Rehabilitation and Upgrading Design of Earth and Gravel Roads in Tropical Developing Countries

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The earth road construction standard that is required for a given traffic volume appears to be a function of the terrain morphology and type of soil. Instead of a formal application of a priori concepts, site investigation of natural conditions and road performance should be a sound basis for design of good-quality and cost-effective rehabilitation and upgrading of earth and gravel roads. An appropriate design methodology based on comprehensive field investigations was developed for road rehabilitation schemes in Madagascar and tested in contract works in that country, and also in Zaire. The methodology proved to save money and time, and rather than resulting in poor design, capturing conditions and resolving design problems in the field may improve the design quality.The methodology comprises three phases. The first phase is the comprehensive inventory and detailed condition survey, the second phase is field design, and the third phase is complementary office design and estimation of quantities. The accuracy of quantity estimates derived from this simplified design methodology appears to be satisfactory for contract rehabilitation works.

The rehabilitation and upgrading of a road presupposes an existing road constructed to certain standards and requiring repair works (rehabilitation) following traffic- and climate-induced deterioration, as well as some improvement of design standards (upgrading) to cope with increasing traffic demands.

Unsurfaced roads show a wide range of construction standards. If the road formation or pavement is considered, the following five design standards or construction stages can be defined:

Standard 0, track beaten by animals and carts;
Standard 1, dust road or track opened and used by motor vehicles;
Standard 2, earth road constructed by labor intensive methods or by scraping with a motor grader;
Standard 3, earth road with supply of selected soils to form a wearing course; and
Standard 4, earth or gravel road with wearing and base courses forming a specific pavement.

At construction Stage 2, clayey pavements will not withstand traffic loads during the rainy seasons. In order to avoid damage to the road pavement, traffic restriction during and after rain is usually recommended but experience has shown that rain gates are often ineffective for social or cultural reasons. Clayey pavement sections should preferably be upgraded to Stage 3.

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Roads constructed to Standard 2 follow land forms with small-radius curves and steep gradients on hills and mountains. Ground undulations and pavement roughness usually do not allow for high speeds, and the average driving speed is normally low in the range of 20 to 50 km/hr.

At Standard 3, improvements to the road alignment such as embankments on swampy stretches and in places liable to flooding are considered. The average driving speed may range from 40 to 60 km/hr.

For Standard 4, upper gradient and lower radius limits are usually imposed and the road width should preferably be designed for two lanes. The average driving speed may range from 50 to 70 km/hr or more.

Mellier (*1*) suggests that earth roads be upgraded to Standards 2, 3, and 4, respectively, for the following traffic levels: up to 25, up to 50, and up to 200 vehicles (vpd).

Considering drainage and water-crossing would result in some different construction stages, but drainage and water-crossing construction standards can also be correlated with the pavement construction standards.

Water-crossing structures are nonexistent or exceptional for Stages 0 and 1; rivers and streams are forded where and when possible. At Stage 2, crossings are usually timber structures of ferryboats, and later, masonry, concrete, and metal bridges. Drainage structures are progressively constructed between Stages 2 and 4 to avoid road closure and damage by run-off.

Pavement surface drainage (longitudinal and diversion ditches, diversion banks, and thresholds) should be contemplated as early as Stage 2, to control erosion by run-off and avoid fast deterioration of the pavement surface. Most roads constructed or upgraded to Standard 2, and even to Standards 3 or 4 without proper control of run-off, appear to have reverted to lower standards after a few rainy seasons or even a single storm.

Subdrainage and slope stability problems require investigation by qualified professionals and the corresponding works are usually contemplated in late stages.

Most often in practice, in tropical developing countries, a single road is composed of different stretches constructed to different standards. Discontinuous construction actually appears to be well adapted to low-volume earth roads.

Typical tropical soils often show exceptionally good performance under traffic. If a road stretch on a lateritic plateau is carrying traffic without distortion and with slight wear (Figure 1), this stretch can be maintained at Stage 1, while other stretches will have to be upgraded to Standards 2, 3, or even 4, for comparable serviceability.

FIGURE 1 A section of the road Lai to Doba, Southern Chad: the pavement material is undisturbed ferruginous soil and the traffic comprises heavy vehicles for collection of cotton crops and transport of miscellaneous goods. A sample of pavement soil was classified as low-plasticity clay, CL, after laboratory testing and exhibited a soaked CBR of 40 percent at 95 percent modified compaction.

Thus, for instance, in contrast to a road on a lateritic plateau, a road on a swampy, clayey depression will have to be constructed to Standards 3 or 4 even before it can be used by traffic.

Thus, the construction standard that is required for a given traffic level appears to be a function of the terrain morphology and the type of soil. Site investigation of natural conditions and road performance, rather than formal application of a priori concepts should be a sound basis for effective rehabilitation and upgrading design of low-volume earth and gravel roads.

APPROPRIATE DESIGN METHODOLOGY

A design methodology based on comprehensive field investigation of the existing roads was developed in Madagascar (2) for application to earth road rehabilitation schemes that were undertaken on force account by the Ministry of Works maintenance gangs under the leadership of specially trained young engineers and technicians. The resulting evaluation of quantities and scheduling of works proved to be accurate and realistic enough for the methodology to be extended to rehabilitation works by contract (Jean Carbonnel, 1987 to 1989, unpublished data on the rehabilitation of 600-km earth roads in southeastern Madagascar).

The methodology was further improved and applied to road projects in other tropical countries, namely the rehabilitation and upgrading design of the road from Kinkondja to Malemba Nkulu, Mwanza Seya, and Musao, a 160-km earth road in Central Shaba, Zaire. Contract works based on this design were afterwards funded by the U.S. Agency for International Development.

The rehabilitation and upgrading design of the road Kinkondja-Musao was completed in 3 months, including specifications and contract documents. It required 2 months of field investigations and 1 month of office work by a team composed of an expatriate engineer, a national soils and materials engineer, and a national survey engineer with some experience of earth roads maintenance. After this project, both national engineers were considered to be trained to carry out similar projects without the assistance of the expatriate engineer.

The equipment required for field work mainly comprised two four-wheel-drive vehicles, camping accessories, two decametric measuring chains, surveyor level, camera, sample bags, shovels, pick-axes, and crowbars. With the exception of drivers, all workers were hired in the field.

The design methodology comprised three phases. The first phase was the inventory and condition survey of the road, including the inventory of culverts and small structures, the inspection of bridges, and the inventory of soils and materials. The tasks comprised in this phase were carried out in the field, except for the testing of possible borrow soil samples that were shipped to a central laboratory in Lubumbashi. However, for large projects, a field laboratory can be contemplated.

The second phase is the design of the maintenance and rehabilitation works required for upgrading. This phase should also be carried out and completed in the field to allow for all necessary checking, collection of further information, and assessment of field conditions.

The third phase is the estimation of quantities after appropriate definition of pay items on the basis of the rehabilitation works resulting from the second phase. This phase is best carried out in the central office with the assistance of computers and technical files.

The rehabilitation and upgrading of the road Kinkondja-Musao was part of a rural development project. Before rehabilitation, this road only carried < 1 vpd. Rehabilitation and upgrading were intended to contribute to the development of commercialization of food crops in a potentially rich area with a relatively dense population.

For this and for most rural roads of developing countries, a conventional design methodology as practiced in developed countries would result in prohibitive costs, the order of magnitude of construction costs, incommensurate with the traffic level. Rather than a drastic decrease in length of road to be rehabilitated to afford the luxury of a conventional design, two options were left: either start the works without design, or apply an appropriate design methodology. The second option appears to have minimized risks and construction costs as well as global service life costs.

INVENTORY AND CONDITION SURVEY PHASE

The preliminary task of this phase is the staking out of the road. Stakes should be put along the road every 50 m to allow for easy location during the field investigations.

The detailed inventory of road features and structures and the condition rating of the pavement and appurtenant features should be made while walking along the road. Depending on terrain and road condition, 5 to 20 km of earth road can be surveyed during a working day walk.

The survey is made by filling a previously prepared form (Figure 2) at scale 1/10 000 (1 mm for 10 m).

In the first band of this form, the linear sketch shall comprise in graphic form all information about junctions, rivers, vil-

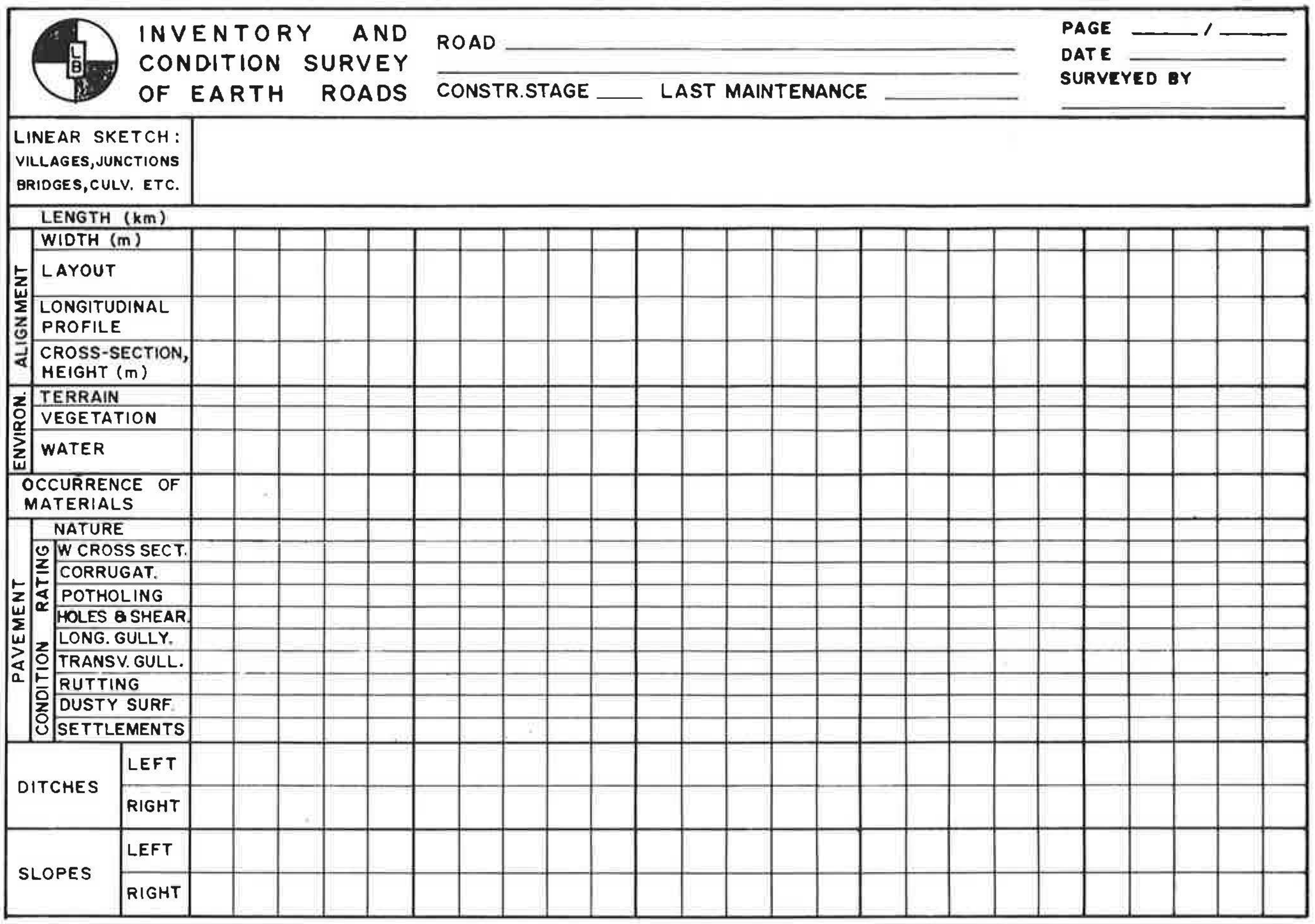
INVENTORY AND CONDITION SURVEY OF EARTH ROADS
ROAD
CONSTR.STAGE
LAST MAINTENANCE
PAGE /
DATE
SURVEYED BY
LINEAR SKETCH: VILLAGES, JUNCTIONS BRIDGES, CULV. ETC.
LENGTH (km)
ALIGNMENT: WIDTH (m); LAYOUT; LONGITUDINAL PROFILE; CROSS-SECTION, HEIGHT (m)
ENVIRON.: TERRAIN; VEGETATION; WATER
OCCURRENCE OF MATERIALS
PAVEMENT: NATURE
CONDITION RATING: W CROSS SECT.; CORRUGAT.; POTHOLING; HOLES & SHEAR; LONG. GULLY.; TRANSV. GULL.; RUTTING; DUSTY SURF.; SETTLEMENTS
DITCHES: LEFT; RIGHT
SLOPES: LEFT; RIGHT

FIGURE 2 Inventory and condition survey form.

lages, as well as numbered symbols indicating the location of drainage structures and water crossings. The former are listed and inventoried with more detail in a separate form (Figure 3), whereas the latter are the subject of special reports after inspection (*3*).

The chainage is inscribed in the second line, and under this line, the form comprises five horizontal sections: road alignment, environment, pavement (type and condition rating), ditches, and slopes.

The first section receives all information relative to width, layout, longitudinal profile, and cross sections collected and estimated without the help of survey instruments. For accurate estimation of earth works, some particular sections, such as important embankments, and additional cuts or rock excavations are separately surveyed by instruments.

The second section of the form is devoted to the environment of the road. In the first-line water surfaces, streams and rivers are positioned with mention of approximate values of level and flow rates as well as flooding and road overtopping evidence. The type and density of vegetation and crop-yielding areas are inscribed in the second line by means of suitable abbreviations or symbols. In the third line, the terrain is characterized by the usual rating (respectively 1 to 5 for flat, rolling, hilly, mountain, and steep mountain terrain) and by additional symbols for particular forms of landscape, such as scarps, erosion gullies, anthills, etc.

The line on materials occurrences comprises mention of superficial occurrences and outcrops as well as occurrences in pits dug along the road. The field identification symbol is noted and, where possible, estimated or measured CBR values as well as estimated minimal volumes in hundreds or thousands of cubic meters are given. This line may receive additional information after laboratory testing of selected soil samples from trial pits.

The third section of the form is devoted to pavement condition rating; it is discussed in more detail later.

In the two lower sections of the form, ditches and important cut and embankment slopes are positioned and rated. Ditches may be missing (Rating +2), obstructed by debris and vegetation (Rating +1), in good condition (rating 0), or show different depths of erosion (ratings 1, −2, and −3, respectively). Slope erosion may require minor repairs by hand and turfing (Rating 1), major repair with borrowed materials (Rating 2), or reconstruction (Rating 3). Slope instability usually requires major repair or reconstruction as well as drainage and retaining works. Specific cases of slope instability men-

INVENTORY OF CULVERTS AND SMALL STRUCTURES

ROAD ________________

PAGE ____/____
DATE ________
SURVEYED BY ________

N°	KM	TYPE OF STRUCT.	SECTION (cm)	LENGTH (m)	INLET	OUTLET	CONDITION

FIGURE 3 Form for inventory of drainage structures.

tioned in the inventory and condition survey form should be the subject of detailed inspection reports with descriptive sketches and pictures.

EARTH PAVEMENT CONDITION RATING

The pavement condition rating is an important task of the first design phase. It requires identification, objective rating and interpretation of pavement distress and deserves special discussion.

Two agents are responsible for earth road pavement deterioration: water and traffic. In tropical countries, water is often the main agent (*4*).

Water flowing along steep gradients and for long distances digs erosion gullies on pavement surfaces. Longitudinal gullying (Figure 4) along steep gradients shows sharp V-shaped cross sections and increasing depth with increasing length. Transverse gullies along the cross-fall usually keep small dimensions and are mainly located in curves at the vicinity of the inner edge. The outlets of longitudinal gullies across the pavement are not considered as transverse gullies. Transverse gullies are often repeated like corrugations (Figure 5).

Traffic-induced distress of earth pavements may be either functional or structural.

Functional distress results from the wearing action of vehicles. Soil elements are pulled out by vehicle tires, with loss of fines into the atmosphere and displacement of coarse elements. Functional earth pavement distress takes the form of W cross sections, corrugations, and potholing.

As traffic wearing develops with low densities of vehicles running in the middle of generally narrow pavements, soil

FIGURE 4 Longitudinal gullying.

FIGURE 5 Transverse gullies.

FIGURE 7 Low-degree W cross section, Southern Madagascar.

elements are thrown to the shoulders and the center of the pavement. This effect together with differential wearing along the wheel paths results in a flat *W*-like cross section. This type of distress is therefore called "W cross section" (Figures 6 and 7) and should not be taken for rutting.

An additional effect of traffic wearing on gravel pavements is the development of corrugations (Figure 8). After breaking of cohesion bonds during dry weather, coarse sand and gravel particles are brought together into transverse ripples with a regular spacing of about 1 m in most cases as a result of heavy vehicles' vibration and pull up by the tires (*5*).

Potholes mainly result from pull out of single coarse elements; thus, potholing is uncommon on sandy and fine soil roads, but typical of gravel and crushed-stone lined pavements (Figure 9).

Structural distress is a result of insufficient soil strength to carry the traffic loads. Soil shearing under traffic seldom results in local shears and usually produces rutting (Figures 10 and 11). Ruts develop longitudinally as the soil is expelled by the wheels and forms lateral rolls. Rutting characterizes soils with

FIGURE 8 Corrugations of a lateritic gravel pavement, road Kelo to Moundou, Chad; W cross section is also apparent.

FIGURE 6 W cross section, Kilometer 10 from northern end, National Road 44, Madagascar; the hollow segments of the cross section are particularly sharp as a result of wearing by iron fellies of bullock carts.

FIGURE 9 Potholing of a well-graded crushed-stone pavement, National Road 5A, Madagascar.

FIGURE 10 Rutting of dry cohesionless sand, Kilometer 131, National Road 35, Madagascar.

FIGURE 11 Rainy season rutting of a recently rehabilitated earth road, Bandundu province, Zaire.

FIGURE 12 Dusty surface of fine soils, Kilometer 55, Kelo-Lai road, Chad.

FIGURE 13 Holes and shearing, Kilometer 35, National Road 10, Madagascar.

low bearing capacity, namely wet fine soils and dry noncohesive, poorly graded sands, as well as poorly compacted soils.

Dry fine soils show an additional particular type of structural distress resulting from breaking of cohesion bonds by traffic-induced vibrations. The upper layer of soil changes into dust with low unit weight, covering and concealing ruts, holes, and surface roughness (Figure 12).

The combined action of seasonal water ponding and traffic wear results in large holes and shearing (Figure 13). This type of distress is typical of sections in which water crosses the pavement and drainage structures or appropriate pavement protection is missing.

Some particular types of soils may develop shrinkage cracks after compaction and during the dry season. However, cracking is neither a significant nor a widespread type of distress on earth and gravel pavements. Where present, as for instance, in clay road pavements of arid regions, it takes the form of alligator and block cracking and originates potholing.

In addition to run-off water and traffic-induced pavement distress, settlements should also be mentioned. Settlements result from slope or earthwork instability.

Any type of pavement distress should be characterized by its extent and degree of severity (*6*). The nine lines under "Condition Rating" in the inventory and condition survey form (Figure 2) allow for the different, possible types of distress (*W* cross section, corrugations, potholing, holes and shearing, longitudinal gullying, transverse gullies, rutting, dusty surface, settlements) to be represented at the exact sections and areas where they occur. Objective rating of the different types of distress is done (see Table 1) by taking measurements and evaluating distress severity parameters such as depth, amplitude, and density. The degree of severity of a given distress type is indicated in the condition survey form by different types of hatching of the relevant extent areas. Digits indicating the degree of severity may also be used for this purpose. Four degrees of severity were considered, but some distress types would only require three degrees for adequate rating.

It is important that the limits between degrees of severity be set in such a way as to characterize the different maintenance and rehabilitation techniques, as described in the next section.

The comprehensive pavement condition survey and rating are effectively an evaluation of soil behavior under traffic that can be considered as more appropriate and secure than conventional laboratory testing. Using this survey and rating sys-

TABLE 1 SEVERITY RATING OF EARTH ROAD DISTRESS

Types of distress	Measurement	Severity rating			
		0. Not detectable	1. Appreciable, possible consequences	2. Important, harmful consequences	3. Utmost, very harmful consequences
W cross-section	depth (cm)	< 5	5-10	> 10	-
Corrugations	amplitude (cm)	< 2	2-5	> 5	-
Potholing	surface (%)	< 5	5-20	20-50	> 50
Holes and shearing	maximum depth (cm)	< 5	5-10	10-25	> 25
Transverse gullies	depth (cm)	< 2	2-5	> 5	-
Longitudinal gullying	depth (cm)	< 5	5-10	10-25	> 25
Rutting	amplitude (cm)	-	5-10	10-25	> 25
Dusty surface	surface (%)	< 1	1-5	5-20	> 20
Settlements	difference in level (cm)	< 5	5-10	10-25	> 25

tem, an experienced geotechnical engineer will be able to identify and characterize the pavement soils with accuracy, and do without laboratory testing of formation soil samples. Collection of samples and laboratory testing may therefore be restricted to the identification of possible borrow areas.

FIELD DESIGN PHASE

A well-formulated problem is a potentially solved problem, and in this sense an accurate inventory and condition survey can be considered as equivalent to rehabilitation design. Specific requirements for rehabilitation works can easily be derived from the inventory and condition survey form for each road section and reported in a field design form (Figure 14).

The field design form comprises several lines corresponding to the road alignment, pavement, ditches, structures, and slopes.

Modification of layout of an earth road should always be contemplated at the time of rehabilitation. Earth roads represent only a small capital investment. Alternative layouts avoiding eroded or low-bearing-capacity sections, as well as sections that proved to be difficult to drain, almost certainly result in lower rehabilitation and maintenance costs. Sometimes after a few maintenance scraping operations, the road becomes entrenched (Figure 15) with long diversion ditches, and in this case the construction of a new earth road alongside the existing one will prove to be the best choice.

The rehabilitation design sometimes requires additional cuts to avoid eroded slopes and often the existing embankments require reconstruction and raising, following erosion by traffic and water. Quantities for small earth works may generally be evaluated with acceptable accuracy without surveying, but preferably, sections requiring important earth works should be surveyed.

Pavement works include light grading or blading without scarification by a motor-grader; heavy grading I, comprising scarification and blading by a motor-grader and final compaction; heavy grading II, if a bulldozer is required in addition to the motorgrader; and overlaying.

Overlaying with selected materials is required for sections showing rutting as well as for sections where low-bearing-capacity soils were previously overlaid, in order to compensate for materials loss under traffic. The overlay thickness is usually designed as a function of traffic and bearing ratio of the formation soil (*7*).

Light and heavy grading I and II are required to repair run-off water induced as well as traffic functional distress showing the Degrees of Severity 1, 2, and 3, respectively (Table 2). Heavy grading II with an additional bulldozer is also required for sections with rock materials.

Miscellaneous pavement works include protection against run-off erosion of sections where the gradient exceeds the critical erosion value for the relevant soil. This can be done by gravel overlaying, stone lining, or chemical stabilization, as well as by diversion banks and thresholds.

Ditch rehabilitation works include excavation, cleaning, and protection against erosion.

Rehabilitation works on drainage structures include maintenance, rehabilitation, and construction with reference to standard design plans.

In the last line of the rehabilitation design form, works for slope stabilization, including tree planting as well as protection against erosion including turfing or grassing, may be specified for relevant sections. Tree planting and grassing are normally the most cost-effective works for slope stabilization and protection, but given sections may require sustaining gabions or other types of works, together with specific design drawings.

ESTIMATION OF QUANTITIES

After field work, the first task of Phase 3 is the identification of adequate pay items consistent with the different works considered appropriate for rehabilitation. Most of the pay items, including earth works items, do not differ from usual construction practice, but for earth or gravel pavements, light grading, heavy grading I and II (measured by length or sur-

REHABILITATION FIELD DESIGN

ROAD ______________________

PAGE ____ / ____

DATE ____________

LINEAR SKETCH OF EXISTING ROAD	
LENGTH (km)	
LAYOUT	
CUTS	
EMBANKMENTS	
PAVEMENT	L. GRADING
	H. GRADING I
	H. GRADING II
	OVERLAYING
	MISCELLANEOUS
DITCHES	EXCAVATION
	CLEARING
	MISCELLANEOUS
STRUCTURES	MAINTENANCE
	REHABILITATION
	CONSTRUCTION
SLOPES	

FIGURE 14 Field design form.

FIGURE 15 A poorly drained entrenched section of an earth road resulting from periodic maintenance by scraping has been deviated by traffic.

face), and overlaying with selected materials (measured by volume), prove to be practical and effective.

The estimation of quantities of works made on the basis of field inventories and condition surveys completed by selective instrument survey proved to be well within a limit of ±20 percent, although certain items, particularly diversion ditches, were poorly evaluated and required exceptions to the contract clause on variation of quantities.

If construction is delayed through a wet season, a new condition survey may be required to update quantities of works.

CONCLUSIONS

A simplified design methodology for rehabilitation and upgrading of low-volume earth and gravel roads based on field work, namely a comprehensive inventory and detailed condition survey by filling forms while walking along the road, proved to result in accurate quantity estimations and low-cost design.

This methodology does not require exhaustive surveying. Instrument surveying may be restricted to cross sectioning of certain sections for accurate estimation of important earth works. Soil testing is restricted to investigation of possible borrow areas as the methodology includes objective rating and interpretation of earth pavement distress.

The design methodology is considered to be most appropriate to developing countries where financial resources are scarce and low traffic volumes do not justify conventional design methodologies. The methodology proved to save money

TABLE 2 PAVEMENT REHABILITATION WORKS AS DERIVED FROM TYPE AND SEVERITY OF DISTRESS

Type of distress	Degree of severity			
	0	1	2	3
Functional traffic and run-off induced distress	No rehabilitation required	Light grading (only motor-grader blade)	Heavy grading I (scarification and blading by motor-grader and final compaction)	Heavy grading II (scarification by bulldozer, blading by motor-grader and final compaction)
Structural distress (rutting or dusty surface)	Overlaying			

Remark: Overlaying of previously overlaid sections could also be required for compensation for traffic induced materials losses and those sections would not necessarily show structural distress prior to rehabilitation.

and time, does not require costly or sophisticated equipment, and is well within the capacity of trained and dedicated road engineers. Rather than resulting in poor design, direct recognition of design problems and conditions in the field may improve the quality of design.

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