Appropriate technology for the design and construction of low-cost unsurfaced roads in developing countries

Une technologie appropriée pour le projet et la construction de routes non revêtues à bas côut dans les pays en voie de développement

T.C.PARTRIDGE, Department of Geology, University of the Witwatersrand, Johannesburg, South Africa
A.B.WILLIAMS, Division of Building Technology, CSIR, Pretoria, South Africa
A.B.A.BRINK, Watermeyer, Legge, Piesold and Uhlmann, Rivonia, South Africa

ABSTRACT
Roads continue to play a fundamental role in the development of most Third World countries, but the establishment of road networks using imported First World design philosophies and construction methods has led to an undue emphasis on high-cost, surfaced roads built using mechanised methods.

Such an approach results in unjustifiable costs, both of initial construction and of maintenance, and is seldom appropriate either to local traffic requirements or to the widespread need for labour-intensive construction projects in underemployed communities.

Under these circumstances the emphasis should be placed on unsurfaced roads built to standards which enable the maximum use to be made of local resources of labour and materials. Experience has shown that such a shift in emphasis must necessarily involve fundamental changes in design philosophy and contractual procedures, as well as a re-evaluation of appropriate vehicle technology.

Four categories of unsurfaced rural road are proposed for use in the planning of infrastructure in developing countries. Design standards appropriate to the use of labour-intensive construction methods are suggested for each, and simple, cost-effective methods are proposed as an aid to route location and the evaluation of in situ soils and construction materials.

1 INTRODUCTION

Of primary importance for the economic advancement of developing communities is the provision of a transportational network. Roads are invariably the major component of this infrastructure; they have in fact played a catalytic role in the development of many isolated rural communities in the Third World.

It is the view of the authors that, in the planning of road networks in many under-developed countries, undue emphasis has been placed on bitumen - surfaced roads. Not only are such roads inappropriate to the needs of most rural communities, with their limited vehicle resources, but, unless built to high standards at commensurately high cost, they are subject to formation failure and potholing, especially where heavy traffic has increased more rapidly than expected. Under these circumstances their utility may be so severely impaired that they become inferior in standard and function to the better class of unsurfaced road.

Maintenance and rehabilitation of failed surfaced roads are both time-consuming and expensive and have become an insupportable burden to many Third World countries. Several authors have pointed to the serious financial implications of importing the requisite capital, technology, plant, fuel and surfacing materials, as well as difficulties in supplying skilled operators and maintenance for the construction plant, as some of the more serious problems associated with the construction and upkeep of First World roads in Third World environments.

Earth or gravel roads are easier and cheaper to construct and maintain using appropriate technology and labour-intensive methods. If properly maintained, the increase in vehicle operating costs (VOC) over those for paved roads is negligible; by comparison the VOC for poor surfaced roads may be up to 33 per cent higher (Roberts, 1981).

Appropriate technology has frequently been construed as an alternative labour-intensive technology which may serve as a panacea for problems of unemployment. While it is clearly desirable that work opportunities be provided in underemployed communities, as Edmonds (1981) has pointed out:

"Appropriate technology is not an alternative, it is purely and simply the technology that the developing countries can afford to use given their level of development, their resource endowments and, presumably, their commitment to provide economic and social growth which benefits all members of society".

Experience in Asia, Africa and South and Central America has shown that some of the most successful applications of appropriate technology have been in the construction, and more especially the maintenance, of rural roads (Green and Clapham, 1981). That appropriate methods of road construction have not achieved the widespread acceptance which they merit is, in our view, due largely to the fact that an overwhelming emphasis has been placed on labour-intensive methods without concomitant adaptation of design philosophy and standards and the formulation of new contractual procedures. All of these changes must be introduced simultaneously if the full benefit of basic infrastructure development, the more effective deployment of limited funds and the creation of new jobs is to be realised. A further obstacle is the perception common to many bureaucrats and First World engineers that labour-based methods are slow, costly and insusceptible to proper quality control.

It is now widely accepted that labour-intensive methods are viable for a broad range of construction activities provided that wage levels are appropriate and that due attention is given to organisation and training, and the provision of efficient hand-tools. Care must also be taken to ensure the most effective mix of technologies, especially in the construction of higher-standard rural roads where at least some sophisticated construction plant will be necessary to achieve the required performance.

Finally, it is illogical to apply appropriate technology to the full spectrum of road design and construction without at the same time considering appropriate vehicle technology: the benefits of heavy transport vehicles, often imported at great cost, are at best questionable in contexts where a high standard of construction is not warranted for other reasons.

2 BASIC PHILOSOPHY

The construction of low-cost unsurfaced roads can be viewed as involving modification of the local geology with a minimum of translocation of materials. The degree of modification will obviously increase as design standards are raised.

According to the International Bank for Reconstruction and Development (IBRD, 1971) it it technically feasible to substitute labour for equipment in all but 10 to 20 per cent of cost items in the construction of higher-quality roads, and this can be reduced to 5 or 6 per cent if standards are reduced to an intermediate level. We believe that, in the cases of our classes 3 and 4 of unsurfaced roads (Table 1), the need for equipment other than rudimentary animal-drawn transportation and basic hand-tools can be eliminated entirely. We have stressed, however, the benefits of such labour substitution can be maximised only if appropriate design philosophy and construction methods are applied. It is vitally important also that wages are set at the appropriate level. Sund et al (1976) concluded that labour-intensive methods were unlikely to be economically justifiable at base rates above US $2 per day; this was revised to US $4 in 1982 and would be approximately US $8 in 1988. Experience in Kenya and Botswana has shown that average working days per kilometre range from about 1500 to 2600 (McCutcheon, 1988); in the mountainous terrain of Lesotho, the time input may exceed 5000 person days per kilometre (Green and Clapham, 1981). In the construction of lower-standard gravel roads wages have been found to constitute about 60 per cent of the total cost; this rises to 80 per cent in road maintenance programmes (McCutcheon, 1988). In countries with high minimum rates labour-intensive methods sometimes compare unfavourably with mechanised methods even for low-standard rural roads. If such countries are beset also by high levels of unemployment it may be necessary to use adjusted or "shadow" prices to permit a proper evaluation of cost benefits and to provide jobs. McCutcheon and Stephenson (1988) argue for the introduction of an "inducement" tendering system in which the labour "shadow-value" is deducted from each tender, thereby favouring contractors using labour-intensive methods.

Equally important are the social and organisational aspects of labour. In Asia where there is a long tradition of labour-intensive construction, problems relating to the organisation of labour are minimal. This is not the case in Africa and South America where such considerations as the sexual division of labour in relation to the agricultural cycle and local social customs need to be taken into account. The advice of social anthropologists should be sought here in the first instance. Organisational considerations must include as a high priority formal training in various construction tasks. This vital component, which must necessarily involve the appointment of an experienced training officer, can be provided at approximately one per cent of the total project cost (McCutcheon, 1988).

The success of any rural road programme for under-developed communities will depend largely on the extent to which the community is actively involved in all aspects of the programme. Consultation must necessarily include route-location (so as to serve the best interests of the majority of the local population), information on sources of possible construction materials, labour conscription, available transportation (such as animal-drawn carts and small trucks) and maintenance strategies.

All of the foregoing considerations involve a radical departure from the engineering procedures practised in the First World; in particular there is an urgent need for the system of tender guarantees, performance bonds, deferred payments etc, to be modified in such a way as to encourage the development of local contracting resources. A strong case can, in fact, be made for the establishment of "labour only" sub-contractors (McCutcheon and Stephenson, 1988).

Finally, the appropriate hand-tools and transportation equipment for labour-intensive construction in different local settings must be considered. For example a hoe has been found to be much superior to picks and shovels for certain activities; and headbaskets, wheel-barrows and animal-drawn carts can be used for transporting materials over distances varying from 100m to 2,5km (Barwill & Howe, 1980; McCutcheon, 1983). It is important to ensure that such basic tools are easily procured and of correct design if productivity is to be maximised. In labour-intensive methods balance between cut and fill is best achieved laterally (i.e. from alongside the road) rather than longitudinally as is the case with mechanised construction (Green and Clapham, 1981). Where mechanised and labour-intensive methods are used in combination, as is usually the case in Class 1 and 2 roads (Table 1), care is necessary in scheduling the different activities.

3 SUGGESTED CATEGORIES OF UNSURFACED RURAL ROAD

Mindful of the foregoing constraints, we propose four categories of unsurfaced rural road for infrastructure planning in developing countries.

Each category is distinguished on the basis of traffic type, traffic level (for which reliable statistics or projections are frequently unavailable in developing areas), and minimum design speed (in favourable terrain). Where traffic data are unavailable, predictions should be based on regional models of potential land use and economic development (Mainwaring and Hasluck, 1988).

Class 1: Rural link roads for district and inter-district traffic, with vehicle counts of up to 300 per day. Design speed 80km per hour.

Class 2: All-weather district roads carrying a preponderance of local traffic, with vehicle counts of up to 150 per day. Design speed 60 km per hour.

Class 3: Most-weather minor roads carrying a preponderance of agricultural vehicles, e.g. tractors, trailers and light trucks, with vehicle counts of less than 50 per day. In some previously inaccessible rural areas these roads may serve also as low-cost link-roads. Design speed 20 to 30km per hour.

Class 4: Roads purely for human- and animal-propelled vehicles. Design speed up to 10km per hour.

In all these classes emphasis is placed on good drainage. This is particularly important where clayey subgrades are present or clayey construction materials are being used, since these lose strength rapidly on wetting. Where fills of any size are used in Class 1 and 2 roads good under-drainage is mandatory; this also applies in cuts through rock or other impermeable materials and in areas of previous or potential slope instability.

Catchwater and mitre drains are essential to forestall erosion in cuts through unconsolidated material and to limit infiltration in the vicinity of steep or potentially unstable slopes. Because they are effective, labour-intensive and cheap, the use of gabions and rock-pitching is advocated wherever small-scale lateral support and protection against erosion is required. Where the use of concrete is unavoidable (e.g. in Class 1 and 2 roads), savings can be effected through the use of natural aggregates, such as hand-picked river gravels; the incorporation of plums (large rocks) and masonry will help to minimise inputs of cement (Mainwaring and Hasluck, 1988).

Except in subdued terrain some longitudinal earthworks will be required in Class 1 and 2 roads to meet minimum geometric standards.

Suggested standards for the four road classes described above are given in Table 1. In the case of Classes 3 and 4 "design" is undertaken on-site and usually goes hand in hand with construction. A small number of activities, relating chiefly to geometrics and the detailing of river crossings, may precede field activities for Classes 1 and 2. The latter involve staking and on-the-spot construction decisions by an experienced supervising engineer or site foreman. No testing is specified for Class 4 roads and the emphasis for Classes 1-3 is on simple tests carried out in the field. At least some grading analyses are required and, as a bare minimum, the 26.5mm, 5.0mm, 2.0mm, 0.425mm and 0.075mm sieves should be used. For purposes of correlation, both between material occurrences and as a guide to basic strength and compaction properties, the use of the Unified Soil Classification system is desirable (Brink et al 1982). This system requires the determination of Atterberg Limits in addition to grading down to the 0.075mm particle size. Simplified procedures for determining the plasticity index by means of correlation with a Sundried Linear Shrinkage test from the Field Moisture Equivalent (carried out on the wet-sieved -0.425mm fraction) have been suggested by Netterberg and Paige-Green (1988). For the grading of sandy materials dry sieving is usually adequate, but particle aggregates in most clayey soils are best broken down in water using sodium hexametaphosphate (Calgon) as a dispersing agent; the sand fractions above 0.075mm are then determined by wet sieving.

In the case of gravel for Class 1 and 2 roads moisture/density relationships must be determined as a basis for compaction control (using volumetric or nuclear methods, or a Dropweight Cone Penetrometer).

Labour-intensive construction methods have been discussed in several texts (e.g. Green and Clapham, 1981; Barwill and Howe, 1980; McCutcheon, 1983). Important is the elimination of oversize (>26,5mm) since large gravel- and cobble-sized fragments contribute more than any other factor to roughness and hence increased vehicle operating costs as well as to accelerated deterioration of the riding surface. This can be done by hand-picking after spreading, through the use of screens, or by means of additional processing either by sledgehammer crushing or, where intermediate technology is available, using a simple tractor-towed crusher which feeds directly onto the road bed. It has not proved worthwhile to undertake compaction of the surfacing material by hand-tamping: better results are achieved through the passage of construction transport (whether human beings, animal carts or wheel-barrows), or of traffic. In Class 1 and 2 roads, however, mechanised compaction using various types of roller and rubber-typed equipment is mandatory. Where active, compressible or waterlogged subgrades are present it may be necessary to place and compact selected fill material, usually to a thickness of no more than 800mm, before laying the gravel.

The maintenance of Class 3 and 4 roads is most effectively undertaken by manual means, and a fair proportion of routine upkeep of Class 1 and 2 roads (e.g. patch-gravelling and drain-clearing) may also be carried out by hand. But in order to maintain the riding surface of Classes 1 and 2 in a condition to permit the design speed to be maintained without undue vehicle deterioration, regular maintenance by mechanical grader is essential.

4 ROUTE LOCATION AND MATERIALS SURVEYS

The importance of consultation with local communities in the planning of road networks to meet both local and regional needs has already been stressed. Such consultation must inevitably influence the overall route; the final alignment will be decided, chiefly in the field, in the light of basic geometric requirements for the desired class, the need to keep earthworks and stream crossings to a minimum, and the presence of problematical soils and geological conditions which are best avoided. Under exceptional circumstances, where good natural gravels are rare, the alignment may be modified to minimise haulage from available sources.

Basic materials specifications for Class 1 - 3 roads are given in Table 1. In all of these categories the location of suitable materials (sand for admixture with clayey earth riding surfaces, or imported gravels) is of vital importance, as is the identification of problematical subgrade conditions. If surveys for both purposes are to be undertaken rationally but at low cost, some form of land classification system must be used. The Land System/Land Facet approach is ideally suited to this purpose (Brink et al, 1982). These authors also describe procedures for terrain classification and the preparation of soil engineering maps for the planning and design of roads making use of airphoto-interpretation. The preparation of such detailed maps is not justified for unpaved rural roads. More appropriate is an initial classification of the terrain which incorporates sufficient field checking to identify those Land Facets (or Facet Variants) which may serve as sand or gravel sources, as well as those which contain problem materials (i.e. active clays, highly compressible materials, seasonally or permanently waterlogged soils, solid rock outcrops or soils with a collapsible fabric) and those which bear signs of previous slope instability. On the basis of this classification a rudimentary map may be prepared, ideally on an airphoto mosaic, showing only these significant facets or variants. In order to ensure that maximum information is obtained for the minimum outlay it is essential that such mapping is carried out by experienced personnel. The cost of such mapping for a new alignment will normally not exceed 1 per cent of the total construction cost, and the cost where used for rehabilitation and maintenance of an existing road will generally not exceed US $20 per kilometre.

Sources of construction material should ideally be located as close as possible to the route at intervals of one or two kilometres. Every attempt should be made to use locally available materials which do not require blending or chemical stabilisation as these are both costly and difficult to control. However, where such materials as active clays are uniformly present over long distances there may be no alternative to the application of such measures. Where sand-blending is used for this purpose, the most effective procedure is to spread the sand on the clay surface and then to hoe it in.

Special emphasis is placed on the investigation of river crossings in view of their susceptibility to flood damage. As Mainwaring and Hasluck (1988) point out, submerged crossings should be placed on rock or stable material. In some cases it may be necessary to remove alluvial sediments prior to placing protective stone or concrete. The probing of such unconsolidated materials is easily and cheaply carried out by hammering in a steel rod, or preferably, using a portable Dropweight Cone Penetrometer (DCP). The use of this instrument has been described by Brink et al, (1982) and is recommended also for assessing the properties of problematical subgrade soils in the field and for calibrating the strength of compacted gravel layers.

5 CONCLUSIONS

The vital need to stimulate development of rural communities in areas lacking infrastructure and employment opportunities demands that roads be built rapidly and at low cost, making maximum use of local resources. This cannot be achieved if authorities persist in applying First World philosophies and standards. The time has now come to apply First World expertise in devising new approaches which harness local resources to serve the best interests of underdeveloped communities at affordable cost.

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TABLE 1 : SUGGESTED STANDARDS FOR UNSURFACED RURAL ROADS

	CLASS 1 80kph (two-way traffic flow)	CLASS 2 60kph (two-way traffic flow)	CLASS 3 20-30kph (one-way traffic flow)	CLASS 4 <10kph (one-way traffic flow)
Width of bush clearing	20.0m	15.0m	10.0m	5.0m
Width of formation	10.0m	7.0m	5.0m (20m length widened to 7.0m every 500m for passing)	NA
Width of riding surface	10.0m	7.0m	4.0m	NA
Camber on riding surface	3.0%	4.0%	10.0%	NA
Drainage	Lateral drains 0.5m deep, 2.5m wide, 1:1.5 side-slopes (except where fill exceeds 0.5m). Minimum gradient 0.5%; stone-pitched where gradient >6%	Lateral drains 0.5m deep, 0.5m wide, 1:1.5 side-slopes. Minimum gradient 0.5%; stone-pitched where >6%	Lateral drains 0.5m deep, 0.5m wide, 1:1.5 side-slopes Minimum gradient 0.5%; stone-pitched where >6%	Shallow oblique channels every 100m to prevent erosion of road bed where gradient >6%
Minimum radius of horizontal curvature	300.0m (minimum 100.0m in rugged terrain)	150m (minimum 50m in rugged terrain)	40.0m (minimum 10.0m in rugged terrain)	5.0m
Maximum gradient	8%	8% (10% in rugged terrain)	Earth surfacing : 10%, Gravel surfacing* : 12% (if steeper cobble-stones can be used)	5%
Thickness of gravel layer	200mm	150mm	100mm where stabilised material or gravel must be used	Gravel placed only where water-logging or quagmiring likely to occur
Stream crossings	Concrete culverts/bridges	Pipe culverts or concrete causeways (with or without underpipes), extended to withstand erosion of 1:50 year flood	Selected packed stone (cemented where possible)	Selected packed stone (100mm maximum size)
MATERIAL SPECIFICATIONS FOR GRAVEL LAYER: Maximum particle size	26.5mm	26.5mm	26.5mm where gravel placed	26.5mm where gravel placed
Minimum grading modulus‡	1.5	1.5	1.3 where gravel placed	NA
Plasticity index (if too high must be reduced by adding sand or, rarely, lime)	6-20 (6-14 in humid# areas)	6-20 (6-14 in humid# areas)	Earth surfacing : arid/semi-arid areas : 6 - 14 Humid# areas : 6 - 10 Gravel surfacing : 6 - 20	NA
Compaction	Minimum 93% Mod.AASHTO by roller	Minimum 93% Mod.AASHTO by roller	Not specified; by construction and vehicular traffic	NA

* Used only where vehicle count >25 per day

‡ The grading modulus (GM) is given by:

$$GM = \frac{P_{2.00mm} + P_{0.425mm} + P_{0.075mm}}{100}$$

Where $P_{2.00mm}$ etc denotes the percentage retained on the indicated sieve size.

\# Well distributed rainfall >600mm; seasonal rainfall >750mm.