2022
Pavement Condition Index Report
Charleston International Airport

For The

Charleston County Aviation Authority

Issued: January 18, 2024

ADC ENGINEERING

SILENT FALCON™
UAS TECHNOLOGIES

SOUTH CAROLINA
LICENSED PROFESSIONAL ENGINEER
No. 24256
1/18/24
PHILIP D. STROPE

SOUTH CAROLINA
ADC ENGINEERING INC.
No. 00253
CERTIFICATE OF AUTHORIZATION

Project Manager: Philip Strope, P.E.
phils@adcengineering.com
ADC Project No. 22409.2

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EXECUTIVE SUMMARY

ADC Engineering, Inc. was commissioned by the Charleston County Aviation Authority (CCAA) to conduct the tri-annual Pavement Condition Index (PCI) Survey for all three of the CCAA owned airports. The PCI Survey is conducted to determine the present condition of the airfield pavements, provide an index for comparing the condition and performance of pavements within a network as well as provide a rational basis for justification, planning and budgeting of pavement repair project.

For the 2022 inspections, ADC Engineering contracted with Silent Falcon UAS Technologies to perform the PCI Surveys utilizing drone technology to collect photogrammetry of nearly 100% of all pavements. Silent Falcon UAS then processed the data collected through proprietary Artificial Intelligence software to quantify pavement distresses in accordance with ASTM D 5340. Silent Falcon's data analysists and pavement engineers then verified the results from the AI analysis to confirm PCI ratings for each network, branch and section.

Partnering with Silent Falcon provided a comprehensive inspection of each airport in lieu of the typical ASTM D 5340 procedure where only 25% - 50% of each section are inspected.

Reports for this year's PCI Survey have been generated for each airport. These reports will include both the results of the PCI survey for each airport. This document reports the results of the 2022 PCI survey for the Charleston International Airport (CHS). The Pavement Management Program (PMP) for CHS is provided in an associated report.

The 2022 PCI survey for CHS concludes the following:

1. The condition of the airfield sections varies from fair to good.
2. Major distresses in the asphaltic concrete pavement include medium severity block cracking, patching and longitudinal and transverse cracking.
3. Major distresses in the concrete pavement include medium severity joint seal damage (in isolated locations), medium severity corner breaks, linear cracking, patching, corner spalls, and joint spalls.
4. The lowest rated pavements are the TWY B and TWY G Shoulders.

Additional details on the condition of all pavements at this airport are contained within this report.

I. INTRODUCTION

A. Intent

The Pavement Condition Index (PCI) procedure provides a systematic method of visually inspecting and evaluating both asphaltic concrete and plain jointed portland cement concrete pavements. Specific objectives of a PCI analysis of a pavement network or networks include:

- Determination of the present condition of pavements in terms of apparent structural integrity and operational surface condition.
- Provide a common index for comparing the condition and performance of pavements within a network or networks.
- Provide feedback on the performance of each type of pavement.
- Provide a rational basis for justification, planning, and budgeting of pavement repair projects.

B. PCI Concept

The basic principle of the PCI procedure is to visually inspect random samples of each pavement section and quantify distresses or defects within each random sample. The quantified distresses result in a reduction in the condition rating for the pavement. Condition ratings for each random sample within a pavement section are averaged to yield an overall condition rating for the pavement section. Condition ratings for each pavement section within a pavement network or facility can then be compiled and compared on an objective basis for evaluation of performance and for planning for pavement repair projects.

Utilizing Silent Falcon's drone technology, nearly 100% inspection coverage has been provided for 2022 PCI Survey. With near 100% coverage, one sample unit is needed to analyze each section with the branch and network.

C. PCI Ratings

PCI	Rating	
86 - 100	Good	
71 – 85	Satisfactory	
56 - 70	Fair	
41 - 55	Poor	
26 - 40	Very Poor	
11 - 25	Serious	
0 – 10	Failed	

*Rating system is in accordance with ASTM D 5340.

D. PCI Procedure

1. Divide the pavement facilities in accordance with the following guidelines:

   Network: Facility Level (i.e. County Airport, City of Charleston, etc.)
   Branch: Function Level (i.e. Taxiway C, River Road, etc.)
   Section: Usage and Type Level (i.e. Low usage area, concrete area, etc.)

   Airport Example:
   Network = Charleston International Airport
   Branch = Taxiway A
   Section = 1 (asphalt taxiway)
   Section = 2 (concrete taxiway)

   Roadway Example:
   Network = City of North Charleston
   Branch = International Boulevard
   Section = 1 (intersections)
   Section = 2 (non-intersection areas)

2. Measure each Section and calculate area.

3. Quantify and record all distresses within each inspected sample unit. Assess each distress for type and severity (low, medium, high). A few typical distress types are:

   Typical Distresses Types

Asphalt Pavement	Concrete Pavement
Alligator Cracking	Spalling
Rutting	Cracking
Longitudinal Cracking	Joint Sealant Damage
Patching	Scaling
Weathering/Raveling	Corner Breaks

4. Calculate the PCI rating for each sample unit inspected. Each sample unit begins with a PCI rating = 100. Based on the quantity and severity of distresses within the sample unit, reductions are made to yield the actual PCI rating for the sample unit.

5. PCI ratings for Sections, Branches and Networks are calculated as follows:

   Section PCI = area weighted average of sample unit PCI ratings within the Section
   Branch PCI = area weighted average of Section PCI ratings within the Branch
   Network PCI = area weighted average of Branch PCI ratings within the Network

In accordance with ASTM D 5340, each section is divided into sample units. For asphalt pavement, these sample units are typically 5,000 sf for airfields and 2,500 sf for roadways. Concrete pavement sample units are typically 20 slabs for airfields and roadways. **Using Silent Falcon's drone technology, sections were not broken up into sample units for this PCI Survey as nearly 100% of all areas were surveyed.**

II. PAVEMENT CONDITION INDEX REPORT – CHARLESTON INTERNATIONAL AIRPORT (CHS)

A. 2022 PCI Rating

The Network PCI rating for the 2022 Survey of Charleston International Airport is 90 (Good).

The following is CHS network rating for the previous and current PCI studies.

TABLE II.1: CHS Network PCI Rating Summary

Network Summary	2012 PCI	2015 PCI	2019 PCI	**2022 PCI**
CHS	85 SATISFACTORY	84 SATISFACTORY	83 SATISFACTORY	**90 GOOD**

Figure II.1 – CHS Section PCI Ratings shows a pictorial overview of the branches and sections with PCI ratings. Refer to Table II.1 for the individual branch/section PCI ratings, and Table II.2 for a network pavement inventory.

B. Construction Since the Last Survey

Minor repair work has been performed on various pavements since the last inspection.

C. Pavement Inventory Updates Since the Last Report

None

D. Future Projects

The mil and overlay of the Taxiway B shoulders is programed for the near future.

E. PCI Rating Analysis

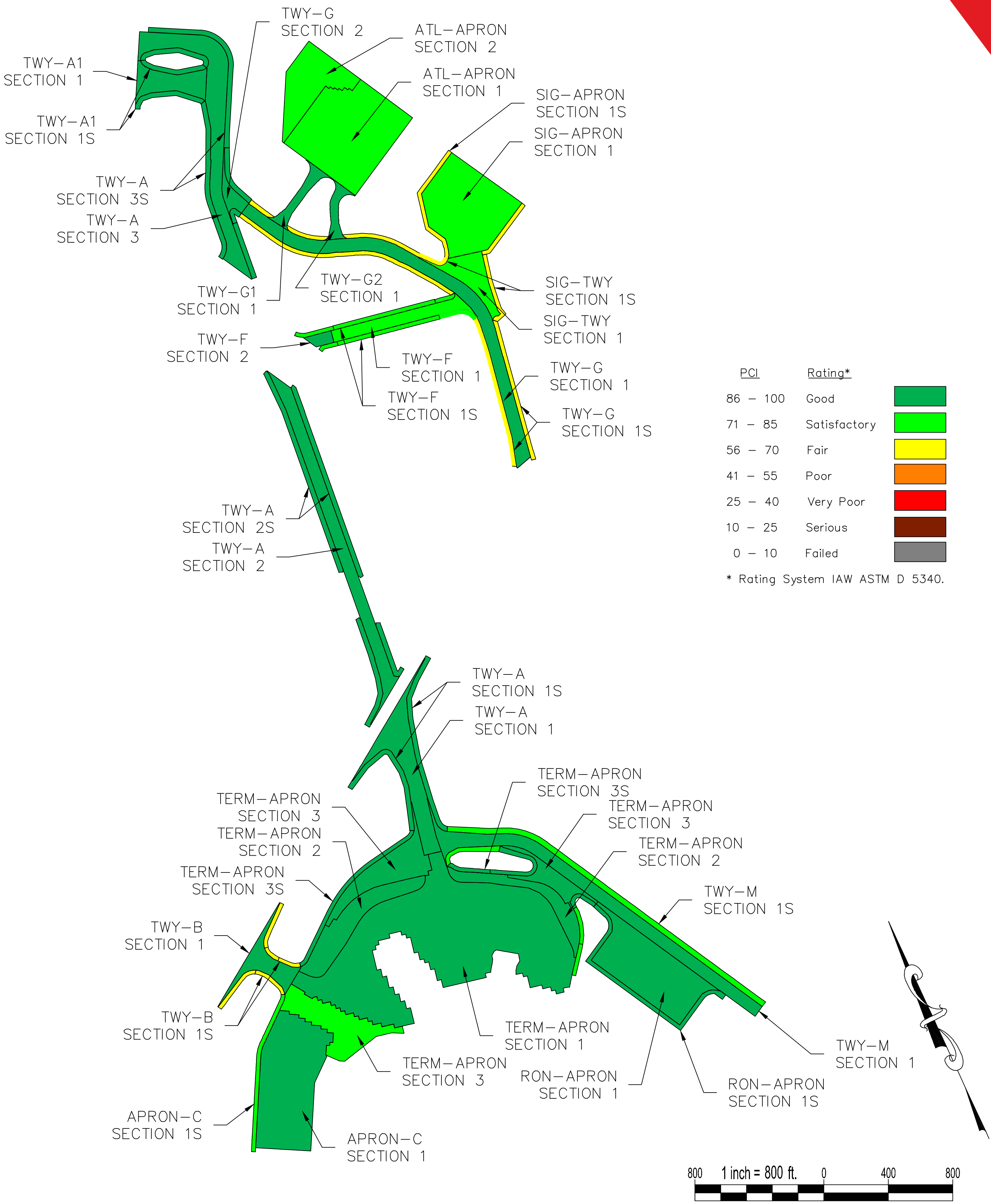
The PCI indicates the condition of the pavement at the time of inspection. As the pavement ages, it is expected that the PCI value will drop at a greater rate than when a pavement is new. For example, a recently constructed pavement will most likely see a one to two point drop between PCI inspections where a pavement that is fifteen years old may see a drop of ten points or greater between inspections.

The majority of the pavement at CHS has deteriorated at a reasonable rate. Some pavements saw an increase in the PCI rating although no M&R work has been done. This can be attributed to the data collection process using drones versus the surveying of random samples of each section.

Refer to the Pavement Management Program for CHS for Maintenance and Repair recommendations.

F. Maintenance and Repair Recommendations

Refer to the Pavement Management Program for CHS for Maintenance and Repair recommendations.



PCI	Rating*
86 – 100	Good
71 – 85	Satisfactory
56 – 70	Fair
41 – 55	Poor
25 – 40	Very Poor
10 – 25	Serious
0 – 10	Failed

* Rating System IAW ASTM D 5340.

ADC ENGINEERING
1226 YEAMANS HALL ROAD
HANAHAN, SC 29410
843-566-0161
ADCENGINEERING.COM

SECTION PCI RATINGS

CHARLESTON INTERNATIONAL AIRPORT (CHS)

FIG II-1

DATE: 01/18/2024

CHARLESTON, SOUTH CAROLINA

REF:

ADC PROJECT#: 22409.1

TABLE II-1: BRANCH / SECTION PCI RATINGS								
Branch ID	Section ID	2010 PCI	2012 PCI	2015 PCI	2019 PCI	**2022 PCI**	Change in PCI From 2019 to 2022	**2022 PCI Rating**
APRON-C	1	98	95	89	87	**96**	+9	**Good**
APRON-C	1S	97	94	89	78	**78**	0	**Satisfactory**
ATL-APRON	1	90	89	87	83	**79**	-4	**Satisfactory**
ATL-APRON	2	90	89	87	83	**76**	-7	**Satisfactory**
RON-APRON	1	N/A	N/A	97	97	**93**	-4	**Good**
RON-APRON	1S	N/A	N/A	96	94	**94**	0	**Good**
SIG- APRON	1	80	78	78	74	**74**	0	**Satisfactory**
SIG- APRON	1S	82	67	64	58	**63**	+5	**Fair**
SIG-TWY	1	77	75	74	72	**82**	+10	**Satisfactory**
SIG-TWY	1S	84	73	69	65	**69**	+4	**Fair**
TERM-APRON	1	84	82	81	77	**90**	+13	**Good**
TERM-APRON	2	*	*	92	91	**93**	+2	**Good**
TERM-APRON	3	N/A	N/A	99	91	**96**	+5	**Good**
TERM-APRON	3S	N/A	N/A	98	98	**94**	-4	**Good**
TWY A	1	N/A	N/A	N/A	97	**97**	0	**Good**
TWY A	1S	N/A	N/A	N/A	98	**89**	-9	**Good**
TWY A	2	N/A	N/A	N/A	98	**98**	0	**Good**
TWY A	2S	N/A	N/A	N/A	99	**90**	-9	**Good**
TWY A	3	N/A	N/A	N/A	98	**98**	0	**Good**

TABLE II-1: BRANCH / SECTION PCI RATINGS								
Branch ID	Section ID	2010 PCI	2012 PCI	2015 PCI	2019 PCI	**2022 PCI**	Change in PCI From 2019 to 2022	**2022 PCI Rating**
TWY A	3S	N/A	N/A	N/A	96	**88**	-8	**Good**
TWY A-1	1	N/A	N/A	N/A	99	**98**	-1	**Good**
TWY A-1	1S	N/A	N/A	N/A	99	**88**	-11	**Good**
TWY B	01	80	79	78	76	**88**	+12	**Good**
TWY B	01S	87	79	72	70	**58**	-12	**Fair**
TWY F	01	85	85	78	74	**73**	-1	**Satisfactory**
TWY F	01S	61	***	75	71	**85**	+14	**Satisfactory**
TWY F	02	N/A	N/A	N/A	98	**97**	-1	**Good**
TWY G	01	89	85	74	70	**94**	+24	**Good**
TWY G	01S	77	72	69	**83**	**66**	-17	**Fair**
TWY G	02	N/A	N/A	N/A	99	**99**	0	**Good**
TWY G-1	01	**	**	93	90	**94**	+4	**Good**
TWY G-2	01	**	**	91	90	**96**	+6	**Good**
TWY M	01	98	93	88	87	**93**	+6	**Good**
TWY M	01S	99	98	94	88	**85**	-3	**Satisfactory**

TABLE II-2: CHS PAVEMENT INVENTORY					
Pavement Name	**PAVER Branch ID**	**Section ID**	**Construction Period (Approximate)**	**Type**	**Remarks**
Air Cargo Apron	APRON-C	1	7/2002 11/2013	PCC	Original Construction (15" PCC/6" CTB) *1 Demo associated with Terminal Apron Exp.
Air Cargo Apron (Shoulders)	APRON-C	1S	7/2002 11/2013	AC	Original Construction (4" AC/8" LRBC) *1 Demo associated with Terminal Apron Exp.
Atlantic Aviation Apron	ATL-APRON	1	9/1997 12/2005	PCC	Original Construction (12" PCC/6" LRBC) *1 Minor demolition for the GA Aprons project.
Atlantic Aviation Apron	ATL-APRON	2	12/2005	PCC	Original Construction (12" PCC/6" LRBC) *1
Remain-Overnight-Apron	RON-APRON	1	11/2013	PCC	Original Construction (17" PCC/6" CTB) *1
Remain-Overnight-Apron (Shoulders)	RON-APRON	1S	311/2013	AC	Original Construction (4" AC/8" RCBC) *1
Signature Flight Services Apron	SIG-APRON	1	2/1998	PCC	Original Construction (15" PCC/8" LRBC) *1
Signature Flight Services Apron	SIG-APRON	1S	2/1998	AC	Original Construction (2.5" AC/8" RCBC) *1
Signature Flight Services Apron	SIG-APRON	2	12/2005	PCC	Original Construction (15" PCC/8" LRBC) *1
Signature Flight Services Apron	SIG-APRON	2S	12/2005	AC	Original Construction (2.5" AC/8" RCBC) *1
Signature Flight Services Taxiway	SIG-TWY	1	9/1984 2/1998	PCC	Original Construction (15" PCC/6" LRBC) * Minor demolition for the GA Aprons project.
Signature Flight Services Taxiway	SIG-TWY	1S	9/1984	AC	Original Construction (2" AC/12" LRBC) *

TABLE II-2: CHS PAVEMENT INVENTORY					
Pavement Name	**PAVER Branch ID**	**Section ID**	**Construction Period (Approximate)**	**Type**	**Remarks**
Terminal Apron	TERM-APRON	1	6/1983 7/2002 11/2013	PCC	Original Construction (15” PCC/6” CTB) *1 Demolition for the Terminal Apron Expansion. Demolition for the Terminal Apron Expansion.
Terminal Apron (Shoulders)	TERM-APRON	1S[2]	6/1983 7/2002 11/2013	AC	Original Construction (2” AC/12” ABC) *1 Demolition for the Terminal Apron Expansion. Demolition for the Terminal Apron Expansion
Terminal Apron	TERM-APRON	2	7/2002 11/2013	PCC	Original Construction (15” PCC/6” CTB) *1 Demolition for the Terminal Apron Expansion.
Terminal Apron (Shoulders)	TERM-APRON	2S	7/2002 11/2013	AC	Original Construction (4” AC/8” LRBC) *1 Demolition for the Terminal Apron Expansion.
Terminal Apron	TERM-APRON	3	11/2013	PCC	Original Construction (17” PCC/6” CTB) *1
Terminal Apron (Shoulders)	TERM-APRON	3S	11/2013	AC	Original Construction (4” AC/8” RCBC) *1
Taxiway Alpha	TWY-A	1	6/1983 9/2017	PCC PCC	Original Construction (15” PCC/6” CTB) Full Reconstruction (17” PCC/6” LCB) *1
Taxiway Alpha (Shoulders)	TWY-A	1S	6/1983 9/2017	AC AC	Original Construction (2” AC/12” ABC) Full Reconstruction (4” AC/8” RCBC) *1
Taxiway Alpha	TWY-A	2	2/1990 9/2017	PCC PCC	Original Construction (15.5” PCC/6” ACBC) *1 Full Reconstruction (17” PCC/6” LCB) *1
Taxiway Alpha (Shoulders)	TWY-A	2S	2/1990 9/2017	AC AC	Original Construction (2.5” AC/10” CABC) *1 Full Reconstruction (4” AC/8” RCBC) *1
Taxiway Alpha	TWY-A	3	2/1990 9/2017	PCC PCC	Original Construction (15.5” PCC/6” ACBC) *1 Full Reconstruction (17” PCC/6” LCB) *1
Taxiway Alpha (Shoulders)	TWY-A	3S	2/1990 9/2017	AC AC	Original Construction (2.5” AC/10” CABC) *1 Full Reconstruction (4” AC/8” RCBC) *1
Taxiway Alpha 1	TWY-A1	1	2/1990 9/2017	PCC PCC	Original Construction (15.5” PCC/6” ACBC) *1 Full Reconstruction (17” PCC/6” LCB) *1
Taxiway Alpha 1 (Shoulders)	TWY-A1	1S	2/1990 9/2017	AC AC	Original Construction (2.5” AC/10” CABC) *1 Full Reconstruction (4” AC/8” RCBC) *1

TABLE II-2: CHS PAVEMENT INVENTORY					
Pavement Name	**PAVER Branch ID**	**Section ID**	**Construction Period (Approximate)**	**Type**	**Remarks**
Taxiway Bravo	TWY-B	1	6/1983 11/2013	PCC	Original Construction (15" PCC/6" CTB) *1 Minor demo for the Terminal Apron Expansion
Taxiway Bravo (Shoulders)	TWY-B	1S	6/1983 7/2002 11/2013	AC	Original Construction (2" AC/12" LRBC) *1 Demolition for the Terminal Apron Expansion Demolition for the Terminal Apron Expansion
Taxiway Bravo (Shoulders)	TWY-B	2S	7/2002	AC	Terminal Apron Expansion (4" AC/11" LRBC) *1
Taxiway Foxtrot	TWY-F	1	Unknown 4/1989 1/2012	PCC	Original Construction (unknown pavement section) Partial Demolition for the TWY G Rehabilitation Partial Demolition for the RWY 15/33 Construction
Taxiway Foxtrot (Shoulders)	TWY-F	1S	Unknown 4/1989 1/2012 5/2012	AC/PCC	Original Construction (unknown pavement section) Partial Demolition for the TWY G Rehabilitation Partial Demolition for the RWY 15/33 Construction Partial Demolition for the TWY F Improvements
Taxiway Foxtrot	TWY-F	2	1/2012	PCC	Partial Reconstruction for the RWY 15/33 Construction (18" PCC/6" SDL/6" SL) *1
Taxiway Foxtrot (Shoulders)	TWY-F	2S	1/2012	AC	Partial Reconstruction for the RWY 15/33 Construction (2" AC/9" GABC) *1
Taxiway Foxtrot	TWY-F	3S	5/2012	AC	Taxiway F Improvements (4" AC/8" RCBC)
Taxiway Golf	TWY-G	1	Unknown 4/1989	PCC	Original Construction (unknown pavement section) Taxiway G Rehabilitation (13.5" PCC/6" CTB) *1
Taxiway Golf (Shoulders)	TWY-G	1S	Unknown 4/1989 11/2013	AC	Original Construction (unknown pavement section) Taxiway G Rehabilitation (2.5" AC/8" LRBC) *1 TWYs A, B & G Upgrades (crack sealing)
Taxiway Golf	TWY-G	2	2/1990	PCC	Original Construction (15.5" PCC/6" ACBC) *1
Taxiway Golf (Shoulders)	TWY-G	2S	2/1990 11/2013	AC	Original Construction (2.5" AC/10" CABC) *1 TWYs A, B & G Upgrades (crack sealing)

TABLE II-1: CHS PAVEMENT INVENTORY					
Pavement Name	**PAVER Branch ID**	**Section ID**	**Construction Period (Approximate)**	**Type**	**Remarks**
Taxiway Golf 1	TWY-G1	1	9/1997	PCC	Original Construction (12" PCC/6" LRBC) *1
Taxiway Golf 2	TWY-G2	1	9/1997	PCC	Original Construction (12" PCC/6" LRBC) *1
Taxiway Mike	TWY-M	1	9/2007	PCC	Original Construction (15" PCC/6" CTB) *1
Taxiway Mike	TWY-M	1S	9/2007	AC	Original Construction (4" AC/8" LRBC) *1

Pavement Inventory Notes:
BOLD indicates updates to the inventory.

1. SCBC = Soil Cement Base Course
   CABC = Crushed Aggregate Base Course
   ABC = Aggregate Base Course
   CTB = Cement Treated Base Course
   Base = Either Crushed Aggregate Base Course or Recycled Concrete Base Course
   LRBC = Lime Rock Base Course
2. Pavement information taken from record drawings for the Runway Pavement Rehabilitation project dated 8/8/1991.The inventory shown has been taken from record drawings of previous projects

G. Photographs – Charleston International Airport

To be provided.

APPENDIX A – SECTION DISTRESSES AND SECTION PCI VALUES

Branch	Section	Material	Distress	Level	Distress Quantity (sq. ft.)	Distress Quantity (lin. Ft.)	Distress Quantity (# of slabs)	Pavement Quantity (sq. ft.)	Pavement Quantity (# of slabs)	Total Section Distresses	Section PCI
APRON-C	1	Concrete	Joint Seal Damage	L			1		738		
APRON-C	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	L			5				96
APRON-C	1	Concrete	Patching Large	L			1				
APRON-C	1	Concrete	Shrinkage Cracking	X			7			4	
ATL-APRON	1	Concrete	Corner Break	L		1	1		697		
ATL-APRON	1	Concrete	Joint Seal Damage	L		1	1				
ATL-APRON	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	L		7	7				
ATL-APRON	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	M		31	31				76
ATL-APRON	1	Concrete	Patching Large	L		7	7				
ATL-APRON	1	Concrete	Patching Small	L		6	6				
ATL-APRON	1	Concrete	Shrinkage Cracking	X		39	39				
ATL-APRON	1	Concrete	Spalling Corner	L		4	4			8	
RON-APRON	1	Concrete	Corner Break	L			1		541		
RON-APRON	1	Concrete	Joint Seal Damage	L			1				
RON-APRON	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	L			13				93
RON-APRON	1	Concrete	Shrinkage Cracking	X			34			4	
RON-APRON	1S	Asphalt	Weathering	L	37,392			37,392		1	94
SIG-APRON	1	Concrete	Corner Break	L			1		437		
SIG-APRON	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	L			21				
SIG-APRON	1	Concrete	Patching Large	L			1				
SIG-APRON	1	Concrete	Patching Large	M			4				74
SIG-APRON	1	Concrete	Patching Small	L			10				
SIG-APRON	1	Concrete	Patching Small	M			1				
SIG-APRON	1	Concrete	Shrinkage Cracking	X			313				
SIG-APRON	1	Concrete	Spalling Longitudinal Transverse Joint	L			6			8	
SIG-APRON	1S	Asphalt	Block Cracking	M	3,318			33,123			
SIG-APRON	1S	Asphalt	Longitudinal and Transverse Cracking	M		1,180					69
SIG-APRON	1S	Asphalt	Weathering	L	25,297					3	
SIG-TWY	1	Concrete	Joint Seal Damage	M			1		116		
SIG-TWY	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	X			8				
SIG-TWY	1	Concrete	Shrinkage Cracking	L			2				82
SIG-TWY	1	Concrete	Spalling Corner	M			1				
SIG-TWY	1	Concrete	Spalling Corner				1			5	
SIG-TWY	1S	Asphalt	Block Cracking	L	1,084			14,600			
SIG-TWY	1S	Asphalt	Longitudinal and Transverse Cracking	L		508					69
SIG-TWY	1S	Asphalt	Longitudinal and Transverse Cracking	M		145					
SIG-TWY	1S	Asphalt	Weathering	L	11,325					4	
TERM-APRON	1	Concrete	Joint Seal Damage	L			1		1369	9	
TERM-APRON	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	L			21				
TERM-APRON	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	M			7				
TERM-APRON	1	Concrete	Patching Large	L			3				
TERM-APRON	1	Concrete	Patching Small	L			16				90
TERM-APRON	1	Concrete	Patching Small	M			1				
TERM-APRON	1	Concrete	Shrinkage Cracking	X			72				
TERM-APRON	1	Concrete	Spalling Corner	L			2				
TERM-APRON	1	Concrete	Spalling Longitudinal Transverse Joint	L			2				
TERM-APRON	2	Concrete	Corner Break	L			1		697	6	
TERM-APRON	2	Concrete	Shrinkage Cracking	X			6				
TERM-APRON	2	Concrete	Spalling Longitudinal Transverse Joint	L			1				
TERM-APRON	2	Concrete	Longitudinal and Transverse and Diagonal Cracking	L			4				93
TERM-APRON	2	Concrete	Longitudinal and Transverse and Diagonal Cracking	M			1				
TERM-APRON	2	Concrete	Shrinkage Cracking	X			119				
TERM-APRON	3	Concrete	Joint Seal Damage	L			1		406	6	
TERM-APRON	3	Concrete	Patching Large	L			2				
TERM-APRON	3	Concrete	Shrinkage Cracking	X			1				
TERM-APRON	3	Concrete	Shrinkage Cracking	X			9				96
TERM-APRON	3	Concrete	Patching Small	L			1				
TERM-APRON	3	Concrete	Shrinkage Cracking	X			2				
TERM-APRON	3S	Asphalt	Weathering	L	15,941			15,941		1	94
TWY-A	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	L			1		390	5	
TWY-A	1	Concrete	Patching Small	L			1				
TWY-A	1	Concrete	Shrinkage Cracking	X			8				97
TWY-A	1	Concrete	Spalling Corner	L			3				
TWY-A	1	Concrete	Spalling Longitudinal Transverse Joint	L			3				
TWY-A	1S	Asphalt	Longitudinal and Transverse Cracking	L		745		61,908		2	91
TWY-A	1S	Asphalt	Weathering	L	59,624						
TWY-A	2	Concrete	Joint Seal Damage	L			1		448	1	98
TWY-A	2S	Asphalt	Longitudinal and Transverse Cracking	L		451		105,082		2	90
TWY-A	2S	Asphalt	Weathering	L	105,082						
TWY-A	3	Concrete	Joint Seal Damage	L			1		519	3	
TWY-A	3	Concrete	Shrinkage Cracking	X			2				98
TWY-A	3	Concrete	Spalling Longitudinal Transverse Joint	L			2				
TWY-A	3S	Asphalt	Longitudinal and Transverse Cracking	L		448		111,588		3	
TWY-A	3S	Asphalt	Weathering	L	111,588						88
TWYA3S	3S	Asphalt	Longitudinal and Transverse Cracking	M		6					
TWY-A1	1	Concrete	Joint Seal Damage	L			1		184	1	98
TWY-A1	1S	Asphalt	Longitudinal and Transverse Cracking	L		67		26,296		3	
TWY-A1	1S	Asphalt	Longitudinal and Transverse Cracking	M		22					88
TWY-A1	1S	Asphalt	Weathering	L	25,032						
TWY-B	1	Concrete	Patching Large	L			2		136	3	
TWY-B	1	Concrete	Shrinkage Cracking	X			7				88
TWY-B	1	Concrete	Spalling Longitudinal Transverse Joint	L			4				
TWY-B	1S	Asphalt	Block Cracking	L	13,826			34,175		6	
TWY-B	1S	Asphalt	Weathering	L	34,175						
TWY-B	1S	Asphalt	Block Cracking	M	6,107						
TWY-B	1S	Asphalt	patching_and_utility_cut_patching	M	663						58
TWY-B	1S	Asphalt	patching_and_utility_cut_patching	L	60						
TWY-B	1S	Asphalt	Longitudinal and Transverse Cracking	L		614				2	
TWY-F	1	Concrete	Joint Seal Damage	L			1		132	6	

Branch	Section	Material	Distress	Level	Distress Quantity (sq. ft.)	Distress Quantity (lin. Ft.)	Distress Quantity (# of slabs)	Pavement Quantity (sq. ft.)	Pavement Quantity (# of slabs)	Total Section Distresses	Section PCI
TWY-F	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	L			2				73
TWY-F	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	M			2				
TWY-F	1	Concrete	Patching Small	L			1				
TWY-F	1	Concrete	Shrinkage Cracking	X			13				
TWY-F	1	Concrete	Spalling Corner	L			1				
TWY-F	1S	Asphalt	Longitudinal and Transverse Cracking	L		306		69,475		3	85
TWY-F	1S	Asphalt	Longitudinal and Transverse Cracking	M		207					
TWY-F	1S	Asphalt	Weathering	L	41,108						
TWY-F	2	Concrete	Longitudinal and Transverse and Diagonal Cracking	L			1		34	3	97
TWY-F	2	Concrete	Shrinkage Cracking	X			8				
TWY-F	2	Concrete	Spalling Corner	L			1				
TWY-F	2S	Asphalt	Longitudinal and Transverse Cracking	M		86		8,639		3	83
TWY-F	2S	Asphalt	Longitudinal and Transverse Cracking	L		4					
TWY-F	2S	Asphalt	Weathering	L	8,639						
TWY-G	1	Concrete	Corner Break	L			2		330	5	94
TWY-G	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	L			12				
TWY-G	1	Concrete	Patching Large	L			2				
TWY-G	1	Concrete	Shrinkage Cracking	X			3				
TWY-G	1	Concrete	Spalling Corner	L			2				
TWY-G	1S	Asphalt	Block Cracking	M	2,685			84,298		5	66
TWY-G	1S	Asphalt	Longitudinal and Transverse Cracking	M		1,493					
TWY-G	1S	Asphalt	Longitudinal and Transverse Cracking	L		4,904					
TWY-G	1S	Asphalt	patching_and_utility_cut_patching	L	483						
TWY-G	1S	Asphalt	Weathering	L	108,188						
TWY-G1	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	L			1		52	4	94
TWY-G1	1	Concrete	Shrinkage Cracking	X			4				
TWY-G1	1	Concrete	Spalling Corner	L			1				
TWY-G1	1	Concrete	Spalling Longitudinal Transverse Joint	L			2				
TWY-G2	1	Concrete	Joint Seal Damage	L			1		44	2	97
TWY-G2	1	Concrete	Shrinkage Cracking	X			4				
TWY-M	1	Concrete	Joint Seal Damage	L			1		468	5	93
TWY-M	1	Concrete	Longitudinal and Transverse and Diagonal Cracking	M			7				
TWY-M	1	Concrete	Patching Small	L			5				
TWY-M	1	Concrete	Shrinkage Cracking	X			9				
TWY-M	1	Concrete	Spalling Corner	L			2				
TWY-M	1S	Asphalt	Longitudinal and Transverse Cracking	L		11,043		171,317		3	85
TWY-M	1S	Asphalt	Longitudinal and Transverse Cracking	M		67					
TWY-M	1S	Asphalt	Weathering	L	111,013						

APPENDIX B – PETROGRAPHIC EXAMINATION OF CONCRETE

CHARLESTON INTERNATIONAL AIRPORT
Petrographic Examination of Concrete from Terminal Apron

North Charleston, SC

Final Report
March 2, 2010
WJE No. 2010.0320

Prepared for:
Mr. Greg Jones, P.E.
Principal Civil Engineer
ADC Engineering, Inc.
1226 Yeanans Hall Poad
Hanahan, SC 2410

Prepared by:
Wiss, Janney, Elstner Associates, Inc.
330 Pfingsten Road
Northbrook, Illinois 60062
847.272.7400 tel | 847.291.5189 fax

CHARLESTON INTERNATIONAL AIRPORT
Petrographic Examination of Concrete from Terminal Apron

North Charleston, SC

Margaret H. Reed
Senior Associate

Final Report
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WJE | ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

CHARLESTON INTERNATIONAL AIRPORT
Petrographic Examination of Concrete from Terminal Apron

North Charleston, SC

INTRODUCTION

One concrete core was received January 22, 2010, from Greg Jones, P.E., of ADC Engineering in Hanahan, South Carolina. The core had reportedly been taken from a terminal apron at the Charleston International Airport in North Charleston, South Carolina. Petrographic examination of the core was requested to help determine the cause(s) of widespread significant surface deterioration.

According to information provided by Mr. Jones, the apron in question is approximately 25 years old. The most significant deterioration has occurred adjacent to construction joints, and the surface deterioration has occurred even in areas that are not exposed to substantial traffic.

SAMPLE

The unlabeled core has a diameter of nearly 1-3/4 inches and is 7 to 8 inches long. The bottom surface of the core had been broken off within the slab and the top surface is deeply worn. No reinforcement was present in the core sample. Figure 1 shows the core in its as-received condition.

PETROGRAPHIC EXAMINATION

Brief Description of Procedures

A sample submitted for petrographic examination is studied visually and microscopically in accordance with the applicable procedures of ASTM C 856, *Standard Practice for Petrographic Examination of Hardened Concrete*. A petrographic examination consists of a series of qualitative observations that are interpreted to draw conclusions about the composition, quality, and probable cause(s) of a number of problems associated with concrete.

A thorough visual examination of a sample is the first step in a petrographic examination. Next, the sample is generally sliced in half lengthwise to prepare it for a more in-depth examination. One of the resultant halves is lapped (polished) to accentuate the appearance of the components of the concrete (cement paste, air-void system, and aggregates). Lapped specimens, as well as freshly fractured surfaces, are examined visually and using a stereomicroscope at magnifications up to about 100X to further characterize the concrete and its individual components.

A typical petrographic examination also involves observation of powder mounts of the paste, thin sections of the concrete, or both, using a petrographic microscope at magnifications up to 500X. Examination of these specimens allows the composition of the cement paste, mineral components of the aggregate, and other significant characteristics of the concrete to be studied in detail.

Visual Examination

The top surface of the concrete represented by the core is deeply eroded, with coarse aggregate particles exposed significantly in relief above the main body of the concrete. We do not know how much of the surface of the concrete had already eroded; however, a number of coarse aggregate particles "stand proud" above the main body of the concrete an estimated 3/16 to 1/4 inch.

A relatively large coarse aggregate socket is also evident on the top surface, where a coarse aggregate particle had de-bonded from the concrete. Both the coarse and the fine aggregate particles that remain are generally tightly bonded to the body of the concrete and do not exhibit any deterioration. Figures 2 thorough 4 show various views of the surface zone of the concrete, with Figure 2 showing the top surface, Figure 3 (and cover photograph) showing a side view of a coarse aggregate particle that is elevated significantly above the main body of the concrete, and Figure 4 providing a closer view of the aggregate socket.

Minor to moderate amounts of dirt and debris are present on the top surface of the concrete. Some of the deposits exhibit a faint green color, suggesting organic growth. The cement paste on the top surface is overall light tan and moderately firm; however, moderate amounts of zones of soft paste are present. This paste is significantly lighter than the paste in the main body of the concrete, indicating that the light-colored paste has been altered. This discolored and softer paste appears to extend up to 1/16 inch in some areas. Figure 5 shows a few pockets of softer paste that are visible along the circumference of the core. Pale-orange discoloration, caused by paste carbonation, is evident in some sections. The aggregate socket also exhibits zones of light-colored, moderately soft paste. Based on the initial visual examination of the surface region of the concrete, its characteristics are similar to some type of chemical attack of the cement paste.

Microscopic Examination

Both the near-surface zone and the main body of the concrete were examined in depth microscopically to determine the cause(s) of the paste deterioration. In addition, the concrete mixture represented by the sample was evaluated to determine its components.

Surface and Near-Surface Zone

Deteriorated paste extends from a negligible depth to 1/16 inch. The deepest alteration occurs adjacent to coarse aggregate particles. One narrow zone of carbonation extends to a depth of 1/2 inch. In general, the paste-aggregate interface is often more permeable than other portions of concrete. A number of other areas of paste in the surface region are very thin and only somewhat altered, suggesting that the soft paste had already eroded off the surface.

The near-surface paste exhibits minor to moderate amounts of especially narrow, microscopic, discontinuous cracks oriented parallel to the top surface. Optical properties of the paste indicate loss of crystallinity and degradation of some unhydrated portland cement clinker particles. Figure 6 shows a lapped cross-section of the concrete. Figures 7 and 8 given progressively closer views of the near-surface zone the sample.

Minor amounts of secondary deposits that have a needle-like form are apparent in air voids in the altered paste in the near-surface. The location and form of the secondary deposits suggest that they are primarily ettringite. Ettringite, a calcium sulfo-aluminate hydrate mineral, may be present in concrete for a number of reasons. Concrete that has been exposed to moisture passing through it for an extended period of time often contains abundant amounts of non-deleterious ettringite. This airport apron has likely been exposed to abundant amounts of water for a long time.

Ettringite can occur in other circumstances. Concrete that is exposed to chemicals from its exterior surface, particularly acid-bearing substances or a sulfur-rich environment, often exhibit abundant amounts of ettringite and other secondary deposits in its near-surface zone due to decomposition of the cement paste. Concrete that is undergoing certain types of deleterious internal reactions may also produce abundant amounts of ettringite. These other types of ettringite-producing reactions also require a lot of moisture to develop. The lack of more abundant amounts of secondary deposits in the near-surface zone of this concrete is not fully understood.

Typical causes of excessive surface erosion, apart from chemical alteration, include an elevated water-cement ratio either in the concrete as a whole or isolated in the near-surface zone, excessive traffic, or possibly both. Although, much of the near-surface paste is no longer present, no evidence for either of these mechanisms was detected.

Main Body

Secondary deposits line or fill nearly all of the air voids throughout the main body of the concrete. Many of the smaller voids are completely filled with white, very-fine-grained, secondary deposits. Localized concentrations of deposits are present throughout the core. Some of the deposits are consistent with ettringite, but the characteristics of many of the deposits are too fine-grained to be discerned.

The deposits do not appear to be non-crystalline or gel, as might be expected if the concrete were suffering from alkali-silica reaction. As discussed previously, secondary deposits may be caused by exposure to moisture for an extended period of time. However, the occurrence of abundant very fine-grained deposits throughout the concrete may also be a characteristic of an internal deterioration mechanism. Even concrete that has been exposed to a lot of moisture rarely exhibits such a uniform occurrence of deposits in air voids.

When the concrete is examined at highest magnifications, thin light-colored partial rims are suggested around some sand particles. No readily-discernable rims were detected around coarse aggregate particles. Trace amounts of short, randomly-oriented, especially fine microcracks are present throughout the paste. Some of these characteristics are consistent with the early stages of delayed ettringite formation (DEF) an internal deterioration mechanism. These rims may also be zones of elevated water-cement ratio, or some other characteristic. The minimal amount and exceeding fineness of this material were too fine-grained to be able to be effectively studied using petrography alone. Scanning electron microscopy is essential to confirm DEF. In addition, the occurrence of DEF under these conditions is unusual.

Concrete Mixture

The characteristics of the aggregates, paste, and air-void system of the concrete represented by the core were evaluated as part of the petrographic examination to determine if the general quality of the concrete may have contributed to the surface deterioration problem. Figure 9 shows the lapped cross-section of the concrete illustrating the concrete mixture.

Paste

Optical and physical properties of the paste are consistent with a low to moderately low water-cement ratio, estimated to be 0.40 to 0.44. No fly ash was detected in the paste. The estimated cement content of the concrete is in the range of 6-1/2 to 7 bags per cubic yard. Relatively abundant amounts of coarsegrained unhydrated portland cement clinker particles compose the paste. Since the concrete has been exposed to copious moisture, the presence of abundant unhydrated portland cement clinker particles is somewhat unusual. Initial hydration of the cement paste was possibly less-than-optimal.

Aggregates
The coarse aggregate is a thoroughly crushed siliceous gravel that has a maximum diameter of 1 inch. Siliceous indicates that the rock consists of mainly of silica-based minerals, as opposed to carbonate-based rocks such as limestone. Gravel indicates that the source of the aggregate is from a former river bed that rounded and smoothed rock particles over time as they moved through the water. Granitic gneiss is the main component of the coarse aggregate. In general, a geologic granite is a lighter-colored rock that consists of a number of both light- and dark-colored minerals and often exhibits a salmon color. Gneiss is also a geologic term that indicates that a rock body has been metamorphosed (exposed to elevated pressures, elevated temperatures, and often both, for an extended period of time), causing mineral grains to align and the rock body to form thick dark- and light-colored bands. Other types of metamorphic rocks also compose the coarse aggregate. Figure 9 shows the general appearance or the aggregate.

The fine aggregate is a natural siliceous sand. Quartz is the main component of the sand. Minor amounts of rocks and minerals similar to those found in the coarse aggregate also compose the fine aggregate.

The shape of both aggregates ranges from angular to subrounded and from equi-dimensional to moderately elongated, indicating that the aggregates contains a high proportion of crushed particles. Some granite gneiss is potentially susceptible to alkali-silica reaction (ASR) given exposure to sufficient moisture for an extended period of time, a sufficiently high alkali content of the cement, and susceptible aggregate. No evidence of ASR was detected in the concrete. Paste-aggregate bond was moderate and not as strong as expected in concrete that has a water-cement ratio as low as this concrete.

Air-Void System
The concrete represented by the core appears to be overall adequately consolidated and air-entrained. Most of the air-void system consists of small, sub-spherical and spherical shaped air voids that are reasonably uniformly distributed throughout the concrete. Minor to moderate amounts of medium size, entrapped air voids also compose the air-void system. The largest air void was approximately 1/8 x 3/8 inches. The estimated air content of the concrete is 6-1/2 to 8 percent. Use of air-entrainment in concrete that is not exposed to cyclic freezing and thawing is somewhat unusual, but air is purposefully added to some concrete to aid in workability.

SUMMARY AND CONCLUSION

Petrographic examination of the concrete represented by the core suggested that it may be in the early stages of delayed ettringite formation (DEF) or some other type of internal deterioration mechanism. A number of characteristics were detected in the concrete that were both consistent and inconsistent with DEF.

The concrete exhibited especially abundant amounts of secondary deposits, likely ettringite, in virtually all of the air voids. Localized concentrations of deposits that completely filled smaller air voids were also detected. These occurrences of ettringite are unusual for concrete that has simply been exposed to moisture migrating through concrete for an extended period of time.

Occasional, partial, light-colored rims of exceedingly fine-grained secondary-deposit-like material around aggregate particles were also identified. Aggregate rims filled with secondary ettringite are usually wider and surround larger particles. These rims may also have been zones of elevated water-cement ratio paste.

Additional characteristics of the concrete were detected that were both consistent and inconsistent with DEF. The amount and fineness of any secondary deposits within the paste were too fine-grained to be able to be effectively studied using petrography alone. The presence of ettringite within the paste is another diagnostic feature of DEF. Only trace amounts of microcracks were detected in the main body of the concrete and the type of surface deterioration were not necessarily consistent with DEF. The microcracks and paste alteration in the surface paste weakened it and lead to its erosion. DEF is atypical of cast-in-place concrete slabs because the heat generated by cement hydration rapidly dissipates into the environment. Rare instances of DEF cast-in-place concrete in hot climates have been encountered.

The overall quality of the concrete mixture represented by the core was considered to be adequate. Although we do not know what the mix design for this concrete required, nor its specified compressive strength, this adequate quality assessment was based primarily on the low water-cement ratio of the concrete. Hydration of the portland cement may have been less-that optimal; however, long-term exposure to moisture enabled the cement to continue to hydrate and no significant concerns from the less-than-optimal hydration were identified. Therefore, overall quality of concrete did not appear to have contributed to the problem.

Briefly, DEF occurs when the ettringite that is normally produced in the early stages of cement hydration ceases due to exposure to high temperature (typically over 140°F). After the concrete hardens and is exposed to significant amounts of moisture, this ettringite can re-form. Ettringite crystallization within the paste is associated with internal expansion.

The occurrence of DEF in concrete that has not been precast is controversial. However, the concrete in this project could have achieved a high internal temperature due to a few circumstances: the Charleston region can be very hot; the thickness of the apron was reportedly about 16 inches, which is relatively massive; and the cement content of the concrete represented by the core appears to be relatively high. It is also possible that the concrete has an elevated sulfur content due to the presence of slowly soluble sulfate minerals in the portland cement clinker, or possibly to excessive sulfate in the cement, aggregate, or mineral admixtures. Internal sulfate attack of concrete may produce similar symptoms to DEF. No other clear-cut cause(s) for the alteration of the paste in the near-surface zone of the concrete was identified. No obvious ASR or acid-attack were detected.

The long-term durability of the concrete is difficult to assess based on the work conducted to date. The concrete represented by the core has been in service for a number of years and only exhibited a minor to moderate degree of deterioration. However, the deterioration mechanism may in its early phases. Additional laboratory studies are suggested to evaluate the apron concrete in more detail.

Recommendation for Additional Studies

Additional examination of the concrete using scanning electron microscopy (SEM) is highly recommended to determine if the concrete is undergoing DEF, as suggested by the petrographic examination. Other characteristics of the concrete could also be studied using SEM. This technique allows high-magnification examination of the location of ettringite and any associated microcracks. Another more definitive characteristic of DEF that could be studied by SEM is the deposition of ettringite around gaps that form between aggregate particles and the paste due to paste expansion. Deposition of especially fine-grained ettringite within the paste is another diagnostic feature of DEF that can be best evaluated identified using SEM. The concrete appears to be in the early phases of a reaction, so use of SEM is especially important. The core sample that was examined petrographically can also be used to conduct SEM.

Examinations of additional samples from various areas of the apron are recommended to evaluate the problem in more detail. Examination of zones the exhibit the most loss of surface, as well as the least loss of surface would be useful. In addition, thin sections of the concrete should be examined to enable more in-depth examination of the paste, paste-aggregate interface, secondary deposits, and near-surface zone.

If DEF is confirmed, additional long-term monitoring of the concrete apron is recommended to track the expected deterioration of the concrete over time. Both a site investigation and laboratory analyses should be conducted. Periodic site visits should be conducted every two to three years. The purpose of the visits would be to identify and document any cracks, spalls, or continued erosion of the top surface. Carefully selected locations for cores could be taken during the site visit. Petrographic examination, SEM, and long-term expansion testing of these cores would be beneficial to monitor the condition and relative rate of expansion of the concrete. If the sulfate source is “used up” and no more is supplied, the reaction may be complete.

Storage: **Thirty days after completion of our studies, the samples will be discarded unless the client submits a written request for their return. Shipping and handling fees will be assessed for any samples returned to the client. Any hazardous materials that may have been submitted for study will be returned to the client and shipping and handling fees will apply. The client may request that WJE retain samples in storage in our warehouse. In that case, a yearly storage fee will apply.**

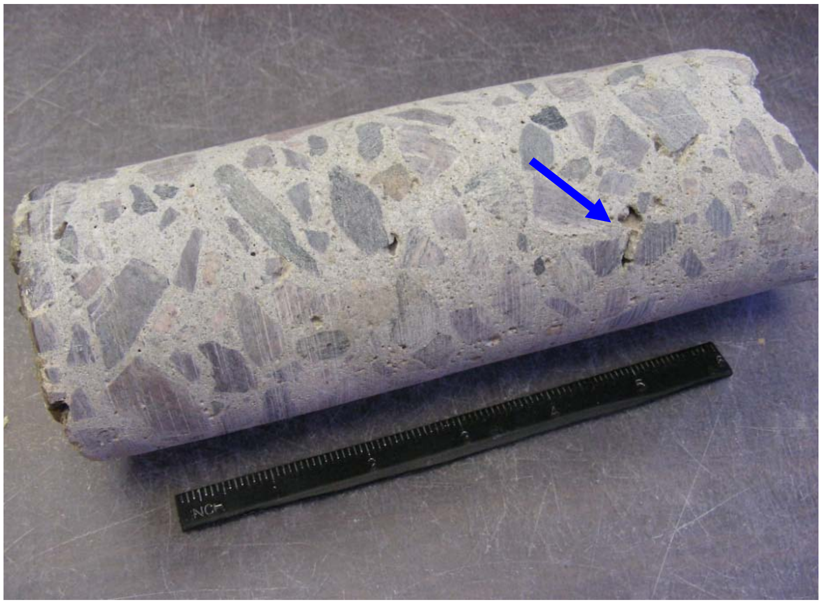

Figure 1. Core as received, with its top surface on the left side of the photograph. Overall minimal amounts of small and medium size unconsolidated air voids are visible. One of the larger voids (5/8 inch long and up to 3/16 inch wide) is indicated by the arrow.

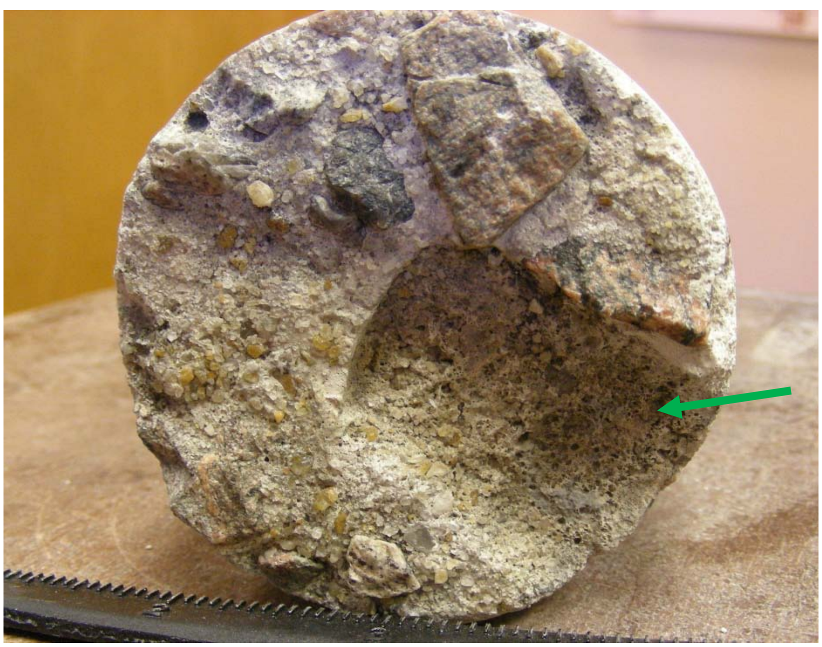

Figure 2. Top surface of core, representing significantly deteriorated top surface of apron. A large coarse aggregate particle (socket is 1-1/4 in. long and 1 inch wide) is indicated by the arrow.

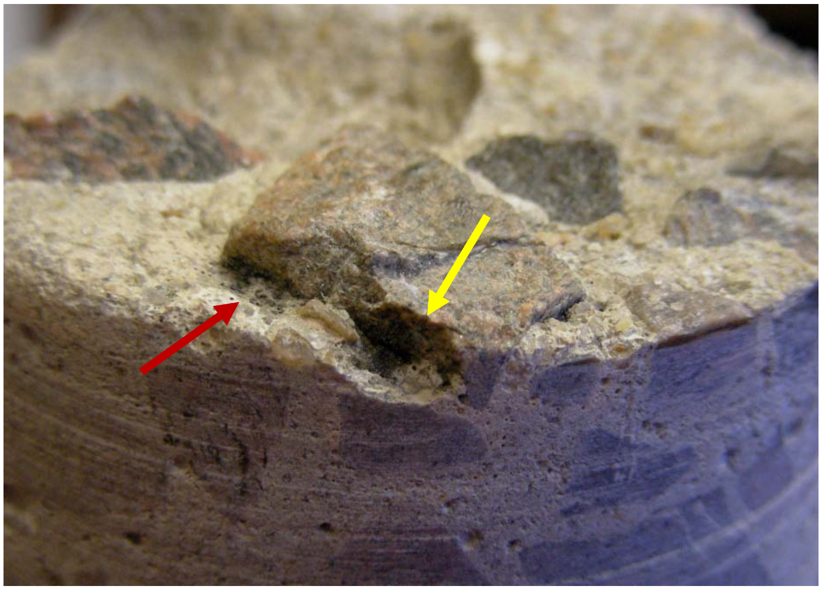

Figure 3. Top surface of core showing a coarse aggregate particle exposed in relief up to approximately 3/16 inch. A small section of the concrete appears to have broken away from the circumference of the core, likely during coring operation (yellow arrow). For scale purposes, the chip appears to be about 3/16 inch deep. Abundant amounts of dirt and debris are present along paste-aggregate interface exposed by the concrete that had broken off (arrow), indicating that a separation between the concrete and paste had been present for an extended period of time and been exposed to moisture. Green, organic growth is evident along this interface and also to the left (red arrow), indicating long-term exposure to moisture.

Figure 4. Depression left when relatively large coarse aggregate particle separated from top surface, arrows indicate original outline of particle. For scale, the width of the socket is approximately 1 inch.

Figure 5. Zone of light-colored, relatively soft, altered cement paste is indicated by arrows. For scale purposes, the aggregate particle in the near-surface zone is approximately 3/8 inch long.

Figure 6. Lapped cross-section of a portion of core sample, top surface of concrete is on left side of photograph. A few areas were circled with a black felt-tip pen to indicate some of the numerous localized concentrations of secondary deposits.

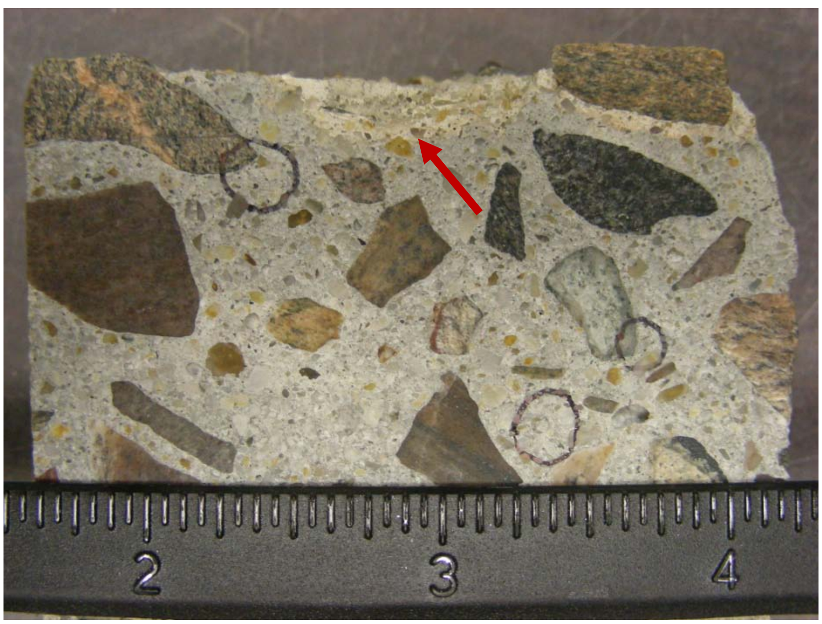

Figure 7. Closer view of near-surface zone. Coarse aggregate particles standing proud above main body of concrete are evident. The empty socket where a relatively large coarse aggregate particle had been located is indicated an arrow centered between the two sides of the socket. This aggregate socket is also shown in Figure 2.

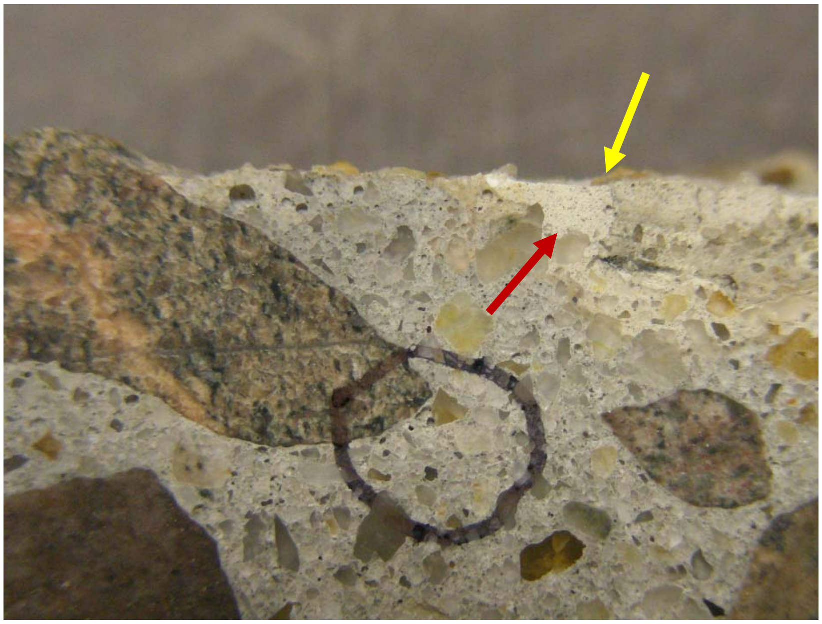

Figure 8. Near-surface zone showing a zone of deteriorated paste (red arrow).The yellow arrow indicates where paste ends and aggregate socket begins.

Figure 9. Closer view of concrete mixture. For scale purposes, the aggregate particle indicated by arrow is 3/4 inch long.