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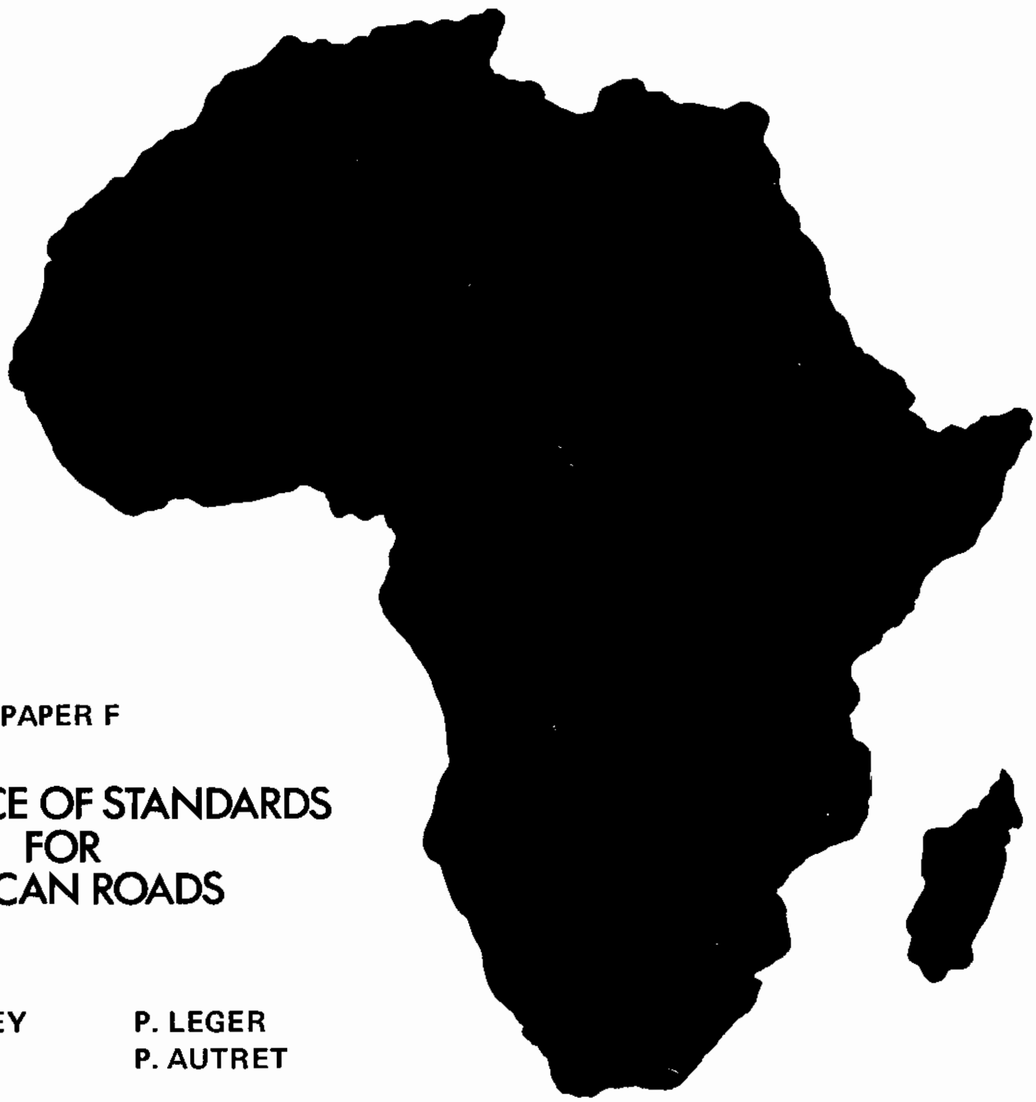

PAPER F

THE CHOICE OF STANDARDS FOR AFRICAN ROADS

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THE CHOICE OF STANDARDS FOR AFRICAN ROADS

ABSTRACT

The provision of an adequate road system must be regarded as an essential part of a programme of economic development. The paper examines what is meant by 'adequate' and adopts as a criterion the concept of lowest total transport cost over the life of the investment. It is suggested that rigidly applied road standards are clearly inappropriate in developing countries and that a programme of stage construction should be used supported by a well planned maintenance programme. One exception is likely to be in urban areas where traffic flows are particularly heavy. In this situation the use of road standards established in developed countries is appropriate but modifications due to climate and traffic composition are discussed.

Benefits resulting from road improvements, (reductions in operating costs, maintenance costs and time savings) are described and it is suggested that relationship between such costs and road characteristics should provide the basic index, as well as a method of establishing optimum standards. A method using vehicle speeds is discussed in detail.

More complex methods are described briefly but the paper points out that whatever approach is adopted it is essential that adequate data are available. It is suggested that all countries should examine how they stand in relation to the data needed to take decisions on road investment and that any deficiencies are rectified.

Pavement design must receive attention and account must be taken of the characteristics of local materials and climatic conditions.

The analysis of road maintenance problems can only be done on the basis of local studies, extrapolation from one country to another being hazardous.

Finally the paper indicates the difficulties of transferring results obtained in one country to another but points out that the basic principles discussed can be utilized by every country in preparing its own policy for road standards.

1. INTRODUCTION

New road construction and the improvement of existing roads in Africa is taking place very rapidly as road traffic grows and new areas are developed. The range of road types and standards is naturally very great: at one end of the scale there are improvised roads following the land contours and at the other extreme high capacity roads which may cut deeply into the relief giving rise to new problems concerning the behaviour of earthworks and the supply of materials. As the length and standard of the road system increases, the need for effective road maintenance also grows both as regards amount and quality, whilst over-all the operation of the vehicle fleet consumes a greater amount of valuable resources.

Africa, south of the Sahara, has certain common physical features: predominance of soils of primary decomposition or of volcanic origin, pronounced transpiration cycles and intense erosion. There are also marked differences, in particular between East Africa where savannahs predominate and West Africa where there are forests and humid conditions. In North Africa the geological and climatic conditions are similar to those in the Sahara and the South of Europe, and this are thus has its own particular characteristics. These latter two areas of Africa are not considered in this paper.

In view of these widely different road needs and environment, it is clearly not appropriate to attempt to give fixed standards generally applicable to the whole of Africa. The objective here is to discuss, and to illustrate with some examples, the different areas which should be considered in deciding the appropriate construction and maintenance of roads, namely:

- the technical-economic criteria.
- analysis of their respective influences.
- data collection procedures and verification of results.
- critical examination of the results and improvement of the proposed criteria.

It is assumed in this paper that the decision to build a road has already been taken and that forecasts of the traffic that this road should carry have been prepared. Similarly data on axle loads have been prepared. Thus this paper is concerned with a limited part of the general technical economic studies of a road network. Given traffic demand data we set out to establish a procedure by which, and using market prices, the most viable engineering answer is found to cover the life of the project. Although the choice between manual and mechanized construction methods is not examined the authors recognize that this is a very important area for decision taking in road construction.

The construction of bridges and other structures is not dealt with in this paper. However, the authors emphasise the importance, in an economic study, of the standards to which structures should be built. These must always relate to the general characteristics of the road, although in certain circumstances it can be advantageous to provide more structures than are necessary at the particular stage in the road's existence.

2. TECHNICAL AND ECONOMIC CRITERIA

The selection of any particular road standard has cost implications for construction, maintenance and vehicle operation. The basic technical decision, therefore, is immediately related to economic criteria and in particular to the criterion of lowest toal transport cost, by which we mean the lowest combined cost of:

- operating vehicles
- road building (geometry, structure)
- road maintenance

over a specified project life. Although in developed countries we would also probably include road accident costs and environmental costs we do not propose to treat with these costs in this paper.

Before we discuss in any greater detail the parameters that affect total transport costs, it is important to emphasize that decisions reached will be examined within the framework of cost:benefit analysis and it is quite possible that assumptions made as part of this analysis can quite easily override technical-economic fact. For example, it may be well known that a gravel road is physically incapable of carrying traffic in excess of 1000 veh/day, but nonetheless analysts frequently assume that a limitless volume can be carried and apply to this volume the vehicle cost coefficient for gravel roads in order to calculate the cost of the "do nothing" solution. To do this sort of thing is to deal in unrealities and thus lead to wrong decisions being made, and engineers and economists must be made aware of such dangers.

Although in some ways it seems rational to begin a discussion of road standards with questions of road geometry, pavement design and construction methods, we believe that it is important to establish first the requirements of the road user. In particular the cost of operating road vehicles in relation to operating conditions. Comfort is also important but is difficult to quantify. We believe that there are two important reasons for this approach:

- it encourages the planner to identify more clearly the target at which he is aiming; for instance, a general reduction in vehicle operating costs, an adequate level of accessibility, a reduction in the number of road accidents or a lessening of a maintenance burden.
- it enables the engineer to pinpoint the areas of technical concentration which will provide the greatest return on engineering investment within the context of providing a sufficient standard of traffic circulation.

Although road standard can affect almost every aspect of vehicle operation we believe that many of the relationships are difficult to define, let alone measure, and we can only sensibly rely on measured quantities. Thus the vehicle operating costs in which we are interested are:

- Fuel and lubricant consumption
- tyre wear and damage
- vehicle maintenance/depreciation
- speed of vehicle
- accident rates and costs

In assessing the economic standard of road construction we are concerned broadly with actual unit costs of vehicles operating under particular conditions and the present and future levels of traffic. However, we also have to take account of the fact that the standard of road itself may affect both the level and growth rate of traffic and also that, if we are planning over a lengthy time period, the types of vehicles using the road may change. Thus the standard of road selected should ideally always be that which just leads to minimum total cost; this can be thought of as continuously maximising the first year rate of return on any improvement. In fact, the nature of road construction is such that a programme of continuous improvement is not possible. But this counsel of perfection does highlight two areas of considerable importance, first the desirability of adopting a flexible system of stage construction (whilst recognising that some discontinuities are unavoidable) related to road user characteristics and traffic growth and secondly the important part that a progressive road maintenance programme can play. The feasibility of such a programme should be a special consideration in adopting a particular design.

The level of vehicle operating costs listed above, other things being equal, is dependent on the geometry and surface characteristics of a road. These in more detail are:

GEOMETRY - radius of curves in the horizontal plane

- radius in the longitudinal profile
- maximum gradient
- width of road
- sight distance

Other factors such as numbers and types of intersections, roadside development, pedestrian facilities and bridge design are also important, but in this paper it is not possible to cover every aspect.

RUNNING SURFACE - evenness of the road in longitudinal profile (roughness)

- rutting and iregularities in the transverse profile
- skidding resistance (paved roads)
- texture or looseness on unpaved roads.

It should be noted that these values are difficult to quantify for surfaced roads and this difficulty is greater on unsurfaced roads where the features can be extremely variable. Again other factors such as superelevation and "slipperiness" of unpaved roads may be important but little quantitative information is available on these.

Thus we have a list of road characteristics which may affect vehicle operating costs in total or severally. Similarly all the road characteristics can be varied or only one may be varied. In order to maximise the return on an engineering investment, in terms of the target specified, we must, therefore, be in a position to place values on the interaction between road characteristics and vehicle operating costs either separately or in combination. These interactions are currently the subject of research in East Africa.

The road characteristics which we are examining under the headings of geometry and surface type have two basic differences. With certain specialized exceptions the construction of a road to certain geometrical standards is independent of either time or traffic influences. However, the construction of the pavement and hence its performance is closely related to time, climatic and traffic influences. For building and maintaining a particular road standard we have two main alternatives. These are the application of adequate structural standards:

- thickness of layers
- quality of materials
- construction conditions

The selection of particular construction standards can result in minimum road maintenance at a particular capital cost. The alternative is to relax construction standards and to consider increased road maintenance:

- type of maintenance operations
- resurfacing materials
- frequency of operations

We are thus presented with the situation that, unlike the relatively stereotyped situation in developed countries, the developing countries' road needs can seldom be answered by a rigid set of standards related to an administrative or even functional classification of roads. If the minimum total transport cost criterion is adopted within severe budgetary constraints then what is needed is a system of arriving at a minimum cost solution. Nevertheless, for construction cost and safety reasons, a degree of homogeneity is necessary and thus the approach we suggest should be used to obtain a range of road standards that can be applied over relatively small traffic ranges for varying physical conditions. We hope within the limited confines of this paper to suggest ways in which such a flexible approach towards the selection of road standards can be adopted.

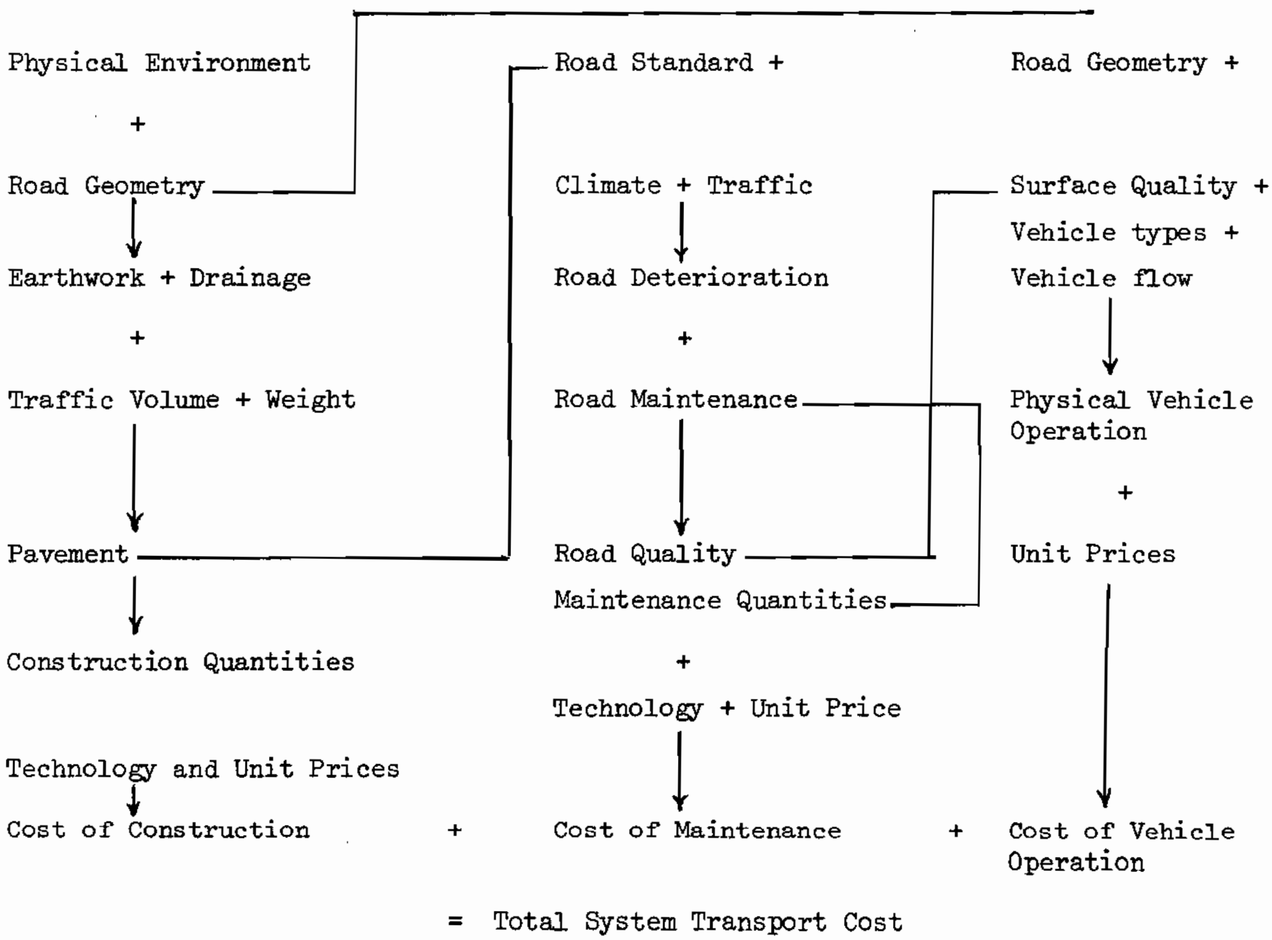
3. GUIDELINES FOR THE SELECTION OF ROAD STANDARDS

3.1 General

The three groups of parameters described in the preceding section - vehicle operation, road construction and road maintenance - interact between groups and within groups and it is the study of the total effects of these interactions in relation to the concept of total cost minimization over time that should lead to highway standards. Such an approach can of course be very time-consuming if one adopts it for every design problem and attempts to include all possible parameters. It is because of this difficulty that the cruder approach of rigid design standards has been adopted in many cases although it achieves most efficient resource use in only a few cases. In order to overcome this difficulty, research groups from Great Britain, France, USA, and the International Bank for Reconstruction and Development have combined to evolve a practical computer model that permits the ready testing of the various interactions and facilitates the selection of the correct standard for a particular set of conditions and a given time horizon. Field work aimed at developing and testing this model is nearing completion in Kenya where a team from the Transport and Road Research Laboratory has been working for the past

three years. A similar research plan has been prepared and proposed for West Africa, possibly the Ivory Coast, but the work has not yet started.

The model is aimed at developing a flexible method which focuses on the interrelationships between construction costs, road maintenance costs and road user costs with the objective of determining that combination of design standards, maintenance standards and policies, and composition of vehicle fleet which results in the least total social costs. The model must also be sufficiently flexible and modular in structure to permit the consideration of alternative technologies jointly with the highway design standards or maintenance policies. The model and the research studies upon which it is based operate in terms of physical units in order to permit the model to be used in economies with different prices. A separate sub-routine permits the input of relevant unit prices in order to provide the cost output. The following diagram summarises the model.



The three groups of costs - vehicle operation, maintenance, construction - have been studied on an experimental basis.

There are several ways of approaching the description of the total transport system cost study but for convenience we start with the consideration of road user costs.

Basically there are four broad groups of road user cost parameters (in physical terms). These are:

a. vehicle design

b. driver behaviour

c. management skills (as they affect vehicle choice, vehicle maintenance and loading policies)

d. road characteristics (geometry, surface type and condition, traffic and altitude).

It is important in any study that all these parameters are given careful consideration, theoretically and empirically, individually and as regards the relationships between them. Several theoretically based approaches already exist, (such as the limiting velocity concept of estimating vehicle speed,) but they cannot be used with confidence until they are tested empirically together with possible alternatives. Also there are more obvious gaps in knowledge where no adequate theoretical or empirical studies have been carried out.

The research approach has been, with the cooperation of road users, to collect data on road user costs from a wide range of areas in Kenya. The sample included a representative range of vehicles and sizes of company, together with operations on a wide range of roads.

Probably the major physical parameter influencing vehicle operating costs is road geometry. Therefore, experimental road sections of two kilometres in length were selected giving different combinations of vertical and horizontal geometry. On these sections test vehicles, representative of the vehicle population, have been operated to establish speed/fuel consumption curves for specified geometric conditions.

It is also clear that surface type and condition can have an important effect on vehicle operating costs. For this reason, within each geometric class, several sections have been selected (with similar soil, climatic, and traffic characteristics) to which different specified maintenance routines have been applied. The test vehicles were then operated over these sections to measure the effect of changes in surface condition on the basic speed/fuel consumption curves. The programme of test vehicle operation took place at regular intervals together with surface condition measurements. The speed/fuel consumption relationships provide the primary link with the data on vehicle operation from the survey of road users.

The assessment of the rate of road deterioration is obviously a crucial aspect of this study and must be related to initial construction quality, climatic factors and road use. Equally it is essential to study the extent to which deterioration of the road can be arrested by different maintenance policies and technologies. The study of these parameters has taken place on the same experimental sections as those used to develop speed/fuel consumption relations.

Although deterioration of non-paved roads takes place quite quickly this is not so in the normal course of events with paved roads. Thus, although the two-year study programme has been adequate for the main objectives of the research, the investigation of the deterioration of paved roads in relation to construction standards and road use will require periodic measurements over a much longer period even on heavily trafficked roads.

In the current study taking place in Kenya, the effect of traffic parameters in the sense of speed/flow relationships has not been examined. This is because with the low flows on most rural roads there is no evidence that such effects are significant. Research results in Europe indicate that such relationships do not become important on two-lane level tangential roads until flows exceed 300 pcu's per hour per lane although this obviously is affected greatly by the proportion of medium/heavy vehicles and vertical geometry. However, research results from an earlier study in Kenya are providing useful information on the effects of vehicle flow together with road characteristics on operating speeds and vehicle operating costs.

Despite the many limitations of available evidence, the existing model, which can be equated to conventional planning methods by employing appropriate simplifying assumptions, does constitute a valid conceptual approach to preliminary highway design. If more complete evidence and data are available, or can reasonably be inferred from experienced engineering judgement, the existing model can be used to provide insights into the trade-offs between construction standards, maintenance standards and vehicle operating costs which are not possible by conventional methods. Certainly the model can facilitate a systematic search over design alternatives which would be impractical with the usual manual methods of cost estimation. Thus it is recommended that the existing model is applied in an experimental sense. Indeed, this should be a continuing process as the approach is progressively refined.

It is important that the output from the model is subjected to critical examination by the engineers in the light of their experience of local conditions and performance of standards already in use. This in turn will lead to progressive improvement of the hypotheses contained within the model.

Resulting from the Kenya study and work elsewhere in Africa some of the more important areas for consideration in arriving at road standards have been identified and are described below. However, it is important, in addition to having available a practical computer model, that certain guidelines for the selection of efficient road standards should be made available. In this section of the paper we intend to describe what we believe to be the more important relationships stemming from research in Africa and elsewhere that should be used in the selection of standards. These relationships are discussed under the headings of vehicle operating costs and road construction costs with road maintenance being considered under each heading.

3.2 Vehicle operating costs

The benefits that result from any given road improvement can be quantified and result mainly from lower vehicle operating costs and reductions in journey times. Work carried out in Great Britain on paved roads has shown that vehicle operating costs decrease as road conditions permit vehicle speeds to increase up to about 60 km/h; beyond this, other things being equal, vehicle speed tends to lead to higher vehicle operating costs. Time savings can be ascribed a value according to the type of journey being made (work, leisure etc), although journey time unit values increase year by year.

Research carried out by the TRRL in East and Central Africa during the early 1960's was aimed at measuring the difference in the average operating costs of medium and heavy commercial vehicles in relation, primarily, to surface condition. Three major categories of road surface were examined:

- two-lane bituminous-surfaced roads 6 to 7.5 metres wide

- gravel-surfaced roads built to specified engineering standards with over 75mm of selected granular surfacing material

- unimproved roads not built to a specified standard and with serviceability affected by rain.

The results of this study are summarized in Fig. 1. Some results were also obtained for vehicle operation on single-lane (3-3.5 metre) bituminous-surfaced roads; although data were limited, they did indicate that such roads were similar to two-lane paved roads up to a vehicle flow of 500 veh/day but, thereafter, costs increased rapidly until at 1500 veh/day they were similar to those on the worst of the unimproved surfaces. This study, however, had certain deficiencies as a tool for specifying minimum cost road standards. These were:

- apart from general classification of surface type there was no quantitative measure of condition, thus engineering judgement had to be used in assessing where a road fell on the scale of operating costs, and the condition of the road could not easily be related to construction standards and road maintenance operations.

- geometric parameters were not included in the study and thus the results could provide no guidelines for this important part of road design as it affected vehicle operating costs.

A study carried out by the International Bank for Reconstruction and Development examined reported vehicle operating costs from many countries of the world in relation to physical operating conditions. Using these data for similar road categories to those in the TRRL study but including also certain geometric parameters, tables of vehicle operating cost coefficients were produced for a range of vehicle types and also including a system of vehicle speed derivation. However, although these tables provided a convenient vehicle operating cost manual, the information was not tested empirically nor was the effect examined of geometrically-caused speed changes on vehicle operating costs. However, if we can use vehicle speed as an index of total operating costs (this is currently being examined) an empirically based model for deriving vehicle speed, taking into account a number of road and traffic parameters, will go some way towards providing guidelines for road standards. Existing relations derived from research in developed countries do not cover the conditions encountered in less developed countries.

There are a large number of factors which can affect vehicle speeds. Recent studies in Kenya have related journey time by type of vehicle to vehicle flow, horizontal and vertical curvature, surface irregularity and road width. Studies were made on both bitumen-surfaced and gravel roads so that benefits resulting from upgrading from a gravel to bitumen surface could be identified.

Journey speeds on gravel roads were found to be on average 24 km/h less for light vehicles (cars and light vans) and 7 km/h less for heavy vehicles (heavy goods and public service vehicles) than on bituminous-surfaced roads. Where alignment and width were very similar, differences between the two types of road were about half the above values.

TABLE 1

Factors which significantly affect vehicle speeds
on surfaced roads

Independent Variables	Type of Vehicles	Range of values	Regression Constant a	Regression Coefficient b	Multiple Correlation Coefficient (R)
Rise and Fall (m/Km)	Light	64.6-0.2	95.7119	-0.5793	0.6911
	Heavy		65.7739	-0.5433	0.6874
Curvature (Deg/ m)	Light	386-0	87.9727	-0.1433	0.6988
	Heavy		55.6347	-0.753	0.3897
Width (m)	Light	7.0-3.0	32.4891	7.308	0.3849
	Heavy		NOT SIGNIFICANT		
Surface irregularity (cm/ m)	Light	476-164	96.0401	-0.0481	0.2672
	Heavy		NOT SIGNIFICANT		

TABLE 2

Factors which significantly affect vehicle speeds on gravel roads

Independent Variables	Type of Vehicles	Range of Values	Regression Constant a	Regression Coefficient b	Multiple Correlation Coefficient (R)
Rise and Fall (m/km)	Light	61.2-5.1	67.3057	-0.3472	0.3966
	Heavy		62.6849	-0.5718	0.6342
Altitude (m)	Light	2210-30	NOT SIGNIFICANT		
	Heavy		38.4984	-0.0050	0.2428
Curvature (Deg/km)	Light	540-5	64.5047	-0.0703	0.7883
	Heavy		51.4371	-0.0566	0.6165
Width (m)	Light	7.9-4.0	29.8633	4.3208	0.4866
	Heavy		11.2215	5.4688	0.5981
S.I. (cm/km)	Light	1227-331	72.4673	-0.0240	0.4579
	Heavy		59.3484	-0.0216	0.4002
Percent of Heavies	Light	84.0.4.6	51.5882	0.2038	0.2954
	Heavy		40.5777	0.1826	0.2571

Tables 1 and 2 show the parameters found to be related (at the 5% level of significance) to vehicle speeds on both types of road. Equations take the form

y (vehicle speed) = $\pm$ bx (independent variable)
where a is the regression constant
and b is the regression coefficient

Thus from Table 1, for example, the relationship between light vehicle speeds on bitumen roads and horizontal curvature is

y (vehicle speed) km/h = 87.97 - 0.1433 (horiz curve in degrees/km)

Of the individual geometric elements, as might be expected, rise and fall had the greatest effect on heavy vehicles, reducing their speed on both bitumen and gravel roads by 22 per cent on average for every 25 metres rise and fall per kilometre. The equivalent value for light vehicles was 14 per cent. Horizontal curvature had a greater effect on the speed of light vehicles than on heavy vehicles. Average speed reductions on surfaced roads were 13 km/h for every 100 degrees of curvature per kilometre for light vehicles and 7 km/h for heavy vehicles. The effect of curvature was less on gravel roads, speed reductions being about half those on surfaced roads.

On gravel roads in this study the mean surface irregularity was 650 cm per kilometre of road. According to the regression equation relating this variable with speed, this amount of irregularity would have the effect of lowering vehicle speeds by 24 per cent. On surfaced roads the mean was only 300 cm per kilometre which would lower speeds by 15 per cent. Furthermore there were sections of gravel road where irregularity reached over 1000 cm/kilometre whereas the maximum on surfaced roads was less than half this.

All the measurements of geometrical parameters were made dynamically using an instrumented car (Ford Cortina Estate) specially developed so that a rapid inventory of highway conditions can be made. The surface irregularity was calculated by measuring the movements of the rear axle in relation to the rest of the car. The results have been compared with those of other vehicles, such as a long-wheel-base Land-Rover, and also with a towed bump integrator. Good correlation was found.

The parameters which were found to have a significant effect on vehicle speeds can be combined by the technique of multiple regression analysis into a single equation. These were found to be as follows.

i. Bitumen surfaced roads

$$y_1 = 73.1837 - 0.357x_1 - 0.0902x_2 + 5.2523x_3 - 0.0188x_4 - 0.0671x_5 - 0.1863x_6$$

$$y_2 = 65.7739 - 0.5433x_1$$

where

y_1 = speed of light vehicles (km/h)

y_2 = speed of heavy vehicles (km/h)

x_1 = rise and fall (m/km)

x_2 = curvature (degrees/km)

x_3 = width (metres)

x_4 = surface irregularity (cm/km)

x_5 = flow including buses (veh/h)

x_6 = percentage of heavy vehicles

ii. Gravel road

$$y_1 = 75.0717 - 0.1296x_2 - 0.0590x_4 - 0.0118x_6$$

$$y_2 = 49.5508 - 0.4175x_2 - 0.0030x_3 - 0.0287x_4 + 2.0525x_5 - 0.0076x_6$$

where

y_1 = speed of light vehicles (km/h)

y_2 = speed of heavy vehicles (km/h)

x_2 = rise and fall (m/km)

x_3 = altitude (m)

x_4 = curvature (degrees/km)

x_5 = width (m)

x_6 = surface irregularity (cm/km)

On bitumen roads 80 per cent of the variation in speed can be 'explained' by rise and fall, curvature and width and on gravel roads 85 per cent can be 'explained' by surface irregularity and horizontal curvature alone. Thus by using these variations only the engineer can estimate vehicle speeds on the two types of road surfaces and should be able to assess the optimum values needed.

Measurements of surface condition on roads in Africa have indicated that, depending on the level of initial construction and quality of maintenance, the roughness of bituminous roads ranges from about 150-500 cm per kilometre and within this range vehicle operating costs (using a speed/cost index) are not particularly sensitive. This, however, assumes that the road is not permitted to fail structurally. However, measurements of roughness on non-bituminous surfaced roads, depending on materials, rainfall, traffic and especially level of road maintenance, will range from about 300 to 1300 cm per kilometre and within this range vehicle operating costs (speed/cost index) are very sensitive. Thus it

would appear that particular attention should be paid to the maintenance of non-bituminous roads in any attempt to minimize vehicle operating costs. Under extreme climatic conditions, and in Africa particularly where there is high rainfall, gravel roads may be unusable for considerable periods during the year. We have not examined in this paper the particular aspects and costs of this, but they could be important.

Until now, the relation between the level of maintenance and vehicle operating costs has not been studied scientifically and it is possible that non-paved roads may, economically, carry a much greater flow of traffic than is conventionally thought possible and this could have a significant effect on the selection of road standards.

3.3 Construction costs

3.3.1 Introduction

It is very difficult to give any numerical data on construction costs which would be generally applicable; indeed the influence of local conditions and the different physical and chemical characteristics of materials lead to very different results from one region to another, particularly for low cost roads that are constructed from local materials. However it is possible to give some general guidance, on the one hand regarding the relationship between the construction and the performance of the surface, and on the other hand the relationship between geometry and pavement construction.

3.3.2 Influence of the pavement structure on the performance of the surface.

There are many factors which influence unpaved roads. For example, the shape of the mean grading curve of the material used as surfacing: one which has too many fines will generally give a satisfactory surface during the dry season but will lead to appreciable deformation and a very slippery surface during the rains. Excess granular material will lead to loose unstable surface, often with large corrugations.

Plates 1 and 2 show what happens when there is excess fine material in lateritic gravel.

In the dry season the road surface looks like clay paving stones; in the wet season slippery wheel tracks are formed and spoil the condition of the surface.

In order to avoid these situations it is necessary to establish standards for the use of these materials. Thus in the Ivory Coast the following classification was adopted for laterite gravel:

TABLE 3

Laterite gravel classification

Classification of gravel	Plastic Index	Passing 80μ	Specification
G1	< 12	< 15%	Used in the sub-base or base, stabilised or unstabilised according to the effect of the mechanical properties
G2	< 20	< 20%	
G3	> 20	> 20%	Only in the subgrade

and the specifications for using it are shown in Table 4.

TABLE 4

Specification for using Laterite gravel

Base layer	P.I. % passing 80 µ CBR	12 20% 80
Sub-base layer	P.I. % passing 80 µ CBR	20 20%

As an example, Fig 2 gives the results of a prospecting survey of a laterite gravel borrow pit and Fig 3 shows a laboratory analysis of a sample representing group G1-G2.

In the first diagram it is evident that each trial pit has yielded something in the laterite gravel classifications G1, G2 and G3. Some samples have been analysed and their mechanical properties have been measured so as to find out whether they could be used.

The recommendations above are valid only for the initial grading curve, which can change because of attrition under traffic and climatic changes.

In this sense the relatively stable laterites differ from already weathered materials or those susceptible to rapid weathering which are found in certain regions. It is necessary therefore to be cautious and to examine carefully the existing conditions (climate, materials, traffic) before comparing the standards in force in the different African countries. In particular, it is necessary to take account of the frequency of reshaping; this can be after passage of about 5000 vehicles but practice varies considerably. For example, in the Ivory Coast,* the frequency of regrading varies in general from:-

7 to 30 days for routes A & B (100 - 500 veh/day)

45 to 90 " " " C (1 - 20 veh/day)

Plate 3 shows the surface condition of a Category A road after reshaping.

For paved roads, things are more complex and, from the start, appreciation of the quality of a road structure must be based on a precise analysis of its behaviour, taking into account physical conditions, which are sometimes very particular to the region studied.

The need to surface a road permanently is a function of the traffic and fulfills many aims:-

1. Reducation of surface maintenance: the grader is no longer used, whereas it would be required more and more on an unpaved road with increasing traffic. Local maintenance required by the deterioration of weak areas and major maintenance such as laying a new carpet are very much less frequent. For example in the Ivory Coast on the Abidjan-Abengourou road, the approaches to Abengourou are surfaced with a sand asphalt carpet, which is still in excellent condition after 15 years (Plate 4).

* (M Cesareo - maintenance of earth roads in the Ivory Coast)

2. Minimisation of the cost of transport. In spite of frequent maintenance operations, the formation of corrugations (Plate 5) on unpaved roads cannot be avoided; these are very detrimental to safety and to the life of vehicles. It is well known that certain makes of vehicles wear out prematurely on these roads.

3. Considering the environment: where roads pass through villages and towns permanent surfacing is justified so as to obviate the clouds of dust which would be raised by vehicles.

4. Economy in the reserves of quality materials. Maintenance and frequent re-shaping of unsurfaced roads result in a loss of gravel which must be replaced. This exhausts the reserves of good quality gravel (eg G_1 and G_2 in the Ivory Coast) and makes it necessary to look for sources farther and farther from the road line, which are therefore more costly to use.

It should be pointed out that these last two considerations are usually left out of the normal economic analysis. The improvement of roads passing through villages and towns is an element which is difficult to quantify but the using up of natural reserves of quality materials weighs heavily in consideration of a project for renewal of a road system and it can be quantified.

It is important to bear in mind that a paved road is not just an earth road which has been surfaced. In fact, the presence of the surfacing imposes new constraints, in particular, the need to have very little deformation in the subgrade. Although longitudinal deformation of the surface caused by subgrade movements can be put right in earth roads by maintenance, it is not the same for a paved road which must retain its longitudinal profile.

Due attention must be paid to the evapotranspiration effects (which can include crystallisation of materials under the surface layer in certain regions of the Sahara) and to seasonal or daily thermal cycles; pronounced thermal gradients in rigid surface layers having no viscous relaxation give rise to flexural movements or appreciable buckling. These in particular should be examined.

For a given type of structure the performance of which is known, we will consider the parameters that were indicated in the introduction. The relationships between these parameters and the development of surface characteristics constitutes the basis for experimental methods concerned with Pavement Design. One must remember that these relationships when they exist have been established in a well defined context. The two examples below illustrate this.

a. The Kenya study

For the test sections in Kenya Fig 4 shows theoretical PSI (Present Serviceability Index) plotted against the following parameters:

The patching and cracking coefficient

Rut depth

Roughness coefficient

It can be seen that the behaviour of these test sections is totally different from that of the test sections examined in the AASHO test and that consequently the maintenance programme for surfaced roads as used in the MIT model requires some modification when applied to the type of construction in developing countries. It is also evident that on these same test sections and as shown on graphs 1 and 2 (patching and cracking,

and rut depth) a difference does exist between the sections that were constructed with carpets of coated crushed material covered by bituminous surfacing of 18-32 cm and the sections with a surface dressing on a cement-stabilised base. The differences between the results of the AASHO test and those in Kenya have caused the TRRL team to employ a group of engineers in order to classify the various test sections using a standard which would be appropriate to Kenya.

b. Traffic spectrum

The behaviour of roads under traffic and the standards of quality that can be deduced experimentally from this can vary from one country to another not only because the maximum legal loads can be different but also because the traffic spectrum can be completely different from one country to another.

As an example the traffic spectra for Madagascar, Ivory Coast, Senegal and Cameroun can be compared (Fig 5).*

On the graphs there are no axles less than 2 tons, ie cars are excluded. The axles shown here (single axles) represent 40 - 50 per cent of the total traffic.

It is very important to emphasise the different sources of inaccuracy in order to avoid too hasty conclusions resulting from the use of approximate formulae.

Meanwhile we can usefully consider the following as a basis for judging the validity of existing formulae.

1. Inadequacy of total thickness or instability of the lower layers or poor quality of materials leading to deformation of the whole.

2. Insufficient thickness of stabilised layers, excess cement leading to cracking (more rapid in the case of materials stabilised with hydraulic binders), followed by general break-up and the formation of potholes.

3. Layers stabilised with cement or lime in regions with wide daily temperature variations which could cause rapid cracking and general break-up.

4. Insurfficient stability of bitumen-bound layers, poor quality of the riding surface resting on a cement-stabilised base (bitumen too soft, poor gradings, etc) giving rise to wheel tracking.

It should be noted also that deflection measurement does not in itself guarantee the quality of a pavement. It shows only for a given type of structure whether the overall mechanical rigidity is adequate in the conditions where it is being used.

This is shown in the following examples.

a. With the publication of a first series of measurements made in West Africa and Madagascar, the CEBTP gave, in the manual of Pavement Design for West Africa and Madagascar, a graph relating deflection and traffic and a suggested line separating roads in good condition from those in poor condition (see Fig 6).

* Paper given by G P Serfass Engineer at CEBTP - Munich, October 1973, IRF - Title: "Development of Construction Techniques for Paved Roads in Tropical and Desert Regions".

After further research the CEBTP had reason to correct this line. This shows that deflection should be used with care and regarded as an excellent indicator of poor quality; this still remains true even when further, more detailed studies lead to modification of the threshold limit values.

b. Example of the cocoa road (Toumodi-Dimbokro-Ouelle road, Ivory Coast

The low deflection on this new section (Fig 7) did not reveal the presence of the soft intermediate layer of 16 cm of clayey silt which would reduce the stability of the road; it showed only the fact that the whole thing (clayey silt and laterite gravel) rests on solid laterite.

The product, deflection x radius of curvature (R x d was approximately 2000) Fig 8, proves the presence of this layer.

It should be remembered that results, theoretical as well as experimental, on roads with non-stabilised bases and on homogeneous subgrades lead to R x d of the order of 5000 (metres x hundredths of a millimetre). A much smaller value of R x d indicates the presence of an intermediate layer of very inferior quality (as in the example quoted) or that of a soil which exhibits non-elastic behaviour under the axle load specified.

The methods of pavement design based on deflection criteria (eg the criterion curve of CEBTP) are not therefore to be discarded but must be used with reasonable caution. The time when the measurements are taken can play a large part; as described above, they do not always show up deterioration due to the inadequacy of certain layers. In general, they are not linked directly with rate of change as determined by the surface characteristics but are derived from a qualitative assessment (a limit above which in a given situation there is a risk, which although not quantified should not be overlooked, of the surface condition becoming rapidly unacceptable).

3.4 The influence of the different factors.

The factors can affect each other not only as between different classes of road (eg the geometry of the road affects the mean speed of vehicles as we have already seen in the experience gained in Kenya), but just as much within one class. We shall give some very significant examples of interactions of this second type.

Example of the interaction between geometry and pavement structure.

The choice of geometric characteristics designed to suit a high road speed usually leads to an increase in the cost of earthworks and in Africa to the risk of other consequences particularly in the structure of the road itself. Let us examine this aspect more closely.

Terraine is frequently found in tropical zones with the following pedological soil profile.

Loam	0.2 m thick, but sometimes absent.
Lateritic gravels	Ferralitic soils of thickness varying between 0.2 and 2 metres having a variable plasticity index and percentage of fines. Soils generally strong (CBR = 20) and sometimes suitable for use in pavement layers.
Clayey gravels	Thickness of the order of 3 to 4 metres. Plastic or very plastic clays slightly damp in situ owing to the protection of the laterite cover. Soils characteristic of low standard roads.
Active clays	Montmorillomite soils, Kaolinites, etc. Very bad, expansive soils.
Parent rock	According to the nature of the rock, it decomposes into sand, blocks etc. In the case of granite, rocky soil between 8 and 12 metres thick.

The engineer will therefore be faced with totally different problems according to whether soils of very high bearing capacity are found at natural ground level, requiring only thin pavement layers (20 cm), materials having acceptable road construction properties being available from small beds of laterite gravel or, as deeper road cuttings are excavated, he finds successively gravel clays (CBR = 4, water susceptible but generally at a moisture content close to optimum in situ) and active clays (CBR 0-2, water susceptible). Clearly, in the latter situation the pavement layers must be thicker (at least of the order of 50 cm) over a formation layer which itself could easily be 0.5 to 1 metre thick. The quantities of material required are therefore increased in considerable proportions and may well make it necessary to find larger deposits, sometimes farther away (opening up quarries for example), which will increase the price of materials considerably. The organisation of the work may be completely changed because of this.

Moreover, the slopes of cuttings vary considerably according to whether very stable laterites are encountered (vertical slopes are then the best) or whether active clays are being excavated giving slopes which are extremely difficult to stabilise (eg La Foret des Abeilles, Gabon).

Finally, the choice made may have a more widespread effect on the road system of the region being considered; for example, how to continue the maintenance of the existing earth roads if the deposits of materials have been used up for the construction of the new road.

At the other extreme, it must be realised that the maintenance of unpaved roads carrying heavy traffic requires the frequent replenishment of gravel and thus leads to a progressive scarcity of resurfacing materials near to the road and to an increase in the cost of maintenance. It is only right then to be well aware of the consequences of the different choices open.

3.5 Summary

From the general indications which have been given, albeit not very encouraging, a number of conclusions can be drawn.

1. The designs which are valid in one country can only be used in another country provided a close examination of the local conditions

shows this to be sound. This is applicable just as much within Africa as it is between Africa and other continents. This examination cannot be limited just to a comparison of previous experience but must also consider new problems (example already quoted of new roads with much improved geometric standards).

2. It is necessary to distinguish between a comparative analysis of different solutions that can sometimes be based on approximate equations (provided that no essential fact has been ignored) and the calculation of readl costs of a solution which would either require better data or which one would be obliged to leave imprecise.

3. Lastly, past projects should be examined to compare the actual costs with the initial estimates.

4. DATA COLLECTION

A theme of this paper has been the desirability of adopting a flexible approach towards highway design standards rather than a rigid "look-up" system if the minimum total transport cost criterion is to be met. Although such an approach places considerable demands on data collection, we believe that the data required will not only be of value in planning road improvements or new road schemes, but also in optimizing recurrent road expenditure and thus in defining more precisely the resources that should be allocated to the transportation sector.

Although we expect to be able to use certain general information, such as speed of vehicles on certain gradients and combinations of pavement layers to obtain levels of serviceability, these are derived relationships and can sensibly be used in an economic evaluation only if adequate data on, for instance, traffic flows and unit construction costs are readily available. Thus regular data collection in a system that allows easy retrieval is a vital part of highway design. It is obviously impossible in a paper of this length to describe in detail the methods of data collection but references are given 1, 2, 3 to work describing the methods. The main areas of concentration should be as follows.

4.1 Roads

An inventory of a country's road system should be made giving not only a detailed physical description of the roads but also details of the purpose that the roads fulfil, road-side development and rainfall. Regarding the physical road parameters there is, of course, a very wide range of measurements that can be made at various levels of sophistication and detail. We would suggest, however, that the most important of these are the following:

4.1.1 Geometry

For all roads there should be a measurement of rise and fall kilometre by kilometre determined by field survey or taken more crudely from topographical maps. Similarly horizontal alignment should also be measured using survey, large-scale maps or aerial photographs. The measurement of road width is also important.

4.1.2 Surface condition

Research is indicating that the roughness of a road is the most important road surface parameter influencing vehicle operating costs, and also one of

the most important parameters categorising road deterioration. Thus we believe that this should be measured wherever possible and related to the road type, materials, rainfall, traffic and road maintenance operations. Simple robust instruments are available at a reasonable price for carrying out these roughness measurements, but regular claibration of the equipment is necessary.

4.2 Traffic

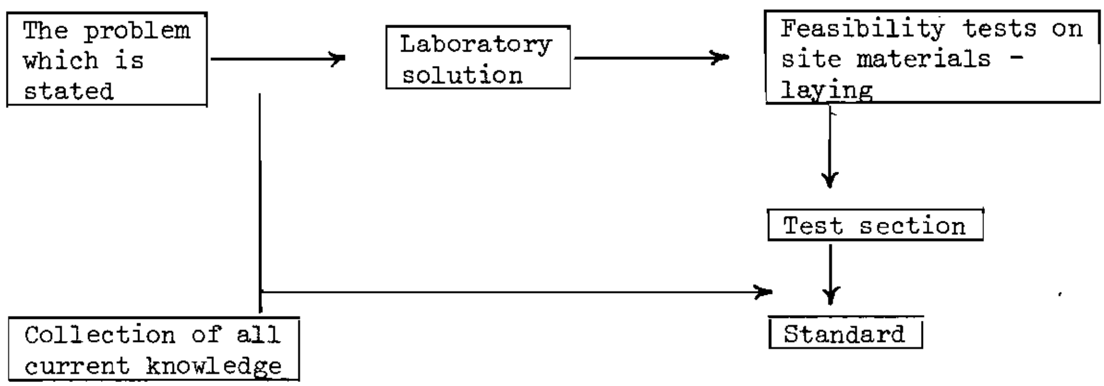
Similarly data on road usage in terms of numbers and types of vehicle should be collected on a statistically sound basis and supplemented by vehicle axle load surveys. This work should be carried out on a regular basis by a special survey unit that could also be employed on specific road construction studies.

4.3 Vehicle operating costs

Vehicle operating costs are so central to all aspects of transport investment policy - road user savings, axle load regulation, transport controls - that all governments should maintain adequate information on as wide a range as possible of vehicles in use. A consistent approach towards the collection of these data should be employed. First, data should be collected in physical as we-l as monetary terms whenever possible. Secondly, it should be decided at the outset which items should be treated as standing charges and which as running costs - vehicle depreciation and labour charges most frequently present problems here. Finally the primary effort should be directed to obtaining base data; that is data for vehicles operating on level well maintained tangetial bituminous surfaced roads. The reason for this last point is that these roads have the least variation in vehicle operating cost parameters and the data derived from them can then most easily be used to calibrate the sorts of relationships described above, and the more comprehensive relationships developed from the current study in Kenya.

4.4 Surface characteristics and pavement structure - general comment

In no case is there any question of establishing general relationships, because that would be much too laborious and almost impossible, but rather to verify the predictions made from current knowledge and from laboratory tests according to the following diagram.



As an example, the results of a deflection study on a road with a cement-stabilised sand base carried out at the University of Lovanium, Kinshasa, in 1970 by M Van Cauwelaert and his team, are given below.

TABLE 5

Comparison of calculated deflections with those measured during construction of the Mdjili-Maluku Road

Composition of the road at the time of measurement	Deflection	
	Calculated 1/100 mm	Measured 1/100 mm
1. Natural sand 1.00 m of compacted yellow sand	61	66.5
2. 1st layer of stabilised sand Yellow sand	91	29; 46.8 52; 38.7
3. 2nd layer of stabilised sand 1st layer of stabilised sand Yellow sand	63.5	32.4 23.2 28.8
4. Binder course 2nd layer of stabilised sand 1st layer of stabilised sand Yellow sand	49	26.4 48.5

4.4.1 Unpaved roads

After pointing out the important factors above it remains to measure the changes in surface characteristics according to the methods described in the preceding paragraph, in particular keeping rainfall records. (Simplified rain gauges have been developed by TRRL).

Gravel loss will also be measured; this in certain conditions can determine the frequenc y of resurfacing.

The ease of measuring this will depend upon what difference there is between the pavement material and the subgrade itself. (An example of difficult differentiation is lateritic gravel on a lateritic soil. In the Ivory Coast, easy differentiation is given by borrow pit material of types C and D of the Kenya specification).

The measurements can be made by levelling on the roadway combined with direct spot measurement of thickness (between metal plates placed at the bottom and in the surface of the pavement structure), so as to allow for settlement occurring in the whole pavement.

It will be possible to take special measurements also for subgrade soils which swell (Firkee, Black Cotton) in order to analyse the gradual movement of the pavement due to swelling. (This will be considered again for paved roads).

Finally it is necessary to take into account the width of the road (for example Category A, B and C in the Ivory Coast) and of the quality of the pavement drainage.

4.4.2 Paved roads

In addition to the parameters which describe the surface characteristics, the mechanical performance will be analysed: deflection (initial value - seasonal variation - permanent changes), cracking of cement-stabilised materials, attrition of granular materials, gradual changes in bituminous materials (stability - creep), all in such a way as to be taken into account in the standard.

Deflection measurements can be made either with the Benkelman beam, or with high output equipment like the Lacroix Deflectograph. Types of equipment for measuring dynamic deflection have also appeared on the market recently, these types of apparatus, which can be advantageous (especially on aerodrome runways on account of their relative ease of handling) should, however, be examined rather cautiously particularly in respect of signals transmitted and received, interpretation of results and the experience gained from them.

It should be noted that deflection measurements provide:

a. First a test of homogeneity of the pavement.

b. Then an indication of the variation of the seasonal behaviour of the pavement structure.

c. Finally, and in certain well-defined conditions, an indication of the pavement quality (with the proviso that the type of structure and its mechanical behaviour are well defined). In this case deflection measurements can be usefully correlated with the measurements of radius of curvature (Dehlen's curviameter, LCPC method, etc).

The values of deflection to be chosen will be calibrated on experimental sections and can then be used in designing pavements or, even more important, in the strengthening of pavements.

5. CONCLUSIONS

The provision of an adequate road system is rightly regarded as an essential part of a programme of economic development. This paper has discussed what is meant by "adequate" and we have adopted as a criterion the concept of lowest total transport cost over the foreseeable life of the investment. Because of this approach we have argued that rigidly-applied road standards are clearly inappropriate for developing countries. The ideal solution would be to adopt a programme of permanent improvement if one wished to keep overall transport costs low but such improvement cost is not at all low; we should therefore aim at a programme of stage construction supported by a well planned and, if possible, intensive maintenance programme. We suggest that possible exceptions to this approach are when traffic volumes reach levels in excess of 10,000 passenger car units per day or have very high existing and predicted rates of growth; also for roads in urban areas. The reasons for these exceptions are:

i. The size and power of the equipment required and the volume of traffic carried are such that a stage construction programme in the accepted sense is impracticable, all the more because research on intervening levels of construction has not been done.

ii. Traffic congestion problems are much more important, so that special attention must be paid to the geometry of the main road layout and this is less amenable to stage construction than the pavement structure or the surface.

iii. Such traffic levels are generally associated with advanced levels of land use development, particularly in urban areas, and frequent changes in road design ostensibly leading to cost minimization can result in very high economic costs, from forced changes in land use, that may not have been included in the calculations.

Thus we believe that at these high traffic levels it is probably justified to use road standards established in developed countries, but suitably modified for differences in climate and traffic composition.

The benefits of most road improvement schemes stem from 'Savings" in vehicle operating costs, including time savings. It is therefore important that the relationship between such costs and road characteristics should provide the basic index (at present vehicle speed is the most practical approach) as well as a method of establishing optimum standards.

Considerable research effort has gone into this subject and this paper has described this work and provided some guidelines on the use of empirical relationships in selecting optimum road standards. Such relationships are being progressively improved and it is hoped shortly to produce a practicable computer model that will facilitate this selection. However, it must be emphasised that such advances in preparing guidelines for selecting road standards can only be effective if adequate data are available. All countries should examine how they stand in relation to the data needed to take wise decisions on road investment and where necessary make a determined effort to rectify any deficiencies.

Furthermore, pavement design must receive attention and in order to obtain the best value for money, one must take account of the physical behaviour characteristics of each material in the local climatic conditions; also of the geotechnical implications which are sometimes considerable, of the surfacing materials etc.

This appreciation can only be made by combining sound knowledge of local conditions (collected from results and also from the experience of local engineers) and of a sufficiently detailed analysis of the ways in which the pavement layers gradually change.

In this respect we cannot emphasise too strongly how careful one must be to avoid applying, without any modification, methods that have been developed in other countries where the prevailing conditions may be very different from those of the country in question.

Moreover, this serves to emphasise the necessity for careful procedure by people using the results derived from a numerical model, interest in which will be all the greater since it will allow better analysis and the continuous improvement of the assumptions made and the relationships used.

Also, the analysis of maintenance problems can only be done on the basis of careful local enquiries, extrapolations from one country to another being very difficult.

Lastly, it is fitting to point out the value of estimating the existing technical possibilities (trained people, material available) in the criteria which lead to the final decision.

As a final conclusion, all that has been said shows how difficult it is to transfer from one country to another the results obtained, but it seems to the authors that the principles expounded above can be used profitably by every country in preparing its own policy for road standards.

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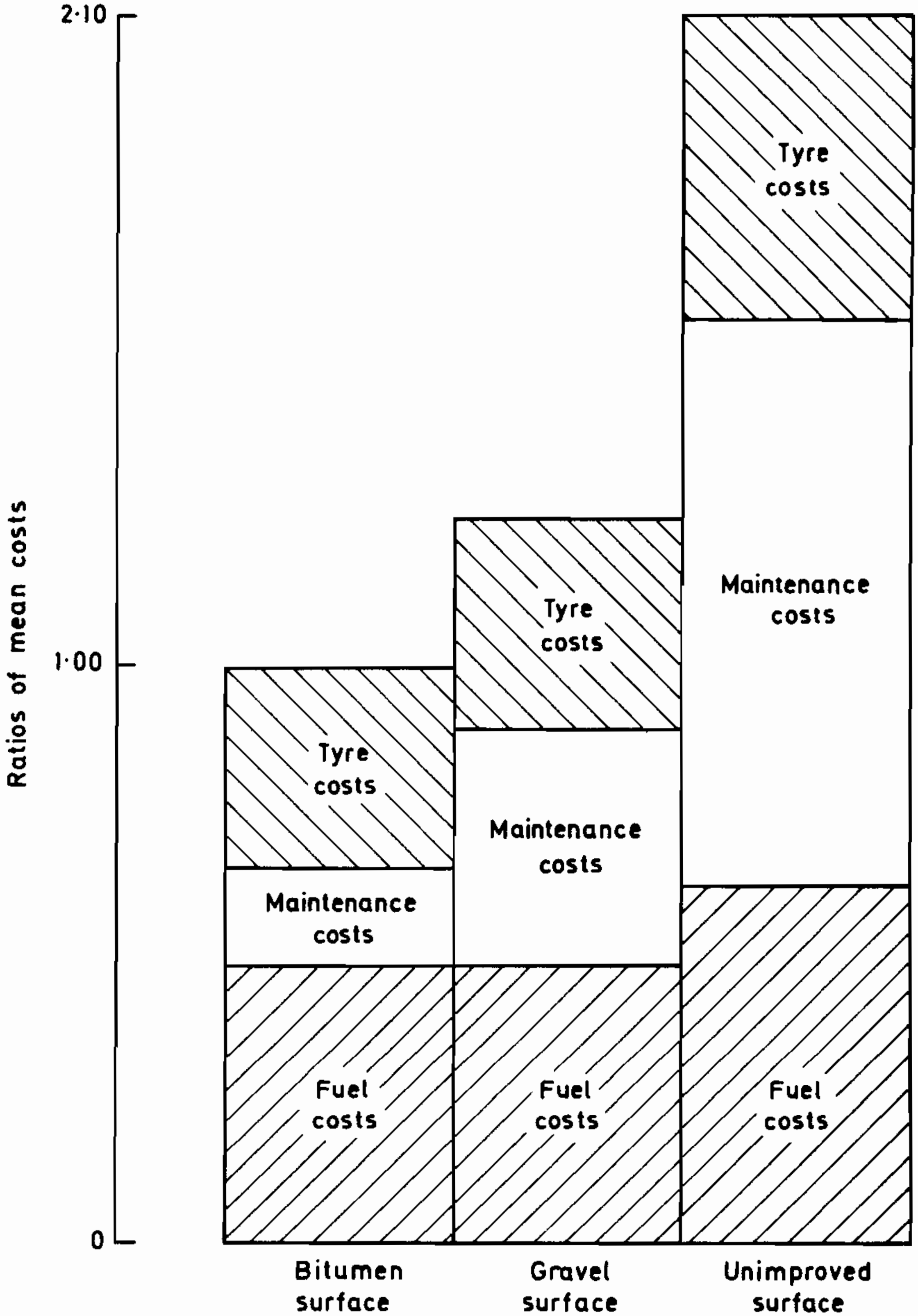
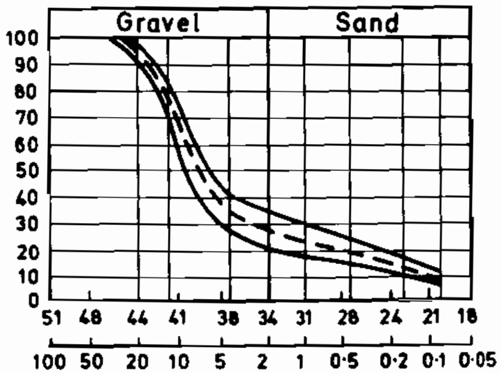


Fig. 1 THE RELATIONSHIP BETWEEN VEHICLE RUNNING COSTS ON VARIOUS ROAD SURFACES IN AFRICA

BORROW-PIT DATA
Type of material : Latertic gravel
Average thickness 0·10 m Topsoil
volumes in m³ 0·40m (a) Base and subbase
0·20m (b) Select material

(a) 10·000m³ (b) 6·500m³

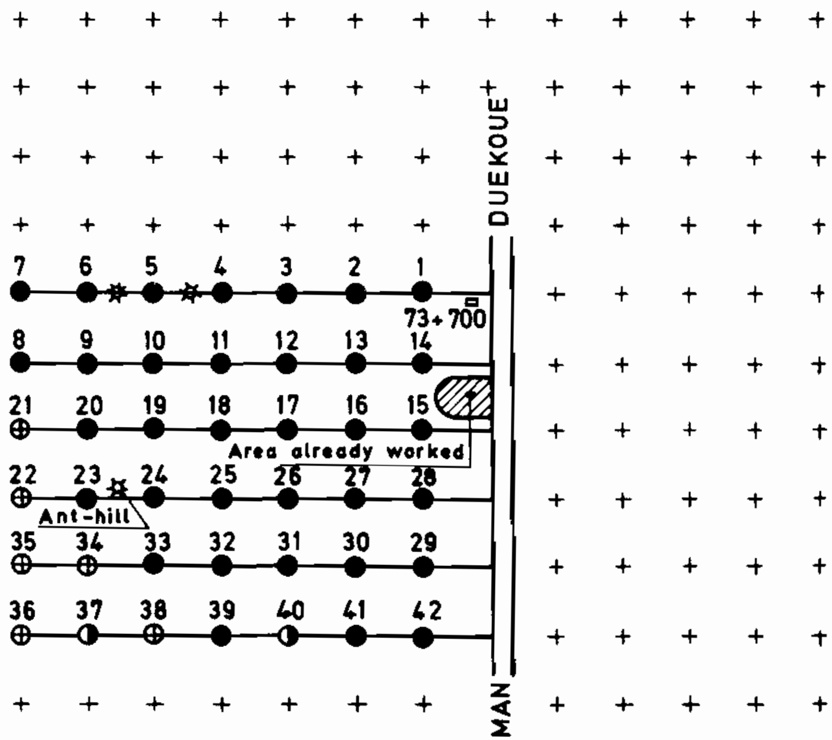
Grading envelope



No	20	12·5	4	2	1	0·4	0·080	0·08	W_L	IP
2	96	78	28	21	17	15	11	8	28	14
6	94	80	38	31	28	24	16	12	31	16
11	97	86	35	26	22	18	11	8	26	11
15	98	86	37	25	23	20	12	9	32	17
25	90	74	39	30	26	21	13	10	30	15
41	93	82	40	3	30	24	14	11	25	13
Av.	95	81	36	27	24	20	11	10		

Borrow-pit investigation for select material
Borrow-pit n² 12 PK 73 + 700

PLAN



Pit spacings 30m

Pit data

Thickness of material in cm

Boxed numbers represent location of sample

⊕ Negative pits without gravel

◑ Pits with select material (G3)

● Pits with select material (G1 and G2)

Identification	of Pits	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	D	10	5	10	5	10	10	10	10	10	10	10	10	40	15	10	5	10	5	10	10			10	5	5
	G1	50	55	50				50	40	50	50	50	50						45					50	55	40
	G2				45	40	40					30		80	35	40	45	40	20	30	30					
	G3	20	20	20	20	30	20	20	30	30	30		30									Negative		20	20	35
	SF																									
	SG																									

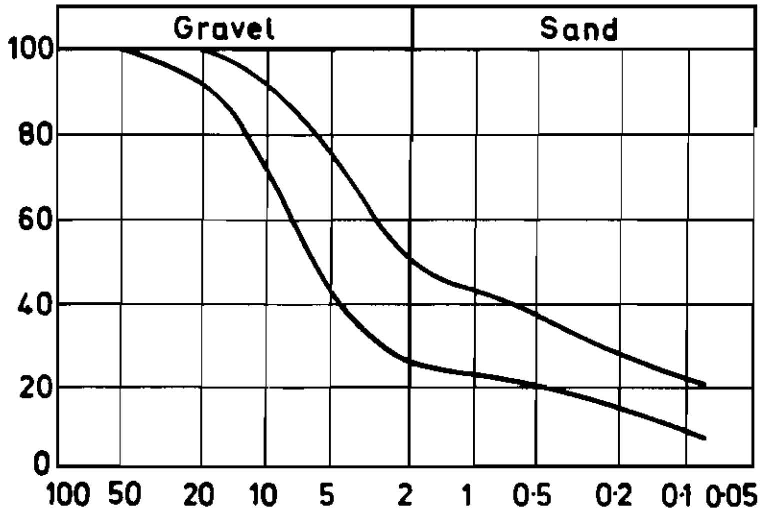
	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
D	5	5	5	30	40	20	40	5				5		10	40	10	35								
G1			55					45								40									
G2	50	40		30	35	40		15						40											
G3	15	20		20			15					25			25		25								
SF																									
SG																									

Fig. 2. RESULTS OF A SURVEY OF A BORROW PIT - MAN - DUEKOUE

BORROW PIT No. 6

STUDY DUEKOUE YABAYO 1 PHASE

Grading envelope

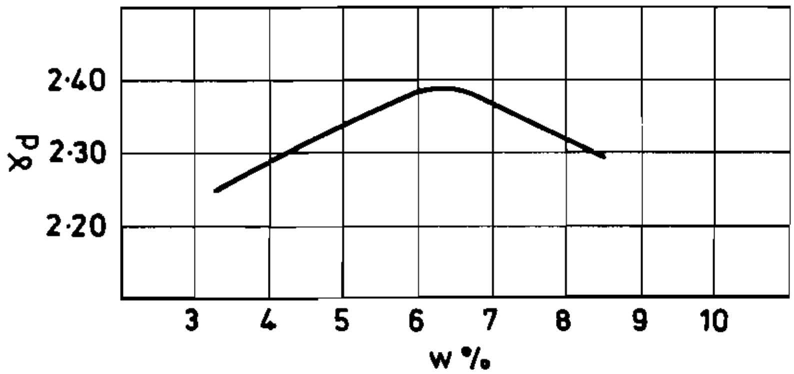


Identification

No	20	10	4	2	1	0·4	0·16	0·08	W_L	IP
1	96	79	41	31	28	25	19	12	36	17
4	98	85	39	30	26	23	13	10	21	9
7	99	90	60	49	45	30	26	20	28	12
12	93	72	31	24	22	20	12	8	25	13
14	99	86	35	28	24	21	16	10	30	13
*	99	88	48	36	32	29	20	13	31	17

* Analysis of mixed sample

Modified proctor test



γ_d Optimum = 2·40
w Optimum = 6 %

□ 55 Blows
△ 35 Blows
○ 10 Blows
□ Before soaking
■ After soaking

Variation of γ_d and CBR as a function of the compactive energy for a moulding moisture content equal to optimum 3% cement

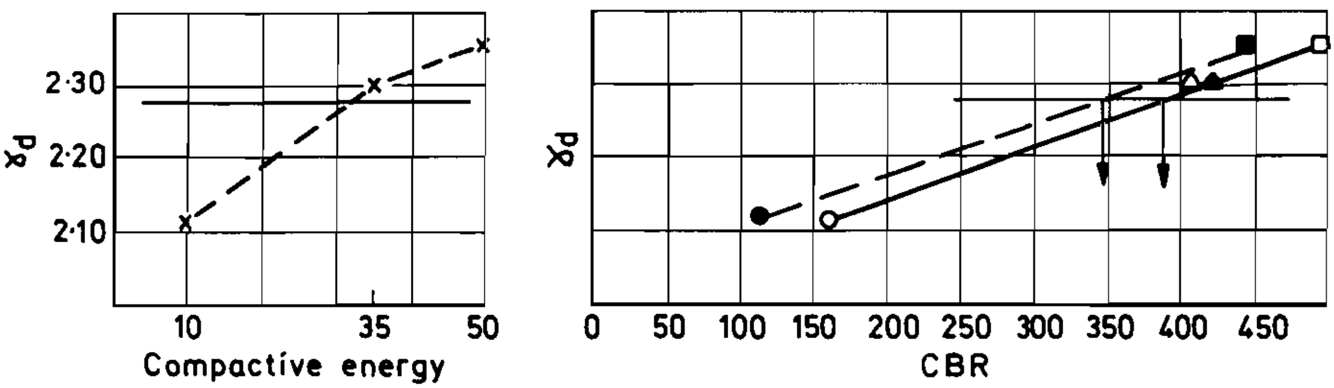
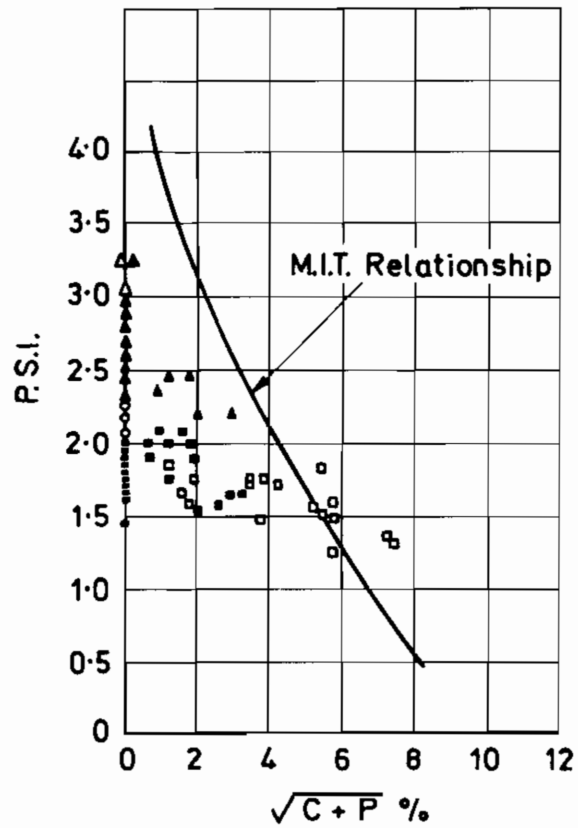
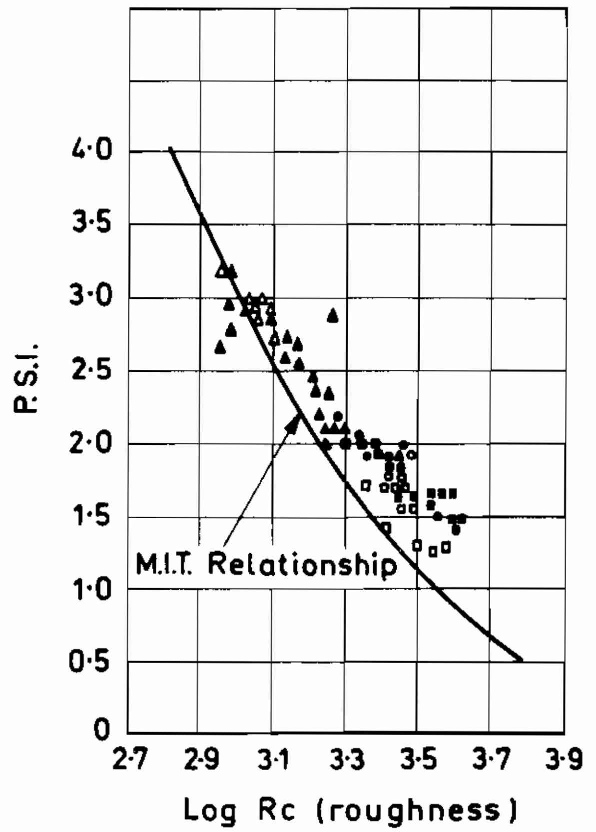


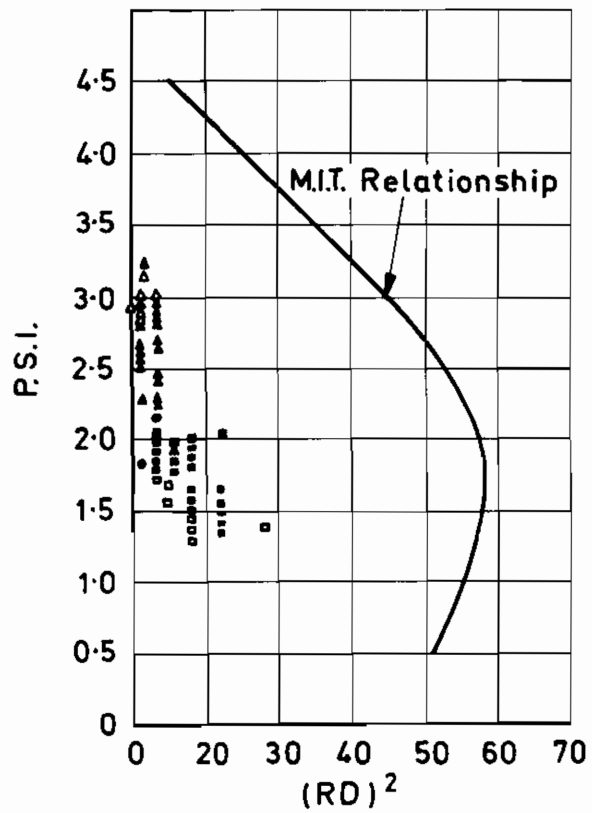
Fig. 3. RESULTS OF LABORATORY TESTS ON A SAMPLE OF G_1-G_2 MATERIAL





These 3 graphs show the relationships obtained in Kenya between the present serviceability index and

- Patching and cracking $\sqrt{C+P}$ %
- Rut depth $(RD)^2$
- Roughness log Rc



Pavements with surface dressing

- ■ Old dressing, high rainfall
- □ Old dressing, low rainfall
- ● Recent dressing, high rainfall
- ○ Recent dressing, low rainfall

Pavements with bituminous carpets

- ▲ High rainfall
- △ Low rainfall

Fig. 4. RELATIONS BETWEEN PRESENT SERVICEABILITY INDEX AND CRACKING, RUT DEPTH AND ROUGHNESS FOR VARIOUS SURFACES

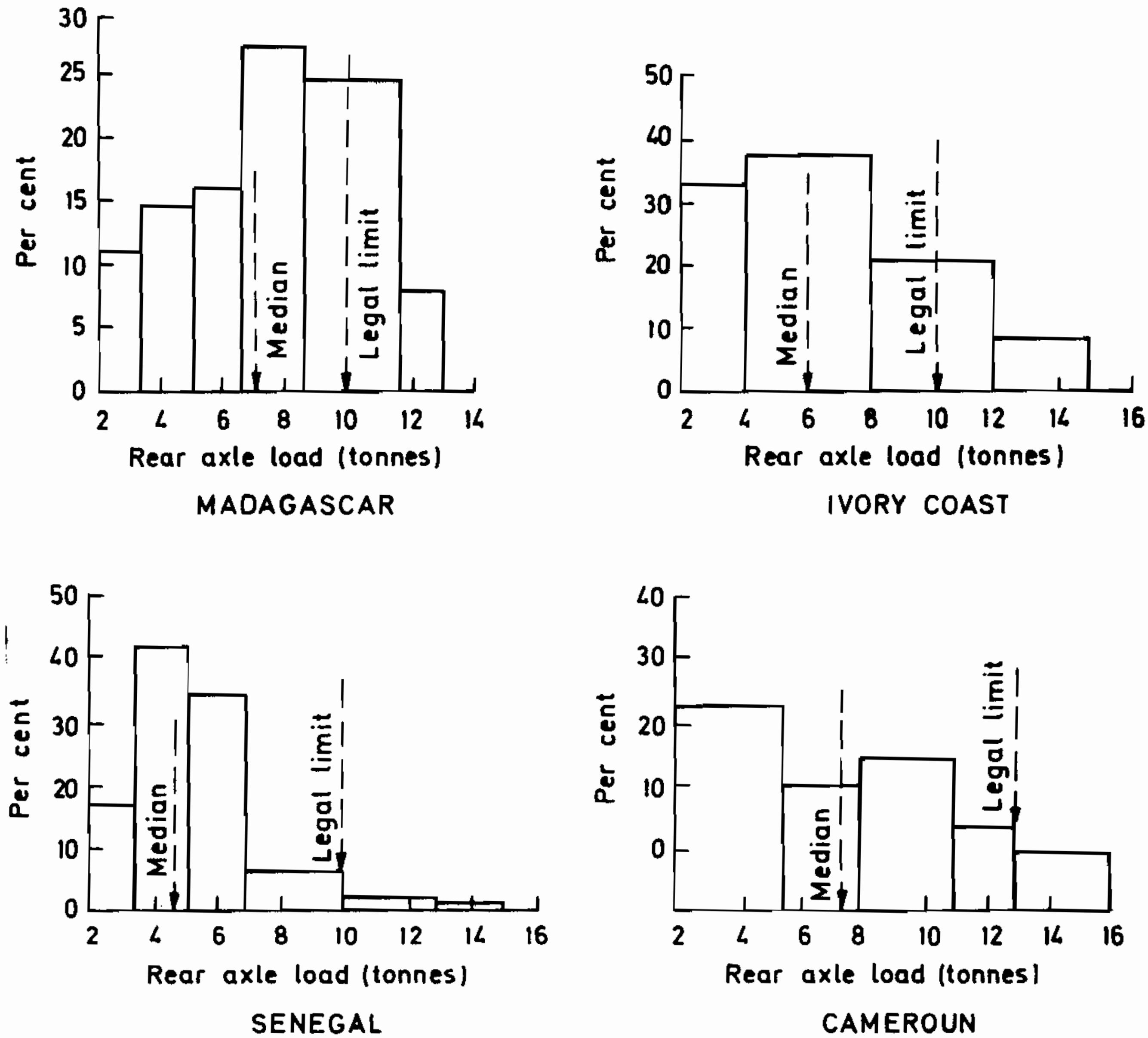


Fig. 5 TRAFFIC SPECTRA IN FOUR AFRICAN COUNTRIES IN 1970

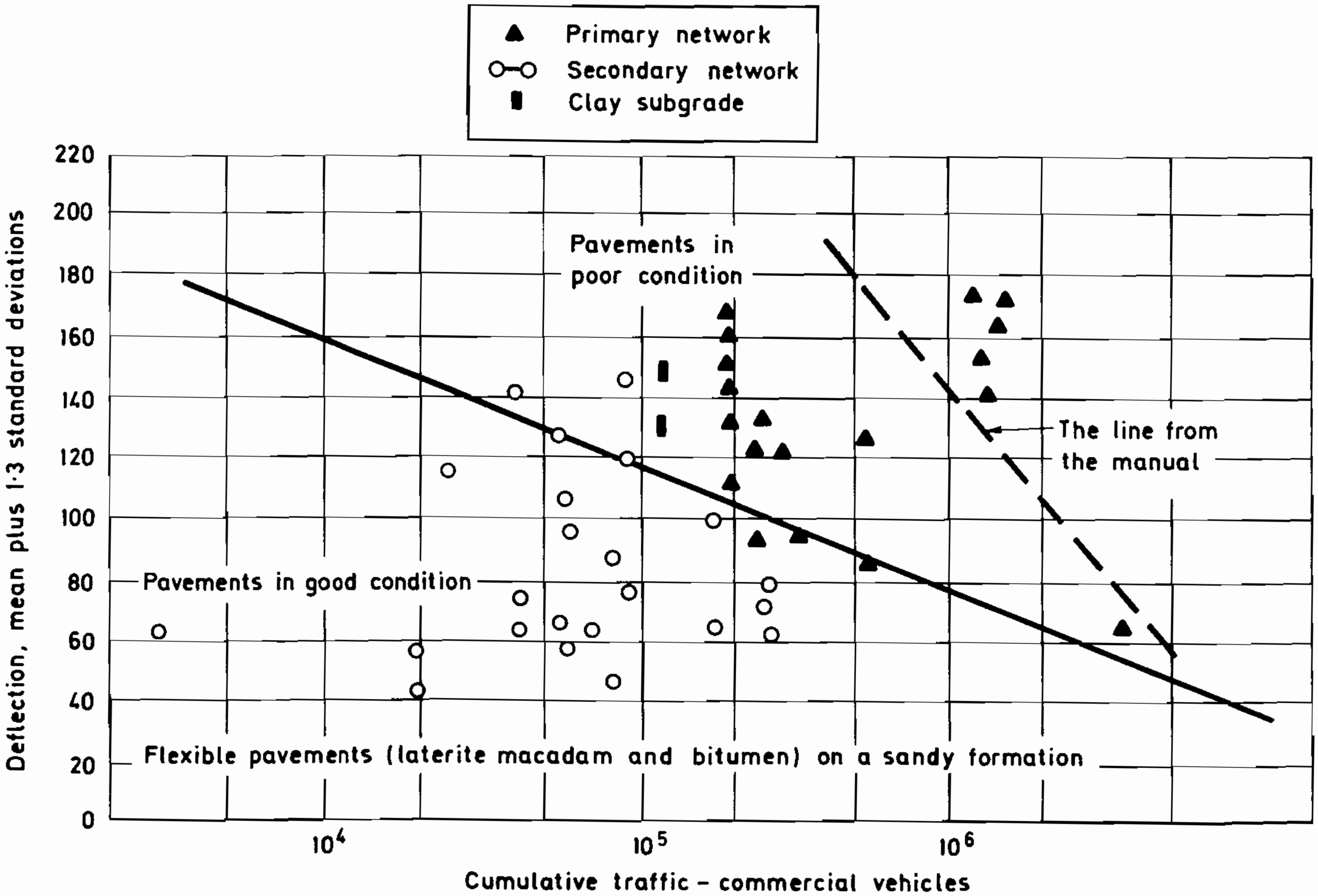


Fig.6 RELATION BETWEEN PAVEMENT CONDITION AND DEFLECTION OBTAINED IN VARIOUS AFRICAN COUNTRIES

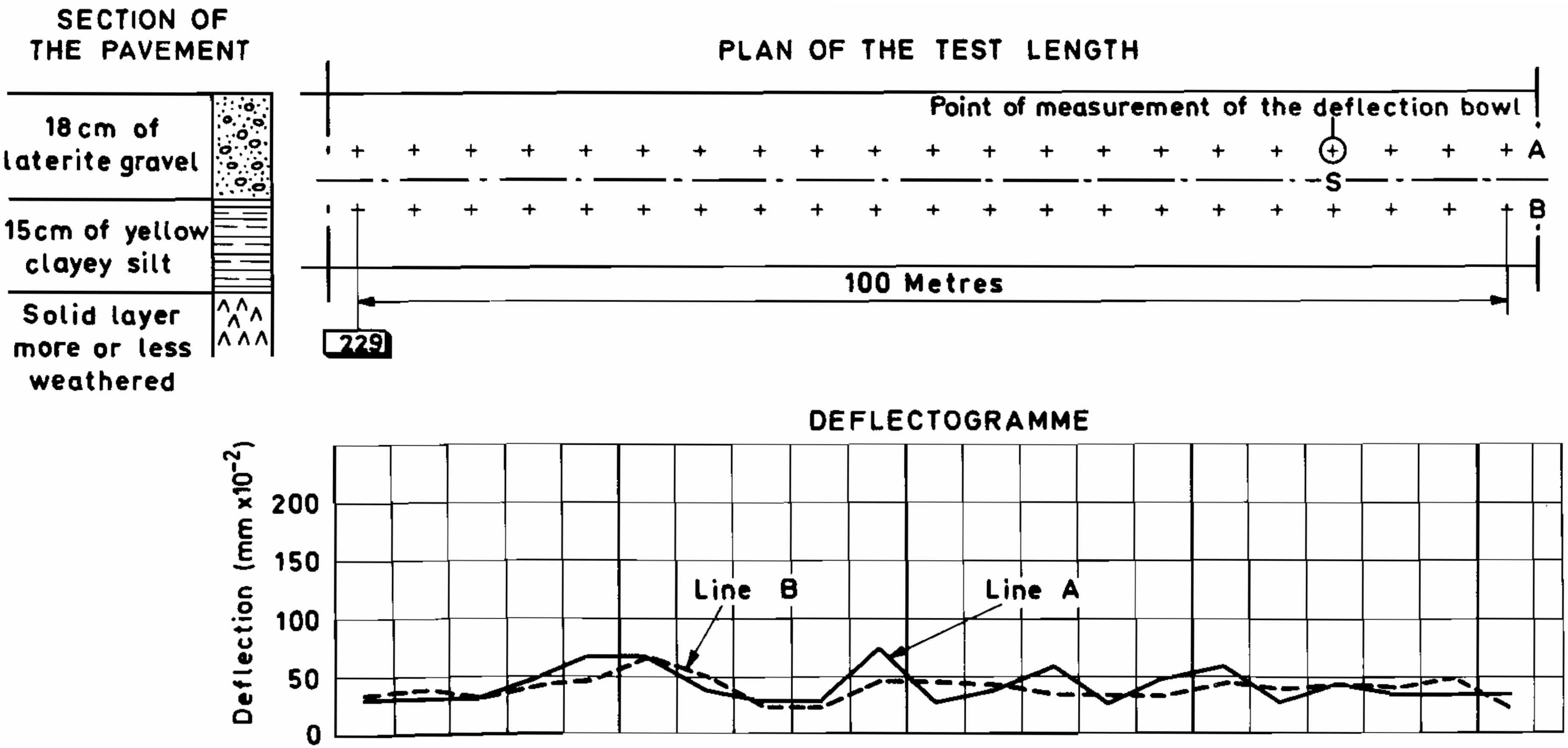
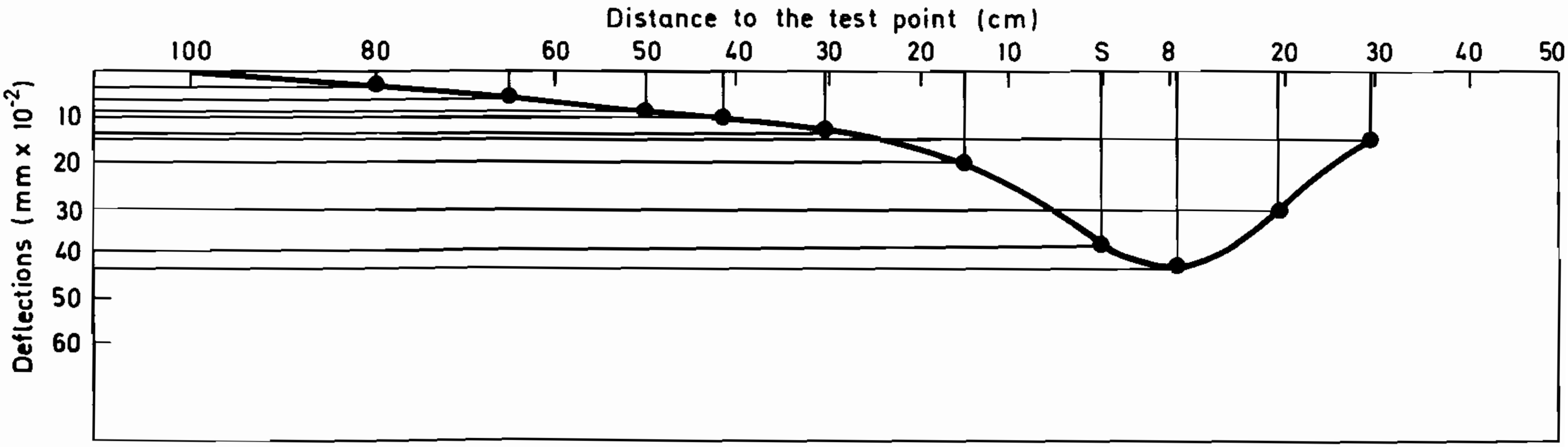


Fig. 7. DEFLECTION SURVEY ON THE DIMBOKAO - BOCANDA - DUELLE ROAD, APRIL 1970 (DRY SEASON)



Product R x d = 2100 with R = 50 metres

Fig. 8 RESULTS OF THE DEFLECTION BOWL STUDY

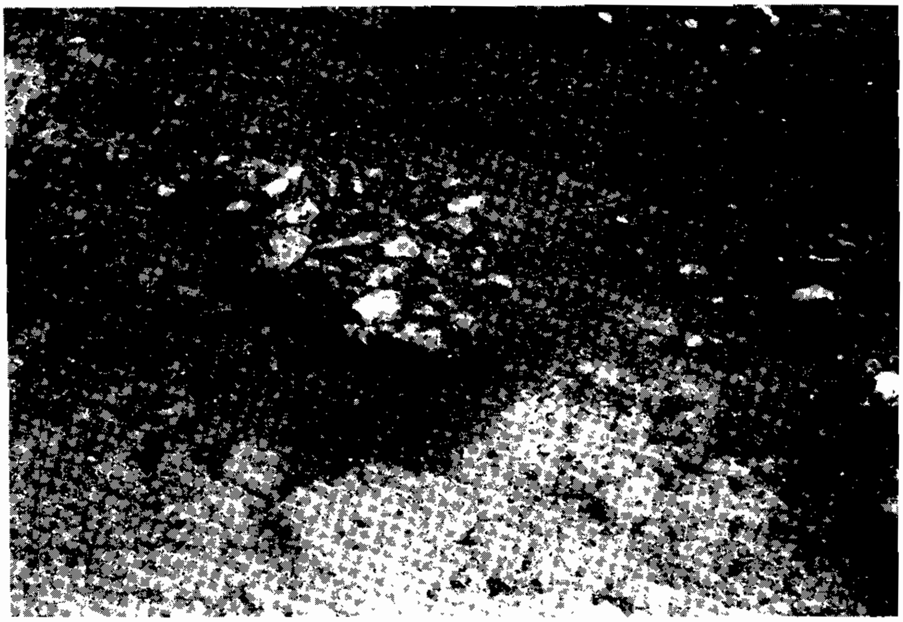


Plate 1 LATERITIC GRAVEL ROAD WITH EXCESS FINES: SURFACE IN THE DRY SEASON

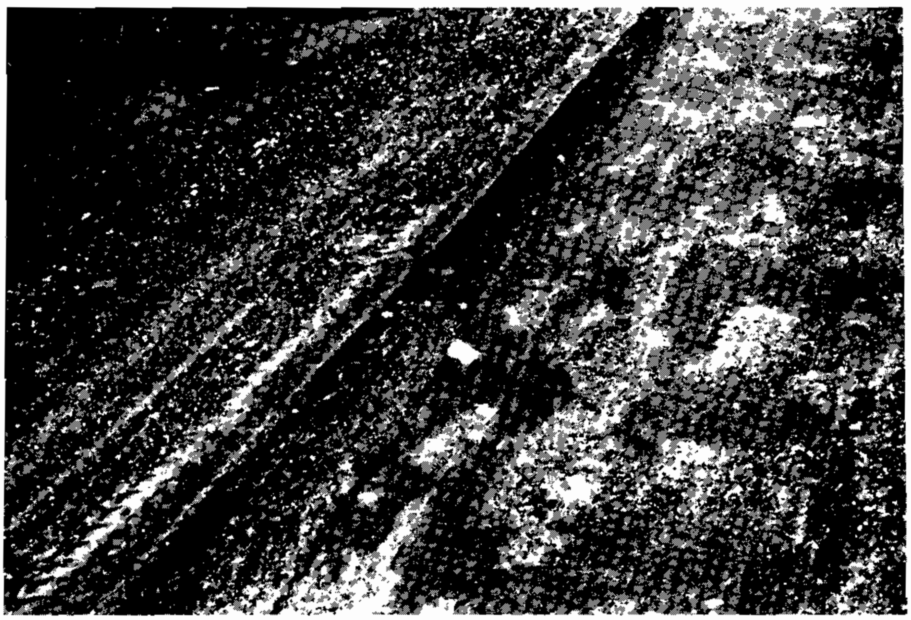


Plate 2 LATERITIC GRAVEL ROAD WITH EXCESS FINES: SURFACE AFTER A DOWNPOUR IN THE RAINY SEASON

Plate 3 THE SURFACE CONDITION OF A CATEGORY A ROAD (9m WIDE) AFTER RESHAPING

Plate 4 ROAD FIFTEEN YEARS OLD WITH A SAND ASPHALT CARPET

Plate 5 FORMATION OF CORRUGATIONS ON AN UNPAVED CATEGORY A ROAD (APPROACH ROAD TO MAN IN THE IVORY COAST)