

**Construction Monitoring of Full-Depth Reclamation in Madison County
for MDOT Project No. NH-0008-03(032)**

FINAL REPORT

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16. Abstract This report presents the results of construction monitoring of the full-depth reclamation (FDR) process used on MDOT project number NH-0008-03(032) in Madison County on US49. FDR is a method of pavement rehabilitation in which the entire pavement structure is milled up, crushed, blended, and placed back in order to provide a homogenous material that, when properly compacted, is suitable for use as a pavement base layer. This report discussed the techniques used, problems encountered, and lessons learned from the FDR project.					
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Introduction

Background

Many of the pavements in Mississippi have exceeded or are beginning to reach the end of their original design life. In the coming years these pavements will require complete reconstruction or extensive rehabilitation. For some of these roads, the standard mill and overlay treatment may be sufficient to extend their use for years. For others, it may be necessary to completely rebuild the pavement structure in order to correct or compensate for an existing structural deficiency. With ever-decreasing state construction budgets and the need to conserve and recycle precious natural resources, the Mississippi Department of Transportation (MDOT) is always looking for environmentally friendly and economical ways to construct and rebuild roadways for the traveling public. One such method under investigation by MDOT is a technique known as Full Depth Reclamation (FDR).

Full Depth Reclamation is a method of pavement rehabilitation in which the entire pavement structure is milled up, crushed, blended, and placed back in order to provide a homogeneous material that, when properly compacted, is suitable for use as a pavement base layer. Depending on the underlying material of the pavement structure or the strength needed from the base layer, the layer of reclaimed material may require stabilization by means of mechanical, chemical, or bituminous stabilization methods. Mechanical stabilization adds strength to a reclaimed layer through the use of additional aggregates. This aggregate can come in many forms including crushed Portland cement concrete, recycled asphalt pavement (RAP), or an untreated virgin aggregate source. Chemical stabilization adds additional strength to the reclaimed material by treating the blended material with lime, Portland cement, fly ash, or other chemical products. The method of bituminous stabilization utilizes liquid asphalt, asphalt emulsion, or foamed asphalt to achieve increased stability in the reclaimed material. If more strength is needed than is provided by only one means of stabilization, multiple techniques can be used together to increase the final strength obtained from the reclaimed pavement structure. This report presents the results of construction monitoring of the FDR process used on Mississippi Department of Transportation Project Number NH-0008-03(032).

Objective

The primary objective of this research project is to monitor the full depth reclamation (FDR) construction process and to evaluate the long-term performance of the process for use as a roadway reconstruction technique. This report will do the following:

- Outline the FDR process in general and the processes specific to the US49 in Madison County project;
- Discuss the material testing and research activities conducted;
- Document problems encountered during construction which may affect the long-term performance of the pavement and the actions taken to counter these problems; and
- Summarize lessons learned during the FDR process in the event this technique is used for future MDOT construction projects.

Project Location

MDOT chose a four-lane section of highway on US Highway 49 in Madison County on which to construct the FDR project. The project began at the Hinds/Madison County line and proceeded 9.193 miles north to the Big Black River (Madison/Yazoo county line). In addition to the reconstruction of the pavement structure, the project also included the removal and reconstruction of two bridges located along US49. The bridges were replaced because of their insufficient width and outdated method of construction.



Figure 1: Beginning of Project

Project Description

The site selected for FDR in Madison County contained several different types of pavement distresses with varying severities. These distresses included but were not limited to reflective cracking, potholes, transverse cracking with spalling, rutting, and surface deformations due to subgrade shrinking/swelling. The photographs below show several of the distresses present prior to beginning construction. As the photographs also show, repair work such as patching had been done on several of the existing distresses prior to beginning the FDR process.



Figure 2: Pothole Repair and Wheelpath Deterioration



Figure 3: Reflective Cracking



Figure 4: Rutting, Compound/Longitudinal Cracking



Figure 5: Transverse Cracking/Spalling

The photographs in this section show only a portion of the distresses present at the selected site in Madison County. The quantity and severity of these distresses made this site a viable candidate for FDR since it was beyond the repair capacity of a typical mill and overlay. Further, this type of construction procedure is relatively untested in the state of Mississippi, which made this project an excellent opportunity for research.

Construction Procedures

Planned Reclamation Technique

Prior to commencing construction, Mississippi Department of Transportation officials decided that two different types of Full Depth Reclamation (FDR) would be used for this construction project. The two different methods would then be evaluated both short-term and long-term to determine the usefulness of the FDR process in transportation construction. Initially the type of FDR stabilization to be used was to be decided according to the direction of travel of the lane of travel. For the northbound lanes, asphalt emulsion would be used as the primary stabilization technique. For the southbound lanes, cement stabilization would be incorporated into the reclamation process in order to achieve the needed strength from the reclaimed pavement structure.

For both lanes of travel the approved reclaimed thickness was to be nine inches below the three-inch milled surface course. The only planned exception to the nine-inch reclamation thickness would occur on portions of the site which were constructed on top of the original two-lane concrete highway. For portions of the existing pavement placed over the original concrete structure, only the existing asphalt structure would be reclaimed. This existing asphalt structure was determined to be approximately six inches of uniform thickness after the initial surface milling course was removed. Also, because the median crossovers were significantly less distressed than the mainline pavement, they would receive only an overlay course instead of the full depth reclamation.

Planned Construction Sequence

The construction project in Madison County also included the removal and replacement of two existing bridges in addition to the reclamation of the pavement structure. For this reason it was necessary to develop a construction sequence prior to beginning construction that would minimize the inconvenience to the traveling public.

Stage 1 of the construction sequence required the reclamation and initial overlay of the areas immediately surrounding the bridges selected for replacement. Once this section had been

reclaimed and overlaid with its initial surface lift of asphalt, traffic would then be routed onto the existing southbound lane in a “head-to-head” fashion. This would allow for construction personnel to use the temporarily closed portion of the northbound lanes for construction-only traffic while maintaining safe working conditions.

After the completion of the first stage of construction, Stage 2 allowed for the simultaneous reclamation of the remainder of the asphalt structure, as well as the removal and reconstruction of the two bridges slated for replacement. During this stage of construction the reclaimed layer would receive its intermediate lift of asphalt.

Upon completion of the replacement bridges and reclamation of all pre-existing asphalt structure, Stage 2 would be concluded and Stage 3 would begin. The last stage of construction for this project called for an overlay of the entire project, which would constitute the final surface lift on which the traveling public would drive after completion of the project.

Reclamation Processes

Initial Cement Reclamation Process

The initial plan for this reclamation project required that the southbound lanes be mixed with cement during the reclamation process in order to increase the strength of the reclaimed material. This section will cover this process as it was initially practiced at the start of the construction process.

The first phase was the removal of the top three inches from the asphalt structure. This step was performed by Delta Construction Inc., through the use of multiple milling machines. This process not only removed minor surface distresses but also created a uniform grade on which to base the reclamation process.



Figure 6: Milling and Surface Removal

After the upper three inches of asphalt surface had been removed and a uniform grade had been established, the FDR could begin. The first step in the cement stabilized reclamation process was the application of raw cement.



Figure 7: Application of Raw Cement

The figure above shows the application of the raw cement to the milled surface. The application rate of the cement is controlled by an auger system whose application rate is determined by the speed of the truck. After the application of the cement, the reclamation process continues with the grinding/pulverization of the pavement structure. This step of the process also includes the introduction of the water needed to hydrate the cement. Once the pavement structure has been ground, it is sent to a pug mill, where it is screened, and oversized chunks of pavement are sent to a crusher before being reintroduced to the reclaimed material. The pulverized and mixed material then exits from the rear of the reclamation train in a windrow. This windrow is formed from an auger bin at the rear of the train whose production rate is also determined by the speed of the reclamation train.



Figure 8: Grinding Head of Reclamation Train



Figure 9: Material Entering Shaker/Pug Mill



Figure 10: Material Windrow

At this point the shape and volume of the windrow of material seen in Figure 10 are largely uniform because of the consistent speed of the reclamation train. The train's speed can remain consistent for whole working days as long as mechanical failure does not occur. Also the issue of material transport to and from the jobsite is not as much of a determining factor for this process as it is in traditional paving.

After the windrow of material is placed, the material is then worked to produce a compacted and smoothed layer of reclaimed asphalt. First, a motor grader is used to smooth the windrow down to a smooth surface of a uniform grade. This part of the material finishing process requires a high level of proficiency on the part of the equipment operator in order to ensure that a smooth final surface is attained. After the motor grader has smoothed the reclaimed asphalt into a smoothed surface, compaction is needed to obtain the optimum strength requirements. For this project compaction of the reclaimed asphalt layer was accomplished by a Rex® 3-70 Compactor, which uses a set of large steel wheels fitted with many rectangular steel pads to achieve the desired level of compaction.



Figure 11: Compaction of Reclaimed Material

After compaction of the reclaimed asphalt, the motor grader is then rerun to smooth the uneven surface left by the compactor. This process also requires significant operator skill in order to obtain a surface with a final longitudinally smooth profile. Once the compacted material has been smoothed and a uniform grade been reestablished by the motor grader, it is then rolled and compacted with a vibratory steel wheel roller, which is used on most highway construction projects for compacting asphalt pavement lifts. This layer of compacted and reclaimed asphalt is then allowed to set before an application of tack coat is applied to prevent excessive moisture loss from the reclaimed material. Finally, the layer is allowed to cure for seven days, per MDOT specifications, before it is milled again to establish a uniform grade surface suitable for its intermediate asphalt overlay.

Initial Emulsion Reclamation Process

The processes associated with the cement and emulsion reclamations of the pavement structure on the US49 project in Madison County were very similar. Both methods used the same reclamation equipment and similar methods of material finishing. However, one of the key differences between the two processes was the addition of lime in the emulsion reclamation. In the cement reclamation technique, raw cement was placed on the milled surface prior to reclamation, whereas in the emulsion reclamation hydrated lime was used instead of raw cement. The purposes of the hydrated lime were to prevent the asphalt from stripping and to reduce the amount of time needed to expedite the moisture from the emulsion reclamation mix once it is placed. The other dissimilarity between the two techniques is the addition of the asphalt emulsion. This emulsion was added and mixed with the reclaimed pavement just prior to the material exiting the reclamation train.



Figure 12: Emulsion Tank and Rate Control Panel

As shown in Figure 12 above, the emulsion to be added to the reclaimed pavement is stored in the light blue tank located on the final piece of the reclamation train. Above the rear two axles is the auger basin, which is responsible for the addition and mixing of the emulsion. The control panel which governs the rate at which the emulsion is added to the reclaimed material can also be seen with its door open in Figure 12. This allows construction personnel to constantly monitor the percent by mass of emulsion being added to the pulverized pavement before it is placed into a windrow, just as is done in the cement stabilization method. From this point onward the material is worked and finished in the same way as the method used for this construction project previously described.



Figure 13: Entire Reclamation Train Assembly

With all the individual processes associated with the reclamation of asphalt pavements, it is worth emphasizing that top-quality machinery and knowledgeable staff who ensure continuous operation are crucial in delivering an acceptable product. Shown above in Figure 13 is the entire reclamation train assembly as it appeared during normal operation. The entire assembly, from

milling head to auger basin, is approximately 100 feet in length, not including the multiple water tankers often present for supply purposes.

Adopted Reclamation Process

After Stage 1 of construction was completed and the reclamation of the asphalt structure at the Beginning of Project (BOP) was commenced, a problem was encountered. Up to this point, the process had predominantly involved reclaiming asphalt that had been placed over the old concrete sections of US49. When Stage 2 construction began at the BOP location, this underlying concrete roadway was not present. The weight of the reclamation train on pavement that lacked the added strength of an underlying concrete structure placed undue stresses on the subgrade of the pavement structure. This added stress to the subgrade surfaced in the reclaimed layer in the manner of severe surface deformations.



Figure 14: Surface Deformation Due to Subgrade Pumping

These surface deformations as shown above in Figure 14 not only presented a problem for paving traffic but also indicated an underlying problem of a subgrade with insufficient strength. In order to compensate for this structural lacking, MDOT engineers and officials decided that, in order to compensate for a subgrade of insufficient strength, stabilization would have to be done to a greater depth than previously planned. To offset the additional costs incurred from this construction change, on all sections of reclamation not constructed over the old concrete roadway, only the cement method of stabilization would be utilized regardless of the lane direction. The agreed-upon depth of cement stabilization was to be 16 inches below the milled surface. For sections constructed over the old concrete roadway, the original reclamation method determined by lane direction would be used. In order to obtain a homogenous blend at such a great depth, a large piece of specialized equipment was needed. For this particular project a Caterpillar RM 500 was used to handle the 16-inch mixing assignment.



Figure 15: Caterpillar RM 500 Mixer

With the addition of the RM 500 mixer to the construction sequence, some changes were made. The raw cement was still placed directly on the milled surface as before, but portions of the reclamation train were removed. The original milling unit was still used to pulverize the uppermost seven inches of remaining asphalt and blend it with the raw cement. The pulverized material was formed into a windrow upon exit of the milling unit. This windrow was spread using the same motor grader as before. After the pulverized material was spread using the motor grader, it was then mixed to a total depth of 16 inches using the Caterpillar RM 500.



Figure 16: Depth Indicator of RM 500 Mixer

After the total depth of 16 inches had been mixed using the RM 500 mixer, the pulverized and mixed material was then smoothed, compacted, and rolled just as with the two previous methods of construction. This construction technique was used for the remainder of the project, excluding those sections of asphalt which were reclaimed over the old concrete roadway.

Reclamation Layer Repair

Despite the pains taken to produce a reclaimed asphalt layer with adequate strength, there were still sections of the project which displayed less than desirable strength capabilities. In order to identify these areas, a dump truck or tandem axle dump trailer was loaded and used to proof-roll the compacted reclaimed material layer. Areas that exhibited less than adequate compaction or stability were marked for replacement or repair. These areas of insufficient strength were repaired by the removal of the reclaimed material and replaced with crushed limestone and overlaid with asphalt.



Figure 17: Cross-Section of Reclaimed Layer Repair

This technique was used throughout the construction project for repair of both the planned reclamation procedure as well as the 16-inch mixed pavement reclamation. It should be noted that areas which were marked for replacement in the 16-inch mixed reclamation sections often

required much deeper areas of repair than those of the asphalt reclamation constructed over the old concrete roadway.

Lessons Learned

The first lesson learned from this construction procedure is that extensive testing of a construction site prior to beginning construction should be done in an attempt to clearly understand the current pavement structure. Many cores were taken from the Madison County site prior to the design of the FDR process which greatly aided the project. However, if this technique is used in the future, more extensive coring and materials testing need to be conducted before beginning construction. This testing should aim to find the limits of underlying materials as well as identify potential problems associated with these underlying structural components.

Secondly, extensive consideration should be taken when designing a traffic control plan for the entire length of construction. The staged construction plan implemented for the Full Depth Reclamation of Highway 49 in Madison County was a great example of how a well-designed traffic control plan can help to reduce congestion, keep MDOT and contractor personnel safe, and minimize inconvenience to the travelling public.

The third lesson learned was the importance of experience of construction personnel in constructing an FDR project. While this technique is relatively new to MDOT, the staff of Hall Brothers Recycling and Reclamation, Inc., was extremely well-trained in FDR. It is the author's opinion that the professionalism, efficiency, and dedication to a quality product exhibited by the staff from Hall Brothers Recycling and Reclamation played a key role in the completion of this project.

Summary and Conclusion

In summary, the construction of the Full Depth Reclamation project in Madison County was a success. While it will take some time to verify how well the construction process withstands the traffic demands present in Madison County, the immediate results of construction seem to be promising. Although several problems were encountered during the course of construction, extensive efforts were made to counteract these problems and produce an economical solution which will also yield a high quality highway structure. This project also increased the exposure of MDOT and contractor to an innovative pavement reconstruction technique that, when implemented properly, offers economic, environmental, and durability benefits.

Appendix I--Mix Designs, Materials Information and Test Results

Design Process and Test Data for FDR Project Hwy 49 Madison County

Consensus Test for Both Designs

Samples were obtained from three locations throughout the project to obtain material representing varying structural buildup. Those samples were transported to Central Lab and consensus properties and design parameters determined. Material was air dried and gradation testing was conducted. Test results are shown below.

	Site 1	Site 2	Site 3
Sieves	Percent Passing %		
1"	100.0	100.0	100.0
3/4"	98.6	97.1	98.5
1/2"	94.9	87.7	92.1
3/8"	86.3	77.7	82.9
No.4	57.9	53.9	55.0
No.8	39.5	36.1	35.5
No. 200	0.6	1.0	1.3

Gradation results indicated the materials from all three sites were similar, so it was decided to combine all materials to form a composite sample and determine a mix design to represent the entire project.

For both emulsion and cement designs a raw proctor was performed to determine optimum moisture content of the material. Optimum moisture was selected 7.4% at a density of 122.9 lbs/ft³.

Mold Used: No. 1 Weight of Mold 2890.8 grams Volume of Mold 340 (Cu. Ft.)
 Tested Under: Case 1 X Case 2 _____ REMARKS _____
 REMARKS _____
 REMARKS _____

Trial No.	Wet Wt Soil & Mold (Grams)	Wet Wt Soil (Grams)	Moisture Determination					Dry Weight (Grams)	Dry Density (PCF)
			Weight of Dish (Grams)	Wt. Wet Soil & Dish (Grams)	Wt. Dry Soil & Dish (Grams)	Loss (Grams)	Moisture Content		
1	7068.9	4186.3	66.0	193.7	188.2	5.5	4006.0	117.8	
2	7258.4	4377.8	66.6	204.0	195.5	8.5	4107.0	120.7	
3	7343.7	4463.1	68.0	203.0	192.4	10.6	4112.7	120.9	
4	7320.9	4440.3	82.2	258.3	242.0	16.3	4029.3	118.4	
5									

Enter Point Selected From Chart Below For (-) 1/2 Material

Std. Density: 121.2
 % Moisture: 7.7

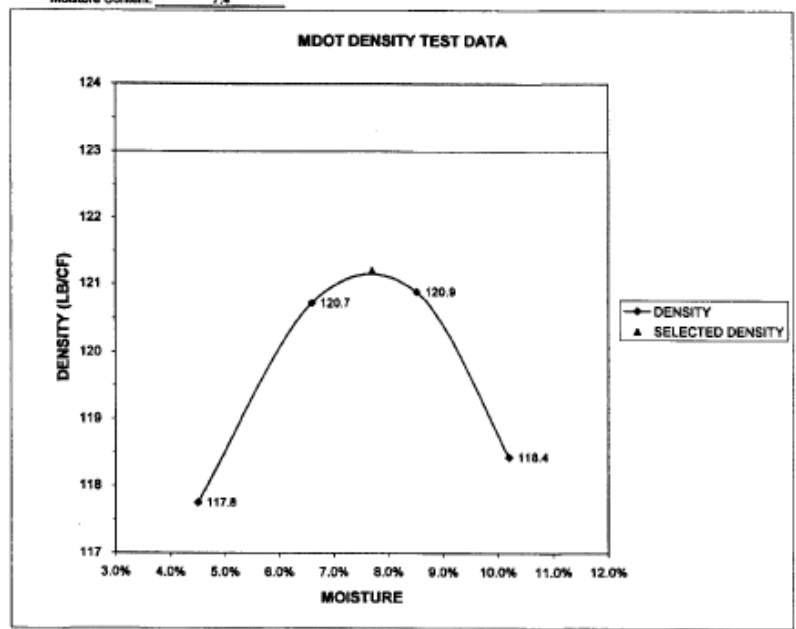
(+) 1/2" Material

% of +1/2" Mat.: 7.1
 Bulk Specific Gravity of +1/2" Mat.: 2.410

Results of Total Sample
 Standard Density: 122.9
 Moisture Content: 7.4

Signed _____
 Title _____

DISTRIBUTION:
 Original - Project Engineer
 Copies - Construction Engineer
 State Materials Engineer
 District (As Instructed)



Cement Design

Samples were compacted using a Superpave Gyrotory Compactor to fabricate specimens to perform unconfined compressive strength analysis. Samples were prepared at optimum moisture content with 5%, 6%, and 7% cement by volume. Materials weights were adjusted such that the final height after 35 gyrations would yield a specimen 6" in diameter and approximately 5 1/2" in height. Specimens were extruded from the mold and cured in the moist room for 7 days. After the curing period, specimens were tested for unconfined compressive strength. Minimum design strength was 200 psi. Results are shown below.

Cement Content	Load (lbs)	Strength (psi)
5%	7474	264
6%	9719	343
7%	12350	437

Final design values were selected at 7.4 % moisture content and 5% cement by volume.

Emulsion Design

The emulsion design was performed by a third party laboratory and verified by MDOT Central Lab. Samples were fabricated using a Superpave gyratory compactor at 35 gyrations and 3%, 4%, and 5% emulsions contents at 4.7% optimum moisture. Samples were cured and tested for indirect tensile strength in accordance with MT-63. Strength results are shown below.

Unconditioned Set (45 psi min requirement):

% Emulsion	Indirect Tensile Strength (psi)
3	69.7
4	74.9
5	46.8

Conditioned Set (25 psi min requirement):

% Emulsion	Indirect Tensile Strength (psi)
3	32.4
4	38.8
5	43.3

Final design values were selected at 5% moisture content and 4% emulsion content

Appendix II--MDOT Research Division DCP Test Results

DCP TEST DATA

File Name: FDR Madison

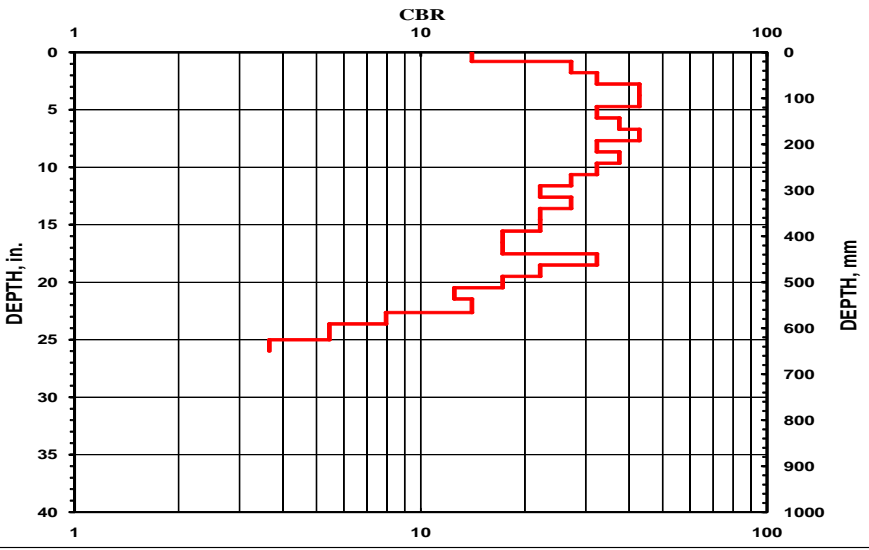
Project: FDR
Location: Madison US49 North

Date: 30-Aug-10
Soil Type(s): Type in the soil type

Hammer
 10.1 lbs.
 17.6 lbs.
 Both hammers used

Soil Type
 CH
 CL
 All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	-10	2
4	20	2
6	45	2
7	70	2
9	95	2
9	120	2
7	145	2
8	170	2
9	195	2
7	220	2
8	245	2
7	270	2
6	295	2
5	320	2
6	345	2
5	370	2
5	395	2
4	420	2
4	445	2
7	470	2
5	495	2
4	520	2
3	545	2
4	575	2
2	600	2
2	635	2
1	660	2
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DCP TEST DATA

File Name: FDR North 1.43

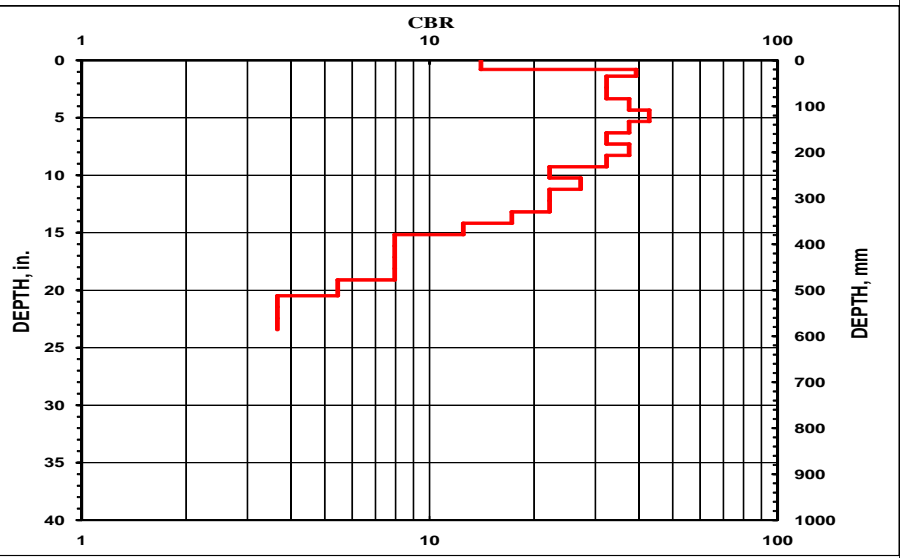
Project: **FDR**
 Location: **Madison US49 North (1.43)**

Date: **13-Sept.-2010**
 Soil Type(s): **Type in the soil type**

Hammer
 10.1 lbs.
 17.6 lbs.
 Both hammers used

Soil Type
 CH
 CL
 All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	-10	2
4	20	2
5	35	2
7	60	2
7	85	2
8	110	2
9	135	2
8	160	2
7	185	2
8	210	2
7	235	2
5	260	2
6	285	2
5	310	2
5	335	2
4	360	2
3	385	2
2	410	2
2	435	2
2	460	2
2	485	2
2	520	2
1	545	2
1	570	2
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DCP TEST DATA

File Name: FDR North 1.43

Project: FDR

Date: 13-Sept.-2010

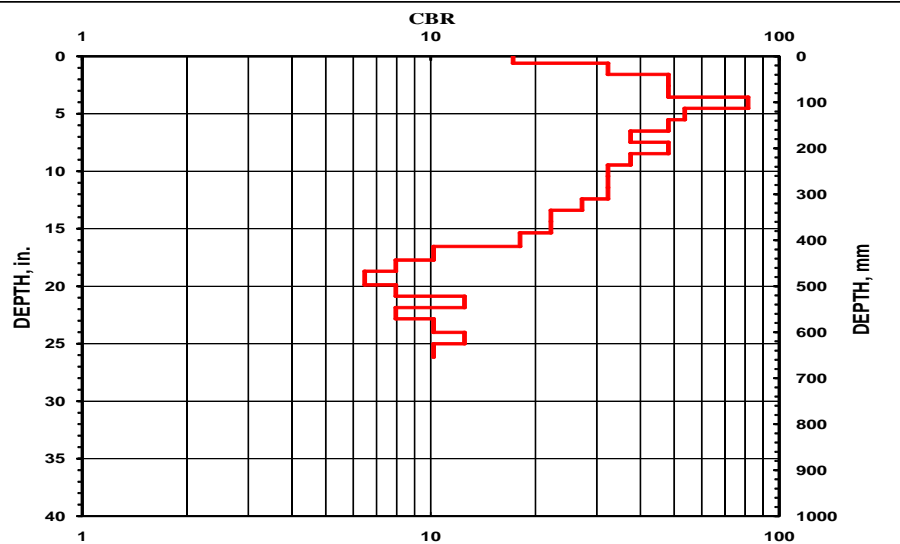
Location: Madison US49 North (1.43)

Soil Type(s): Type in the soil type

- Hammer
 10.1 lbs.
 17.6 lbs.
 Both hammers used

- Soil Type
 CH
 CL
 All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	-10	2
4	15	2
7	40	2
10	65	2
10	90	2
16	115	2
11	140	2
10	165	2
8	190	2
10	215	2
8	240	2
7	265	2
7	290	2
7	315	2
6	340	2
5	365	2
5	390	2
5	420	2
3	450	2
2	475	2
2	505	2
2	530	2
3	555	2
2	580	2
3	610	2
3	635	2
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DCP TEST DATA

File Name: FDR North 1.43

Project: **FDR**
Location: **Madison US49 North (1.43)**

Date: **13-Sept.-2010**
Soil Type(s): **Type in the soil type**

- Hammer
- 10.1 lbs.
 - 17.6 lbs.
 - Both hammers used

- Soil Type
- CH
 - CL
 - All other soils

No. of Blows	Accumulative Penetration (mm)	Type of Hammer
0	-10	2
4	15	2
6	40	2
6	65	2
12	90	2
12	115	2
14	140	2
10	165	2
12	190	2
10	215	2
9	240	2
7	265	2
7	290	2
9	315	2
6	340	2
4	365	2
4	390	2
5	415	2
5	440	2
8	465	2
5	490	2
5	515	2
5	540	2
5	565	2
4	590	2
2	615	2
2	640	2
2	665	2
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