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I-55 OGFC FIELD PERMEABILITY TESTING

REPORT NO.
FHWA/MS-RD-09-201
CMRC-09-4

Prepared by
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December 30, 2009

JAMES WORTH BAGLEY COLLEGE OF ENGINEERING
MISSISSIPPI STATE UNIVERSITY
CIVIL & ENVIRONMENTAL ENGINEERING

FINAL REPORT

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16. Abstract

An OGFC test section was constructed on I-55 in Copiah County, MS during the spring/summer of 2007. As part of the study, literature was reviewed and a falling head permeability device was identified that has been used in laboratory and field studies of OGFC/PFC permeability. The falling head device was fabricated along with a vehicle mounted reaction frame. Drawings for the apparatus are included in the report. In situ permeability tests were conducted in wheel paths and between the wheel paths of the driving and passing lanes of the highway in one tenth mile increments. The measurements were initiated approximately six months after construction and then every six months for two and one-half years.

A goal of the research was met in that it has been shown OGFC can be successfully designed using local Mississippi aggregates and polymer modified asphalt. In service, the resulting OGFC can carry significant traffic while maintaining an adequate level of in situ permeability. The OGFC did not exhibit loss of aggregate through surface raveling or significant spalling along cracks generated at the juncture of the laydown machine screed and screed extensions during construction.

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Open Graded Friction Course, OGFC, PFC, Falling Head Permeability, Condition	Unclassified

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CHAPTER 1

INTRODUCTION

For a number of years, Open Graded Friction Course (OGFC) has been shown to decrease hydroplaning potential, spray, and noise. In addition, there is indication an OGFC surface will reduce underlying pavement temperatures. Test sections of OGFC were built in Mississippi in the 1970's with local aggregate and neat asphalt. These sections performed poorly. The mixtures exhibited stripping and severe raveling. As a result of this poor experience, use of OGFC in Mississippi was discontinued. On a national level, some states experienced similar performance as Mississippi while other states and agencies experienced good performance. Aggregate quality, binder type and climate appear to be factors affecting OGFC performance. Binder type seems particularly important and may be able to mitigate effects of aggregate quality and climate.

During this early experience, some state and federal agencies constructed OGFC using aggregates with wide a range of qualities in combination with polymer modified asphalt. The resulting mixes performed well. However, these early polymer modified asphalts were not readily avaiable and expensive which limited their use. Today polymer modified asphalts are readily available and cost effective. The Mississippi Department of Transportation (MDOT) has significant experience with polymer modified asphalts in dense hot mix asphalt (HMA) and decided to construct an OGFC test section using polymer modified asphalt and significant amounts of local aggregates. The potential benefits of using OGFC justify investigation of its use in the state.

A test section of OGFC was constructed on Mississippi I-55 in Copiah County during the spring/summer of 2007 (Figure 1). The OGFC test section was constructed as part of an eleven mile long project on I-55 which has two lanes in each direction. A one mile section of both lanes in both directions received an OGFC as surfacing. Selection of the site for the OGFC section was on a tangent without ramps or bridges.

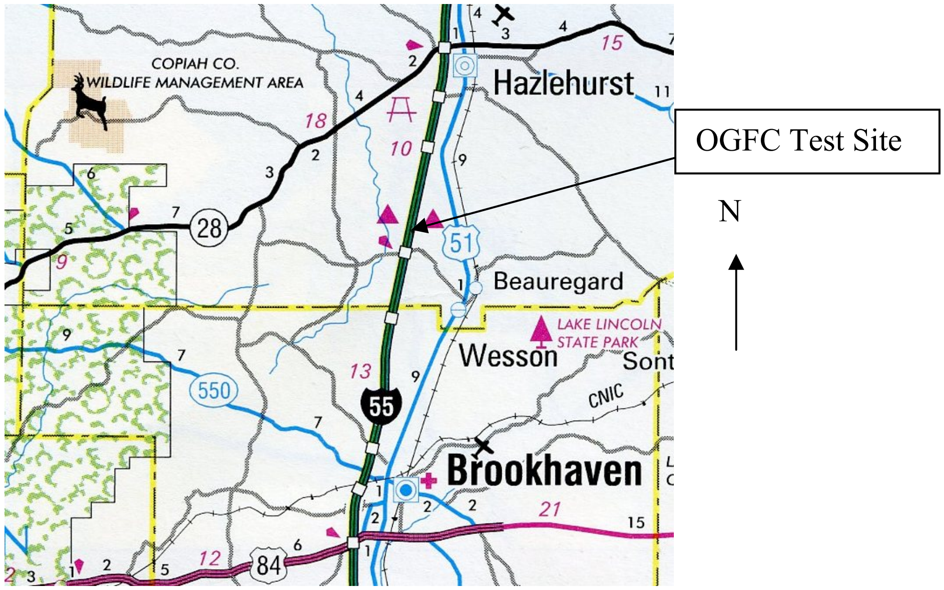

Figure 1 Site Map for I-55 OGFC Test Section (from MDOT Official Highway Map)

The current research project was initiated to observe if the OGFC test section could sustain significant traffic and maintain an adequate level of in situ permeability.

CHAPTER 2

LITERATURE REVIEW

OGFC Functional Characteristics

The concept of OGFC in terms of its function has evolved since the 1970s. White (1976b) outlined OGFC functions as:

1. *High internal voids.*
    a. *Provides internal pressure relief channels.*
    b. *Provides flow channels for internal drainage of surface water.*
    c. *Provides temporary storage of a small amount of surface water.*
2. *Coarse surface macro-texture.*
    a. *Provides pressure relief channels on the surface.*
    b. *Provides flow channels for surface water.*
    c. *Provides, in general, tire-pavement contact above surface water film.*

White also recorded unreported temperature measurements showing a lower temperature profile at the same depth under an OGFC. This was postulated to be the result of the high, connected air voids of the OGFC.

On dense pavement surfaces, spray caused by passing vehicles during or after rain events results in poor visibility. An OGFC will significantly reduce spray and increase visibility as reported by Szatkowski and Brown (1976). A number of state departments of transportation including MDOT have photographic evidence of this benefit.

An OGFC can reduce vehicular tire and mechanical noise. Harland (1974) indicated a reduction in noise of 6-8 dBA when compared to a dense asphalt surface. In Europe, the noise reduction feature of OGFC is considered real and is a surface type widely required in urban areas. Europeans have continued research on OGFC, evolving a two layer OGFC system that has increased noise reduction capabilities but also does not clog as readily with sediment (Kandhal 2004). On the other hand, the Federal Highway

Administration (1995) has not proactively adopted OGFC for noise reduction. In fact, as stated:

> *"Studies have shown open-graded asphalt pavement can initially produce a benefit of 2-4 dBA reduction in noise levels. However, within a short time period (approximately 6-12 months), any noise reduction benefit is lost when the voids fill up and the aggregate becomes polished. The use of specific pavement types or surface textures must not be considered as a noise abatement measure."*

Fuel, oil, hydraulic fluid, and grease are fluids that can drip from vehicles on to pavement surfaces. As indicated by Barrett and Stanard (2008), OGFC or porous friction course (PFC) has the ability to mitigate some pollutants that run off dense pavement surfaces. By sampling and testing runoff before and after construction of an OGFC surface suspended solids and metals were significantly lowered in runoff from the OGFC.

Other attributes of OGFC are improved pavement marking visibility and reduced light reflection compared to dense graded pavement surfaces. The improved pavement marking visibility has an increased cost because more material is required to cover the OGFC macro texture. Reduced light reflectivity occurs because OGFC essentially eliminates the surface water film that reflects the light.

OGFC Mixture Design

Open graded friction courses are subject to the severest effects of traffic, climate, and snow and ice removal operations. At the same time the OGFC layer is thin, approximately 3/4in to 1 and 1/4in, and has a small range in aggregate particle sizes. Performance of OGFC depends in large part on the binder, aggregate quality, and additives. In dense graded mixtures, fines combine with the binder to form a matrix that encapsulates the coarse aggregate, establishing mixture integrity. Many early OGFC surfaces were constructed with neat asphalt and without additives. Performance of these OGFC surfaces ranged from bad to good. Bad performance could be categorized as immediate loss of aggregate and failure within weeks. Good performance could be categorized as acceptable performance over two to five years. During this time OGFC permeability was suspect. As a result of the Strategic Highway Research Program (SHRP) and adoption of performance grading (PG) of asphalts, polymer modified binders were accepted and are widely used in all types of hot mix asphalts including OGFC. As with dense graded HMA performance, OGFC performance has benefited from use of polymer modified binder. The basic characteristic of polymer modified binders that improves performance of both dense HMA and OGFC is its higher stiffness (viscosity)

In application of OGFC on highways, agencies have generally applied the same aggregate quality requirements as those for dense graded HMAs. There have been restrictions on some aggregates often based on experience with specific aggregates in HMA. These aggregates have been restricted or their use limited by blending with other aggregates. Specific problems such as stripping are treated conventionally with hydrated lime or liquid anti-stripping agents. Highway agencies have not changed toughness or durability requirements such as Los Angles abrasion, typically 40 to 50 percent. On the other hand OGFC (PFC) aggregate Los Angles abrasion for airports was reduced from 40 to 25 (White 1975).

The overall concept of determining OGFC design binder content is to provide enough binder to coat the aggregate with a thick enough film to hold aggregates in place, as well as have some binder drainage to the underlying surface during construction to bond the OGFC to that surface. In the US, focused efforts on developing mix design methods and understanding OGFC/PFC characteristics were conducted for highways by Smith, et al (1974) and for airports by White (1975, 1976a). The current MDOT OGFC specification including mixture requirements (Mississippi Department of Transportation 2005) is based on research by Robinson (2005).

Both the Federal Highway Administration (FHWA) (Smith, et al 1974) and the Federal Aviation Administration (FAA) (White 1975) use the same formula (Percent Asphalt = $2.0\ K_c + 4.0$) to estimate design binder content. The constant, K_c, is determined with ASTM D 5148, Standard Test Method for Centrifuge Kerosene Equivalent. For the FAA method other criteria includes significant asphalt drain down to the bottom of a glass pie plate and a 1000ml/min minimum permeability discussed below. At the time of research, the FAA method included an alternate method of estimating the binder content based on aggregate specific gravity. The current MDOT method uses aggregate specific gravity to determine minimum binder content. Other criteria are also applied as shown in Table 1.

Table 2 MDOT OGFC Criteria

Property	MDOT Test Method	Criteria
Minimum Air Voids, %	MT-83	≥15%
Ratio of Compacted Mix Coarse Aggregate Void to Dry Rodded Coarse Aggregate Voids	MT-83	< 1.0
Draindown	MT-82	< 0.3
Laboratory Permeability	MT-84	≥ 30ml/day
Unaged Abrasion of Compacted Mixture	MT-85	≤ 30%
Aged Abrasion of Compacted Mixture	MT-85	≤ 40%

Laboratory compaction and bulk density determination vary between the methods. The FHWA utilized vibratory compaction (refusal), FAA utilized Marshall compaction (10 blows on one side) and MDOT utilizes Superpave gyratory compaction (N_{design} = 50). The FAA compaction produces a six inch diameter specimen with a ¾in OGFC/PFC layer compacted on a previously compacted dense HMA core. Since providing and maintaining surface permeability is the major function of OGFC/PFC, the Marshall compaction effort was based on achieving a target permeability. Because of the knobby OGFC/PFC specimen surface and large, connected air voids; bulk density and air voids depend on the method used in determining specimen volume. The two methods with better approximation of volume are:

1. Calculated volume from measured height and diameter (FAA).
2. CorLok vacuum chamber device (MDOT).

The Corlok device provides a more consistent but slightly lower volume than the calculated volume (Robinson 2005).

OGFC Permeability

The Mississippi Department of Transportation measures OGFC permeability in the laboratory using MT 84, Permeability of Open Graded Friction Course Asphalt

Mixtures (MDOT 2005). This is a laboratory test and measures falling head permeability through the height of a compacted specimen. White (1975, 1976a) developed a falling head permeability test to evaluate OGFC/PFC in the laboratory as well as on in situ pavements. In the test, laboratory permeability is conducted on specimens six inches in diameter consisting of a dense core capped with a compacted OGFC/PFC layer. Base of the falling head stand pipe is four inches in diameter and when centered on the core, water is forced to flow horizontally and radial but emerging around the base perimeter. This configuration is similar to that of water flowing from beneath a tire. In the permeability tests on in situ pavements, the same type of flow was observed. In fact, six inch diameter cores taken from pavements and tested in the laboratory had permeability equivalent to the in situ pavement permeability. There is a foam seal between the base and pavement surface. The test is sensitive to surcharge load on the top of the standpipe and a standard 100 lb surcharge was adopted for the test, both in the laboratory and in the field.

Standiford, et al (1985) evaluated several devices to measure PFC permeability. One of the devices was the one developed by White (1975, 1976a). This study was conducted for the FAA and US Air Force (USAF). The devices were categorized as static (hydraulic loadings approximately ≤40mph) or dynamic (hydrodynamic pressure range). Devices included air and water as the percolating fluid. Evaluation was based on:

1. *Type of seal used at the equipment-pavement surface.*
2. *Comparison of the device to some standard.*
3. *Repeatability of the testing device data.*
4. *Ease of equipment use.*
5. *Portability for field use.*

The study recommended the falling head device developed by White (1975) for both laboratory and field permeability testing of OGFC/PFC pavement surfaces. This is the device fabricated to evaluate permeability of the I-55 OGFC test section. A view of the falling head device being used for current in situ permeability measurements is shown in Figure 2. The standpipe dimensions are shown in Figure 3. The rubber gasket used on the bottom of the current standpipe is neoprene foam rubber, one-quarter inch thick. It has a textured finish on one side and an acrylic adhesive on the other side. The foam rubber meets ASTM D1056, 1C1 and 1C2 and has a Firmness (25% deflection) of 5-9psi, Tensile Strength of 85psi, Stretch Limit of 275% and Density of 31-39pcf.

Falling head permeability has been expressed in terms of time for head to fall (seconds) between the 10 inch and 5 inch marks on the standpipe. Alternatively, the permeability can be expressed in ml per minute. This is the rate of fall for the column of water in the 2 inch inside diameter standpipe. The falling head permeability is given by:

$$Falling\ Head\ Permeability\,(ml/\mathrm{min}) = \frac{\pi d^2 h}{4x}\frac{in^3}{\mathrm{sec}}16.387\frac{ml}{in^3}60\frac{\mathrm{sec}}{\mathrm{min}}$$

where d = standpipe inside diameter (inches)

h = falling water column height (inches)

x = time to fall (seconds)

Figure 2 OGC Falling Head Permeability Test

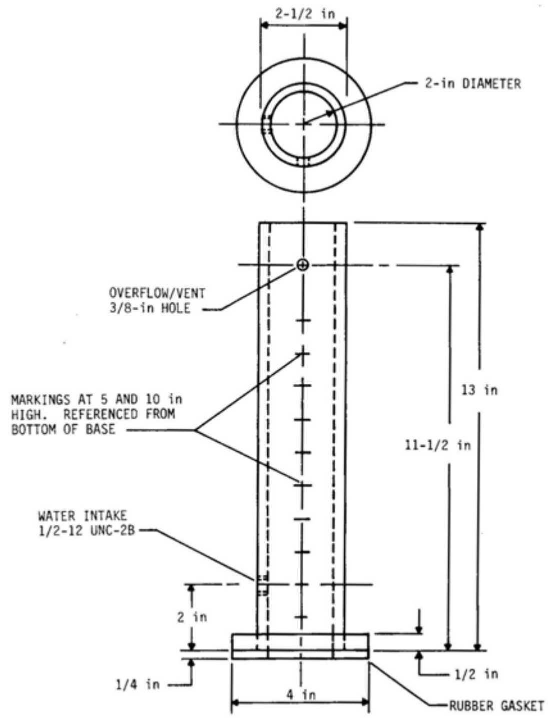

Figure 3 Permeability Standpipe (White, 1976a)

Open graded friction course permeability criteria suggested by White (1976a) was 1000 ml per minute or more which translates to about 15 seconds or less for time of the water level to fall from 10 to 5 inches.

CHAPTER 3

MATERIALS AND TEST SECTION CONSTRUCTION

The OGFC test section location is on I-55 south of Jackson, MS, between Hazlehurst and Brookhaven. General location of the site is shown in Figure 1. The section was constructed in the spring and early summer of 2007. In situ permeability testing was initiated approximately six months after construction and continued periodically as shown in Table 2.

Table 3 Schedule of OGFC Permeability Testing

Fall 2007
Spring 2008
Fall 2008
Spring 2009
Fall 2009

Goals of the periodic testing were to capture any effects of summer and winter traffic and to conduct testing long enough to determine any OGFC deterioration or change in permeability.

The OGFC consists of a one mile section in both the south and north bound driving and passing lanes of the interstate. Prior to the initial permeability tests, test locations were marked at approximately 0.1 mile increments on each side of the interstate. The locations were marked on the shoulder with spray paint. These markings were used to approximate locations for permeability tests in both travel and passing lanes.

OGFC Test Section Mixture Design

Table 3 shows the laboratory work sheet for the OGFC mix design.

Table 4 Mix Design Work Sheet (After MDOT)

TMD-042 MISSISSIPPI DEPARTMENT OF TRANSPORTATION
Rev. 12/2/04

MDOT Mix No. **Producer:**
Design Specification: 907-402-1 **Designer:**
Date 5/2/2007
Type Mix OGFC 9.5mm

TYPE	-1/2"	#8	CRUSHED	AG LIME	HL	#N/A	#N/A	AGG BLEND	JOB MIX	SPEC DESIGN RANGE
MTL	CR GR	LST	FINES	0	0	#N/A	#N/A			
AGG				0	0	0	0			
SOURCE						0	0			
% USED	50	38	6	5	1	0	0	% PASSING	% PASSING	
1.5"/37.5mm	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0	100	
1.0"/25.0mm	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0	100	
3/4"/19.0mm	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0	100	
1/2"/12.5mm	100.0	100.0	100.0	100.0	100.0	0.0	0.0	100.0	100	100
3/8"/9.5mm	95.5	98.7	100.0	100.0	100.0	0.0	0.0	97.3	97	90-100
#4/4.75mm	10.6	34.4	90.2	100.0	100.0	0.0	0.0	29.8	30	15-30
#8/2.36mm	3.2	8.3	57.7	98.9	100.0	0.0	0.0	14.2	14	10-20
#16/1.18mm	2.0	6.8	32.6	81.9	100.0	0.0	0.0	10.6	11	
#30/.600mm	1.3	4.2	18.2	63.9	100.0	0.0	0.0	7.5	8	
#50/.300mm	1.2	3.8	9.1	45.1	99.0	0.0	0.0	5.8	6	
#100/.150mm	1.1	3.5	5.8	33.2	98.6	0.0	0.0	4.9	5	
#200/.075mm	0.7	3.3	3.9	25.6	98.0	0.0	0.0	4.1	4.1	2.0-5.0
								% AC	6.20	
Gsa	2.610	2.744	2.648	2.724	2.320	0.000	0.000	2.664	MIX TEMP	322
Gsb	2.518	2.697	2.526	2.588	2.320	0.000	0.000	2.585	VOIDS	18.9
%CR +#4	96.1	100	100	0	0	0	0	97.5	VMA	0.0
HUMPRATIO								34.1	VFA	0.0
% CLAY	0	0	0	0	0	0	0	0.0	Gmm	2.373
PI -#4 MTL	0	0	0	0	0	0	0		Gsb	2.585
% ABS MOIST	1.40	0.64	1.82	1.93	0.00	0.00	0.00	1.15	Pba (mix)	0.15
	Comp. Temp.	300-310 (F)	Mixing Temp.	320-340 (F)		% Gmm @ Ni	#DIV/0!		Pbe	6.05
ANTI STRIP	NONE	RATE =	0.0	% by weight of AC		% Gmm @ Nm	0		D/B	0.68
AC SOURCE	ERGON	TSR =	98.0	F/E =	0.0	FAA =	0.0		Gse	2.596
AC TYPE	PG76-22		Ni N/A	Nd 50	Nm N/A				Gb	1.033

REMARKS: %FIBER: 0.4
% Rap Used = 0.0 **% AC (RAP) =** 0.0 **% AC (Add) =** 6.20 **%AC (Total) =** 6.2
Stripping (MT-59)= <5% 0
The percentage of ERGON PG76-22 asphalt cement used with the above blend of mineral aggregate for the course is 6.2.

The OGFC is designated as a 9.5 OGFC mixture. Target gradation band is in the furthest right column in Table 3. Mineral aggregate blended to meet the specified gradation included crushed gravel, limestone, crushed fines and Ag lime. In addition, the blend included one percent hydrated lime. The aggregate blend and target job mix blend are in the two columns preceding the specified gradation. The design binder content was 6.2

percent of paving grade (PG) 76-22 asphalt. Fiber was added in the amount of 0.4 percent.

Gradation tests for quality construction control (QC) are shown in Table 4.

Table 5 QC Gradations (After MDOT)

	JOB MIX	QC Number 1	QC Number 2
	% PASSING	% PASSING	% PASSING
1.5"/37.5mm	100	100	100
1.0"/25.0mm	100	100	100
3/4"/19.0mm	100	100	100
1/2"/12.5mm	100	100	100
3/8"/9.5mm	97	96.6	95
#4/4.75mm	30	28	29.8
#8/2.36mm	14	12.2	12.4
#16/1.18mm	11	--	--
#30/.600mm	8	6.2	6.3
#50/.300mm	6	4.8	5
#100/.150mm	5	--	--
#200/.075mm	4.1	3.2	3.6

OGFC Construction

Figures 4, 5 and 6 show views during OGFC construction. In Figure 4, there appears to be a anomaly in the OGFC surface at the junctures of the laydown machine screed and the screed extensions. This anomaly exists on both sides of the lane. The anomalies are still visible after one pass of the roller in Figure 5 but are hard to discern in Figure 6 after rolling is complete. This type of anomaly in any type of HMA construction will manifest itself with time.

Figure 4 OGFC Laydown (After MDOT)

Figure 5 Rolling OGFC (After MDOT)

Figure 6 After Rolling (After MDOT)

CHAPTER 4

PERMEABILITY APPARATUS AND FIELD TESTING

Permeability Apparatus

In preparation for field permeability testing, the falling head device detailed in Figure 3 was fabricated. The only change to the original standpipe design is that a quick disconnect fitting was added to facilitate connecting and disconnecting the water supply line. However, the water supply system and reaction frame mounted on the back of the field vehicle were redesigned.

The water supply system includes an 80 gallon water tank, 5gpm pump, solenoid valve, and wireless receiver. Figure 7 shows the water tank and controls mounted in the rear of a van used for field testing. The 80 gallons of water was adequate for about three to four hours of testing. The tank was fabricated from steel and tended to rust internally which affected the appearance of water during the permeability test. Recommendations are that a plastic tank be used instead of the steel tank. Pump and controls are shown in Figure 8. Turning the pump on and off to fill up the standpipe was accomplished with a wireless switch. A digital stopwatch was used to determine time for the water level to fall between timing marks.

The reaction frame mounted on the rear bumper is shown in Figure 9. Other components of the field apparatus in addition to the standpipe include a compression load ring and an integral bracket and jack. The frame is designed with extensions on each end and such that the bracket can slide from one end to the other. Details on the frame and fixtures are in drawings in Appendix A. Figures 10 and 11 show additional views of the apparatus and testing. Rust in the water is obvious.

Field Permeability Testing

The Mississippi Department of Transportation provided traffic control during permeability testing. For reference, permeability measurements were made in the direction of traffic in driving and passing lanes. Both driving lanes were tested and then both passing lanes were tested. At each of the test locations, the van was stopped with the

Figure 7 Water Tank

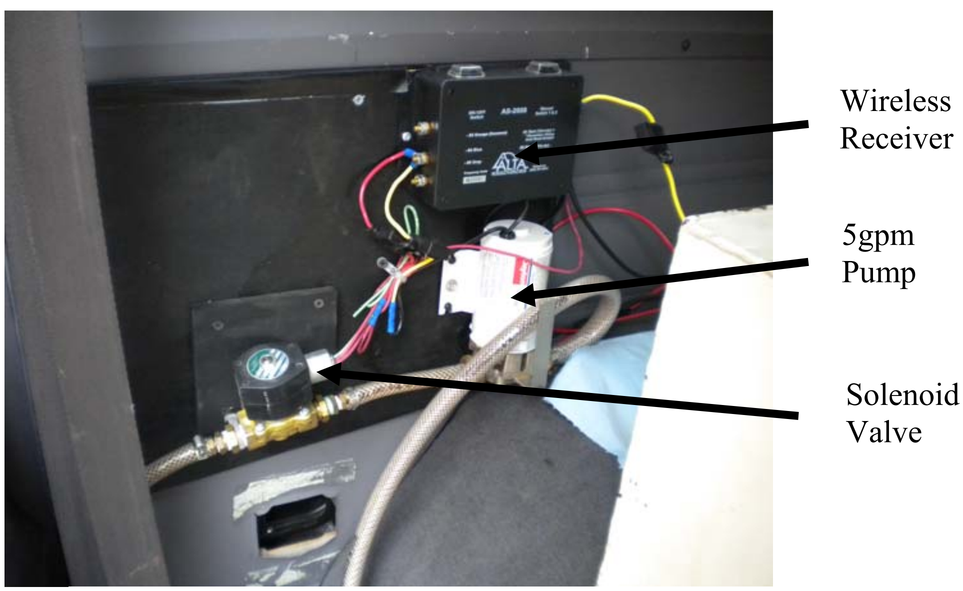

Figure 8 Water Supply Pump and Controls

Figure 9 General View of Apparatus with Extension toward Pavement Centerline

Figure 10 Testing on Outside Lane, Between Wheel Path

Figure 11 Test on Inside Lane, Inside Wheel Path

rear mounted frame as a reference to the shoulder location mark. The van was positioned transversely so the permeability test could be conducted in the outside wheel path, between the wheel paths and inside wheel path. Outside wheel path is toward the pavement shoulder (outside or inside shoulder) and the inside wheel path is toward the pavement centerline. After the standpipe was positioned and the 100 lb. surcharge load applied, the permeability test was repeated three times at each test position. Individual tests and the average of the three are reported in Appendix B.

CHAPTER 5

OGFC PERFORMANCE AND PERMEABILITY RESULTS

OGFC Test Section Performance

After two and one-half years the OGFC on I-55 South is performing well. There is no general raveling of the surface or in wheel paths. Figures 12 and 13 show representative surface conditions. Occasional marks are noted from something scarring the surface such as a piece of equipment or vehicle. There is no evidence of excess asphalt from high asphalt content, segregation or drain down. The longitudinal anomalies (cracks) discussed relative to Figures 4, 5 and 6 are clearly visibly in Figures 12 and 13. This crack exists on both sides of the lane. Crack severity varies and is shown in a more pronounced state in Figure 14. There is limited spalling and raveling along the crack. The polymer modified asphalt is beneficial in this regard. In Figure 12 there is a pattern parallel and about 8 inches from the longitudinal crack toward the pavement centerline that may be the effect of early traffic picking up some of the surface or a crack developing. The OGFC surface is performing well during inclement weather. Figure 15, obtained from MDOT, shows the transition from the OGFC surface to a dense HMA surface.

Permeability Results

Results of permeability tests in approximately six month increments of time over a two and one-half year period are given in tables in Appendix B. These data indicate replicate permeability tests without moving the standpipe are reproducible. The data shows permeability can vary from point to point both transversely and longitudinally. To

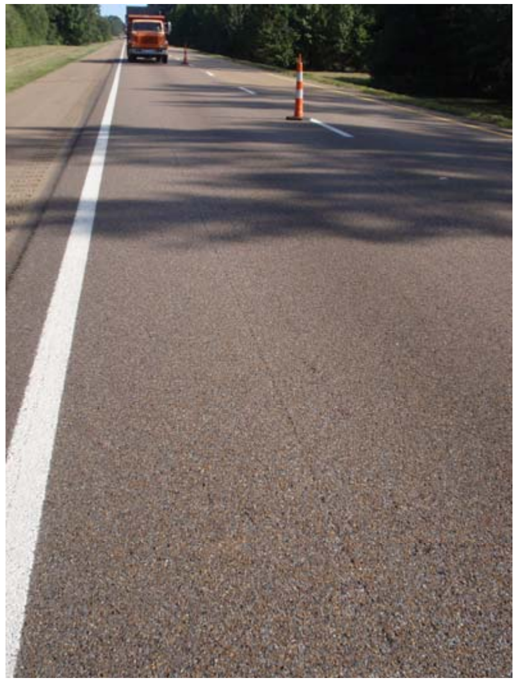

Figure 12 General Surface Condition and Longitudinal Crack Relative to Shoulder

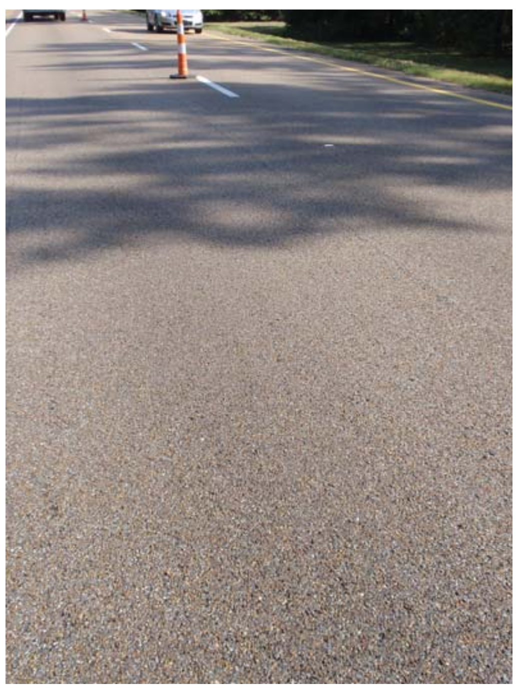

Figure 13 General Surface Condition and Longitudinal Crack Relative to Pavement Centerline

Figure 14 Severe Longitudinal Crack

Figure 15 Transition From OGFC to Dense HMA During Rain Event (After MDOT)

examine permeability over the period of observations, plots are provided of average permeability for each lane and as a summary of all lanes in Figures 16 through 21. These data show permeability variability during the two and one-half years the OGFC has been in service. In Figure 21, the long term trend (based on average of all lanes) indicates moderate decrease in permeability. Another perspective of performance is provided in Figures 22 and 23. The south end of the test section on both sides of the interstate is at a higher elevation than the north end. In these two figures, permeability for driving and passing lanes, respectively, are plotted by station and with the stationing starting from the southern end on both sides of the interstate. These data are permabilities from the last set of measurements for the outside wheel path of both the driving and passing lanes. They represent the highest volume and longest period of traffic as well as higher load from eccentricity caused by the pavements cross slope. Of the four lanes, the north bound driving lane exhibits more variability from point to point. This lane also has incidences of the lowest permeability compared to the other lanes. It could be there is an effect of heavy trucks moving north from the I-10 corridor.

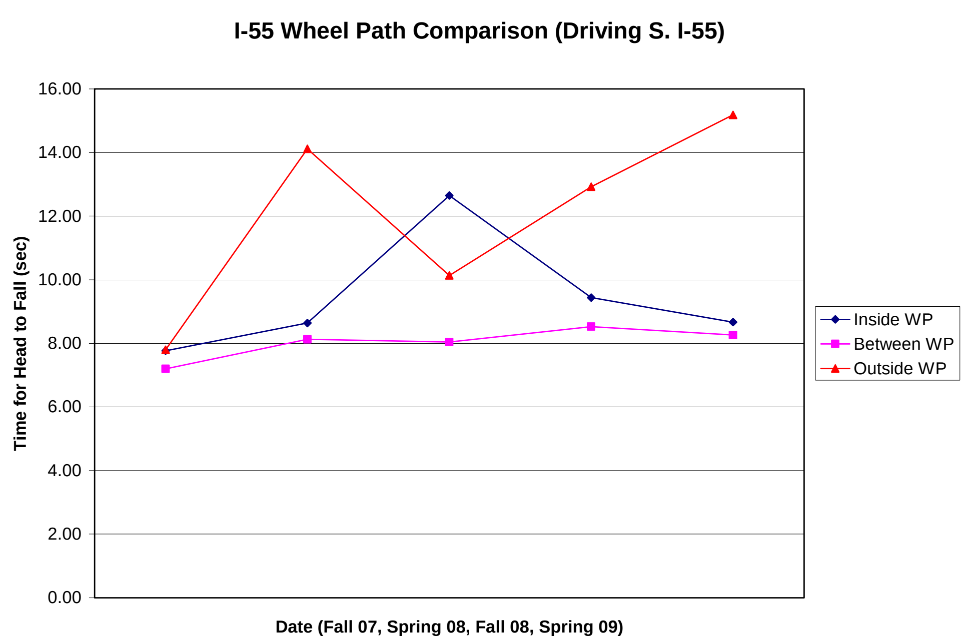

Figure 16 Average Permeability in Driving, South Bound Lane

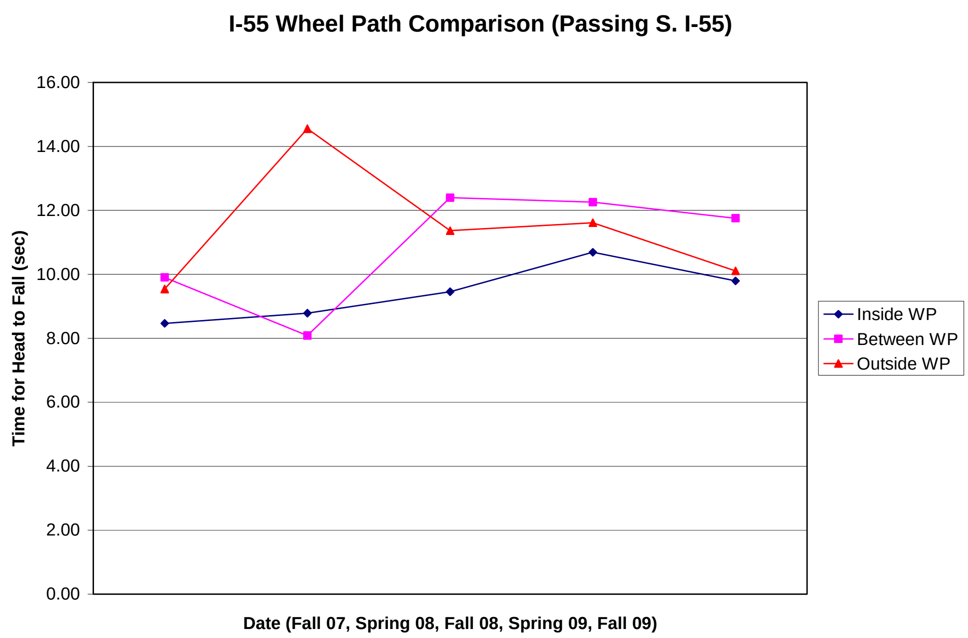

Figure 17 Average Permeability in Passing, South Bound Lane

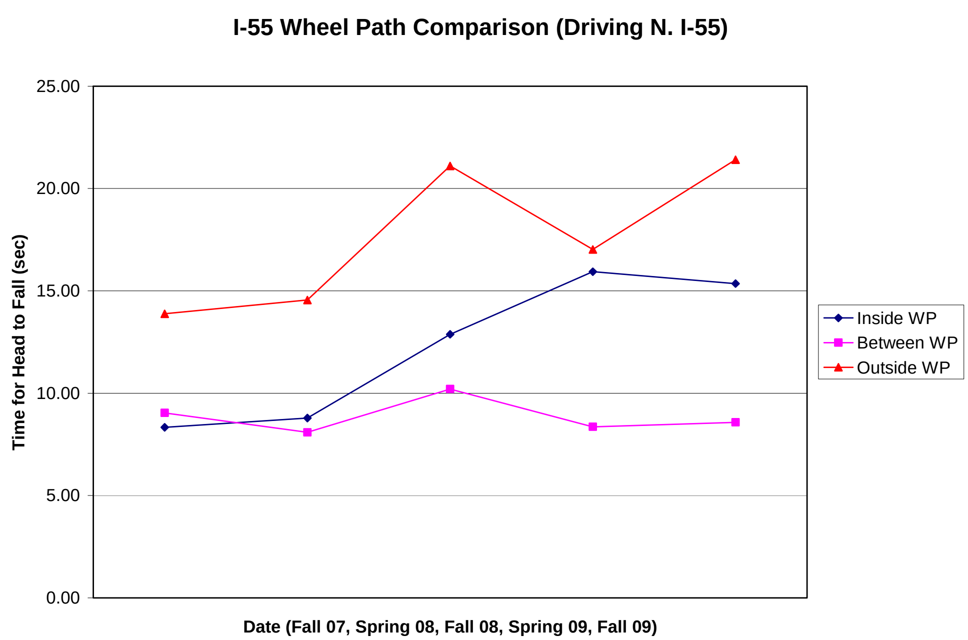

Figure 18 Average Permeability in Driving, North Bound Lane

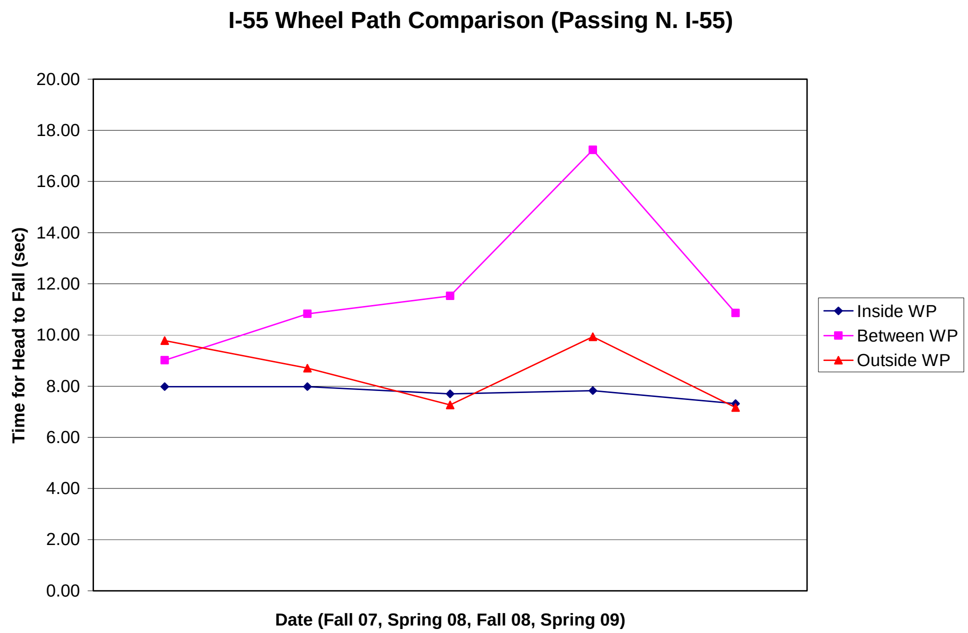

Figure 19 Average Permeability in Passing, North Bound Lane

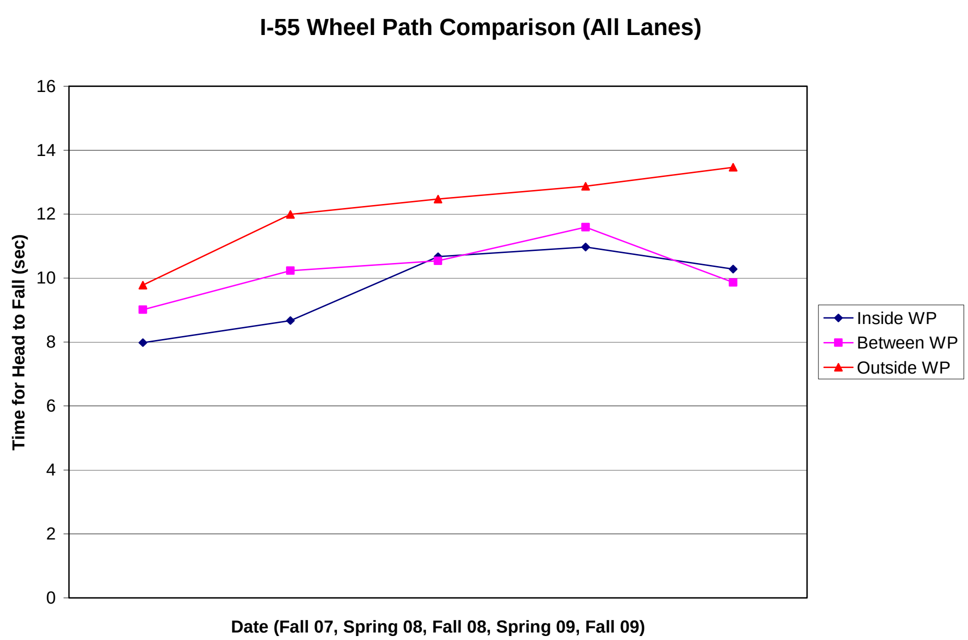

Figure 20 Average Permeability for All Lanes

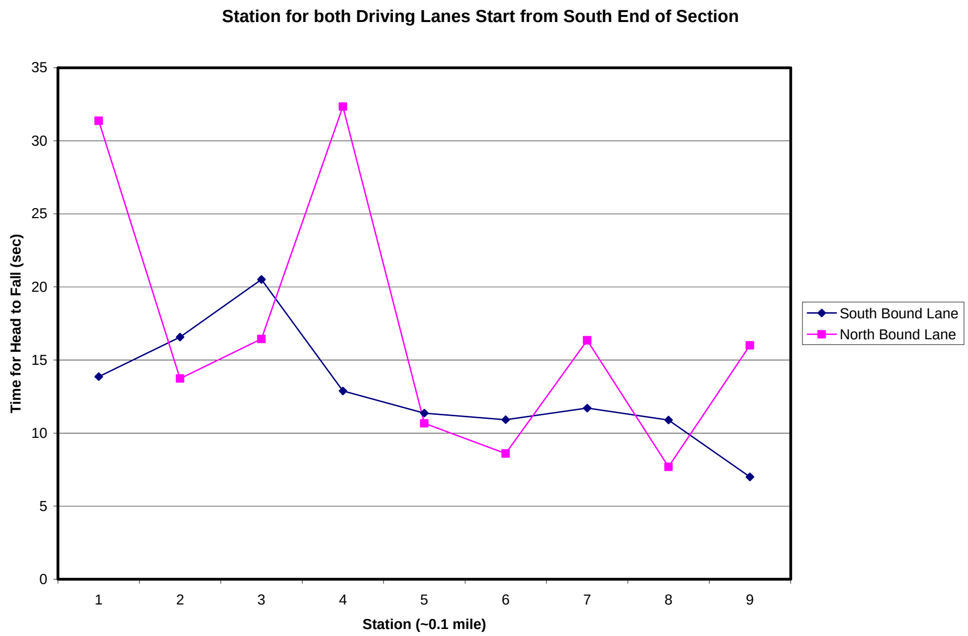

Figure 21 Fall 2009 Permeability for Driving Lanes, Stationing Starting from South End of Section on Both Sides

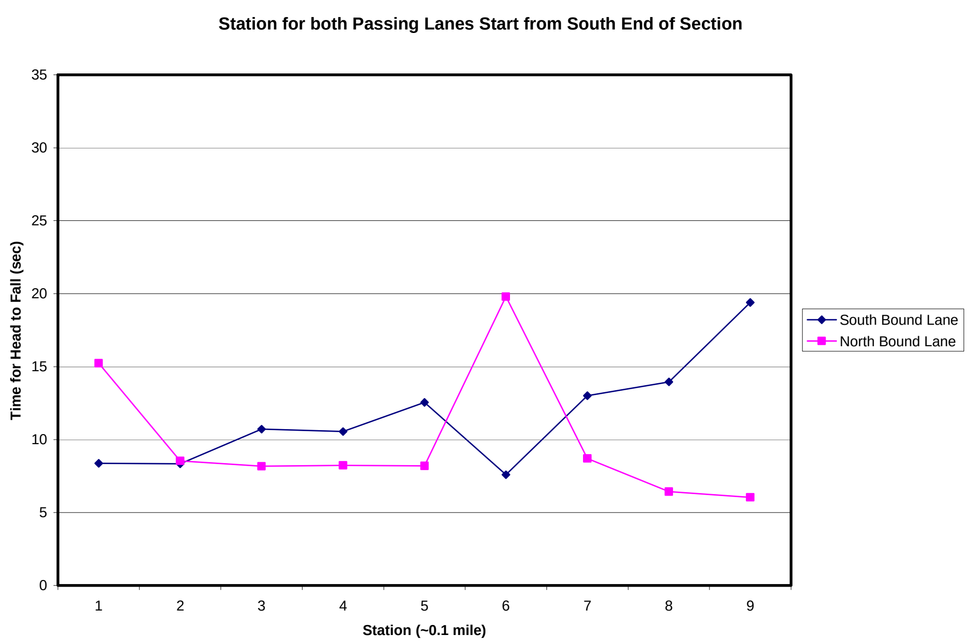

Figure 22 Fall 2009 Permeability for Passing Lanes, Stationing Starting from South End of Section on Both Sides

CHAPTER 5

CONCLUSIONS

The OGFC test section constructed on I-55 in Copiah County during the spring/summer of 2007 has provided an excellent basis for evaluating OGFC performance built with current materials, mix design methods and construction practice. Open graded friction courses have a number of beneficial attributes such as:

1. Inhibits hydroplaning,
2. Decreases tire and vehicular spray,
3. Decreases noise,
4. Decreases temperature in underlying pavement,
5. Captures suspended solids and metals that drop in fluids from passing vehicles,
6. Improves pavement marking visibility, and
7. When dark, greatly reduces light reflection compared to dense pavements with a covering water film.

The current research project results are positive in that it has been shown OGFC can be successfully designed using local Mississippi aggregates and polymer modified asphalt. In service, the resulting OGFC can carry significant traffic while maintaining an adequate level of in situ permeability. The OGFC did not exhibit loss of aggregate through surface raveling or significant spalling along cracks generated at the juncture of the laydown machine screed and screed extensions during construction.

Both the falling head permeability device and the redesigned vehicle mounted reaction frame worked well. It is recommended a plastic tank be used in lieu of the steel tank because of the steel tank rusting. Extensions on the frame allow permeability tests to be conducted across a full lane width. Detail drawings of the frame are provided in an appendix of the report. Replicate tests show the falling head device has excellent repeatability. The device is also recommended for laboratory testing.

It is recommended that MDOT and industry address the issue of the laydown machine screed and screed extension junctures to alleviate the longitudinal cracking in OGFC. There may be a benefit to dense HMA as well.

Mississippi Department of Transportation may want to follow the condition of the OGFC test section as well as conduct permeability tests on a yearly basis.

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APPENDIX A

DRAWINGS OF FRAME FOR FIELD PERMEABILITY APPARATUS

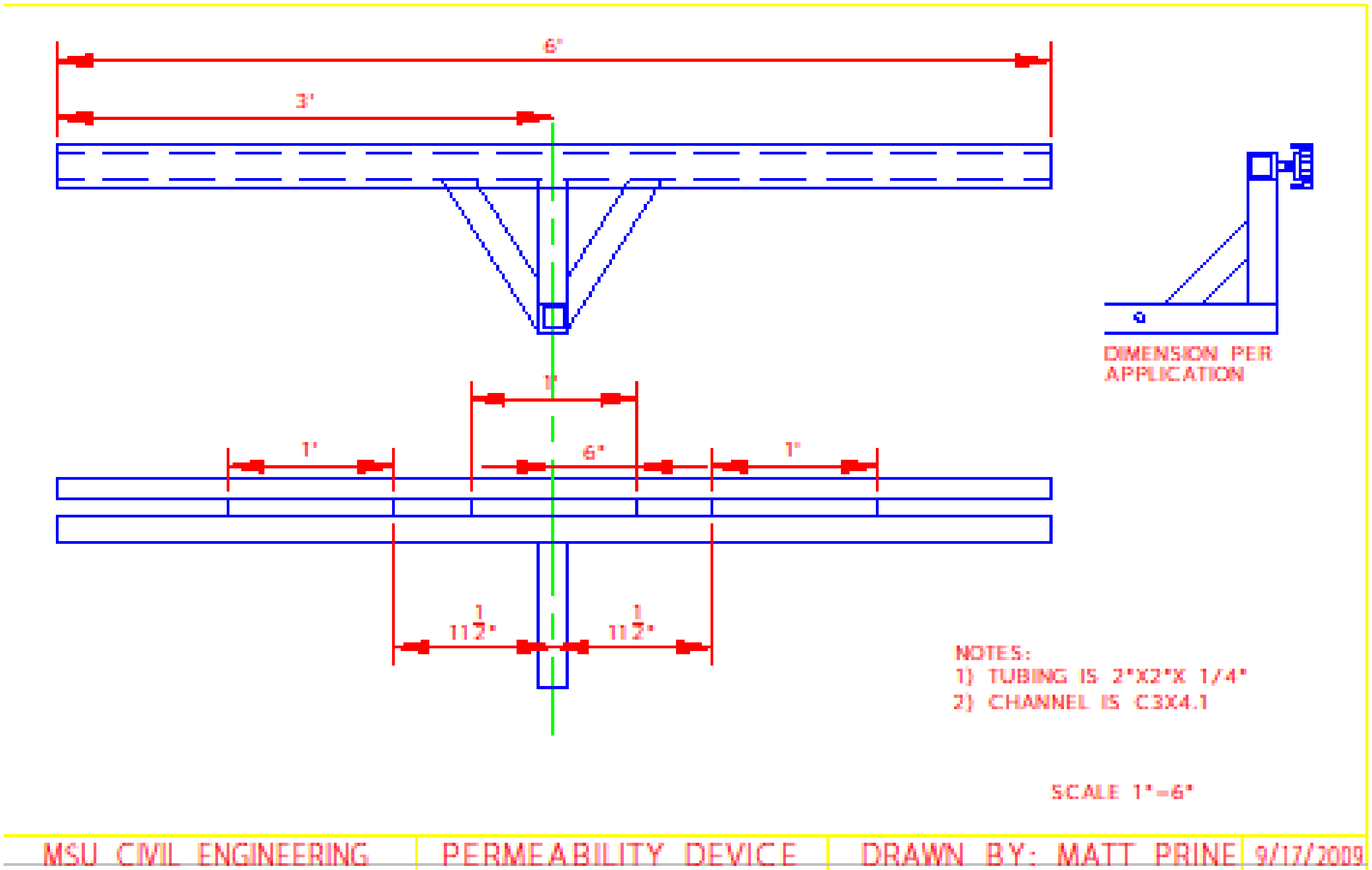

Figure A 1 Main Frame

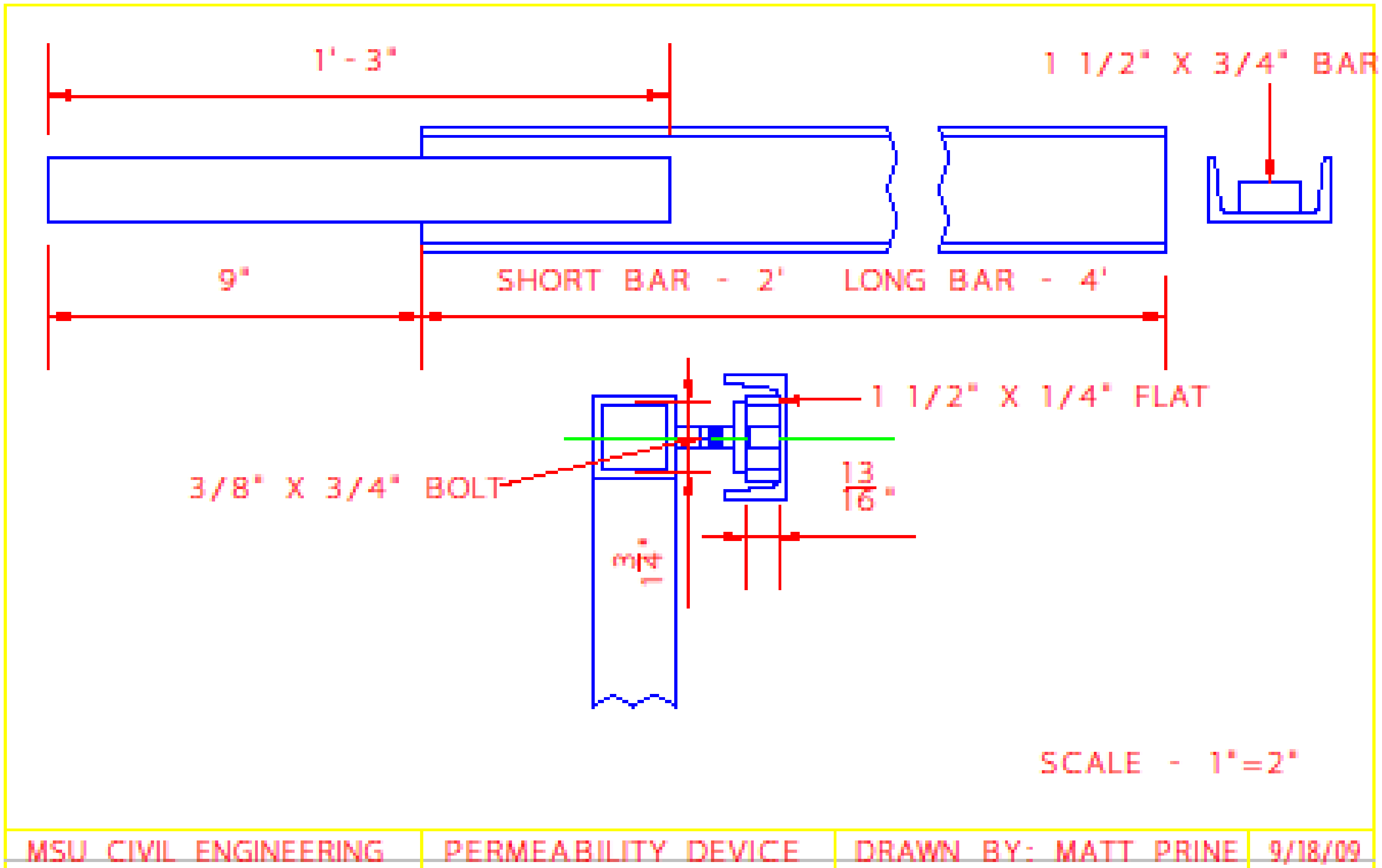

Figure A 2 Frame Extensions

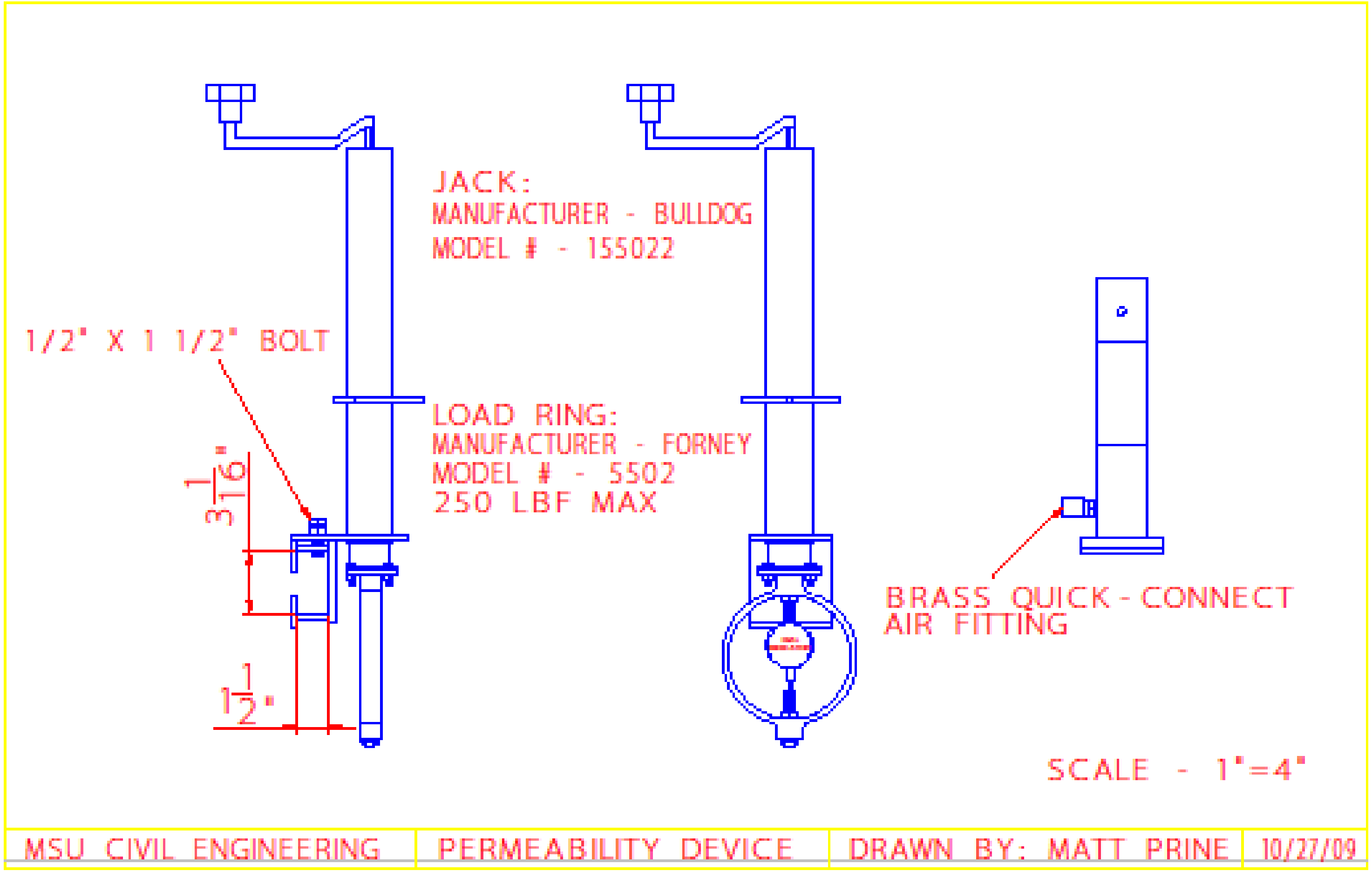

Figure A 3 Integral Jack and Bracket and Standpipe Fitting

Appendix B

Permeability Test Results

Table B-1 Nov 27, 2007. Lane: Driving S. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	5.97	5.93	5.82	5.91	4.73	4.71	4.48	4.64	8.82	9.14	8.58	8.85
2	5.09	4.87	5.03	5.00	4.20	4.11	4.12	4.14	6.90	6.81	6.85	6.85
3	6.00	5.97	5.76	5.91	5.37	5.34	5.48	5.40	8.39	8.20	8.32	8.30
4	6.44	6.39	6.51	6.45	8.16	8.26	8.13	8.18	11.51	11.25	11.17	11.31
5	6.68	7.03	7.39	7.03	5.90	5.84	5.88	5.87	4.77	4.74	4.98	4.83
6	8.55	8.57	8.79	8.64	7.18	7.34	7.52	7.35	5.93	5.82	5.54	5.76
7	8.96	9.14	9.30	9.13	7.49	7.30	7.35	7.38	6.58	6.63	6.57	6.59
8	10.55	10.30	10.35	10.40	11.10	10.91	10.94	10.98	7.27	7.39	7.82	7.49
9	10.45	10.33	10.10	10.29	7.79	7.73	7.74	7.75	8.63	8.73	8.67	8.68
10	9.06	8.70	8.99	8.92	9.79	10.05	10.99	10.28	9.36	9.12	9.47	9.32
Sum				77.67				71.98				77.99
Average				7.77				7.20				7.80

Table B-2 Nov 27, 2007. Lane: Passing S. I-55 .

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
2	11.65	11.82	12.03	11.83	7.72	7.73	7.74	7.73	11.51	11.84	11.60	11.65
3	15.55	15.64	15.84	15.68	10.73	10.91	10.74	10.79	11.95	11.89	12.16	12.00
4	8.50	8.55	8.45	8.50	5.33	5.29	5.30	5.31	10.89	10.80	11.25	10.98
5	4.67	4.60	4.61	4.63	4.74	4.69	4.92	4.78	4.79	4.77	4.81	4.79
6	6.88	7.06	7.24	7.06	10.10	10.45	10.48	10.34	9.26	9.28	9.42	9.32
7	7.63	7.53	7.77	7.64	15.91	16.08	16.41	16.13	7.89	8.11	8.05	8.02
8	6.61	6.45	6.55	6.54	15.27	15.68	16.12	15.69	8.97	9.14	9.32	9.14
9	6.11	6.47	6.17	6.25	8.54	8.72	8.81	8.69	11.51	11.57	11.90	11.66
10	8.34	7.87	8.06	8.09	9.77	9.59	9.60	9.65	8.30	8.31	8.24	8.28
Sum				76.22				89.12				85.84
Average				8.47				9.90				9.54

Table B-3 Nov 27, 2007. Lane: Driving N. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	9.15	9.41	9.41	9.32	7.35	7.47	7.28	7.37	22.66	22.84	22.61	22.70
2	10.43	10.43	10.50	10.45	6.75	6.76	6.78	6.76	19.65	19.34	19.40	19.46
3	11.49	11.23	11.23	11.32	7.64	7.73	7.70	7.69	11.59	11.62	11.66	11.62
4	11.11	11.39	11.44	11.31	14.17	14.26	14.21	14.21	10.16	10.28	10.30	10.25
5	7.60	7.49	7.48	7.52	8.59	8.45	8.32	8.45	8.72	8.82	8.91	8.82
6	6.81	6.77	6.98	6.85	11.12	11.05	11.11	11.09	10.21	10.38	10.16	10.25
7	7.08	7.10	7.17	7.12	10.59	10.83	10.79	10.74	16.17	16.01	16.10	16.09
8	4.58	4.75	4.69	4.67	8.89	8.58	8.69	8.72	7.28	7.38	7.44	7.37
9	6.36	6.21	6.55	6.37	6.37	6.13	6.41	6.30	18.23	18.40	18.31	18.31
Sum				74.95				81.34				124.88
Average				8.33				9.04				13.88

Table B-4 Nov 27, 2007. Lane: Passing N. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	6.36	6.27	6.23	6.29	24.31	24.76	25.33	24.80	8.59	8.41	8.40	8.47
2	5.86	5.78	5.82	5.82	6.34	6.48	6.54	6.45	6.15	6.20	6.34	6.23
3	6.04	6.23	6.07	6.11	4.63	4.80	4.61	4.68	6.16	6.18	6.16	6.17
4	7.68	7.64	7.53	7.62	11.48	11.62	11.57	11.56	7.67	7.67	7.84	7.73
5	10.17	10.07	10.11	10.12	7.77	7.80	7.79	7.79	8.93	9.01	9.23	9.06
6	11.92	11.94	11.97	11.94	9.38	9.16	9.26	9.27	11.62	11.94	11.37	11.64
7	6.92	7.05	6.88	6.95	12.44	12.35	12.46	12.42	10.03	10.32	10.24	10.20
8	4.70	4.70	4.56	4.65	4.80	4.71	4.74	4.75	4.91	5.06	4.92	4.96
9	6.90	6.74	6.71	6.78	7.43	7.34	7.29	7.35	6.83	6.78	6.90	6.84
Sum				66.28				89.06				71.29
Average				7.36				9.90				7.92

Table B-5 May 13, 2008. Lane: Driving S. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	6.29	6.39	6.27	6.32	4.22	4.16	4.30	4.23	7.09	7.09	6.85	7.01
2	6.81	6.71	6.78	6.77	5.98	5.85	5.87	5.90	7.13	6.96	6.75	6.95
3	7.16	7.34	7.51	7.34	5.79	5.80	6.01	5.87	10.10	10.11	10.10	10.10
4	11.04	10.60	10.63	10.76	7.96	7.80	8.01	7.92	21.41	21.34	21.34	21.36
5	9.20	9.19	9.27	9.22	7.58	7.57	7.41	7.52	11.54	11.43	11.54	11.50
6	8.07	7.97	8.01	8.02	6.60	6.68	6.54	6.61	12.90	12.97	12.84	12.90
7	8.77	8.46	8.53	8.59	8.07	7.48	7.87	7.81	15.04	14.69	14.48	14.74
8	12.38	12.20	12.59	12.39	12.58	12.24	12.27	12.36	32.61	32.02	33.03	32.55
9	7.16	7.10	7.13	7.13	11.93	12.03	11.72	11.89	8.60	8.39	8.71	8.57
10	9.71	9.97	9.97	9.88	11.43	11.02	11.08	11.18	15.21	15.63	15.57	15.47
Sum				86.40				81.28				141.16
Average				8.64				8.13				14.12

Table B-6 May 13, 2008. Lane: Passing S. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
2	9.26	9.23	9.18	9.22	8.77	9.20	9.16	9.04	9.96	10.56	10.71	10.41
3	21.21	19.03	20.64	20.29	16.94	16.09	16.69	16.57	10.28	10.35	10.91	10.51
4	8.01	8.35	8.92	8.43	7.65	8.00	7.77	7.81	9.78	9.76	9.42	9.65
5	10.18	10.26	10.78	10.41	4.16	4.36	4.29	4.27	8.28	8.38	8.65	8.44
6	7.09	7.13	7.22	7.15	14.60	13.36	13.24	13.73	10.45	10.96	10.96	10.79
7	7.30	8.11	8.53	7.98	20.53	23.30	23.86	22.56	8.09	8.67	8.23	8.33
8	7.94	8.21	8.67	8.27	21.58	23.37	19.03	21.33	10.07	10.63	10.64	10.45
9	5.72	5.40	6.12	5.75	9.68	10.42	11.02	10.37	16.90	14.34	15.60	15.61
10	5.80	6.15	6.29	6.08	20.53	17.91	18.79	19.08	10.21	11.08	11.65	10.98
Sum				83.58				124.77				95.17
Average				9.29				13.86				10.57

Table B-7 May 13, 2008. Lane: Driving N. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	13.12	12.73	12.69	12.85	10.20	10.18	10.14	10.17	22.98	22.88	22.53	22.80
2	7.43	7.45	7.62	7.50	6.81	6.78	6.99	6.86	9.61	9.41	9.34	9.45
3	9.81	10.01	10.05	9.96	7.47	7.62	7.45	7.51	18.85	18.36	18.82	18.68
4	10.42	10.49	10.45	10.45	12.06	12.17	12.45	12.23	18.27	18.12	18.08	18.16
5	10.73	10.70	10.66	10.70	8.71	8.51	8.71	8.64	15.04	15.00	14.80	14.95
6	6.85	7.23	6.78	6.95	7.55	7.56	7.41	7.51	11.08	11.15	10.98	11.07
7	7.41	7.20	7.22	7.28	6.32	6.29	6.30	6.30	15.53	15.32	15.35	15.40
8	6.43	6.44	6.39	6.42	5.87	5.73	5.52	5.71	7.20	7.22	7.10	7.17
9	7.02	6.89	6.93	6.95	7.68	8.01	7.83	7.84	13.64	13.12	13.15	13.30
Sum				79.05				72.77				130.98
Average				8.78				8.09				14.55

Table B-8 May 13, 2008. Lane: Passing N. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	8.21	8.63	9.02	8.62	15.46	17.63	18.64	17.24	12.03	13.29	13.88	13.07
2	6.11	6.67	7.06	6.61	7.82	8.53	8.81	8.39	5.48	5.98	6.15	5.87
3	6.29	6.57	6.78	6.55	8.35	8.85	9.44	8.88	5.66	5.45	6.12	5.74
4	8.56	9.37	8.55	8.83	5.77	6.12	6.47	6.12	8.07	8.98	9.13	8.73
5	9.44	9.86	10.56	9.95	20.57	23.20	24.63	22.80	6.99	7.30	7.37	7.22
6	10.81	10.98	11.89	11.23	11.80	11.37	11.36	11.51	16.97	16.27	16.82	16.69
7	8.49	9.20	6.88	8.19	9.93	10.31	10.77	10.34	10.24	10.77	11.36	10.79
8	5.98	6.01	4.56	5.52	5.06	5.17	5.31	5.18	4.08	4.30	4.16	4.18
9	6.00	6.32	6.71	6.34	6.81	6.92	7.17	6.97	5.90	6.08	6.19	6.06
Sum				71.84				97.42				78.34
Average				7.98				10.82				8.70

Table B-9 Nov 5, 2008. Lane: Driving S. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	6.60	6.13	6.25	6.33	6.40	6.40	6.35	6.38	8.28	8.47	8.78	8.51
2	9.41	9.38	9.34	9.38	5.07	5.12	5.12	5.10	6.65	6.90	6.60	6.72
3	7.65	7.44	7.72	7.60	6.47	6.28	6.31	6.35	9.50	9.50	9.44	9.48
4	37.22	36.28	36.50	36.67	9.16	8.78	8.81	8.92	11.78	11.37	11.60	11.58
5	7.78	7.63	7.64	7.68	11.27	11.31	11.53	11.37	9.50	9.40	9.56	9.49
6	7.84	7.88	7.91	7.88	8.06	7.19	7.21	7.49	9.87	9.94	9.81	9.87
7	8.12	8.00	7.97	8.03	7.69	7.78	7.59	7.69	14.47	14.50	14.47	14.48
8	19.12	19.07	18.62	18.94	10.35	10.22	10.07	10.21	12.31	12.32	12.09	12.24
9	8.16	8.06	8.16	8.13	9.06	8.78	8.75	8.86	8.06	6.91	9.08	8.02
10	16.13	16.03	15.44	15.87	8.00	7.98	8.10	8.03	10.84	11.18	10.91	10.98
Sum				126.49				80.40				101.36
Average				12.65				8.04				10.14

Table B-10 Nov 5, 2008. Lane: Passing S. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
2	9.21	9.88	9.94	9.68	10.00	10.50	10.65	10.38	9.71	9.84	10.35	9.97
3	21.82	22.75	23.59	22.72	12.63	13.07	13.97	13.22	8.94	9.31	9.65	9.30
4	7.28	7.63	7.87	7.59	7.75	8.31	8.54	8.20	10.32	10.56	10.97	10.62
5	6.47	6.88	7.03	6.79	5.81	5.38	5.75	5.65	6.44	6.37	6.97	6.59
6	9.50	9.97	10.41	9.96	11.79	12.19	13.12	12.37	13.94	14.01	14.21	14.05
7	7.00	7.41	7.81	7.41	16.78	17.34	18.03	17.38	14.56	15.47	15.34	15.12
8	8.04	8.43	8.97	8.48	14.13	15.22	15.31	14.89	12.09	12.46	13.47	12.67
9	5.97	6.41	6.91	6.43	13.18	13.98	15.53	14.23	12.47	12.72	13.68	12.96
10	5.81	6.00	6.22	6.01	14.94	15.32	15.43	15.23	10.72	11.13	11.13	10.99
Sum				85.07				111.55				102.28
Average				9.45				12.39				11.36

Table B-11 Nov 5, 2008. Lane: Driving N. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	7.84	8.19	8.72	8.25	8.25	8.72	9.22	8.73	26.52	27.72	28.28	27.51
2	16.15	17.18	17.18	16.84	8.44	8.72	8.75	8.64	34.72	36.06	36.88	35.89
3	10.97	12.12	12.53	11.87	8.94	8.34	8.11	8.46	24.56	26.38	26.25	25.73
4	31.78	35.53	38.50	35.27	23.72	27.25	28.50	26.49	14.56	15.28	14.97	14.94
5	13.15	13.87	14.01	13.68	10.84	11.47	11.08	11.13	14.12	14.93	15.53	14.86
6	10.00	10.28	10.59	10.29	7.04	8.16	7.37	7.52	22.31	23.97	24.81	23.70
7	7.35	8.06	8.32	7.91	7.09	7.75	7.77	7.54	21.94	23.59	25.00	23.51
8	5.40	5.47	5.56	5.48	6.79	6.90	6.81	6.83	9.50	9.72	9.77	9.66
9	6.28	6.34	6.37	6.33	6.25	6.59	6.50	6.45	14.09	14.37	14.02	14.16
Sum				115.91				91.79				189.95
Average				12.88				10.20				21.11

Table B-12 Nov 5, 2008. Lane: Passing N. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	8.10	7.40	7.75	7.75	18.04	18.44	18.13	18.20	10.47	10.41	9.97	10.28
2	5.97	5.34	5.78	5.70	10.19	9.91	10.61	10.24	4.72	4.72	4.88	4.77
3	7.09	7.13	7.00	7.07	9.22	10.12	9.54	9.63	6.18	7.03	6.87	6.69
4	6.37	6.47	6.41	6.42	17.59	17.66	17.37	17.54	7.88	8.13	8.00	8.00
5	9.47	9.34	9.31	9.37	11.88	11.72	11.28	11.63	8.22	8.68	8.57	8.49
6	14.81	14.11	14.47	14.46	9.03	9.43	9.57	9.34	9.13	9.38	8.84	9.12
7	8.81	8.25	8.50	8.52	17.68	14.27	14.31	15.42	6.94	6.81	7.13	6.96
8	5.22	5.13	5.13	5.16	5.44	5.53	5.47	5.48	4.47	4.25	4.31	4.34
9	4.94	4.59	4.91	4.81	6.23	6.37	6.15	6.25	6.63	6.72	6.78	6.71
Sum				69.27				103.73				65.37
Average				7.70				11.53				7.26

Table B-13 May 20, 2009. Lane: Driving S. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	5.19	5.56	5.18	5.31	3.78	3.85	3.25	3.63	13.40	13.63	13.46	13.50
2	6.31	6.34	6.41	6.35	5.28	5.22	5.20	5.23	7.19	6.97	6.84	7.00
3	10.56	10.50	10.75	10.60	5.21	5.44	5.22	5.29	11.13	10.81	10.75	10.90
4	13.03	12.85	12.81	12.90	5.66	5.69	5.63	5.66	11.72	11.62	11.78	11.71
5	10.06	10.00	10.09	10.05	8.13	8.25	8.19	8.19	11.06	10.91	10.78	10.92
6	7.54	7.50	7.53	7.52	10.09	10.38	10.53	10.33	11.28	11.35	11.47	11.37
7	9.34	9.47	9.90	9.57	7.39	7.97	7.69	7.68	12.49	13.25	12.90	12.88
8	10.97	11.16	11.28	11.14	13.59	13.90	13.93	13.81	20.53	20.47	20.53	20.51
9	10.25	10.44	10.34	10.34	14.25	14.16	14.22	14.21	16.63	16.60	16.50	16.58
10	10.53	10.62	10.62	10.59	11.44	11.18	11.03	11.22	13.79	13.87	13.94	13.87
Sum				94.38				85.25				129.22
Average				9.44				8.53				12.92

Table B-14 May 20, 2009. Lane: Passing S. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
2	14.97	15.59	16.28	15.61	8.25	8.56	8.69	8.50	18.84	19.59	19.78	19.40
3	22.18	22.78	23.06	22.67	14.50	15.03	15.12	14.88	13.34	14.00	14.53	13.96
4	9.54	10.23	10.03	9.93	8.38	8.78	8.84	8.67	12.44	13.12	13.47	13.01
5	7.16	7.63	7.63	7.47	4.00	4.16	4.10	4.09	7.31	7.79	7.69	7.60
6	8.43	8.97	9.12	8.84	13.87	15.09	16.13	15.03	11.85	12.90	12.91	12.55
7	9.28	9.53	9.69	9.50	16.56	18.66	18.69	17.97	10.09	10.66	10.90	10.55
8	7.41	8.07	8.13	7.87	18.03	20.25	21.09	19.79	10.06	10.91	11.19	10.72
9	5.91	6.22	6.22	6.12	11.50	12.09	12.70	12.10	8.10	8.56	8.34	8.33
10	7.91	8.22	8.38	8.17	8.82	9.32	9.62	9.25	8.15	8.35	8.63	8.38
Sum				96.19				110.28				104.50
Average				10.69				12.25				11.61

Table B-15 May 20, 2009. Lane: Driving N. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	10.12	9.72	9.75	9.86	9.31	9.40	9.35	9.35	31.31	31.28	31.50	31.36
2	12.03	12.07	12.04	12.05	9.06	9.15	9.06	9.09	13.88	13.59	13.72	13.73
3	10.38	10.00	9.97	10.12	8.69	8.66	8.46	8.60	16.53	16.44	16.37	16.45
4	65.12	65.85	65.97	65.65	11.65	11.53	11.59	11.59	31.97	32.34	32.69	32.33
5	11.28	11.41	11.31	11.33	9.56	9.50	9.50	9.52	10.65	10.75	10.62	10.67
6	10.38	10.38	10.44	10.40	6.47	6.38	6.41	6.42	8.63	8.50	8.67	8.60
7	10.07	10.00	10.10	10.06	8.31	8.25	8.37	8.31	16.44	16.15	16.44	16.34
8	6.53	6.69	6.47	6.56	6.32	6.44	6.43	6.40	7.65	7.66	7.75	7.69
9	7.41	7.35	7.54	7.43	6.03	5.94	5.75	5.91	16.15	15.84	16.03	16.01
Sum				143.46				75.19				153.18
Average				15.94				8.35				17.02

Table B-16 May 20, 2009. Lane: Passing N. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	8.81	9.09	9.47	9.12	30.94	32.56	33.47	32.32	14.25	15.75	15.69	15.23
2	7.32	7.69	7.81	7.61	5.53	5.78	5.71	5.67	8.25	8.56	8.81	8.54
3	6.28	6.47	6.62	6.46	10.37	10.72	10.97	10.69	7.97	8.22	8.34	8.18
4	7.34	7.37	7.84	7.52	17.60	17.71	18.62	17.98	8.03	8.22	8.44	8.23
5	10.35	10.53	10.79	10.56	39.31	41.62	41.62	40.85	8.07	8.22	8.31	8.20
6	9.60	10.06	10.19	9.95	10.28	11.47	11.47	11.07	19.56	20.00	19.84	19.80
7	6.41	6.47	6.63	6.50	23.63	25.06	25.16	24.62	8.53	8.85	8.75	8.71
8	5.37	5.31	5.75	5.48	5.28	5.47	5.72	5.49	6.40	6.24	6.66	6.43
9	7.06	7.25	7.44	7.25	6.28	6.40	6.53	6.40	5.93	5.94	6.25	6.04
Sum				70.44				155.09				89.36
Average				7.83				17.23				9.93

Table B-17 Sept 29, 2009. Lane: Driving S. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	6.72	6.68	6.65	6.68	7.16	7.34	7.35	7.28	7.72	7.56	7.38	7.55
2	6.40	6.09	6.16	6.22	6.15	6.06	6.25	6.15	6.78	6.62	6.56	6.65
3	8.03	7.97	7.91	7.97	5.22	5.00	5.19	5.14	8.13	8.19	8.03	8.12
4	14.12	14.28	13.97	14.12	8.22	8.34	8.47	8.34	27.66	27.88	27.50	27.68
5	9.31	9.44	9.41	9.39	6.56	6.53	6.53	6.54	10.87	10.96	10.66	10.83
6	7.35	7.34	7.20	7.30	11.40	11.50	11.25	11.38	15.19	15.54	16.31	15.68
7	9.25	9.31	9.50	9.35	8.91	8.78	8.62	8.77	13.87	13.78	14.00	13.88
8	8.56	8.60	8.40	8.52	11.91	12.12	12.12	12.05	24.10	24.62	24.75	24.49
9	6.81	6.90	6.91	6.87	8.22	8.22	8.47	8.30	23.09	22.78	22.50	22.79
10	10.21	10.06	10.41	10.23	8.62	8.69	8.60	8.64	14.34	14.09	14.12	14.18
Sum				86.65				82.60				151.86
Average				8.67				8.26				15.19

Table B-18 Sept 29, 2009. Lane: Passing S. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
2	16.62	16.91	17.37	16.97	6.31	6.63	6.65	6.53	12.72	13.22	13.29	13.08
3	18.41	20.00	20.12	19.51	15.15	16.35	16.87	16.12	7.93	8.16	8.35	8.15
4	5.38	6.62	7.28	6.43	8.96	9.19	10.00	9.38	12.06	12.10	12.35	12.17
5	5.87	5.94	6.31	6.04	5.75	5.91	5.91	5.86	5.19	5.22	5.38	5.26
6	9.03	9.22	9.68	9.31	10.72	11.13	11.98	11.28	12.19	13.53	13.81	13.18
7	7.85	8.09	8.19	8.04	17.28	19.06	20.37	18.90	7.88	8.03	8.37	8.09
8	7.69	7.97	8.22	7.96	14.12	15.19	15.72	15.01	11.53	12.25	12.72	12.17
9	5.41	5.38	5.31	5.37	13.84	14.63	15.28	14.58	8.25	8.18	8.62	8.35
10	8.06	8.69	8.77	8.51	8.03	8.18	8.13	8.11	10.31	10.41	10.78	10.50
Sum				88.13				105.78				90.94
Average				9.79				11.75				10.10

Table B-19 Sept 29, 2009. Lane: Driving N. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	11.94	12.29	12.68	12.30	11.63	12.37	12.94	12.31	30.25	31.94	32.88	31.69
2	15.06	15.56	15.91	15.51	8.28	8.53	8.82	8.54	30.28	32.50	33.28	32.02
3	14.84	15.81	16.35	15.67	7.12	7.28	7.31	7.24	17.43	18.53	19.00	18.32
4	40.72	43.66	45.35	43.24	10.31	10.69	10.85	10.62	23.44	25.75	26.70	25.30
5	15.46	16.44	17.19	16.36	10.25	10.66	10.85	10.59	16.50	16.91	17.44	16.95
6	10.75	10.97	11.29	11.00	6.22	6.37	6.23	6.27	14.56	14.78	15.13	14.82
7	8.75	8.93	9.31	9.00	7.84	8.03	8.28	8.05	24.97	26.72	28.32	26.67
8	7.84	7.88	7.97	7.90	6.03	6.22	6.31	6.19	9.40	9.66	9.88	9.65
9	7.10	7.22	7.25	7.19	7.37	7.34	7.50	7.40	16.91	17.10	17.66	17.22
Sum				138.17				77.21				192.64
Average				15.35				8.58				21.40

Table B-20 Sept 29, 2009. Lane: Passing N. I-55

Time For Head to Fall (sec.)

Location	Inside WP				Between WP				Outside WP			
	1	2	3	Average	1	2	3	Average	1	2	3	Average
1	7.00	7.00	6.87	6.96	26.00	26.53	26.07	26.20	8.22	8.32	8.13	8.22
2	7.28	7.19	7.19	7.22	7.53	7.56	7.44	7.51	5.65	5.81	5.69	5.72
3	5.16	5.28	5.18	5.21	7.32	7.50	7.53	7.45	6.88	6.84	6.94	6.89
4	8.40	8.19	8.04	8.21	8.82	8.94	9.09	8.95	7.00	6.84	6.82	6.89
5	11.50	11.47	11.18	11.38	10.78	10.81	10.63	10.74	8.90	8.90	8.75	8.85
6	7.91	7.85	7.88	7.88	14.90	14.84	14.96	14.90	10.44	10.38	10.47	10.43
7	8.18	7.72	8.06	7.99	10.10	10.15	10.10	10.12	6.56	6.50	6.46	6.51
8	4.97	4.87	4.84	4.89	5.10	5.03	5.03	5.05	4.97	4.85	4.97	4.93
9	6.19	5.97	6.22	6.13	6.82	6.78	6.81	6.80	6.15	6.03	6.03	6.07
Sum				65.86				97.72				64.50
Average				7.32				10.86				7.17