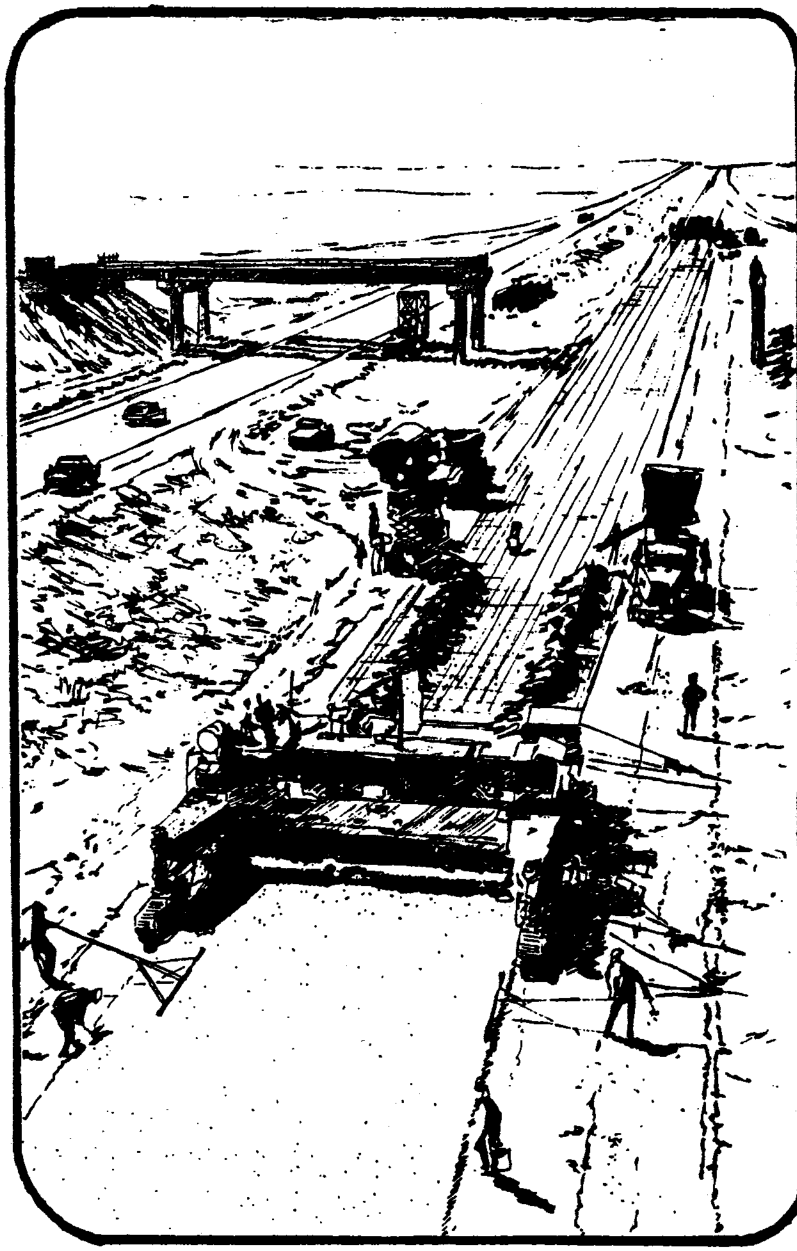
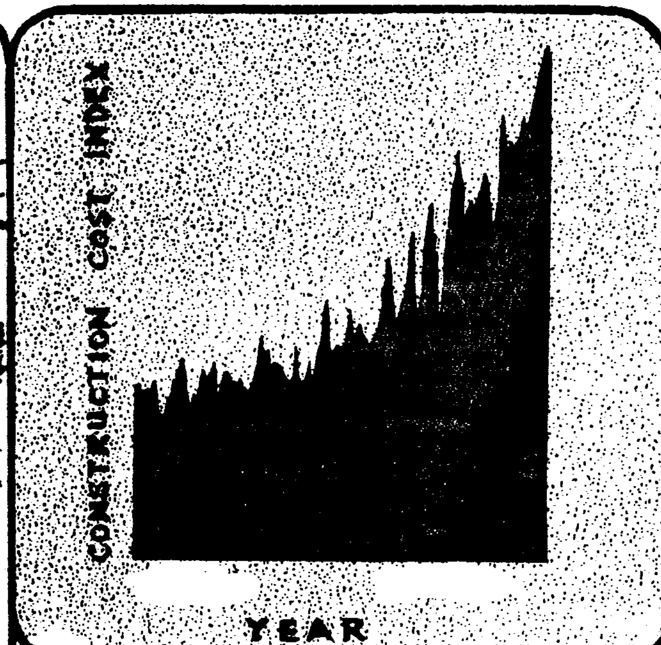
ENGINEERING ECONOMY AND ENERGY CONSIDERATIONS

GUIDELINES FOR FLEXIBLE PAVEMENT FAILURE INVESTIGATIONS

RESEARCH REPORT 214-16

JULY 1980





COOPERATIVE RESEARCH PROJECT 2-9-74-214

"ENGINEERING, ECONOMY AND ENERGY CONSIDERATIONS IN DESIGN, CONSTRUCTION AND MATERIALS"

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

AND

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY

STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

TASK FORCE ON ENGINEERING, ECONOMY AND ENERGY CONSIDERATIONS

Larry G. Walker, Task Force Chairman and Materials and Tests Engineer

Charles H. Hughes, Sr., Study Contact Representative and Assistant Materials and Tests Engineer

A.H. Pearson, Jr., Assistant State Engineer-Director

Wayne Henneberger, Bridge Engineer

Robert L. Lewis, Chief Engineer, Highway Design

Byron C. Blaschke, Chief Engineer, Maintenance Operations

J.R. Stone, District Engineer

William V. Ward, Urban Project Engineer-Manager

Phillip L. Wilson, State Planning Engineer

Franklin C. Young, District Engineer

Theodore E. Ziller, Construction Engineer

GUIDELINES
FOR
FLEXIBLE PAVEMENT FAILURE INVESTIGATIONS

by

F. N. Finn and J. A. Epps

Research Report 214-16

Engineering, Economy and Energy Considerations in Design,
Construction and Materials

2-9-74-214

Sponsored by

State Department of Highways
and Public Transportation

July 1980

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843

INTRODUCTION

Rehabilitation and maintenance of the 70,000 mile state highway system requires in excess of one-half billion dollars annually. Optimal use of these funds is a challenge to the highway engineer considering today's inflation, existing manpower limitations, material shortages and the present condition of the highway system. This report presents a set of brief guidelines which can be used by the field engineer to identify types of pavement failures (distress) and select suitable rehabilitation and maintenance alternatives.

Companion reports provide information from which the field, laboratory, design and research engineers can perform detailed pavement distress investigations and select the most cost effective and energy efficient rehabilitation or maintenance alternative (1, 2, 3).

ORGANIZATION OF GUIDELINES

The guidelines have been prepared in sections according to the type of pavement distress: (1) rutting and corrugations, (2) raveling, (3) flushing, (4) alligator cracking, (5) longitudinal cracking, (6) transverse cracking, (7) roughness and (8) seal coat and surface treatment distress (see page 5 for photographic examples). Each section of the report has been further divided into seven parts: photographs of typical forms of the distress, description of the type of distress, possible causes of distress, rehabilitation alternatives, failure investigation approach, a general discussion, and references from which more detailed information can be obtained.

INFORMATION PROVIDED

The information contained in the manual will provide a quick overview to allow the field engineer to identify (1) various types of distress, (2) techniques and equipment which are available for identifying the probable cause of distress, and (3) rehabilitation and maintenance alternatives for the various types of distress. If the occurrence of distress is considered of sufficient importance it may be desirable to carry out a systematic investigation using information given in the appropriate references for each distress type.

Systematic investigations of pavement failures will provide the following benefits to the Department:

1. Identification of causes of premature failure for each project investigated.

2. Development of more reliable criteria for interpreting both observations and test results from distressed pavements.

3. Development of information necessary to justify changes in structural designs, materials specifications, and construction and maintenance requirements.

Experience has shown that, in most investigations relating to premature distress, there will be more than one contributing factor. Thus, any investigation should consider each possible cause before coming to a conclusion regarding the probable cause(s).

Investigations should also be made on pavements which have exhibited better than average performance to assure that the determinants of distress are properly identified and to develop reliable criteria for making interpretations from information designed to identify the causes of distress.

IMPLEMENTATION

If a decision is made to conduct a field distress investigation, it will be necessary to develop an appropriate plan for the investigation. Such a plan will assure the collection of appropriate information relevant to the specific type of distress.

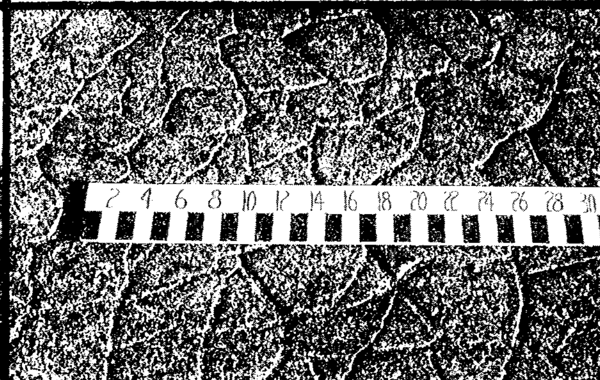
In all probability both field and laboratory activities will be involved. In each case it will be important to make use of trained technologists and the laboratory facilities available. Assistance in planning and testing can be obtained by contacting the Materials and Tests Division, File D-9, State Department of Highways and Public Transportation, Austin, Texas 78703.

Types of Flexible Pavement Distress

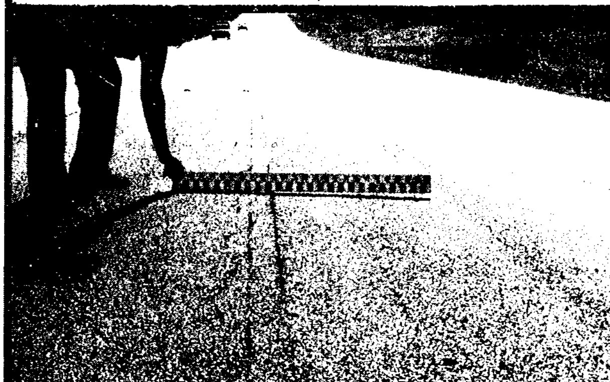
Rutting (page 6)

Raveling (page 8)

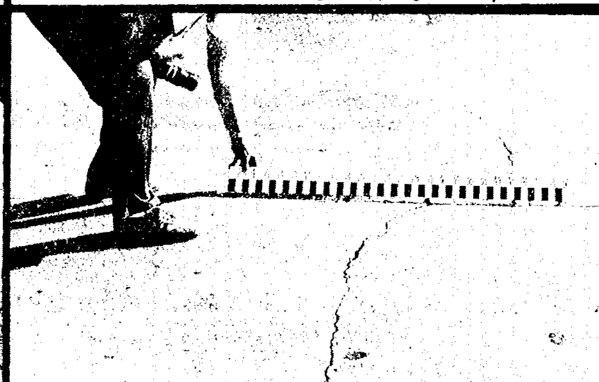
Flushing (page 10)



Alligator Cracking (page 12)



Longitudinal Cracking (page 14)

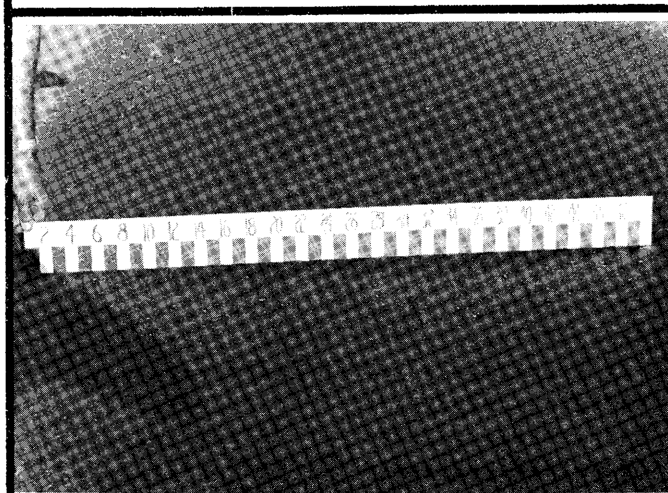


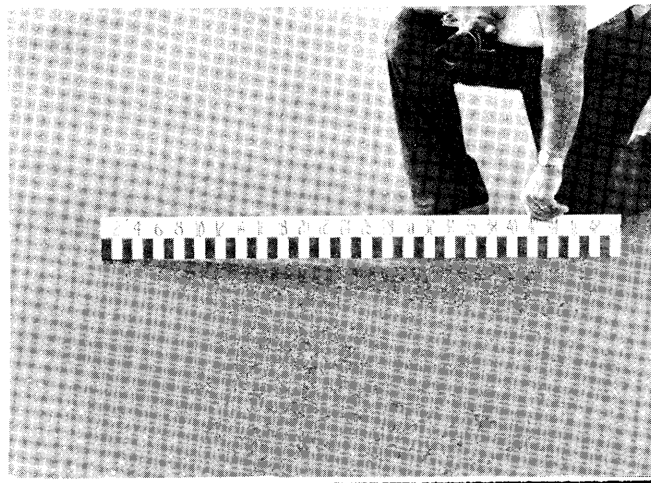
Transverse Cracking (page 16)

Roughness (page 18)

Seal Coat Distress (page 20)

RUTTING AND CORRUGATIONS





DESCRIPTION

Rutting is the channeling or grooving of the pavement surface in longitudinal depressions which develop in the wheel path area. Corrugations are transverse depressions and ridges in the pavement surface. Corrugations often occur in traffic areas associated with acceleration, deceleration, or turning movements. Both rutting and corrugations are traffic related forms of distress and initially appear in the wheel path area.

POSSIBLE CAUSES

Structural deficiency
HMAC mix design
Asphalt cement properties
Stability of pavement layers
Compaction (density) - all layers

REHABILITATION ALTERNATIVES

Cold milling including profile requirements, with or without overlay
Heater scarification with surface treatment or thin overlay
Heater planing with surface treatment or thin overlay
Replacement (particularly applicable to corrugations in localized areas)

FAILURE INVESTIGATION

1. Traffic (per lane)
   a. Accumulated equivalent 18 kip axle loads to date
   b. Design average ten heaviest wheel loads daily (DATHWLD)
2. Construction records
   a. Mix design - all stabilized materials
   b. Material properties - base, subbase, subgrade
   c. Pavement layer thicknesses
3. Maintenance activities
   a. Type
   b. Amount
   c. Effectiveness
4. Laboratory evaluation
   a. HMAC properties
      Stability
      Asphalt content
      Asphalt properties (penetration, viscosity)
      Aggregate properties (gradation, absorption, shape, surface texture)
      Water susceptibility, air void content
   b. Base, Subbase, Subgrade
      Gradation, stiffness coefficients
      Triaxial classification
   c. Stabilized bases
      Asphalt treated (see item 4a above)
      Cement or lime - compressive and tensile strength
5. Field evaluation
   a. Condition survey
   b. Drainage
   c. Cores of stabilized pavement layers
   d. Deflection (Dynaflect)
   e. Roughness (Mays Ride Meter)

DISCUSSION

Rutting and corrugations are most frequently associated with a lack of stability in the HMAC followed by inadequate shear strength in the base, subbase or foundation layers. However, shear strength requirements are influenced by the thickness of the various pavement layers which in turn is a function of the thickness design or actual construction thickness.

Research has shown that rutting can also be a function of deflection. The greater the deflection the greater is the chance for permanent or non-recoverable deformation.

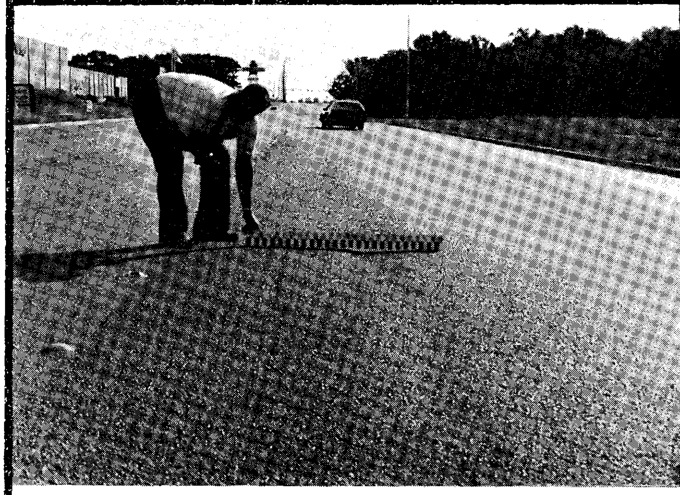
Stripping of the asphalt from the aggregate can effectively reduce the tensile strength (cohesion) within the HMAC and contribute to rutting, and should be considered a possible cause of rutting.

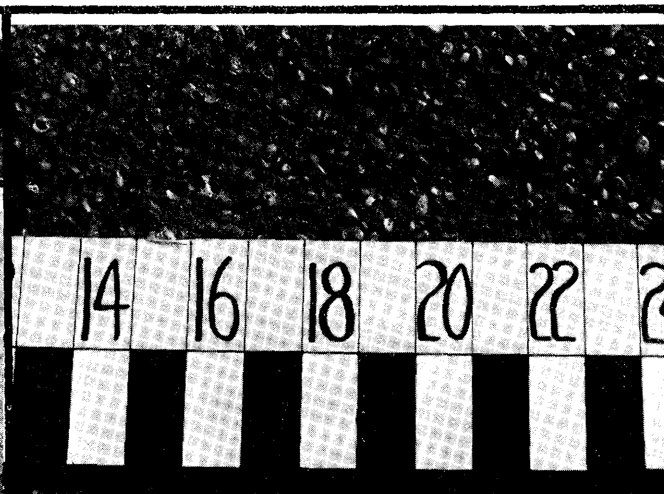
Investigations of rutting will normally concentrate on material properties (stability) and in-place condition (density). However, the investigation should not overlook the possibility of structural deficiencies and excessive deflections.

Rutting and alligator cracking are two of the most difficult types of distress to rehabilitate and require careful planning of alternative treatments.

Reference 1

RAVELING





DESCRIPTION

Raveling is the progressive loss of surface material from HMAC by weathering and/or traffic abrasion. Usually the fine aggregate as binder (matrix) will wear away first to be followed by the larger sized aggregate. As raveling progresses the pavement surface can become rough and in extreme cases can develop potholes. Seal coats can also exhibit a form of raveling in which the uniformly sized aggregate is lost from the surface resulting in an excess of asphalt on the surface of the pavement. Probable causes of seal coat raveling or loss of aggregate are covered under the section on "Seal Coat Failure".

POSSIBLE CAUSES

- Low asphalt content
- Excessive air voids in HMAC
- Hardening of asphalt
- Water susceptibility (stripping)
- Aggregate characteristics
- Hardness and durability of aggregate

REHABILITATION ALTERNATIVES

- Dilute emulsion or rejuvenating "fog" seal
- Seal coat with aggregate
- Slurry seal
- Thin HMAC overlay

FAILURE INVESTIGATION

1. Traffic (per lane)
   a. Average daily traffic
   b. Percent trucks
2. Construction records
   a. HMAC mix design
   b. Asphalt content, source, type and grade
   c. Aggregate characteristics
3. Maintenance activities
   a. Type
   b. Amount
   c. Effectiveness
4. Laboratory evaluation of HMAC
   a. Asphalt content
   b. Asphalt properties (penetration, viscosity)
   c. Aggregate properties (gradation, absorption, shape, surface, texture, mineralogy)
   d. Water susceptibility
   e. Air voids
5. Field evaluation
   a. Condition survey
   b. HMAC cores for laboratory evaluation

DISCUSSION

Raveling is usually associated with the asphalt in the HMAC. The amount of asphalt actually incorporated in the HMAC and the hardness (consistency) of the asphalt are prime considerations. Density of the HMAC can also be a major factor contributing to raveling.

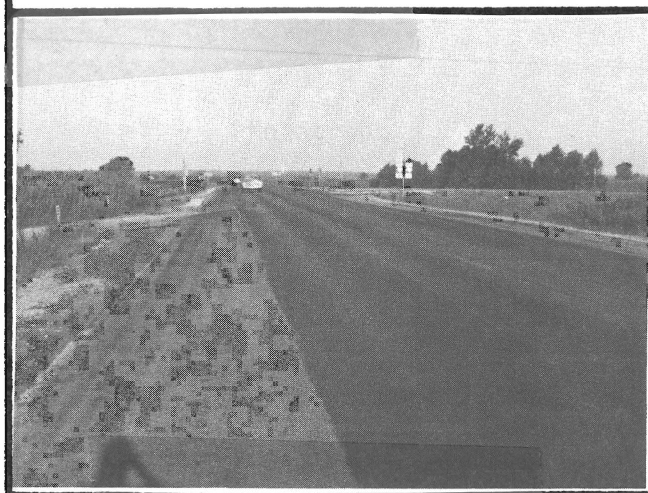
Raveling can also be caused by poor asphalt-aggregate adhesion in the presence of water (stripping). The identification of stripping as a probable cause will require careful evaluation and comparison with available distress criteria.

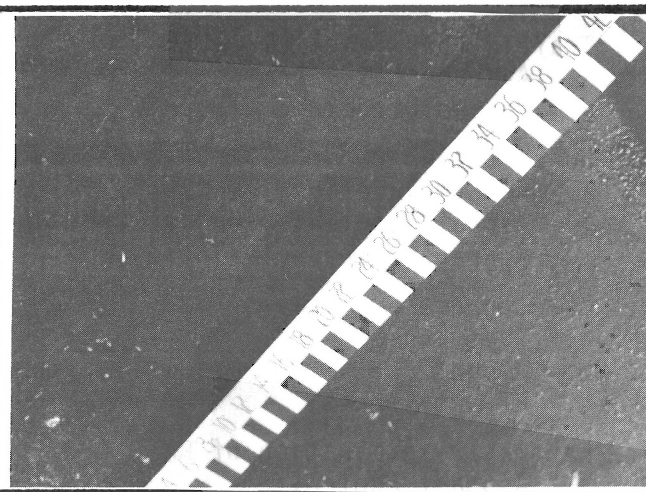
There are a number of ways to retard or correct raveling which are relatively inexpensive.

However, if there are systematic and identifiable causes of raveling, they should be corrected by changes in specification or construction requirements.

REFERENCE	1

FLUSHING (BLEEDING)





DESCRIPTION

. Flushing is the presence of an excess amount of asphalt on the surface of the pavement. Flushing or bleeding will be most prevalent in the wheelpath areas, although in some situations the entire pavement surface may exhibit flushing to some degree.

Seal coats can exhibit surface characteristics similar to flushing if there has been a significant loss of aggregate or if excess asphalt was utilized. Probable causes of seal coat bleeding are covered under the section on "Seal Coat Failures".

POSSIBLE CAUSES

- High asphalt content
- Excessive densification of HMAC during construction or by traffic (low air void content)
- Temperature susceptibility of asphalt (soft asphalt at high temperatures)
- Excess application of "fog" seal or rejuvenating materials
- Water susceptibility of underlaying asphalt stabilized layers together with asphalt migration to surface

REHABILITATION ALTERNATIVES

- Overlay of open graded friction course
- Seal coat (well designed with good field control during construction)
- Cold milling with or without seal coat or thin overlay
- Heater-scarification with seal coat or thin overlay
- Heat surface and roll-in coarse aggregate

FAILURE INVESTIGATION

1. Traffic (per lane)
   a. Average daily traffic
   b. Percent trucks
2. Construction Records
   a. HMAC mix design
   b. Amount and type of prime and tack coat materials
   c. Asphalt content
3. Maintenance activities
   a. Type
   b. Amount
   c. Effectiveness
4. Laboratory evaluation of HMAC
   a. Asphalt content
   b. Asphalt properties (penetration, viscosity, temperature susceptibility)
   c. Air voids
   d. Water susceptibility of asphalt stabilized base
5. Field evaluation
   a. Condition survey
      - HMAC cores for laboratory evaluation
      - Asphalt stabilized base cores for laboratory evaluation
      - Accident records
      - Skid number

DISCUSSION

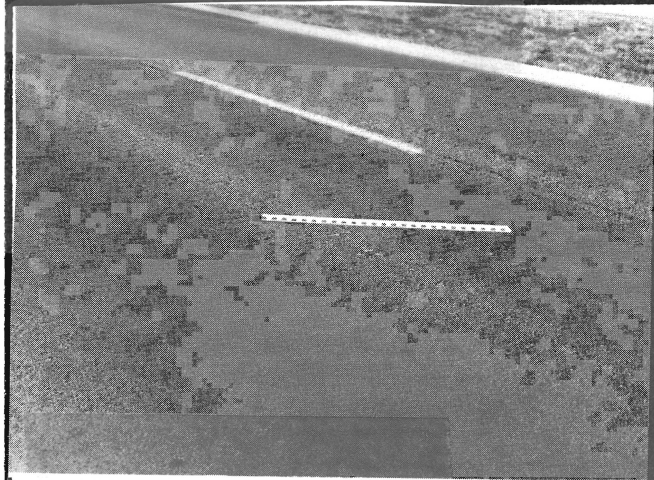
Flushing is generally associated with an excessive amount of asphalt in the HMAC. Laboratory procedures have been developed to prevent use of too much asphalt; however, in some situations the laboratory procedures may not reliably estimate the effect of traffic (densification), weather (high temperature), and the temperature susceptibility of the asphalt cement.

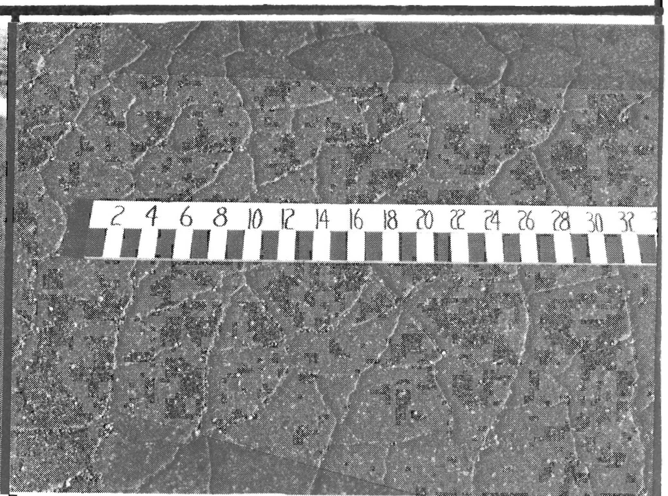
There are a number of corrective treatments for flushing. One such treatment is to cover the surface with a seal coat. Extreme care should be exercised in using this treatment since the condition could be exaggerated by a poor seal coat application.

Flushing is a safety consideration relative to the performance of a pavement and should be corrected as soon as possible after being reported and evaluated.

REFERENCES

ALLIGATOR CRACKING





DESCRIPTION

Alligator cracks are a network of multi-sided blocks (polygons) resembling the skin of an alligator. This type of cracking is frequently referred to as fatigue cracking. It is associated with traffic and initially appears in the wheel path area.

POSSIBLE CAUSES

- Structural deficiency
- Excessive air voids in HMAC
- Asphalt cement properties
- Stripping of asphalt from aggregate
- Construction deficiencies

REHABILITATION ALTERNATIVES

- Seal coat
- Replacement (dig-out and full depth HMAC replacement in failed areas)
- Overlay of various thicknesses with or without special treatments to minimize crack reflection
- Recycle (central plant or in-place)
- Reconstruction

FAILURE INVESTIGATION

1. Traffic (per lane)
   a. Accumulated equivalent 18 kip axle loads to date
   b. Design average ten heaviest wheel loads daily (DATHWLD)
2. Construction records
   a. Mix design - all stabilized materials
   b. Material properties - base, subbase, subgrade
   c. Pavement layer thicknesses
3. Maintenance activities
   a. Type
   b. Amount
   c. Effectiveness
4. Laboratory evaluation
   a. HMAC properties
      - Asphalt content
      - Asphalt properties (penetration, viscosity)
      - Aggregate properties (gradation, absorption, shape, surface texture)
      - Water susceptibility
      - Air voids
   b. Base, subbase, subgrade
      - Gradation
      - Stiffness coefficients
      - Triaxial classification
   c. Stabilized bases
      - o Asphalt treated (see Item 4a above)
      - 0 Cement or lime - compressive and tensile strength
5. Field evaluation
   a. Condition survey
   b. Drainage
   c. Cores of stabilized pavement layers
   d. Deflection (Dynaflect)
   e. Roughness (Mays Ride Meter)

DISCUSSION

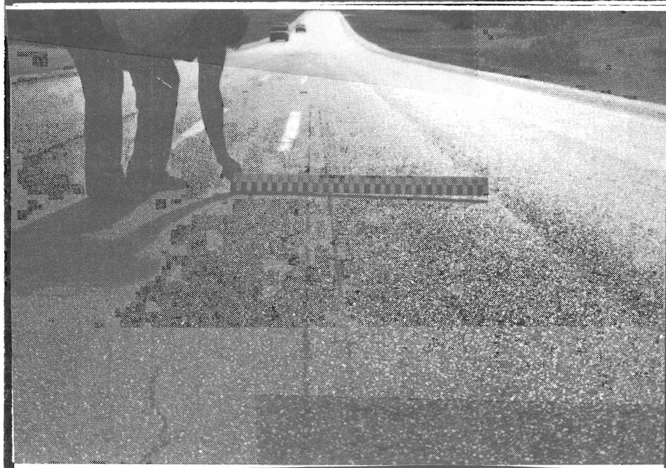
Alligator cracking is an indication that the pavement has been deflected (stressed) an excessive number of times and has formed a system of cracks as a result of such deflections. In most engineering materials alligator cracking would be referred to as fatigue cracking or the cumulative effect of multiple load applications.

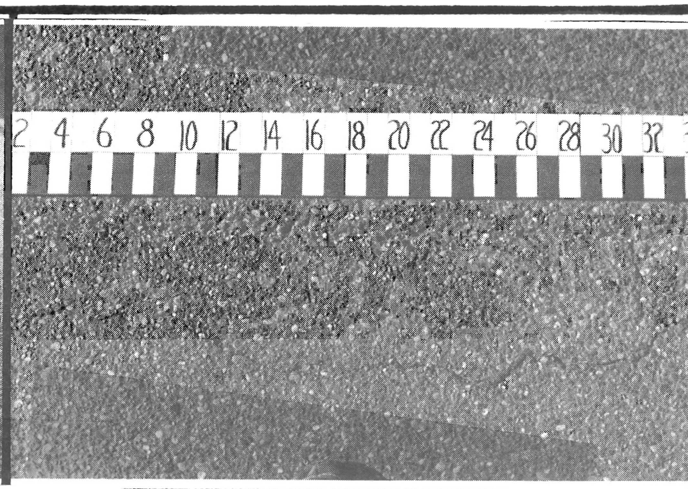
Alligator cracking is one of the most serious and complicated forms of pavement distress. Its occurrence can be influenced by all phases of design and construction as well as material properties and environment. Rehabilitation of pavements with alligator cracking requires some of the most expensive rehabilitation procedures.

REFERENCES

1, 2, 3, 4, 5

LONGITUDINAL CRACKING





DESCRIPTION

A longitudinal crack is a break or fracture of the pavement surface which is approximately parallel to the pavement centerline. Longitudinal cracks may be either traffic (load) associated or non-load associated.

Longitudinal cracking such as edge cracks, construction joints, settlement and possibly reflection cracking are non-load associated (not related to traffic) and usually result from some type of volume change in the paving or foundation materials.

Longitudinal cracks in the general vicinity of the wheel paths are indications of load associated effects. Such cracks are usually the first indicator that alligator cracks will occur in the pavement surface.

Reflection cracks may be either load associated or non-load associated. In all probability most reflection cracking is a combination of traffic, materials and environmental effects.

POSSIBLE CAUSES

- <u>Load Associated</u>
  Structural deficiency
  Excessive air voids in HMAC
  Asphalt cement properties
  Stripping of asphalt from aggregate
  Aggregate gradation
  Construction deficiencies

<u>Non Load Associated</u>
Volume change potential of foundation soil
Slope stability of fill materials
Settlement of fill or in-place materials as a result of increased loadings
Segregation due to laydown machine
Poor Joint construction
Other construction deficiencies

REHABILITATION ALTERNATIVES

- Crack sealing
- Seal coat (applied to areas with cracking)
- Replacement (dig-out and replace distressed areas)
- Thin overlay with special treatment to seal cracks and minimize reflection cracking
- Asphalt-rubber membrane with aggregate seal or thin overlay
- Heater-scarification with a thin overlay

FAILURE INVESTIGATION

- Load Associated
  See those factors enumerated in the section on "Alligator Cracking"
- Non-Load Associated
  1. Traffic (per lane)
     a. Average daily traffic
     b. Percent trucks
  2. Construction records
     a. Properties of fill and subgrade materials (plastic index, etc.)
     b. Laydown and joint construction details
     c. Condition of underlying pavement (type and amount of cracks)
  3. Maintenance activities
     a. Type
     b. Amount
     c. Effectiveness
  4. Laboratory evaluations
     a. Volume change properties of fill and subgrade soils
     b. Density profile of fill
     c. Consolidation properties of in-place materials
     d. Shear strength of fill material
     e. Segregation of HMAC near crack
  5. Field evaluation
     a. Condition survey
     b. Roughness (Mays Ride Meter)
     c. Drainage
     d. Undisturbed samples of fill and subgrade foundation soils
     e. Geometric factors - width of lane, paved or unpaved shoulder

DISCUSSION

Longitudinal cracking may occur as a consequence of either traffic or non-traffic related factors. It is important to recognize the difference. Detailed condition surveys will be required in order to reliably identify which category of distress is contributing to the problem.

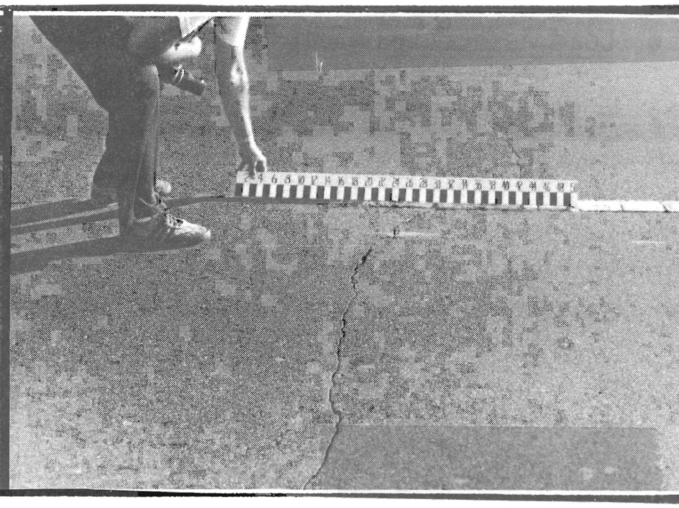
If the problem is non-traffic related it will not be necessary to implement a study comparable to that used for alligator cracking.

Cracking associated with settlement or slope stability becomes a foundation problem and can be analyzed by conventional procedures. Visual examination by experienced foundation engineers may be sufficient to identify slope stability and consolidation effects.

Edge cracking may be a function of volume changes in the foundation soil; it may also be a lack of shoulder support or lane width. In most cases the cause of edge cracking can be identified from field observation by a trained observer.

REFERENCE	1, 6

TRANSVERSE CRACKING



DESCRIPTION

A transverse crack is a break or fracture of the pavement surface which is approximately perpendicular to the pavement centerline. Transverse cracks are normally non-load associated (not related to traffic) and usually result from some type of volume change in the HMAC, base or subbase material. Transverse cracks may or may not extend across all lanes of contiguous paving and are often caused by reflection from underlying layers. In all probability most reflection cracking is a combination of traffic, materials and environmental effects.

POSSIBLE CAUSES

- Hardness of asphalt cement
- Stiffness of HMAC
- Volume changes in base and subbase
- Unusual soil properties

REHABILITATION ALTERNATIVES

- Crack sealing
- Seal coat
- Overlay with special treatment to seal cracks and minimize reflection cracking
- Asphalt-rubber membrane with aggregate seal or thin overlay
- Heater scarification with a thin overlay

FAILURE INVESTIGATION

1. Traffic (per lane)
   a. Average (per lane)
   b. Accumulated equivalent 18 kip axle loads to date
2. Construction records
   a. HMAC mixture design
   b. Material properties - base, subbase, subgrade
   c. Pavement layer thickness
   d. Condition of underlying pavement (type and amount)
3. Maintenance activities
   a. Type
   b. Amount
   c. Effectiveness
4. Laboratory evaluation
   a. HMAC Properties
      Asphalt content
      Asphalt properties (penetration, viscosity, temperature susceptibility, stiffness at low temperatures)
      Mixture properties (tensile strength, stiffness at low temperatures)
      Aggregate properties (gradation, absorption)
   b. Treated bases and subbases
      Volume change potential
      Tensile strength
   c. Untreated aggregate bases
      Gradation
      Mineralogy of clay fraction
5. Field evaluation
   a. Condition survey
   b. Roughness (Mays Ride Meter)
   c. Cores of stabilized pavement layers
6. Climatological information
   a. Minimum temperatures
   b. Rate of temperature drop
   c. Daily temperature change

DISCUSSION

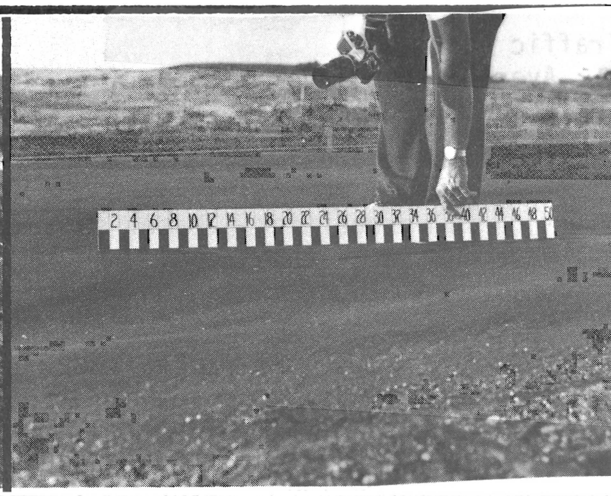
Transverse cracking is most commonly associated with stabilized bases (portland cement and lime) and low temperature or thermal cracks. The naturally occurring volume change cracks associated with portland cement and lime stabilized materials are reflected through the asphalt concrete to the surface of the pavement.

Low temperature or thermal cracking can occur in asphalt concrete and may occur in untreated aggregate base. The low temperature cracking in asphalt concrete is most frequently associated with the properties of the asphalt; stiffness and temperature susceptibility are the major contributing factors. Low temperature cracking in untreated aggregates has been related to the mineralogy of the clay fraction.

Observations indicate that traffic volumes and weights may contribute to the frequency of low temperature cracking.

Reference	1

ROUGHNESS



DESCRIPTION

Roughness is the absence or lack of smoothness in the longitudinal or transverse surface profile which causes poor vehicular riding quality.

POSSIBLE CAUSES

- Presence of physical distress (cracking, rutting, corrugations, potholes, etc.)
- Volume change in fill and subgrade materials
- Non-uniform construction

REHABILITATION ALTERNATIVES

- Overlay
- Cold milling with or without overlay
- Heater scarification with overlay
- Heater planing with overlay (primarily for local areas and areas with corrugations)
- Recycle (central plant or in-place)

FAILURE INVESTIGATION

1. Traffic (per lane)
   a. Average daily traffic
   b. Accumulated equivalent 18 kip axle loads to date
2. Construction records
   a. Density - all layers and subgrade soil
   b. Site conditions - natural drainage locations, amount of cut and fill
   c. Pavement layer thickness
3. Maintenance activities
   a. Type
   b. Amount
   c. Effectiveness
4. Laboratory evaluation
   a. Volume change potential of subgrade material
5. Field evaluation
   a. Condition survey
   b. Roughness (Mays Ride Meter)
   c. In-place density
6. Climatological information
   a. Minimum temperature
   b. Freezing index
   c. Precipitation

DISCUSSION

Since roughness can be a secondary result of any of the various forms of distress discussed in this manual it will be necessary to first determine which of the three possible causes indicated in this section is the most probable cause.

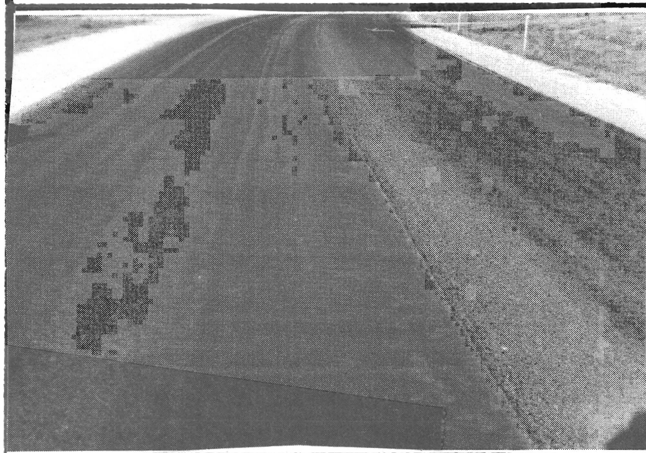
If condition surveys indicate physical distress is the probable cause, the investigation would be directed to the form of distress identified; probably alligator cracking, rutting or transverse cracking.

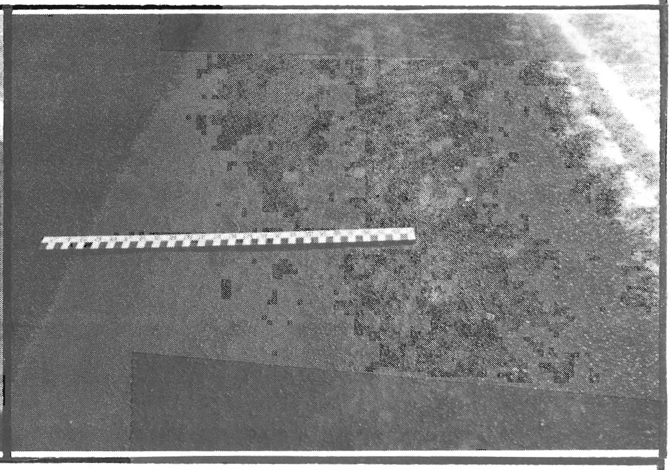
If physical distress is not the probable cause, expansive soils would be the next easiest to evaluate (eliminate). Knowledge of local soils would be the first clue; laboratory tests would follow.

Non-uniform construction may be hard to determine; however, statistical evaluation of construction data and field tests would provide good indicators if this factor has contributed to roughness.

Reference	1

SEAL COAT AND SURFACE TREATMENT FAILURES





DESCRIPTION

Failures associated with aggregates or chip seal coats. These failures are normally associated with the loss of coverstone or the use of excess asphalt.

POSSIBLE CAUSES

- Properties of asphalt
- Characteristics of aggregate
- Quantities of asphalt and aggregate
- Construction procedures
- Climate
- Excessive amount of traffic or nature of traffic (acceleration, deceleration, turning movements)

REHABILITATION ALTERNATIVES

- Seal coat (well designed with good field control during construction)
- Overlay
- Recycle surface (seal coat only)
- Heater scarification with surface treatment or overlay (seal coat only)
- Cold milling with or without overlay (seal coat only)

FAILURE INVESTIGATION

1. Traffic (per lane)
   a. Average daily traffic
   b. Percent trucks
2. Construction records
   a. Seal coat design information (spread rates for aggregate and asphalt, adjustment factors for type or condition of existing surface)
   b. Asphalt source, type and grade
   c. Aggregate source, type and gradation, moisture content
   d. Traffic control procedures
   f. Climate during and date of construction
3. Maintenance activities
   a. Type
   b. Amount
   c. Effectiveness
4. Laboratory evaluation
   a. Asphalt properties (penetration, viscosity)
   b. Aggregate properties (gradation, shape, absorption, texture, water susceptibility)
5. Field evaluation
   a. Condition survey
   b. Depth of aggregate embedment
6. Climatological information
   a. Maximum and minimum temperature during and immediately after construction
   b. Precipitation during and immediately after construction

DISCUSSION

The successful application of a seal coat or surface treatment is dependent on more different factors than any other single type of pavement construction or maintenance procedure. The primary difficulties are often with the spread rates of the asphalt for a specific size of aggregate. However, every step of the operation can be a potential cause for failure. Even the intermittent presence of shade trees can cause failures in seal coat applications.

It is often very difficult to diagnose failures; however, if a careful accumulation of information can be obtained the cause of failures (or successes) can usually be identified.

References

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