56	3.50	0.00	
500	8.40	6.51	4.61	0.00	
600	9.20	7.45	5.70	0.00	Average temp 32oC
800	10.60	8.50	6.39	0.00	Tyre pressure 80 psi
900	11.00	8.15	5.30	0.00	Average speed 7.2km/hr
1000	11.50	9.40	7.29	0.00	Gross vehicle weight
1100	12.10	10.00	7.90	0.00	= 13,600 kgs
1200	14.60	13.25	11.90	0.00	(4 wheel truck)
1300	15.21	13.11	11.00	0.00	
1400	12.60	10.95	10.30	0.00	
1500	13.30	11.70	10.09	0.00	
1600	13.70	12.15	10.60	0.00	
1800	14.20	10.90	9.60	0.00	

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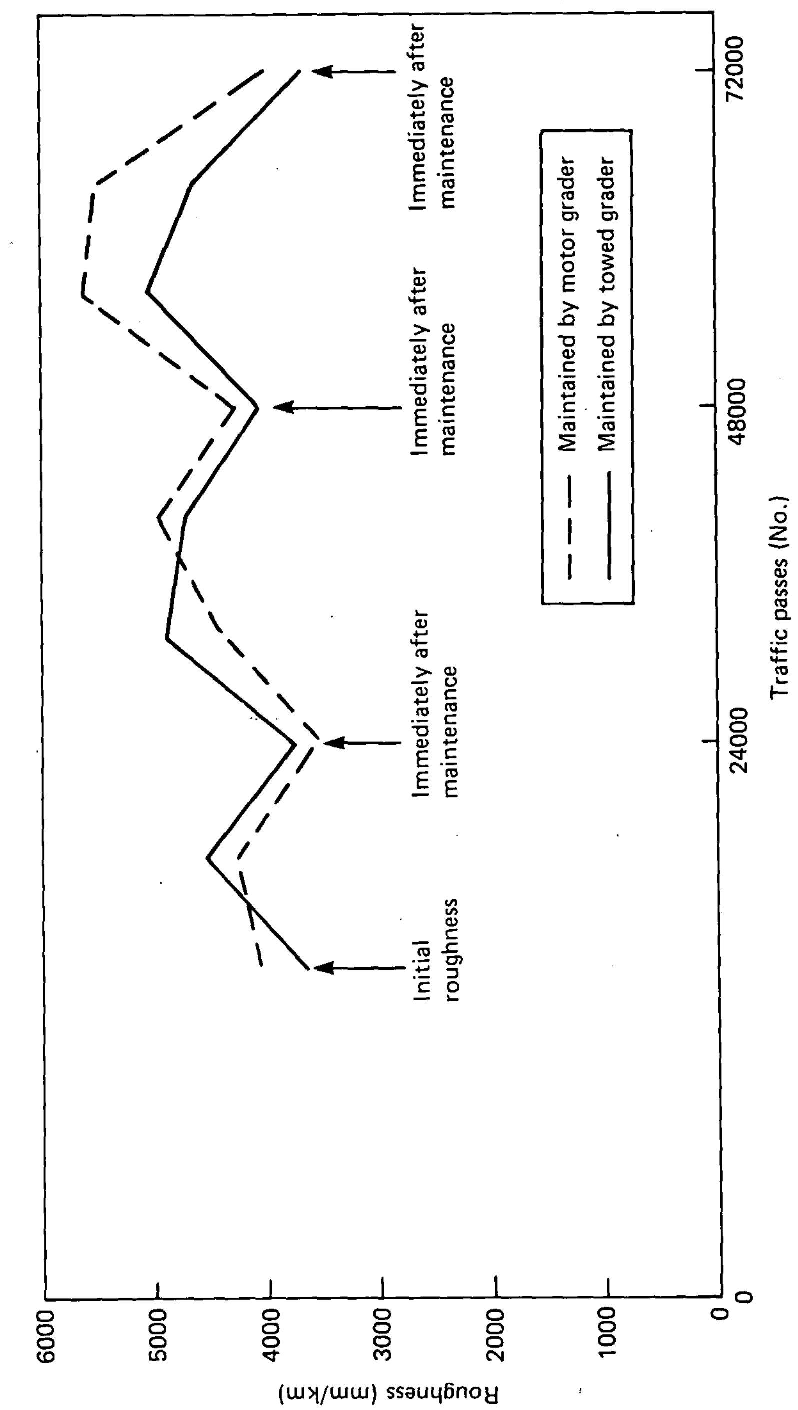


Fig. 1 Examples of reductions in roughness achieved with motor grader and towed grader on two trial sections

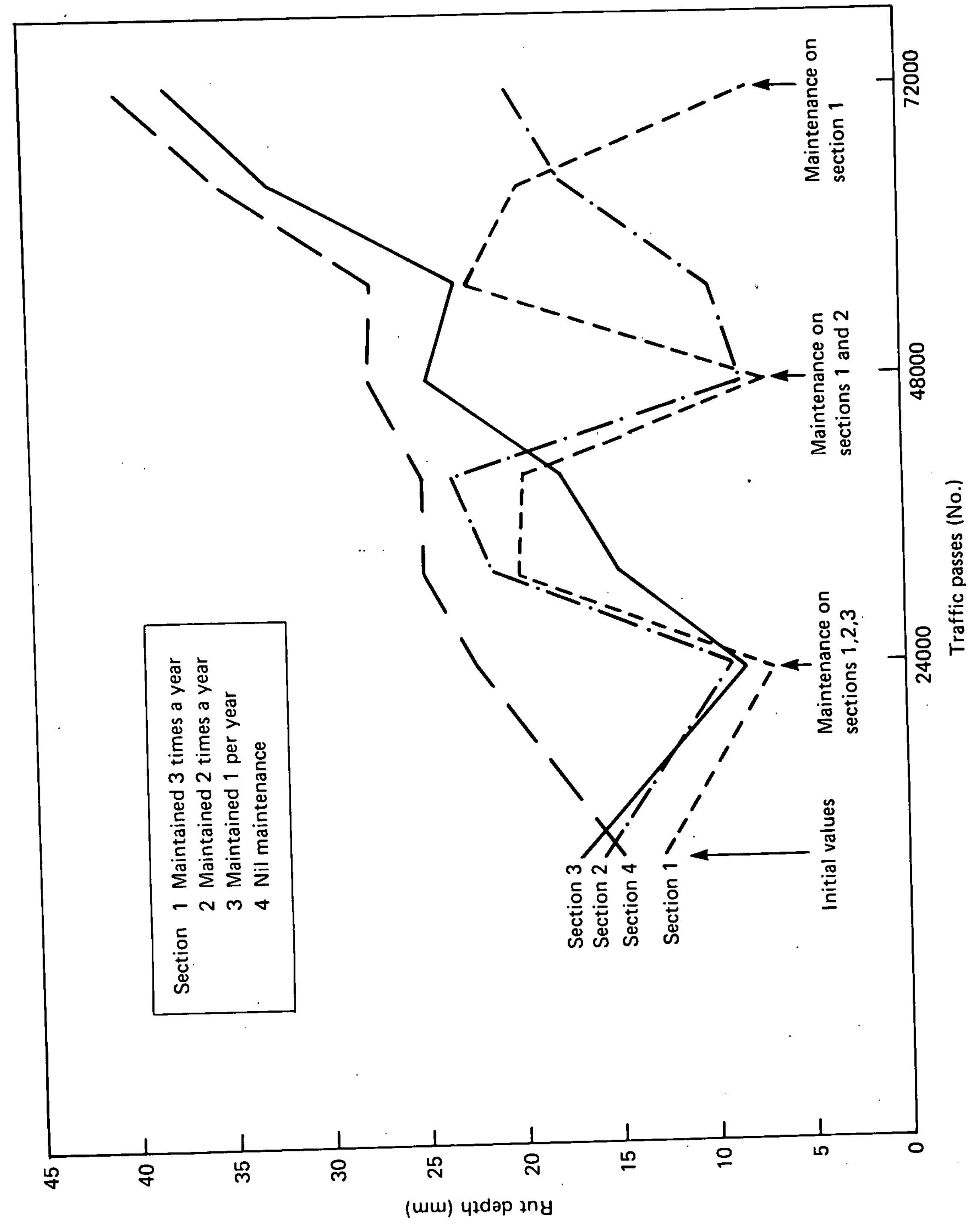
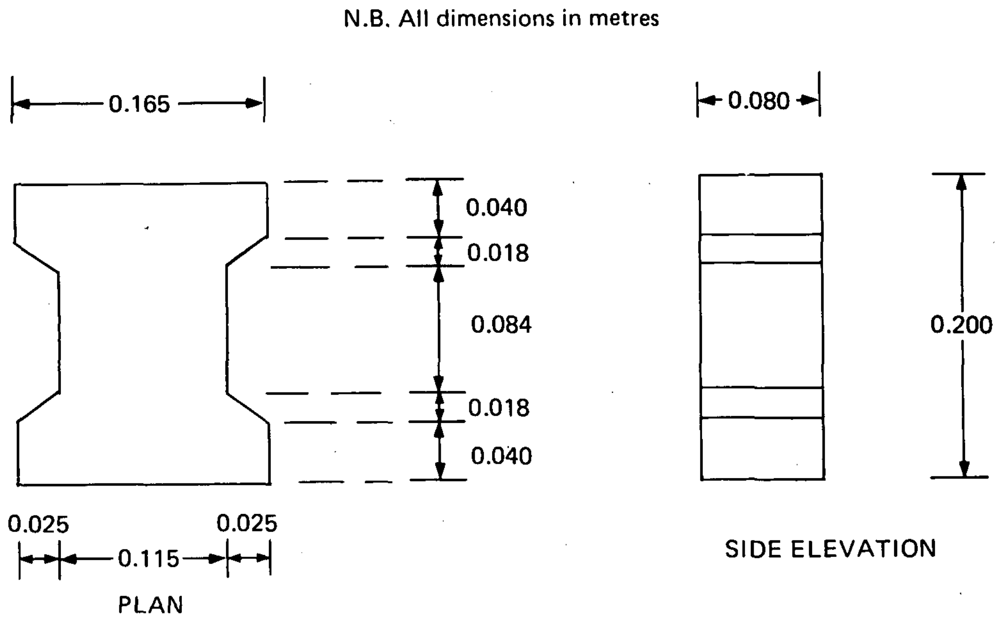
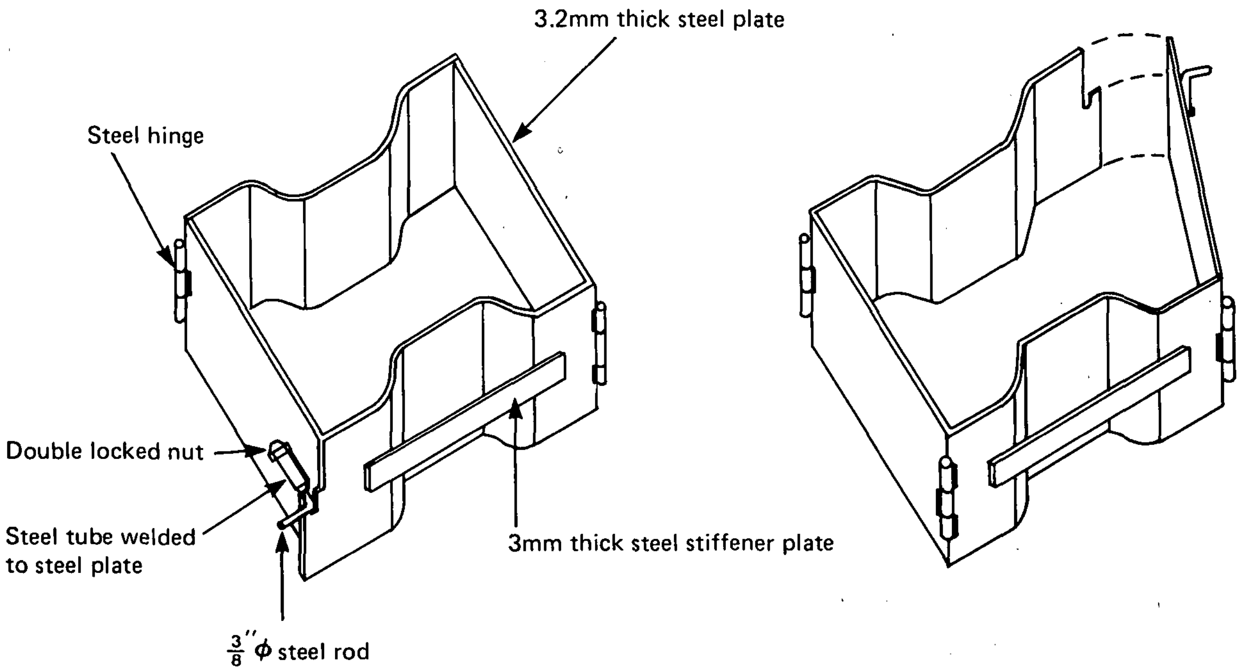


Fig. 2 Examples of reductions in rut depth achieved with different grading frequencies (towed grader)



Concrete block



Steel mould

Fig. 3 Concrete block and mould specification

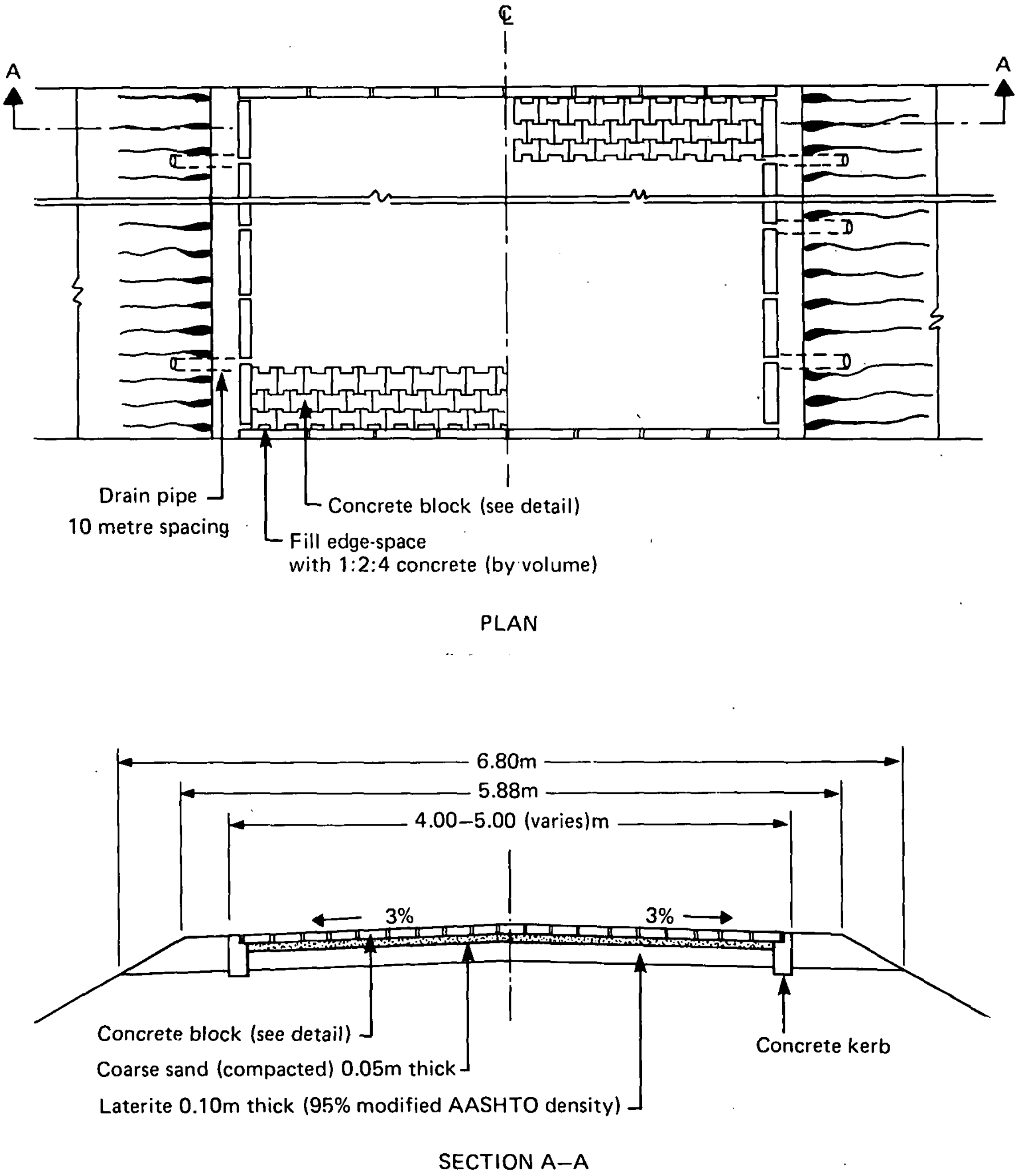


Fig. 4 Method of construction of interlocking concrete block pavement

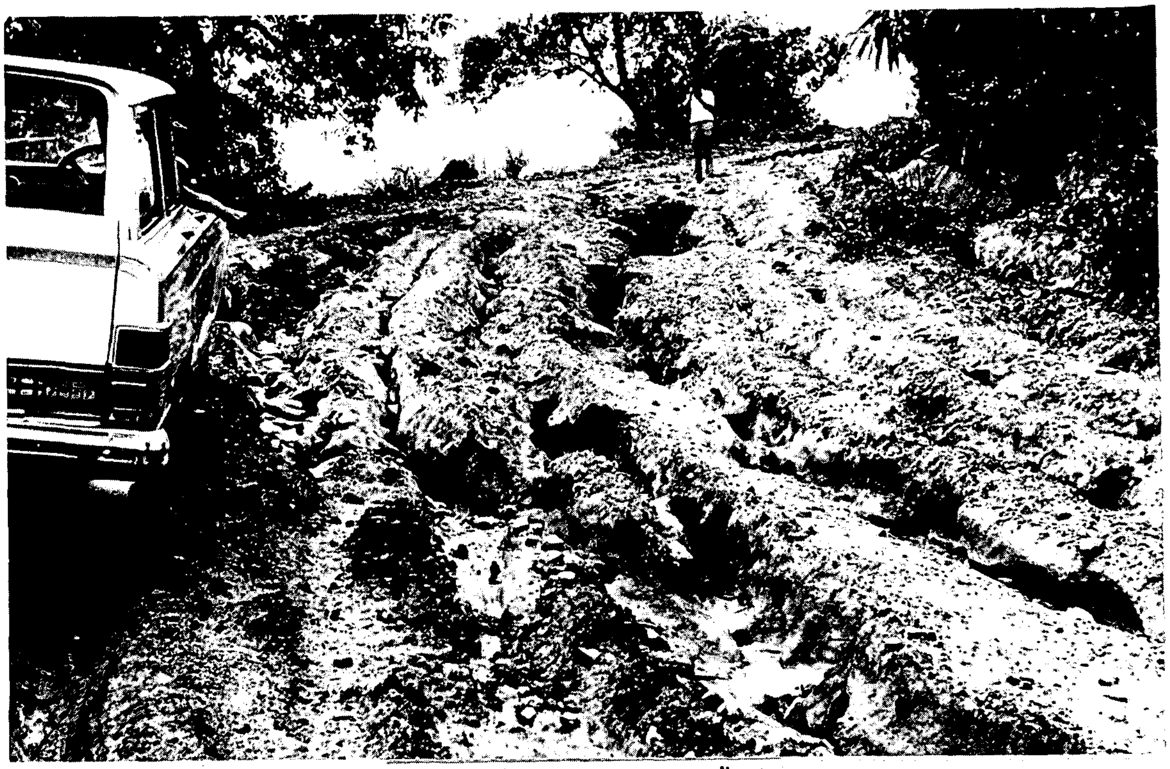


Plate 1 Erosion on steep gradient

Plate 2 Concrete block pavement on steep gradient

Plate 3 Heavy traffic on block pavement

Plate 4 Concrete block pavement after 18 months trafficking

Plate 5 Laying concrete blocks

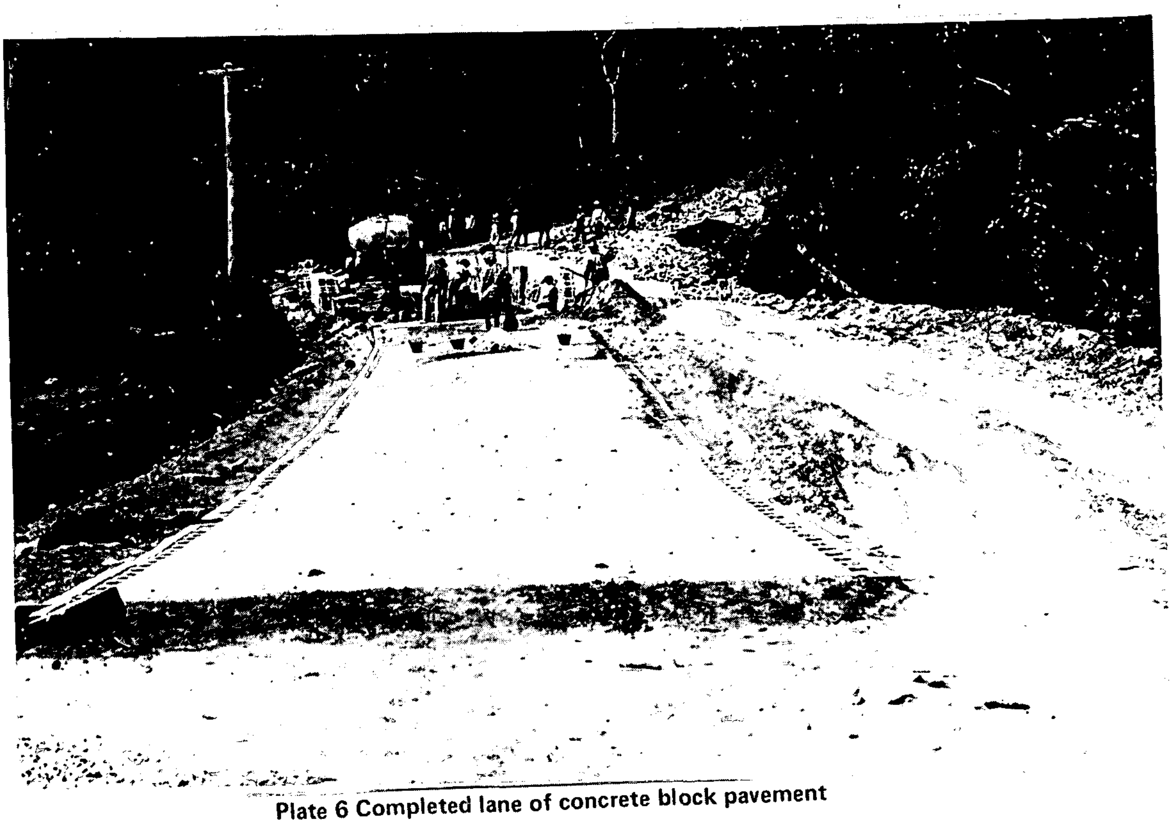


Plate 6 Completed lane of concrete block pavement