Types and Causes of Failure in Highway Pavements

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● A DESCRIPTION or discussion of failures in highway pavements presents some difficulty because in many cases there is no agreement on terminology; furthermore, the same type of distress may be variously described by engineers in different areas of the country and in different engineering organizations. Among those who use language for communication, engineers are not the most meticulous in their choice of terms, and it is at times difficult clearly to understand just what is being discussed. In addition to the use of different phrases and expressions to describe types of pavement construction and types of failure, there is lack of distinction between "failure" and the evidence of some condition that makes the pavement less than perfect. It appears that there is a too prevalent tendency to use the one word "failure" to describe all manner of phenomena, some of which are, strictly speaking, not failures at all and may be only warnings of possible future adverse developments, or may be nothing more than a minor defect. For example, pumping of water through the joints in concrete pavements is generally viewed with alarm, but if this never progressed beyond the pumping of water, there should be little cause for concern. The same may be said of many forms of cracking in pavements of all types. It is certainly a moot question whether or not a crack in any type of pavement should be regarded as a failure. It often seems that if a crack is placed in a concrete pavement by the engineer, that is "design," but if the pavement cracks where it wants to, that is a failure, although the traveling public may use the road with satisfaction for years without being aware of such fine distinctions. In any event, it seems that some grouping and classification of so-called failures is necessary for discussion purposes.

The types of pavement distress are first logically divided into two primary groups, depending upon the type of pavement. Certain characteristic defects develop in asphaltic pavements and others are typical of portland cement concrete types. It also appears that there is a greater variety in the distress patterns developed in bituminous pavements compared to portland cement concrete. This is partly attributable to the fact that there are a great many more variations and varieties of bituminous types of road surfacing. Also, under-design is far more frequent in the "flexible" types, prompted by the urge for economy in first costs.

Considering the bituminous or so-called flexible types first, failures may be grouped under three headings depending upon the primary cause or source of the trouble. First, are the types of failure or unsatisfactory performance that are attributable solely to the quality of the pavement itself. Deficiencies of this type may be in the form of stripping, raveling, disintegration, cracking and instability (or plastic distortion) of the road surface which may develop regardless of foundation support. The second group is represented by several manifestations but represents only one type of failure; that is, slippage caused by lack of bond between the top course of the pavement and the underlying leveling course or base layer. In the third group are the pavement failures attributable to deficiencies in the base or the underlying support. Chart A is an attempt to classify failures characteristic of bituminous pavements. This chart separates the failures into those caused by qualities of the surface layer alone, those that are due to improper relationship between the surface course and the next layer, and finally those that are chargeable solely to weak, yielding or unstable foundations. Chart B (see "Concrete Pavements") represents a similar arrangement of the failures characteristic of concrete pavements.

It is difficult to describe each of these failures clearly so that everyone will recognize the distinguishing characteristics of each. Attempts have been made to secure photographs representing typical examples. The following series have been selected to illustrate the most common types of failure and are shown accompanied with a brief explanation in an attempt to diagnose the cause and to assign reasons for the particular development. Due to space limitations, no detailed discussion of preventive measures or proper maintenance repair has been undertaken.

ANALYTICAL CHART
Classification of Failures in Bituminous Road Surfaces

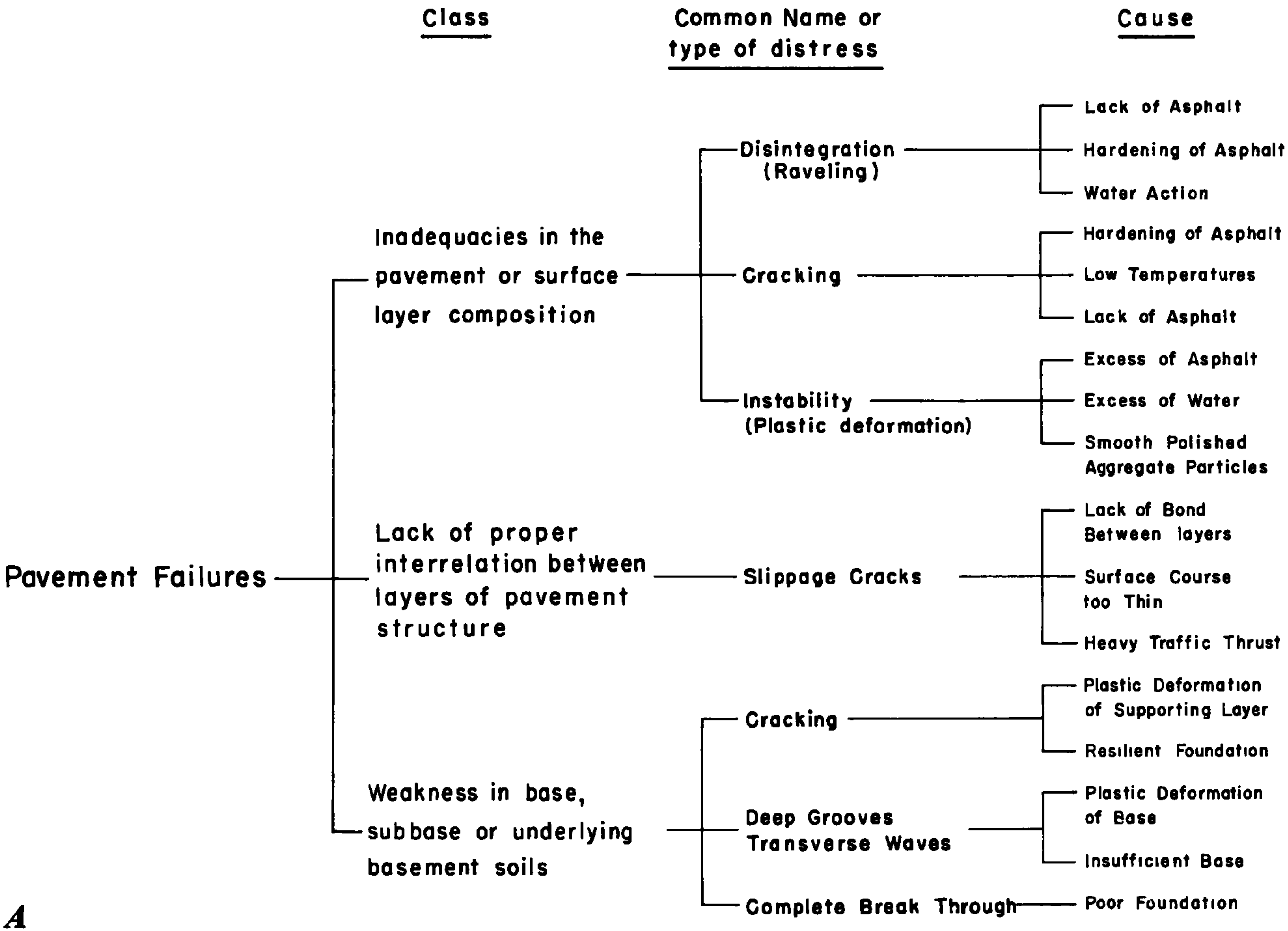

Chart A

BITUMINOUS PAVEMENTS

Failures and Distress

Figures 1 to 12, inclusive, show types of failure or unsatisfactory performance that are attributable solely to the quality of the pavement itself.

Figures 13 to 17, inclusive, show types of distress caused by lack of bond or lack of friction between layers of surface and/or level course or base.

Figures 18 to 36, inclusive, show failures and distress appearing in the surfacing, but primarily due to weakness and instability in the base or underlying soil.

Figure 1. Raveling of a pavement in grooves corresponding to the alternate strips of light and heavy application left by an asphalt distributor.

Cause: Poor adjustment of the distributor sprays causing application in streaks; or insufficient asphalt in the mix to prevent raveling where unprotected by the surface application.

Figure 2. Screenings (or stone chips) whipped off from a seal coat leaving right hand lane almost bare in contrast to the left hand lane which shows good coverage and retention of stone cover.

Cause: Failure of emulsified asphalt binder to dehydrate and set up properly because work was done on right hand side in cold, damp weather.

Figure 3. Disintegration of a level course consisting of hot plant mix using 120-150 pen asphalt.

Cause: Hydrophilic fine material in a mixture subjected to rain shortly after construction. Traffic whipped out fine material leaving the mosaic of coarse aggregate particles.

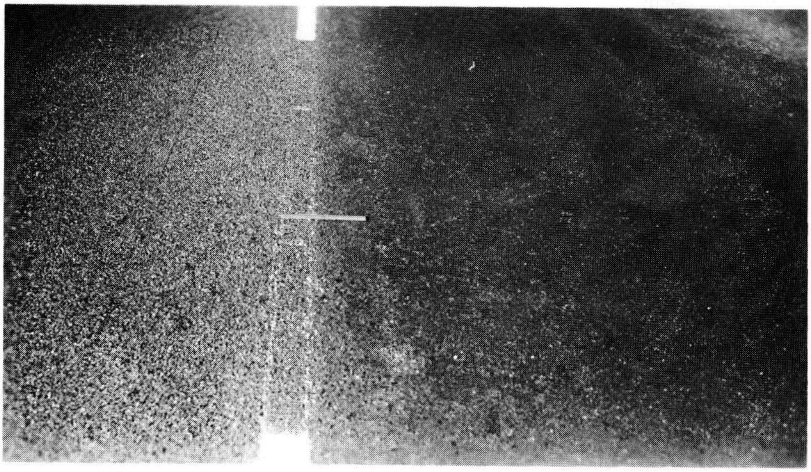

Figure 4. Extensive deterioration of new plant mixed dense graded bituminous surface. Hot mix material with 85-100 pen asphalt.

Cause: Surfacing was spread and compacted with steel tired roller in October but was not open to traffic until a month later and was subjected to a heavy rain and heavy high speed traffic on the opening day before a "traffic seal" could be developed by the pneumatic tires; or aggregate particles were coated with fine clay-like material. Total amount passing No. 200 was within specification limits but material would not pass the Sand Equivalent Test.

Note: Aggregates from same quarry have given no trouble since washing required at plant.

Figure 5. Extensive raveling in oil mix surfacing in the Mojave desert. A dense graded plant mix with SC oil constructed in 1929.

Cause: Insufficient amount of asphalt aggravated by a coating of colloidal clay on all sand grains. An initially high percentage of moisture caused the mix to appear well oiled when first laid down.

Note: Aggregate was hydrophilic and would not have passed the present day Sand Equivalent Test.

Figure 6. Extensive raveling of a dense graded mix using liquid asphalt placed as resurfacing over an existing pavement.

Cause: Insufficient quantity of asphalt in the mix.

Figure 7. Unstable pavement. Deformation evidenced by distortion in traffic stripe. Surface scarred by attempts to blade off the bumps.

Cause: Too much asphalt in the mix.

Figure 8. Somewhat unusual irregular pattern of an unstable road mixed surfacing.

Cause: Primary cause—excess amount of asphalt. Lack of uniformity in pattern of distorted surface probably due to scattered pieces of large stone in the mixture.

Figure 9. An unstable surface, distortion evidenced by substantial grooving in the wheel path.

Cause: Moisture entering from the subgrade and flushing the relatively liquid asphalt to the surface.

Figure 10. An unusual example of an unstable distorted surface which is also raveling under the action of traffic.

Cause: Same project as Figure 5. Aggregate contained a high percentage of colloidal clay of the montmorillonite type and from 3 percent to 4 percent moisture. The total liquid content of asphalt plus moisture was too high for a stable mix and surface developed transverse waves and grooving under the initial traffic. As moisture on exposed surface was dried out under the hot desert sun, surface began to ravel due to deficiency in amount of binding agent.

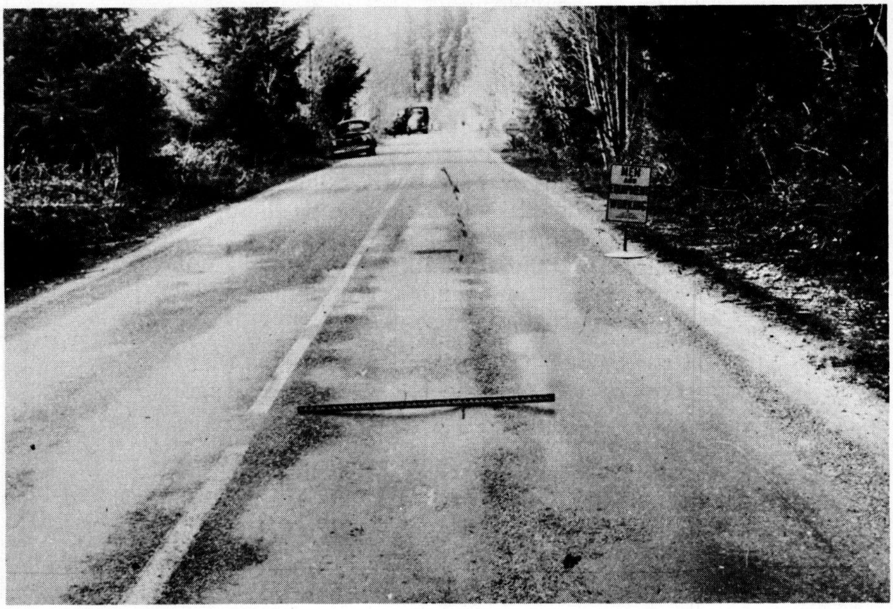
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Figure 11. Shrinkage cracks in a sheet asphalt pavement characteristic of mixtures containing a relatively high content of low penetration asphalt and subject to little or no traffic.

Cause: Shrinkage due to the volume change characteristics of the asphalt. Shrinkage cracks are usually distinguished by the primary and secondary sequence of crack formation and by the shape of the polygons which tend to have sharp corners and angles—many of which approach 90 degrees.

Note: Asphalt has about four times the thermal coefficient of expansion of the average stone or sand particle. Such cracks are characteristic of rich mixtures subjected to insufficient traffic to close the cracks and to offset thixotropic hardening.

Figure 12. Another example of shrinkage cracks in a mixture containing coarser aggregates. Even though separated into small blocks, such road surfaces may remain quite smooth with little signs of distortion indicating that the cracking is not caused primarily by poor foundation, or heavy loads.

Cause: Shrinkage and drying out of the mix.

Figure 13. Crescent shaped cracks in a stable surfacing over a sound base.

Note: The larger cracks have been patched.

Cause: Slippage of the surface course on a smooth textured asphalt base or level course. Lack of bond between the two layers frequently caused by a layer of fine dust, moisture or both.

Figure 14. Another example of slippage. Movement of pavement is indicated by distortion in transverse paint stripes. Traffic moves to the left in the far lane and to the right in the lane just beyond the longitudinal stripe.

Cause: Vehicle wheels form a depression however slight in all pavements. Wheels tend to push a wave before the wheel in the direction of travel. Surface may slide if bond is too weak. Braking and deceleration of heavy loads may also cause slippage.

Note: An unstable sand mix may also flow in direction of traffic.

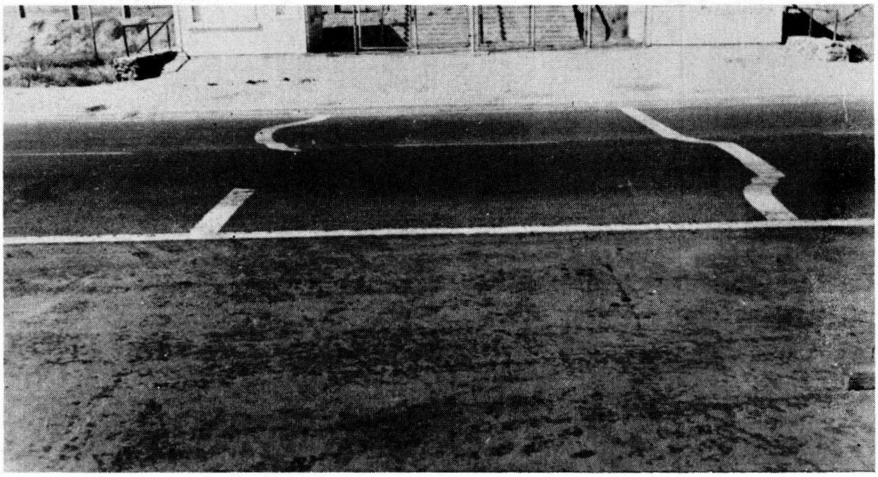
Figure 15. Another example of slippage failure illustrating the lateral movement that frequently occurs where shoulder support is weak or non-existent.

Cause: Primary cause same as for Figure 12.

Note: The thrust is in the direction of travel and toward the low side of the cross-section.

Figure 16. Another example of slippage failure.

Cause: In this case, under heavy truck traffic on a steep downgrade. Loose sandy surface on the cement treated base.



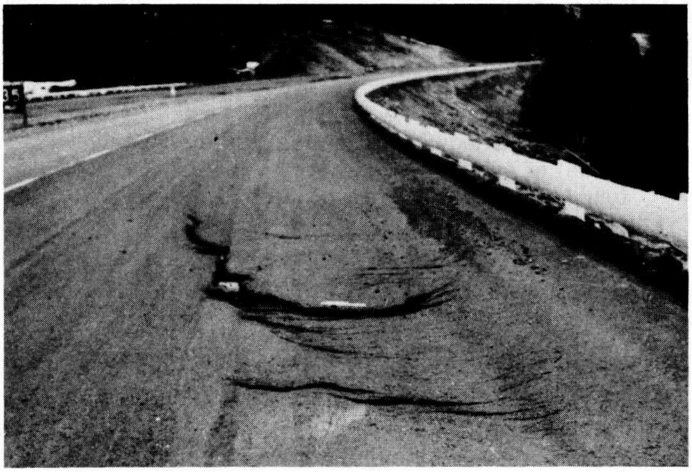

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Figure 17. A close-up view of large cracks caused by slippage.

Note: It is useless to seek to prevent this type of failure by changes in the surface mix design or composition.

Figure 18. Depressions in the wheel path and upheavals along-side causing breaking and rupture of the asphalt surfacing.

Cause: An unstable base and poor foundation saturated with water.

Figure 19. Failures in the outer wheel lane on WASHO test track showing depression and breakup of surfacing accompanied by upthrusts of the uncemented granular material on the shoulder.

Cause: Inadequate thickness (for the wheel loads) of pavement and base over plastic foundation soil; or lack of lateral support in shoulder material.

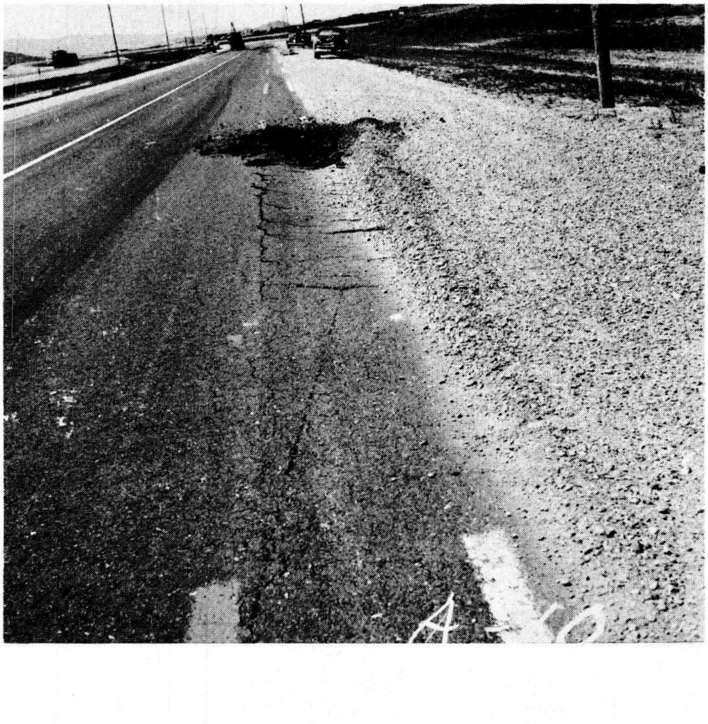

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Figure 20. Failure in the wheel path on the Brighton test track.

Cause: Lateral and upward movement of the gravel base which was not sufficiently stable to resist the heavy truck loads on the thin bituminous surface.

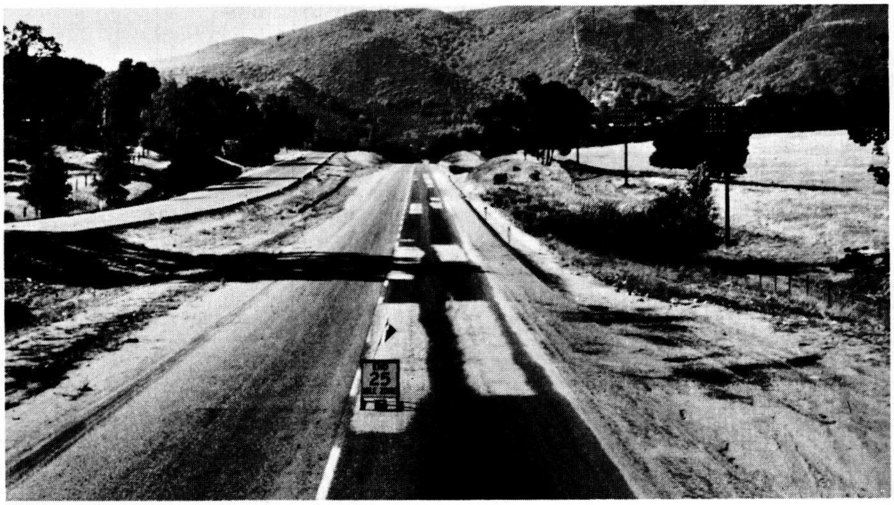
Note: Gravel base had a CBR of 90 at 0.1 in. pen and a "minimum CBR" of 54.

Figure 21. Extensive patches over areas of distress in an outer traffic lane which carries virtually all of the heavy vehicle loads.

Cause: Springy or resilient foundation. Pavement shows high deflection readings under the Benkelman beam; or heavy vehicle loads.

Figure 22. Typical "alligator" type crack pattern characteristic of failures in a stable asphalt pavement when subjected to heavy wheel loads over yielding foundations.

Note: Foundation may be unstable (plastic) or resilient (springy).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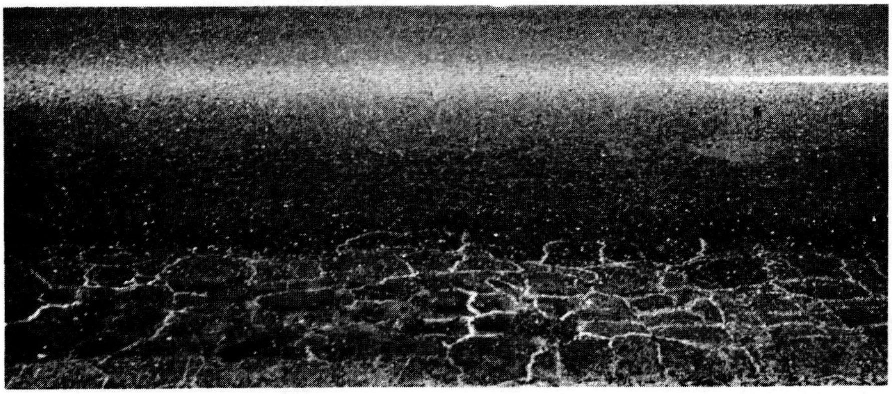


Figure 23. Close-up of an alligator crack pattern in a heavy asphaltic concrete pavement. (4 in. of A.C. over 13 in. of stable granular base and subbase.)

Cause: Springy or resilient soil beneath the subbase; unusually hard and brittle asphalt; or heavy traffic.

Figure 24. Block type cracking in an asphalt surface over a cement treated base.

Cause: Base was of insufficient thickness and strength to sustain the heavy truck loads over a local area of poor basement soil; or heavy truck traffic.

Figure 25. Examples of local spot failures in bituminous surfacing over a cement treated base on a 6 percent grade.

Cause: Water being forced upward through cracks in the base.

Note: Water is standing about 3 in. deep in hole in surfacing.

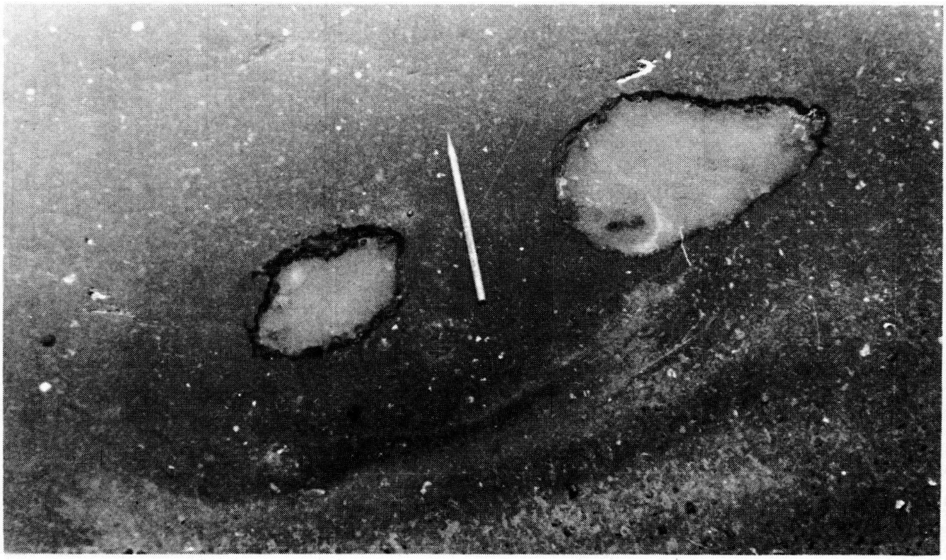


Figure 26. Same as Figure 25. Local failure in a bituminous surface at right of photo.

Note: Water flowing out through a core hole cut through the bituminous surface and cement treated base.

Cause: Water under pressure beneath the base due to impervious soil beneath base and a steep grade with superelevations.

Note: Water pressure actually lifted the base and surface in certain areas.

Figure 27. Longitudinal crack in the outer shoulder parallel to the pavement.

Cause: Fill settlement involving both downward and lateral movement.

Note: No traffic loads on this area.

Figure 28. Longitudinal cracks in the outer traffic lane.

Cause: Deep seated movements involved in fill settlement.

Figure 29. Alligator cracking and extensive distress in a thin bituminous surface over a cement treated base in an arid region subjected to irrigation.

Primary Cause: Alkali attack which weakened and destroyed the slab strength of the cement treated base.

Secondary Cause: Insufficient thickness of surface and weakened base over a poor basement soil.

Figure 30. Wide double cracks near edge of pavement over cement treated base. Surface has been sealed and material in cracks has settled slightly.

Cause: Cracking in a cement treated base which was of insufficient thickness and strength to support heavy traffic over a weak foundation.

Figure 31. Typical crack pattern in a bituminous surface reflecting cracks in a cement treated base.

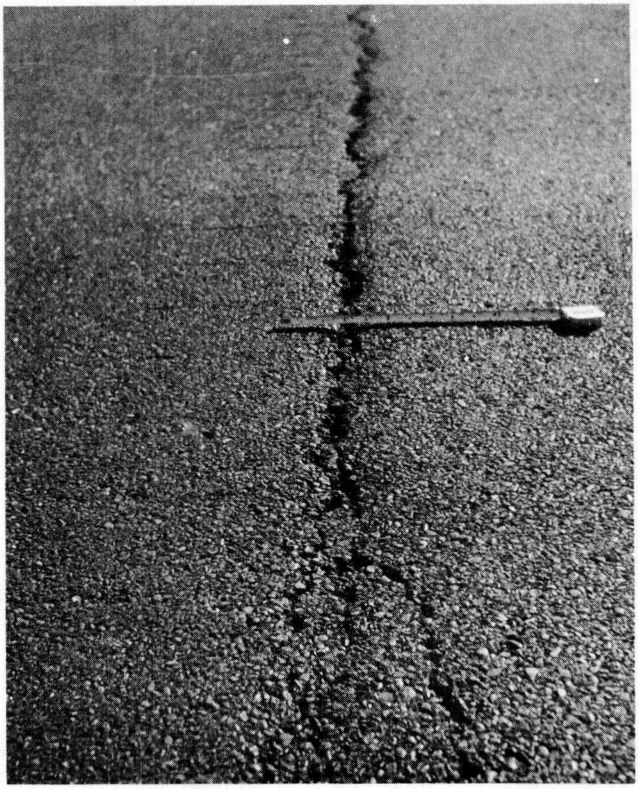
Cause: Shrinkage of cement treated base.

Note: Cracks in this area are more numerous in the passing lane than in the outer lane that is subjected to heavy traffic. Obviously, this cracking is not due to heavy loads or lack of support.

Figure 32. Longitudinal crack in asphalt pavement coinciding with longitudinal construction joint in cement treated base.

Cause: Weak vertical plane created by a juncture of two spreads of cement treated base material. Neither base nor surfacing had sufficient tensile strength to prevent separating along this line. Could be prevented by better construction techniques.

Figure 33. Core from same pavement as shown under Figure 32 showing that crack in the surfacing coincides with wide crack in the base.



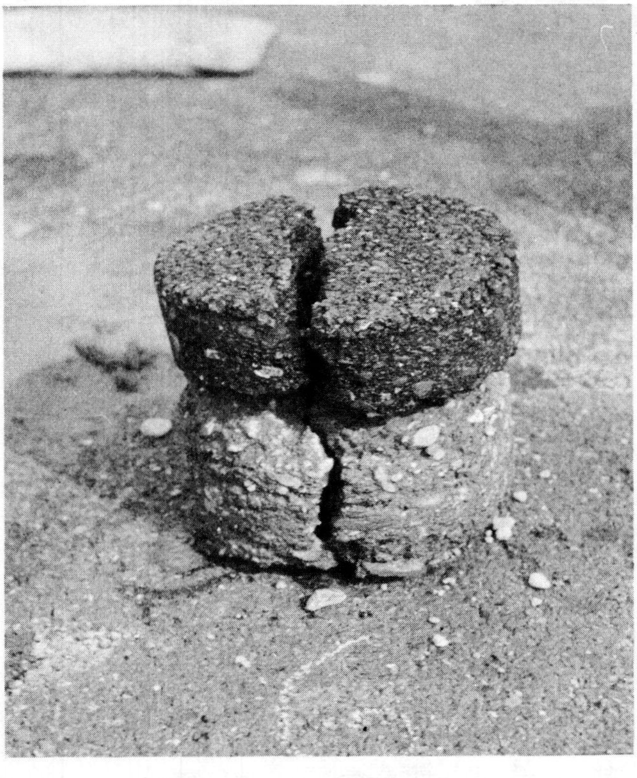


Figure 34. Localized distortion of patching material used to resurface a trench excavation across pavement.

Cause: Unstable mix containing too much asphalt.

Figure 35. Poor repair of a pavement failure.

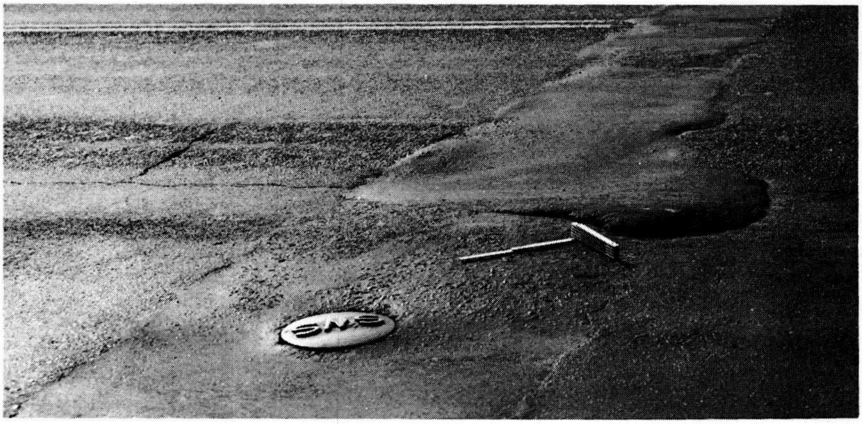
Primary Cause: Trying to correct a base failure with a thin surface patch.

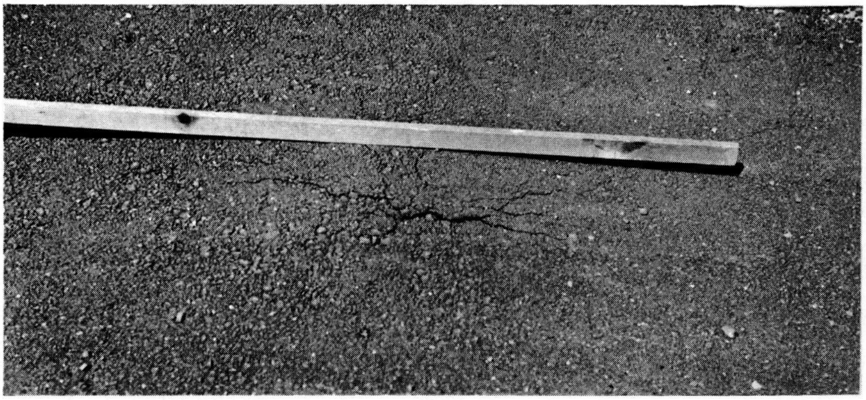
Secondary Cause: Over-rich unstable material used for patching. (An example of an all too common bad maintenance practice.)

Figure 36. A pronounced bump accompanied by cracking of a newly constructed bituminous pavement.

Cause: Localized expansion of subgrade material.

Note: Material was secured from waste piles of a magnesium plant. Expansion developed slowly and was not detected in preliminary tests. See Figures 57 and 58 for effect on concrete pavement.





ANALYTICAL CHART

Classification of Failures in Portland Cement Concrete Pavements

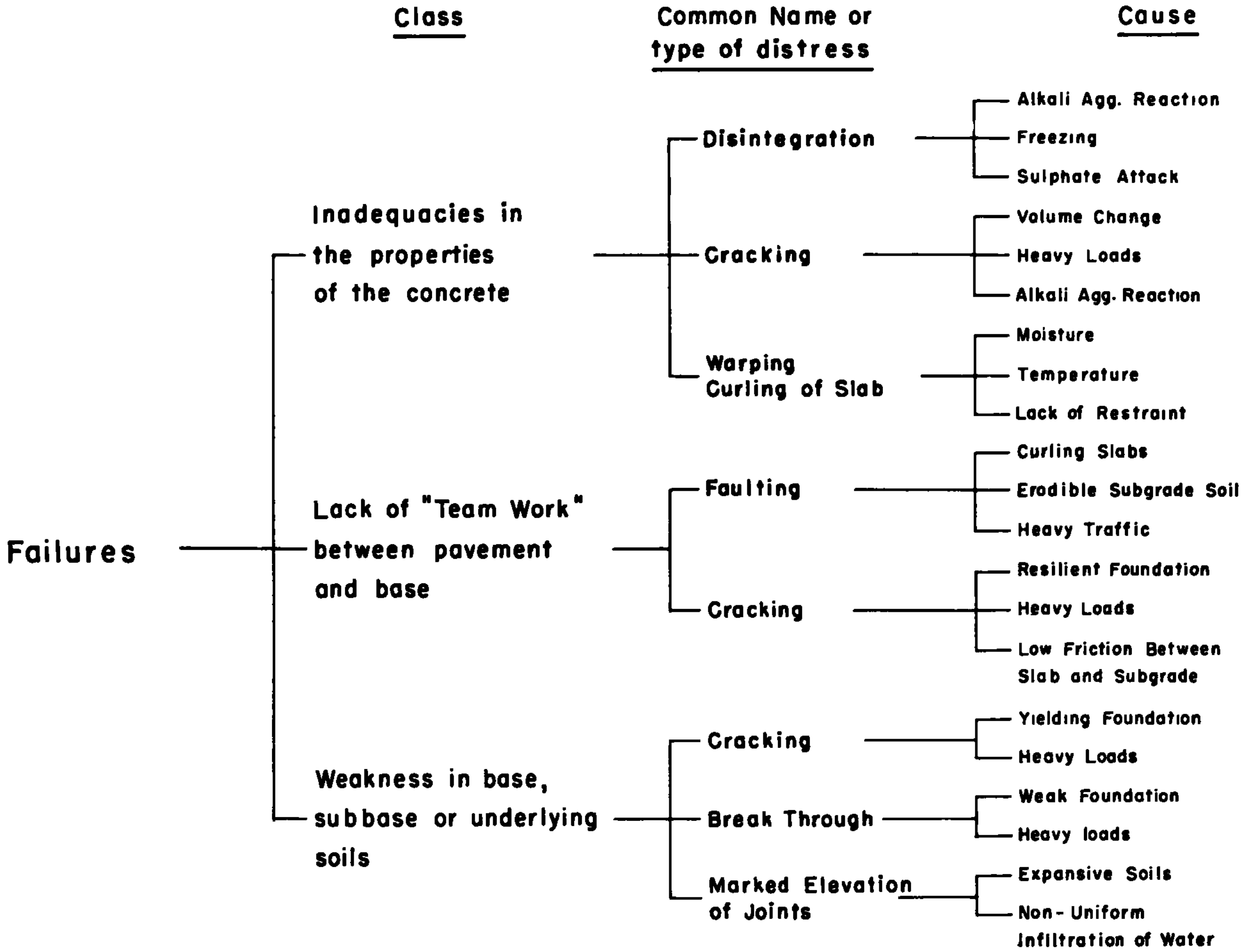


Chart B

CONCRETE PAVEMENTS

Failures and Distress

Chart B classifies failures in portland cement concrete pavements by distress type and cause.

Figures 37 to 43, inclusive, show types of failure or conditions developing primarily because of qualities of the concrete pavement slab.

Figures 44 to 55, inclusive, show types of distress largely caused by failure of slab and foundation to act in unison or to afford mutual protection and support.

Figures 56 to 62, inclusive, show failures and distress appearing in the concrete pavement which are primarily due to weakness and instability of the base or underlying soil.

Figure 37. A random crack showing slight spalling.

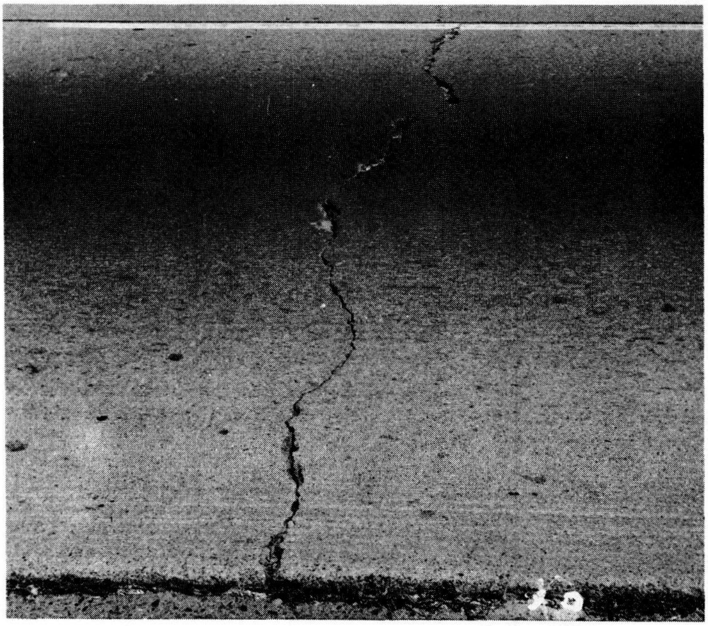
Cause: The primary cause for such cracks is shrinkage and expansion of the concrete. Whether or not such a crack is serious is debatable. Its unsightly appearance is probably the chief reason why engineers insist on cutting contraction joints at close intervals. Cracks of this type are probably more annoying to the engineer than to the traveling public. Many old concrete pavements have given excellent performance over a long period of years where all "joints" were of the type shown here.

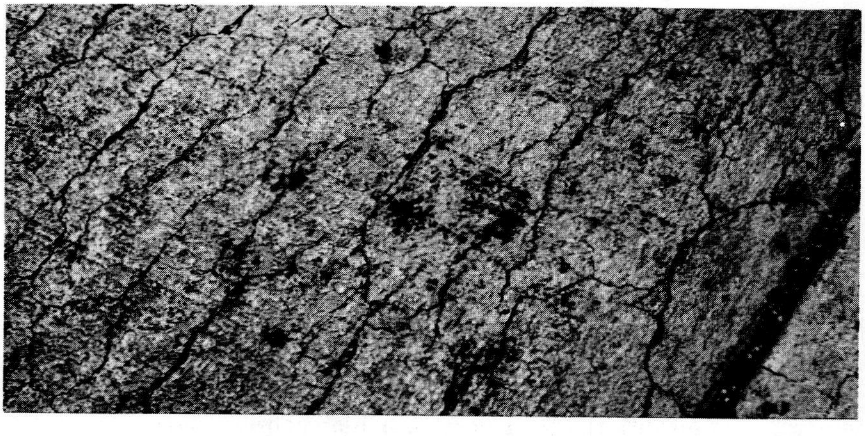
Figure 38. Badly cracked pavement nearing the stage of disintegration.

Cause: Expansion of the concrete due to reaction between alkalies in the portland cement and opaline silicate particles in the aggregate.

Figure 39. Striking contrast in appearance of adjacent lanes of concrete pavement. The aggregates, foundation conditions and traffic are the same on both slabs.

Cause: Right hand slab—although all of the aggregates contained reactive material, the cement used in the right hand side was high in alkali while that used in the left hand slab was not. A clear example of alkali aggregate reaction in the right hand slab.





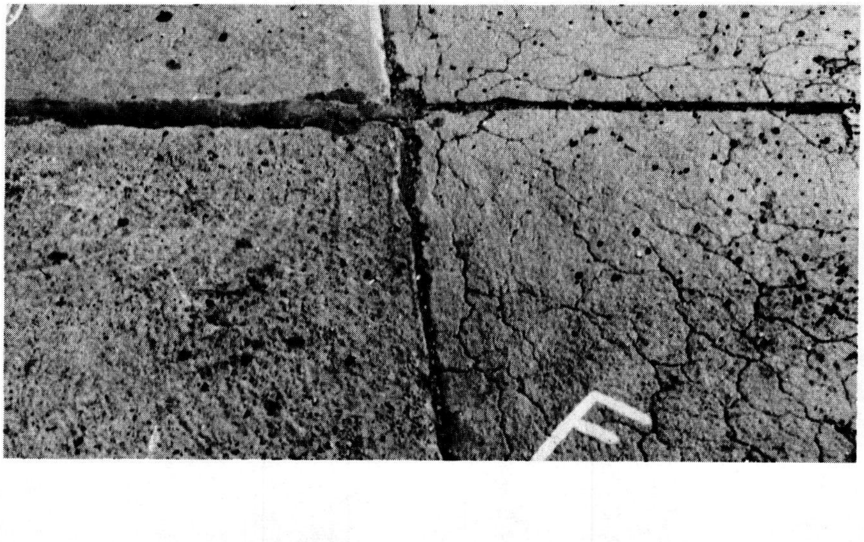

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Figure 40. Advance deterioration in a concrete floor slab. While not a "pavement failure" it demonstrates that such failures can develop in slabs submitted to no load heavier than pedestrians.

Cause: High alkali cement and reactive aggregate.

Figure 41. Contrasting performance of adjacent pavement slabs subjected to freezing conditions. Foreground shows slab in good condition; upper portion is slab showing surface scaling. Both subjected to chemically treated abrasives for traffic safety.

Cause: Action of salt and freezing temperatures.

Note: Concrete in lower slab is protected by an air-entraining agent, upper slab is not.

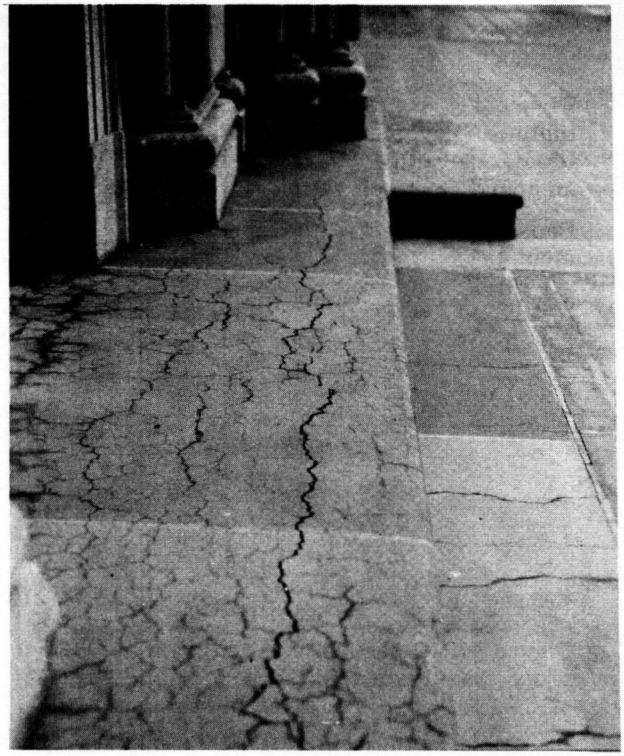


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Figure 42. Extensive patching of a thin bituminous pavement "second story" subject to low temperatures in northern California at an approximate elevation of 3,000 ft.

Cause: Failures in the old concrete pavement beneath.

Figure 43. Close-up of failed highway. Same project as Figure 61 showing disintegration of concrete beneath a bituminous surface.

Cause: Freezing and thawing action on concrete without air-entrainment.

Figure 44. Water being ejected through a joint in a concrete pavement. This is the phenomenon called pumping. Strictly speaking, it is not a failure. It simply indicates a condition which may lead to distress or failure of a pavement.

Cause: Under the influence of differential moisture and/or temperature pavement slabs curl upward in the vicinity of a joint leaving a void space between pavement slab and subgrade for the accumulation of water. Entrapped water is subjected to considerable pressure with each passage of heavy axle loads. Water flows laterally at high speed and exerts considerable erosive action upon subgrade; muddy water is ejected with considerable force through transverse cracks and along edge of slab. Characteristics of both subgrade and concrete slabs contribute to this condition.

Figure 45. View through a core hole showing space (about ¼ in.) beneath the underside of the slab and the subgrade.

Cause: Curling of the slab due to expansion of the underside from moisture. Curling also varies with changes in temperature of the upper surface of the slab.

Note: The existence of this void space "sets the stage" for pumping. There is reason to believe that the so-called pumping action would never start if the slab were firmly in contact with the subgrade at all times. Furthermore, pumping action would not be serious if the subgrade layer were not eroded away.

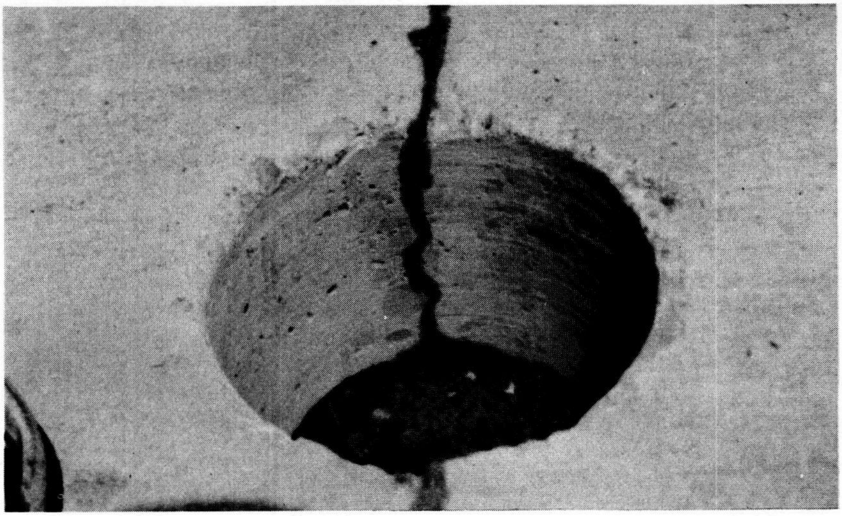
Figure 46. A badly faulted joint or "step-off."

Cause: Usually a development from the pumping action of the slabs that results in the removal of some subgrade material and the transfer from the low side to the higher. Although it is commonly assumed that the low side of the joint has been "pounded" down, there is much evidence to support the theory that in many cases the higher side may have been elevated above its original position. Faulting has also been observed in pavements over clean granular material with no evidence of pumping.

Figure 47. Characteristic transverse break that develops under heavy axle loads just beyond a transverse joint. These cracks are generally from 5 to 7 ft beyond the joint.

Cause: Long continued pumping action of a slab erodes and removes subgrade material leaving a deep void space beneath the slab. Pavement slab becomes an unsupported cantilever which finally breaks under load.

Note: The end of the slab approaching the joint is often supported or bolstered in its elevated position by the accumulation of coarser particles pumped from beneath the slab beyond the joint.



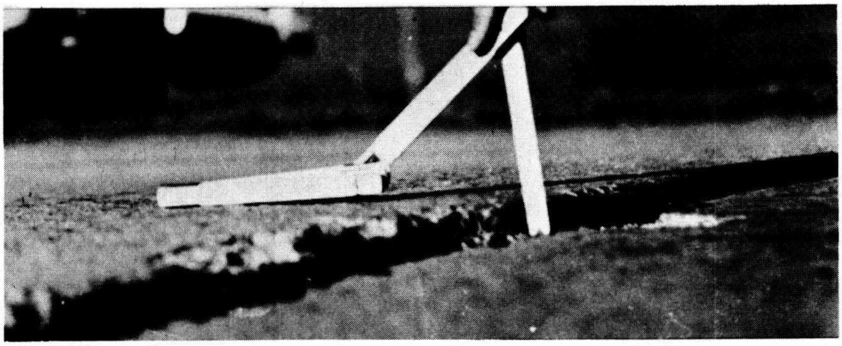



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Figure 48. Second stage of slab failures at a pumping joint. Second crack develops as traffic approaches the joint.

Cause: Primarily, curling of the slab. Secondarily, removal of subgrade support by erosion from the pumping slab.

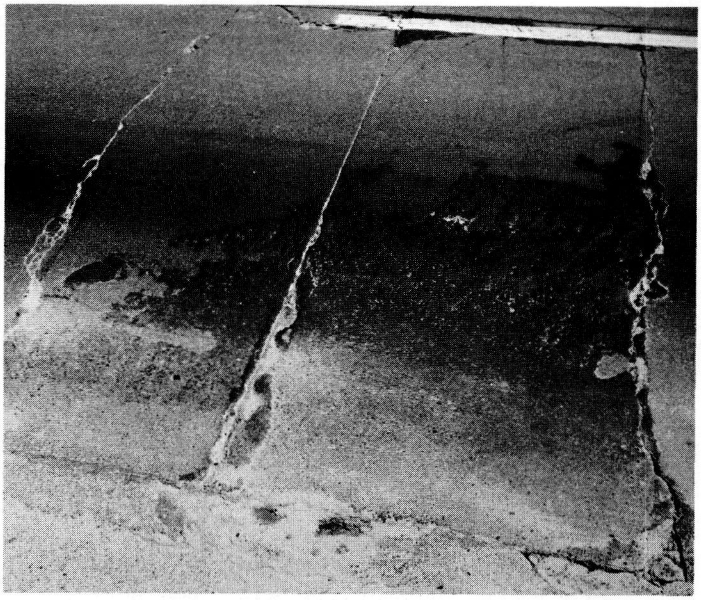
Note: Slab end on approach side is less susceptible to being broken as the sequence of action under one-way traffic tends to transfer the coarser sand particles from the far side of the joint to the approach side, thus tending to support the slab in its uplifted condition; hence, reducing the length of the cantilever arm.

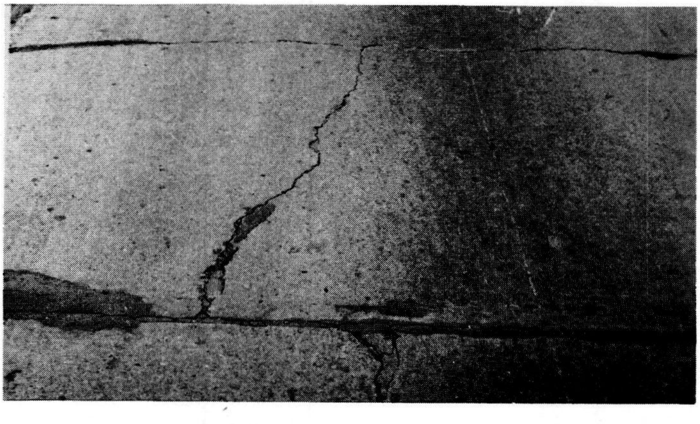
Figure 49. A third stage of failures in the vicinity of a transverse joint showing longitudinal cracks through the short slabs adjacent to the joint.

Cause: Continued repetition of heavy loads on the poorly supported short slabs.

Figure 50. A corner break at the junction of a longitudinal and transverse joint.

Cause: Probably due to the effects of heavy load on an unsupported corner of the curled or warped slab.





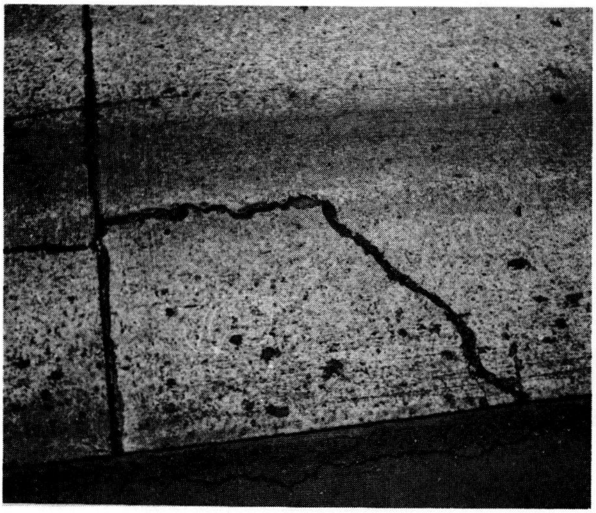


Figure 51. A more extensive corner break.

Cause: In this example, it appears that there is a local weak spot of poor soil beneath the pavement as evidenced by failure in the bituminous shoulder alongside.

Figure 52. Diagonal cracks that have developed in the vicinity of a pavement joint.

Cause: Slab curling followed by pumping out of the subgrade support soil. Slabs broken by heavy truck loads on the unsupported slab ends. Photograph from report on Test Road One-MD.

Figure 53. Spalling of the slab at an expansion joint.

Cause: In this case coarse gravel or uncompressible material in the upper levels of the joint subjected the concrete to heavy local pressures when pavement expanded.

Note: It should be recognized that movement at the joint usually involves wider opening and closing at the top of the pavement due to the warped condition of the slab and the combination of horizontal and vertical movement.

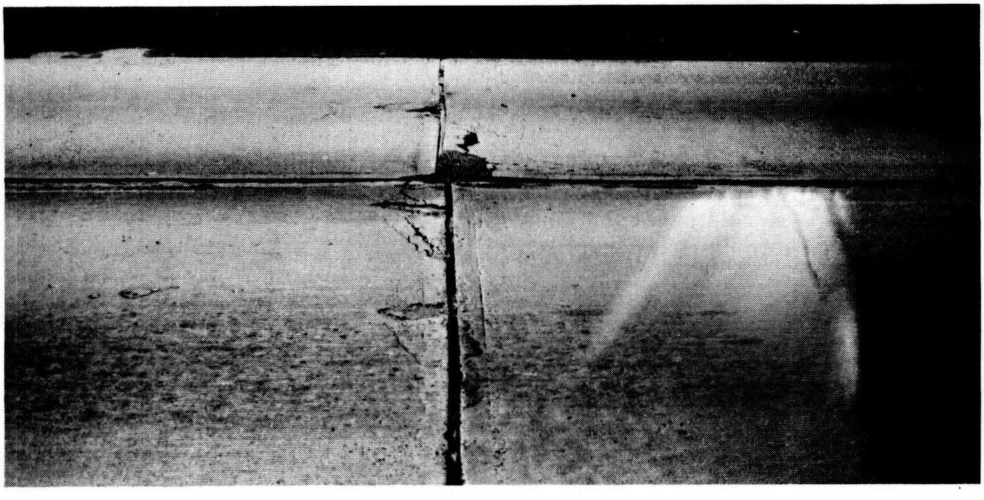


Figure 54. A "blow-up" in a concrete pavement. Photograph taken a few minutes after pavement broke. Loose material is still lying on the surface.

Cause: Expansion of the concrete exceeding the available joint space.

Figure 55. Badly spalled random crack close to and approximately parallel to a contraction joint 2 in. in depth. Crack occurred before pavement was subjected to traffic.

Cause: Expansion and contraction of the concrete due to temperature changes. It must be inferred that the strength of the full 8-in. slab along the irregular line of the crack was less than the 6-in. net section under the contraction joint. The spalling appeared to follow "planes" of weakness along the surfaces of the coarse aggregate. Bond between the cement paste and the siliceous, glassy, coarse gravel is relatively poor: or movement possibly facilitated by bituminous treated sand subgrade with low friction. Cracks ultimately opened 1 or 2 in.

Figure 56. Longitudinal crack in a thin concrete pavement constructed in 1917.

Cause: Vertical and lateral alternate expansion and shrinkage of a heavy clay soil.

Figure 57. Longitudinal and transverse cracks in a modern 8-in. concrete slab constructed in 1955.

Cause: Abnormal expansion of imported borrow material secured from waste piles at a magnesium plant.

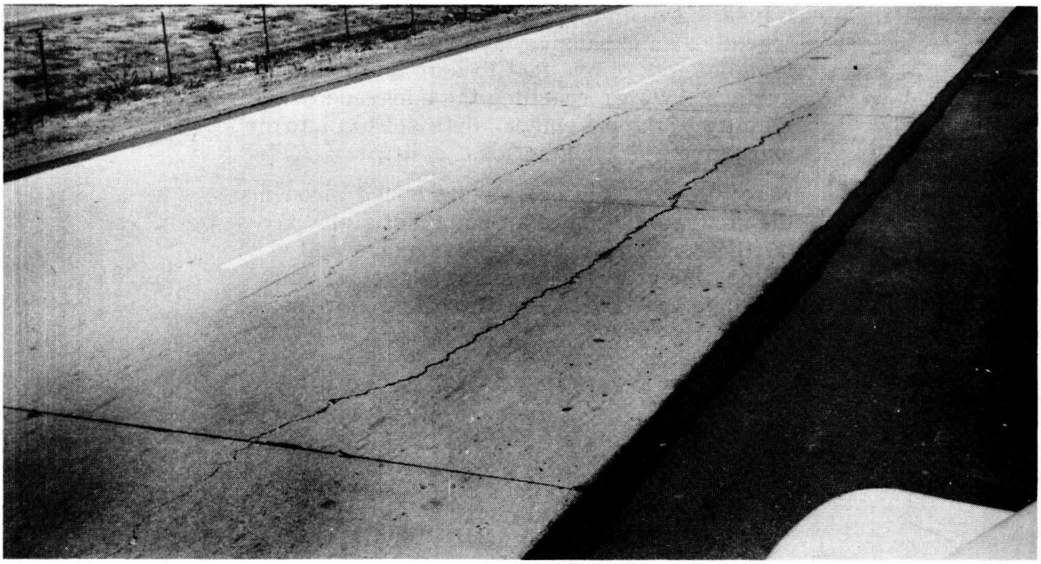
Note: Expansion of this material developed slowly; hence, was not detected in preliminary tests, but expansive action has continued to develop after being placed on the roadbed. (See Figure 36 for effect on asphaltic pavement.)

Figure 58. A more recent view of the cracked pavement shown in Figure 57.

Cause: Same as Figure 57. Note two approximately parallel cracks and greater width of opening.

Figure 59. Transverse cracks, corner breaks and general distress in a concrete pavement.

Cause: Very poor soil beneath the pavement as further evidenced by the marked alligator cracking of the bituminous border which is normally subjected to little traffic.



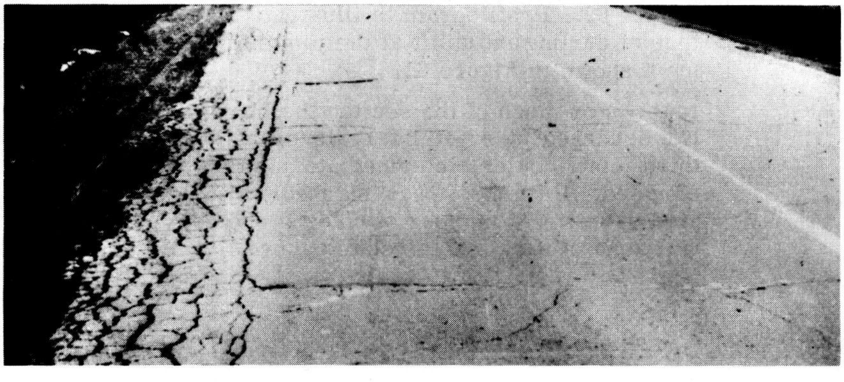


Figure 60. Distress and serious breakup of an airfield pavement used as a test track.

Cause: Heavy wheel loads and poor subgrade support.

Figure 61. Badly curled or warped slabs in a new concrete pavement approximately one year old.

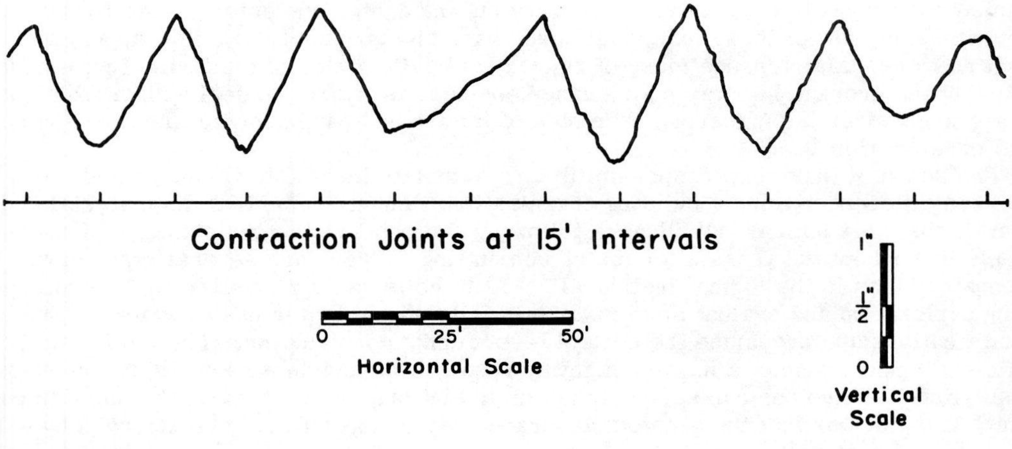
Cause: Extreme upthrust at the joints was traced to an expansive layer of soil ranging from a depth of one foot to four feet below the surface. Water reaching the subgrade in the vicinity of the pavement joints soaked into the expansive soil causing local uplift.

Note: A series of holes were bored through the central portion of a number of slabs permitting water to reach the expansive soil at all points. The roughness was greatly reduced as the slabs were lifted to a more nearly uniform plane.

Figure 62. Profilogram to illustrate magnitude of curling and uplift at the joints of pavement shown in Figure 61.

Note: For much of the section the initial uplift occurred at 45-ft intervals or at every third joint. Later, intermediate joints were elevated. Roughness was markedly alleviated by boring a number of holes in the central zone of each slab as stated above.


11 Sept 1942
15485 Cycles
Sect A Slab 30
First fracture Occurred
40000 lbs cycles


Contraction Joints at 15' Intervals
0
25'
50'
Horizontal Scale
1"
$\frac{1}{2}$"
0
Vertical Scale

It is hoped that the foregoing catalog and brief description of the various types of failure will be of interest to engineers responsible for rural highways, city streets and airfield pavements. However, it is pertinent to point out that highway engineering today has been sub-divided into a number of specialties and there is inevitably a difference in viewpoint and motivation between design engineers, construction engineers and maintenance engineers, to say nothing of materials engineers. Many of the failures shown could have been prevented only by a more adequate design which, in turn, can only result from a better understanding of the properties and limitations of materials. Another group of failures may be charged to faulty construction practices. Of the failures shown, only those in Figures 34 and 35 could properly be charged to faulty maintenance.

Having been in turn a construction man, a maintenance superintendent, and a member of the materials department, the author can sympathize with the problems and viewpoint of each. Although the burden of responsibility for providing durable pavements rests jointly with the materials, design, and construction departments, the maintenance engineers cannot escape the responsibility for many poor or inadequate repairs. It is hoped that a study of highway failures will encourage greater cooperation between the "specialists" in the several departments represented in most organizations constructing pavements. It is also hoped that maintenance engineers will have a greater tendency to look beneath the surface when repairs are being contemplated and that they will have money enough to do something more than place a thin "skin patch" over a failure caused by a weak base. Failures of the type illustrated by Figures 1 to 12, inclusive, may be corrected or halted by relatively light applications; but all of those covered by Figures 13 to 36 will require something more than a thin surface patch or surface treatment to effect a permanent restoration.

From the viewpoint of the materials engineer, there is an unfortunate and all too widespread tendency for many engineers engaged in design or planning to regard detailed quality specifications as nuisances. The materials engineer is often somewhat taken aback to find that his adverse test results and rejection of materials sources are not always appreciated as a timely warning of probable troubles and failures in the finished construction. A laboratory man often is made to feel that he is an unpopular obstacle and handicap to those who are "trying to get things done." There also is the fear in many quarters that too restrictive requirements will "frighten" contractors into higher bids. Construction engineers or resident engineers have many things to think about and often are inclined to leave the control testing to the youngest and least experienced men on the resident engineer's crew.

Although individuals may differ, no one can seriously maintain that there is any generic difference in the abilities or conscientious devotion to the job between materials engineers, design engineers, or engineers in any other departmental grouping. There is, however, a definite difference in the opportunities to observe the results and performance of completed pavements under traffic over a long period of time. In most large organizations, design departments continue to design and plan and construction men administer the contracts and attempt to carry out the design and enforce specifications. Nevertheless, few of these individuals ever have an opportunity to follow up and see what happens. Maintenance men, of course, are fully aware of the facts of pavement life, but the average highway maintenance engineer is trained to deal with trouble and is apt to consider the numerous examples of failure and pavement weakness as the normal order of things.

The scope of individual responsibility and authority inevitably varies considerably between different pavement building organizations, but it seems that the materials engineer is the most logical individual to follow up and observe the performance of pavements throughout the years after the ribbon cutting. There are several reasons why the laboratory man is the logical individual. First, he is usually involved in the preliminary exploration and evaluation of materials. He should be the one to write materials specifications and prescribe the control tests during construction. The intelligent and efficient construction of a modern highway requires the combined efforts of a number of specialists, and no one can seriously maintain that one or the other is the more important. It is obvious that the greatest assurance of success will only be achieved by teamwork, cooperation and interchange of information. It is true, however, that the die is not cast until the construction engineer takes over the project, and even though deficiencies exist in the plans and specifications it is often possible for the construction engineer to offset such weaknesses and turn out a good job in spite of everything.

Therefore, no matter how well the preliminary work—such as materials evaluation, design, planning and specification writing—has been done, the problem of turning out a good job still rests with the construction engineer. Consequently, if the construction man often is blamed or criticized for failures which may develop, he also is entitled to a large share of the credit for the many miles of good pavement that have been and are being constructed. In spite of the variety of failures shown in this report, it is encouraging to note that there are more miles of good roads than of poor ones.

Discussion

W.H. CAMPEN, Omaha Testing Laboratories, Omaha, Nebraska—Mr. Hveem has done a fine job of classifying and picturing the types of failures in bituminous pavements. It is not believed, however, that he covered the following types of distress:

1. Pitting, due to soft particles in the coarse aggregate.
2. Rapid wear which resembles raveling but which is due to the action of snow chains on coarse asphaltic concretes.
3. Shoving or rutting of mixtures laid on strong concrete bases, due to excessive asphalt or inherently weak aggregate mixtures.

In regard to item 1, coarse aggregates may meet wear and soundness requirements but may still contain sufficient amounts of soft particles to cause progressive surface disintegration. The allowable percentage of soft particles should be kept very low in asphaltic concretes, not over 2 percent.

As far as item 2 is concerned, it can be said that in recent years the tendency has been to obtain stability at the expense of durability; thus asphaltic concretes are being laid coarse and lean. The stability is thereby increased but the rate of wear is increased. This situation leads to the observation that the designer is now, and probably will always be, confronted with the problem of choosing between stronger short-lived pavements and weaker long-lived ones. Of course, in most instances, he can achieve satisfactory results along both lines.

Item 3 is closely related to item 2; however, the distress can be eliminated or reduced by incorporating angular aggregates, both coarse and fine, and by limiting the asphaltic content.

F.N. HVEEM, Closure—Mr. Campen has mentioned several varieties of distress which were not covered in the examples shown in the paper. Before commenting upon the three types, the author acknowledges that there are other varieties of failures that were not included. One very important type is identified with frost boils. This was omitted not because frost boil failures are unknown in California, but because a photograph was not readily available.

Taking up Mr. Campen's three suggestions:

1. Pitting has been observed in some bituminous surfaces in California, but rarely due to soft stone as some very satisfactory bituminous surfaces have been constructed with aggregates that were far softer than the maximum permitted by any standard abrasion test. The only cases where such pitting has become noticeable was in certain road-mix projects in which lumps of clay or weakly cemented disintegrated granite would dissolve and leave pits in the finished surface. At times these pits were quite numerous, but they appeared to cause little real harm other than to be a little upsetting to the engineer. Only two or three examples have been encountered in an asphaltic concrete pavement that developed some pitting of the coarse aggregate. One particular section in the desert region developed marked disintegration, apparently due to complete softening and disintegration of the coarse stone following infrequent rains. The stone in question met ordinary rattler and hardness requirements, but the road had to be resurfaced because of disintegrated surface. No photographs are available.

Figure 63.

2. Failures or distress caused by rapid wear resembling raveling but due to the action of snow chains on coarse asphaltic mixtures have been noted. Wear from this source has not been a frequent cause of trouble in California, although examples have been known. This type of problem was simply overlooked in the paper. Figure 63 shows surface loss attributed to action of tire chains.

3. The author cannot agree that shoving or rutting of mixtures laid on concrete bases, due to excessive asphalt or inherently weak aggregate mixtures is in any important sense different from distortion of asphalt mixtures on any other type of support. Observations in California have indicated that, other things being equal, unstable mixtures may have less tendency to distort on a rigid concrete base than if resting directly upon a resilient soil. The type of instability shown by Figure 7 or Figure 9 is not essentially different from that which may occur over a concrete base. Shoving or rutting means a mixture having insufficient stability; this is usually attributable to an excessive amount of asphalt, excess moisture content, or both.

In general, there is no disagreement with Mr. Campen's comments, although the necessity for limiting the soft particles to not over 2 percent is questionable. Here it probably is necessary to define more precisely what is meant by "soft" particles. His comments about recent tendencies "to obtain stability at the expense of durability" is a sound observation. Unfortunately, in spite of laboratory test methods and means for accurately estimating the optimum asphalt content, too many construction men will still vary the asphalt content in accordance with the appearance of the fresh mixture. This error is most marked, of course, where the aggregates are more or less porous or absorbent. The total amount of asphalt required for good durability and resistance to abrasion for a period of years always looks excessive before absorption into the aggregate takes place. It is fairly common experience for a laboratory to evaluate absorption and porosity by means of the CKE test only to have the resident engineer or the plant inspector reduce the amount of asphalt because it "just looked too rich" and there is, of course, no doubt that it did "look rich." In these circumstances, as in many others, the engineer on the job must have the courage of his convictions—but, of course, he should first have the right convictions.