Associations of Distress and Diagnosis of Bitumen-Surfaced Road Pavements

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As a contribution to the implementation of a high-quality and cost-effective road maintenance management system, a catalog of pavement distress and defects was prepared for the low-volume bitumen-surfaced rural roads of Madagascar. The catalog comprises the description, definition, and methods of measuring and rating the different types of distress and defects found in the rural road network as well as checklists of possible causes and guidelines for remedial works. It also comprises a discussion of associations of distress types and their interpretation as clues for proper diagnosis of the actual causes of distress. Not all types of individual distress inventoried in the catalog and discussed in the literature are listed or described. The purpose is to illustrate associations of distress types currently found in low-volume road pavements of Madagascar and other tropical countries and show how identification of certain combinations of distress types can be used for proper pavement maintenance and management. The following associations of distress types can provide clues to diagnosis of distress causes and remedies: raveling and cracking; wide ruts and alligator cracking; longitudinal cracks and settlements along the lower shoulders; crack-bounded settlements; and the association of longitudinal cracks, differential settlements, and undulations. Other associations of distress discussed are bird bath and alligator cracking, eroded-shoulder and longitudinal edge cracking, narrow rut and longitudinal heaving, block cracking of cement bound bases, crescent-shaped cracks and peeling, longitudinal cracks and settlements, and local shearing, as well as corrugations and undulations. Cracked blisters are also discussed.

Engineers concerned with maintenance and rehabilitation of bitumen-surfaced roads should be able to interpret the patterns of distress of individual road sections and to make a diagnosis of the possible causes of actual distress in order to select and implement the most effective remedial works.

Pavement distress types have previously been described and agencies of different countries have published indexes or catalogues of pavement distress and defects (*1–4*).

As a contribution to the implementation of a high-quality and cost-effective road maintenance management system in Madagascar, a catalog of pavement distress and defects was prepared for the low-volume rural road network of that country (*5*). It comprises the description, definition, and methods of measuring and rating 43 different types of distress found on the bitumen-surfaced pavements of the island, as well as checklists of the possible causes and guidelines for remedial works.

The standardization of distress definition and rating is a necessary step for the evaluation and implementation of the proper remedial works. But a catalog or index of distress types alone does not appear to be sufficient for that purpose even when illustrated by photographs of typical examples.

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The essential step for implementation of the proper remedial works is distress diagnosis. For this purpose, destructive testing, comprising verification of pavement thicknesses as well as sampling and testing of pavement materials, is widely used. However, when associations of different types of distress give clues to diagnosis, destructive testing may be minimized and efficiency improved.

The Malagasy catalog also contains a discussion on the significance of different distress associations as a base for well-founded judgment by road engineers and appropriate diagnosis of the causes of distress of road pavements.

In Madagascar, bitumen-surfaced pavements generally comprise a subbase with varying thickness (usually 15 to 30 cm) of selected soil, a 15- to 20-cm-thick processed base (penetration of water-bound macadam or graded crushed stone or soil-cement), and a 2.5- to 5-cm-thick surface layer (hot-mix or surface dressing). Shoulders are usually selected soil with turfing.

PAVEMENT DISTRESS TYPES AND CLASSIFICATION

The different types of distress of bitumen-surfaced road pavements may be classified into three groups: cracking, distortion, and loss of materials.

Cracks resulting from breaking of pavement layers are seldom to be found isolated. Cracks are usually branching out or building families. They may also form particular patterns such as alligator and block cracking.

Distortion of the pavement surface under traffic loading may take the form of bird baths in its initial stages, but usually develops into rutting. It is important to make a distinction between narrow and wide ruts. Narrow ruts have small radii and result from strain in surface or shallow pavement layers, whereas wide ruts with large radii result from strain in the subgrade or deep pavement layers.

Settlements are particular distortions in the form of depressions open to one or both pavement edges. They may result from traffic loading as well as from water action and landslides.

Other types of distortion include corrugations with decimetric wavelengths, longitudinal undulations with metric to decametric wavelengths, collapsed voids, as well as different types of heaving and shearing.

The most popular type of loss of materials is potholing. Potholing is the end result of development of most types of pavement distress. After raveling along their edges, cracks develop into potholes. Raised areas of distortion result in damage and potholes through dynamic traffic loading. Individual loss of materials, such as stripping, develops into raveling and potholing. Loss of entrapped water and fines or dissolved matter also cause potholes. The causes of potholes are thus multiple and varied, and this type of distress cannot provide clues for diagnosis by itself. In combination with other types, it indicates advanced stages of distress.

Other types of loss of materials are stripping or loss of individual aggregates, raveling and disintegration with loss of binder and aggregate lumps, edge breaking and raveling, peeling, glazing or polished aggregates, bleeding, and loss of water with fines and dissolved matters.

A given type of distress may have multiple causes. Associations of two or three distress types may characterize different processes of road pavement failure, and identification of these associations can be used as a method of diagnosis of causes of distress and failure.

CHARACTERISTIC ASSOCIATIONS OF DISTRESS TYPES

Fifteen characteristic associations of distress types are discussed and illustrated in this section.

Table 1 presents information and indicates possible remedial works for the different associations of distress.

Most distress associations have a unique relationship to diagnosis but some may require additional information for proper diagnosis.

Raveling and Cracking

The association of alligator cracking, disintegration, and loss of aggregates and binder from an undistorted pavement surface is typical of bitumen aging and announces the end of the useful life of the bituminous wearing course (Figure 1). If resealing is not provided in due time, the pavement distress will quickly develop into functional failure by potholing and may require costly rehabilitation works such as recycling, overlaying, or reconstruction.

Bird Bath and Alligator Cracking

The association of alligator cracking with local surface depressions (bird bath) points to localized low bearing capacity of granular pavement structures (Figure 2).

This pattern of distress may form along the wheel paths and develop into wide ruts and alligator cracking.

Wide Ruts and Alligator Cracking

The association of wide ruts and alligator cracking (Figure 3) is the typical distress pattern of fatigue of granular pavements.

Low-volume roads may usually exhibit this type of structural distress where the traffic includes heavy loads. Pavements exhibiting wide ruts and alligator cracking should be reconstructed or strengthened by overlaying or by recycling with particular attention to drainage. In the Malagasy rural roads network, wide ruts and alligator cracking were only present on two roads carrying trucks loaded with chrome ore.

Sometimes wide ruts result from consolidation of open graded or soft pavement materials such as telford and macadam of lateritic boulders (Figure 4). In this case, a leveling course will restore driving comfort.

Narrow Ruts and Heaving

Narrow ruts indicate strain in the upper pavement layers, whereas adjacent heaving points to shearing. Hence, for pavements with adequate thickness this pattern of distress is symptomatic of low-grade materials in the base or wearing course. If the wearing course is thin, as in Madagascar, where hotmixes usually have thicknesses of 1 in. or slightly more, the cause lies in the base course. Laboratory testing of the base material will provide diagnostic information such as inadequate grading (lack of gravel fraction or excess of sand fraction), high plasticity of fines, or in-service weathering of basaltic natural gravels (Figure 5).

Underdesigned, thin pavements may fail with development of narrow ruts and adjacent longitudinal heaving.

Crack-Bounded Settlements

Crack-bounded settlements are also associated with pavement distress associations.

Branching, multiple parallel cracks or single cracks are actually the intersection of a slide surface with the pavement surface. In some cases, the cracks cross the pavement at variable angles and the difference in height of the crack edges exceed a few decimeters: the settlement and the cracks result from a landslide of the natural slope where the road is located. Transverse cracks and smaller settlements may result from slides of the transition surface between cuts and embankments where well-known construction codes were ignored. But slides and instability in embankment slopes causing longitudinal curved cracks with both ends on one side of the pavement (Figure 6) are most widespread.

Longitudinal Cracks and Settlement Along the Shoulder

Ingress of water in pavements can be restricted but not totally avoided by proper design and good construction. Pervious pavement layers must therefore be provided with adequate drainage. Where drainage is absent, water may seep into pavement pervious layers, usually crushed-stone base courses, and flow to lower sections along the transverse and the longitudinal grades, and may soak the subgrade along the lower shoulder in curves, and both shoulders in straight alignments. This process will cause the subgrade and pavement-bearing capacity to fall. Traffic loads then cause settlements and longitudinal cracks along the shoulders. This association of distress, of course, does not develop along superelevated shoulders.

After rainfall, water may flow out of longitudinal cracks along the shoulders in low sections.

TABLE 1 SUMMARY OF ASSOCIATIONS OF DISTRESS TYPES

Distress type	Diagnosis	Possible remedies
Ravelling, alligator cracking, no distortions	Ageing of bituminous wearing course	Patch., reseal. if low, recycl., overl., reconst. if high degree of severity
Bird bath, alligator cracking	Local low bearing capacity	Replace pav. materials, improve drainage
	Incipient fatigue	Drainage, recycling or overlaying
Wide ruts, alligator cracking	Fatigue granular materials	Drainage, overlaying or recycling
	Consolidation gran. materials	Levelling course
Narrow ruts, heaving (thin wearing course)	Insufficient thickness	Overlaying or reconstruction
	Low grade materials	Recycling, overlaying or reconstruction
Crack bounded settlement	Slope slide or instability	No pavement remedy
Longit. cracks, settl. along low shoulders	Poor pavement subdrainage	Place transv. interceptor and shoulder drains; reconstr. pervious shoulders
Longitudinal crack, settlement with constant width	Underdesigned, poorly compact. widening	Excav. widening, cut pav. at 45 degr., reconst. with adequate thickness., materials and compaction
Eroded shoulder, longitudinal crack	Poor lateral support	Patch pav.and reconstruct shoulder using erosion resistant materials
Block cracking (unif. spacing)	Shrinkage of base material	Seal reflex cracks
Block cracking on wheel paths	Structural failure	Overlaying, recycling or reconstruction
Crescent-shaped cracks, peeling	Weak tack or prime coat	Patching
Peeling in the wheel paths	Constr. defect, weak base	Overlay; recycle; scarify and reconstruct upper pavement layers
Longit. cracks and settlements	Poor embankm. compaction	Levelling course
Longit. cracks, differential settlements, undul.	Expansive soil subgrade	Reconst. and treat subgr. with lime; place imperv. membrane and overlay
Local shearing (depression and heaving)	Low grade pav. materials	Excavate and replace pavement materials
	Water seepage	Excavate, drain and patch

TABLE 1 *(continued on next page)*

TABLE 1 *(continued)*

Corrugations, undulations	Unstable pav. materials	Overlaying; recycling
	Poorly compact. labor intensive construction	Levelling course
Loss of water and fines	Poor subdrain., attrition of pav. materials	Place transv. interceptor and shoulder drains; reconst. perv. shoulders
Blisters, cracking	Salt heaving (arid envir.)	Patch, seal to restrict evaporation; reconstruct with barrier to stop salt migration
Blisters, crack., rust staining	Tropical weathering volcanic aggregates	Patch; recycle or overlay

FIGURE 1 Alligator cracking and raveling without distortion indicating bitumen aging.

FIGURE 2 Alligator cracking of a depressed area indicating low bearing capacity of pavement structure.

FIGURE 3 Wide ruts and alligator cracking indicating fatigue of a granular pavement.

FIGURE 4 Wide ruts resulting from traffic consolidation of a lateritic boulder pavement on a lateritic plateau (National Road 4, Tampoketsa Plateau, Madagascar).

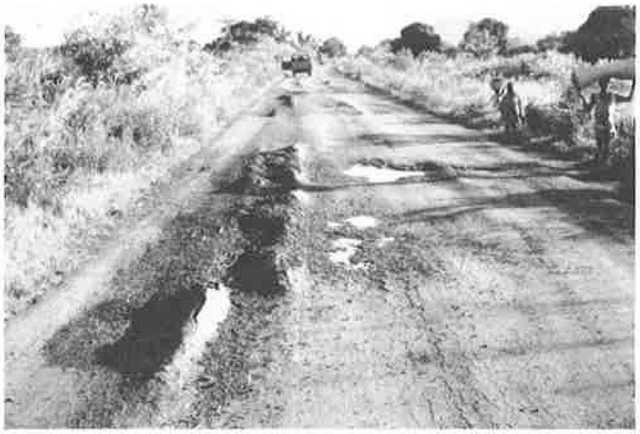

FIGURE 5 Narrow ruts and longitudinal heaving resulting from weathering of a basaltic natural gravel (National Road 5B, near Sambava, Madagascar).

FIGURE 7 Block cracking of a soil-cement base: Kilometer 89, National Road 6, Madagascar.

Longitudinal cracks resulting from subdrainage inadequacies are usually irregularly curved and multiple. Underdesigned or poorly compacted partial-lane pavement widenings also cause longitudinal cracks and settlements, but in this case the cracks are straight and parallel to the pavement edge.

Eroded Shoulder and Longitudinal Edge Crack

After shoulder erosion by water and traffic, the pavement edge has no lateral support and traffic loads cause longitudinal cracks with tilting but without settlement. This association of distress may develop on superelevated shoulders.

Block Cracking

The pattern formed by regularly spaced transverse and longitudinal cracks is known as block cracking (Figure 7).

Soil-cement and some other pavement materials develop shrinkage cracks forming a block pattern with dimensions usually in the range of 0.6 to 1.2 m. The initial cracks are transverse cracks starting at the pavement edges. These progress to the pavement center and the longitudinal cracks develop later. Sometimes the whole pavement surface is affected by block cracking. In other cases, cracking does not go beyond the initial transverse cracks along the shoulders.

Shrinkage block cracking of stiff bases reflects to the wearing course. It is not associated with distortion and only requires crack sealing.

Block cracking resulting from failure of stiff pavement materials under loading has shorter transverse than longitudinal spacing. It may be associated with rutting. It develops along wheel paths and will require pavement strengthening (Figures 8 and 9).

Crescent-Shaped Cracks and Peeling

Peeling of the wearing course occurs following tangential shearing by traffic. It is often associated with crescent-shaped cracks pointing in the direction of traffic flow (Figure 10).

In most cases, peeling indicates some weakness of the prime or tack coat binding the wearing course and the base course,

FIGURE 6 Longitudinal curved crack and settlement resulting from embankment slope slide, National Road 7, in the vicinity of Ambatolampy, Madagascar.

FIGURE 8 Block cracking resulting from tensile failure of a soil-cement pavement: Masiaka Road, Sierra Leone, 1982, before rehabilitation.

FIGURE 9 Two different families of block cracking, Kilometer 0 + 200, National Road 32, Madagascar: widely spaced shrinkage cracks, and narrow tensile failure block cracks associated with ruts.

FIGURE 11 Longitudinal cracks and settlements of a poorly compacted embankment between Malaimbandy and Miandrivazo, National Road 35, Madagascar.

but in some cases the level of the shear surface is underneath the prime coat and results from construction defects such as low cement content of soil-cement bases or compaction of thin layers of base material for leveling purposes without previous scarification.

Longitudinal Cracks and Settlements

Traffic compaction of poorly compacted embankments results in longitudinal cracks and settlements with development of a concave cross section (Figure 11).

Undulations, Longitudinal Cracks, and Differential Settlements

Shrinkage of expansive soil subgrades during the dry season causes longitudinal cracks starting at the shoulders and progressing to the axis. Transverse cracks do not develop (Figures 12 and 13).

Rainfall during the wet season flows into the cracks causing internal erosion along the deep shrinkage cracks. After some climatic cycles, traffic loading and internal erosion will either cause differential settlements along the longitudinal cracks or collapsed voids (Figures 14 and 15).

Differential swelling along the road results in longitudinal undulations (Figure 16). Transverse settlements are typically found above culverts.

Local Shearing

Local shearing of pavement or subgrade materials takes the form of rounded depressions with some peripheral heaving (Figure 17).

It can either result from local water seepage in the subgrade (natural springs) or from low-grade pavement materials (with

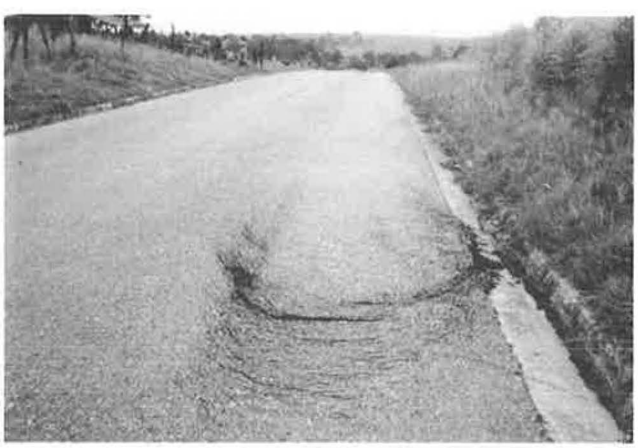

FIGURE 10 Peeling and crescent-shaped cracks, National Road 1, Zaire: the tack coat binding the soil-cement base to the wearing course was sheared by driving up heavy vehicles.

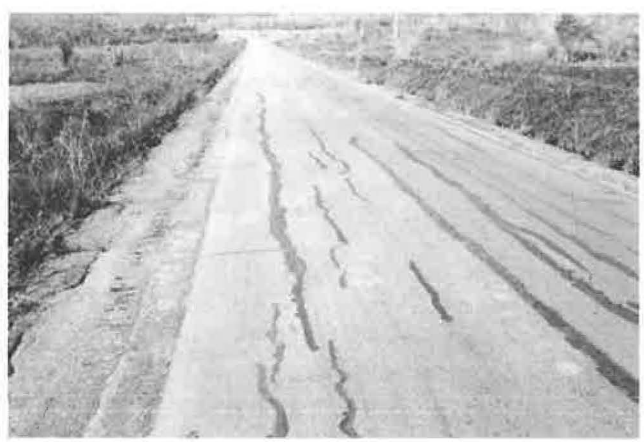

FIGURE 12 Longitudinal cracks developed during the first dry season in sections of National Road 3, Kilometer 73, Benin, where the embankment had been constructed with expansive clays (lama depression). The cracks were carefully sealed but reopened during the next dry season.

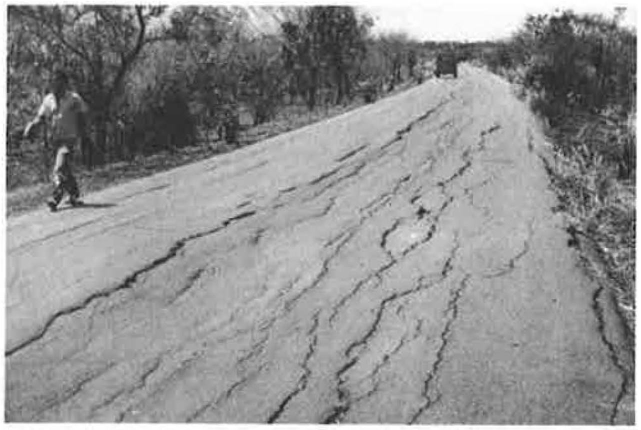

FIGURE 13 Well-developed distress pattern typical of expansive subgrade soils; longitudinal cracks and differential settlements (National Road 6, Kilometer 225, Madagascar).

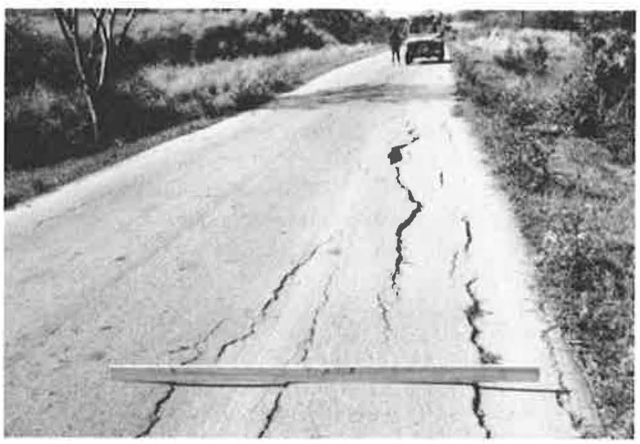

FIGURE 14 Longitudinal cracks and collapsed voids (National Road 6, between Port Bergé and Antsohihy, Madagascar).

FIGURE 15 Longitudinal cracks, settlements, and collapsed voids (National Road 6, between Mampikony and Port Bergé, Madagascar).

FIGURE 16 Longitudinal cracks, settlements, and undulations typical of expansive subgrade soils (National Road 6, between Mampikony and Port Bergé, Madagascar); the car is parked on a stable subgrade section.

high local clay content or friable gravel fraction). Figure 17 shows a local shearing of a friable lateritic sandstone base.

Corrugations

Corrugations of bitumen-surfaced roads usually result from oscillating traffic loading of unstable bitumen mixes, soft aggregates, or soft-penetration-grade bitumen (Figure 18).

Irregular undulations are typical of pavements constructed by labor-intensive methods, particularly telford and macadam pavements, and result from traffic compaction.

Loss of Water and Fines

Water and fines ejected through cracks indicate poor pavement subdrainage. Water ingress may cause saturation of pavement layers. Traffic loading may result in high pore water pressure and create conditions for accelerated attrition of pavement materials and ejection of fines.

FIGURE 17 Local shearing of a soft sandstone gravel, Kilometer 3 from Pobe, National Road 3, between Porto Novo and Pobe, Benin, 1985, before rehabilitation.

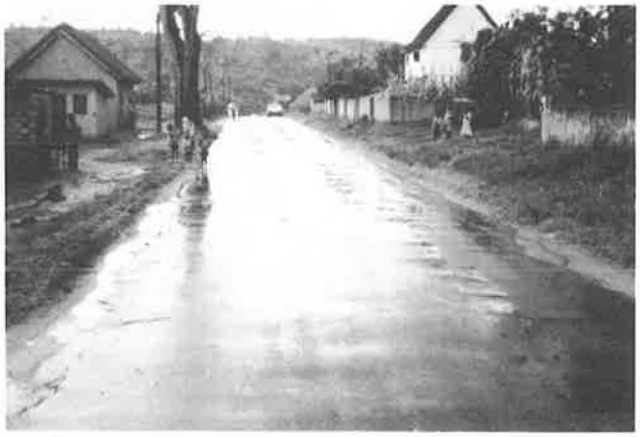

FIGURE 18 Corrugations at Kilometer 20, National Road 7, Madagascar.

FIGURE 19 Cracked blisters and rust staining along the shoulders of National Road 12, Kilometer 133, between Manakara and Farafangana, Madagascar.

Blisters and Cracking

Under arid climates, blisters result from salt heaving (*6*). They are not necessarily associated with cracks, although evaporation of pavement moisture through cracks may cause blistering along these.

Blisters developing along the shoulders of National Road 12, Farafangana, Madagascar, were found to be associated with small radiating cracks and rust staining (Figure 19). They resulted from tropical weathering of volcanic rock aggregates, subsequent migration of dissolved iron, and expansion of residual clay minerals being formed within the aggregates of the hot-mix wearing course.

CONCLUSIONS

The assessment of bitumen-surfaced road pavements before maintenance or rehabilitation works should be based on detailed condition surveys and well-founded engineering judgment to achieve good-quality and low-cost goals.

The basis for sound engineering judgment is careful observation of distress types, with an objective rating of the extent and degree of severity and interpretation of distress associations.

Individual distress types may have different possible causes but distress associations can provide clues to proper diagnosis of the causes of pavement distress and to the required maintenance and rehabilitation work.

Thus, for instance, the association of raveling and cracking on an undistorted pavement results from bitumen aging and indicates that a resealing is required, whereas wide ruts and alligator cracking may result from fatigue of granular pavements and indicate the end of the structural design life and the need for strengthening. The association of cracks and settlements along the lower shoulders unequivocally indicates the lack of proper pavement subdrainage.

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