

Research Report  
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WATER-INDUCED SURFACE FAILURES ON  
I 65, HARDIN COUNTY, KENTUCKY

by

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16. Abstract This report documents an investigation of water-related distress on portions of I 65 in Hardin County, Kentucky, on Muldraugh Hill. An open-graded surface placed on a full-depth asphaltic concrete pavement had shown areas of flushing and shallow shear failures in the outer lanes after one year of service. Cores were obtained from the outer lanes in areas exhibiting no problems to shear and flow failures. Core sites also were chosen across the lane to represent edge, wheel track, and between wheel track conditions. Visual inspection of the cores was made under normal lighting and an ultraviolet light and photographs were taken. Construction data and records indicated no abnormal construction problems. Results of laboratory density, extraction, and gradation tests coupled with nuclear density tests and visual inspection of the cores indicate water had caused the asphalt to be stripped from the aggregate. Soft particles in the dense-graded surface course below the open-graded course had deteriorated. The stripped asphalt and deteriorated soft particles had migrated toward the surface causing the pores to be filled in most locations. Where the asphalt/matrix was particularly weak, heavy truck tireloads had caused the material to move laterally over the adjacent stiffer material. Water is being held in the pores of the open-graded course and allowing the dense-graded surface course below to become saturated causing the asphalt to be stripped from the aggregate and softer particles to become deteriorated.					
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## SUMMARY AND RECOMMENDATIONS

This report documents an investigation of water-related distress on portions of I 65 in Hardin County, Kentucky, on Muldraugh Hill. The pavement consists of multiple courses of asphaltic concrete base, asphaltic concrete surface(s), and an open-graded friction course. The intent of the study was:

1. to identify the type and extent of distress,
2. to sample and test pavement components as needed to develop data to enlarge, clarify, and/or confirm observations,
3. to obtain and analyze construction data with regard to possible procedural contributions to the problem,
4. to analyze mixture design data with regard to possible contributions to the observed distress,
5. to evaluate the potential for further or similar distress on this or other projects,
6. to evaluate all data with respect to desirable changes in the Transportation Cabinet's specifications or procedures, and
7. to provide insights to corrective actions needed to restore this or similar pavements to acceptable and/or desirable service conditions.

## PAVEMENT INSPECTION

The pavement was carefully inspected in both dry and wet conditions. Distress is currently concentrated in sections of the outer lanes subjected to high concentrations of heavy truck traffic. Slight distress was observed in all lanes with the second lanes, also subjected to appreciable truck traffic, showing much more advanced distress than the inner lanes. Distress sufficient to affect traffic use is limited to the outer lanes at this time.

Forms of distress observed were densification of the open-graded surface, flushing of asphalt to the surface, and rutting with shallow shear movements. The latter begins with slight shear displacement of material forming very slight heaving at the outer edges of wheel tracks. Once movement begins, it tends to develop rapidly into severe displacement of surfacing materials and severe upheaval of displaced material. In all observed cases, the shear pattern indicates shear movement is occurring only in the upper portion of the pavement. The distress observed is due to stripping and the loss of strength in a shallow course. Later investigations confirmed that the dense surface course was the affected layer.

In a dry state, the open-graded surface course appears normal over much of the surface area. During rain, many areas in the wheel tracks failed to exhibit the reduced tire splash expected from this type surface. This condition indicated closing of surface pores by traffic or by filling with stripped asphalt migrating upward with water flow to

the surface. Careful observations indicated that transverse flow of water was impeded by increased densities in the wheel tracks. This resulted in a fully saturated pavement for long periods. It was observed that drainage from the open-graded surface continued at random locations for at least one day after rainfall ceased. It is this prolonged storage of water within the open-graded surface that provides water to keep the underlying dense surface layer near saturation.

#### SAMPLING AND TESTING

Six locations exhibiting a range of all observed conditions were selected for sampling. Three to six cores were cut from each location. A total of 26 cores were obtained for study and testing. These were supplemented by seven additional cores and one trench sample obtained earlier by the Division of Materials.

Prior to testing, each core was carefully inspected for visible evidence of distress. These observations indicated water effects on the dense surface layer ranging from very slight damage to severe stripping. Deeper courses showed little or no damage.

Principal testing consisted of determining the densities and asphalt contents of selected samples from the two upper courses. A limited number of additional tests were run. From these tests and data obtained earlier, voids relationships could be established. The accumulated data indicated that the dense surface course remained dense even when stripping was well advanced. However, it obviously had lost strength, permitting shear displacement to occur. There were no indications of construction deficiencies in the dense surface course. Thus, stripping was confirmed as the major cause of distress. Mixtures very similar to the damaged dense surface layer are providing good service when used as the principal wearing surface.

#### CONSTRUCTION DATA

Construction data provided little indication of abnormalities that could have contributed to the observed distress. Some segregation was noted in the base courses. This may have long-term influence on pavement life but did not appear to contribute to the problem being investigated.

#### MIXTURE DESIGN DATA

Mixture design data on this and similar projects were carefully reviewed. The design on this project was slightly less than desired but should have provided good service under different exposure conditions. Mixtures provided for six similar projects do not have as good voids relationships as did this mixture. Unless they possess a very high resistance to water actions, some degree of surface distress can be anticipated in those projects.

#### POTENTIAL FOR CONTINUING DISTRESS

Further development of distress on this project

currently is expected to continue until corrective action is taken. Several similar construction projects were inspected, of which the oldest is several years old and the youngest was just completed. All projects showed some surface evidence of water-related distress. Fortunately at this time most distresses are minor in nature and extent. Reasonable service can be anticipated in the older projects. Newer ones do not permit an estimate of performance capability. All pavements should be evaluated frequently with respect to distress development.

#### SPECIFICATIONS AND PROCEDURES

From the findings in this investigation, some changes in Cabinet procedures should be considered to minimize the possibility of similar future problems.

A skid-resistant surface is essential for the protection of highway users. This protection can be provided effectively by a relatively coarse-textured dense surface course. Such a surface can provide adequate safety and provide much longer service life. Suggested gradations for such mixtures are contained in the report.

Additional requirements for mixture properties should be incorporated into Cabinet procedures to assure more consistently high quality mixtures. The traditional emphasis on gradation is a part of the problem. Gradation is very important, but it must be supplemented with criteria that better control the behavioral characteristics of the total mixture.

#### CORRECTIVE MEASURES

There are options available to the Cabinet with respect to corrections to the Muldraugh Hill pavement and similar pavements. Currently, the outer lanes on Muldraugh Hill are showing advanced and rapidly developing distress. Corrective action is planned for the immediate future in the outer southbound lane. The northern one-third of the northbound outer lane is nearly as severe and has a similar urgent need to be corrected. This correction could be comprised of several operations such as 1) milling to remove all distressed material to a depth of approximately 2 inches; 2) carefully tack the milled trench, including the edges, and replace the removed material with a carefully designed skid-resistant dense surface mixture to the elevation of the adjacent dense surfacing layer; and 3) taper existing open-graded surface to avoid a noticeable elevation difference in riding surface. This procedure is the best correction available and should prove to be the best investment. Further, all lanes on this project will need replacement of the existing surface within the next few years. Consideration should be given to replacement of the second lane in 1985.

A much less effective option is local patching to remove and replace distressed areas. This may be necessary at times, but when used should be considered as a temporary expedient.

It is possible to replace the surface with a two-course construction such as is currently in place. This option should not be considered unless, or until, procedures can be developed to assure expected behavior will result. Such procedures are available at this time.

Another option, do nothing, also is available. This should not be applied to the Muldraugh Hill pavement. However, it is an appropriate option for similar construction on other projects. These should receive high priority in the Cabinet's Pavement Management Program as pavements to be evaluated frequently with regard to distress type, extent, and rate of development. The expense of correcting the type distress occurring on Muldraugh Hill is great and the longest lead time possible is needed for planning purposes.

It is strongly suggested that the Cabinet concentrate its efforts in the development of effective, dense, skid-resistant surface mixtures. These mixtures should be employed for all high-trafficked pavements. The open-graded friction courses should be installed only as specifically designed projects that may overcome problems currently encountered with this type of surfacing.

## INTRODUCTION

This report documents an investigation of water-related distress on portions of I 65 in Hardin County, Kentucky, on Muldraugh Hill. The pavement consists of multiple courses of asphaltic concrete base, asphaltic concrete surface(s), and an open graded friction course. The intent of the study was:

1. to identify the type and extent of distress,
2. to sample and test pavement components as needed to develop data to enlarge, clarify, and/or confirm observations,
3. to obtain and analyze construction data with regard to possible procedural contributions to the problem,
4. to analyze mixture design data with regard to possible contributions to the observed distress,
5. to evaluate the potential for further or similar distress on this or other projects,
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7. to provide insights to corrective actions needed to restore this or similar pavements to acceptable and/or desirable service conditions.

What appears to be water-related damage has developed in the asphalt pavement on I 65, Muldraugh Hill, Hardin County, on Project I-65-5(19)95. Rutting, with shear development, is developing intermittently in the wheel tracks, varying from slight to severe. Excessive asphalt is appearing at both rutted and non-rutted locations. Observed defects are water related. The Kentucky Transportation Cabinet engaged the Kentucky Transportation Research Program to investigate the failures with respect to cause, correction, and minimization of future problems of a similar nature.

The affected pavement is a full-depth asphalt structure having a total thickness of 18.5 inches. This structure consists of 16.75 inches of asphaltic concrete base, a 1-inch asphaltic concrete surface, and approximately 0.75 inches of an open-graded friction course in the southbound lanes. The northbound lanes were constructed first and were used for all traffic while the southbound lanes were being constructed. The pavement structure in the northbound lanes was altered slightly by reducing the asphaltic concrete base thickness by 1 inch and constructing a temporary surface course (1 inch) for use while the southbound lanes were being constructed. When the southbound lanes were opened to traffic, the northbound lanes received a 1-inch additional dense asphaltic concrete surface and a 0.75-inch layer of open-graded friction course to complete the structure.

The entire project is located on Muldraugh Hill and has grades up to approximately 3.5 percent. To accommodate climbing trucks, a fourth lane was included in the southbound construction. Northbound traffic is adequately

accommodated by three traffic lanes. Paved shoulders are provided.

Southbound truck traffic appears to be concentrated in the two outer lanes, with the outside lane carrying most of the heavier trucks, as is also the case for the northbound lanes. However, it is believed that a higher percentage of northbound trucks use the second traffic lane.

Southbound lanes are constructed on a silty clay approximately 1 foot thick over a rock cut. Northbound lanes are underlain by rock subgrade. Visible distress is concentrated in the outside lanes, in both directions, but are not limited to those lanes. The second lanes show relatively minor indications of distress, except at isolated locations in the northbound direction. Inner lanes show very limited distress at this time.

It is the purpose of this study to identify and investigate all phases of the problem with respect to cause, correction, and prevention of future occurrences. This includes a determination of water sources, layer affected, type and extent of damage, and remedial actions as well as recommendations for preventive actions in future construction. The information gained from this study may be used to provide more resistant pavements through revisions to mixture design, material usage, design strategies, and construction procedures as applicable.

## INSPECTION OF PAVEMENT

The pavement was inspected carefully to identify locations, types, and extents of distress and to locate suitable sites for sampling the pavement that would represent all forms of observed distress, and apparent non-distressed conditions, for testing and study. Inspection was conducted over a three-day period. Two of those days provided dry, or draining, pavement conditions while the third was rainy.

Both severe and moderate distress is principally associated with lanes carrying high concentrations of truck traffic and occurs intermittently in those lanes. Other areas show slight distress or none at all. It seems reasonable to expect rapid continuing distress in truck lanes with far slower development in other lanes.

## TYPES OF DISTRESS

In general, observed forms of distress were identified as rutting, lateral shear displacement, and flushing of asphalt/matrix to the surface. Each form was observed in stages varying from very slight to very severe.

### Rutting

Rut development varies greatly from very slight depressions (that are difficult to detect) to advanced conditions coupled with shear displacement. Typically, the early stages are associated with very slight curvatures. A



slight densification is occurring and appears principally as a change in surface texture. Densification may, or may not, be followed with slight flushing. As the rut develops, slight upheavals begin to appear just outside the wheel tracks. Further development produces pronounced heaving as the wheel track depresses further. If not already present, flushing begins and/or continues to increase. Also, particle rotation and shear movement may be seen in the open-graded surface course.

In final stages of development, the rut approaches a maximum depth with severe movement of mixtures from the wheel track. This movement appears to involve more than could be attributed to the open-graded surface and therefore, involve portions of the underlying dense surface course. At many locations, an overthrust condition has developed with the open-graded surface and dense surface course being forced over adjacent surface material. At this stage, the center area of the rut consists principally of asphalt and fine matrix materials.

Rutting and shearing patterns at all locations indicate very shallow movement of material. This led to the early belief that damage was limited to the upper layers of the pavement, that is the combined thicknesses of the open-graded and dense surface courses. Those courses had suffered severe losses in stability, permitting displacement under traffic-induced stresses. Such losses of strength can be associated with plastic mixes having excessively high asphalt contents. Records indicate this is not the case for surface courses on this project. The condition also is associated with severe stripping of asphalt from mixtures. If stripping is coupled with nearly complete water saturation, stress resistance is reduced to nearly that of a similar uncoated saturated layer. Such a weakened layer would readily deform under traffic in the manner observed. No surface evidence of stripping in the open-graded surface layer was seen. Based on this inspection, rutting appeared to have resulted from losses of strength in the dense surface course, probable stripping and saturation of that layer, and high stress levels from truck traffic.

#### Lateral Shear Displacement

For advanced stages of shear-stress induced rutting to occur, the affected material must behave in a plastic manner, which results most frequently when mixture voids are essentially filled with liquid -- asphalt, water, or both. An excess of asphalt is not indicated on this project. Thus, the condition on this project appears to be associated with an excess of water.

A mixture saturated with water can remain reasonably stable and stress resistant if its internal adhesion and cohesion remain high. However, if stripping occurs, a loss in both forces results. It seems reasonable to assume that most of the dense surface course is highly saturated if it has been extensively exposed to water for substantial periods. Thus, areas that have retained their performance

capability without distress have retained sufficient adhesion and cohesion to provide adequate shear resistance up to this time. Those areas showing lateral shear displacement have suffered a loss of adhesion and/or cohesion and are responding to horizontal shear stresses.

It appears that sheared areas are expanding longitudinally, suggesting that stripping is progressing in both directions from locations now exhibiting major distress. Major movement of material is lateral even though some longitudinal movement is apparent. The surface pattern of shear distress advances from small upheavals on rut edges, to large upheavals, to an overthrust condition when displaced surfacing material is forced over stable adjacent surfacing.

Longitudinal extensions of distress areas suggest pressure stripping is occurring. As asphalt in an area is displaced by water, adjacent areas are affected. Water from those saturated areas is forced by traffic pressures into adjacent areas, causing rapid development of stripping and asphalt displacement. This action is discussed in Appendix A.

#### Flushing of Asphalt/Matrix

Flushing consists of asphalt/matrix filling or overfilling surface voids. Usually, the asphalt is brought to the surface by water, water vapor, or expanding air. It usually indicates stripping but can result from flow of the asphalt film without stripping. The action is accelerated greatly by traffic pressures on water within stripped courses.

In some cases, flushing first appears as a small, nearly circular spot. In such locations, the water source may be deep within the pavement or may be near the surface. Those spots tend to expand and develop into more extensive distress. Several severe areas were observed in the outside southbound lane. Those had expanded, or were expanding, into severely rutted areas. It is believed that those areas initially were very small flushed spots. As they developed, surface water and traffic pressures provided mechanisms to produce severe distress that was observed.

Flushing in minor forms (streaks or spots) exists to some degree in all lanes. Where traffic pressures are small (inner lanes), severe distress may not occur. Initially, those areas are observed as densified locations, filling of voids, or a slight glazing of the surface. In most cases, flushing indicates some degree of stripping.

#### EXTENT OF DISTRESS

The forms of distress described as severe are principally located in portions of the outside southbound lane and the outside northbound lane. Two areas in the center northbound lane are in early stages of shear displacement, and distress will continue to develop. Other areas show some densification and minor flushing, especially the second southbound lane, but are not rutting at this

time. This seems to indicate that the major portion of this pavement is serviceable at the present. Due to the broad distribution of evidence that stripping is progressing, further extensive distress should be anticipated.

#### SURFACE WATER MOVEMENT

Movement of surface water was observed during rain, during coring operations, and one day after rain. This provided a reasonably complete description of the general effectiveness of the open-graded surface layers on surface drainage. Road splash under tires of moving trucks appeared very similar to road splash observed on surfaces without an open graded surface. This indicates densification had occurred in the wheel tracks, thus preventing escape of water through the open-graded pore spaces. Road splash appeared more severe in the outside lane than in the second lane. Tire splash in inner lanes was small but increased appreciably in some sections, probably indicating densification.

Gravity flow of water was observed. Within the inner lanes, surface water entered the open-graded surface layer, leaving little surface water. As water flowed downgrade and toward edges of the open-graded surface layer, it was observed to surface at some locations, indicating a differential in permeability of those courses. This especially was prominent adjacent to wheel tracks in the outer lanes. Thus, it is reasonable to assume nearly complete saturation of a substantial portion of the wheel track had taken place. This condition especially is the result of pressure stripping. It was noted that water reaching the outer wheel tracks tended to flow down the wheel track whenever any rut existed. To a lesser degree, this condition existed where densification existed but no rut had developed. During coring operations, drill water movement was observed to flow downgrade in the wheel track for several feet before entering the open-graded surface or flowing to the edge. This indicates low surface porosity in areas having little or light traffic. Approximately 18 hours after cessation of rainfall, water continued to slowly drain from the open-graded surface course, indicating transverse permeability is low and inadequate to rapidly remove free water within the course. Thus, a rather high degree of saturation continued to exist in portions of the open-graded surface layer after a rather lengthy drainage period. It is not known how long this drainage continued. This greatly extends the period of wetting within pavements and lends to a pressure stripping condition.

The above observations indicate that water could have, and probably did, serve as the principal source contributing to existing and developing distress. It is apparent that free water is available for long periods due to poor drainage and poor drying conditions. This resulted in near saturation of the dense-graded course, leaving it very susceptible to both static and pressure stripping.

## INSPECTION OF EXISTING CORE HOLES

The Division of Materials had sampled this project by coring and by trenching four locations -- two in the outer southbound lane and two in the outer northbound lane. Three of those sites were inspected and photographs were taken while sampling was in progress. The Division's work preceeded this investigation by about three weeks. Four-inch core holes were left open to permit later inspection.

At the northernmost location in the southbound lanes, three holes were drilled in a severely rutted area. At the time of this inspection, one hole was totally obliterated by movement of surfacing materials. A second hole had decreased in diameter to about 2 inches and the third to about 3 inches. In all cases, this movement appeared to be limited to surface courses. The second location in the southbound lanes showed less severe movement of surfacing materials.

Only one location, near the north end of this project, was inspected in the northbound lanes. At that location, all upper courses could be observed in a core hole on the outer edge of the wheel track. In that hole, the upper base course showed no distortion, the dense-graded surface course had moved downgrade about 0.75 inches, and the open-graded surface had moved downgrade about 1.25 inches. Should such movement continue, the surface would migrate downgrade more than one foot per year. Such movement could occur only if the mixtures 1) were of very low stability, 2) lacked cohesion between courses, or 3) were suffering from severe stripping, thereby creating the first two conditions. The open-graded surface course was very rich and did not exhibit stripping. The dense surface course was exposed in an area of about 25 square inches. The material remained intact but no asphalt could be seen, indicating almost complete stripping. Thus, the dense surface course is identified as a weak layer that could not adhere to either the open-graded surface layer or the stable underlying base layer. Although the dense surface course was almost totally stripped, it had dried sufficiently to regain enough stability to remain intact under limited traffic loadings at the edge of the wheel track, even though it was slipping downgrade under traffic pressure.

## SAMPLING

Sampling requirements were established after the project was inspected initially to observe the extent, nature, and probable types of distress. It was desired to obtain specimens representing all observed conditions. This included all stages of distress as well as locations showing no distress. As a minimum, samples were to include the open-graded surface course, the dense-graded surface course, and the upper base course. Where practical, it was desirable to sample all courses in the pavement structure to permit assessment of deep damage or the potential for

deep damage.

To cover the desired spectrum of conditions, six locations were selected; four were in the outside southbound lane and the other two were in the outside northbound lane. Several samples were obtained from each location to include any observed conditions. In addition to those locations, samples obtained earlier by the Division of Materials were available for inspection. Those samples were obtained from two locations in the outside lane in each direction. That provided a total of ten locations for study.

To permit possible evaluation of the rate distress was progressing, one location in the southbound lanes and one in the northbound lanes were replicated in the second sampling. Replicates were located in the same distress zone within a few feet of the original sample location.

Samples consisted of 4-inch diameter cores except at one location in the southbound lanes sampled by the Division of Materials. At that location, a trench was cut across the outside lane and all material removed through and including the upper two base courses. All samples were transported to the Division of Materials laboratory for further study and testing.

Prior to drilling each specific core location, in-place density measurements were made by District personnel with a nuclear density meter. Such measurements provided density data on the upper 2 to 3 inches of the in-place pavement. Thus, they included the open-graded friction course, the dense asphaltic concrete surface course, and in most cases, the upper portion of the upper base course. Those measurements were made principally to develop data on variations of composite densities at each sampling location and variations among similar areas throughout the project.

Sampling locations, observed surface conditions, and core locations are summarized in Table 1 and detailed in Appendix B. Observations are summarized below to provide a general perspective of this effort.

Location Number 1 was in early stages of shear failure and was appreciably rutted in the outside wheel track. The inside wheel track showed only densification. Four cores were located transversely across the lane. Two additional cores were obtained in apparently undamaged areas located 25 feet upgrade and downgrade of the main site.

Location Number 2 represents an area of severe rutting and shear failure. Six cores were obtained in a similar pattern to Location Number 1. The location is only a few feet from Station 402+38, the same location previously sampled by the Division of Materials.

Location Number 3 is near Station 388+10 and shows severe distress in the inside wheel track. It differs from Location Number 2 in that a deep water source is suspected. Four cores were obtained to attempt to show all variations in distress.

Location Number 4 is in the outside lane that currently (October 1984) is closed to traffic. The pavement is in relatively good condition, showing no distress except some

densification and a very slight glazed streak. Three cores were obtained.

Location Number 5 shows no rutting but represents an extensive area where glazing is intermittently appearing in the inside wheel track. Three cores were obtained.

Location Number 6 is about 12 feet downgrade of the Division of Materials site at Station 403+10 sampled earlier. The area is showing severe distress in both wheel tracks. Four cores were obtained.

The samples obtained provided adequate visual and laboratory test data to define the broad range of conditions observed. Additional distressed locations are distributed over broad areas of the outside lanes in both directions. It was more alarming to note signs of developing distress in the second lanes, with the more advanced development in the northbound lanes. Such areas exhibited no new distress forms and were not sampled.

### NUCLEAR DENSITIES AT CORE SITES

Nuclear density measurements represent composite densities of the pavement mass within the zone of influence. Both the open-graded friction course and the dense asphaltic concrete surface courses are included as well as varying portions of the upper base course. Table 2 summarizes measured densities at each core site, broadly identifies the site as disturbed or undisturbed, and indicates the observed surface condition. Table 3 summarizes density data by descriptive characteristics.

Measured densities represent not only the mixtures and reflect their condition, but also reflect varying amounts of water present at the site. Regretably, water content cannot be quantified. Thus, the values tabulated are believed to be somewhat higher than actual. Also, variations may reflect variable amounts of retained water. A moisture differential of one percent represents a unit weight differential of about 1.25 pounds per cubic foot. Thus, the spread in densities may be as measured, may be less, or could be greater. However, the trends and variations in cores at each location and as a whole are expressive and worth noting.

1. An area of severe shear displacement is indicative of upheavals with much lower unit weights than other areas. Those areas should have the highest void contents and highest capacity for storing water. Thus, it is suspected that actual densities of the asphaltic mixtures are considerably lower than reported.

2. Glazed but non-rutted areas have the highest unit weights, suggesting migration of stripped asphalt and matrix into these areas with consequent filling of void space in the open-graded layer.

3. Rutted areas show increases in unit weight, which is the result in part from densification and also increased asphalt and matrix. Those areas have become thinner, and

measurements may reflect the inclusion of more of the base course material within the zone of influence.

4. Densified areas at all but one location showed unit weight increases of relatively small magnitude. Those areas represent wheel tracks that have not glazed or rutted. In those areas, shear distress has not developed. Permeability is lower relative to adjacent untrafficked areas.

5. Untrafficked areas have density values slightly less than non-rutted wheel-track areas. Those areas most nearly reflect the original condition of the pavement.

In a few cases, unit weights were considerably greater than thought to be representative for the observed condition. This probably resulted from filling of aggregate void space with fine aggregate (dust sizes) generated by disintegration of stripped soft particles. Those fine aggregates have a specific gravity of approximately 2.5 times that of asphalt, and they may displace asphalt. This could produce a very dense, largely uncoated layer having a much higher unit weight. Where such stripping existed, surface layers were usually thinner than normal. Thus, more of the heavier base course was included in the measurements.

In general, unit weight variations tend to agree with observed conditions and seem valid in a qualitative sense. Differing values rather adequately indicate variations in the upper portion of the pavement structure that has resulted from the combined actions of water and traffic.

## LABORATORY TESTING

Laboratory testing is considered here to include visual and photographic evaluation of cores and materials as well as determination of the density, asphalt content, and voids relationships of selected specimens. Testing was limited principally to the upper courses, usually the dense asphaltic concrete surface course and the open-graded friction course with some tests on the upper base course. A few tests were run on deeper layers of base. Base course testing also included determination of stability and flow values.

## VISUAL EVALUATION

Each of the 26 cores obtained as a part of this study, six of the seven cores cut earlier by the Division of Materials, and materials from the trench excavation were carefully inspected. Base, dense surface, and open surface samples were studied to detect distress or damage indicators.

Principal indicators differ for the several courses. In general they include:

- (1) surface texture of the open-graded surface course,
- (2) presence and degree of stripping,
- (3) presence of water,

- (4) reorientation of aggregate particles,
- (5) migration of asphalt and/or matrix,
- (6) particle disintegration,
- (7) relative course thickness, and
- (8) segregation of coarse aggregate particles.

Each indicator was evaluated visually; thus, the evaluation is subjective. For this reason, each indicator is rated as severe, some, or none for each core. Table 4 gives the codes used in Table 5, which lists the observations for the 26 cores cut in this study. Table 6 provides a summary of Table 5.

#### OPEN-GRADED FRICTION COURSE

The open-graded friction course was evaluated with respect to texture, particle reorientation, migration of asphalt, and stripping. This course showed little or no stripping.

##### Texture

Texture is very important in this course and includes both rough, open, surface texture and open surface pores permitting circulation of free water. Where texture and open pores were essentially as expected, the texture was rated as good. This condition existed at eight percent of the observed cases. Where texture was "good" but surface voids were partially blocked, the texture was rated as "some". This condition existed in 19 percent of the observed cases. The "severe" category included all locations where excess asphalt/matrix had closed surface pores and prevented, or severely impeded, water movement in or out of the course. This condition existed in 73 percent of the locations studied. Four of the six locations studied represented visually distressed areas. Thus, these percentages suggest a severe condition that generally exists in the total pavement and that is believed to be reasonably representative of conditions that now exist or are rapidly developing in truck lanes.

##### Particle Reorientation

Particle reorientation in the open-graded surface is limited primarily to areas showing active shear of a severe nature such as overthrusts and thin pavement in ruts. Rounded particles suggest that some particle movement may have gone undetected. In 69 percent of all locations, no movement could be identified, 8 percent showed limited movement, and 23 percent showed severe movement and were located in badly sheared areas.

##### Asphalt Migration

Asphalt migration results from stripping of asphalt from lower strata and forcing this material upward into pores of the open-graded surface. The asphalt often contains fine aggregate and thus is classified as an asphalt matrix. Surplus asphalt may originate from a stripped tack



coat or from asphalt stripped from underlying layer(s). In 54 percent of the cases studied, this condition was evaluated as "severe". In 23 percent, the rating was "some", and the same percentage received a rating of "none". Thus, 77 percent of all cases showed evidence of migration of stripped asphalt in the open-graded asphalt surface.

#### ASPHALTIC CONCRETE SURFACE COURSE

In the southbound lanes, a single course of dense-graded surface mix was constructed. In the northbound lanes, a dense-graded surface course served as the wearing surface for approximately one year. A second layer of the same mix was constructed just prior to placement of the open-graded surface.

The initially constructed dense surface course showed relatively little damage. The presence of water could be detected, but evidence of stripping was very slight and confined to the immediate area of the interface between the two dense-graded surface courses. This condition existed even when stripping of the upper course virtually was complete. It is apparent that the lower course has provided good service by being resistant to water action.

The following comments are directed to the dense surface course on the southbound lanes and the upper dense surface course on the northbound lanes. Stripping to some degree was present in 87 percent of the locations and was rated as "severe" in 42 percent of the cases. Samples showed a severe loss of asphalt. Disintegration of soft particles was observed in 9 percent of these cases. Other soft particles that have not disintegrated at this time were observed.

Particle reorientation was noted in 36 percent of the cases, indicating shear movement was in progress. Migration of asphalt was apparent in 70 percent of all cases and the presence of water was noted in 87 percent. Appreciable shear movement was observed in only 12 percent of the cores. Since particle reorientation was three times as prevalent, it appears that additional locations soon will become active shear areas.

This course appears to be irrecoverably damaged by water in many locations. It is reasonable to expect that these conditions will expand rapidly in truck lanes and at a slower rate in other lanes. Stripped and disintegrated soft particles are apparent. These particles probably aggravated the problem once stripping exposed them to water. Similar soft materials were observed in the lower surface course and in the base course. Where stripping had not occurred, the particles have remained as an intact and functioning portion of the aggregate structure.

Damage to this course results from both static and pressure (dynamic) stripping. Static stripping is strongly supported by the prolonged periods of wetting common to this type construction. Pressure stripping requires a high degree of saturation in the layer plus surges of stress provided by traffic loads. Again, the necessary presence of

water is supported by the type of construction (see Appendix A).

#### BASE COURSE

These courses have sustained little damage from water. Limited stripping was observed in 23 percent of the cores. With one exception, this was limited to the immediate interface area with the dense surface course in the southbound lanes. The exception, also in the southbound lanes, was within the second base course above the subgrade in a badly segregated mixture. The water source is suspected to have been the subgrade, but this could not be established during this study.

The presence of water was detected in 35 percent of the cores but had little, or no, effect except as noted above. Segregation was noted in 8 percent of the cores at some level. This condition existed in southbound lanes much more frequently than in the northbound lanes. The most serious cases were in the first base course in contact with the subgrade. Segregation in other courses may represent areas of stress concentration that eventually may affect pavement performance.

Possibly the most serious defect noted in the base courses was a weak bond between courses. This condition was noted at one or more interfaces in 69 percent of the cores and 22 percent of the interfaces between base courses. To provide the structural design capacity, interfaces must be tightly bonded to assure continuity of stress transfer from one layer to the next. Where separation occurs, considerable increases in stress can occur at a given locale. While this condition was noted in cores from both directional lanes, it was more prevalent in the southbound lanes.

Defects in the base course as noted above may contribute to some loss of performance capability. It is not anticipated, however, that their effect will be substantial. The upper base course appears to have suffered very slight damage from the action of water entering from above.

It is not believed that the base courses contribute in any way to the observed surface distress. Further, when the surface condition is corrected, the base will continue to serve as intended.

The observed water distress is progressing downward. If the surface condition is not corrected, prolonged exposure of the base courses to water well may result in stripping in the upper base layer.

#### MATERIALS, MIXTURES, AND CONSTRUCTION

Data were obtained from the Department of Highways, Division of Materials, for the component materials utilized in construction of this project and includes data on mixture designs, mixture control, construction, and construction

densities. This information is necessary to understanding potential responses of materials to conditions and loading existing on this project and contributions they may have made to the observed distress.

#### ASPHALT

Asphalt used in the mixtures on this project was an asphalt cement, Grade AC-20, meeting Departmental requirements. Asphalt for the open-graded friction course was treated with 0.5 percent of a liquid anti-stripping agent meeting Departmental requirements. Asphalt cement for other courses was untreated.

Asphalt emulsion, SS-1h, was provided for tack coats. This was applied at a dilution rate of 50 percent water and 50 percent emulsion. This material was applied between courses as directed at a rate of 0.1 gallon per square yard. Core separation at the interface between the third and fourth base courses occurred in 16 of 26 cores. This suggests that a tack coat was not applied on this interface.

#### AGGREGATE

Several aggregates were used in this construction. They were limestone coarse aggregates in two sizes, quartz coarse aggregate in one size, limestone sand, and natural quartzitic sand.

Limestone coarse aggregate was supplied as No. 57 and No. 8 sizes. The limestone sand came from the same source. Data on these aggregates were obtained from the Division of Materials. Data indicate that these materials conformed to specification requirements. However, it is somewhat variable in properties.

Bulk specific gravities varied from 2.49 to 2.60 for the several samples that were tested. This suggests either a rather porous aggregate or one containing considerable silicious material. It does not indicate the material was unsuitable.

Water absorption varied from 1.2 percent to 3.3 percent. This range is not unusual for limestones. Average absorption is 1.9 percent. In an all-limestone mix, the expected asphalt absorption could be one percent or more.

Wear of this stone indicates that hardness tends to vary from very satisfactory to slightly soft. However, it does readily conform to specification requirements. Higher wear values may indicate the presence of some hard calcareous shale particles, but this is not established by the data. Sizes used on this project tended to fall in the middle range and indicate satisfactory materials.

Soundness loss varied from 5.2 percent to 15.8 percent for the sizes used on this project. The average value was 12.3 percent. Some specimens had higher losses, but it is presumed these were rejected. It does show that, although the aggregate generally is sound, some soft particles could be encountered.

Data indicate aggregate used should have been satisfactory, although some soft particles could have been

expected. The aggregate has a long history of satisfactory use in asphalt mixtures. However, in badly stripped material, some soft particles were observed in varying stages of decomposition. In layers where stripping was not occurring, no deterioration was observed. It is believed that soft particles contribute to the observed distress but are not responsible for its initiation.

#### ASPHALT-AGGREGATE MIXTURES

Mixtures used on this project were an asphaltic concrete base, an asphaltic concrete surface, and an open-graded friction course. Design data on the asphaltic concrete mixtures were reviewed with regard to possible contributions to the observed distress. The Marshall Stability Test Method for mixture design was employed using 75 blows for both base and surface mixtures.

Gradation of the base course mix is very dense and would be expected to produce a very low value for "Voids in Mineral Aggregate". The surface course also is very dense but not seriously so. The low percentages of aggregate passing the No. 100 and No. 200 sieves tend to open up an otherwise very dense material. The optimum properties of base and surface mixtures for traffic lanes are presented in Table 7.

#### Asphaltic Concrete Surface

Considering first the dense asphalt surface mix, the voids in mineral aggregate value is 15.4 percent. This value is slightly lower than desired but is not in a highly critical range. Voids in the compacted mix are 4.9 percent and within an acceptable range. The mixture would have benefited from 0.3 to 0.4 percent more asphalt, providing greater lubrication, lower air void content and slightly greater film thickness of asphalt. Asphalt absorption at 0.4 percent is quite low, probably due to the quartz sand. This resulted in an effective asphalt content of 5.0 percent. Stability of approximately 2,400 pounds is high and flow is low at 0.08 inch. These values indicate a very stiff mix that might be hard to compact but should not readily deform under traffic loading. In general, this mixture could have been improved but should have provided acceptable service if well compacted. No data on moisture resistance testing are available.

#### Asphaltic Concrete Base

The asphaltic concrete base course mix has an extremely dense gradation that results in too low a value of 11.6 percent voids in mineral aggregate. This indicates a harsh mix that requires very high energy input to develop good in-place density, but the mix should not be prone to appreciable segregation. The absorbed asphalt in this mixture is about 1.3 percent and the calculated effective asphalt content is 3.3 percent. This is enough asphalt for the very dense aggregate structure and provides an air void content of 3.3 percent. The stability of 3,650 pounds is

very high and a flow of 0.15 inch is moderately high.

Data indicate a very dense, stable base mixture that should provide good service. However, it has a thinner film thickness of asphalt than desired that under some circumstances might be susceptible to action by water. This mixture could have been improved by a more open gradation providing 13 percent or more voids in the mineral aggregate. Test data does not indicate the mix used was excessively sensitive to variations in asphalt content. Although harsh and requiring a high compactive effort, it should provide good service if constructed to a high density.

#### Open-Graded Friction Course

The open-graded friction course was not designed in the manner used for dense-graded mixes. From observations, asphalt film thicknesses were adequate and the mixture appears to have been adequately compacted. Aggregate gradation closely approximates requirements for No. 8 stone graded toward the fine side. Approximately 65 percent of this aggregate is between the 3/8-inch and No.-4 sieve sizes, 20 percent between the No.-4 and No.-8 sieves, and 10 percent finer than a No.-8 sieve. This should have provided an open mixture having an estimated void content of about 15 to 20 percent in the original construction. Aggregate is crushed quartz gravel that conforms to specification requirements. However, it has a rounded shape that lends itself to movement under traffic pressures. No such movement could be observed in the pavement prior to stripping of the underlying course.

#### CONSTRUCTION CONTROL

Density control records were reviewed to determine the effectiveness of compaction. Density data were obtained with a nuclear density meter. Thus, the surface course density could not be checked because the depth of influence is considerably greater than the 1-inch thickness of this course.

Table 8 provides the data used to estimate the percent voids in the pavement as a function of in-place density. A total of 332 measurements were made on the first five layers of the base course. Those measurements were analyzed with respect to voids in the compacted mix. The average air void content was about 4.5 percent and ranged from 0 to 12 percent (Table 9). The 2 percent having void contents above 8 percent and the 7.5 percent having void contents of less than 2 percent are undesirable although neither group represents a dangerous condition. Thus, compacted densities can be considered adequate and the base courses well constructed.

It is known from core inspections that segregation did exist at many locations in the base course. Those locations can contribute to water channels within the pavement if segregated areas are connected. Little evidence indicates this to be the case, but spot flushing could have resulted from this condition. Segregated areas also can become water

storage areas within the pavement structure. One such area is believed to have existed in a core cut from the southbound lanes, Location Number 3. These areas can lead to stripping due to prolonged exposure of the mixture to water. Segregated areas also cause deviation of normal stress paths within the pavement structure and can produce stress concentrations of a higher level than normal. Despite the limited imperfections noted, the base course generally is well constructed and should provide good service.

## LABORATORY TESTING PROGRAM

### SELECTION OF SAMPLES

Cores selected for testing represented the observed range of water-related distress and pavement condition. Each coring location was represented by one or more samples for a total of 12 cores. Bulk samples of both surfacing types were tested for asphalt content. At three locations, sections of the asphalt base course were sampled (cores) for strength testing.

Selected courses were carefully removed from the core by sawing to isolate the sections (courses) to be tested. Saw cuts were made at the interface between courses. The first cut removed both the dense surface course and the open-graded surface course as a single unit. After measurement and density testing, a second saw cut separated these two courses for similar measurement and testing. Last, selected sections of base course were sawed from the cores.

### TESTS PERFORMED

Testing consisted of determining the density and asphalt content of each specimen. Density was determined first on the combined dense and open-graded surface courses. Then each course was tested separately. This was followed by a vacuum extraction procedure to determine asphalt content. Due to the small sample size, gradation tests would have little meaning and were not run. Base course samples were tested for density but not for asphalt content. They were also tested for Marshall stability and flow.

Test specimens obtained from surface mixes were small and thus may not provide fully representative data. They do provide the best available summary of the properties of in-place materials.

## LABORATORY TEST RESULTS

### THICKNESS MEASUREMENTS

Table 10 contains the thickness measurements for all core sections tested. It is assumed that nominal thicknesses of surface courses were 0.75 inch for the open-

graded surface and 1 inch for the dense surface course for a total of 1.75 inches of surfacing. In the northbound lanes, this thickness was supplemented by an additional 1-inch temporary surface course.

It is seen from the tabulation that the thickness of the combined surface courses exceeded the nominal in seven of twelve cases and are less in five cases. Variations are of such magnitude that they may represent normal construction variations (+/-0.5 inch) in all but five cases. Three of these seem to indicate shear movement has resulted in shoving additional material into the area. The remaining two seem to show removal of material from the area by the same type forces. The thickened sections are in areas where shear displacement was observed. Thinned sections are in wheel tracks with some densification but do not necessarily exhibit shear displacement.

The Kentucky Standard Specifications for Road and Bridge Construction states, "The thickness of the course shall be approximately 3/4 inch." Open-graded surfaces vary beyond usual construction tolerances in six of twelve cases. Two of those are abnormally thick indicating movement of the open course, sometimes mixed with dense-graded aggregate from adjacent areas. At four locations, thinness indicates loss of open-graded course material due to shear movement. Some intermingling of aggregate was noted at locations where thickness was near nominal, suggesting additional movement was occurring.

The dense surface course thickness was near normal at five of twelve locations. Five of the remaining cases were thicker than normal and two were thinner. Both thickened and thinned sections suggest migration of material in this course under the shear stresses imposed by traffic.

The temporary surface layer and the base courses in the northbound lanes are believed to be the same as the constructed thicknesses.

#### CORE DENSITIES AND VOIDS

Density and voids data are summarized in Tables 11 and 12. Measured densities of the combined surface courses, the open-graded surface course, the dense surface course, and base courses of the tested cores are shown. In each case, density is expressed in pounds per cubic foot. For the dense surface and base courses, the percent of Marshall density, air voids, and voids in mineral aggregate are presented.

It was intended to compare core densities with nuclear densities measured at the core locations. An examination of both sets of data indicate this should not be done. Nuclear densities average about seven percent less than core densities for open-graded surface and about nine percent less than those for the combined surface courses. There is an indication that course thickness variations influence nuclear density measurement to an extent that is not defined. The major factor affecting nuclear densities appears to be surface texture. The open-graded surface

tends to be very coarse textured, even when surface pores are largely closed. This provides an air gap of undefined volume that reduces the density value. A nuclear meter operates on the principal that more radioactive particles are absorbed as the density of materials increases. Thus, as the density of a material increases, the number of particles to be counted decreases. The air gap allows the radioactive particles to be reflected to the meter and thus more radioactive particles are counted by the meter than normally would be expected. Where extreme densification or glazing had occurred, the nuclear density values increased to near, or above, core densities of the open-graded surface. For these reasons, nuclear densities will be considered as site specific and used only to express variations at each core location.

#### DENSITY TESTING

Laboratory density tests were performed on combined open-graded and dense-graded surface courses followed by tests on the separated individual courses. Base course samples also were tested for density. Because of the potentially high porosity of surface courses, densities for the open-graded surfaces (by design) and dense surfaces (due to stripping) were determined on the basis of paraffin-coated samples prepared according to ASTM D-1188. The densities are expressed as a percentage of the design Marshall density. This procedure results in a potential error because the mixtures may have been altered by stripping and shearing actions. It is believed that this potential error is small and that the indicated percentages are very nearly correct.

#### VOIDS

Voids relationships determined are "voids in mineral aggregate" and air voids in the compacted mix. Although extracted asphalt contents are used, these measurements also may be in error. Again the error is believed to be small and the determined values essentially are correct. All density and voids data for surface courses are summarized in Table 11 and data for base courses are summarized in Table 12.

#### AGGREGATE DURABILITY

Observations indicated that soft aggregate particles were present in the dense surface course and that at least part of these had been adversely affected by water action. It was desired to learn if these particles remained in sufficient quantity to further affect the performance. For this reason, extracted aggregates from several cores were combined and tested for soundness. These data may be compared to results of similar tests made prior to acceptance of the aggregate for use in these mixtures. As stated earlier, soundness loss varied from 5.2 percent to 15.8 percent for the sizes used on this project and the average value was 12.3 percent.



## ANALYSES OF TEST RESULTS

### THICKNESS

Analyses of thickness data confirmed and quantified observations on pavement conditions. In general, locations showing shear movements were thicker in overthrust areas and thinner in center of rut areas than nominal design thicknesses. Rutted and densified locations were thinner. Thickness changes usually resulted from movement in both surface courses when stripping was severe, with mixing of the courses in overthrust locations. Where only rutting exists, it appears the open-graded surface tends to slip over the stripped dense surface course, becoming thinner as seen in several cores including three of those prepared for density testing.

As stripping of the dense surface course progresses, cohesion of that course is severely reduced. Adhesion to both the open-graded surface and base course is deficient or totally lost. Thus, the unstripped open-graded surface course loses the confinement necessary to its stability and the dense surface course no longer has the required stability to resist shear stresses induced by traffic. It is reasonable to believe that all observed thickness changes resulted from migration of the two surface courses under traffic stresses after stripping was well advanced.

### DENSITY

Nuclear density testing at each location indicated rather large differences between lanes. These generally can be characterized as lower densities in areas having visible evidence of movement, higher densities in rutted wheel paths, and intermediate densities in both untrafficked areas and wheel tracks that had not rutted. At the untrafficked location No. 4, a major density increase occurred in a glazed area.

Laboratory densities of the combined surface courses tend to be relatively consistent except where severe shear movement has occurred. In such cases, reduced densities are found. Densities of the open-graded surfaces can be judged best relative to the dense surface course densities. Where little or no visible damage had occurred, the open-graded surface is approximately 10 pounds per cubic foot lighter than for the dense course. Where visible damage has occurred, the difference is much smaller and decreased to zero in one case. Increases primarily are attributed to migration of stripped asphalt/matrix into voids of the open-graded surface. Such movement results from both stripping and traffic-induced stress.

Measured densities of the dense surface courses were compared to the design Marshall density. Those values ranged from 94.8 to 101.6 percent. Thus, the structure of the dense surfaces are acceptable whether stripped or unstripped. The three lowest values of 94.8, 95.5, and 96.7

percent are associated with severely stripped areas. Densities in excess of 100 percent are associated with partially stripped areas. Thus, a deficiency in measured density does not appear to exist.

#### VOIDS IN MINERAL AGGREGATE

Calculation of voids in mineral aggregate are based on the extracted asphalt content for each core and should be accurate and reliable. The design voids in mineral aggregate value was 15.4 percent. In the dense surface course, 50 percent of the values are within plus or minus 1 percent of the design value, 33 percent are greater than the design value, and 17 percent are less.

In the four cases of severest stripping, the voids in mineral aggregate values tend to be high in three cases and low in the fourth. It cannot be determined with certainty whether changes in voids in mineral aggregate occurred as particle reorientation developed under stress, or whether variations existed from construction. The former is believed to be the case.

It may be significant that the three lowest voids in mineral aggregate values (14.2, 14.3, and 14.5 percent) occurred at locations where flushing but no shear movement was observed. Very dense aggregate structures lend themselves to this type of distress when stripping occurs.

From the above, it can be concluded that the design voids in mineral aggregate value could have contributed to the stripping problem only by limiting the asphalt content and thus the asphalt film thickness. There is no definite indication that this was the case except at locations 3C and 5C, which suffer from flushing.

#### AIR Voids

The range of in-place air voids is from 2.7 to 9.1 percent and the design value was 4.0 percent. The range is not extreme. The three highest void contents are at severely stripped locations. One other location is within 0.1 percent of the design value. It is believed the high values resulted from shear movement. There is little question that mixtures with these void contents would be expected to provide good service.

#### ASPHALT CONTENT

Asphalt contents of open-graded and dense surface specimens were evaluated by vacuum extraction. These specimens were very small and made testing difficult. However, results appear to be consistent and are considered reasonably accurate and reliable.

The design asphalt content of the open-graded surface course is believed to have been 6.2 percent. Extracted asphalt contents vary from 5.2 to 7.4 percent. Considering construction tolerances ( $\pm 0.3$  percent), two specimens were beyond the tolerance below the design value, eight were within tolerance, and two were above the tolerance. None of these specimens appeared deficient in asphalt when observed

from the surface. The two high values represented flushing of asphalt to the surface. It was expected that a higher percentage would have high asphalt contents because surface pores were seen to be closed. This apparently indicates that such closure is occurring without enrichment in many cases.

Design asphalt content of the dense surface course was 5.4 percent. Four of twelve cores were below this value in excess of construction tolerance ( $\pm 0.3$  percent) and two were below this tolerance. The low values occurred in locations where stripping was evident. Severe loss of asphalt was noted in four of five locations rated as severely stripped. In the remaining case, asphalt content was normal. The losses observed are believed to be caused by migration of stripped asphalt into adjacent areas.

It can be concluded that asphalt contents were normal in most areas. Where excesses or deficiencies existed, advanced stripping was observed. It is believed that prior to the onset of stripping, all locations would have shown normal variations in asphalt content around the design value.

#### TEMPORARY SURFACE COURSE

Samples from two sites were taken from the temporary surface course placed in the northbound lanes to accommodate traffic during construction of the southbound lanes. The same tests were performed on those samples. Both of those specimens had high density, high voids in mineral aggregate, high air voids, and high asphalt content. Although both specimens contained water, neither demonstrated any stripping and both are in good condition.

#### ASPHALT BASE

Two asphalt base samples for each of three core locations were tested. These tests consisted of density, voids in mineral aggregate, air voids, and Marshall stability and flow.

Densities were low on two specimens, very slightly low on one, and acceptable on the remaining three. Only one specimen is suspected of slight stripping and that one shows no appreciable damage.

The design voids in mineral aggregate value is very low at 11.1 percent. In-place values range from 12.4 to 19.4 percent. This value should exceed 13 percent and probably should not exceed 15 percent. Two specimens are slightly below the desired minimum and three exceed the preferred upper limit.

Marshall stability values range from 800 to 1,820 pounds. The three lowest values are associated with excessively high voids in mineral aggregate values and may result from segregation within the specimen. None of these values are considered dangerously low for core measurements.

Marshall flow values (Table 12) vary from 0.09 to 0.25 inch. Three are in excess of the recommended maximum of 0.16 inch. Two of those also have low stability values and

one is quite high. Those having high flow and low stabilities may have suffered slight stripping damage that could not be observed. It is more likely that each of the high flow values result from intrusion of water into pore spaces. This can have the same effect as excessive asphalt, producing specimens that deform extensively prior to breaking. The load-deformation curves seem to indicate this is the case.

It can be concluded that the base courses may have sustained very limited water damage and that some contain considerable pore water. There is the possibility that, if water remains available, stripping could become a future problem. At this time, the base courses that were tested are considered fully functional.

## EVALUATION OF POTENTIAL FOR CONTINUING DISTRESS

### HARDIN COUNTY, MULDRAUGH HILL

Both visual inspection and test data indicate that water-related distress on this project is widely distributed and severe in many locations. Locations investigated that are not currently showing visible distress on the surface have been found to be in the early stages of stripping at most locations where core samples were obtained. All such samples were obtained from outside lanes. Visible surface indications exist in other lanes and strongly suggest that distress extends to portions of all lanes. The onset of rutting was observed in the second lanes in both directions, with rutting greater in the northbound lanes.

It is believed that all lanes carrying a high percentage of truck traffic will develop major distress. This first will be observed as local conditions but will enlarge into general conditions. The first appearance will be densification and possibly flushing followed by rut development.

Rut development results from severe strength losses due to stripping in the dense surface layer. Rut appearance will be accompanied with slight heaving adjacent to the wheel track. As rutting progresses, overthrusts at the rut edge should be expected. The rutting pattern is expected to be shallow with lateral displacement occurring only in the surface courses.

The base course currently is stable, although some minor water damage is evident. The upper base course can be considered sound and functional. If exposure continues over an extended period, the upper base course may not retain its properties.

Corrective measures need to be instituted in the near future. These can be of a local, temporary nature; but such an approach is not expected to remain effective. Adjacent areas will continue to fail. As a minimum, replacement should be undertaken on a full lane basis. At the present, outer lanes warrant such treatment and the second lanes also will need to be replaced early in the coming year.

It certainly is possible that severe distress conditions will develop this winter. The dense surface course is retaining water and ice action may cause expansion and popouts. Low temperatures will retard rut development, but this may not be sufficient to prevent severe distress as seen currently at some locations.

Major distress and the current potential for distress development exist only in the open-graded and dense surface courses. In the northbound lanes, the temporary surface remains stable and need not be replaced. Thus, major problems are anticipated only in the upper 1.75 to 2.00 inches of the pavement. If milling is employed to remove deficient material, it would be best to extend this to 2.00 inches to assure roughening of the base course and removal of all dust from the stripped layer.

The milled material may be acceptable for recycling. If such use is contemplated, both the milled material and the recycled mixture should be thoroughly tested to assure water resistance.

#### OTHER PROJECTS

As a part of this investigation, several projects having similar designs were observed. These included projects now in service and projects still under construction. This included inspection of projects in service for visible evidence of water action and evaluations of mixture designs of projects under construction for potential water susceptibility.

#### In-Service Projects

In-service projects included all sections of I 75 north of the I 71 intersection, sections of I 71, and the section of I 64 in Jefferson and Shelby Counties. Sections on I 75 have the longest service history. The oldest project shows relatively minor damage, but flushing and minor rutting were observed. It is evident that water action is occurring, but it is not serious at this time. The best section observed on I 75 is in the northbound lanes extending from near Fort Walton to the Ohio River. This section retains good texture and shows only minor flushing at widely dispersed locations.

On I 71, older projects exhibit some glazing, flushing of asphalt, but very little rutting or displacement. Flushed areas are believed to be increasing, but no severe rutting exists at this time. Reasonable service is anticipated. The most recently completed project, beginning at I 75 and extending southward, exhibits very limited flushing of a very localized nature. Flushing observed could have originated from uncured tack coat.

The newly completed surface on I 64 also exhibits some localized flushing of uncertain origin. Water continues to drain from this open-graded surface for more than 24 hours after rainfall has ceased. Thus, portions of the underlying dense-graded surface remain wetted for extended periods.

#### Projects Under Construction

Design of dense-graded surface mixtures was reviewed on six projects now under construction. On some of these, the open-graded surface is partly constructed. On others, this stage has not been reached and the open-graded surface is not scheduled for construction until 1985.

In each case, design data of the dense surface course was reviewed with respect to potential water susceptibility. Properties that have the greatest significance are gradation, asphalt content, asphalt absorption, voids in mineral aggregate, and air voids. Asphalt content is important with respect to both film thickness and to air voids content. Asphalt absorption identifies that portion of the total asphalt that is not available for binding aggregate particles together, which is identified as effective asphalt content. Some absorption is a desirable attribute since it tends to increase water resistance. Voids in mineral aggregate is very important in that it strongly influences the asphalt content, the workability of the mixture, and the compactive effort needed to produce high densities. Air voids in the compacted mix must be within the proper range to provide good service and water resistance.

Gradation has a strong influence on all other properties. It largely determines the void space available in the aggregate (voids in mineral aggregate). The air voids and asphalt content needed for proper coating are a function of aggregate gradation. It also strongly influences the strength properties, stability and flow. Thus, improvements in any mixture must normally start with a provision for gradations that will produce desired mixture properties. It is not known whether these mixtures were evaluated with respect to moisture resistance. For the intended usage, this becomes important although similar mixtures have been produced from the same aggregates and have excellent service records.

Properties for the various projects are summarized in Table 14; Project Number 1 is the I-65 section being investigated. Gradations are not tabulated but were studied.

Gradations on all projects tend to be very similar in the coarse fraction (plus No.-4 sieve). This portion of the aggregate tends to be consistently dense. Quantities between the No.-4 and No.-8 sieves also are similar. Aggregates finer than a No.-8 sieve, however, differ considerably. It is apparent from voids in mineral aggregate data that all gradations stack quite densely, and some are critically so. It seems probable that gradations submitted as job-mix formulas, and used for mixture design, resulted from an effort to provide, as nearly as possible, a central distribution within specification limits. Regretably, such gradation often approach maximum density distributions and result in too low values for voids in the mineral aggregate. Appreciable departures from the maximum density condition occur only in the minus No.-50 dust sizes. In the mixtures reviewed, gradation revisions would have

been desirable.

Voids in mineral aggregate is the result of aggregate gradation. It indicates if enough space is provided to accommodate needed asphalt and air. Dense surface mixtures of the type used should have a minimum of 16 percent voids in mineral aggregate. As a gradation is made denser, several undesirable conditions can result. First, the surface area increases which requires more asphalt to coat all of the surfaces with the desired film thickness of asphalt cement. The net result is a deficiency in air void content and the asphalt will flush to the surface of the pavement as the summer heat rises. Second, it becomes more difficult to coat the surface with the correct film thickness of asphalt cement with the net result in either a deficiency in content of asphalt cement, air voids, or a combination of both. Third, if increasing density is a result of additional fines, then for a fixed asphalt content, the total amount absorbed by the aggregate may increase, resulting in a decreased effective asphalt content.

Analyses of the voids in mineral aggregate indicate two of the mixtures studied are only slightly deficient and under other circumstances would be expected to provide good performance. Three mixtures are considerably denser than desired and well might be questionable even for use as surfacing materials. Two mixtures are considered critically dense. They have resulted in mixtures that could not provide minimum desirable air voids without significant reductions in asphalt content which then would decrease the resistance to water. Optimum asphalt content was considered to be 5.4, 5.5, or 5.6 percent in all designs. These values should have been adjusted to provide acceptable air void content in five of seven cases. In each case, the revision would have reduced the asphalt content used.

Asphalt absorption ranges from 0.3 to 0.9 percent. This is acceptable in all cases.

The effective asphalt content varies from 4.6 to 5.2 percent. These values are acceptable, although a slight increase would have been desirable.

Unit weight, stability, and flow values were acceptable in all cases.

Air voids are acceptable in two cases, slightly low in three cases, and critically low in two cases. Low air voids result in very dense mixtures but allow little opportunity for the mixture to densify under traffic without becoming plastic. This occurs at, or slightly below, 2.0 percent air voids. Two mixtures are below this limit.

The dense surface mixtures reviewed tend to be denser than desired in varying degrees. This results from a strong emphasis (by contractors) on approaching the central permissible gradation. This can and should be corrected by placing greater emphasis on mixture properties than on gradation. Current practices and requirements should be studied and revised toward this end. Changes in gradation limits may be needed to effectively implement such changes.

In summary, these mixtures (Projects 2 through 7 in Table 14) do not appear to be more resistant to water action than the mixture employed on I 65 (Project 1 in Table 14). In general they have somewhat less desirable properties. However, they are composed of other aggregates and may, or may not, be more resistant to water action. As a minimum, all should be suitably treated with anti-stripping materials when they are to underlay an open-graded surface.

## CONSIDERATION OF DEPARTMENTAL PROCEDURES

Some revisions to Cabinet procedures may be desirable to minimize possible reoccurrence of the water-related problem experienced on this project. These revisions concern component materials, mixture design, and construction control. In addition, the Cabinet may want to reevaluate the use of open-graded surfaces with respect to potential user safety and to potential performance.

### COMPONENT MATERIALS

Current requirements are providing materials quite capable of good performance in most pavements. When the course to be constructed must serve in an adverse environment, as beneath an open-graded surface, more stringent requirements may be desirable. In such cases, consideration should be given to lowering wear to a 35-percent maximum and lowering soundness to a 15-percent maximum loss. Changes, if adopted, need only apply to the specific construction noted.

### GRADATION

Current gradation limits for asphaltic concrete base courses need to be reviewed to provide increased voids in the mineral aggregate. Current gradation limits for surface courses may need to be broadened slightly to permit better use of suitable available aggregate. Current emphasis on gradation as the major consideration in selecting the job-mix formula can, and has, resulted in mixtures deficient in other respects.

Consideration should be given to establishing a gradation that will provide relatively coarse texture for use in skid-resistant surface courses. Such a gradation could be provided and, when constructed with a reasonable proportion of skid-resistant aggregate, satisfy obvious safety needs. The gradation should be relatively coarse but should retain the density range accepted for dense-graded mixtures.

Two projects currently under construction or completed this year have been constructed with variations of the skid-resistant type surface mix described above. One of these is in Boyd County and the other in Rowan County. Different gradation limits were provided for each project. Both projects have gradations that should provide suitable surface textures. The Boyd County project may be slightly



more open than desired.

A gradation similar to those used above should satisfy requirements. Such a gradation is suggested in Table 15. Forty to sixty-five percent of this gradation is coarser than the No.-4 sieve, assuring a rather coarse texture. A well-graded fine aggregate fraction is encouraged to provide a dense matrix. This mixture can be gap graded, although this might encourage segregation. This can be prevented by refusing to approve gap graded job-mix formulas. It may be determined that other gradation limits are better suited to particular available materials. This should be determined through evaluation of generally available aggregate and by testing a variety of mixtures.

The gradation limits shown can produce the desired surface texture. To assure retention of skid-resistant properties, coarse aggregate should include not less than 50 percent approved skid-resistant aggregate. Further, the fine aggregate fraction should contain not less than 50 percent-polish resistant material.

#### MIXTURE CRITERIA

Criteria providing limits for the several critical mixture properties are well established. These criteria should be considered as part of the normal mixture design procedure that must be conformed to before the job-mix formula is approved. The criteria referred to are those published by The Asphalt Institute. They are not in any respect unreasonable and do provide a high degree of assurance that good performance will result.

Current testing for moisture sensitivity has proven reasonably satisfactory for most projects and should be continued. When the dense surface is to serve beneath an open-graded surface, a more severe criteria should be sought or anti-stripping additives should be incorporated into all such mixtures, or both. Liquid additives in the open-graded surface on Muldraugh Hill have been very effective to date. Other similar materials also may be effective. Hydrated lime, in amounts of 0.5 to 1.0 percent, is often and effectively used.

#### CONSTRUCTION CONTROL

There is little indication that construction control of the dense surface course was not a high quality effort. One deficiency in this respect applies to segregation observed in the base courses. Many of the cores cut indicated that segregation had occurred in one or more base courses. This condition is mixture associated to some extent. More frequently, segregation is developed in mixture handling, such as when stored in silos, loaded or unloaded into trucks, or improper handling of the material in the paver. Causes vary from job to job. They should be studied and corrective actions adopted.

Base courses in some cases were not well bonded to the underlying or overlying course. This resulted from lack of aggregate interlock at the interface and from insufficient

asphalt to assure a bond. This can be corrected by application of a light tack coat between courses. The loss of bond between courses can result in strength reduction of the structure with consequent reduction in service life.

TABLE 1. LOCATION OF TEST SITES IN OUTSIDE LANE OF I 65,  
MULDRAUGH HILL (MILES SOUTH FROM CHANGE IN  
PAVEMENT TYPE AT NORTH END OF PROJECT)

Location Number	Miles	Lane Direction
1	0.23	South
2	0.40	South
3	0.64	South
4	1.45	South
5	1.10	North
6	0.29	North

Cores 1, 2, and 3 Taken by the Division of Materials Prior to this Investigation Were Located at Station 403+10 and Correspond to Location 6.

Cores 5, 6, and 7 Taken by the Division of Materials Prior to this Investigation Were Located at Station 402+38 and Correspond to Location 3.

Core 4 Taken by the Division of Materials Prior to this Investigation and the Trench Were Not Located by Station.

TABLE 2. NUCLEAR DENSITIES AT CORE LOCATIONS

CORE NUMBER	DENSITY (LB/CF)	CONDITION		COMMENTS
		DISTURBED	UNDISTURBED	
1A	111.1	X		Upheaval Area
1B	128.6	X		Rut, Wheel Track
1C	120.7	X		Slight Upheaval
1D	128.1	X		Rut, Wheel Track
1E	131.2	X		Densified Wheel Track
1F	121.9		X	Wheel Track
2A	128.2		X	Untrafficked
2B	120.6	X		Upheaval Area
2C	137.8	X		Rut, Wheel Track
2D	124.8	X		Rut, Wheel Track
2E	129.4	X		Rut, Wheel Track
2F	127.2		X	Wheel Track
3A	131.6		X	Untrafficked
3B	139.4	X		Upheaval Area
3C	137.8	X		Rut, Wheel Track
3D	132.5		X	Wheel Track
4A	125.3		X	Untrafficked
4B	131.1		X	Glazed, Wheel Track
4C	116.9		X	Wheel Track
5A	132.0		X	Wheel Track
5B	127.4		X	Untrafficked
5C	137.4		X	Glazed, Wheel Track
6A	127.3	X		Overthrust Area
6B	132.2	X		Rut, Glazed
6C	127.1	X		Between Wheel Tracks, Slight Upheaval Area
6D	131.7	X		Rut

TABLE 3. SUMMARY OF CORE DENSITIES  
BY CHARACTERISTIC DESCRIPTION

CHARACTERISTIC	CORE NUMBER	DENSITY (LB/CF)	
		RANGE	AVERAGE
Upheaval Area	1A, 1C 2B, 3B* 6A, 6C	111.1-127.3	121.4
Rut	1B, 1D 2C, 2D 2E, 3C 6B, 6D	124.8-137.8	131.3
Glazed	4B, 5C 6B	131.1-137.4	133.6
Densified, With Texture	1E, 1F 2F, 3D 4C, 5A	113.9-132.5	127.0
Untrafficked	2A, 3A 4A, 5B	125.3-131.6	128.1

\*Not Included

Table 4. Codes for Visual Inspection of Cores

=====	
Longitudinal Location	Lateral Location
-----	
1. Main Site	1. Outside Edge
2. 25' Downgrade of Main Site	2. Outer Wheel Track
3. 25' Upgrade of Main Site	3. Inbetween Wheel Tracks
	4. Inner Wheel Track
Texture	Upheaved Area
-----	
1. Good as Original Condition	1. No
2. Open but Filling with Asphalt and Matrix	2. Yes
3. Filled with Asphalt and Matrix	
4. Extra Asphalt	
Particle Reorientation	Particle Disintegration
-----	
1. None	1. None
2. Yes, some	2. Yes, some
3. Yes, severe	3. Yes, severe
4. Migration	4. Migration
Asphalt Migration	Segregation of Aggregate
-----	
1. No	1. No
2. Yes, some	2. Yes, some
3. Yes, severe	3. Yes, severe
	A. All base courses
Presence of Water	Presence of Shear
-----	
1. No	1. No
2. Yes	2. Yes
Visible Stripping	Layer Thickness
-----	
1. No	1. Normal
2. Yes, some	2. Thinner than Normal
3. Yes, severe	3. Thicker than Normal
4. Yes, severe at Joint	
5. Variable	
Joint Separation	
-----	
1. None	
2. Between Open-Graded Surface and Dense Surface Course	
3. Between Dense Surface Course and 4th Base Course	
4. Between 4th and 3rd Base Courses	
5. Between 3rd and 2nd Base Courses	
6. Between 2nd and 1st Dense Surface Courses	
=====	

TABLE 5A. VISUAL DESCRIPTION OF CORES

DESCRIPTION	CORE NUMBER															
	1A	1B	1C	1D	1E	1F	2A	2B	2C	2D	2E	2F	3A	3B	3C	3D
<b>Location</b>																
Lateral	1	2	3	4	2	2	1	2	4	4	2	2	1	2	3	4
Longitudinal	1	1	1	1	2	3	1	1	1	1	2	3	1	1	1	3
Unheaved Area	2	1	1	1	1	1	1	2	1	1	1	1	1	2	1	1
<b>Open-Graded Surface</b>																
Texture	4	3	4	4	3	3	2	2	3	2	3	1	3	3	3	3
Particle Reorientation	2	1	1	1	1	1	1	3	3	1	1	1	1	2	2	1
Migration of Asphalt	1	2	1	3	3	3	2	2	3	2	2	1	3	3	3	3
<b>Dense Surface Course</b>																
Stripping	1	2	2	2	3	5	3	3	3	2	3	2	2	3	3	1
Presence of Water	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	1
Migration of Asphalt	2	1	2	2	3	1	3	3	3	2	3	2	1	2	3	1
Particle Reorientation	1	3	1	2	2	1	3	3	1	1	1	1	1	3	1	1
Particle Disintegration	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	1
Thickness	3	1	1	2	1	1	1	1	1	1	1	1	1	3	1	1
Shear Present	2	1	1	1	1	1	1	2	1	1	1	1	1	2	1	1
<b>Base Course</b>																
Stripping	1	1	1	1	1	2	1	1	1	2	2	1	2	1	2	2
Presence of Water	1	2	1	1	1	1	1	2	2	1	2	2	2	2	2	2
Migration of Asphalt	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Particle Reorientation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Particle Disintegration	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2
Segregation (Layer No.)																
None			X		X		X	X		X	X	X				
Some	4	4											1		3	
Severe				2		3			4					1		3
<b>Separation at Interface</b>																
	3	4	4	4	4	4	4	3	4	4	4	4		4	3	4
	4										5	5				

TABLE 5B. VISUAL DESCRIPTION OF CORES

DESCRIPTION	CORE NUMBER																
	4A	4B	4C	5A	5A	5B	5B	5C	5C	6A	6A	6B	6B	6C	6C	6D	6D
<b>Location</b>																	
Lateral	1	2	4	1	1	3	3	4	4	1	1	2	2	3	3	4	4
Longitudinal	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Upheaved Area	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1
<b>Open-Graded Surface</b>																	
Texture	1	3	3	2		2		3		3		3		3		3	
Particle Reorientation	1	1	1	1		1		1		3		3		1		1	
Migration of Asphalt	1	3	3	1		2		3		3		3		3		1	
<b>Dense Surface Course</b>																	
Stripping	2	2	2	3	1	3	2	3	2	3	2	3	2	2	1	3	2
Presence of Water	2	2	2	2	1	2	2	2	2	2	2	2	2	2	1	2	2
Migration of Asphalt	2	2	2	2	1	3	1	3	2	3	1	3	1	2	1	2	1
Particle Reorientation	1	1	1	2	1	2	1	3	1	3	1	3	1	1	1	2	1
Particle Disintegration	1	1	1	1	1	3	1	1	1	3	1	1	1	1	1	1	1
Thickness	1	1	1	1	1	1	1	1	1	3	1	2	1	1	1	1	1
Shear Present	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1
<b>Base Course</b>																	
Stripping	1	1	1	1		1		1		1		1		1		1	
Presence of Water	1	1	1	1		1		1		1		1		1		1	
Migration of Asphalt	1	1	1	1		1		1		1		1		1		1	
Particle Reorientation	1	1	1	1		1		1		1		1		1		1	
Particle Disintegration	1	1	1	1		1		1		1		1		1		1	
Segregation (Layer No.)																	
None	X																X
Some		3	A	A		A		A		A		A		A			
Severe																	
Separation at Interface			4	5						6				6			



TABLE 6. SUMMARY OF TABLE 5 EXPRESSED AS PERCENTAGES

VERBAL DESCRIPTION	PERCENTAGE OF TOTAL		
	SEVERE	SOME	NONE
CODE NUMBER	3 OR 4	2	1
DESCRIPTION			
<b>Open-Graded Surface</b>			
Texture	73	19	8
Particle Reorientation	23	8	69
Migration of Asphalt	54	23	23
<b>Dense Surface Course</b>			
Stripping	42	45	12
Presence of Water	-	85	15
Migration of Asphalt	30	40	30
Particle Reorientation	21	15	64
Particle Disintegration	9	0	91
Thickness	9	6	85
Shear Present	-	12	88
<b>Base Course</b>			
Stripping	0	23	77
Presence of Water	-	35	65
Migration of Asphalt	0	0	100
Particle Reorientation	0	0	100
Particle Disintegration	4	4	92
Segregation (Layer No.)			
None			63
Some		32	
Severe	5		
<b>Separation at Interface</b>	16		

TABLE 7. PROPERTIES OF ASPHALTIC CONCRETE  
BASE AND SURFACE MIXTURES

DESCRIPTION	DENSE SURFACE	BASE
Unit Weight, LB/CF	146.6	148.2
Voids in Compacted Mix, Percent	4.9	3.3
Voids in Mineral Aggregate, Percent	15.4	11.1
Asphalt Content, Percent	5.4	4.5
Absorbed Asphalt, Percent	0.4	1.3
Effective Asphalt, Percent	5.0	3.3
Marshall Stability, Lbs	2390	3650
Flow, 0.01 In.	8	15

TABLE 8. ANALYSIS OF NUCLEAR DENSITY TESTS ON BASE COURSES

UNIT WEIGHT	PERCENT		
	TARGET DENSITY	MAXIMUM DENSITY	AIR VOIDS
130	87.7	84.6	15.1
135	91.1	88.1	11.9
140	94.5	91.4	8.6
145	97.8	94.6	5.4
148.2	100.0	96.7	3.3
150	101.2	97.9	2.1
153.2	101.2	100.0	0.0
155	104.6	101.2	-1.2

Reference Data

Maximum Specific Gravity	=	2.455
Maximum Unit Weight	=	153.2 LB/CF
Marshall Density	=	148.2 LB/CF
(Unit Weight or Target Density)		
Voids in Compacted Mix	=	3.2 Percent

TABLE 9. AIR VOID CONTENT,  
CONSTRUCTION DATA

RANGE IN PERCENT VOIDS	NUMBER	PERCENT FINER
0.0	1	0.3
0.1-0.9	5	1.8
1.0-1.9	19	7.5
2.0-2.9	24	14.8
3.0-3.9	46	28.6
4.0-4.9	69	49.4
5.0-5.9	66	69.3
6.0-6.9	56	86.1
7.0-7.9	39	97.9
8.0-8.9	4	99.1
9.0-9.9	1	99.4
10.0-10.9	1	99.7
11.0-11.9	1	100.0

TABLE 10. CORE THICKNESSES

CORE NUMBER	COURSE THICKNESS, INCHES					
	A	B	C	D	E	F
1A	2.35	1.12	1.16		2.66	2.28
1B	1.82	0.76	0.99		2.40	2.47
1D	2.41	0.79	1.50			
2B	2.31	1.04	1.30			
2C	1.59	0.46	1.01			
2F	2.09	0.74	1.26			
3C	1.92	0.43	1.42		2.55	2.48
3D	2.06	0.65	1.28			
4B	1.34	0.54	0.71			
4C	1.67	0.60	0.94			
5C	1.30	0.46	0.73	1.11		
6C	1.74	0.63	1.01	1.34		

DEFINITIONS OF COLUMN HEADINGS

- A Open-Graded Surface Plus Dense Surface Courses
- B Open-Graded Surface Course
- C Dense Surface Course Number 1
- D Dense Surface Course Number 2
- E Base Course Number 1
- F Base Course Number 2

TABLE 11. CORE DENSITIES AND VOIDS FOR SURFACE COURSES

CORE NUMBER	DENSITY, LBS/CF			PERCENT*		
	A	B	C	D	E	F
Recommended Minimum					16.0	
1A	132.5	125.5	137.0	95.5	18.8	8.5
1B	140.8	133.9	143.3	99.8	15.8	4.3
1D	141.2	133.9	143.3	99.8	16.1	4.3
2B	139.8**	135.9	138.8	96.7	17.1	7.3
2C	140.1	134.8	140.7	98.1	16.9	6.0
2F	139.7	132.3	142.3	99.2	16.1	5.0
3C	143.5	143.6	143.7	100.1	14.2	4.1
3D	143.0	128.2	145.3	101.2	14.3	3.0
4B	145.1	140.9	145.8	101.6	15.8	2.7
4C	143.9	136.2	145.4	101.3	16.5	2.9
5C	143.4	141.9	144.4	100.6	14.5	3.6
	2nd Surface, Temporary		143.7	99.9	16.1	4.8
6C	138.3	134.5	136.1	94.8	19.1	9.1
	2nd Surface, Temporary		139.7	97.1	17.9	7.5

Definition of Column Headings

- A Open-Graded Friction Course Plus Dense Surface Course
- B Open-Graded Friction Course
- C Dense Surface Course
- D Percent of Marshall Density
- E Percent of Voids in Mineral Aggregate
- F Percent of Air Voids
- \* Applies to Dense Surface Course Only
- \*\* Water Penetration of the Paraffin Coating Suspected

TABLE 12. CORE DENSITIES, VOIDS, AND STABILITY FOR BASE COURSES

CORE NUMBER	DENSITY		PERCENT		MARSHALL DATA	
	A	B	C	D	E	F
Recommended Minimum			13.0			
1A						
1st Base	134.26	90.3	19.4	12.1	900	25
2nd Base	140.80	94.7	15.5	7.8	850	22
1B						
1st Base	145.8	98.3	12.5	4.5	1370	14
2nd Base	138.1	92.8	17.1	9.6	800	16
3C						
1st Base	143.9	96.8	13.6	5.7	1820	9
2nd Base	146.0	98.2	12.4	4.4	1720	23

Definition of Column Headings

- A Density, lb/cf
- B Percent of Marshall Density
- C Percent of Voids in Mineral Aggregate
- D Percent of Air Voids
- E Marshall Stability, lb
- F Marshall Flow, 0.01 in.

TABLE 13. RECOVERED ASPHALT CONTENTS

CORE NUMBER	OPEN GRADED FRICTION COURSE	DENSE SURFACE COURSE	OBSERVED STRIPPING	PERCENT ASPHALT	CHANGE IN PERCENT ASPHALT*
Pan No. 1		X	Severe	4.8	-0.6
Pan No. 2	X		None	6.4	+0.2
1A	X		Severe	5.7	-0.5
		X	Some	5.5	+0.1
1B	X		None	6.5	+0.3
		X	Some	5.6	+0.2
1D	X		None	6.2	+0.2
		X	Some	5.9	+0.4
2B	X		None	5.2	-1.0
		X	Severe	4.1	-1.3
2C	X		None	6.2	0.0
		X	Severe	5.2	-0.2
2F	X		None	7.4	+1.2
		X	Some	5.3	-0.1
3C	X		None	6.0	-0.2
		X	Severe	4.1	-1.3
3D	X		None	6.3	+0.1
		X	Some	5.2	-0.2
4B	X		None	7.0	+0.8
		X	Some	5.0	-0.4
4C	X		None	6.5	+0.3
		X	Some	5.6	+0.2
5C	X		None	6.5	+0.3
1st Course		X	Some	4.9	-0.5
2nd Course		X	None	6.2	+0.8
6C	X		None	6.0	-0.2
1st Course		X	Severe	5.3	-0.1
2nd Course		X	None	5.6	+0.2

\*Change from Design Value

\*\*Bulk Samples



TABLE 14. PROPERTIES OF DENSE SURFACE MIXTURES  
IN CURRENT CONSTRUCTION PROJECTS

MIXTURE PROPERTY	PROJECT*							
	1	2	3	4	5	6	7	8
Optimum Asphalt, Percent	5.4	5.5	5.4	5.5	5.6	5.5	5.5	
Asphalt Absorption, Percent	0.4	0.3	0.6	0.9	0.4	0.6	0.6	
Effective Asphalt, Percent	5.0	5.2	4.9	4.6	5.2	4.9	4.9	
Unit Weight Lbs/CF	143.6	150.0	151.4	145.3	147.8	150.2	150.2	
Marshall Stability, Pounds	2520	2350	2510	2280	2070	2740	2740	1500+
Marshall Flow 0.01 In.	8	9	10	8	8	8	8	8-16
Air Voids Percent	4.9	1.9	1.5	3.4	2.7	2.8	2.8	3-5
Voids in Mineral Aggregate, Percent	15.4	12.7	13.3	14.3	15.1	14.6	14.6	16.0+

\*Project Identification

1. I-65-5(19)95, Hardin, Scotty's Construction
2. EAC1R 75-7(64)165, Grant, Kenton, Boone, G & G Construction
3. EAC1R 75-6(57)143, Grant, G & G Construction
4. I-65-5(17)92, Hardin, K.A. Barker Construction  
I-65-4(24)90, Hardin, K.A. Barker Construction
5. FSP-025-006A 101-105, Clark-Montgomery, Walker Construction  
FSP-087-0064 104-113, Clark-Montgomery, Walker Construction
6. EAC1R 71-1(65)6, Jefferson, Eaton Asphalt
7. EAC1R 71-1(64)22, Oldham-Henry, Hinkle Construction

8. Recommended Criteria

TABLE 15. RECOMMENDED GRADATION  
 FOR COARSE-TEXTURED  
 SURFACE COURSE OR  
 SKID-RESISTANT SURFACE  
 COURSE

SIEVE SIZE	PERCENT PASSING
1/2 "	100
3/8 "	70-100
NO. 4	35-60
NO. 8	25-45
NO. 16	15-35
NO. 30	9-25
NO. 50	5-16
NO. 200	2-6

## APPENDIX A.

### DETRIMENTAL BEHAVIOR OF WATER IN AND UNDER OPEN GRADED SURFACE COURSES

#### INTRODUCTION

Open-graded surface and base courses are not new to highway construction. Penetration macadam and cold mixes have been used successfully for a long time in appropriate situations. In many cases, open-graded hot mixes have been used as base courses and for other purposes. However, such mixtures are generally limited to specific functions on high-traffic roads.

One such use is the Open-Graded Friction Course that has frequently been constructed as a safety feature. This course, usually less than 1 inch thick, is intended to provide and retain high wet skid resistance and to reduce tire splash.

When properly designed and constructed with skid-resistant aggregates, these courses initially are very effective. After varying periods of service, water-related distress has been observed in many geographic areas. It is understood that many agencies that have used such construction have experienced such difficulty. Further, many agencies have discontinued such use pending identification of suitable solutions to those problems.

Kentucky's experience with open-graded surfaces dates back to the late 1950's. Generally, the early use was reasonably satisfactory, although some problems were encountered. Only in recent years has Kentucky employed open-graded surfaces extensively on the interstate system or other very heavily trafficked roads. Currently Kentucky has installed, or plans to install, open-graded surfaces on many major pavements as part of rehabilitation or reconstruction.

One such facility is the reconstructed section of I 65 on Muldraugh Hill in Hardin County. This pavement, after a short period of service, has developed severe water-related problems that is the subject of this study.

The following is a discussion of water-related stripping problems observed with regard to the contribution of the open-graded surface to these problems. This involves only the upper courses of the pavement, the open-graded surface, the dense-graded asphaltic concrete surface, and possibly the upper asphaltic concrete base course. The first two courses are the most important at the present time. The base course becomes involved only when, or if, stripping penetrates to that layer.

Characteristics of the materials have a strong bearing on the problem, on the time of development, and upon the extent of damage suffered. The open-graded surface is constructed of an open-graded quartz aggregate that tends to be rounded. Gradation is intentionally open. Asphalt content is approximately six percent; the asphalt usually is treated with an anti-stripping additive, which has been

quite effective.

Stability of this mixture is not measured. However, stability of open-graded mixes usually is high when adequately confined but low if unconfined. For this reason, such courses are constructed thin to provide as much confinement by the tire as possible.

The air void content of open-graded surfaces should be within a range of 15 to 25 percent. It is probable that the mixture used on Muldraugh Hill was well within this range initially and that much of the surface retains a high void content.

The dense-graded surface course underlying the open-graded surface is a standard Kentucky mixture. It has a long and successful history under traffic of all types. The mixture employed on this particular project had no unusual features. The asphalt was the usual AC-20, but was not treated with an anti-stripping agent. The asphalt content could have been slightly higher but was not seriously low. Some soft particles were present in the aggregate. These may have contributed to stripping, and once stripped, did disintegrate rapidly. Mixtures constructed with this aggregate have been widely and successfully used for many years. Stripping of such mixtures has not been a major problem in the past. Properties of the mixture were in full conformance with specification requirements.

The base course has a very low voids in mineral aggregate value, but all other characteristics are satisfactory. It is now a very minor portion of the problem as stripping from above penetrates to this level. It can become a major affected layer if the current condition of overlying courses is permitted to progress.

## STRIPPING

Stripping mechanisms actively causing distress in the dense surface layer are both static and dynamic. Static stripping occurs when a water film intrudes between the asphalt-stone interface. The same separation occurs during dynamic stripping. However, it is hastened by repeated pressures in the pore water induced by traffic. It is probable that both mechanisms are involved. For dynamic stripping, pores must be essentially saturated.

The saturated condition is not maintained very long in the open-graded surface but persists in the dense-graded surface. Gravity flow, pressure flow, and capillary flow combine to provide a high degree of saturation in this course. The open-graded surface also acts as a mulch layer that retards evaporation from the dense-graded course.

Stripping may, or may not, be associated with upward movement of the asphalt to the surface. In all cases, a severe strength loss occurs generally or locally. The asphalt coating no longer functions as a binder to keep the aggregate structure firmly in place. In addition, emulsification of asphalt can occur under some circumstances. A detailed discussion of stripping mechanisms is beyond the scope of this study. How those

mechanisms are influenced adversely by the type of construction is pertinent.

It need only be considered that, in this use, static and dynamic stripping are major contributors to the problem as a first consideration. In each case, a water source must exist over a sufficient time to permit the stripping action to occur. Further, the water must penetrate into, and be retained by, pores of the mixture either initially or progressively with time. When pressure stripping occurs, a pressure source also is required. This source is most effective if it supplies reasonably high stresses on a pulsating basis.

In any form of stripping, the first phase is the penetration of water to the stone-asphalt interface. The second phase is the separation of asphalt from the stone. The third phase is the movement of asphalt, usually with some fine aggregate, to a free, or unstressed, surface. All phases can be enhanced by applied pressures.

In static stripping, flushing is accomplished in the third phase by expansion of air/water entrapped within a nearly saturated mix as paving temperatures increase. Such pressures are quite small but are sustained over periods of several hours on a sunny day. For this condition to exist over an extended period, the mixture must remain in a nearly saturated state. Thus, the water supply must remain available for relatively long periods.

During the third phase of dynamic stripping, conditions noted previously still apply. They are aided and hastened by multiple applications of pressure having variable magnitudes.

Rain is the principal source of surface water on this project, and the water must reach and saturate the dense surface course for the observed conditions to occur. To do so, it must penetrate the open-graded surface and the tack coat. Several conditions contribute to this penetration.

First, the open-graded surface is designed to accept and hopefully internally drain water to the pavement edges. If completely saturated, within the void content range of 15 to 25 percent, the void space could contain from 70 to 112 gallons per lane per station. This condition is unlikely to occur except during a rain. The internal water percolates down grade or toward the edge or both. In the southbound lanes, this quantity could be from 280 to 450 gallons per station for all lanes. In the northbound lanes, the total quantity could be 210 to 337 gallons per station.

During such rainy periods, it is apparent that all pavements, either dense or open graded, are covered with a water film. However, dense surfaces permit very limited entry of water. It is more important that when the rain stops, dense surfaces immediately start to dry. Water in surface pores begins to evaporate and internal water is removed quickly. Since periods of no rain far exceed periods of rain, the dense surface is in a dehydrating condition a large portion of the time.

A dense surface course under an open-graded surface

must survive in a very different environment. During the rain, both the open-graded and dense-graded surface courses are wet. After the rain, the dense-graded surface remains wet for long periods, due in part to the slow drainage of water through the open-graded layer, but probably even more so because of the high humidity that exists within that layer.

It has been noted that densification occurs in the wheel tracks. This densification results in lower permeability in these longitudinal regions. Thus, water upgrade from a wheel track can percolate faster to the track than through the denser zone. This encourages longer retention and high degrees of pore saturation as well as flow parallel to the track. This retarded cross flow undoubtedly contributes to the observed problems to some extent.

Some water may continue to drain onto the shoulder many hours after rainfall has ceased. On Muldraugh Hill, such drainage was seen at numerous locations 18 hours after rain had ceased, and drainage probably continued much longer. The continued presence of free water within the course assures near 100-percent humidity at the interface with the underlying course. Thus, the time for drying of that course and the removal of pore water may be greatly extended, or drying may not occur during the next cycle of no rain. In either case, saturated pores in the underlying layer should be affected, and it is these wet conditions that produce the observed stripping actions.

The dense-graded surface received a tack coat before the open-graded surface was applied. If this coat remained completely intact and impervious, water penetration into the dense surface could not occur. This coat is applied to promote adherence of the open-graded surface and not as a seal. It is entirely possible that it is not impervious and that water enters through discontinuities. Also, it is possible that pressure stripping initiated the penetration and it certainly contributed to its extension.

In periods when the open-graded surface is near saturation, each passing vehicle provides several pressure surges. Magnitudes vary with vehicle weight and speed as well as the internal resistance to flow.

These pressure surges also assist in saturating the smaller pores of the dense layer. However, they are not essential to such saturating actions. The pores in the dense layer are much smaller than in the open-graded layer. Thus, capillary movement of water may continue as long as any moisture film exists within the open layer. This mechanism may be fully as important in creating and maintaining saturation as gravity or pressure intrusions.

The presence of free water for long periods can be expected due to storage capacity and drainage characteristics of the open-graded layer. Much longer periods of water retention in the dense layer can result from the mulch effect the open-graded layer provides. Even when that layer has lost essentially all free water, it can

provide a zone of high humidity that prevents, or retards, evaporation from pores of the dense layer. Thus, those pores may remain filled for even longer periods. It seems reasonable that in a climate such as Kentucky's, complete drying may rarely, or never, occur.

Pressure stripping differs in open-graded surfaces and dense surfaces. In the open-graded surface, water flows rapidly to relieve pressure. Water in the pores of a dense surface mixture lacks this ability. As a result, pressure surges within those pores are much higher and have a much greater stripping effect. Subjectively, this is seen in many locations as virtually complete stripping of the dense layer while the open-graded surface remained intact, in fact enriched by asphalt from the dense layer.

The adverse mechanisms broadly discussed above are not limited to the type of construction employed on the project. However, they are encountered on a great many projects of this type. They do represent the most prevalent type failure observed where open-graded surfaces have been used. In varying degrees, they seem to occur on every project.

To utilize this type of construction successfully with respect to prevention of stripping, the dense underlying course must be totally protected. It is possible to treat such materials to greatly enhance their resistance to stripping. It is possible to provide an essentially impervious layer between the open-graded surface and the dense surface. It is not practical to assume that such measures can always be constructed to meet expectations. Thus, some distress similar to that encountered on this project should be considered normal to such construction.

## APPENDIX B.

### VISUAL INSPECTION OF CORES FROM I 65

#### DESCRIPTION OF CORES

##### CORE 1A

The core shows the open-graded surface is approximately 1.25 inches thick in an upheaval area 1 foot from the outside edge of the pavement. There is apparent migration of the open-graded surface from the loaded area. The dense surface course is approximately 1 inch thick with no apparent reorientation of the aggregate. There is some migration of asphalt upward but no severe stripping can be seen when looking at the side of the core. The dense surface course is separated from the fourth base course. Advanced stripping can be seen in the dense surface course adjacent to the interface with the fourth base course. There is some evidence of segregation in the lower base courses. The interface between the dense surface course and the fourth base course is weak. The core separated at the interface between the third and fourth base courses.

##### CORE 1B

The core was cut from the outside wheel track and, specifically, to the outside of the center of the wheel track. The open-graded surface is very dense and is almost filled with asphalt and/or matrix, and is 5/8 inch thick. The dense surface course shows particle orientation and the color indicates there has been water action. Stripping of the asphalt is well advanced. The base course shows the presence of water but no evidence of stripping. There is some segregation, especially at the bottom of the base course. The third and fourth base courses are separated at the interface.

##### CORE 1C

The core was taken between wheel tracks. The open-graded surface course has good texture, but surplus asphalt appears to exist within the course. The open-graded surface and dense surface courses appear to be near their original thicknesses. There is evidence of stripping in the dense surface course, but it is very limited in extent. In general, the surface layers are the best seen at this location. Base courses are in very good condition. The third and fourth base courses separated at the interface.

##### CORE 1D

The core was taken from the inside wheel track. The open-graded surface is dense and filled with asphalt, but the thickness appears to be normal. The dense surface course appears to have particle reorientation in the upper 5/8 inch with evidence of water action in some portions of



the layer but not in others; this suggests progressive action. Base courses show no damage due to water action, but there is severe segregation in the second base course. Again, the third and fourth base courses separated at the interface.

#### CORE 1E

The core location is 25 feet downgrade from Cores 1A-1D and is in the outer wheel track. The surface shows very little apparent deformation and no shear movement. The open-graded surface shows considerable densification with pore space largely filled with asphalt and/or matrix. Advanced water action with some particle reorientation is apparent in the dense surface course. Shear has not developed yet. There is evidence of limited water action to a depth of 1/2" into the top of the fourth base course but without any particle movement. The remainder of the base courses appear to be in good condition, except the core separated between the third and fourth courses at the interface.

#### CORE 1F

The core location is 25 feet upgrade from Cores 1A-1D. The open-graded surface has densified and the pores are largely filled with asphalt and/or matrix. The dense surface course shows limited water action differing in severity on opposite sides of the core. The fourth base course shows no evidence of water damage. Again, the third and fourth base courses separated at the interface and the presence of water was noted. There was very limited stripping action on the soft particles at the separated interface. The third base course is very badly segregated at this location, with very large pore spaces. There is no apparent stripping except on the soft particles at the interface. Other base courses are in good condition.

#### CORE 2A

The core was taken 18" from the outside edge of the pavement. The pavement appears to be sound. The open-graded surface has good texture but shows some penetration of excess asphalt and/or matrix. The dense surface course shows severe damage due to water action and the color indicates migration of asphalt. There has been considerable particle reorientation. The base courses appear to be sound; the presence of water was noted, but no evidence of stripping was observed. Again, the third and fourth base courses separated at the interface and there is limited evidence of some stripping on the soft particles.

#### CORE 2B

The core was taken from an overthrust area. The open-graded surface shows particle migration and rotation with some apparent excess asphalt. Some loose particles exhibit limited separation of asphalt and aggregate. The dense surface course is severely and completely stripped and

indicates a severe loss of asphalt. Particle movement is highly evident. Complete stripping penetrates to the fourth base course. Water is present in the fourth base course, but there is little apparent damage beyond the interface. The third and fourth base courses separated at the interface. There is water present, but without apparent stripping. Other base courses are in good condition.

#### CORE 2C

The core was taken from the inside wheel track. The open-graded surface is very thin, indicating migration of this mixture, primarily in a lateral direction. The open-graded surface is almost completely filled with asphalt and/or matrix. Portions of this layer are only one particle thick. Stripping in the dense surface course is complete and uniform throughout the thickness. Particles are held together with very minor asphalt residues. The interface between the fourth base course and the dense surface course remains intact with little, or no, apparent water damage in the base course, although water undoubtedly was present. The fourth base course shows considerable segregation and separated from the third base course at that interface. There is evidence of water at that interface but there is no stripping. The remainder of the base courses are in good condition.

#### CORE 2D

The core was taken from the inside wheel track. The open-graded surface texture is in good condition although there is some evidence of migration of asphalt and/or matrix. The dense surface course shows limited stripping and the course is in generally good condition. The fourth base course shows no signs of water action, although it is slightly porous. The fourth and third base courses separated at the interface. There is limited water action on the soft particles only. The remaining base courses are in good condition.

#### CORE 2E

The core was taken in the outer wheel track 25 feet downgrade of Cores 2A-2D. The area appeared to be reasonably intact with limited rut development and no apparent shear. The open-graded surface retains some texture, which is largely filled with asphalt and/or matrix. The dense surface course shows severe and complete stripping with appreciable disintegration of the particles. The condition is such that severe shear displacement would have been expected; the reason for its non-occurrence is not known. Soft particles in the dense surface mix are almost totally disintegrated and reduced to silt and clay. Severe shear failure should be anticipated in the very near future. There is evidence of very limited water action just below the interface between the dense surface course and the fourth base course, but there is no particle breakdown or movement. The course is generally in very good condition

but separated from the third base course at that interface. Very limited water action could be seen at that interface. The remainder of the base courses are in very good condition, but there is a weak interface between the third and second base courses.

#### CORE 2F

The core was taken from the outer wheel track 25 feet upgrade from Cores 2A-2D. Pavement appears to be in generally good condition in the outside wheel track. The open-graded surface has excellent texture and appears to be very near its original condition. The dense surface course shows limited water action in several areas with apparent asphalt migration upwards in some areas. The course is generally intact and in the early stages of stripping. The fourth base course is in good condition with no apparent water damage except at the interface with the third base course where the two courses separated. Water is present within the mix but does not appear to have produced any stripping. The other base courses appear to be in good condition. The third and second base courses separated at the interface.

#### CORE 3A

The core was taken in the outer wheel track 18 inches from the outer edge of the pavement. The area appears to be in a sound condition. The open-graded surface has good texture with the pores almost filled with asphalt and/or matrix. Excessive asphalt appears to be at the bottom of the open-graded surface. The dense surface course shows no displacement of particles or particle rotation and has limited evidence of any damage due to water action. This part of the core should be classified as in the early stages of stripping with the course remaining functional. The fourth base course is fairly porous and contains water but shows little evidence of any water action. The fourth course separated from the third course at the interface and evidence of water action occurs at the interface but is limited to soft particles. Remaining base courses are in very good condition with some segregation at the bottom of the first base course.

#### CORE 3B

The core was taken in an upheaval area in the outer wheel track. The open-graded surface is completely filled with asphalt and/or matrix. The core appears to show overthrust of dense-graded material through portions of the open-graded surface material. A layer of asphalt and/or matrix exists at the original interface between the open-graded surface and dense-graded surfaces. The dense-graded surface in the overthrust is completely stripped. The remaining portion of the dense-graded surface below the original dense-graded surface shows limited stripping. The fourth base course is in excellent condition but is separated at the interface with the third base course. The

first base course is severely segregated and has almost no matrix. Soft particles show strong evidence of water action with stripping and particle disintegration. This is one of only two locations where severe deep water action is apparent. It is entirely possible that subsurface water may have contributed to the deep condition, although no current evidence was seen. Seepage that could surfaced approximately 50 to 100 feet upgrade from this location and flowed downgrade within, or under, the pavement was observed in the adjacent cut. The observed condition is unique with respect to the locations tested.

#### CORE 3C

The core was taken in a depressed inner wheel track. The open-graded surface was completely filled with asphalt and/or matrix, leaving a glazed condition. The open-graded surface thinned to a thickness of 1/8 to 1/4 inch. Coarse aggregate from the open-graded surface has been dispersed within the dense surface mix to a depth of 1.5 inches. The dense surface course is completely stripped with very little visual evidence of any remaining asphalt, although a slight amount must be present because the core remained intact. The fourth base course had water present but shows no evidence of any stripping action. The fourth base course separated from the third base course at the interface with limited evidence of water action shown at the interface and on the bottom of the fourth base course. The third base course exhibits segregation, which contains water, and some soft particles have disintegrated. There does not appear to be any stripping on the hard particles, although conditions are highly conducive to stripping. This is the same elevation noted in Core 3B as segregated.

#### CORE 3D

The core was taken from the inside wheel track 25 feet upgrade of Cores 3A-3C. The open-graded surface has reasonably good texture but is largely filled with asphalt and/or matrix. The open-graded surface appears to be thinner than normal and has almost a solid asphalt layer at the interface with the dense surface course. The dense surface course shows almost no water damage and is in generally good condition. The fourth base course is in good condition but separated from the third base course at their interface. The third base course shows considerable segregation in the top 1 inch but otherwise is in good condition. There is limited water action on the soft particles, but not the hard particles, in the segregated area.

#### CORE 4A

The core was taken 12 inches from the outside edge of the pavement. The surface condition is normal without deformation or excess filling of pore spaces. The interface between the open-graded and dense-graded surface courses appears to contain considerable excess asphalt, but this has

not penetrated to the surface. The dense-graded surface course shows no particle movement but does seem to indicate some asphalt migration. Water action is evident but is not in an advanced stage. The remainder of the core is in normal condition.

#### CORE 4B

The core was taken in the outside wheel track 3 feet from the edge of the pavement. The open-graded surface is in a glazed condition. All surface voids have been completely filled with asphalt and/or matrix. The dense surface course shows no particle movement and only limited evidence of stripping action. The base course has some porous areas but generally is in good condition with no evidence of any water action.

#### CORE 4C

The core was taken in the inside wheel track. The open-graded surface texture generally is good, but pore spaces are rapidly filling with asphalt and/or matrix. The edge of the cut suggests the lower half is completely filled. The dense-graded surface course shows very limited water action with no severe displacement of the aggregate. The fourth base course is in excellent condition but separated from the third base course at their interface; there is very limited water action on the soft particles at the interface. Each of the remaining base courses show some segregation but generally are in good condition with no apparent evidence of water action.

#### CORE 5A

The core was taken 18 inches from the outside edge of the pavement. The open-graded surface is partially filled with asphalt and/or matrix but retains a fair surface texture; it is, however, approaching a glazed condition. The location has two dense surface courses. The upper course shows some particle reorientation and appreciable stripping action. A few open-graded particles have penetrated into the top surface course. Stripping action extends throughout the top surface course but is essentially discontinued at the interface with the bottom surface course. The lower dense surface course shows little, or no, visual evidence of stripping. The tack coat between the two dense surface courses is apparent and differentiates between sound and unsound mixtures. The base courses show some segregation in each course, but no water damage is apparent. The third and second base courses separated at their interface.

#### CORE 5B

The core was taken five feet from the outside edge of the pavement and is between wheel tracks. Two dense surface courses are present. The texture of the open-graded surface is reasonably good but the pores are filling with asphalt and/or matrix. There is some evidence of asphalt migration

into the open-graded surface as well as some densification. The upper dense-graded surface course is almost completely stripped, but the aggregate shows very little displacement or rotation. This course appears to have a higher concentration of soft particles than usual and they are rapidly disintegrating due to water action. The hard particles show some stripping, but to a lesser degree. The lower surface course appears to be in good condition with very limited evidence of water action. Soft particles exposed in coring exhibit no stripping or disintegration. The base courses show limited segregation but generally are in excellent condition.

#### CORE 5C

The core was taken eight feet from the edge of the pavement in the inner wheel track. Two dense surface courses are present. The open-graded surface is completely filled and the surface is slightly glazed. It will be totally filled with a solid asphalt layer in the near future. The upper dense surface course shows evidence of strong water action and is partially stripped throughout. It is believed that asphalt migration has occurred and minor particle reorientation is occurring. There is limited evidence of water action just below the interface between the upper and lower dense surface courses. The remainder of the lower dense surface course appears to be in good condition. There is limited segregation in the base courses, but generally they are in excellent condition.

#### CORE 6A

The core was taken from an overthrust area at the outer edge of the pavement. The overthrust area is composed of sheared surface material. The thickness of the open-graded surface varies from 0.5 to 1.5 inches across the width of a 4-inch core. The course shows appreciable particle rotation plus some cracking of the mix. The area also has two dense surface courses. The upper dense surface course thickness varies from 0.75 to 1.5 inches with some open-graded particles penetrating into the dense surface mix to a depth of 0.5 inch. Severe particle rotation is apparent in this course. Stripping is virtually complete with shearing action reducing the soft particles to silt and/or clay. The mix has virtually no cohesion. The lower surface course separated from the upper surface course and striation marks on the interface show migration of the upper layer over the lower layer. The lower dense surface course shows very limited water action at the interface with the upper dense surface course; virtually no other damage exists. The base courses show some porosity but are in good condition.

#### CORE 6B

The core was taken in the outer wheel track. The open-graded surface is completely filled and the surface is glazed with asphalt and/or matrix. The thickness of this course varies from 1/4 to 3/8 inch. There are two dense-

graded surface courses. The upper one is completely stripped and shows severe loss of asphalt. Traffic has reoriented the particles and the course appears to have thinned to approximately 3/4 inch, a loss of 1/4 inch. Stripping is complete and continuous to the interface with the lower dense-graded surface course. The lower dense-graded surface course shows limited evidence of water action without particle reorientation or appreciable stripping action. The base courses are slightly porous and in excellent condition.

#### CORE 6C

The core was taken between wheel tracks. The open-graded surface retains an acceptable texture, but the pores are largely filled with asphalt and/or matrix. The upper of the two dense surface courses shows limited stripping action, no particle reorientation, and limited asphalt migration. The upper dense surface course separated from the lower dense surface course at their interface. No water damage is evident in the lower dense surface course below that interface. The base courses are slightly porous but are still in excellent condition.

#### CORE 6D

The core was taken in the inner wheel track. The open-graded surface is almost completely filled with asphalt and/or matrix. Some texture remains. In the upper of the two dense surface courses the asphalt has been almost completely separated from the aggregate and reorientation of the particles has started. Stripping is complete throughout the depth of the upper dense surface course. There is little evidence of water action below the interface between the upper and lower dense surface courses. No particle reorientation is apparent in the lower dense surface course. The base courses are in excellent condition.

### SUMMARY

#### SOUTHBOUND LANES

In general, severe water damage exists to a depth of approximately 2 inches. Below 2 inches, some influence of water is noted but is relatively minor at this stage. Considerable separation between base courses was observed with the most consistent separation occurring between the third and fourth base courses. More segregation was observed in the base courses in the southbound lanes than in the northbound lanes and the severity of the segregation was much higher. The severest condition of segregation usually existed in the lowest base course and may reflect difficulty in compaction over the subgrade.

#### NORTHBOUND LANES

Deep base courses appear to be fully equal with the upper base courses based upon visual observation. Severe

water action at the cored locations extends through the upper dense-graded surface course with very limited water action extending into the top of the lower dense surface course. In general, the lower dense surface course is in good condition, showing no evidence of particle movement and very limited to no evidence of stripping. Severely damaged material at this time extends to 1.75 inches below the existing surface. It is suggested that milling be extended to a 2-inch depth where this operation is considered desirable.

General structural condition as estimated from visual observation of cores is very good. Some relatively weak areas may exist due to potential for course separation and to isolated areas of mix segregation. Any problems developing from these sources should not be evident for a number of years and do not impinge upon current observed distress.