STH 95
HIXTON – MERRILLAN
JACKSON COUNTY
PCC PAVEMENT DISTRESS INVESTIGATION

Findings and Recommendations

Prepared by:
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Division of Transportation System Development
Bureau of Technical Services
Material Management Section

March 6, 2013

Background

Between April and November of 2007 the Wisconsin Department of Transportation's (WisDOT) Southwest (SW) Region completed projects 7520-00-71, 7520-00-72, and 7520-00-73, involving the reconstruction of STH 95 from approximately Hixton to Merrillan in Jackson County. The scope of the projects included the replacement of the existing asphaltic pavement with 8 inches of Portland cement concrete (PCC) pavement.

Approximately 4 to 6 weeks after opening to traffic, the pavement began to exhibit premature cracking. Two independent investigations into the observed premature distresses were completed. One commissioned by the paving contractor and completed by The Transtec Group in the fall/winter of 2007 and one commissioned by the Department and completed by Applied Research Associates, INC (ARA) in the summer of 2008. The two reports offer conflicting views as to the cause of the cracking. The report completed by The Transtec Group offers the explanation that the cracking distress was due to early traffic loading in the vicinity of relatively fresh concrete. The Department and ARA contend that the premature distress was the result of a combination of environmental factors, material characteristics, and construction methods.

Since the completion of these investigations, widespread spalling has become problematic, again bringing into question the possibility of substandard materials and workmanship. Figure 1 depicts the typical distress being investigated in this report. Additional images depicting distress locations, and core locations prior to extraction are available in Appendix A.

For the safety of the traveling public, the widespread spalling observed on STH 95 requires repairs. WisDOT's Northwest (NW) region (Jackson County was reassigned to the NW region during a Department reorganization) requested the assistance of the Bureau of Technical Services (BTS) to investigate the cause of the PCC distress and recommend a proper repair strategy to address the distress present and avert damage to the pavement structure

Figure 1 – Typical Observed Distress

Problem Statement

The purpose of this investigation was to determine the origin of the spalling distress and in the process assess the most effective repair option,

Investigation Procedures

The investigation began with field reviews of the distress. On the initial review, the spalled areas were located and documented. There was no immediately discernable environmental or loading cause.

Next, the project records (primarily the project materials information) that could be located were reviewed. Instances of failing material tests were identified, and the areas of the project where these materials may have been incorporated were located. These locations were compared to the areas exhibiting the spalling distress. Again, no discernable pattern or cause could be identified. Most of the failed slump and air tests were located in areas of what appeared to be sound concrete.

Finally, cores of distressed pavement; as well as controls, pavement exhibiting good performance, were collected on July 25, 2012. The distressed cores collected were of varying levels, or stages, of spalling

The original work plan proposed collecting 12 cores and analyzing 4 (2 distressed and 2 controls). As the cores were collected, the commonality (segregation) between the distressed cores became very evident and a sampling was halted after 8 cores had been extracted. Figures 2 – 4 depict the cores that were collected. Of the 8 cores extracted, two, cores 5 and 6 shown in Figure 5, were submitted to Schmitt Technical Services, Inc (STS) for analysis. Figure 1 depicts the pavement condition at the location of core 5. Core 6 was extracted in non-distressed concrete in close proximity to core 5. These two cores were chosen because of this close proximity. This provided for consistent environmental and loading factors. Furthermore, core 5 provided the most significant example of the segregation observed in the distressed pavement. The remaining 6 were retained by BTS in the event further analysis was required.

Cores submitted to STS were subjected to petrographic examination. The results of this examination are summarized in the findings section of this report. The full petrographic examination report prepared by STS is included in Appendix B.

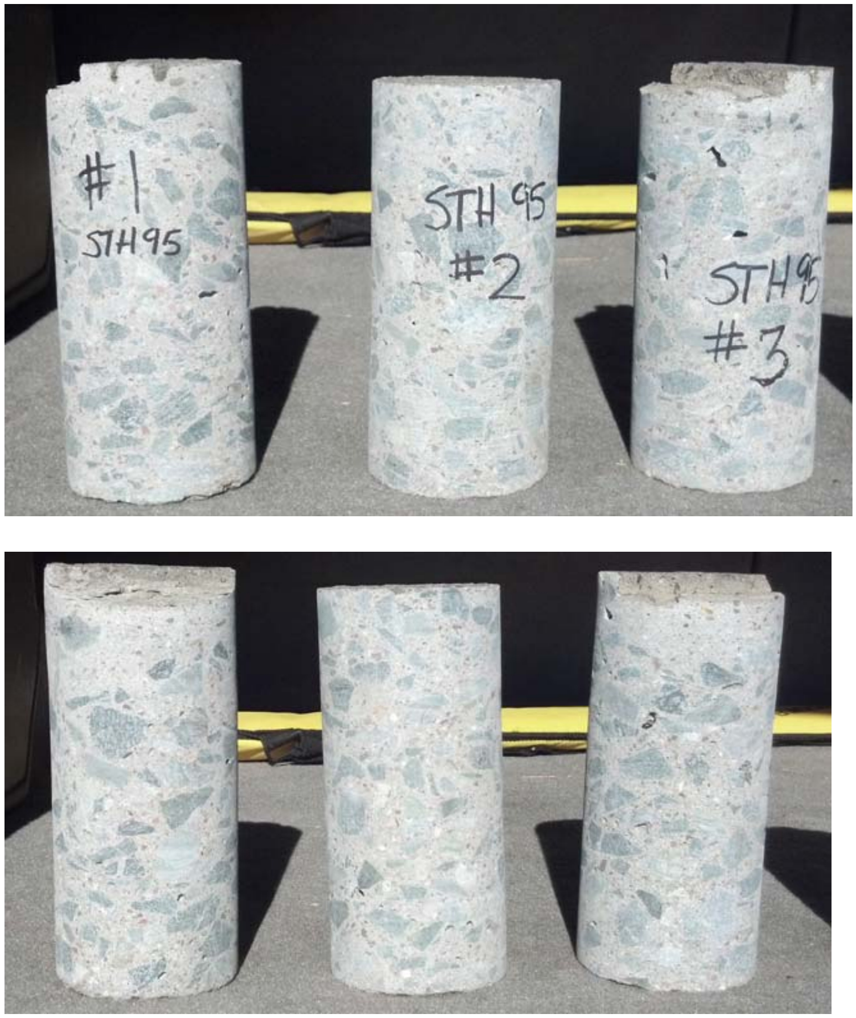

Figure 2 – Cores 1, 2, and 3 (“Front” and “Back”)

Figure 3 – Cores 4, 5, and 6 (“Front” and “Back”)

Figure 4 – Cores 7 and 8 (“Front” and “Back”)

Figure 5 – Cores 5 and 6 Submitted for Analysis

Findings and Observations

As was mentioned previously, while collecting cores, and as can be seen in Figures 2 – 5, it was noticed that the distressed cores (cores 1, 3, 5, and 8) all have little or no coarse aggregate near the surface of the pavement structure. This segregation of the aggregate is also evident in cores collected to represent areas that appear to be in early stages of spalling, particularly cores 4 and 7. Figures 6 and 7 show the pavement surface condition at the locations of cores 4 and 7 respectively.

Figure 6 – Core 4 Pavement Surface Condition

Figure 7 – Core 7 Pavement Surface Condition

The examination completed by STS further investigated the segregation in core 5 and compared the materials of core 5 with the materials of core 6. In general the air voids and coarse aggregate are "virtually non-existent" in the upper 2.3" of core 5. The air voids are estimated to be 0.5% to 2.0%. The theorized cause of the lack of air and coarse aggregate is over-vibration of the fresh concrete during placement. Over-vibration would cause the coarse aggregate to settle to the bottom and the air to vibrate out the top.

The remaining bottom approximately 5.5" of core 5 and all of core 6 appear to meet the WisDOT specifications for: fine and coarse aggregate, replacement of supplementary cementitious materials (fly-ash and ground granulated blast furnace slag), and water-to-cementitious ratio.

Examination of the air content of the same bottom 5.5" of core 5 and all of core 6 however, found that air was variable, but the entrained air is estimated to be 7.0% to 8.0%. The entrained voids are irregularly dispersed and an abundance of air-void clustering adjacent to aggregate particles indicate possible over vibration and/or addition and incomplete mixing of retempering water.

A similar result of segregated aggregates, reduction of entrained air, and coalescing of air-voids around aggregate particles was observed when vibrators were used to produce cylinders in a recent Wisconsin Highway Research Program (WHRP) project (0092-11-06: Field Study of Air Content Stability in the Silp Form Paving Process). When the results of this project were discussed at the 2013 Wisconsin Concrete Pavement Association's annual workshop, the presenting researcher, Dr. Thomas Van Dam contended that these observations may be the effect of over-vibration of the fresh concrete; further corroborating the hypothesis of over-vibration when the STH 95 concrete was placed.

Based on the petrographic examination and WisDOT's forensic site visits, it can be concluded that the primary origin of the observed spalling distress is improper material handling and placement; specifically over-vibration and retempering of the concrete mixture.

Recommendations

The premature pavement spalling on STH 95 is widespread and sporadic. The pavement cores collected in the sections experiencing the premature distresses exhibit severe segregation of aggregate. Further petrographic analysis of the cores determined that there is also severe segregation of air content in the PCC mixture. Based on the petrographic evaluation of the collected cores, the upper portions of the segregated concrete areas have an extremely low air-content, and therefore limited freeze-thaw durability of the hardened concrete. The pavement surface spalling is due to this limited air content. To provide for a sound and uniform pavement surface, the low air portion of the current pavement structure should be removed and replaced with a suitable pavement material.

Since the spalling, and therefore segregated, areas are sporadic, the most cost effective repair would be to grind and inlay only the segregated areas. As of the fall of 2012, the segregation was discovered in sections of STH 95 that had not yet become distressed. For this reason; to ensure the effectiveness of a grind and inlay option, the entire length of the concrete pavement in question would have to be investigated to determine the location and extent of the segregated concrete.

Currently, the technology the Department has available to quickly and efficiently complete an investigation of this nature is ground penetrating radar (GPR). To ascertain the feasibility of using GPR to identify the segregated areas, BTS attempted to locate areas of segregation using a hand-operated unit on several locations known to be impacted. After analyzing the data, it was determined that the GPR is simply not sensitive enough to differentiate between the segregated, non-conforming concrete and an acceptable structure. This provides the region with several other options to consider.

The first and still most cost effective option would be to complete a grind and inlay on the segregated areas already exhibiting, or showing early signs of spalling. The areas addressed should be ground a full lane and shoulder width for a depth of approximately 2 inches. The ground concrete will then be covered with a bonded concrete overlay, providing a monolithic concrete pavement structure. This process may have to be repeated over the life of the pavement if other segregated areas become evident as they begin to spall.

The second option would be to grind the areas of segregated concrete as outlined above and then overlay full length with HMA pavement. This option will require significantly more grinding, as the grinding depth would have to be tapered from 0 inches to 2 inches.

The third and fourth options would be to grind the existing concrete pavement full width for a depth of approximately 2 inches along the length of STH 95. The ground concrete could then be paved with either a bonded concrete overlay or an HMA overlay.

Square yard unit prices for completing the various options were compiled and are provided in Table 1. The distressed pavement areas were estimated based on summer and fall of 2012 field reviews and a total estimated cost for pavement rehabilitation was compiled and is presented in Table 2. These prices include only pavement and shoulder related items. There are no costs include for traffic control, pavement marking replacement, or any other incidental items.

Estimating the rehabilitation prices required some assumptions be made. First, regarding the bonded concrete overlay, the overlay is assumed to be 2 inches thick and is anticipated to closely resemble the cost of a concrete masonry approach overlay. Second, if the HMA overlay is selected, a structural analysis would need to be completed by the region to determine the proper overlay thickness. For the purposes of cost estimating, the HMA overlay thickness is estimated at 3.5 inches to provide for structural adequacy and minimum layer thicknesses. The HMA overlay cost estimates provided in Tables 1 and 2 are based upon an anticipated structure of two 1.75 inch layers of 12.5 mm E-3 mixture. These unit prices may require adjusting based upon a region pavement design; as well as highly volatile asphalt prices. It should be further noted that an HMA overlay greater than 2” in thickness will require additional shoulder material. Third, any full length overlay options exclude the urban section in Alma center. During the 2012 field reviews, this concrete did not exhibit any of the spalling distress of interest. Detailed cost calculations, estimate limitations, and assumptions are provided in Appendix C.

Table 1 - Rehabilitation Pavement Bid Items Historical Cost Information

Item	Low Estimated Bid Price	High Estimated Bid Price	Avg Estimated Bid Price
Partial Depth Removal of Concrete	$0.10/SY	$9.50/SY	$2.50/SY
Bonded Concrete Overlay/Inlay – 2” thick	$11.40/SY	$52.80/SY	$26.40/SY
HMA Overlay – 3.5” thick	$3.89/SY	$43.45/SY	$14.47/SY
Additional Cost of Base Aggregate Dense for HMA overlay	$0.00021/SY	$0.91/SY	$0.30/SY

Table 2 - Rehabilitation Options Estimated Pavement Costs

Rehabilitation Strategy	Estimated Cost (Pavement and BAD items only) Low	High	Avg
Option 1: Spot Grind and Bonded Inlay	$ 333,960	$ 1,809,192	$ 839,256
Option 2: Spot Grind then full HMA Overlay	$ 616,076	$ 9,758,672	$ 4,526,896
Option 3: Full Grind and Bonded Overlay	$ 1,801,360	$ 9,758,672	$ 4,526,896
Option 4: Full Grind and Full HMA Overlay	$ 624,853	$ 9,601,438	$ 2,733,058

Finally, it should be noted that based on the observations and analysis of the cores, the distresses in question are the result of contractor operations and/or materials. It is recommended that the NW region investigate the available contractual and legal options regarding contractor participation in the necessary repair work.

Years ago, Allyn Lepeska from OGC provided the following regarding implied warranty:

> *“When we build a project we enter into a contract. If we believe that the contract is not honored and we cannot reach a satisfactory resolution of the issue, we have the option of going to court. If we go to court the action must be filed within six years after the cause of action accrues. That statutory limitation is provided by:*
>
> *893.43 Action on contract. An action upon any contract, obligation or liability, express or implied, including an action to recover fees for professional services, except those mentioned in s. 893.40 , shall be commenced within 6 years after the cause of action accrues or be barred.*
>
> *Case law has held that the time begins when the applicable contract work is completed: A breach of a roofing contract occurred when the faulty roof was completed, not when the building was completed. State v. Holland Plastics Co. 111 Wis. 2d 497, 331 N.W.2d 320 (1983).”*

This statement provides for one possible legal channel for the NW region to investigate and possibly pursue.

Conclusion

After a thorough investigation including field site visits, project record reviews, and analyzing pavement cores; it has been determined that the cause of the spalling pavement distress present on STH 95 between Hixton and Merrillan in Jackson County is the result of over-vibration and possible retempering of the concrete.

There are four implementable options that will address the spalling distress and as a result, protect the safety of the traveling public. The first two options begin with grinding the concrete pavement in the locations exhibiting the spalling distress. The ground concrete would then either be covered with bonded concrete inlays, or full length asphalt overlay.

The third and fourth options both employ a full length, full width concrete grind. The ground concrete would then be overlaid with a bonded concrete overlay, or again a full length asphalt overlay.

Of the four options, a spot grind and concrete inlay rehabilitation strategy would provide the most cost efficient repair.

Finally, as the finding of this investigation was pavement distress/failure due to improper contractor methods or operations; it is suggested that participation on the part of the contractor be further investigated.

Appendix A: Field Review Photos

Photo Date Stamps are Inaccurate

Figure A.1 – Wheel Path Spalling

Figure A.2 – Wheel Path Spalling

Figure A.3 - Wheel Path Spalling Depth

Figure A.4 - Shoulder Spalling

Figure A.5 - Early Stage Spalling

Figure A.6 - Wheel Path Spalling with Early Stage Spalling Surrounding It

Figure A.7 – Core 1 Pavement Surface

Figure A.8 - Core 2 Pavement Surface

Figure A.9 - Core 3 Pavement Surface

Figure A.10 - Core 6 Pavement Surface

Figure A.11 - Cores 7 and 8 Pavement Surface

Appendix B: Petrography Report

Schmitt
Technical Services INC

Report of Laboratory Evaluation
For
Wisconsin Dept. of Transportation
Division of Trans. Systems Development

Petrographic Examination of Two (2) Concrete Cores
From State Highway 95
Wisconsin

August 27, 2012

(STS Job No. 12058)

REPORT

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Schmitt
Technical Services INC

August 27, 2012

Mr. Jed P. Peters, P.E.
Wisconsin Department of Transportation
Division of Transportation System Development
3502 Kinsman Boulevard
Madison, WI 53704-2507

Re: Petrographic Examination of Two (2) Concrete Cores from State Highway 95, WI – STS Job. No. 12058

Dear Mr. Peters:

Schmitt Technical Services, Inc. (STS) has completed petrographic examinations of two (2) concrete cores from the referenced project. The cores were reported to have been sampled from a highway where severe surface delamination has occurred.

Two (2) concrete cores, identified as "5" and "6" (Figures 1 and 2), were received from Mr. Jed Peters of the Wisconsin Department of Transportation (WISDOT) on August 6, 2012. Schmitt Technical Services, Inc. was requested to perform petrographic analysis on the cores to determine the cause(s) of surface deterioration.

FINDINGS AND CONCLUSIONS

Subject to the qualifications in the attached Appendix, results of the petrographic examination are as follows:

1. The wearing surface of Core "5" is severely delaminated. Air voids and coarse aggregate in the upper 58 mm (2.3 in.) are virtually nonexistent in Core "5", due to over vibration.

2. The original cementitious materials paste at the wearing surface of Core "6" has been abraded to a depth of 0.5-to-0.8 mm (0.02-to-0.03 in.).

3. Both cores contain fly-ash and ground granulated blast furnace slag (GGBFS) as supplementary cementitious materials. Residual fly ash content is estimated to be 12-to-15%, by volume of paste. Residual GGBFS content is estimated to be 7-to-10%, by volume of paste. Together, the supplementary cementitious materials would represent a 20-to-25% replacement of cement with supplementary cementitious materials. The replacement ratio is consistent with Department of Transportation Specifications.

4. Based on the paste properties observed in the body of the cores, concrete of both cores have an estimated water-to-cementitious materials ratio of 0.40-to-0.50.

5. Core "5" is highly carbonated to a depth of 25 mm (1.0 in.), and Core "6" is variably carbonated to a depth of 2.0-to-8.0 mm (0.08-to-0.31 in.) from the top of the core possibly indicating poor curing.

6. Both cores are air entrained. Air content is variable, estimated to be 7.0-to-8.0% in the body of the concrete in both cores. The air voids in both cores are irregularly dispersed and there is also an abundance of air-void clustering in the paste and adjacent to aggregate particles, indicating the possible addition and incomplete mixing of retempering water.

7. The irregular dispersion and quantity of air voids in the concrete of Core "5" is not considered adequate for protection from freezing and thawing cycles. The type of cracking and delamination observed is typical of freeze-thaw damage; and therefore, the poor air-void system in the surface region of Core "5" caused by over vibration is the cause of surface delamination.

Details of the petrographic examinations are provided in the following section of this report.

METHODS OF TEST

Petrographic Examination

The concrete cores were examined using selected techniques and procedures outlined in ASTM C 856, "Standard Practice for Petrographic Examination of Hardened Concrete" and the Federal Highway Administration's Publication No. FHWA-HRT-04-150, "Petrographic Methods of Examining Hardened Concrete: A Petrographic Manual."

Each examination included sawing the core longitudinally; followed by lapping one-half of the core slice with successively finer lapping grits to produce a finely ground (and nearly polished) surface. The lapped surface of each core and freshly broken surfaces of the concrete were examined visually (with the unaided eye) and under a stereomicroscope at magnifications of 7 to 40X.

In addition, a thin section was made from each core, as were temporary, crushed fragment (i.e., "powder or immersion") mounts of paste and aggregate. The thin section and immersion mounts were examined under plane and cross-polarized light at magnifications of 50 to 400X using a polarizing light microscope.

Estimates of water-to-cement ratio were done using techniques outlined in FHWA-HRT-04-150 and methods developed by Dr. Donald Campbell (unpublished).

PETROGRAPHIC EXAMINATION

Core "5"

General Description

The sample consists of a concrete core identified as "5" (Figure 1). The core is 203 mm (8.0 in.) long and has a diameter of 94 mm (3.7 in.).

The core top is a very rough surface that has experienced severe delamination to a depth of 10 mm or about 3/8 in. (Figure 1a). There are remnants of a broom finish that has been tined to have grooves. Significant cracking and microcracking is observed parallel to the wearing surface at depths ranging up to18 mm (0.7 in.) below the original wearing surface (Figure 4).

Coarse aggregate and entrained air are virtually nonexistent in the upper 58 mm (2.3 in.) of the core (Figure 3), indicating the concrete was severely over-vibrated causing coarse aggregate to settle below 2.3 in. depth and air voids in the same upper region have been eliminated by the excessive vibration.

A vertical microcrack is observed in the core extending from the wearing surface to a depth of 40 mm (1.6 in.). The crack passes around coarse and fine aggregate particles (Figure 5), indicating that the crack likely formed prior to the development of adequate paste aggregate bond, as could occur by early shrinkage.

The core bottom is an irregular surface embedded with base course aggregate particles, indicating the full thickness of the slab was cored.

Steel reinforcement is not present in the core. Nor is there any evidence of damage due to corrosion of steel reinforcement in this core.

Aggregate

Coarse aggregate is well-graded but very poorly dispersed throughout the concrete. Coarse aggregate is concentrated in the lower ¾ of the core, with virtually no coarse aggregate observed within 58 mm (2.3 in.) of the current wearing surface (Figure 3). Measured maximum aggregate size is 19 mm (3/4 in.). Fine aggregate is well-graded and uniformly dispersed.

Coarse aggregate is composed of crushed stone containing gabbro with occasional diabase and granite particles. Coarse aggregate particles are primarily medium to dark gray, black and occasionally white. Coarse aggregate is moderately hard; dense; subrounded to angular; equant to less commonly elongate and has a rough surface texture.

Cracks and microcracks are observed within the coarse aggregate particles, but the cracks do not extend into the adjacent cementitious materials paste. The cause of the coarse aggregate cracking is not readily apparent.

Fine aggregate is natural sand containing a variety of rock and mineral types including, quartz, plagioclase and microcline feldspar, biotite, ferromagnesian minerals, gabbro, sandstone and a minor amount of other rock and mineral types. Fine aggregate is translucent and various shades of brown, gray and opaque. Fine aggregate is hard; dense; angular to rounded; equant to less commonly elongated and has a smooth to rough surface texture.

Cement Paste

The cementitious materials paste is light to medium gray, hard, tight and moderately bonded to aggregate particles; as laboratory induced fractures occur both around and through aggregate particles. Paste exhibits a vitreous to subvitreous luster, microgranular texture and an irregular fracture.

Residual cement particles are common in THE thin section. Residual cement particles are estimated to be 6-to-8%, by volume of paste. Calcium hydroxide, a normal reaction product, is estimated to be 10-to-12%, by volume of paste. Residual fly ash and ground granulated blast furnace slag (GGBFS) are observed as supplementary cementitious materials. Residual fly ash content is estimated to be 12-to-15%, by volume of paste. Residual GGBFS content is estimated to be 7-to-10%, by volume of paste. Hydration rims are frequent along the periphery of the residual cement and slag particles. Paste is carbonated to a depth of 2-to-25 mm (0.08-to-1.00 in.), due to significant surface cracking.

Properties of the paste previously described are evaluated to provide an estimate of the water-to-cementitious materials ratio. Based on paste properties observed, water-to-cementitious materials ratio is estimated to be moderate; that is, estimated to be 0.40-to-0.50.

Air Voids

The concrete contains an abundance of very small spherical voids typical of entrained air and a lesser amount of small to large, sub-spherical to irregularly shaped voids, indicative of entrapped air. Therefore, the concrete is deemed to be air-entrained.

However, entrained air voids in the upper 58 mm (2.3 in.) of the core are virtually nonexistent. Therefore, air voids are irregularly dispersed throughout the concrete. There is an abundance of air-void clustering in the paste and adjacent to aggregate particles in the body of the concrete (Figure 5).

Air content in the upper region of the core is estimated to be 0.5-to-2%. Below this surficial region, the air content is estimated to be between 7.0-to-8.0% with clustered areas greater than 8.5%.

One large, 35 mm (1.4 in.) deep by 5-to-15 mm (0.2-to-0.6 in.) wide void was encountered at a depth of 13 mm (0.5 in.) below the wearing surface (Figure 8).

Core "6"

General Description

The sample consists of a concrete core identified as "6" (Figure 2). The core is 204 mm (8.0 in.) long and has a diameter of 94 mm (3.7 in.).

The core top is a relatively rough, tined surface where fine aggregate particles are predominantly exposed to a depth of 0.5-to-0.8 mm (0.02-to-0.03 in.); likely due to abrasion of the original cementitious materials paste (Figure 9). There is no surface distress in this core.

The core bottom is an irregular surface embedded with base course aggregate particles, indicating the full thickness of the slab was cored.

Steel reinforcement is not present in the core. Nor is there any evidence of damage due to corrosion of steel reinforcement in this core.

Aggregate

Coarse aggregate in Core "6" is of a similar composition to the coarse aggregate in Core "5" but is evenly distributed throughout the core sample. Measured maximum aggregate size is 19 mm (3/4 in.). Fine aggregate is also of a similar composition and distribution as the fine aggregate in Core "5".

Cracks and microcracks are observed occasionally within the coarse aggregate particles, but the cracks do not extend into the adjacent cement paste. The cause of the coarse aggregate cracking is not readily apparent. Pyrite is observed in some of the coarse aggregate particles (Figure 10), but not in large enough quantities to be considered deleterious.

Cement Paste

Cementitious materials paste is light to medium gray, hard, tight and well bonded to aggregate particles. Paste exhibits a vitreous to subvitreous luster, microgranular texture and an irregular fracture.

Residual cement particles are common in thin section. Residual cement particles are estimated to be 6-to-8%, by volume of paste. Calcium hydroxide is estimated to be 10-to-12%, by volume of the paste. Residual fly ash and ground granulated blast furnace slag (GGBFS) are observed as supplementary cementitious materials. Residual fly ash content is estimated to be 12-to-15%, by volume of paste. Residual GGBFS content is estimated to be 7-to-10%, by volume of paste. Paste at the wearing surface of the core is variably carbonated to a depth of 2.0-to-8.0 mm. (0.08-to-0.31 in.).

Properties of the paste previously described are evaluated to provide an estimate of the water-to-cementitious materials ratio. Based on paste properties observed, water-to-cementitious materials ratio is estimated to be moderate; that is, estimated to be in the range of 0.40-to-0.50.

Air Voids

The concrete contains very small spherical voids typical of entrained air and small to large, sub-spherical to irregularly shaped voids, indicative of entrapped air. Therefore, the concrete is deemed to be air-entrained.

Air voids are irregularly dispersed throughout the concrete. Air content is estimated to be 7.0-to-8.0% when averaged across the lapped section of the core. However, areas of higher variable air contents are observed in the central portion of the core. Some areas contain few entrapped or entrained air voids and are estimated to have an air content of less than 4.0% and other areas have an abundance of both entrained and entrapped air voids with an estimated air content of greater than 9.0%. An abundance of air void clustering is observed in the paste and adjacent to aggregate particles indicating the possible addition of retempering water with incomplete re-mixing; which is further indicated by the variable air content throughout the core.

*****

It is a pleasure to be of service on this project. If you have any questions or need additional consultation, please contact me.

Sincerely,

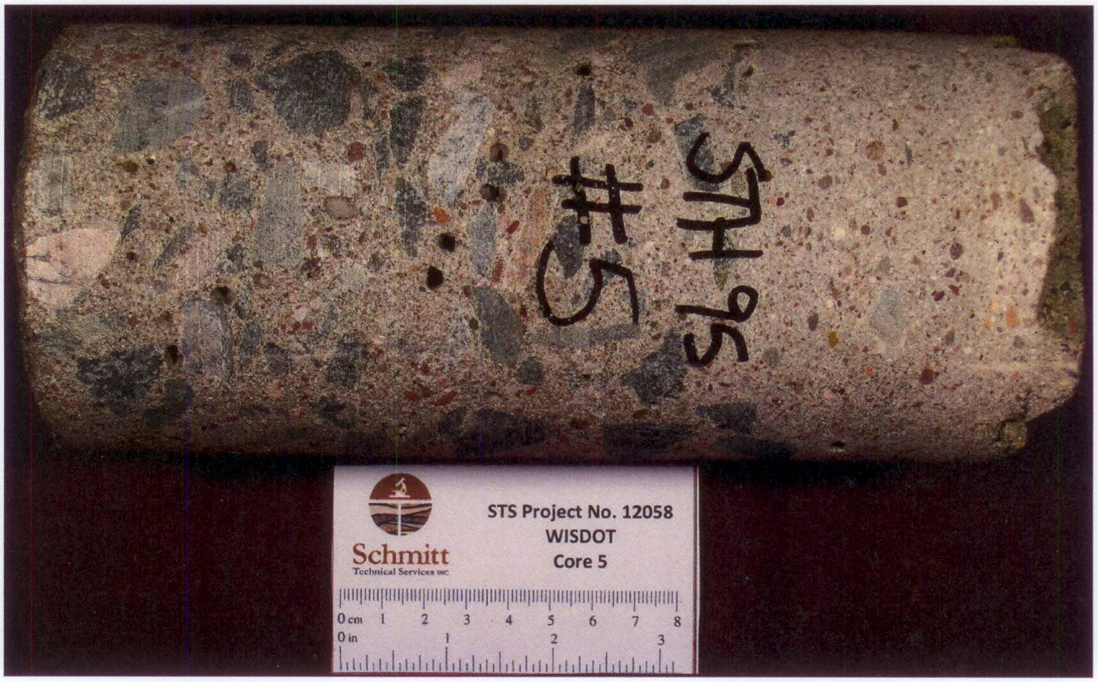
Schmitt Technical Services, Inc.

Michael J. Markgraf
Senior Geologist/Petrographer

James W. Schmitt, P.G.
Principal/President

MJM/jws

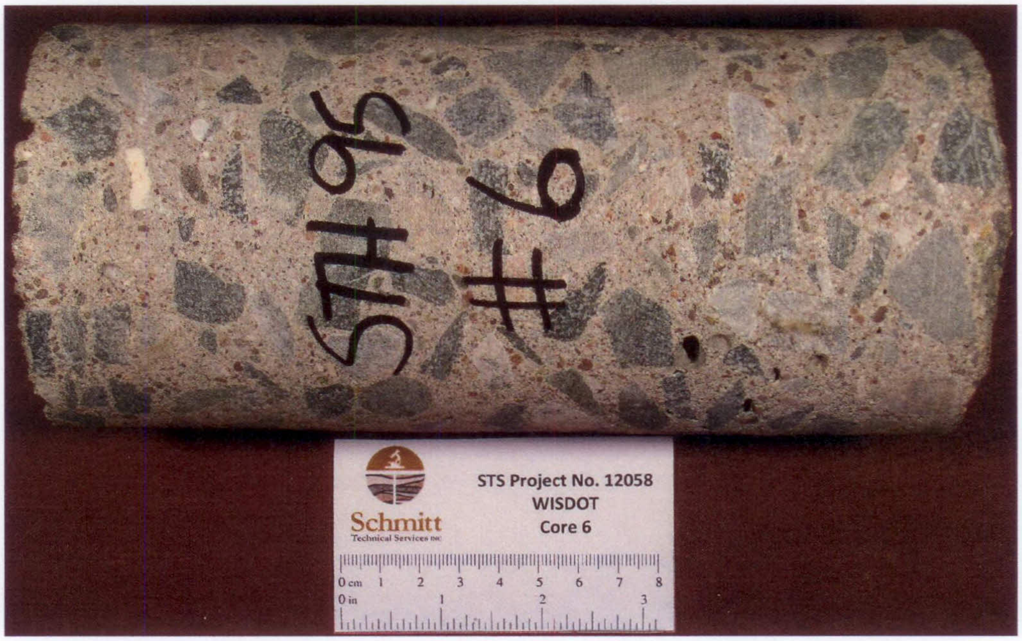
(a) Core top surface.



(a) Core side, core top is to the right.

Figure 1. Core "5" as received for petrographic, hardened air content and chloride analyses. Top scales are in millimeters and centimeters. Bottom scales are in inches.

(a) Core top surface.



(a) Core side, core top is to the left.

Figure 2. Core "6" as received for chloride and petrographic analyses. Top scales are in millimeters and centimeters. Bottom scales are in inches.

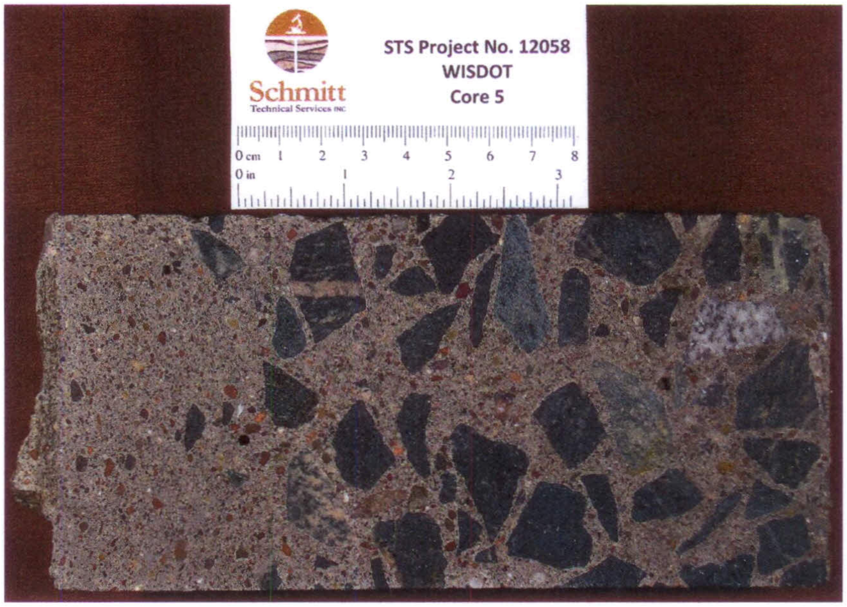


Figure 3. Lapped section of Core "5" illustrating the poor distribution of coarse aggregate particles, which are concentrated in the lower ¾ of the core. Core top is to the left. Top scale is in millimeters and centimeters. Bottom scale is in inches.

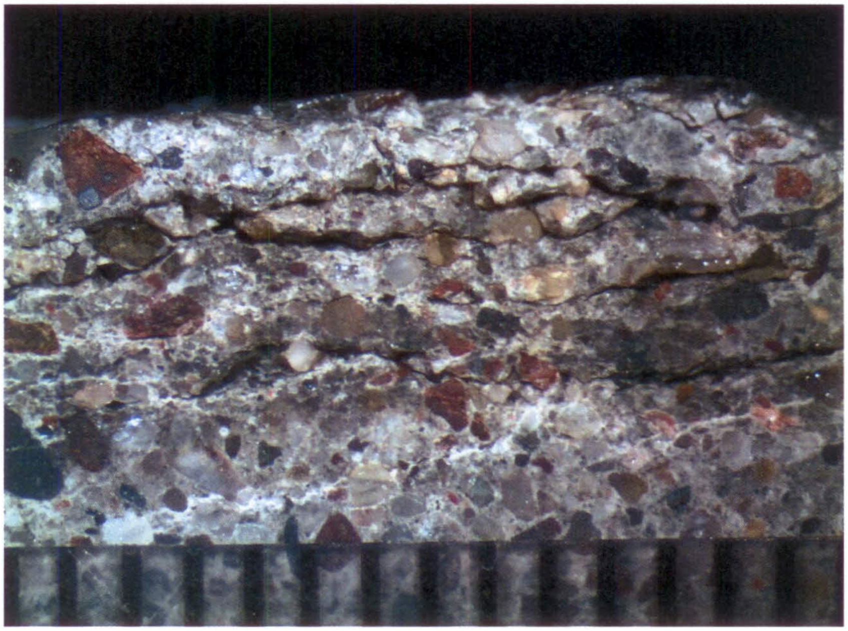


Figure 4. Photomicrograph of lapped section of Core "5" showing cracking and delamination of the wearing surface. Cracks are filled with secondary white calcite. Scale is in millimeters

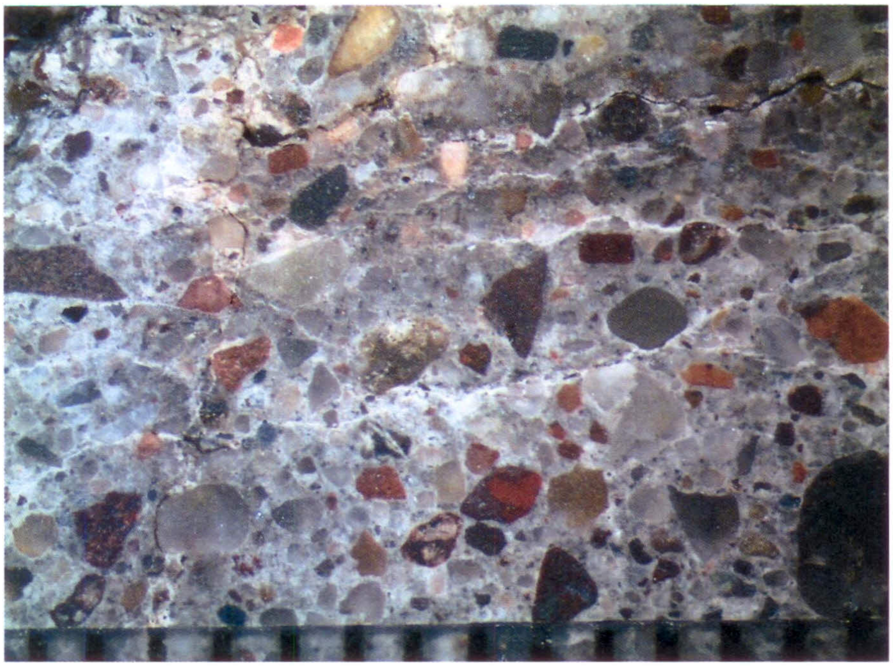


Figure 5. Photomicrograph of lapped section of Core "5" illustrating both horizontal and vertical microcracking near the wearing surface. Scale is in millimeters.

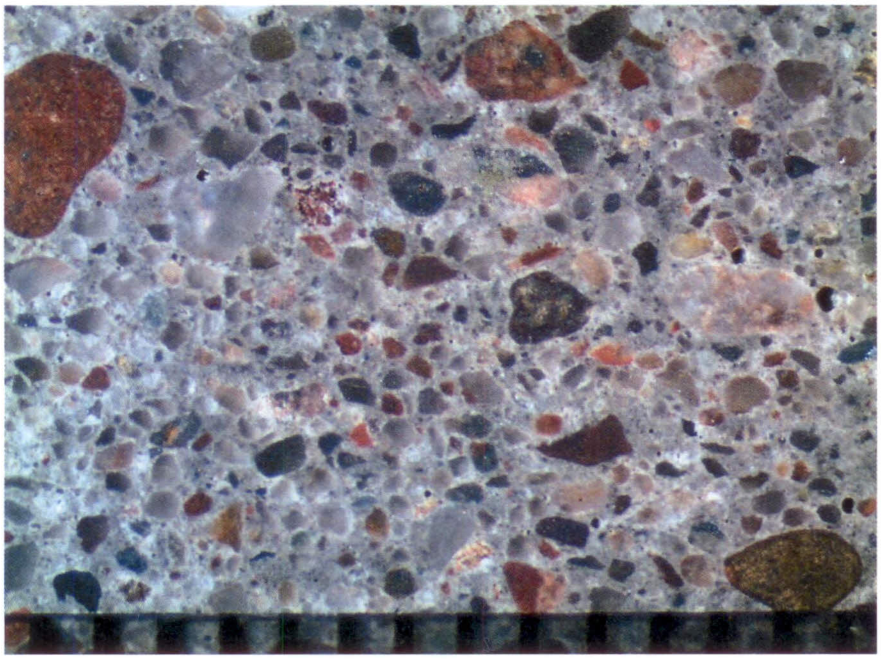


Figure 6. Photomicrograph of lapped section of Core "5" illustrating low air content in the upper 58 mm (2.3 in.) of the core. Scale is in millimeters.

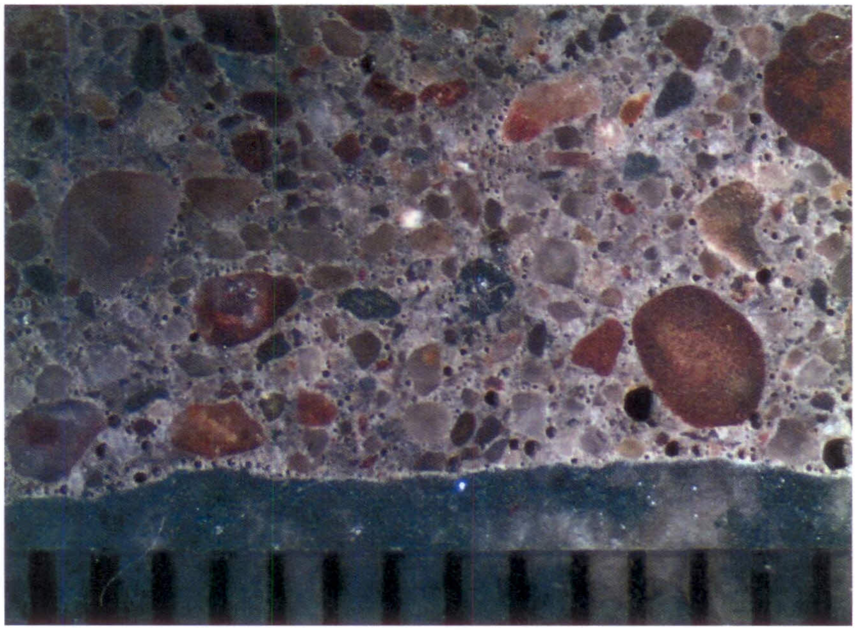


Figure 7. Photomicrograph of the lapped section of Core "5" illustrating clustering of air voids in the paste and adjacent to aggregate particles at greater depths. Scale is in millimeters.

Figure 8. Core "5" showing a 35 mm (1.4 in.) deep by 5-to-15 mm (0.2-to-0.6 in.) wide void at a depth of 13 mm (0.5 in.) from the top of the core. Core top is toward top of photograph. This figure also illustrates the depth of carbonation from the wearing surface which is 25 mm (1.0 in.). Top scale is in millimeters and centimeters. Bottom scale is in inches.

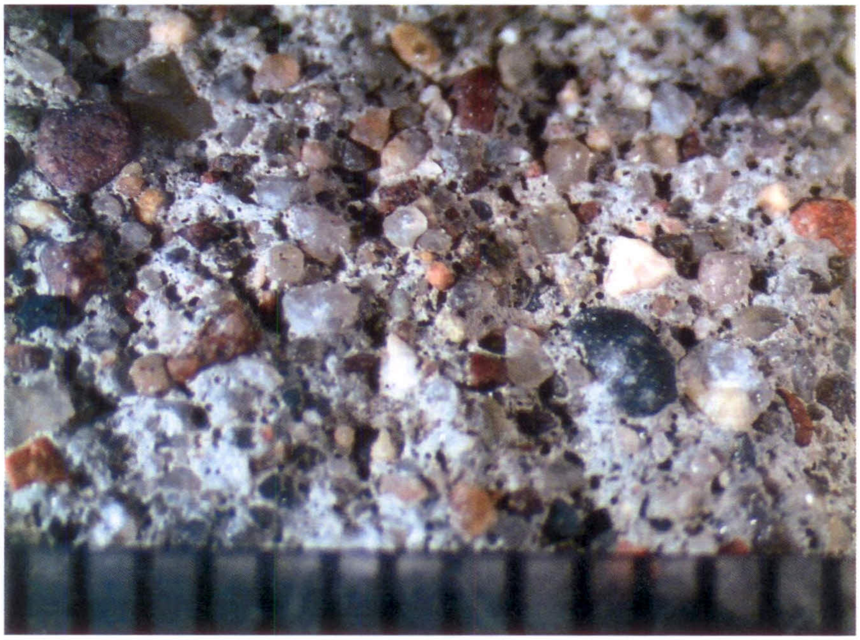


Figure 9. Photomicrograph of the wearing surface of Core "6" illustrating the degree of surficial aggregate exposure, due to abrasion of paste at the wearing surface. Scale is in millimeters.

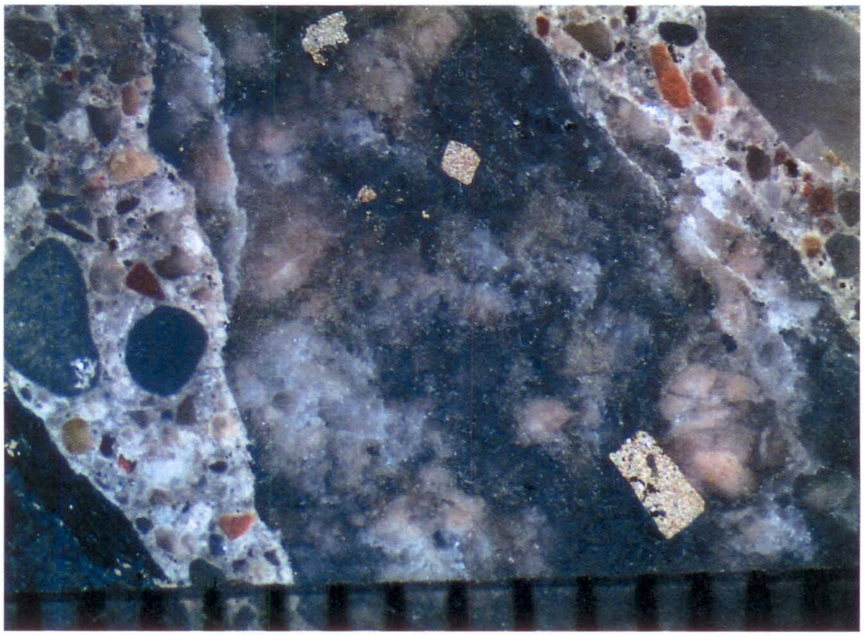


Figure 10. Photomicrograph of Core "6" showing the occurrence of pyrite in coarse aggregate particles. This interior portion of the core also exhibits lower air content. Scale is in millimeters.

APPENDIX

DOCUMENT QUALIFICATIONS

Standard of Care

This report has been prepared for the exclusive use of the Client for specification application to their project. This report is not intended for use by others. Schmitt Technical Services, Inc. (STS) has provided professional services consistent with generally accepted evaluative and geologic practices. No other warranties are expressed or implied. The opinions and recommendations submitted in this report are based on interpretation of field observations, samples taken from specific locations and/or field and/or laboratory test results.

Samples

The samples taken during the field observations depict conditions only at specific locations and times indicated in the report. Conditions at other locations may differ from conditions where sampling was conducted. The passage of time may also result in changes in conditions interpreted to exist at the locations where sampling was conducted.

Completion of Characterization of Site Conditions

The scope of services described in this report is based on a limited number of samples. The nature and variations in other locations may exist and may not become evident until repairs are performed. If variations or other latent conditions become evident, additional evaluation and testing may be warranted.

Conceptual Level of Project Scope

The field activities, testing procedures and evaluative approaches used in this study are consistent with those normally used in testing of construction materials and products. The number of samples and tests and scope of testing were done within Client's budget, but represents less data than that generally needed to evaluate the extent of less than expected performance.

Test Repair and Repair Observations and Testing

Since findings, discussion and observations are based on limited numbers of observations and tests, the Client should be particularly sensitive to the potential need for adjustment in extent of repair, repair procedures and repair materials in the field. It is in the best interest of the client to retain STS to observe and test repair materials and repairs to observe general compliance with repair design concepts, specifications and contractor/manufacturer recommendations and to assist in development of changes should field conditions differ from those anticipated before the start of repair construction.

Limitations-Repair Construction Considerations

The recommendations made in the report are not intended to dictate type of repair materials to be used, construction methods or construction sequences. Prospective contractors and material suppliers must evaluate potential repair problems on the basis of their knowledge and experience in the local area and on the basis of similar project in other localities, taking into account their own proposed repair construction methods and procedures.

Testing Conducted by Others

When subcontracted outside field and/or laboratory services and analyses are used, STS will rely upon the data provided by the outside field service or laboratory, and will not conduct an independent evaluation of the reliability of their data.

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Appendix C: Cost Calculations and Assumptions

Cost and Assumption Information

Assumptions

Estimated Project Length =	9.46 miles		
Estimated Rural Project Length=	8.90 miles	= Area of	156640 SY
Typical rural pavement width =	30 LF		

Removing Concrete Pavement Partial Depth

Historical Bid Prices

Low=	$	0.01	/SF
High=	$	1.06	/SF
Average=	$	0.28	/SF

Estimated Concrete Grinding Costs

Low=	$	0.10	/SY
High=	$	9.50	/SY
Average=	$	2.50	/SY

Bonded Concrete Overlay

Concrete Masonry Overlay Approaches Historic Bid Prices

Low=	$	205.00	/CY
High=	$	950.00	/CY
Average=	$	475.00	/CY

Assumed thickness of 2 inches

1 CY of concrete could cover 162 SF or 18 SY

Estimated Bonded Concrete Overlay Prices

Low=	$	11.40	/SY
High=	$	52.80	/SY
Average=	$	26.40	/SY

HMA Pavement

Type E-3 Historical Bid Prices (1/1/2012 - 2/25/2013)

Low=	$	19.10	/ton
High=	$	220.00	/ton
Average=	$	64.14	/ton

PG58-28 Historical Bid Prices (1/1/2012 - 2/25/2013)

Low=	$	10.00	/ton
High=	$	700.00	/ton
Average=	$	185.10	/ton

Tack Coat Historical Bid Prices (1/1/2012 - 2/25/2013)

Low=	$	1.50	/gal
High=	$	9.00	/gal
Average=	$	3.19	/gal

Assumed 2 layers at 1.75" for total thickness of 3.5".
Assumed 2 applications of tack coat at 0.025gal/SY
Assumed unit weight of asphalt of 112 lbs/SY-in
Assumed Asphalt Content of 5.5%

Estimated HMA Overlay Prices

Low=	$	3.89	/SY
High=	$	50.89	/SY
Average=	$	14.65	/SY

Base Aggregate Dense

BAD - 3/4 " Historical Bid Prices (1/1/2012 - 2/25/2013)

Low=	$	0.01	/ton
High=	$	43.45	/ton
Average=	$	14.47	/ton

Assumed 6' total width of aggregate shoulder
Assumed 1.5" of BAD required
Assumed unit weight of 2.5 tons/CY
Assumed full rural overlay of 8.90 miles
Assumed typical width of 30 LF, therefore total overlay area of 156,640 SY

Estimated BAD Prices

Low=	$	0.00021	/SY of rural overlay
High=	$	0.91	/SY of rural overlay
Average=	$	0.30	/SY of rural overlay

Estimated Distressed Areas

EB Lengths		Total Length; Full Width; with Tapers for Spot Grind and HMA Overlay
422.4	LF	1620
475.2	LF	828
52.8	LF	1778.4
105.6	LF	669.6
52.8	LF	616.8
264	LF	458.4
528	LF	2834.4
686.4	LF	669.6
369.6	LF	405.6
1848	LF	300
52.8	LF	1778.4
633.6	LF	933.6
633.6	LF	933.6
2376	LF	2676
422.4	LF	722.4
422.4	LF	880.8
52.8	LF	1831.2
		722.4

WB Lengths	
422.4	LF
1531.2	LF
580.8	LF
52.8	LF
105.6	LF
686.4	LF
792	LF
158.4	LF
316.8	LF
369.6	LF
1478.4	LF
528	LF
211.2	LF
792	LF

Total Length= 17424 LF

Assumed width of rehab=30 LF (12' lane +3' shoulder)

Total Area= 29040 SY

Total area of spot grind and full HMA overlay = 68864 SY