Cross Sections and Pavement Subdrainage of Low-Volume Roads in Madagascar

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Distress of poorly drained pavements typically takes the form of longitudinal settlements and cracks along shoulders (both shoulders of straight aligned stretches and the lower shoulder of superelevated curves) and results from water penetrating the structural layers of the pavement system, flowing along the transverse and longitudinal grades, and saturating materials of lower areas. Water flowing in the pavement along the longitudinal gradient may feed perched water tables in pavement layers of low embankment sections. Seepage from the perched water tables into the shoulders and subgrade may originate edge slides. Pavement cross-section design should take into account the permeability of available natural materials as well as processed base materials. Adequate provision for prompt outflow of pavement water should be given except for impervious pavements that do not require to be drained and for pavements over pervious subgrades where efficient subdrainage is achieved by percolation to deep-water tables. A catalog containing eight standard pavement cross sections has been proposed for the Malagasy low-volume, bitumen-paved roads and the unit prices of 10 road construction and rehabilitation projects were used to derive comparative construction costs of the different standard cross sections.

What is most important for low-volume road pavements: thickness design or subdrainage design? Both thickness and subdrainage design are essential for good performance of low-volume road pavements. However, thickness design is usually carefully studied and investigated whereas subdrainage design is not always contemplated.

Neglecting pavement subdrainage design results in reduction of pavement service life, but in many cases the role of poor drainage in pavement distress and failure goes unnoticed as inaccuracy of traffic assumptions may also account for shorter service lives.

From time to time, the occurrence of pavement failures obviously caused by poor subdrainage is warning road engineers of the importance of subdrainage design.

A CASE HISTORY

National Road 12 between Irondro and Manakara along the southeastern coast of Madagascar was designed for a service life of 15 years. During construction, the subgrade compaction and bearing capacity were carefully checked and the pavement thickness design adjusted to comply with the actual subgrade California bearing ratio (CBR) value. Construction was completed by the middle of 1983 (*1*).

The pavement comprised a subbase with variable thickness of natural sandy materials selected on the basis of a soaked CBR exceeding 30 percent, a 15-cm-thick crushed basalt base, and a double surface dressing. The base course was 40 cm wider than the surface dressing. The base course edges did not receive surface dressing and were simply primed. Subbase materials were used in the shoulders. The shoulders and subbase materials were either impervious clayey sands and fine soils or pervious, coarse river sands.

The very pervious crushed basalt base course extending beyond the wearing course provided conditions for the easy ingress of water in the pavement. Water outflow and pavement drainage were provided by transverse crushed stone drains located in the shoulders every 10 m as usual in Madagascar.

The eastern coast of Madagascar is exposed to a humid climate without a dry season. The average yearly rainfall in the region where the road was constructed is around 2400 mm. The so-called "summer," from November to April, is the season of tropical cyclones with heavy rainfall. During this season, the hourly precipitation may reach 60 mm or more. Rain may fall continuously for 3 days or more.

Before the end of the warranty period and during the heavy rainy season from November 1983 to March 1984, severe pavement distress including settlements, longitudinal cracks, alligator cracking, rutting, stripping, raveling, and potholes as well as embankment instability developed in many sections of the road (*2*). By this time, the traffic using the road was less than 50 vehicles per day. In many places (Figure 1), water was seen flowing from potholes and cracks after rain showers. These pavement springs were situated both in cut and embankment sections, in plains, as well as slopes and the tops of hills.

Distress only occurred in stretches where the shoulders and the subbase were constructed with impervious materials. Sections of pavement with pervious shoulders and subbase remained in good condition and did not show signs of distress even after the heavy rainy season. The only exception was a pothole and pavement spring that appeared soon after construction in the lower part of a horizontal and vertical curve. The pothole was obviously caused by water pressure buildup following infiltration in the superelevated upper shoulder and showed abundant water outflow.

The relationship between inadequate pavement drainage and premature failure was clear for National Road 12.

TYPICAL DISTRESS OF POORLY DRAINED PAVEMENTS

The ingress of water in road pavements should be avoided and limited by appropriate design and construction materials.

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FIGURE 1 Alligator cracking, loss of fines, and springs along the centerline of an embankment section at Kilometer 21 + 700, National Road 12.

The construction of watertight wearing courses may be achieved by using good materials and workmanship but this condition cannot be maintained for long periods of time. After a few years of service, joints, cracks, and relatively pervious areas will allow water to ingress into the pavement. When appropriate drainage is provided, the harmful effects of water in the pavement structure can be avoided.

In the absence of appropriate pavement subdrainage, water may seep into the pavement system and flow along the transverse grade to the pavement edges as well as along the longitudinal gradient to low sections. Where impervious shoulders oppose flow, seepage of water into the subbase and the subgrade results in a loss of bearing capacity and traffic loads produce longitudinal settlement and cracks along the shoulders (Figure 2). This combination of distress types is characteristic of poorly drained pavements. In straight alignments, water-related distress develops along both pavement edges but in curves it only develops along the lower shoulder.

Longitudinal flow of water in poorly drained pavement layers may feed perched water tables in low embankment sections. Seepage from perched water tables through the subgrade and the shoulders may cause edge slides.

POSSIBLE DIFFERENT WAYS OF DRAINING PAVEMENTS

Where the base course has low permeability (soil-cement, soil-lime, soil-bitumen) relative to the shoulders, the subbase, and the subgrade, pavement subdrainage is not critical.

If the base course materials are pervious, one possible way of draining the pavement is vertical infiltration or percolation to a deep water table through a pervious subgrade. Cohesionless sand or gravel may be pervious enough that specific pavement subdrainage is not required.

On impervious subgrades, another possible way of draining pavements is through pervious subbase and shoulders.

A third possibility is lateral drainage from the base to the shoulders. These may be constructed with pervious materials or made selectively pervious by means of shoulder transverse drains. The drain section and spacing should be properly designed (*3–6*).

A fourth possible way of draining pavements is by means of a special drainage layer or blanket at the base of the pavement with longitudinal perforated collector pipes at one or both edges and outlet pipes under the shoulders.

Transverse interceptor drains and herringbone drains may be useful under certain conditions. Herringbone drains are often used to improve drainage of sections where a drainage blanket was neglected during construction. For this purpose, trenches at a certain angle with the centerline are cut through both lanes and filled with draining materials.

Shoulder drains were traditionally used in Madagascar. Their performance is sensitive to construction conditions and workmanship. Problems occur if the drain trenches across the shoulders are cut before base course compaction. If the trenches are cut before completion of base course construction, the drain inlet may be disturbed and plugged by construction equipment. The shoulder drain should penetrate at least 10 cm into the pavement base course and the bottom of the drain should be lower than the bottom of the base course. As natural gravels are scarce in the Red Island, shoulder drains were traditionally constructed by backfilling the drain trench with crushed stone and priming the surface. This technology gives no proper security against penetration of fines, plugging by vegetation and animals, and damage by occasional traffic.

FIGURE 2 Longitudinal cracks and settlements along the shoulder, typical of poorly drained pavement.

FIGURE 3 Edge settlement and water outflow through longitudinal cracks.

Geotextile encapsulation appears to be a sound alternative for proper operation of shoulder drains and should be promoted.

Section design and spacing of shoulder drains should be based on the expected rainfall, the infiltration rate, and the permeability of the base course. The experience of National Road 12 showed that the usual 10-m spacing was conservative for the highly pervious crushed basalt base course in the conditions of the heavy rainfall season. Shorter spacings of 5 and 3 m are recommended in tropical countries (7), when a continuously pervious shoulder would be too costly.

CATALOG OF PAVEMENT STANDARD CROSS SECTIONS

The case of National Road 12 called attention to the utmost importance of subdrainage design. One of the main lessons to be learned from this experience is that standard pavement cross sections cannot be considered independently from local pavement materials, particularly the pavement materials permeabilities.

One efficient way to ensure pavement drainage is to extend the pavement materials across the shoulders. This is usually done for the subbase materials, which are low-cost natural materials, but not for the base materials. These are usually crushed stone in Madagascar. In order to decrease construction costs, natural materials, usually the same as the subbase materials, are used in the shoulders.

In Madagascar, most subbase and shoulder materials are impervious clayey sands. Turfing is applied to the surface of shoulders to protect against erosion. Gravels such as rolled river gravels and lateritic gravels are very scarce in the island. In some particular regions, soft limestone and volcanic gravels are available. Gravelly, coarse well-graded sands can be found along some rivers.

In order to avoid future mistakes in pavement cross-section design, a catalog of pavement standard cross sections (*8*) was prepared by the highway department in Madagascar.

This catalog did not specifically address the problem of water ingress from the subgrade into the pavement. Where required, this problem should receive particular treatment. The specific problem of the catalog was to provide drainage for water trapped in pervious, coarse pavement materials. Consequently, the problems of internal drainage and the requirements for filter layers were not developed.

The Malagasy catalog (Figure 4) comprises eight different cross sections to choose from for each pavement stretch in accordance with the available natural or processed pavement materials.

Cross Section 1: Impervious Base

For better lateral support, the impervious base (soil-cement, soil-lime, soil-bitumen, or waterbound macadam with impervious filling) is extended 20 to 30 cm laterally beyond the wearing course. Low-grade shoulder materials with turfing may be used. Cross Section 1 should not be used with pervious base materials such as crushed stone. The base edges without wearing course would allow the ingress of water with resulting distress, as discussed previously.

Cross Section 2: Full-Width Base

The pervious or impervious base is extended the full pavement width. The resulting cross section is costly but has many advantages: easy construction comparative to cross sections where base and shoulder materials are different, good lateral support, strong shoulders, and easy subdrainage for pervious base materials.

Crushed-stone shoulders are erodible by occasional traffic. To avoid shoulder erosion, surface protection can be contemplated. Simple priming is often suggested but does not appreciably improve surface resistance to erosion by traffic. Surface dressing and stone lining or paving are effective for this purpose and, in order to reduce costs, can be restricted to particularly exposed shoulder sections.

Cross Section 3: Pervious Base, Impervious Subbase, and Pervious Shoulders

The base course is not extended over the shoulders, but shoulder materials different from the subbase materials and more pervious than the base are used to ensure lateral permeability.

Construction cost is reduced relatively to Cross Section 2 because of low-cost shoulder materials such as crusher run or pervious natural gravels, but the latter are only available in a few regions of the Great Island.

Overlaying of an existing pavement with a pervious base or subbase would require previous reshaping of existing impervious wearing courses to avoid water ponding in the new base or subbase. The same result can be achieved at lower cost by total or selective scarification of the existing bituminous surfacing. Grooves excavated across the existing surfacing may ensure drainage of the overlay provided the existing pavement has suitable subdrainage.

Cross Section 4: Pervious Base and Subbase

The pavement is drained by the pervious subbase. Water may infiltrate through superelevated shoulders, seep towards the structural pavement layers, and cause waterhead build-up. To avoid this, the higher superelevated shoulder in curves should either be surfaced or constructed with impervious materials. Cross-section design with adequate subgrade transverse grading (Figure 4b) would also avoid or limit seepage of rain water toward the center of the pavement and along the longitudinal gradient to build up high pressure.

Cross Section 5: Pervious Subgrade and Subbase

In sandy areas, pavement subdrainage takes the form of percolation through the pervious subgrade provided that the water table is deep enough. Most often in Madagascar, the pervious subgrade is cohesionless, uniformly graded sand (coastal sands, Isalo, or Karroo formation sands). This type of material does not give lateral support to the pavement and, to avoid edge raveling, concrete or stone block alignments are recommended. As the subbase and the subgrade are pervious, lateral subdrainage is not required and the stone blocks or concrete curbs may be laid deep along the pavement edges.

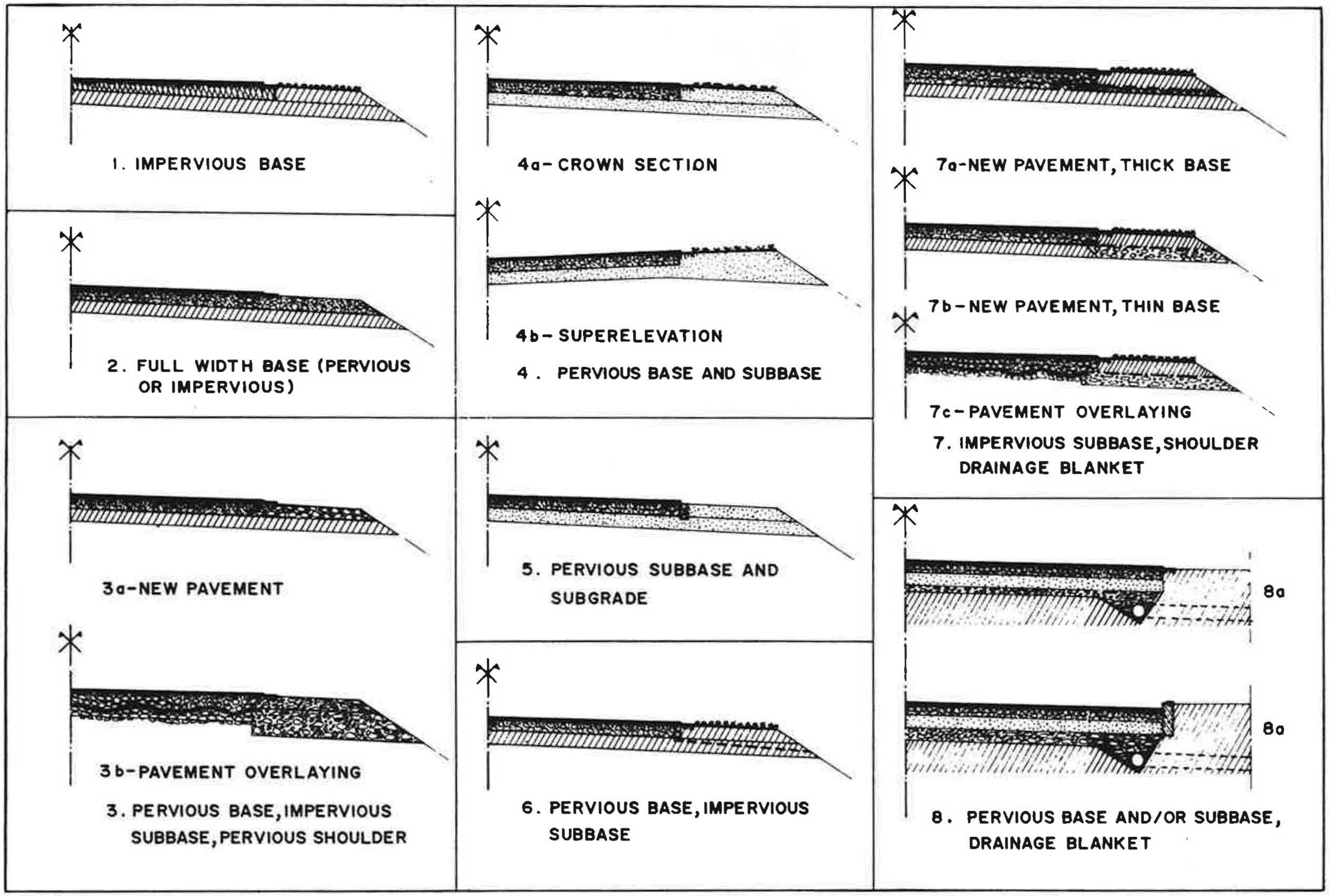

FIGURE 4 Catalog of typical pavement cross sections, Madagascar, 1986. Impervious pavement materials are represented by hatching. Pervious subbase (and shoulder) materials are most often sands and represented by dotting. Coarse materials in bases, shoulders, and blanket layers as well as turf surfacing of shoulders are represented by suggestive graphics.

Cross Section 6: Impervious Subbase and Shoulders With Drains

The pervious base receives a full-width surfacing to avoid or reduce ingress of rain water. Shoulder drains are conveniently spaced to provide adequate subdrainage.

The distance between successive drains should be designed based on the expected volume of water to flow through the pavement. Because frost is not a problem in Madagascar, the shoulder drains should simply be designed for an outflow rate at least equal to the design infiltration rate. Cedergren (*3,4*) related the design inflow rate to the 1-year frequency, hourly precipitation, whereas Ridgeway (*6*) considered infiltration through cracks. In this case, storm duration is more significant than intensity.

More research is required to establish reliable design infiltration rates in Madagascar. Tropical rainfall has both high intensity and long duration and the current bituminous seals are rather designed for minimum construction costs in the Red Island. The design infiltration rate is therefore most likely to take high values and the resulting drain spacing is most likely to be short.

As discussed previously, the shoulder drains should be carefully constructed for efficient operation.

Cross Section 7: Impervious Subbase, Shoulders With Drainage Blanket

This cross section has continuous, lateral drainage through a pervious layer under the shoulder.

Construction methods would be different depending on the thickness of the base. If the base is thick, it will have to be constructed in two layers. Construction of the upper shoulder layer may cause contamination and clogging of the inner edge of the drainage blanket at the base-shoulder interface. To avoid contamination during construction as well as later clogging during the service life, an intermediate geotextile membrane may be used.

The performance of turfing above the drainage blanket requires monitoring. Turfing and the shoulder upper layer may dry quickly during the dry season and lose bearing capacity and be damaged following saturation during the wet season.

Cross Section 8: Draining Blanket With Collector and Outlet Pipes

In some circumstances, particularly in towns, the pavement has to be placed in a previously prepared excavation. This type of trench pavement must have a special, properly designed subdrainage system with a drainage blanket as well as collector and outlet pipes.

Draining blankets are also required in cut sections where water inflow from the water table into the pavement could take place.

COMPARATIVE COSTS OF PAVEMENT DRAINAGE

In order to compare construction costs of pavement drainage alternatives, 1-km-long pavement stretches of the eight different standard cross sections described herein were considered. The assumed widths were 6.0 m for the pavement and 1.5 m for each shoulder. The wearing course was assumed to be a double surface dressing and thicknesses of 15 and 20 cm were taken for the base and subbase, respectively.

Unit costs were derived from 10 different contracts by averaging and updating to January 1986. However, the contracts did not have prices for fabrics and pipes and these had to be estimated.

After computation of construction costs for 1-km-long pavement stretches, a reference cross section was considered to derive comparative, relative costs expressed as percentages. As impervious stabilized bases would have high construction costs compared to crushed stone, the reference cross section was defined as Cross Section 1 with a 6-m-wide, impervious water-bound macadam. Thus, its construction cost was the lowest.

The base of standard Cross Section 6 was assumed to be a pervious water-bound macadam with the same unit price as the impervious water-bound macadam of Cross Section 1, so that only shoulder drains accounted for differences in construction costs of Sections 1 and 6.

A few different alternatives were considered within single standard cross sections, namely surfaced and unsurfaced shoulders for Cross Section 2, different spacings of shoulder drains with and without geotextile encapsulation for Cross Section 7 and one or two collector pipes for Cross Section 8.

Earth works as well as excavation costs for standard Cross Section 8 were not considered.

The relative construction costs of the different pavement cross sections are presented in Table 1. Because Cross Section 1 does not require any subdrainage, the cost percentage over 100 of the other sections can be considered as a good approximation of the cost of pavement subdrainage.

Table 1 indicates that the construction cost of pavement subdrainage is not excessive and is even low in some cases.

Extending the base course in full width (Cross Section 2) results in pavement costs that are about 25 percent higher than the reference cross section, but using low-cost pervious materials such as crusher run or natural gravels (Cross Section 3) only increases construction costs by 15 percent. Proper surfacing of shoulders costs 8 percent more.

Where pervious subbase natural materials are available, there is no extra cost for proper pavement subdrainage (Cross Section 4). The extra cost of Cross Section 4 only results from the higher cost of graded crushed stone over water-bound macadam in Cross Section 1.

The extra cost of Cross Section 5 results from additional costs of protection against edge raveling, which are relatively high and amount to 10 percent.

Pavement subdrainage by means of shoulder drains (Cross Section 6) has relatively low construction costs that vary with the drain spacing. Encapsulation of shoulder drains with geotextile is cost-effective and only represents an extra cost of 3 percent for the drain spacing of 5 m. For spacings of shoulder drains smaller than 5 m, the cost of this type of discontinuous lateral drainage tends to be higher than the cost of continuous lateral drainage through pervious crusher run or natural gravel shoulders.

The cross section with a continuous drainage blanket under the shoulders does not appear to be cost-competitive.

TABLE 1 RELATIVE CONSTRUCTION COSTS OF DIFFERENT PAVEMENT CROSS SECTIONS

Standard cross-section No.	Base course		Shoulders	Subdrainage		Construction cost (%)
	Width(m)	Materials				
1	6.0	impervious water bound macadam	impervious soil and turfing	not required		100
	6.4					102
2	9.0 extended over shoulders	graded crushed stone	unsurfaced	lateral, through pervious shoulders		124
			single surface dressing and sand seal			132
3a			pervious crusher run or natural gravel			115
4a			pervious sand: the same material as subbase	lateral, through pervious shoulders and subbase		103
5			blocks along pavement edges	vertical, through pervious subbase and subgrade		116
6	6.0	pervious water bound macadam	impervious soil and turfing	lateral, discontinuous, through shoulder drains	spacing=10m	105
					spacing= 5m	110
					spacing= 3m	117
				lateral, discontinuous, through geotextile enca-psulated shoulder drains	spacing= 5m	113
7b		graded crushed stone	upper layer impervious soil and turfing lower layer pervious drainage blanket	lateral through drainage blanket		126
			as above with intermedi-ate geotextile			135
8a			impervious soil	drainage blanket, collector pipes on both sides and outlet pipes		157
				drainage blanket, collector pipe on one side and outlet pipes		146

The construction cost of a subdrainage system comprising a drainage blanket, collector, and outlet pipes appears to be the highest and not competitive for relatively thin, low-volume road pavements. However, this cross section is recommended for sections of trench pavement, and drainage blankets must also be considered for particular hill sections showing shallow, seasonal water tables or seepage from rock fractures.

CONCLUSIONS

Neglecting pavement subdrainage results in shorter pavement lives and experience indicates that under high tropical rainfall properly structurally designed, poorly drained pavements are subject to premature failure.

Poor subdrainage often results either from inadequate cross-section design or from the concern of the project engineer with minimizing construction costs.

On the basis of unit costs of 10 road construction and rehabilitation projects in Madagascar, a comparison has been made of construction costs of eight different cross sections and four methods of draining pavement systems.

The comparison showed that the low cost of percolation drainage through pervious subgrades can be canceled by the cost of protection against edge raveling in the case of cohesionless, uniformly graded sands.

Lateral subdrainage has a very low cost where natural pervious subbase and shoulder materials are available. Where shoulder materials have to be crushed or hauled for long distances, the cost of subdrainage may increase up to 15 percent. Extending the base course over the full width of the formation has a relatively high cost but is advantageous from the viewpoints of construction and performance.

Shoulder drains if properly designed and constructed have costs that are comparable to those of pervious shoulders but require manual work and careful construction.

Lower costs can be achieved by constructing pervious shoulders only in pavement sections and at the pavement sides where they will actually drain the pavement. The higher superelevated shoulders of curves should preferably be impervious.

As construction costs are sensitive to site location as well as economic environment, these conclusions resulting from cost comparison in Madagascar by the year of 1986 can prove wrong and inaccurate elsewhere and should not encourage design engineers to fail to evaluate design alternatives on a site-specific basis.

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