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16. Abstract

In many instances rubblization may be a good option to convert a deteriorated concrete pavement into a flexible pavement structure. In this project, the Texas Department of Transportation conducted rubblization on portions of a concrete pavement originally constructed in the 1920s to validate project analysis and construction specifications. This project truly pushed the limit with respect to how poor the concrete pavement support can be before rubblization is not a viable option. Fortunately, project personnel knew from the start that this project was a marginal candidate for rubblization, so contingency plans were already in place. Rubblization on this project showed that the project analysis procedures and construction specification worked well. These procedures and specification are included in this report as Appendices A and B, respectively, and should be used for planning and controlling construction of future rubblization projects. Post-construction monitoring revealed no differences in ride existed among the sections of differing treatments. The main structural differences observed were between sections rubblized with different equipment. The sections rubblized with Type II equipment had rubblized and base layer modulus values greater than those observed in the section where Type I equipment was used.

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Rubblization, Pavement Rehabilitation, Multiple Head Breaker, Resonant Breaker

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RUBBLIZATION AND BASE OVERLAY OF FM 912 AND FM 1155

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The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The engineer in charge was Tom Scullion, P.E. (Texas, #62683).

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EXECUTIVE SUMMARY

This report presents activities and findings from TxDOT's implementation of rubblization for rehabilitating FM 912 and FM 1155 in Washington County. The project consisted of:

- shoulder widening,
- rubblization of existing jointed-concrete pavement (JCP),
- flex base overlay, and
- single course surface treatment.

Additionally, sections without rubblization were constructed as control.

TxDOT used Special Specification (SS) 3123 to govern rubblization activities and employed both Type 1 (resonant breaker) and Type II (multiple-head breaker) rubblization equipment. Additionally, TxDOT employed two base materials for the base overlay. A traditional Grade 2 base, along with a low fines Grade 4 "drainable" base, were used for base overlays. The project was planned such that sections were constructed containing all possible combinations of JCP treatment and base overlay.

Construction proceeded smoothly with the Type II equipment. With the Type I equipment the JCP tended to get broken down finer and more stability problems were encountered after rubblization, resulting in the early suspension of Type I rubblization activities. With both pieces of equipment, the rubblization selection chart used in the planning stage matched well with actual field construction. The contractor placed the base overlay with a paver, which did not result in any issues. The main base issue encountered was raveling of the Grade 4 base under traffic before construction of the surface treatment.

Post-construction monitoring revealed the entire pavement had poor ride; however, no differences in ride existed among the sections of differing treatments. The main structural differences observed were between sections rubblized with different equipment. The sections rubblized with Type II equipment had rubblized and base layer modulus values greater than those observed in the section where Type I equipment was used.

This project truly pushed the limit with respect to how poor the concrete pavement support can be before rubblization is not a viable option. Fortunately, project personnel knew from the start that this project was a marginal candidate for rubblization, so contingency plans were already in place. Rubblization on this project was initiated primarily to validate the prior-developed guidelines and specifications for rubblization, which are included as Appendices A and B in this report, respectively, and should be used for planning and controlling construction of future rubblization projects.

CHAPTER 1.

CONSTRUCTION PLAN FOR FM 912 AND FM 1155

SUMMARY

As part of a shoulder widening project to enhance safety on FM 912 and FM 1155 in Washington County, TxDOT also sought to improve the condition of the jointed-concrete pavement that was originally constructed in the late 1920s. Due to substantial distress on parts of the project, TxDOT considered rubblization as one option for accomplishing this objective. After pre-screening the project with ground-penetrating radar (GPR), falling weight deflectometer (FWD), and dynamic cone penetrometer (DCP) tests, TxDOT selected portions of the project for rubblization. Report 0-4687-2, previously published, contains details and results from the screening tests performed.

DETAILS OF PLANNED CONSTRUCTION

Figure 1.1 shows the partitioning of the project for rubblization and base placement activities. This partitioning resulted in each of the concrete treatments (none, Type I rubblization, or Type II rubblization) receiving a section overlaid with the Grade 2 base and a section overlaid with the Grade 4 base. TxDOT used SS 3123 to govern the rubblization operations, and Standard Specification Item 247 controlled flexible base construction.

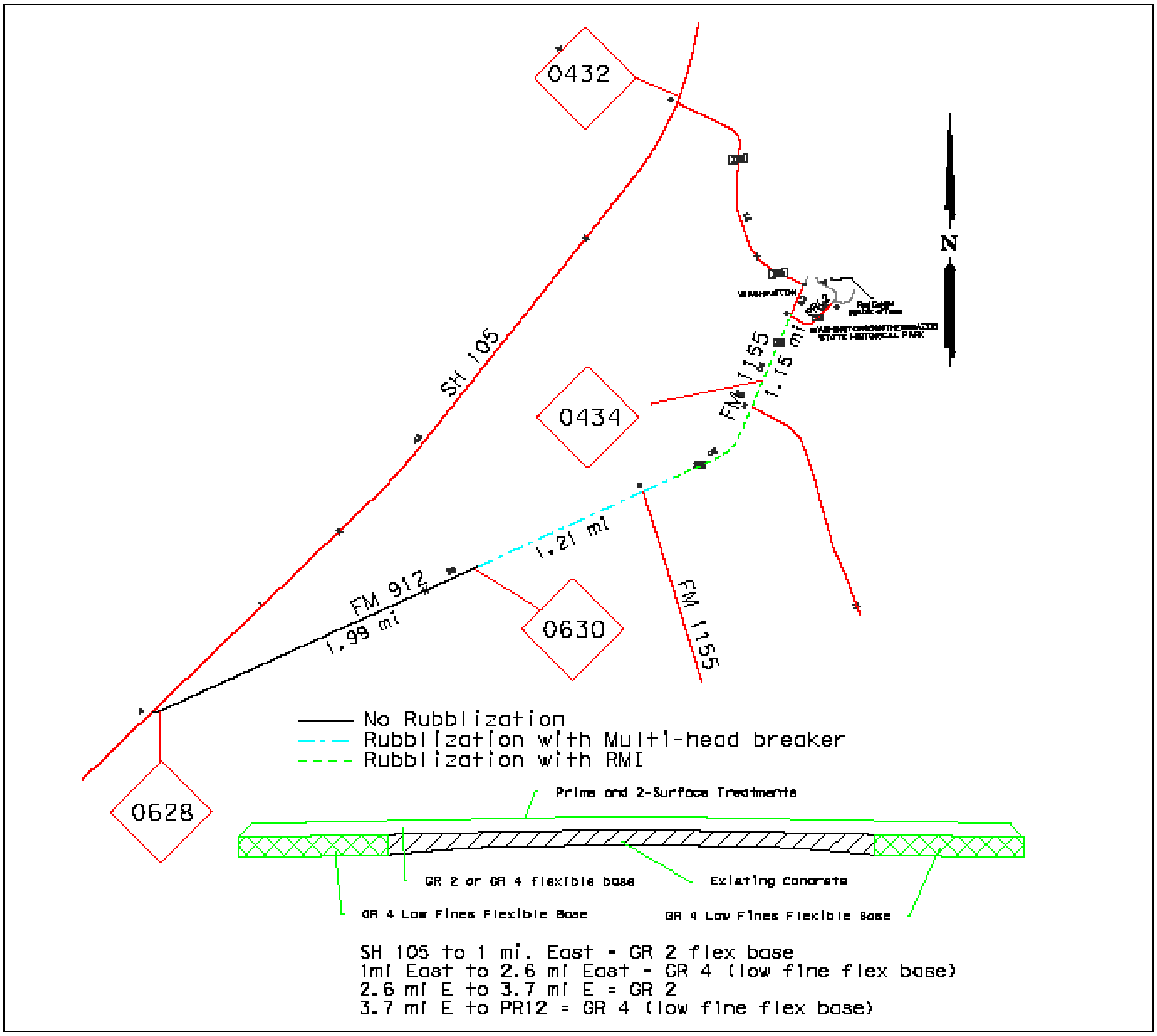


Figure 1.1. Limits of JCP Treatments and Base Material Types on FM 912 and FM 1155. (courtesy of Darlene Goehl, P.E.)

CHAPTER 2.

RUBBLIZATION AND BASE OVERLAY OPERATIONS

SUMMARY

Glenn Fuqua, Inc. initiated the shoulder widening activities in early 2008. Type II rubblization took place the week of June 23, 2008, and Type I rubblization took place the week of August 4, 2008. Type II rubblization was more successful under the soil conditions at the project than Type I rubblization. The finer break pattern and multiple passes required by the Type I rubblizer resulted in a larger percentage of the rubblized area requiring full-depth repair as compared to the Type II rubblizer. Approximately 6 percent of the area rubblized with Type II equipment required full-depth repair whereas approximately 14 percent of the area rubblized with Type I equipment required full-depth repair. Placing the base with a paver worked relatively well, where the only concerns resulted from some segregation and loss of finish quality under traffic when working with the Grade 4 drainable base. The contractor addressed these concerns by reworking the finish immediately prior to sealing the base.

CONSTRUCTION OF TYPE II SECTION

Type II rubblization, employing a multiple head breaker, took place June 23–27, 2008. The Type II equipment rubblizes the entire lane width in one pass. Antigo Construction performed the Type II rubblization, with planned station limits from 105+00 to 169+00. Figure 2.1 shows the unfractured concrete ahead of the breaker, along with the surface view of the rubblized concrete after the operation.

Figure 2.1. Unfractured (Left) and Rubblized (Right) JCP during Type II Rubblization.

Establishing Type II Rubblization Break Pattern

After rubblizing approximately 200 feet, the contractor excavated the first test pit. Obtaining entry into the concrete with the back hoe proved difficult, indicating that the concrete still maintained a high degree of interlock. Figure 2.2 shows both a surface and cross-section view of the test pit. Although the break pattern appeared acceptable from the surface, the test pit revealed that the particle size distribution did not meet the specification. The specification required all particles in the top half of the slab to be less than 6 inches, with at least 40 percent under 3 inches. The test pit revealed only the top 1.5 to 3 inches of the slab were fractured to this particle size distribution.

Figure 2.2. Surface and Side View of Test Pit with Type II Rubblization.

After examining results from the first test pit, the contractor rubblized another 200 feet while applying more energy to the concrete by increasing the drop height of the hammers and slowing the rubblizer's travel speed. The contractor then dug a second test pit at station 108+00. This test pit revealed that the depth of the smaller surface particles did indeed increase; however, excavation of the pit was much easier with the back hoe, with the rubblized JCP showing minimal evidence of interlock. Due to the lack of interlock in the rubblized layer with the second break pattern, TxDOT instructed the contractor to continue rubblizing using the original break pattern.

Locating Sections needing Full-Depth Repair with Type II Rubblization

The prior site investigation, detailed in Report 0-4687-2, identified this project as "marginally suitable" for rubblization. As such, researchers anticipated encountering sections during construction needing full-depth repair. Two important parameters for assessing the rubblized product include break pattern and stability. Prior work documents the fact that, when support beneath the slab is lacking or non-existent, rubblization operations will not produce the desired break pattern. Additionally, regardless of the break pattern achieved, the rubblized layer must provide a stable foundation for construction traffic, subsequent pavement layers, and vehicle traffic.

SS 3123 includes criteria on gradation after rubblization and a requirement for proof rolling in attempts to ensure a quality product after rubblization. The break pattern provides an early indicator of where suspect locations may exist, then the proof rolling operation validates whether the location is unstable and thus in need of repair.

As an example, Figure 2.3 shows a location where the break pattern significantly shifted. Large concrete blocks, typically 12 inches in size or larger, remained visible at the surface after rubblization. The photo on the right in Figure 2.3 illustrates the drastic difference in break patterns between the suspect location (foreground), and a normal area.

Figure 2.3. Poor Break Pattern at Unstable Location.

To validate the locations of areas in need of full-depth repair, the contractor performed proof rolling with an IR PT-240R (see Figure 2.4), reportedly loaded to 30 tons. The location shown in Figure 2.3 indeed required full-depth repair. Per the specification, the contractor excavated unstable areas to a depth of 18 inches then repaired them with flexible base. Table 2.1 summarizes the locations on the project receiving full-depth repair within the limits of the Type II rubblization. Approximately 6 percent of the area rubblized required full-depth repair.

Figure 2.4. Proof Rolling.

Table 2.1. Locations Receiving Full-Depth Repair within Limits of Type II Rubblization.

Direction	Beginning Station	Ending Station
Both	105+80	106+10
Both	113+00	114+10
Both	118+82	119+66
South	127+00	127+34
South	154+97	155+21
South	155+86	155+98
Both	159+00	159+40
North	159+75	160+15

In addition to these full-depth repair locations, some sections were skipped due to cross structures. Table 2.2 shows these skipped sections.

Table 2.2. Locations Skipped for Cross Structures within Limits of Type II Rubblization.

Station	Dimensions (ft x ft)
109+40	6 x 18
123+49	10 x 18
141+68	12 x 18
161+93	40 x 18

Potential Alternative to Full-Depth Repair

Clearly full-depth repair involves extra labor and cost on a project, so after discussion with the TxDOT engineer, the decision was made to utilize a reduced break pattern on sections at high risk of instability after rubblization. Such an approach relies largely on the operator of the rubblizing equipment, who through experience must assess the machine's operation to determine whether a reduced break pattern is necessary. The goal of the reduced break pattern is to adequately fracture the concrete to eliminate slab action, yet retain stability. Such a pattern could be thought of as between crack-and-seat and rubblization. Figure 2.5 shows a section employing the reduced break pattern. Table 2.3 summarizes the locations on the project known to receive the reduced break pattern.

Figure 2.5. Modified Break Pattern with Type II Rubblization.

Table 2.3. Locations Receiving Reduced Break Pattern with Type II Rubblization.

Direction	Beginning Station	Ending Station
South	127+05	127-28
North	139+00	153+06

Comparison of Rubblization Selection Chart with Field Construction

During the construction of this project, the Texas Transaportation Institute (TTI) collected DCP readings at selected locations exhibiting both good breakage and poor breakage with the goal of validating the rubblization selection chart outlined in report 0-4687-2. Figure 2.6 shows these results plotted on the rubblization selection chart previously employed to evaluate the project's suitability for rubblization. In Figure 2.6, locations showing a poor break pattern upon visual inspection are annotated as "poor." Locations that proved unstable as determined by proof rolling are highlighted in red. The results indicate the rubblization selection chart matched well with field experience. Additionally, the results reiterate the importance of the support immediately beneath the slab; each measurement where the concrete thickness versus base California Bearing Ratio (CBR) plotted in the High Risk zone was found unstable during proof rolling and required removal. In contrast, two observations exist where only the concrete plus base thickness versus subgrade CBR plotted in the High Risk zone, and these locations remained stable upon proof rolling.

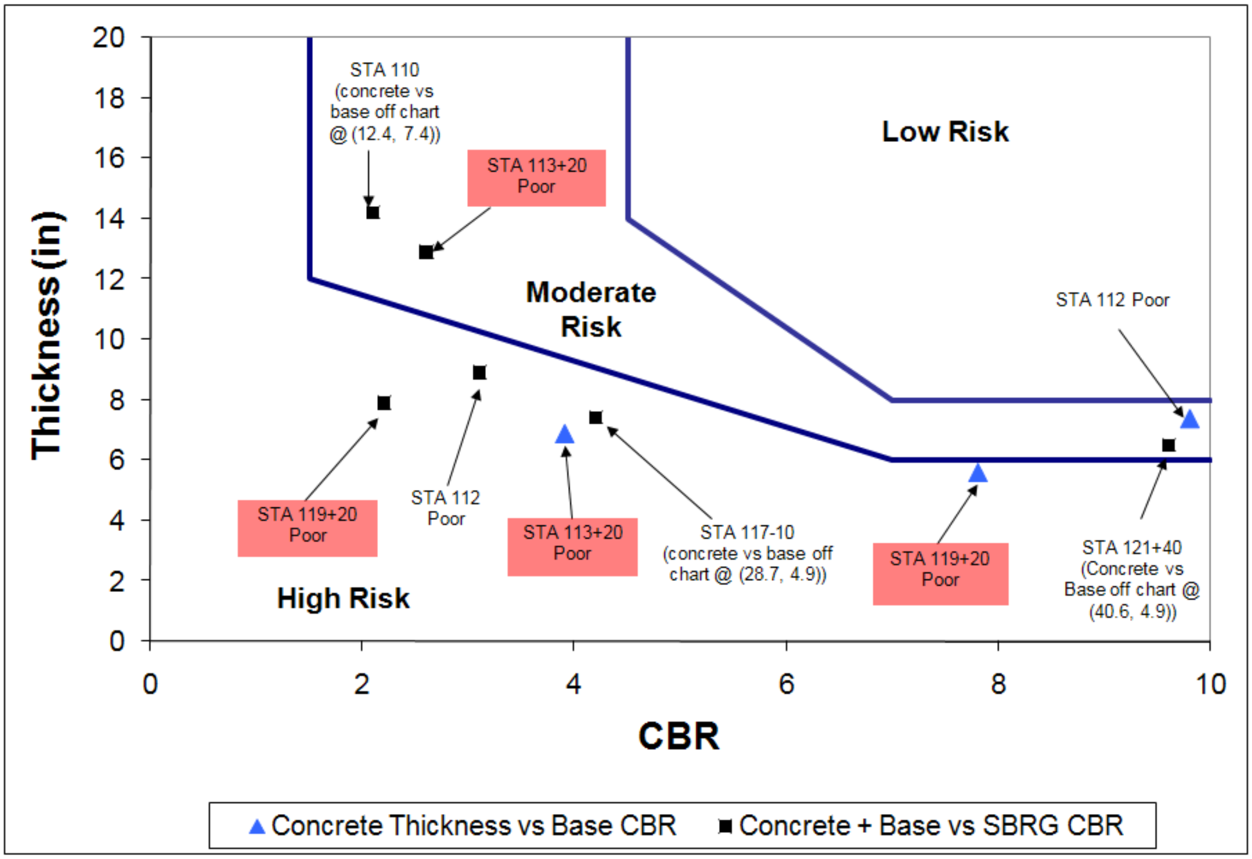


Figure 2.6. Selection Chart Data from Construction for Type II Rubblization.
Note: Locations highlighted in red required full-depth repair.

CONSTRUCTION OF TYPE I SECTION

Type I rubblization, employing a resonant breaker, took place August 4–8, 2008. The Type I rubblizer uses a vibrating shoe to impact and fracture the concrete. RMI Worldwide performed the Type I rubblization, with planned station limits from 169+00 to 230+00. Figure 2.7 shows the Type I rubblization in progress along with a representative completed section.

Figure 2.7. Type I Rubblization in Progress and Completed Section.

Establishing Type I Rubblization Break Pattern

TxDOT elected to not specifically conduct a test pit upon startup of the Type 1 rubblization. Instead, they used the observed break pattern at the first location needing full-depth repair as the test pit. Figure 2.8 shows an excavation of the JCP rubblized with the Type I equipment. When contrasted with the excavation from the Type II equipment shown in Figure 2.2, the JCP rubblized with Type I equipment was easier to excavate and exhibited a finer gradation through the depth profile.

Figure 2.8. Test Pit with Type I Equipment.

Locating Sections Needing Full-Depth Repair with Type I Rubblization

Due to the number of passes the Type 1 rubblizer must perform to break the entire lane width, the machine itself serves as a good proof roller and oftentimes the locations of instability were evident even before rubblizing the entire lane width. However, TxDOT also required a roller on the section after completion of rubblization to finalize the limits of any removal locations. As is typical, many sections of instability also exhibited larger particle sizes after rubblization, and in some cases substantial rutting from the Type I equipment performing passes over the pavement. Figure 2.9 illustrates one such location that required removal.

Figure 2.9. Example Location Requiring Full-Depth Repair with Type I Rubblization.

Table 2.4 presents the locations receiving full-depth repair that were rubblized with Type I equipment. Additionally, Table 2.5 presents limits of sections that were skipped due to suspected instability that would occur after rubblization. In some of these cases, the concrete condition combined with the already-known marginal soil conditions throughout the project led to the decision to skip the section. For example, Figure 2.10 shows the JCP at station 214. Of the area that was rubblized with the Type I equipment, approximately 14 percent required full-depth repair.

Table 2.4. Locations Receiving Full-Depth Repair within Limits of Type I Rubblization.

Direction	Beginning Station	Ending Station
North	196+41	197+57
North	175+67	175+83
South	175+93	176+48
North	196+00	196+41
North	223+28	224+32
South	225+20	223+28
South	225+90	226+90

Table 2.5. Locations Skipped within Limits of Type I Rubblization.

Beginning Station	Ending Station
191+50	196+00
196+00	197+57*
203+00	223+28

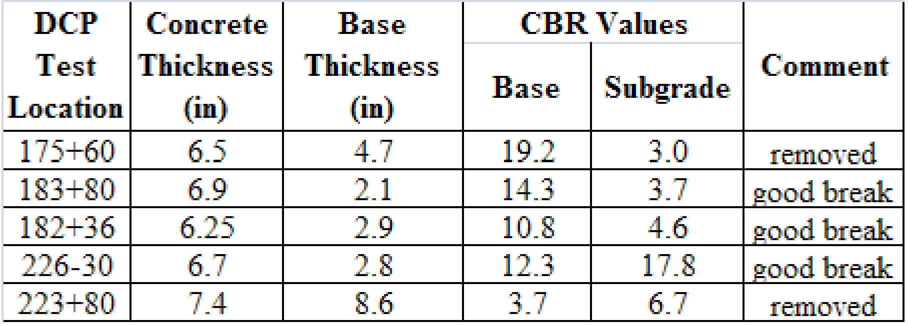
*Skipped in southbound direction; northbound required full-depth repair.

Figure 2.10. Existing JCP at Station 214.

Comparison of Rubblization Selection Chart with Field Construction

TTI researchers sought to evaluate how the rubblization selection chart compared with field experience for the Type I rubblizer. Table 2.6 presents data collected at five locations, two of which required removal and replacement after proof rolling. Figure 2.11 plots these data on the rubblization selection chart. Locations noted in red required removal due to instability after rubblization. The field experiences match the chart reasonably well, with both locations requiring removal having at least one data point in the High Risk zone of the selection chart.

Table 2.6. DCP Data at Type I Rubblization Locations.



DCP Test Location	Concrete Thickness (in)	Base Thickness (in)	CBR Values		Comment
			Base	Subgrade	
175+60	6.5	4.7	19.2	3.0	removed
183+80	6.9	2.1	14.3	3.7	good break
182+36	6.25	2.9	10.8	4.6	good break
226-30	6.7	2.8	12.3	17.8	good break
223+80	7.4	8.6	3.7	6.7	removed

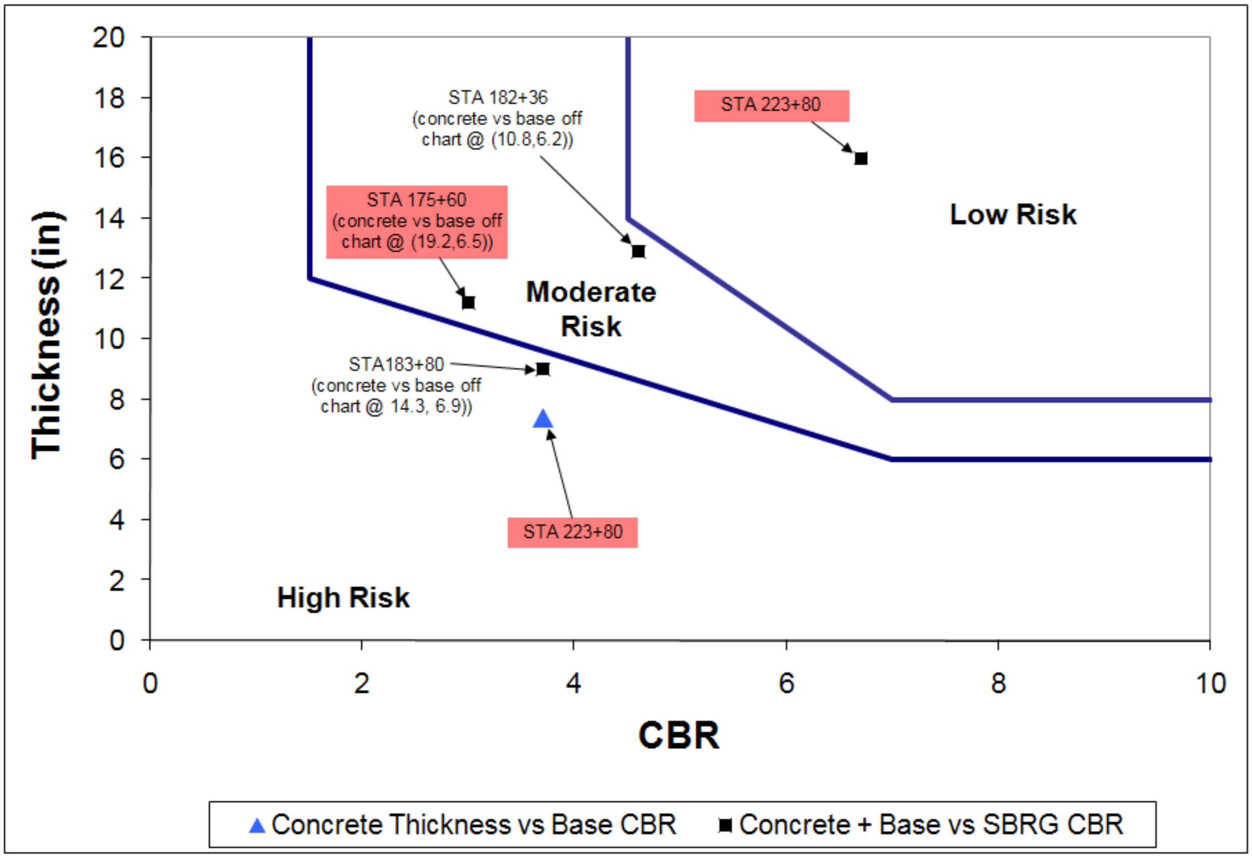


Figure 2.11. Selection Chart Data from Construction for Type I Rubblization.
Note: Locations highlighted in red required full-depth repair.

CONSTRUCTION OF BASE OVERLAY

Regardless of the type of rubblization employed, the flexible base was wetted in a pugmill then placed at the site with an asphalt pave, as Figure 2.12 shows. Instead of blade-spreading the base, a paver was used in attempts to minimize segregation of the base at the project site. A pneumatic and steel wheel roller compacted the base, as Figure 2.13 shows.

Figure 2.12. Placing Base with Paver.

Figure 2.13. Compacting Base with Pneumatic and Steel Wheel Rollers.

Two concerns that arose at the project were segregation and raveling of the drainable base. The contractor off-loaded the base onto the existing JCP at the project site, and after the haul trucks off-loaded, wheel loaders stockpiled the base and transferred the material into the paver hopper.

This handling did result in segregation of the base both inside the paver hopper and on the ground as Figures 2.14 and 2.15, respectively, illustrate. Additionally, traffic had to be allowed on the base after compaction, and the drainable base tended to ravel, particularly at the segregated locations, as Figure 2.16 illustrates. To remedy the deterioration in surface finish, the contractor re-worked the surface immediately prior to sealing.

Figure 2.14. Segregation of Grade 4 Base in Paver Hopper.

Figure 2.15. Segregation of Grade 4 Base after Placement.

Figure 2.16. Raveling and Loss of Surface Finish of Grade 4 Base under Traffic.

CONCLUSIONS FROM CONSTRUCTION OPERATIONS

The construction operations indicated the existing rubblization selection guidelines worked well. Field comparison of subgrade conditions requiring full-depth repair matched well with the rubblization selection chart. In one case with the Type I rubblizer, a location plotting in the Moderate Risk area did require removal. All other locations that were tested that required removal and replacement had at least one point plot in the High Risk location of the selection chart.

SS 3123 seemed to work well for monitoring the rubblization operations. The Type II equipment may not always provide the specified gradation in the top half of the slab thickness, although the specified break pattern is achieved in the top few inches. The Type I rubblizer tends to break the concrete into smaller particles through the depth profile as compared to the Type II equipment. Since the goal of rubblization is to destroy slab action and eliminate the risk of reflective cracking, consideration could be given to reducing the required thickness of smaller particles at the top portion of the JCP.

Placing the base with the paver did not prevent any significant problems with construction and in general seemed better than field mixing and spreading the base with a blade. However, a better system to transfer the base from the trucks to the paver potentially could have reduced segregation and increased production rate.

CHAPTER 3.

PERFORMANCE MONITORING OF FM 912 AND FM 1155

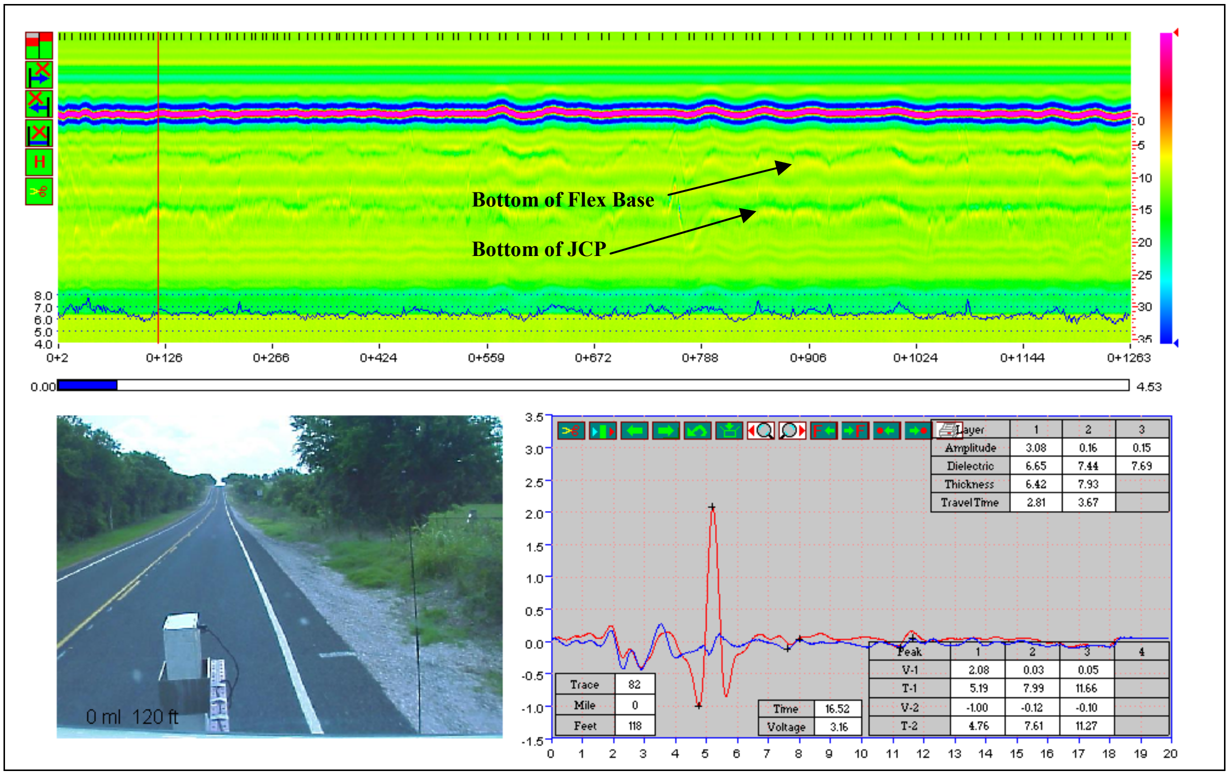
SUMMARY

TTI researchers evaluated the pavement in June of 2009 using GPR, ride, and Falling Weight Defelctometer (FWD) tests. Other than remaining locations of voids beneath the concrete slabs, GPR tests did not reveal any unusual signatures. Ride results showed no differences among sections of varying treatments; the entire pavement had poor ride quality with an average Ingernational Roughenss Index (IRI) of 157. FWD tests showed no differences in modulus between the Grades 2 and 4 bases; the main differences observed were between sections rubblized with different equipment. The sections rubblized with Type II equipment had rubblized and base layer modulus values greater than those observed in the section where Type I equipment was used.

RESULTS FROM GPR

Figure 3.1 shows the sections receiving a flexible base overlay on top of the unrubblized existing JCP, and Figure 3.2 shows representative GPR data from these sections. The season leading up to the time of surveying had been unusually dry, and the strength of reflections from the layers was typically small. The most unusual reflections observed in these sections were the continued negative reflections indicative of voids underneath the concrete approximately 1.5 miles into the project as Figure 3.3 shows. TxDOT purposefully did not include the limits of this section in the rubblization plans due to the poor soil and history of voids and washouts underneath the concrete.

Figure 3.1. Existing JCP with Grade 4 (Left) and Grade 2 (Right) Overlay.



Bottom of Flex Base

Bottom of JCP

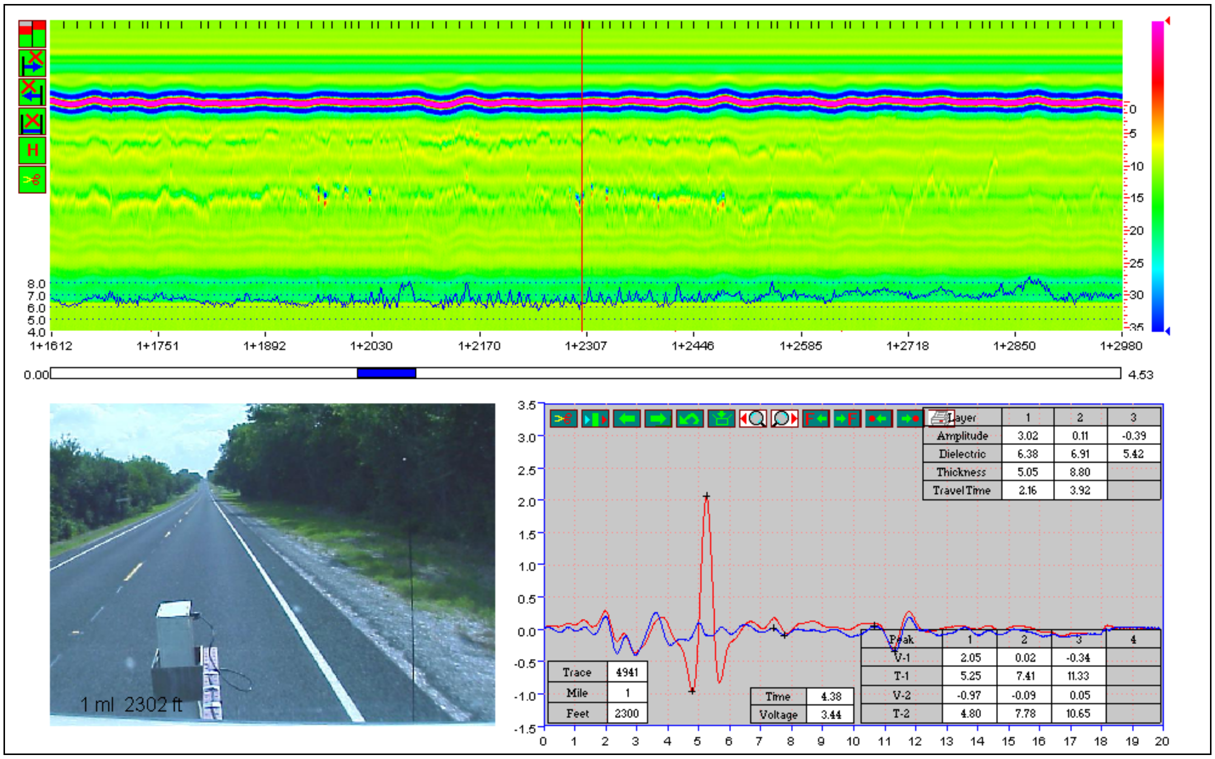
Layer	1	2	3
Amplitude	3.08	0.16	0.15
Dielectric	6.65	7.44	7.69
Thickness	6.42	7.93	
Travel Time	2.81	3.67	

Trace	82
Mile	0
Feet	118

Time	16.52
Voltage	3.16

Peak	1	2	3	4
V-1	2.08	0.03	0.05	
T-1	5.19	7.99	11.66	
V-2	-1.00	-0.12	-0.10	
T-2	4.76	7.61	11.27	

Figure 3.2. GPR Survey Beginning at West End of FM 912.



Layer	1	2	3
Amplitude	3.02	0.11	-0.39
Dielectric	6.38	6.91	5.42
Thickness	5.05	8.80	
Travel Time	2.16	3.92	

Trace	4941
Mile	1
Feet	2300

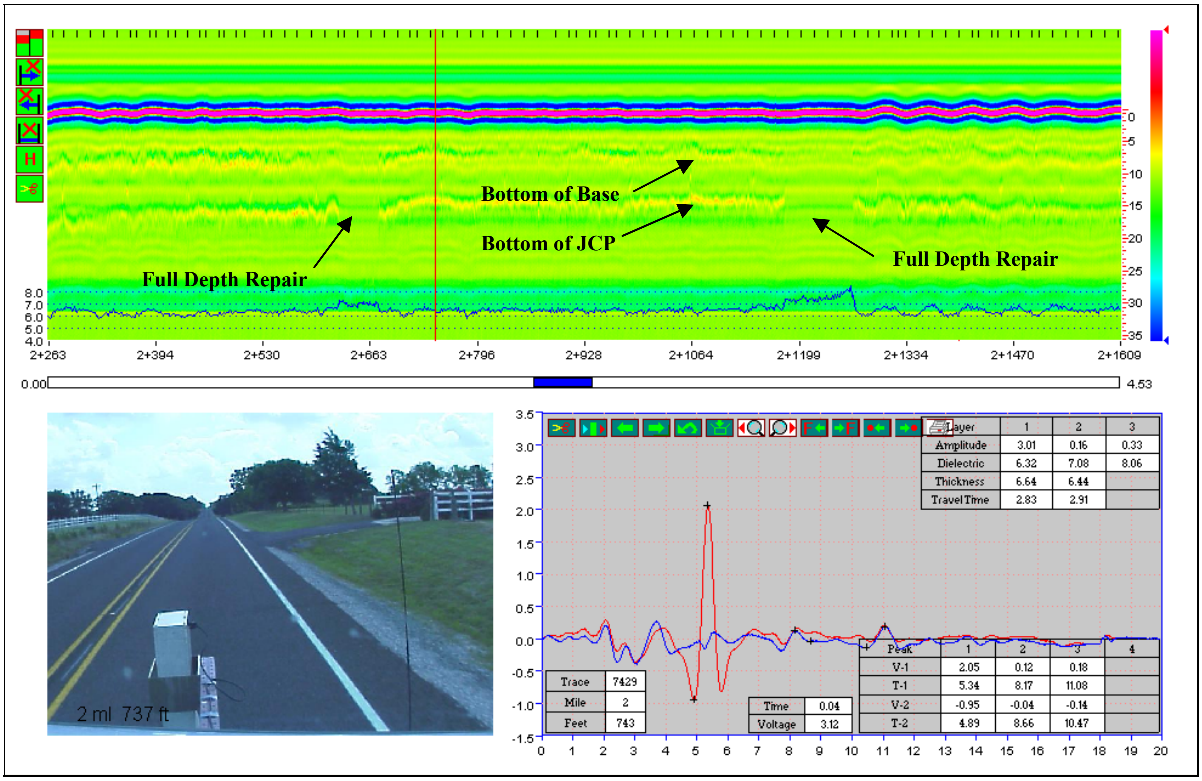
Time	4.38
Voltage	3.44

Peak	1	2	3	4
V-1	2.05	0.02	-0.34	
T-1	5.25	7.41	11.33	
V-2	-0.97	-0.09	0.05	
T-2	4.80	7.78	10.65	

Figure 3.3. Evidence of Voids beneath JCP at Approximately 1.5 Miles.

Figure 3.4 shows the start of the section rubblized with Type II equipment looking northbound. The GPR data in this section, as Figure 3.5 represents, revealed nothing unusual. The waviness of the surface reflection indicates pavement roughness, and the locations of full-depth repairs are typically evident.

Figure 3.4. Start of Type II Rubblization.



Layer	1	2	3
Amplitude	3.01	0.16	0.33
Dielectric	6.32	7.08	8.06
Thickness	6.64	6.44	
Travel Time	2.83	2.91	

Trace	7429
Mile	2
Feet	743

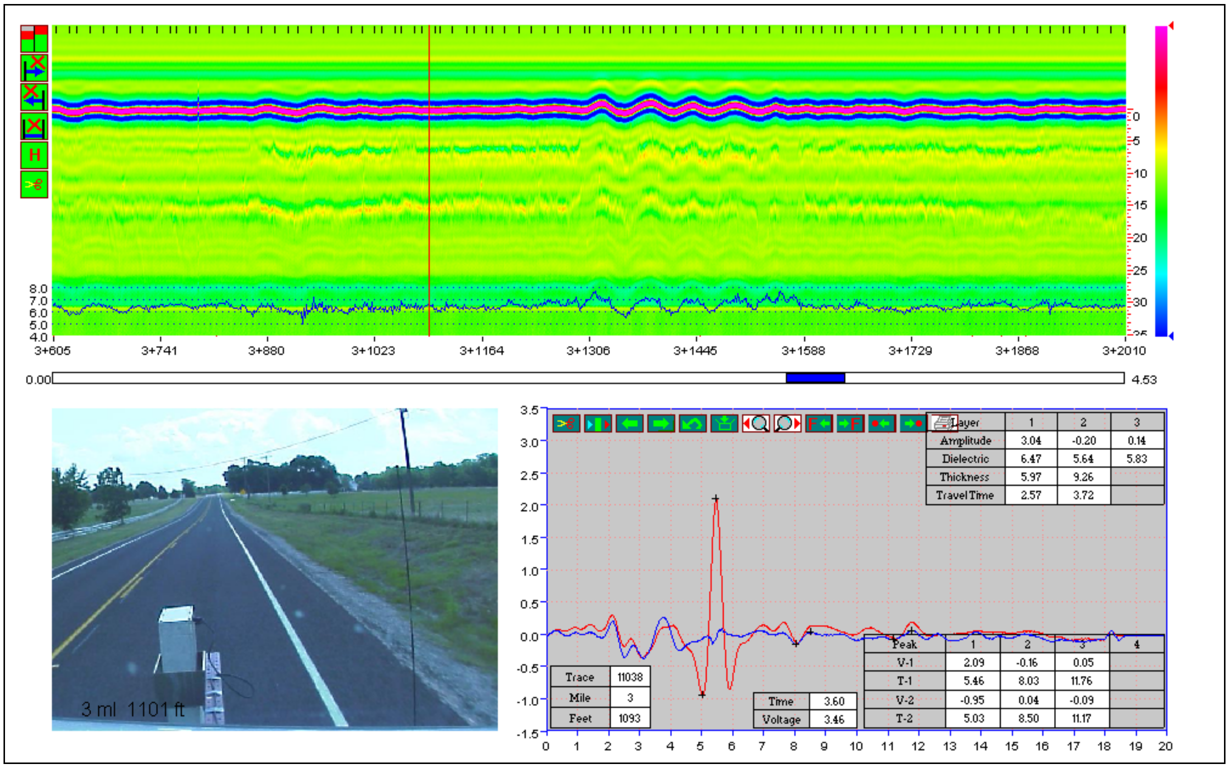
Time	0.04
Voltage	3.12

Peak	1	2	3	4
V-1	2.05	0.12	0.18	
T-1	5.34	8.17	11.08	
V-2	-0.95	-0.04	-0.14	
T-2	4.89	8.66	10.47	

Figure 3.5. Representative GPR from Type II Rubblization.

Figure 3.6 shows the start of the section rubblized with Type I equipment looking northbound, and Figure 3.7 shows representative GPR from this section. Similar to the data from the section rubblized with Type II equipment, the GPR data are clean and do not indicate any problems within the pavement structure. Again, roughness in the surface reflection is evident and scrolling through the data reveals locations evident of full-depth repair.

Figure 3.6. Start of Type I Rubblization with Grade 2 Base Overlay.



Layer	1	2	3
Amplitude	3.04	-0.20	0.14
Dielectric	6.47	5.64	5.83
Thickness	5.97	9.26	
Travel Time	2.57	3.72	

Trace	11038
Mile	3
Feet	1093

Time	3.60
Voltage	3.46

Peak	1	2	3	4
V-1	2.09	-0.16	0.05	
T-1	5.46	8.03	11.76	
V-2	-0.95	0.04	-0.09	
T-2	5.03	8.50	11.17	

Figure 3.7. Example GPR from Type I Rubblization with Grade 2 Overlay.

RESULTS FROM RIDE TESTING

TTI collected ride results on the pavement using the profiler shown in Figure 3.8. Table 3.1 shows the ProVAL 2.7 analysis output. To evaluate the results researchers first evaluated the left and right wheel path results for equivalence with a paired t-test; the result showed the left and right wheel path results were not equivalent. Therefore, researchers segmented the data according to treatment (omitting the segment from 8448 to 8976 feet due to a bridge) then evaluated IRI among the treatments for the left and right wheel paths independently. Analysis of variance results showed that, for both wheel paths, the mean IRI was equivalent among all the treatments. Figure 3.9 shows the mean IRI values. Since this entire project received a flexible base overlay and only a surface treatment, the ride quality largely depends on the smoothness of the finished base and in the longer term could be impacted by movement in the subgrade soil.

Figure 3.8. TTI Profiler.

Table 3.1. ProVAL 2.7 Analysis Output.

	Left			Right			HRI	MRI
Interval (ft)	IRI (in/mi)	PTRN (in/mi)	RN	IRI (in/mi)	PTRN (in/mi)	RN	(in/mi)	(in/mi)
0.0 to 528.0	184	301.7	2.33	169.4	250.9	2.65	149.3	176.7
528.0 to 1056.0	180.8	221.9	2.86	174.5	224.6	2.84	157.5	177.6
1056.0 to 1584.0	192.1	248	2.67	239.5	280.4	2.46	185.8	215.8
1584.0 to 2112.0	216.2	281	2.46	225.1	330.8	2.17	185.9	220.7
2112.0 to 2640.0	148.7	261.8	2.58	148.1	242.1	2.71	124.3	148.4
2640.0 to 3168.0	163.2	268	2.54	161.9	250.6	2.66	130.1	162.6
3168.0 to 3696.0	141.1	244.9	2.69	163.9	271.7	2.52	121.7	152.5
3696.0 to 4224.0	204.7	312.1	2.27	167.4	303.9	2.32	151.2	186.1
4224.0 to 4752.0	97.3	203.4	2.99	103.2	210.4	2.94	79.5	100.2
4752.0 to 5280.0	141.3	225	2.83	147.7	251.8	2.65	113.7	144.5
5280.0 to 5808.0	217.4	307.1	2.3	181.5	295.9	2.37	164.8	199.5
5808.0 to 6336.0	149.9	239.1	2.73	129.4	215.3	2.9	114.9	139.7
6336.0 to 6864.0	132.6	217.6	2.89	129.3	214	2.91	102.4	130.9
6864.0 to 7392.0	142	255.8	2.62	160.5	242.9	2.71	123.2	151.2
7392.0 to 7920.0	129.2	283.9	2.44	148	271.3	2.52	109.5	138.6
7920.0 to 8448.0	177.6	302.3	2.33	168.1	286.6	2.42	135.2	172.8
8448.0 to 8976.0	245.4	388.4	1.87	269.5	420	1.73	205.3	257.5
8976.0 to 9504.0	144.9	316.8	2.25	132.3	267.6	2.54	106.7	138.6
9504.0 to 10032.0	145.6	307.2	2.3	153.2	267.8	2.54	111.2	149.4
10032.0 to 10560.0	161.8	278.9	2.47	177.7	295	2.37	132.2	169.7
10560.0 to 11088.0	178.7	265.8	2.56	195.4	252.9	2.64	149.9	187
11088.0 to 11616.0	141.8	246.8	2.68	148.1	237.6	2.74	115	145
11616.0 to 12144.0	146.7	276.1	2.49	146.7	227.8	2.81	119.3	146.7
12144.0 to 12672.0	160	254.7	2.63	166.4	243.3	2.7	137.8	163.2
12672.0 to 13200.0	197.3	325.5	2.2	156	253.2	2.64	135.8	176.7
13200.0 to 13728.0	170.3	329.5	2.18	146.1	255.1	2.63	129.3	158.2
13728.0 to 14256.0	212	337.5	2.13	166.3	284.1	2.44	162	189.1
14256.0 to 14784.0	149.6	269.9	2.53	133	271.3	2.52	120.5	141.3
14784.0 to 15312.0	154.8	308.5	2.29	137.5	263.6	2.57	119	146.2
15312.0 to 15840.0	148.2	299.9	2.34	132.4	245	2.69	111.2	140.3
15840.0 to 16368.0	164.2	253.6	2.64	150.3	229.4	2.8	135.7	157.2
16368.0 to 16896.0	119.7	250.3	2.66	99.9	209.6	2.94	89.4	109.8
16896.0 to 17424.0	161.8	345.4	2.09	167.7	332.4	2.16	134.4	164.8
17424.0 to 17952.0	165.1	293.2	2.38	159.5	276.2	2.49	134.9	162.3
17952.0 to 18480.0	151.5	281.9	2.45	140.4	264.9	2.56	112.8	145.9
18480.0 to 19008.0	106.8	221.3	2.86	123.2	233.2	2.77	90.5	115
19008.0 to 19536.0	146.2	320.7	2.22	127.8	259.3	2.6	111.3	137
19536.0 to 20064.0	154.5	303.6	2.32	166.1	321.9	2.22	118.3	160.3
20064.0 to 20592.0	198.2	316.2	2.25	144	287	2.42	144.3	171.1
20592.0 to 21120.0	175.9	289.8	2.41	126.6	270.9	2.52	126.7	151.2
21120.0 to 21648.0	161.1	307.8	2.3	130.2	265.4	2.56	114.9	145.6
21648.0 to 22176.0	236.9	344.1	2.1	153.9	292.2	2.39	168.5	195.4
22176.0 to 22704.0	248.7	385.5	1.89	179.1	303.8	2.32	179	213.9
22704.0 to 23232.0	198.2	344	2.1	171.4	287.4	2.42	154.3	184.8
23232.0 to 23760.0	159.3	269	2.53	157.7	248.5	2.67	128.6	158.5
23760.0 to 23935.2	154.2	262.3	2.58	176.8	241	2.72	140.5	165.5

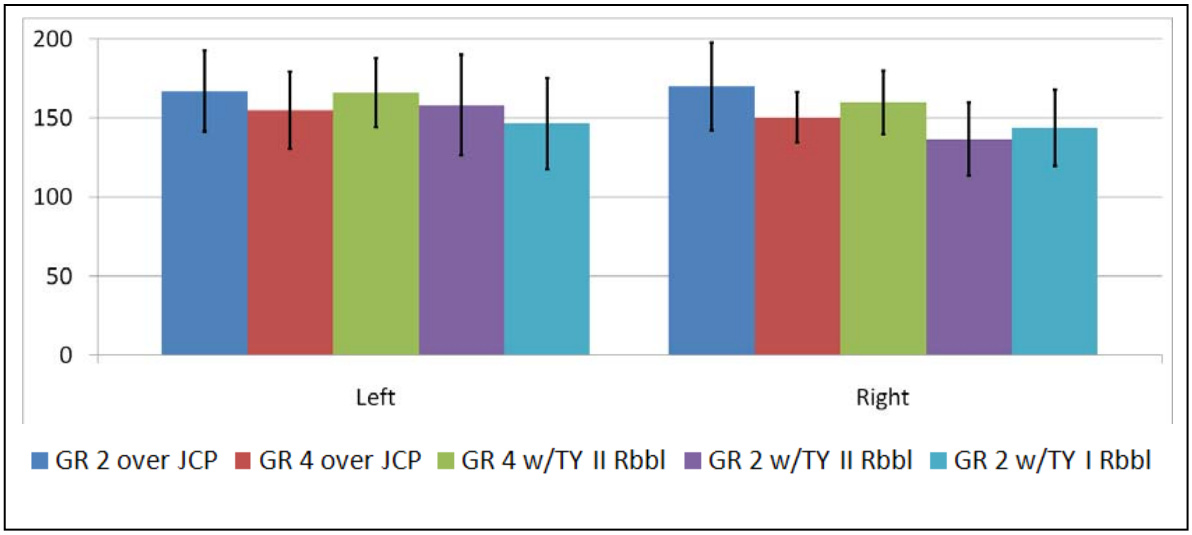


Figure 3.9. Mean IRI Values with 95 Percent Confidence Intervals.

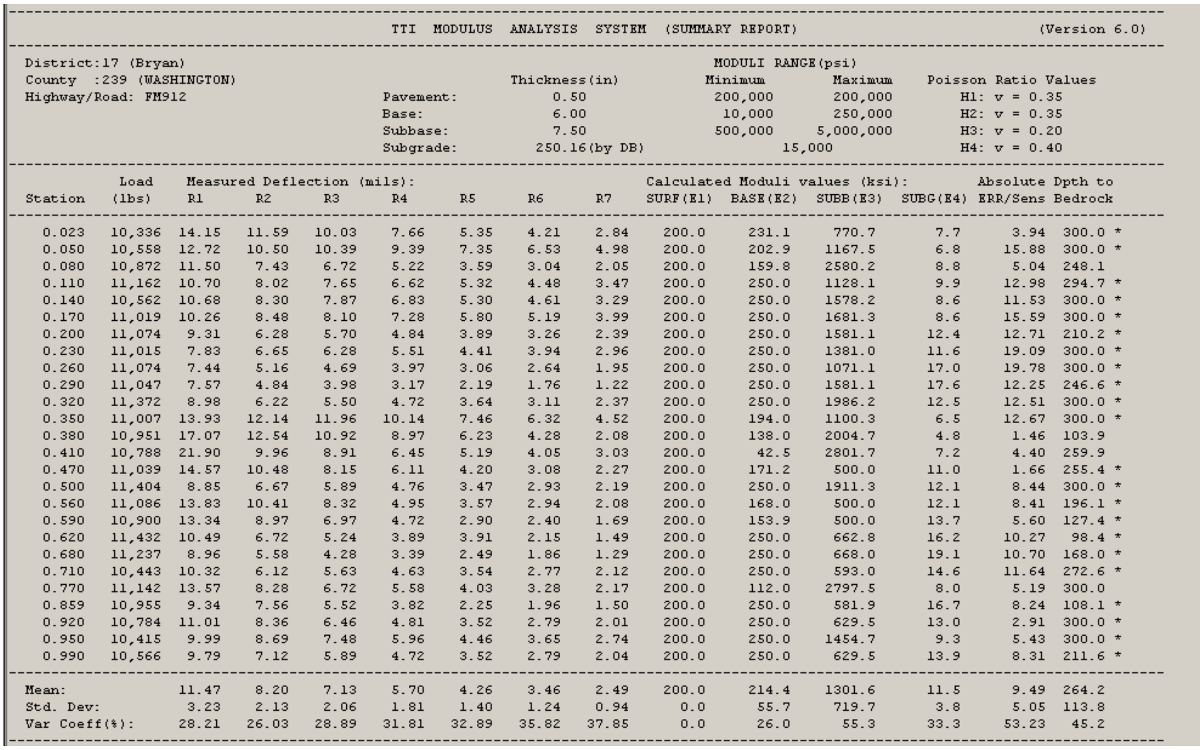
RESULTS FROM FWD TESTING

Researchers collected an FWD survey in the summer of 2009 to evaluate the following:

- What modulus values of the unrubblized concrete and flex base overlays were observed?
- How does the modulus of the rubblized layers compare with the value of the unrubblized JCP?
- Does the modulus of the rubblized layers vary depending on the equipment and break pattern achieved?
- What modulus values for the flex base overlays over the rubblized concrete were observed? Was there a difference between the Grade 2 and Grade 4 base?

Tables 3.2 through 3.7 present the FWD data analysis outputs for the different sections.

Table 3.2. FWD Result for Grade 2 Base over JCP.



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                                     TTI  MODULUS  ANALYSIS  SYSTEM  (SUMMARY REPORT)                  (Version 6.0)
--------------------------------------------------------------------------------------------------------------
 District:17 (Bryan)                                                           MODULI RANGE(psi)
 County  :239 (WASHINGTON)                                 Thickness(in)     Minimum      Maximum    Poisson Ratio Values
 Highway/Road: FM912                          Pavement:        0.50          200,000      200,000       H1: v = 0.35
                                              Base:            6.00           10,000      250,000       H2: v = 0.35
                                              Subbase:         7.50          500,000    5,000,000       H3: v = 0.20
                                              Subgrade:      250.16(by DB)          15,000              H4: v = 0.40
--------------------------------------------------------------------------------------------------------------
          Load    Measured Deflection (mils):                             Calculated Moduli values (ksi):        Absolute Dpth to
 Station  (lbs)   R1      R2      R3      R4      R5      R6      R7    SURF(E1)  BASE(E2)  SUBB(E3)  SUBG(E4) ERR/Sens Bedrock
--------------------------------------------------------------------------------------------------------------
   0.023  10,336  14.15   11.59   10.03    7.66    5.35    4.21    2.84    200.0     231.1     770.7       7.7     3.94  300.0 *
   0.050  10,558  12.72   10.50   10.39    9.39    7.35    6.53    4.98    200.0     202.9    1167.5       6.8    15.88  300.0 *
   0.080  10,872  11.50    7.43    6.72    5.22    3.59    3.04    2.05    200.0     159.8    2580.2       8.8     5.04  248.1
   0.110  11,162  10.70    8.02    7.65    6.62    5.32    4.48    3.47    200.0     250.0    1128.1       9.9    12.98  294.7 *
   0.140  10,562  10.68    8.30    7.87    6.83    5.30    4.61    3.29    200.0     250.0    1578.2       8.6    11.53  300.0 *
   0.170  11,019  10.26    8.48    8.10    7.28    5.80    5.19    3.99    200.0     250.0    1681.3       8.6    15.59  300.0 *
   0.200  11,074   9.31    6.28    5.70    4.84    3.89    3.26    2.39    200.0     250.0    1581.1      12.4    12.71  210.2 *
   0.230  11,015   7.83    6.65    6.28    5.51    4.41    3.94    2.96    200.0     250.0    1381.0      11.6    19.09  300.0 *
   0.260  11,074   7.44    5.16    4.69    3.97    3.06    2.64    1.95    200.0     250.0    1071.1      17.0    19.78  300.0 *
   0.290  11,047   7.57    4.84    3.98    3.17    2.19    1.76    1.22    200.0     250.0    1581.1      17.6    12.25  246.6 *
   0.320  11,372   8.98    6.22    5.50    4.72    3.64    3.11    2.37    200.0     250.0    1986.2      12.5    12.51  300.0 *
   0.350  11,007  13.93   12.14   11.96   10.14    7.46    6.32    4.52    200.0     194.0    1100.3       6.5    12.67  300.0 *
   0.380  10,951  17.07   12.54   10.92    8.97    6.23    4.28    2.08    200.0     138.0    2004.7       4.8     1.46  103.9
   0.410  10,788  21.90    9.96    8.91    6.45    5.19    4.05    3.03    200.0      42.5    2801.7       7.2     4.40  259.9
   0.470  11,039  14.57   10.48    8.15    6.11    4.20    3.08    2.27    200.0     171.2     500.0      11.0     1.66  255.4 *
   0.500  11,404   8.85    6.67    5.89    4.76    3.47    2.93    2.19    200.0     250.0    1911.3      12.1     8.44  300.0 *
   0.560  11,086  13.83   10.41    8.32    4.95    3.57    2.94    2.08    200.0     168.0     500.0      12.1     8.41  196.1 *
   0.590  10,900  13.34    8.97    6.97    4.72    2.90    2.40    1.69    200.0     153.9     500.0      13.7     5.60  127.4 *
   0.620  11,432  10.49    6.72    5.24    3.89    3.91    2.15    1.49    200.0     250.0     662.8      16.2    10.27   98.4 *
   0.680  11,237   8.96    5.58    4.28    3.39    2.49    1.86    1.29    200.0     250.0     668.0      19.1    10.70  168.0 *
   0.710  10,443  10.32    6.12    5.63    4.63    3.54    2.77    2.12    200.0     250.0     593.0      14.6    11.64  272.6 *
   0.770  11,142  13.57    8.28    6.72    5.58    4.03    3.28    2.17    200.0     112.0    2797.5       8.0     5.19  300.0
   0.859  10,955   9.34    7.56    5.52    3.82    2.25    1.96    1.50    200.0     250.0     581.9      16.7     8.24  108.1 *
   0.920  10,784  11.01    8.36    6.46    4.81    3.52    2.79    2.01    200.0     250.0     629.5      13.0     2.91  300.0 *
   0.950  10,415   9.99    8.69    7.48    5.96    4.46    3.65    2.74    200.0     250.0    1454.7       9.3     5.43  300.0 *
   0.990  10,566   9.79    7.12    5.89    4.72    3.52    2.79    2.04    200.0     250.0     629.5      13.9     8.31  211.6 *
--------------------------------------------------------------------------------------------------------------
 Mean:            11.47    8.20    7.13    5.70    4.26    3.46    2.49    200.0     214.4    1301.6      11.5     9.49  264.2
 Std. Dev:         3.23    2.13    2.06    1.81    1.40    1.24    0.94      0.0      55.7     719.7       3.8     5.05  113.8
 Var Coeff(%):    28.21   26.03   28.89   31.81   32.89   35.82   37.85      0.0      26.0      55.3      33.3    53.23   45.2
--------------------------------------------------------------------------------------------------------------
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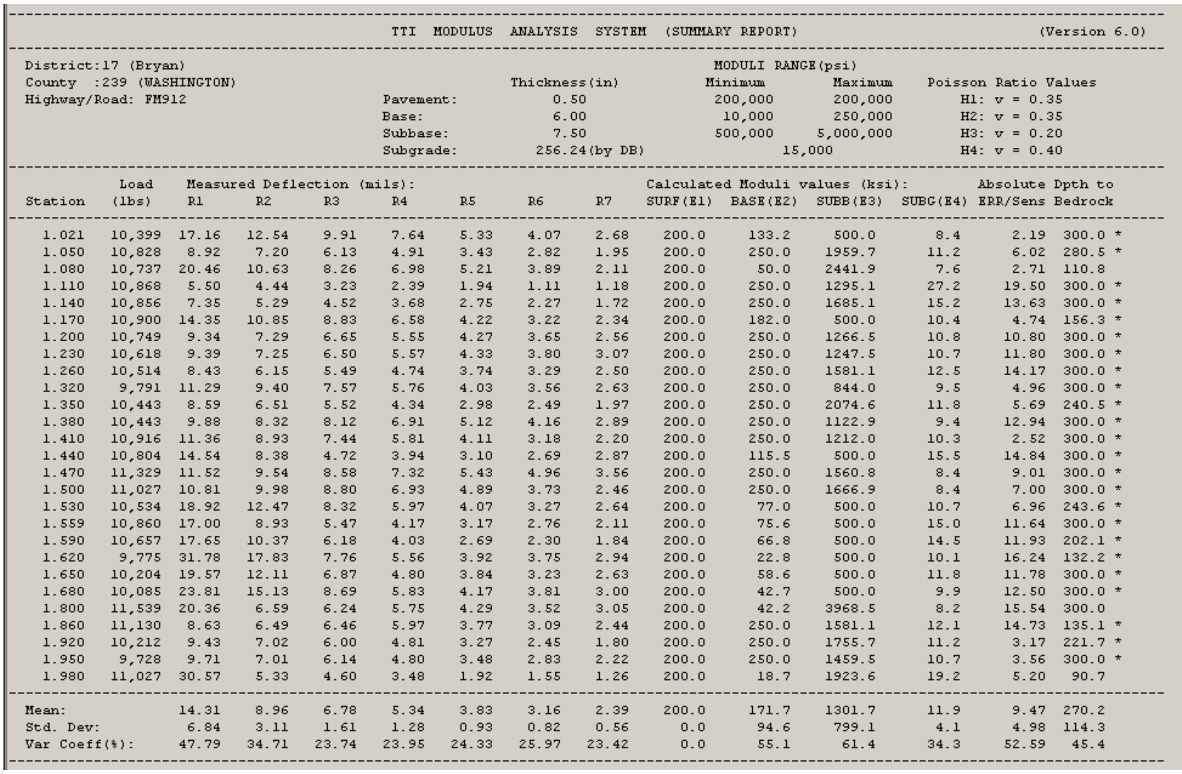
Table 3.3. FWD Result for Grade 4 Base over JCP.



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                                     TTI  MODULUS  ANALYSIS  SYSTEM  (SUMMARY REPORT)                  (Version 6.0)
--------------------------------------------------------------------------------------------------------------
 District:17 (Bryan)                                                           MODULI RANGE(psi)
 County  :239 (WASHINGTON)                                 Thickness(in)     Minimum      Maximum    Poisson Ratio Values
 Highway/Road: FM912                          Pavement:        0.50          200,000      200,000       H1: v = 0.35
                                              Base:            6.00           10,000      250,000       H2: v = 0.35
                                              Subbase:         7.50          500,000    5,000,000       H3: v = 0.20
                                              Subgrade:      256.24(by DB)          15,000              H4: v = 0.40
--------------------------------------------------------------------------------------------------------------
          Load    Measured Deflection (mils):                             Calculated Moduli values (ksi):        Absolute Dpth to
 Station  (lbs)   R1      R2      R3      R4      R5      R6      R7    SURF(E1)  BASE(E2)  SUBB(E3)  SUBG(E4) ERR/Sens Bedrock
--------------------------------------------------------------------------------------------------------------
   1.021  10,399  17.16   12.54    9.91    7.64    5.33    4.07    2.68    200.0     133.2     500.0       8.4     2.19  300.0 *
   1.050  10,828   8.92    7.20    6.13    4.91    3.43    2.82    1.95    200.0     250.0    1959.7      11.2     6.02  280.5 *
   1.080  10,737  20.46   10.63    8.26    6.98    5.21    3.89    2.11    200.0      50.0    2441.9       7.6     2.71  110.8
   1.110  10,868   5.50    4.44    3.23    2.39    1.94    1.11    1.18    200.0     250.0    1295.1      27.2    19.50  300.0 *
   1.140  10,856   7.35    5.29    4.52    3.68    2.75    2.27    1.72    200.0     250.0    1685.1      15.2    13.63  300.0 *
   1.170  10,900  14.35   10.85    8.83    6.58    4.22    3.22    2.34    200.0     182.0     500.0      10.4     4.74  156.3 *
   1.200  10,749   9.34    7.29    6.65    5.55    4.27    3.65    2.56    200.0     250.0    1266.5      10.8    10.80  300.0 *
   1.230  10,618   9.39    7.25    6.50    5.57    4.33    3.80    3.07    200.0     250.0    1247.5      10.7    11.80  300.0 *
   1.260  10,514   8.43    6.15    5.49    4.74    3.74    3.29    2.50    200.0     250.0    1581.1      12.5    14.17  300.0 *
   1.320   9,791  11.29    9.40    7.57    5.76    4.03    3.56    2.63    200.0     250.0     844.0       9.5     4.96  300.0 *
   1.350  10,443   8.59    6.51    5.52    4.34    2.98    2.49    1.97    200.0     250.0    2074.6      11.8     5.69  240.5 *
   1.380  10,443   9.88    8.32    8.12    6.91    5.12    4.16    2.89    200.0     250.0    1122.9       9.4    12.94  300.0 *
   1.410  10,916  11.36    8.93    7.44    5.81    4.11    3.18    2.20    200.0     250.0    1212.0      10.3     2.52  300.0 *
   1.440  10,804  14.54    8.38    4.72    3.94    3.10    2.69    2.87    200.0     115.5     500.0      15.5    14.84  300.0 *
   1.470  11,329  11.52    9.54    8.58    7.32    5.43    4.96    3.56    200.0     250.0    1560.8       8.4     9.01  300.0 *
   1.500  11,027  10.81    9.98    8.80    6.93    4.89    3.73    2.46    200.0     250.0    1666.9       8.4     7.00  300.0 *
   1.530  10,534  18.92   12.47    8.32    5.97    4.07    3.27    2.64    200.0      77.0     500.0      10.7     6.96  243.6 *
   1.559  10,860  17.00    8.93    5.47    4.17    3.17    2.76    2.11    200.0      75.6     500.0      15.0    11.64  300.0 *
   1.590  10,657  17.65   10.37    6.18    4.03    2.69    2.30    1.84    200.0      66.8     500.0      14.5    11.93  202.1 *
   1.620   9,775  31.78   17.83    7.76    5.56    3.92    3.75    2.94    200.0      22.8     500.0      10.1    16.24  132.2 *
   1.650  10,204  19.57   12.11    6.87    4.80    3.84    3.23    2.63    200.0      58.6     500.0      11.8    11.78  300.0 *
   1.680  10,085  23.81   15.13    8.69    5.83    4.17    3.81    3.00    200.0      42.7     500.0       9.9    12.50  300.0 *
   1.800  11,539  20.36    6.59    6.24    5.75    4.29    3.52    3.05    200.0      42.2    3968.5       8.2    15.54  300.0
   1.860  11,130   8.63    6.49    6.46    5.97    3.77    3.09    2.44    200.0     250.0    1581.1      12.1    14.73  135.1 *
   1.920  10,212   9.43    7.02    6.00    4.81    3.27    2.45    1.80    200.0     250.0    1755.7      11.2     3.17  221.7 *
   1.950   9,728   9.71    7.01    6.14    4.80    3.48    2.83    2.22    200.0     250.0    1459.5      10.7     3.56  300.0 *
   1.980  11,027  30.57    5.33    4.60    3.48    1.92    1.55    1.26    200.0      18.7    1923.6      19.2     5.20   90.7
--------------------------------------------------------------------------------------------------------------
 Mean:            14.31    8.96    6.78    5.34    3.83    3.16    2.39    200.0     171.7    1301.7      11.9     9.47  270.2
 Std. Dev:         6.84    3.11    1.61    1.28    0.93    0.82    0.56      0.0      94.6     799.1       4.1     4.98  114.3
 Var Coeff(%):    47.79   34.71   23.74   23.95   24.33   25.97   23.42      0.0      55.1      61.4      34.3    52.59   45.4
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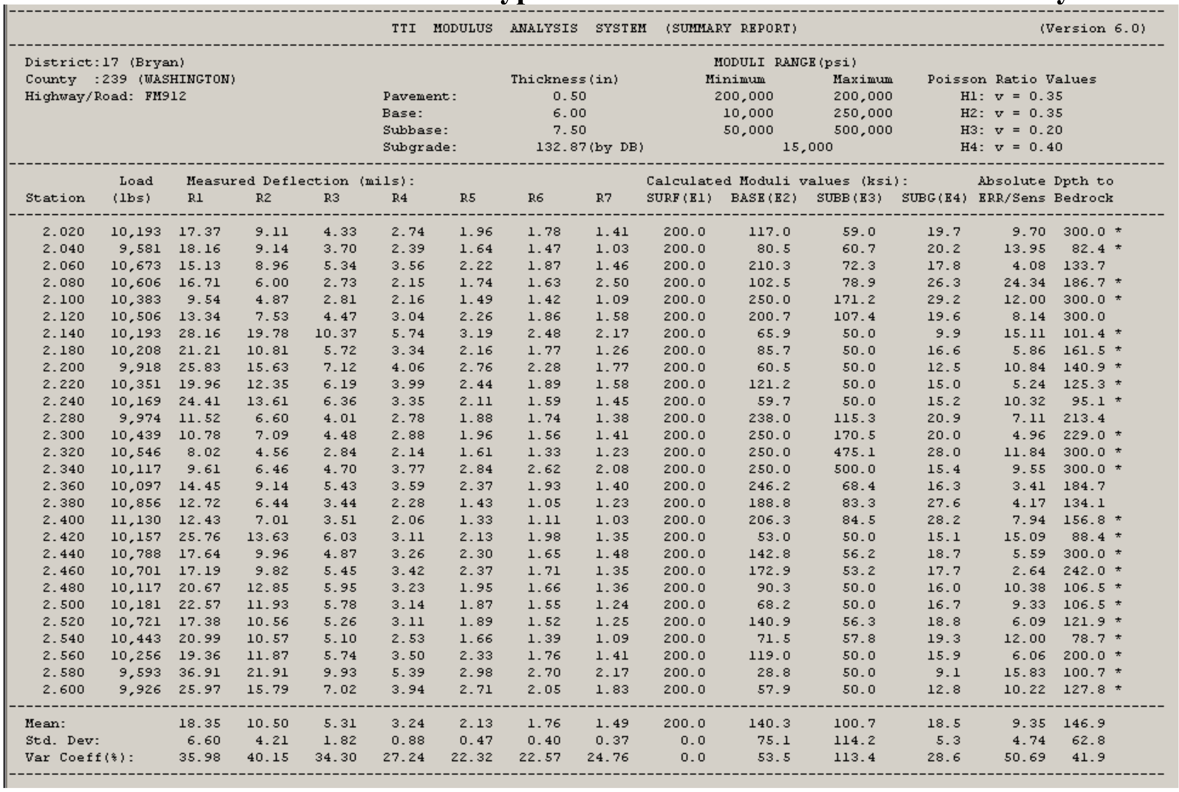
Table 3.4. FWD Result for Type II Rubblization with Grade 4 Overlay.



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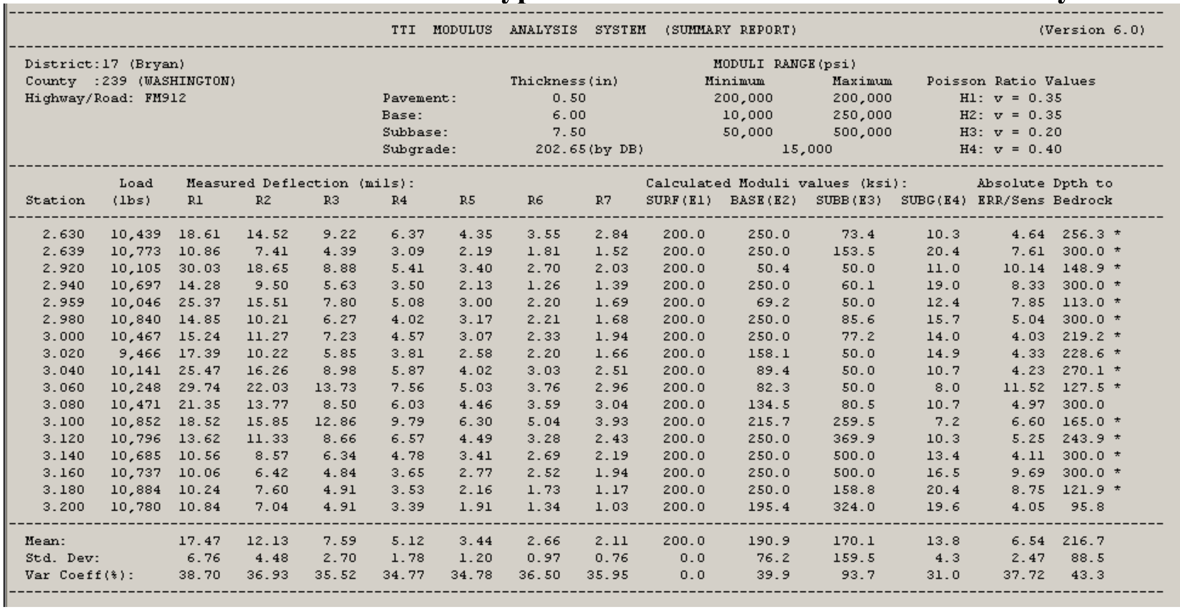
                                            TTI  MODULUS  ANALYSIS  SYSTEM  (SUMMARY REPORT)                        (Version 6.0)
----------------------------------------------------------------------------------------------------------------------------------
District:17 (Bryan)                                                                MODULI RANGE(psi)
County  :239 (WASHINGTON)                                   Thickness(in)       Minimum     Maximum     Poisson Ratio Values
Highway/Road: FM912                       Pavement:             0.50            200,000     200,000          H1: v = 0.35
                                          Base:                 6.00             10,000     250,000          H2: v = 0.35
                                          Subbase:              7.50             50,000     500,000          H3: v = 0.20
                                          Subgrade:           132.87(by DB)            15,000                H4: v = 0.40
----------------------------------------------------------------------------------------------------------------------------------
          Load    Measured Deflection (mils):                              Calculated Moduli values (ksi):          Absolute Dpth to
Station   (lbs)   R1      R2      R3      R4      R5      R6      R7     SURF(E1)  BASE(E2)  SUBB(E3)  SUBG(E4)  ERR/Sens Bedrock
----------------------------------------------------------------------------------------------------------------------------------
   2.020   10,193  17.37    9.11    4.33    2.74    1.96    1.78    1.41    200.0     117.0      59.0      19.7       9.70  300.0 *
   2.040    9,581  18.16    9.14    3.70    2.39    1.64    1.47    1.03    200.0      80.5      60.7      20.2      13.95   82.4 *
   2.060   10,673  15.13    8.96    5.34    3.56    2.22    1.87    1.46    200.0     210.3      72.3      17.8       4.08  133.7
   2.080   10,606  16.71    6.00    2.73    2.15    1.74    1.63    2.50    200.0     102.5      78.9      26.3      24.34  186.7 *
   2.100   10,383   9.54    4.87    2.81    2.16    1.49    1.42    1.09    200.0     250.0     171.2      29.2      12.00  300.0 *
   2.120   10,506  13.34    7.53    4.47    3.04    2.26    1.86    1.58    200.0     200.7     107.4      19.6       8.14  300.0
   2.140   10,193  28.16   19.78   10.37    5.74    3.19    2.48    2.17    200.0      65.9      50.0       9.9      15.11  101.4 *
   2.180   10,208  21.21   10.81    5.72    3.34    2.16    1.77    1.26    200.0      85.7      50.0      16.6       5.86  161.5 *
   2.200    9,918  25.83   15.63    7.12    4.06    2.76    2.28    1.77    200.0      60.5      50.0      12.5      10.84  140.9 *
   2.220   10,351  19.96   12.35    6.19    3.99    2.44    1.89    1.58    200.0     121.2      50.0      15.0       5.24  125.3 *
   2.240   10,169  24.41   13.61    6.36    3.35    2.11    1.59    1.45    200.0      59.7      50.0      15.2      10.32   95.1 *
   2.280    9,974  11.52    6.60    4.01    2.78    1.88    1.74    1.38    200.0     238.0     115.3      20.9       7.11  213.4
   2.300   10,439  10.78    7.09    4.48    2.88    1.96    1.56    1.41    200.0     250.0     170.5      20.0       4.96  229.0 *
   2.320   10,546   8.02    4.56    2.84    2.14    1.61    1.33    1.23    200.0     250.0     475.1      28.0      11.84  300.0 *
   2.340   10,117   9.61    6.46    4.70    3.77    2.84    2.62    2.08    200.0     250.0     500.0      15.4       9.55  300.0 *
   2.360   10,097  14.45    9.14    5.43    3.59    2.37    1.93    1.40    200.0     246.2      68.4      16.3       3.41  184.7
   2.380   10,856  12.72    6.44    3.44    2.28    1.43    1.05    1.23    200.0     188.8      83.3      27.6       4.17  134.1
   2.400   11,130  12.43    7.01    3.51    2.06    1.33    1.11    1.03    200.0     206.3      84.5      28.2       7.94  156.8 *
   2.420   10,157  25.76   13.63    6.03    3.11    2.13    1.98    1.35    200.0      53.0      50.0      15.1      15.09   88.4 *
   2.440   10,788  17.64    9.96    4.87    3.26    2.30    1.65    1.48    200.0     142.8      56.2      18.7       5.59  300.0 *
   2.460   10,701  17.19    9.82    5.45    3.42    2.37    1.71    1.35    200.0     172.9      53.2      17.7       2.64  242.0 *
   2.480   10,117  20.67   12.85    5.95    3.23    1.95    1.66    1.36    200.0      90.3      50.0      16.0      10.38  106.5 *
   2.500   10,181  22.57   11.93    5.78    3.14    1.87    1.55    1.24    200.0      68.2      50.0      16.7       9.33  106.5 *
   2.520   10,721  17.38   10.56    5.26    3.11    1.89    1.52    1.25    200.0     140.9      56.3      18.8       6.09  121.9 *
   2.540   10,443  20.99   10.57    5.10    2.53    1.66    1.39    1.09    200.0      71.5      57.8      19.3      12.00   78.7 *
   2.560   10,256  19.36   11.87    5.74    3.50    2.33    1.76    1.41    200.0     119.0      50.0      15.9       6.06  200.0 *
   2.580    9,593  36.91   21.91    9.93    5.39    2.98    2.70    2.17    200.0      28.8      50.0       9.1      15.83  100.7 *
   2.600    9,926  25.97   15.79    7.02    3.94    2.71    2.05    1.83    200.0      57.9      50.0      12.8      10.22  127.8 *
----------------------------------------------------------------------------------------------------------------------------------
Mean:                    18.35   10.50    5.31    3.24    2.13    1.76    1.49    200.0     140.3     100.7      18.5       9.35  146.9
Std. Dev:                 6.60    4.21    1.82    0.88    0.47    0.40    0.37      0.0      75.1     114.2       5.3       4.74   62.8
Var Coeff(%):            35.98   40.15   34.30   27.24   22.32   22.57   24.76      0.0      53.5     113.4      28.6      50.69   41.9
----------------------------------------------------------------------------------------------------------------------------------
```

Table 3.5. FWD Result for Type II Rubblization with Grade 2 Overlay.



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                                            TTI  MODULUS  ANALYSIS  SYSTEM  (SUMMARY REPORT)                        (Version 6.0)
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District:17 (Bryan)                                                                MODULI RANGE(psi)
County  :239 (WASHINGTON)                                   Thickness(in)       Minimum     Maximum     Poisson Ratio Values
Highway/Road: FM912                       Pavement:             0.50            200,000     200,000          H1: v = 0.35
                                          Base:                 6.00             10,000     250,000          H2: v = 0.35
                                          Subbase:              7.50             50,000     500,000          H3: v = 0.20
                                          Subgrade:           202.65(by DB)            15,000                H4: v = 0.40
----------------------------------------------------------------------------------------------------------------------------------
          Load    Measured Deflection (mils):                              Calculated Moduli values (ksi):          Absolute Dpth to
Station   (lbs)   R1      R2      R3      R4      R5      R6      R7     SURF(E1)  BASE(E2)  SUBB(E3)  SUBG(E4)  ERR/Sens Bedrock
----------------------------------------------------------------------------------------------------------------------------------
   2.630   10,439  18.61   14.52    9.22    6.37    4.35    3.55    2.84    200.0     250.0      73.4      10.3       4.64  256.3 *
   2.639   10,773  10.86    7.41    4.39    3.09    2.19    1.81    1.52    200.0     250.0     153.5      20.4       7.61  300.0 *
   2.920   10,105  30.03   18.65    8.88    5.41    3.40    2.70    2.03    200.0      50.4      50.0      11.0      10.14  148.9 *
   2.940   10,697  14.28    9.50    5.63    3.50    2.13    1.26    1.39    200.0     250.0      60.1      19.0       8.33  300.0 *
   2.959   10,046  25.37   15.51    7.80    5.08    3.00    2.20    1.69    200.0      69.2      50.0      12.4       7.85  113.0 *
   2.980   10,840  14.85   10.21    6.27    4.02    3.17    2.21    1.68    200.0     250.0      85.6      15.7       5.04  300.0 *
   3.000   10,467  15.24   11.27    7.23    4.57    3.07    2.33    1.94    200.0     250.0      77.2      14.0       4.03  219.2 *
   3.020    9,466  17.39   10.22    5.85    3.81    2.58    2.20    1.66    200.0     158.1      50.0      14.9       4.33  228.6 *
   3.040   10,141  25.47   16.26    8.98    5.87    4.02    3.03    2.51    200.0      89.4      50.0      10.7       4.23  270.1 *
   3.060   10,248  29.74   22.03   13.73    7.56    5.03    3.76    2.96    200.0      82.3      50.0       8.0      11.52  127.5 *
   3.080   10,471  21.35   13.77    8.50    6.03    4.46    3.59    3.04    200.0     134.5      80.5      10.7       4.97  300.0
   3.100   10,852  18.52   15.85   12.86    9.79    6.30    5.04    3.93    200.0     215.7     259.5       7.2       6.60  165.0 *
   3.120   10,796  13.62   11.33    8.66    6.57    4.49    3.28    2.43    200.0     250.0     369.9      10.3       5.25  243.9 *
   3.140   10,685  10.56    8.57    6.34    4.78    3.41    2.69    2.19    200.0     250.0     500.0      13.4       4.11  300.0 *
   3.160   10,737  10.06    6.42    4.84    3.65    2.77    2.52    1.94    200.0     250.0     500.0      16.5       9.69  300.0 *
   3.180   10,884  10.24    7.60    4.91    3.53    2.16    1.73    1.17    200.0     250.0     158.8      20.4       8.75  121.9 *
   3.200   10,780  10.84    7.04    4.91    3.39    1.91    1.34    1.03    200.0     195.4     324.0      19.6       4.05   95.8
----------------------------------------------------------------------------------------------------------------------------------
Mean:                    17.47   12.13    7.59    5.12    3.44    2.66    2.11    200.0     190.9     170.1      13.8       6.54  216.7
Std. Dev:                 6.76    4.48    2.70    1.78    1.20    0.97    0.76      0.0      76.2     159.5       4.3       2.47   88.5
Var Coeff(%):            38.70   36.93   35.52   34.77   34.78   36.50   35.95      0.0      39.9      93.7      31.0      37.72   43.3
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```
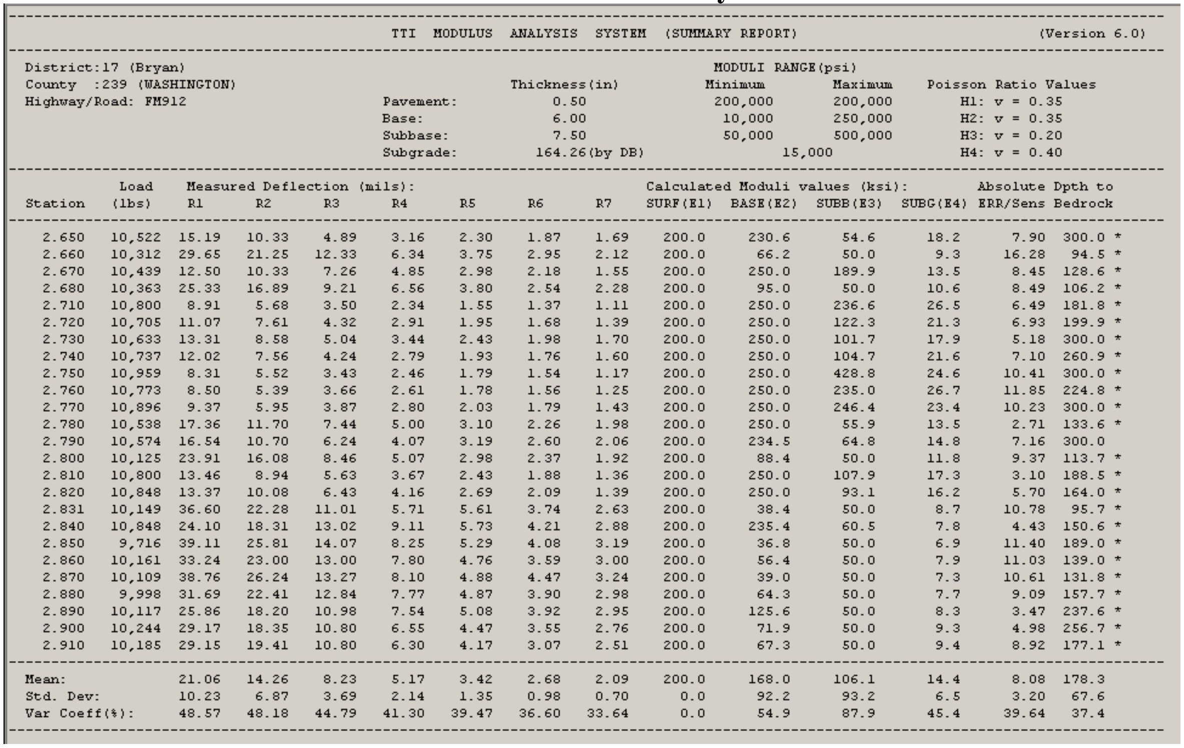

Table 3.6. FWD Result for Type II Rubblization with Reduced Break Pattern and Grade 2 Overlay.



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                                                TTI  MODULUS  ANALYSIS  SYSTEM  (SUMMARY REPORT)                      (Version 6.0)
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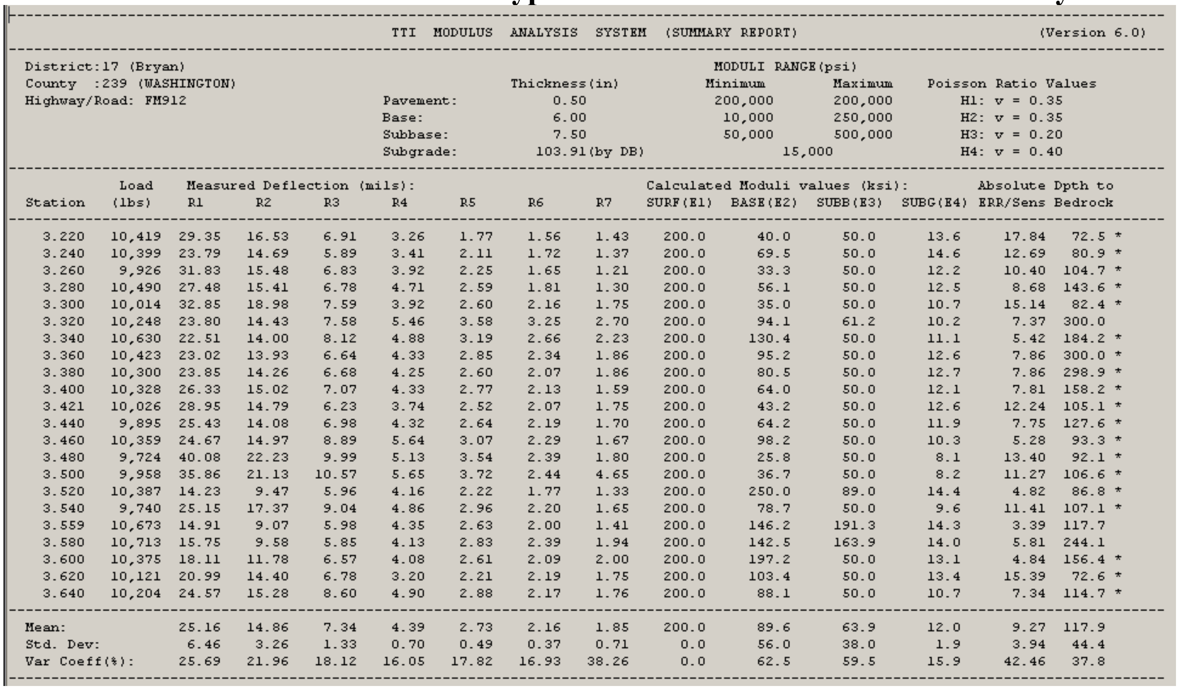
 District:17 (Bryan)                                                          MODULI RANGE(psi)
 County  :239 (WASHINGTON)                              Thickness(in)        Minimum      Maximum     Poisson Ratio Values
 Highway/Road: FM912                       Pavement:         0.50            200,000      200,000        H1: v = 0.35
                                           Base:             6.00             10,000      250,000        H2: v = 0.35
                                           Subbase:          7.50             50,000      500,000        H3: v = 0.20
                                           Subgrade:       164.26(by DB)            15,000               H4: v = 0.40
-----------------------------------------------------------------------------------------------------------------------------------
             Load   Measured Deflection (mils):                                   Calculated Moduli values (ksi):       Absolute Dpth to
 Station    (lbs)     R1      R2      R3      R4      R5      R6      R7    SURF(E1)  BASE(E2)  SUBB(E3)  SUBG(E4)  ERR/Sens Bedrock
-----------------------------------------------------------------------------------------------------------------------------------
    2.650   10,522  15.19   10.33    4.89    3.16    2.30    1.87    1.69     200.0     230.6      54.6      18.2      7.90  300.0 *
    2.660   10,312  29.65   21.25   12.33    6.34    3.75    2.95    2.12     200.0      66.2      50.0       9.3     16.28   94.5 *
    2.670   10,439  12.50   10.33    7.26    4.85    2.98    2.18    1.55     200.0     250.0     189.9      13.5      8.45  128.6 *
    2.680   10,363  25.33   16.89    9.21    6.56    3.80    2.54    2.28     200.0      95.0      50.0      10.6      8.49  106.2 *
    2.710   10,800   8.91    5.68    3.50    2.34    1.55    1.37    1.11     200.0     250.0     236.6      26.5      6.49  181.8 *
    2.720   10,705  11.07    7.61    4.32    2.91    1.95    1.68    1.39     200.0     250.0     122.3      21.3      6.93  199.9 *
    2.730   10,633  13.31    8.58    5.04    3.44    2.43    1.98    1.70     200.0     250.0     101.7      17.9      5.18  300.0 *
    2.740   10,737  12.02    7.56    4.24    2.79    1.93    1.76    1.60     200.0     250.0     104.7      21.6      7.10  260.9 *
    2.750   10,959   8.31    5.52    3.43    2.46    1.79    1.54    1.17     200.0     250.0     428.8      24.6     10.41  300.0 *
    2.760   10,773   8.50    5.39    3.66    2.61    1.78    1.56    1.25     200.0     250.0     235.0      26.7     11.85  224.8 *
    2.770   10,896   9.37    5.95    3.87    2.80    2.03    1.79    1.43     200.0     250.0     246.4      23.4     10.23  300.0 *
    2.780   10,538  17.36   11.70    7.44    5.00    3.10    2.26    1.98     200.0     250.0      55.9      13.5      2.71  133.6 *
    2.790   10,574  16.54   10.70    6.24    4.07    3.19    2.60    2.06     200.0     234.5      64.8      14.8      7.16  300.0
    2.800   10,125  23.91   16.08    8.46    5.07    2.98    2.37    1.92     200.0      88.4      50.0      11.8      9.37  113.7 *
    2.810   10,800  13.46    8.94    5.63    3.67    2.43    1.88    1.36     200.0     250.0     107.9      17.3      3.10  188.5 *
    2.820   10,848  13.37   10.08    6.43    4.16    2.69    2.09    1.39     200.0     250.0      93.1      16.2      5.70  164.0 *
    2.831   10,149  36.60   22.28   11.01    5.71    5.61    3.74    2.63     200.0      38.4      50.0       8.7     10.78   95.7 *
    2.840   10,848  24.10   18.31   13.02    9.11    5.73    4.21    2.88     200.0     235.4      60.5       7.8      4.43  150.6 *
    2.850    9,716  39.11   25.81   14.07    8.25    5.29    4.08    3.19     200.0      36.8      50.0       6.9     11.40  189.0 *
    2.860   10,161  33.24   23.00   13.00    7.80    4.76    3.59    3.00     200.0      56.4      50.0       7.9     11.03  139.0 *
    2.870   10,109  38.76   26.24   13.27    8.10    4.88    4.47    3.24     200.0      39.0      50.0       7.3     10.61  131.8 *
    2.880    9,998  31.69   22.41   12.84    7.77    4.87    3.90    2.98     200.0      64.3      50.0       7.7      9.09  157.7 *
    2.890   10,117  25.86   18.20   10.98    7.54    5.08    3.92    2.95     200.0     125.6      50.0       8.3      3.47  237.6 *
    2.900   10,244  29.17   18.35   10.80    6.55    4.47    3.55    2.76     200.0      71.9      50.0       9.3      4.98  256.7 *
    2.910   10,185  29.15   19.41   10.80    6.30    4.17    3.07    2.51     200.0      67.3      50.0       9.4      8.92  177.1 *
-----------------------------------------------------------------------------------------------------------------------------------
 Mean:                21.06   14.26    8.23    5.17    3.42    2.68    2.09     200.0     168.0     106.1      14.4      8.08  178.3
 Std. Dev:            10.23    6.87    3.69    2.14    1.35    0.98    0.70       0.0      92.2      93.2       6.5      3.20   67.6
 Var Coeff(%):        48.57   48.18   44.79   41.30   39.47   36.60   33.64       0.0      54.9      87.9      45.4     39.64   37.4
-----------------------------------------------------------------------------------------------------------------------------------
```

Table 3.7. FWD Results for Type I Rubblization with Grade 2 Overlay.



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                                                TTI  MODULUS  ANALYSIS  SYSTEM  (SUMMARY REPORT)                      (Version 6.0)
-----------------------------------------------------------------------------------------------------------------------------------
 District:17 (Bryan)                                                          MODULI RANGE(psi)
 County  :239 (WASHINGTON)                              Thickness(in)        Minimum      Maximum     Poisson Ratio Values
 Highway/Road: FM912                       Pavement:         0.50            200,000      200,000        H1: v = 0.35
                                           Base:             6.00             10,000      250,000        H2: v = 0.35
                                           Subbase:          7.50             50,000      500,000        H3: v = 0.20
                                           Subgrade:       103.91(by DB)            15,000               H4: v = 0.40
-----------------------------------------------------------------------------------------------------------------------------------
             Load   Measured Deflection (mils):                                   Calculated Moduli values (ksi):       Absolute Dpth to
 Station    (lbs)     R1      R2      R3      R4      R5      R6      R7    SURF(E1)  BASE(E2)  SUBB(E3)  SUBG(E4)  ERR/Sens Bedrock
-----------------------------------------------------------------------------------------------------------------------------------
    3.220   10,419  29.35   16.53    6.91    3.26    1.77    1.56    1.43     200.0      40.0      50.0      13.6     17.84   72.5 *
    3.240   10,399  23.79   14.69    5.89    3.41    2.11    1.72    1.37     200.0      69.5      50.0      14.6     12.69   80.9 *
    3.260    9,926  31.83   15.48    6.83    3.92    2.25    1.65    1.21     200.0      33.3      50.0      12.2     10.40  104.7 *
    3.280   10,490  27.48   15.41    6.78    4.71    2.59    1.81    1.30     200.0      56.1      50.0      12.5      8.68  143.6 *
    3.300   10,014  32.85   18.98    7.59    3.92    2.60    2.16    1.75     200.0      35.0      50.0      10.7     15.14   82.4 *
    3.320   10,248  23.80   14.43    7.58    5.46    3.58    3.25    2.70     200.0      94.1      61.2      10.2      7.37  300.0
    3.340   10,630  22.51   14.00    8.12    4.88    3.19    2.66    2.23     200.0     130.4      50.0      11.1      5.42  184.2 *
    3.360   10,423  23.02   13.93    6.64    4.33    2.85    2.34    1.86     200.0      95.2      50.0      12.6      7.86  300.0 *
    3.380   10,300  23.85   14.26    6.68    4.25    2.60    2.07    1.86     200.0      80.5      50.0      12.7      7.86  298.9 *
    3.400   10,328  26.33   15.02    7.07    4.33    2.77    2.13    1.59     200.0      64.0      50.0      12.1      7.81  158.2 *
    3.421   10,026  28.95   14.79    6.23    3.74    2.52    2.07    1.75     200.0      43.2      50.0      12.6     12.24  105.1 *
    3.440    9,895  25.43   14.08    6.98    4.32    2.64    2.19    1.70     200.0      64.2      50.0      11.9      7.75  127.6 *
    3.460   10,359  24.67   14.97    8.89    5.64    3.07    2.29    1.67     200.0      98.2      50.0      10.3      5.28   93.3 *
    3.480    9,724  40.08   22.23    9.99    5.13    3.54    2.39    1.80     200.0      25.8      50.0       8.1     13.40   92.1 *
    3.500    9,958  35.86   21.13   10.57    5.65    3.72    2.44    4.65     200.0      36.7      50.0       8.2     11.27  106.6 *
    3.520   10,387  14.23    9.47    5.96    4.16    2.22    1.77    1.33     200.0     250.0      89.0      14.4      4.82   86.8 *
    3.540    9,740  25.15   17.37    9.04    4.86    2.96    2.20    1.65     200.0      78.7      50.0       9.6     11.41  107.1 *
    3.559   10,673  14.91    9.07    5.98    4.35    2.63    2.00    1.41     200.0     146.2     191.3      14.3      3.39  117.7
    3.580   10,713  15.75    9.58    5.85    4.13    2.83    2.39    1.94     200.0     142.5     163.9      14.0      5.81  244.1
    3.600   10,375  18.11   11.78    6.57    4.08    2.61    2.09    2.00     200.0     197.2      50.0      13.1      4.84  156.4 *
    3.620   10,121  20.99   14.40    6.78    3.20    2.21    2.19    1.75     200.0     103.4      50.0      13.4     15.39   72.6 *
    3.640   10,204  24.57   15.28    8.60    4.90    2.88    2.17    1.76     200.0      88.1      50.0      10.7      7.34  114.7 *
-----------------------------------------------------------------------------------------------------------------------------------
 Mean:                25.16   14.86    7.34    4.39    2.73    2.16    1.85     200.0      89.6      63.9      12.0      9.27  117.9
 Std. Dev:             6.46    3.26    1.33    0.70    0.49    0.37    0.71       0.0      56.0      38.0       1.9      3.94   44.4
 Var Coeff(%):        25.69   21.96   18.12   16.05   17.82   16.93   38.26       0.0      62.5      59.5      15.9     42.46   37.8
-----------------------------------------------------------------------------------------------------------------------------------
```

The results of the sections not rubblized show the following:

- The modulus value of the unrubblized concrete beneath the flex base overlay averaged 1279 ksi. This is substantially less than the approximately 3000 ksi average that was observed for the JCP when the project was surveyed in the planning stage.
- No meaningful difference in the modulus of the flexible base overlays over the unrubblized JCP was observed; in most instances the backcalculated values limited out at the upper user-defined threshold of 250 ksi. The average backcalculated base modulus value was approximately 200 ksi. For design purposes this value should be limited to 100 ksi.

For further data analysis in the rubblized sections, unusually high backcalculations (> 1 standard deviation above the mean) were eliminated to avoid the risk of overestimating design modulus values. The results show the following:

- The different sections of JCP rubblized with Type II equipment had statistically equivalent means, and Type II rubblization produced an average modulus value exceeding the value observed from Type I equipment, as Figure 3.10 shows. The average rubblized JCP modulus from Type II equipment was 79 ksi; from Type I equipment this value was 52 ksi. For design purposes, since the equipment to be used will not be known ahead of time, a rubblized concrete modulus value of 50 ksi would be recommended.
- Within the sections rubblized with Type II equipment, the base modulus was higher in the section where the JCP received the reduced break pattern. In Type II sections receiving identical break patterns, the mean modulus value of the Grades 2 and 4 bases were statistically equivalent with an overall average value of 115 ksi. Additionally, the sections rubblized with Type II equipment exhibited higher base modulus values than the section where Type I equipment was used. This may be at least partially due to the fact that the section where Type I equipment was employed had an observed lower rubblized concrete modulus. The base overlay in the section rubblized with Type I equipment averaged 69 ksi. Figure 3.11 illustrates the base modulus results from these sections. For design purposes, since the equipment to be used will not be known ahead of time, a flexible base modulus value of 69 ksi would be recommended.

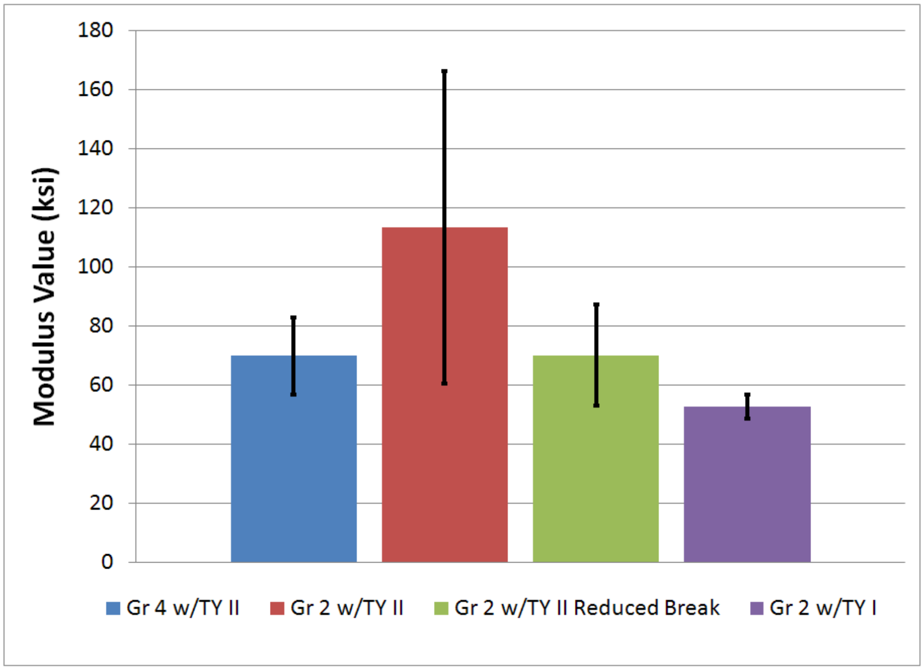


Figure 3.10. Modulus Values of Rubblized JCP with 95 Percent Confidence Intervals.

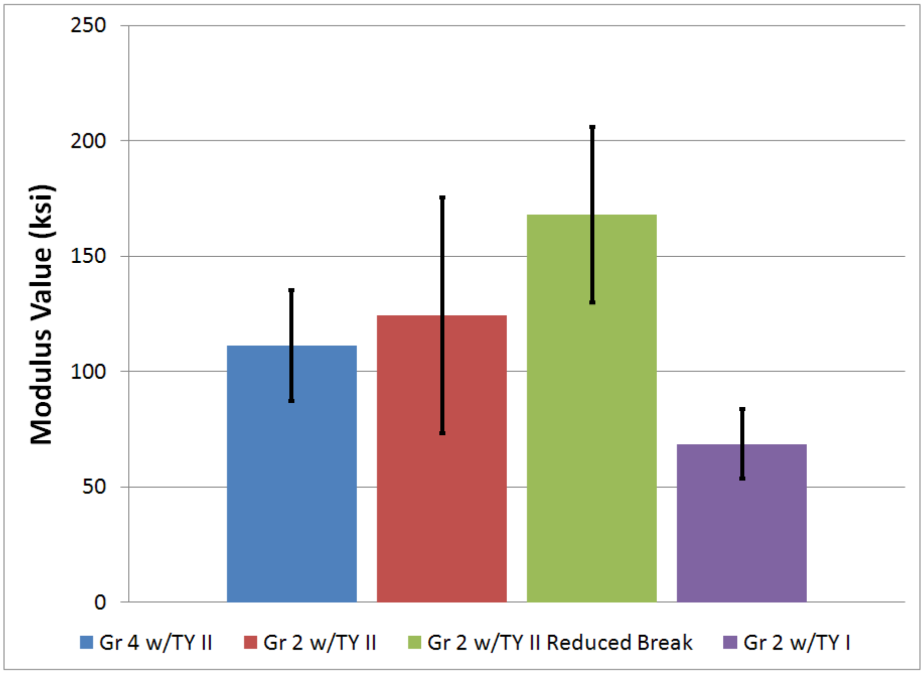


Figure 3.11. Modulus Values of Flexible Base Overlays in Rubblized Sections with 95 Percent Confidence Intervals.

CHAPTER 4.

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

In many instances rubblization may be a good option to convert a deteriorated concrete pavement into a flexible pavement structure. Performing rubblization on this project showed that the project analysis procedures and construction specification worked well. These procedures and specification are included as Appendices A and B in this report, respectively. On this project the Type II rubblization equipment was better able to produce a product that maintained stability after fracturing the concrete, largely because of differences in the break pattern produced. With respect to the two types of base materials used for the flexible base overlay, the Grade 4 base exhibited some construction issues that did not occur with the Grade 2 base. Once in service, the different base materials produced equivalent modulus values assuming the support beneath the base was equivalent.

CONCLUSIONS REGARDING TYPE OF RUBBLIZATION EQUIPMENT

As on other projects, the Type I (resonant breaker) machine was observed to produce a smaller particle size throughout the depth profile of the concrete as compared to the Type II (multiple head breaker) equipment, as Figure 4.1 illustrates. Additionally, with both pieces of equipment, the break pattern serves as a first indicator of stability. While break pattern alone cannot serve as the only stability check, both machines produce break patterns with significantly larger particles at areas of poor stability, as Figure 4.2 shows.

Figure 4.1. Rubblized Product from Type I (Left) and Type II (Right) Equipment.

Figure 4.2. Poor Break Patterns Observed at Areas of Instability from Type I (Left) and Type II (Right) Equipment.

On this project, the post-construction analysis showed the rubblized layer produced by the Type II equipment (79 ksi) was slightly higher than that from the Type I equipment (52 ksi). Both of these values are somewhat low as compared to results from other projects, which typically easily exceed 100 ksi.

CONCLUSIONS REGARDING TYPE OF FLEXIBLE BASE OVERLAY

On this project the main difference observed between the two bases involved finishing. The Grade 4 drainable base tended to segregate during placement and ravel while under traffic prior to construction of the surface treatment, as Figures 2.15 and 2.16 showed. The data do not suggest either base produced a different modulus value for comparable support conditions; the only observed differences in base modulus value appeared attributable to varying modulus of the material beneath the base.

RECOMMENDATION FOR PROJECT ANALYSIS

The project analysis procedure, presented as Appendix A in this report, worked well to outline segments to attempt rubblization and the rubblization selection chart in this procedure matched well with field construction. These procedures are recommended for evaluating projects to determine if they are suitable for rubblization. Report 0-4687-2, which is already published, presents the pre-construction project analysis results from FM 912 and FM 1155. For reference, this report includes these analyses for FM 912 and FM 1155 as Appendices C and D, respectively.

RECOMMENDATION FOR CONSTRUCTION SPECIFICATION

The construction specification worked well and no major issues were encountered. Particularly with the Type II equipment, this project required some engineering judgment regarding the particle size requirements. On this project, which had marginal subgrade support, the depth of smaller particles with the Type II equipment was judged adequate even though that depth did not reach half the slab thickness (see Figure 4.1). It is recommended therefore that the particle size requirements be modified to relax the minimum required depth of the smallest particles to the top third of the slab thickness, instead of half the slab thickness, as Table 4.1 shows. Appendix B of this report presents a revised construction specification with the rubblization requirements modified as discussed.

Table 4.1. Recommended Rubblization Requirements.

Location Largest	**Particle Dimension**	**Allowable Percentage Exceeding**
Top 1/3 of slab thickness or above reinforcing steel[1]	3 in.	40
	6 in.	0
Bottom half of slab or below reinforcing steel	9 in.	25
	12 in.	0

[1] Any particle greater than 6 inches in largest dimension remaining on the pavement surface shall be reduced to an acceptable size or removed. Fill area with flexible base and compact.

APPENDIX A:

GUIDELINES FOR EVALUATING PROJECTS FOR RUBBLIZATION

PROCEDURE

This procedure for evaluating projects for rubblization uses information on pavement structure, pavement condition (distress and structural properties), and subgrade condition (bearing capacity and moisture condition). For a thorough analysis of the project, this plan includes reviews of plans, a visual site assessment, and surveys with ground-penetrating radar, falling weight deflectometer, and dynamic cone penetrometer. The GPR survey can be used to estimate pavement layer thicknesses, identify changes in the pavement structure, and detect locations of wet subgrade. The FWD provides data to evaluate the structural condition of the pavement layers. For jointed concrete pavements, the FWD also provides data to evaluate joint transfer efficiency. The DCP data serve for validation of the subgrade conditions. Use the following steps to evaluate a project:

- Plans: Collect and review plan sheets from the project to identify the existing pavement structure. Identify important parameters such as: existence of any treated subgrade layers, presence and thickness of base (if any), thickness of concrete pavement, thickness of any overlays, and presence of any pavement widening with non-uniform construction.
- Visual Condition Survey: Review the project for the overall level of and type of distresses present. Examine and note the location of any maintenance treatments where the structure may be different. Look for low-lying areas or areas with poor drainage where subgrade conditions may be poor.
- GPR: Perform a GPR survey over the entire project, collecting data at 1-foot intervals. Use Colormap to analyze the GPR data to estimate pavement layer thicknesses, locate limits of potential section breaks in the pavement structure, and identify locations where the subgrade may be excessively wet. For increased reliability, survey the section again prior to rubblization but after the contractor mills off all hot mix asphalt (HMA).
- FWD: Collect FWD data on the project at 0.2 mile intervals, or at intervals sufficient to obtain at least 30 drops on the project, whichever is less. Collect the drops in the center of the concrete slabs. If the project is jointed concrete, randomly collect joint transfer tests to aid in evaluating the joint transfer efficiency. Process the FWD data with Modulus 6.0.
- DCP: From the FWD data, identify the locations with the highest and lowest deflections at the outermost deflection sensor. Perform DCP tests at these locations. Test a minimum of two locations of high outer sensor deflection with the DCP. Test at least one location with low outer sensor deflection with the DCP. Estimate the thickness of the base layer from the DCP data, and use the Corps of Engineers equation to convert the DCP penetration rate to CBR. Determine the CBR and thickness of the base layer. If the DCP data do not clearly detect a base layer, then use the CBR of the first 6 inches beneath the concrete as a “dummy” base layer (many older concrete pavements in Texas do not have a base beneath them). Determine the CBR of the first 6 inches of subgrade.

PAVEMENT TYPE SELECTION PROCESS

The collection of the pavement evaluation data allows the project to be analyzed for its suitability for rubblization. Performing the following steps enables making this determination:

- Evaluate the DCP data using an adaptation of the Illinois Department of Transportation (IDOT) rubblization selection chart (shown in Figure A.1) as follows:

    - Plot the concrete thickness versus the CBR of the base. These data are used to gauge whether the concrete will rubblize, since sufficient support beneath the slab is crucial for satisfactory breakage.
    - Plot the combined thickness of the concrete and base versus the CBR of the subgrade. Use a "dummy" base layer of 6 inches if the DCP data do not distinguish a base layer. These data are used to evaluate whether the subgrade can support construction traffic after rubblization.

- If all the data points fall in the zones that indicate rubblization is feasible, the project should be suitable for rubblization.
- If all the data points fall in the "Do Not Rubblize" zone of the chart, rehabilitation options other than rubblization should be considered.
- If some, but not all, of the data points fall in the "Do Not Rubblize" zone, certain portions of the project may not be suitable for rubblization. More analysis, interpretation, and judgment are required. Typically in Texas these instances are encountered on the older (pre-1960) concrete pavements with little to no identifiable base present. Perform additional analysis as follows:

    - Determine the average CBR of the first 12 inches beneath the concrete.
    - From the rubblization selection chart, determine the minimum CBR necessary to support rubblization for the known concrete thickness at the project. Do this by starting on the Y-axis at the known concrete thickness, then project horizontally until intersecting the boundary where rubblization is feasible. At this intersection, project down to the X-axis, and read the minimum subgrade CBR required.
    - Form a relationship between the subgrade modulus and CBR by graphing the average CBR of the first 12 inches beneath the concrete versus the subgrade modulus. Input the minimum CBR necessary into this relationship to determine the anticipated minimum subgrade modulus needed. Typically this modulus value ranges between 10 and 15 ksi.
    - Graph the subgrade modulus with distance for the project. Where the modulus does not exceed the minimum subgrade modulus needed, a risk exists that the project may not rubblize. At this point the data must be reviewed on a case-by-case basis and a judgment made as to where, if at all, rubblization should be attempted.

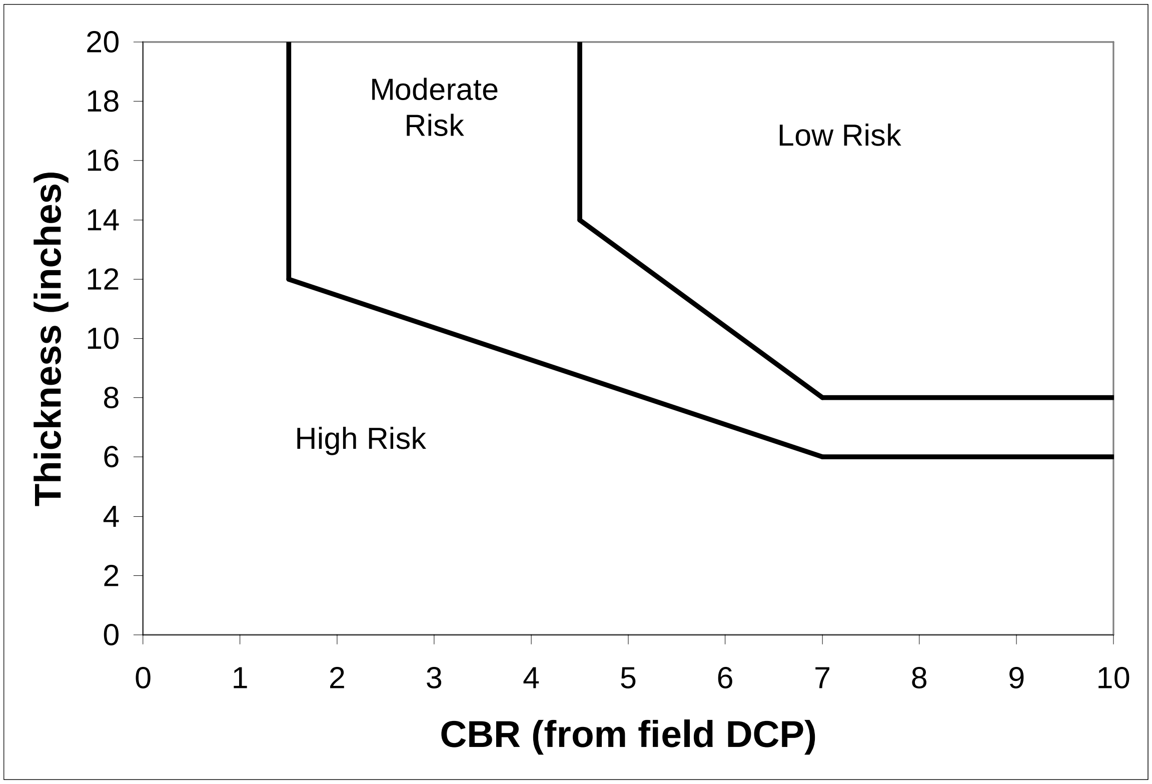


Figure A.1. Rubblization Selection Chart.

NOTES TO PROCEDURE

Although use of these procedures provides a rather complete view of the project, all tests are spot tests, with the exception of GPR. Therefore, the possibility exists that problem locations can be missed between spot test locations. Closer sampling frequencies and special attention to visual site surveys such as locations of standing water, stock tanks, etc., can reduce the likelihood of overlooking a problem location. Experience from multiple projects indicates the planning stage should include an allowance for up to 20 percent full-depth repair.

APPENDIX B:

RECOMMENDED RUBBLIZATION CONSTRUCTION SPECIFICATION

Rubblizing Concrete Pavement

1. **Description.** Rubblize and compact concrete pavement.

2. **Materials.** Furnish materials of uniform quality that meet the requirements of the plans and specifications. Notify the Engineer of the proposed material sources and of changes to material sources. The Engineer may sample and test project materials at any time throughout the duration of the project to assure specification compliance.

   A. **Flexible Base.** Furnish material of the type and grade shown on the plans and conforming to the requirements of Item 247, "Flexible Base" or Special Specification, "Engineered Flexible Base."

3. **Equipment.** Provide machinery, tools, and equipment necessary for the proper execution of the work. Provide either a Type I or Type II rubblizer and necessary rollers for proof rolling and compacting the rubblized pavement, unless otherwise shown on the plans.

   A. **Type I Rubblizer.** Provide a self-contained, self-propelled, resonant frequency breaker, capable of producing low-amplitude, 2000 lb blows, at a rate not less than 44 Hz.

   B. **Type II Rubblizer.** Provide a self-contained, self-propelled, multiple-head breaker, with each hammer independently adjustable, and capable of rubblizing a width of up to 13 ft. in one pass.

   C. **Roller-Vibratory.** Provide a Drum (Type C) roller, with a static weight ≥ 10 tons, meeting the requirements of Item 210, "Rolling."

   D. **Roller-Medium Pneumatic.** Provide a roller conforming to the requirements of Item 210, "Rolling."

   E. **Roller-Heavy Pneumatic.** Provide a roller conforming to the requirements of Item 210, "Rolling."

   F. **Roller-Z Grid Vibratory.** When rubblizing with Type II equipment, furnish a steel wheel, self-propelled vibratory roller, with a minimum weight of 10 tons, and a Z-pattern cladding bolted transversely to the surface of the drum.

   G. **Concrete Saw.** When rubblizing is required adjacent to concrete pavement to be retained, furnish a concrete saw capable of sawing a vertical cut full depth through the concrete pavement in a single pass.

4. **Construction.** Prepare, rubblize, compact, and proof roll concrete pavement. Operate equipment in a manner that will not damage the base, underground utilities, drainage structures, and other facilities on the project. Repair damaged facilities. Alternate breaking methods may be used in areas of identified underground utilities and drainage structures if approved. If required elsewhere in the plans, construct the pavement drainage systems at least two weeks prior to rubblization.

A. Preparatory Work. Before rubblization, complete the following:

- Remove all material overlaying the concrete pavement. Material removed will remain property of the Department unless otherwise shown on the plans. Transport and stockpile the removed material at locations shown on the plans or as directed. Remove in accordance with Item 105, "Removing Stabilized Base and Asphalt Pavement," except measurement and payment.
- Before rubblizing a section, cut full-depth saw cut joints at any locations shown on plans to protect facilities that will remain in place.
- Adjustments or additions to the pavement adjacent to the concrete must be complete to the elevation of the top of the concrete pavement to be rubblized. Perform this work in accordance with pertinent bid items.
- Reconstruct adjacent shoulders and adjacent ramp areas prior to rubblization, when shown on the plans. Perform this work in accordance with pertinent bid items.

B. Rubblization and Compaction. Use a Type I or Type II rubblizer to completely de-bond any reinforcing steel and rubblize the existing concrete pavement. Use other types of rubblizing equipment only if shown on the plans or approved by the Engineer.

Table B.1. Rubblization Requirements.

Location Largest	**Particle Dimension**	**Allowable Percentage Exceeding**
Top 1/3 of slab thickness or above reinforcing steel[1]	3 in.	40
	6 in.	0
Bottom half of slab or below reinforcing steel	9 in.	25
	12 in.	0

[1] Any particle greater than 6 inches in largest dimension remaining on the pavement surface shall be reduced to an acceptable size or removed. Fill area with flexible base and compact.

Cut off any projecting reinforcing steel below the rubblized surface. Dispose of removed steel in an approved manner.

1. **Type I Rubblization.** Begin rubblization at a free edge or previously broken edge and work transversely toward the other edge. In the event the rubblizer causes excessive deformation of the pavement, the Engineer may require high flotation tires with tire pressures less than 60 psi. Any displaced areas shall be considered non-conforming and treated as described above. Reduce any particle greater than 6 inches in largest dimension remaining on the pavement surface to an acceptable size or remove and fill the area with flexible base. Compact by seating rubblized pavement with the following rolling pattern:

   - one pass from a vibratory roller, followed by at least one pass with the pneumatic roller; and
   - followed by at least two more passes with the vibratory roller.

   The rolling pattern may be changed as directed.

2. **Type II Rubblization.** Unless otherwise directed, rubblize the entire lane width in one pass. Provide a screen to protect vehicles from flying particles as directed. Reduce any particle greater than 6 inches in largest dimension remaining on the pavement surface to an acceptable size or remove and fill the area with flexible base. Compact by seating the pavement with the following rolling pattern:

   - a minimum of four passes with the Z-grid vibratory roller,
   - followed by four passes with a vibratory roller, and
   - by at least two passes from a medium weight pneumatic roller.

   The rolling pattern may be changed as directed.

C. **Verification of Rubblization Process**. Before full production begins, the Engineer will select approximately 200 linear ft. of one lane width to verify the rubblization operation. The contractor shall rubblize the test section, using the section to adjust equipment. From within this test section, the Engineer and Contractor shall agree upon a test pit location. At the test pit, excavate a 4 ft. square test pit. Verification testing of particle size distribution will be by the Engineer. Additional test pits may be required during the project to confirm ongoing compliance with the particle size specification. Replace excavated material with flexible base and compact. The Engineer may waive density control testing.

If the rubblized material from the test pit does not meet specifications, another test strip shall be conducted and tested. Should this pit also fail, rubblization operations shall be suspended until the Contractor demonstrates to the satisfaction of the Engineer that specifications can be met, at which time the Engineer shall allow the Contractor to conduct another test strip.

D. **Proof Rolling.** Unless otherwise shown on the plans, perform proof rolling of the rubblized areas using a heavy pneumatic roller in accordance with Item 216, “Proof Rolling.” Unless otherwise directed by the Engineer, load the heavy pneumatic roller to an approximate weight of 25 tons. Increase the roller weight up to 50 tons when directed by the Engineer.

E. **Localized Repair.** Repair areas identified by the Engineer as unstable or non-uniform in accordance with Item 351, “Flexible Pavement Structural Repair,” except measurement and payment. Excavate repair areas to a depth of 18 inches from the surface of the concrete pavement. Use flexible base, as shown on the plans, to replace excavated material. The Engineer may waive density control testing. If unsuitable material is encountered below the 18 inches of excavated material, take corrective measures as directed.

F. **Finishing.** After completion of proof rolling and repairs, place the next successive course on the rubblized area before opening to all traffic. Cease operations if rain occurs after rubblization but before placing of the next course has been completed. Resume operations only after the Engineer has determined that the rubblized area is dry and stable. After rainfall remove natural soil from edges of the pavement area to facilitate drainage from the rubblized areas when directed by the Engineer. Restore soil to former condition when directed.

1. Avoid unnecessary trafficking of construction equipment on the rubblized pavement.
2. Restrict public traffic on the rubblized pavement, except at Engineer-approved access points. When the Engineer permits public traffic on the rubblized concrete, use traffic control methods that conform to requirements shown on the plans or as directed to minimize damage to the rubblized section.
3. Monitor the surface of the rubblized section for any reinforcing steel that may migrate to the top and cut off any projecting reinforcing steel below the rubblized surface.

5. **Measurement.** This Item will be measured as follows:

   A. **Rubblization.** Rubblization will be measured by the square yard of surface area rubblized in place.

   B. **Repair of Localized Areas.** Repair of localized material by the square yard of repaired area as defined by the Engineer. In areas where material is excavated, as directed, to depths greater than those specified on the plans, measurement will be made by dividing the actual depth of such area by the plan depth and then multiplying this figure by the area in square yards of work performed. Calculations for each repaired area will be rounded up the nearest 1/10 sq. yd. At each repair location, the minimum area for payment purposes will be 1 sq. yd.

6. **Payment.**

   A. **Rubblization.** The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Rubblizing Concrete Pavement" of the type specified. This price is full compensation for removal transportation and stockpiling of surface materials removed; rubblizing and compacting concrete pavement; saw-cutting required locations; cutting, removing and disposing of exposed reinforcing steel; conducting required test pits; repairing any damaged facilities; removing and replacing soil at pavement edges to facilitate drainage, materials, equipment, labor, tools, and incidentals.

   Proof rolling will be paid for in accordance with Item 216, "Proof Rolling."

   B. **Repair of Localized Areas.** The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Pavement Structure Repair." This price is full compensation for cutting and removing reinforcing steel in the repair area; removing, hauling, spreading, disposing of, and stockpiling existing pavement structure; removing objectionable or unstable material; furnishing and placing materials; maintaining completed section before surfacing; applying tack or prime coat; hauling, sprinkling, spreading, and compacting; and equipment, labor, tools, and incidentals.

APPENDIX C:

PRE-CONSTRUCTION PROJECT ANALYSIS OF FM 912

SUMMARY

In efforts to identify potential rehabilitation strategies for FM 912 in Washington County, researchers conducted a field investigation in October 2005 to investigate if rubblization (RBBL) would be an option for the JCP pavement. The section investigated is from the intersection with SH 105 to FM 1155. Based upon GPR, FWD, and DCP results, the majority of the project is not suitable for rubblization. Most of the project has either a history of voids beneath the slabs, insufficient subgrade support, or both, for rubblization to be feasible. Two sections are marginally suitable for rubblization. These sections are from reference marker (RM) 628 + 0.557 to RM 628 + 0.826 and from RM 630.019 to 630.658. In sections not suitable for rubblization, a flexible base overlay should be considered.

RESULTS FROM FIELD INVESTIGATION

Based on the field investigation the structure on FM 912 consists of approximately 7 inches of JCP over the subgrade. Within the section, substantial cracking exists such as illustrated in Figure C.1. The average joint spacing is 40 feet, and the average transverse crack spacing is 6 to 7 feet. To evaluate if the FM 912 project is suitable for rubblization, the Texas Transportation Institute (TTI) performed a field analysis using GPR, FWD, and DCP testing. Figure C.2 illustrates representative GPR data from the project.

The GPR survey serves two primary purposes. First, the survey can identify locations of excessively wet subgrade or trapped water, both of which hinder the rubblization process. Second, the GPR survey can identify section breaks or changes in structure. In the GPR data, no locations of excessively wet subgrade were identified. The highest subgrade dielectric value was 7.3 (values above 10 can indicate excessively wet material). However, at the time of testing the weather had been dry for several months. From discussions with TxDOT personnel, portions of the FM 912 project have a history of developing voids underneath the slabs, particularly in the low-lying areas. While TxDOT reported that maintenance work had recently been performed on locations with voids, the GPR data still detected areas of voids beneath the slabs. Figure C.3 illustrates GPR data where voids exist. Follow-up testing with the DCP at selected locations verified the existence of voids beneath the slab. In the southbound (SB) travel direction, evidence of intermittent voids in the GPR data exist from RM 629 + 0.108 to 629 + 0.513. In the northbound (NB) travel direction, evidence of intermittent voids beneath the slabs exist from RM 629 + 0.898 to 628 + 0.936.

Figure C.1. Cracked Slabs on FM 912.

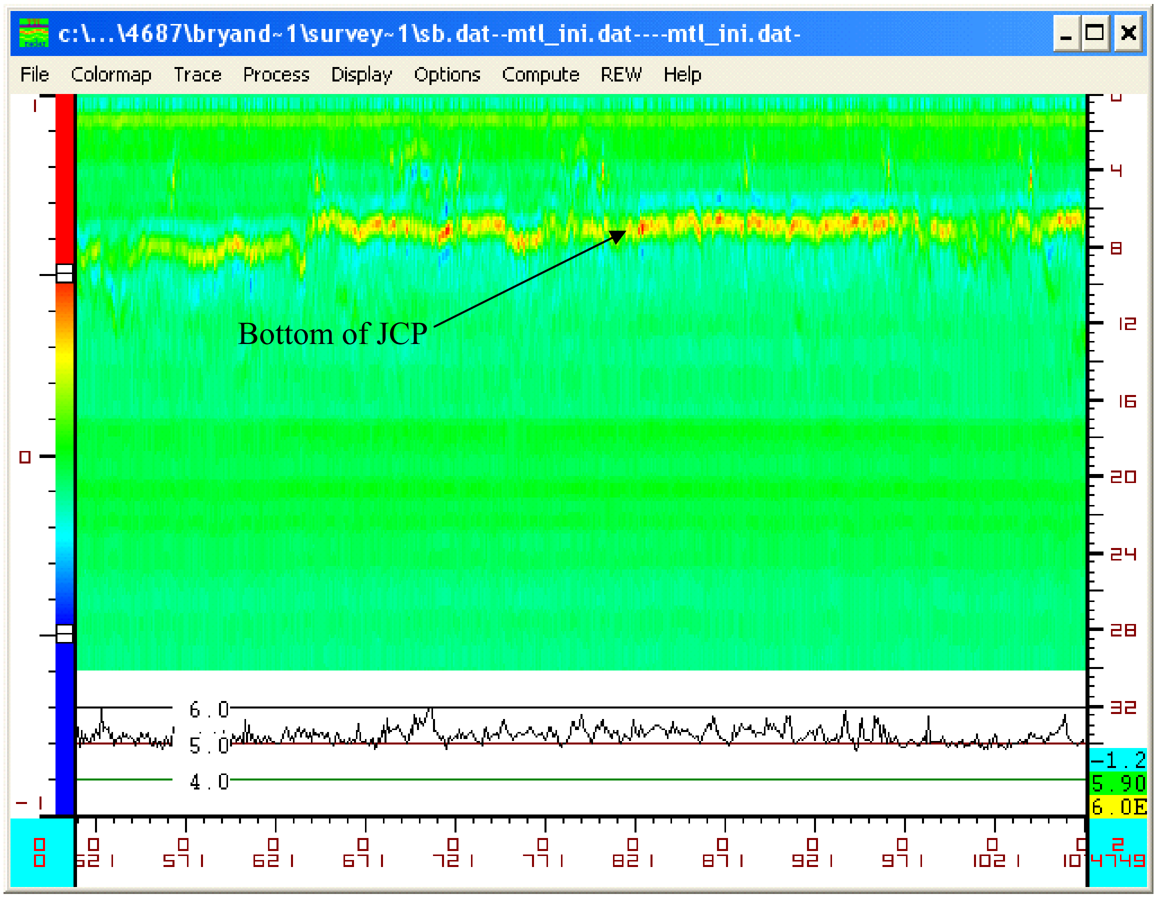


Figure C.2. Representative GPR Data from FM 912.

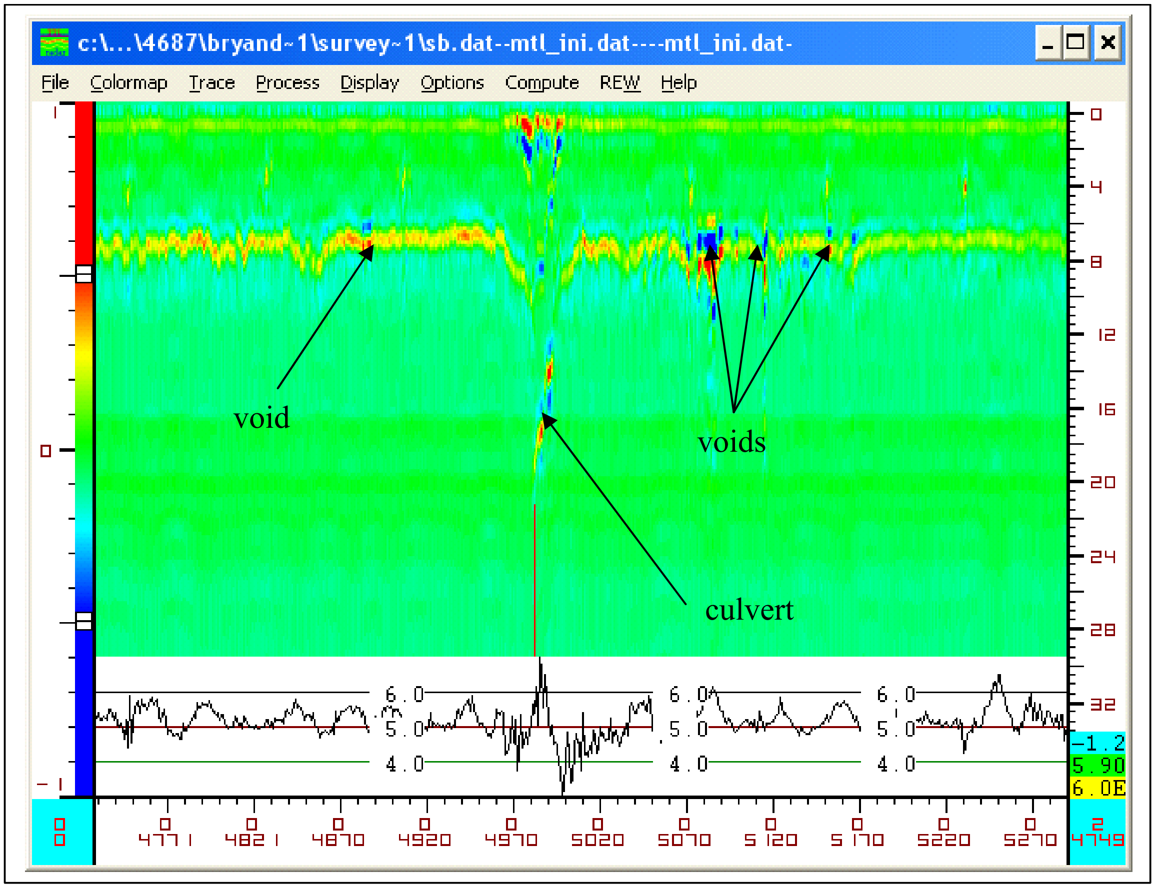


Figure C.3. Voids beneath Slabs on FM 912.

Table C.1 shows the FWD backcalculation results for the FM 912 project. After studying FWD results in the field, DCP tests were performed at selected locations to verify whether adequate subgrade support exists. Table C.2 summarizes the DCP results as needed for application in the rubblization selection chart developed by Illinois DOT. The DCP data allow for evaluation of two governing parameters:

- *Support immediately beneath the slab*: If there is inadequate support immediately beneath the slab, rubblization may not be feasible. To evaluate the project for this parameter, the concrete thickness versus the California Bearing Ratio (CBR) of the base layer immediately beneath the slab is plotted. In instances where the DCP data did not reveal a clear layer distinction, a dummy base layer value of 6 inches was assigned.

- *Support at deeper depths into the subgrade*: Even if support is sufficient immediately beneath the slab for concrete breakage, weak soils deeper in the pavement can create problems. Shear failures can occur, particularly with the resonant breaker equipment due to the multiple passes required over the rubblized pavement to break the entire pavement width. To evaluate this parameter, the combined thickness of the concrete and base is plotted against the CBR value of the first 6 inches of subgrade.

Table C.1. FWD Results for FM 912.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.0)

District:Bryan
County: Washington
Highway/Road: FM 912

MODULI RANGE (psi)

	Thickness(in)	Minimum	Maximum
Pavement:	7.5	340,000	5,000,000
Base:	0		
Subbase:	0		
Subgrade:	100.38	15,000	

Poisson Ratio Values
H1: v = 0.20
H2: v=0.00
H3: v=0.00
H4: v=0.40

Station	Load (lbs)	Measured Deflection (mils) R1	R2	R3	R4	R5	R6	R7	Calculated Moduli Values (ksi) SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERR/Sens	Dpth to Bedrock
0	10,030	21.2	18.42	15.17	12.51	10.14	8.4	7.17	2323.1	0	0	2.6	3.59	300
0.052	10,320	9.5	8.79	7.53	6.28	5.11	3.96	3.06	5000	0	0	5.4	2.22	148.6 *
0.1	10,073	12.57	10.85	8.68	6.88	5.25	3.88	2.77	2785.4	0	0	5.6	2.15	117.9
0.145	10,177	7.78	6.73	5.28	3.98	2.84	2.02	1.39	3560.4	0	0	10.9	1.2	100
0.198	10,105	7.87	6.98	5.5	4.29	3.2	2.34	1.71	4118.5	0	0	9.3	1.46	115.7
0.243	10,165	10.51	9.8	8.4	7.07	5.81	4.63	3.67	4652.6	0	0	4.7	2.64	178.9 *
0.287	10,951	12.65	11.16	9.45	7.92	6.38	5.02	3.81	4372.1	0	0	4.4	1.74	140.7
0.337	9,855	12.21	10.89	9.15	7.79	6.5	5.3	4.15	4035.9	0	0	4	3.46	165.4 *
0.375	9,831	9.74	8.41	6.46	4.92	3.56	2.47	1.61	2712.1	0	0	8.6	1.4	93.3
0.406	10,570	17.78	13.96	9.91	6.82	4.5	2.83	1.66	972.4	0	0	7.5	2.57	89
0.406	11,055	14.43	11.3	7.99	5.61	3.7	2.3	1.31	1274	0	0	9.7	2.57	82.6
0.447	9,970	12.35	10.21	7.85	5.8	4.12	2.77	1.63	1919.8	0	0	7.7	1.91	85.6
0.487	10,046	8.5	7.22	5.56	4.2	3.06	2.17	1.5	3185.6	0	0	10.2	2.12	101.9
0.546	10,014	7.39	6.65	5.18	4.06	3.07	2.31	1.72	4534.5	0	0	9.5	2.23	121.3
0.595	9,994	7.85	7.03	5.61	4.39	3.31	2.41	1.74	4279.2	0	0	8.8	1.08	112.1
0.644	9,907	10.63	9.6	7.9	6.3	4.76	3.33	2	3313.3	0	0	6	0.92	84.4
0.699	10,053	9.75	8.57	6.69	5.15	3.86	2.82	2.09	3190.7	0	0	7.8	1.93	129.4
0.739	9,823	6.94	6.09	4.63	3.43	2.46	1.71	1.18	3565.3	0	0	12.4	1.41	99.5
0.792	9,899	8.98	8.39	6.82	5.41	4.04	2.84	1.85	3828.1	0	0	7.1	1.4	92.1
0.836	9,760	12.72	10.89	8.44	6.49	4.78	3.55	2.67	2272.9	0	0	6.2	2.6	147.5
0.846	9,807	15.14	12.02	8.82	6.37	4.41	2.85	1.74	1280.7	0	0	7.3	2.98	91.4
0.864	9,664	17.44	14.2	10.65	7.67	4.98	2.43	1.51	917.1	0	0	6.6	5.64	67.2
0.909	9,771	22.92	19.39	15.51	12.18	8.87	5.79	3.37	1220.6	0	0	3.5	2.2	91
0.959	8,953	21.72	20.14	18.33	17.79	17.52	17.74	18.26	1764.1	0	0	1.8	19.2	300.0 *
0.959	9,263	22.26	20.58	18.71	18.17	17.99	18.25	18.83	1738.6	0	0	1.7	19.8	300.0 *
0.99	9,942	11.57	9.19	6.49	4.3	2.44	1.69	1.2	1207.9	0	0	11.7	3.13	71.2
1.043	10,057	9.08	7.91	6.61	5.34	4.2	3.06	2.09	4471.8	0	0	6.8	1.46	98.5
1.096	9,851	10.61	9.22	7.32	5.64	4.15	2.88	1.84	2743.2	0	0	7.2	0.89	92.2
1.11	9,851	12.29	10.19	7.73	5.76	4.15	2.86	1.93	1964.5	0	0	7.6	2.59	104.2
1.145	9,720	7.64	6.41	4.86	3.65	2.67	1.92	1.32	3340.7	0	0	11.4	2.96	98.8
1.199	9,887	8.86	7.78	6.47	5.29	4.13	3.04	2.14	4579.4	0	0	6.7	1.26	104.1
1.247	10,546	14.78	12.02	9.33	6.94	4.96	3.44	2.16	1774.4	0	0	6.7	2.62	94.4
1.288	9,684	12.63	10.41	7.84	5.86	4.09	2.57	1.67	1687.4	0	0	7.7	1.76	87.8
1.355	9,255	29.28	4.4	3.72	3.33	2.9	2.55	2.2	504.3	0	0	16.8	53.05	300.0 *
1.355	9,064	33.78	27.29	21.02	16.48	12.78	9.82	7.4	871	0	0	2.2	5.39	179.1
1.356	9,561	18.06	15.76	12.86	10.47	8.13	6.03	4.32	2078.7	0	0	3.3	1.75	128.2
1.38	9,537	12.42	11.27	9.3	7.45	5.52	3.69	2.26	2589.5	0	0	5.1	2	89.1
1.382	9,783	12.28	11.12	9.09	7.25	5.47	3.88	2.77	2833.7	0	0	5.2	0.73	119.9
1.431	9,140	35.02	9.98	7.72	6.44	5.14	4.09	3.24	340	0	0	8.3	38.8	174.9 *
1.431	9,251	25.03	20.44	15.7	12.12	8.83	6.11	4.51	988.7	0	0	3.3	3.02	129.4
1.453	11,384	16.94	13.89	10.63	7.96	5.6	3.67	2.28	1570.3	0	0	6.5	1.81	93
1.496	9,775	10.3	9.43	7.74	6.3	4.98	3.9	3	4196.9	0	0	5.2	1.61	152.7
1.569	9,918	10.53	9.19	7.49	6.14	4.85	3.65	2.65	3897.3	0	0	5.7	2.18	116.6
1.627	10,081	10.53	9.06	7.18	5.7	4.39	3.29	2.39	3373.6	0	0	6.7	2.69	118.8
1.671	9,934	9.86	9.26	7.7	6.44	5.05	3.72	2.61	4531.5	0	0	5.3	1.38	104.2
1.71	9,644	17.81	6.24	4.98	3.98	3.16	2.5	1.96	894.7	0	0	13	31.23	152.1
1.71	9,684	20.84	15.8	11.38	8.17	5.73	3.96	2.85	904.8	0	0	5.5	5.62	124.9
1.76	9,752	11.17	9.8	7.72	5.93	4.39	3.34	2.57	2758.3	0	0	6.5	2.43	163.7
1.793	9,926	7.91	6.89	5.32	4.03	2.91	2	1.29	3354.6	0	0	10.6	1.02	88.8
1.837	9,497	21.72	5.75	4.95	4.1	3.24	2.52	1.94	449.6	0	0	15	42.32	133.3 *
1.837	9,243	27.37	21.35	15.32	10.77	6.78	3.77	2.54	519.6	0	0	4.4	2.75	79.1
1.861	9,843	8.4	7.15	5.47	4.16	2.98	2.1	1.43	3078.5	0	0	10.3	1.78	98.1
1.903	9,875	7.98	7.04	5.57	4.38	3.31	2.48	1.86	4201.1	0	0	8.7	1.96	127.6
1.998	9,763	13.81	12.73	10.69	8.96	7.01	5.31	3.52	3288.3	0	0	3.7	0.63	98.6
2.099	9,760	9.44	8.95	7.33	5.99	4.7	3.53	2.54	4457.7	0	0	5.6	0.91	113.8
2.2	9,831	9.45	8.57	6.91	5.53	4.17	2.94	1.81	3625.5	0	0	6.9	0.93	84.5
2.304	9,910	8.61	8.08	6.73	5.49	4.31	3.29	2.46	5000	0	0	6.2	0.84	127.9 *
2.396	9,954	10.7	9.22	7.01	5.23	3.64	2.24	1.12	2087.8	0	0	8.9	1.65	73.7
2.468	9,589	9.4	8.77	7.2	5.84	4.54	3.46	2.61	4302.7	0	0	5.7	0.93	137.1
2.596	9,716	8.72	7.73	5.93	4.43	3.13	2.17	1.48	2846.6	0	0	9.6	1.02	101.6
2.701	9,700	23.29	20.29	16.24	12.98	9.98	7.21	4.91	1468.6	0	0	2.9	1.81	116.8
Mean:		13.92	10.93	8.68	6.89	5.29	3.98	3	2714.8	0	0	7.1	5.23	107.9
Std. Dev:		6.66	4.66	3.77	3.31	3.06	3.03	3.14	1360.5	0	0	3.1	10.4	30.8
Var Coeff	(%):	47.82	42.66	43.45	48.02	57.9	76.12	104.52	50.1	0	0	43.9	198.59	28.6

Table C.2. Summary DCP Results for FM 912.

DCP	Concrete Thickness (in)	Base Thickness (in)	CBR Values		Subgrade Modulus from FWD (ksi)	Location (RM)	Comment
			Base	Subgrade			
1	5.6	1.5	17.2	5.4	10.2	628.669	
2	6.7	6*	3.4	2.4	3.5	629.091	
3	6.5	6*	1.3	2.0	Not tested with FWD	629.145	Test location selected from GPR. DCP verified void beneath slab.
4	5.8	3.8	13.4	7.5	11.4	629.327	Within limits of intermittent voids
5	7.5	6*	0.6	4.2	4.1	629.457	Test location selected from GPR. DCP verified void beneath slab
6	6.8	8.2	7.9	3.4	3.7	630.180	
7	6.5	2.5	10.3	2.4	2.9	630.882	

*Assigned to 6 inches because not distinguishable in DCP data

Figure C.4 shows this chart with the FM 912 data. Of particular attention in this graph are the data from DCP tests 1, 4, 6, and 7, because these are the only locations where the support immediately beneath the slab is sufficient to where rubblization may be feasible. The location represented by DCP 4 should not be rubblized because the section falls within the limits of the project where voids occur beneath the slab. Of the remaining locations 1, 6, and 7, the data show the portions of the project represented by tests 1 and 7 may not be suitable for rubblization because of the poor soil conditions a few inches below the bottom of the concrete. Only at location 6 do the data indicate the project is suitable for rubblization with minimal risk.

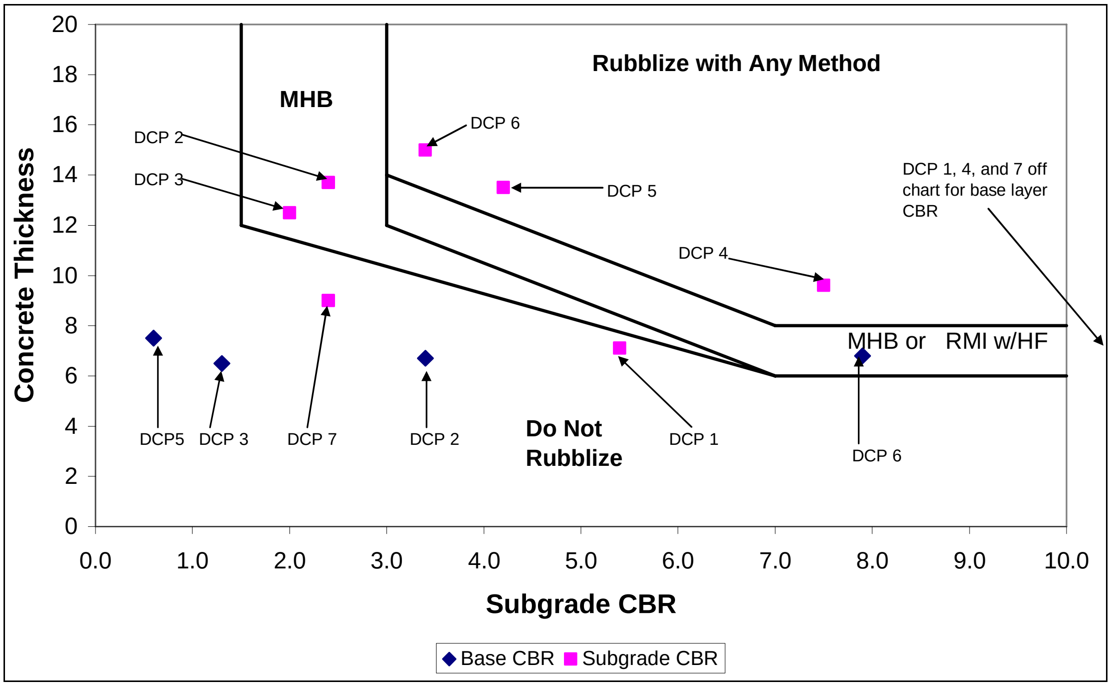


Figure C.4. DCP Results from FM 912 on IDOT Rubblization Selection Chart.
Note: MHB = Multi-head breaker; RMI = Resonant Machines Inc; HF = High Flotation.

Because the DCP testing is spot-specific, researchers made efforts to use the FWD data to better partition the project into limits where rubblization may be an option. To accomplish this segmenting, a relationship between the FWD and CBR of the top 12 inches of subgrade was developed. For the concrete thickness on FM 912, a subgrade CBR of approximately 6.5 would be required according to the selection chart shown in Figure C.4. From the relationship between the DCP and FWD data illustrated in Figure C.5, the minimum backcalculated subgrade modulus should be at least 7 ksi.

To segment the project, the backcalculated subgrade modulus with distance is graphed in Figure C.6. Segments 2 and 6 are marginally suited for rubblization. The average subgrade value exceeds (segment 2) or nearly meets (segment 6) the required minimum value. The DCP data from within these sections indicate they are marginally suitable for rubblization. The limits of these sections are from RM 628.557 to 628.826 and 630.019 to 630.658.

The first segment is not suitable for rubblization because the subgrade modulus is less than the required minimum value. Segments 3 through 5 should not be rubblized due to their proximity to locations where voids have occurred beneath the slabs.

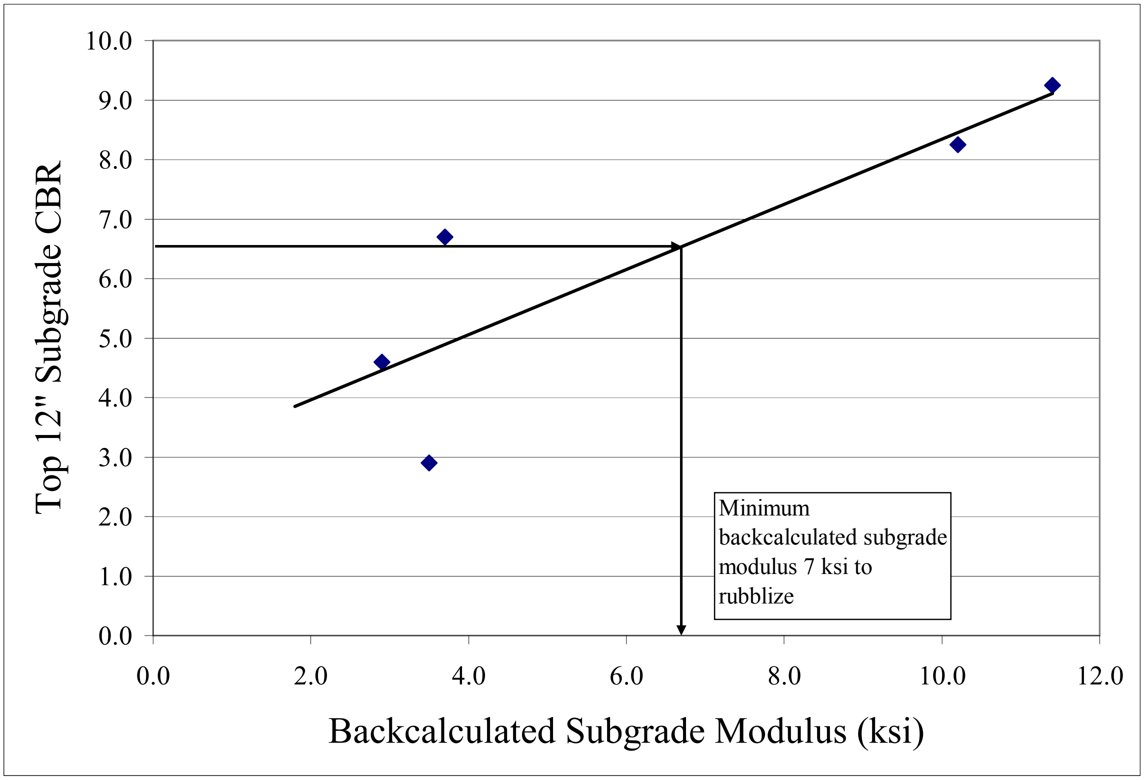
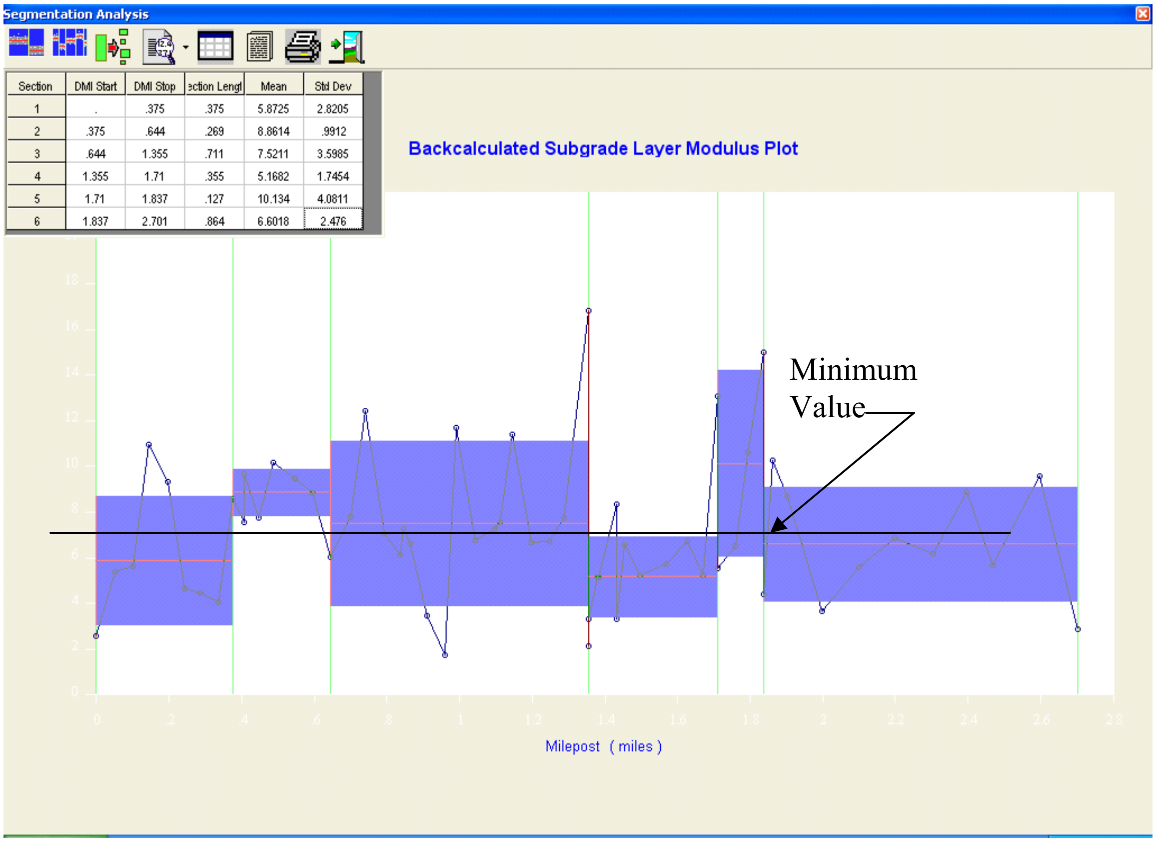


Figure C.5. Relationship between DCP and FWD on FM 912.



Section	DMI Start	DMI Stop	ection Lengt	Mean	Std Dev
1	.	.375	.375	5.8725	2.8205
2	.375	.644	.269	8.8614	.9912
3	.644	1.355	.711	7.5211	3.5985
4	1.355	1.71	.355	5.1682	1.7454
5	1.71	1.837	.127	10.134	4.0811
6	1.837	2.701	.864	6.6018	2.476

Figure C.6. FM 912 Backcalculated Subgrade Modulus with Distance (SB Direction).
Note: Milepost Zero is at RM 628 + 0.182

RECOMMENDATION

Based upon the results presented and discussed above, the majority of the FM 912 project should not be rubblized. Most of the project has either a history of voids beneath the slabs, insufficient subgrade support, or both. Two sections are marginally suitable for rubblization. These sections are from RM 628 + 0.557 to RM 628 + 0.826 and from RM 630.019 to 630.658. In sections not suitable for rubblization, a flexible base overlay should be considered.

APPENDIX D:

PRE-CONSTRUCTION PROJECT ANALYSIS OF FM 1155

SUMMARY

The JCP pavement evaluated for rubblization on FM 912 continues as FM 1155 in Washington County. The section investigated on FM 1155 is from the intersection with FM 912 to just past Park Road 12, where the JCP pavement ends. The investigation was begun at RM 631 on FM 912 then progressed northbound. Based upon GPR, FWD, and DCP results, the majority of the project is marginally suitable for rubblization. On one section, from 4550 to 5250 feet north of RM 631, the subgrade support is likely too poor to support rubblization operations.

RESULTS FROM FIELD INVESTIGATION

Based on the field investigation, the structure consists of approximately 7 to 8 inches of JCP over the subgrade. Figure D.1 shows the pavement section looking northbound from RM 631 on FM 912.

Figure D.1. JCP Pavement Tested for Suitability for Rubblization.

To evaluate whether the project is suitable for rubblization, TTI performed a field analysis using GPR, FWD, and DCP testing. Several sections of the project have asphalt concrete patches over the concrete. Table D.1 shows the sections that exist based upon observation and GPR data. Figure D.2 illustrates representative GPR data from the project where the structure consists solely of JCP. Figure D.3 shows GPR data illustrating the transition from a location with asphalt concrete pavement (ACP) back to solely JCP.

Table D.1. Sections on JCP Pavement Investigated.

Location North from RM 631 (Feet)	Pavement
0-360	JCP
360-700	~2.5 inch ACP over JCP (at culvert)
700-3446	JCP
3446-3875	~4 inch ACP over JCP (at culvert)
3875-4580	JCP
4580-5250	~7 to 9 inch ACP over JCP
5250-5520	JCP
5520-6545	~2.5 inch ACP over JCP
6545-7256	JCP
7256-8380	~2 inch ACP over JCP

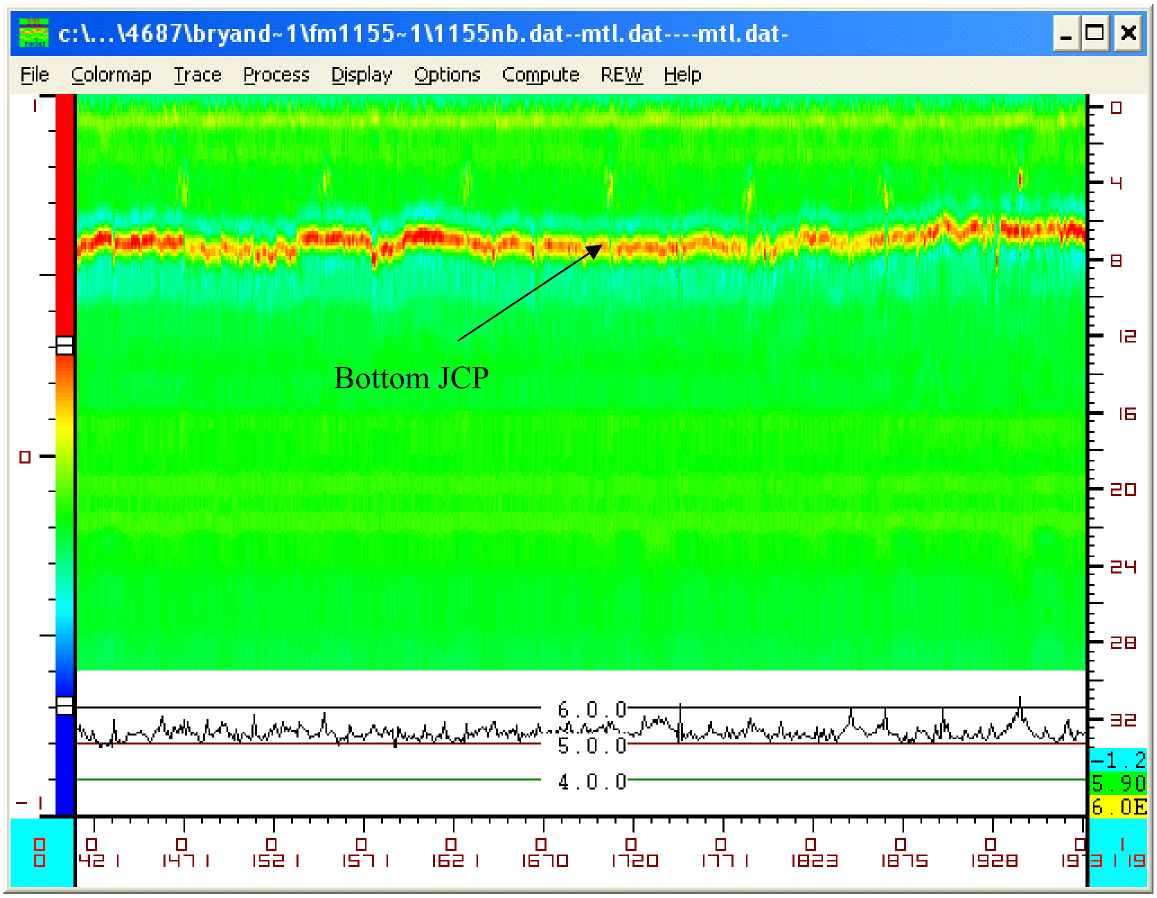


Figure D.2. Representative GPR Data from JCP on FM 1155.

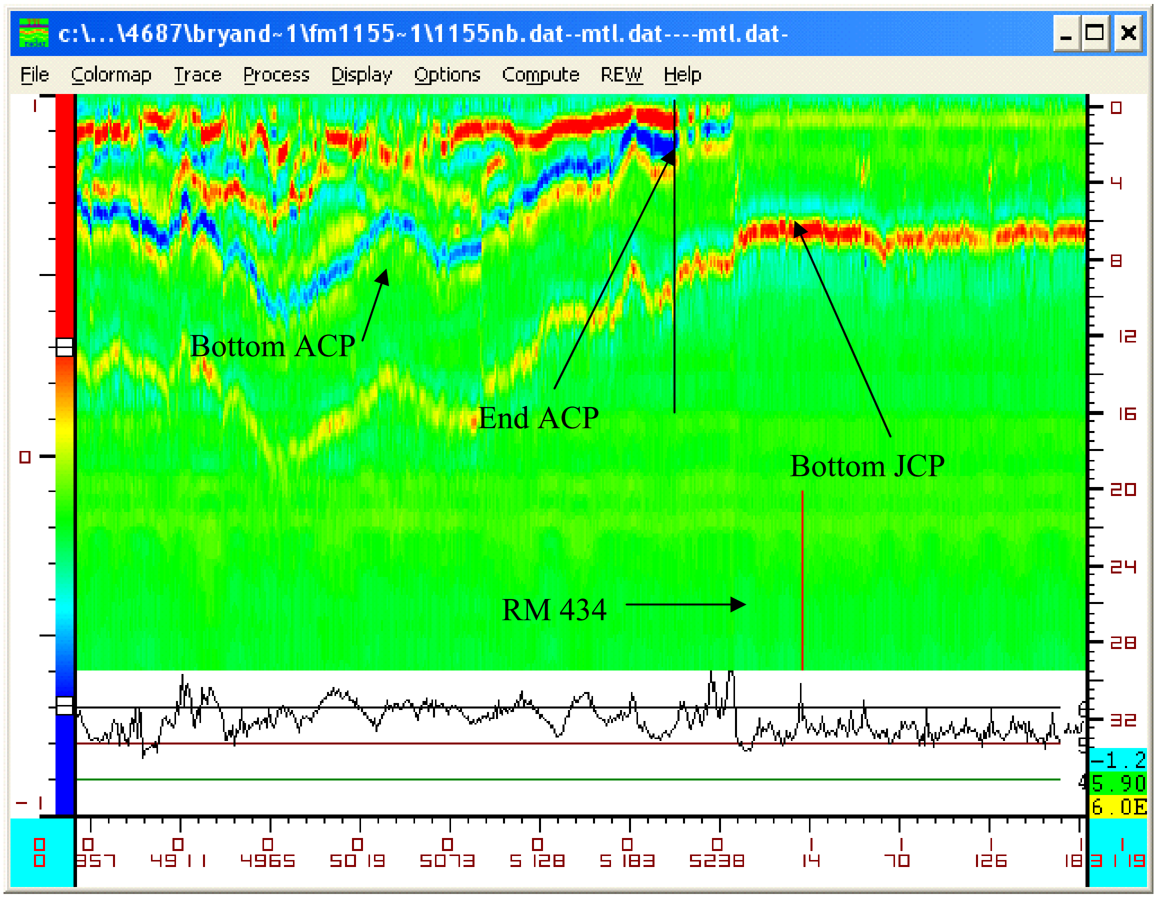


Figure D.3. GPR Where ACP Exists over JCP on FM 912.

The GPR survey serves two primary purposes. First, the survey can identify locations of excessively wet subgrade or trapped water, both of which hinder the rubblization process. Second, the GPR survey can identify section breaks or changes in structure. In the GPR data, no locations of excessively wet subgrade were identified. The highest subgrade dielectric value was 8.7 (values above 10 can indicate excessively wet material). The only changes in structure seen were at locations where ACP has been placed on top of the JCP.

Table D.2 shows the FWD backcalculation results for the locations with only JCP. Tables D.3 and D.4 show the FWD backcalculation results for the sections with ACP over JCP. The data in Table D.4 reveal unusually low backcalculated base moduli values, indicating the JCP is severely deteriorated or possibly has been replaced with cement treated base (CTB). However, the GPR data from this section (an excerpt of which is in the left side of Figure D.3) seem to indicate the JCP is still in place. A core should be taken within this section (between 4580 to 5250 feet north from RM 631) to verify the pavement structure.

Table D.2. FWD Results for FM 1155 Sections with Solely JCP.

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                                              TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT)                            (Version 6.0)

District:     Bryan                                                     MODULI RANGE (psi)
County:       Washington                             Thickness (in)  Minimum   Maximum            Poisson Ration Values
Highway/Road:  FM 1155 NB            Pavement:         7.50          1,000,000  5,500,000  5,500,000    H1:     v = 0.20
                                     Base:             0.00                                             H2:     v = 0.00
                                     Subbase:          0.00                                             H3:     v= 0.00
                                     Subgrade:       131.49 (by DB)         20,000                      H4:     v= 0.40
------------------------------------------------------------------------------------------------------------------------------------
             Load   Measured Deflection (mils):                       Calculated Moduli values (ksi):             Absolute   Dpth to
  Station   (lbs)    R1     R2     R3     R4     R5     R6     R7     SURF(E1)  BASE(E2) SUBB(E3) SUBG(E4)  ERR/Sens   Bedrock
------------------------------------------------------------------------------------------------------------------------------------
     0      9,152   7.26   6.35   5.17   3.97   2.96   2.2    1.71    3815.8      0        0       11.1       0.89      149.2
   254      8,941  12.68  10.54   8.21   5.99   4.01   2.31   1.52    1274.5      0        0        8.7       4.08       78.6
   753      8,969   8.09   7.01   5.87   4.66   3.59   2.7    2.11    3978.8      0        0        8.7       1.17      163.4
  1002      9,048   6.4    5.69   4.56   3.5    2.59   1.87   1.43    4062.8      0        0       12.7       0.32      123
  1250      9,021   6.74   5.61   4.35   3.09   1.98   1.06   0.58    2121.3      0        0       17.7       5.91       66.6
  1500      8,894   6.94   6.23   5      3.78   2.74   1.92   1.46    3422        0        0       11.9       1.06      112.6
  1754      9,176   9.67   8.3    6.81   5.21   3.7    2.56   2.11    2503.1      0        0        9.2       1.36      113.7
  2002      8,897   9.09   7.75   6.08   4.61   3.32   2.4    1.76    2466.8      0        0       10         1.14      127.1
  2256      8,874   7.67   6.98   5.76   4.54   3.4    2.49   1.88    3852.1      0        0        9.2       0.74      137.4
  2496      9,040   9.28   8.63   7.31   5.79   4.3    3.03   2.17    3317.5      0        0        7.3       2.37      119.4
  2752      9,033   6.2    5.52   4.5    3.48   2.56   1.87   1.42    4377.3      0        0       12.6       0.41      129.3
  3006      9,084   7.99   7.1    5.76   4.42   3.25   2.37   1.89    3329        0        0       10.1       0.4       138.1
  3260      8,953  10.67   9.76   8.44   6.9    5.44   4.17   3.24    3766.8      0        0        5.3       0.47      174.1
  4000      9,052   8.89   8.39   7.33   6.13   4.89   3.72   2.9     5066.4      0        0        5.8       1.45      162.1
  4251      8,977   7.19   6.58   5.44   4.34   3.28   2.47   1.97    4471.4      0        0        9.4       0.55      158.9
  4528      8,905   7.21   6.5    5.39   4.28   3.32   2.54   2.04    4625.5      0        0        9.2       0.75      180.6
  5250      9,116   8.98   8.08   6.96   5.63   4.31   3.11   2.3     3897.2      0        0        7.3       1.6       128.9
  5502      8,798   9.81   8.83   7.29   5.5    4      3.06   2.38    2699.1      0        0        7.7       1.61      186.3
  6629      8,766   9.15   8.43   7.21   5.91   4.72   3.69   2.99    4450.8      0        0        5.9       0.24      230.1
  6750      8,719   9.02   8.11   6.66   5.05   3.63   2.44   1.63    2587.9      0        0        8.9       2.2       102.2
  7000      8,921   9.15   8.63   7.34   5.93   4.54   3.28   2.33    3779.2      0        0        6.6       2.13      114.5
  7257      8,937   9.98   8.81   7.18   5.58   4.19   3.06   2.29    2782.2      0        0        7.7       0.33      142.1
------------------------------------------------------------------------------------------------------------------------------------
Mean:                8.55   7.63   6.3    4.92   3.67   2.65   2.01    3484        0        0        9.2       1.42      139
Std. Dev:            1.56   1.37   1.2    1.01   0.85   0.71   0.59     935.5      0        0        2.8       1.35       41.8
Var Coeff (%)       18.25  17.94  19.04  20.61  23.08  26.66  29.44      26.9      0        0       30.3      95.26       30.1
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Table D.3. FWD Results for FM 1155 Sections with Thin ACP over JCP.

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                                          TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT)                   (Version 6.0)

District:   Bryan                                                    MODULI RANGE (psi)
County:     Washington                            Thickness (in)  Minimum   Maximum              Poisson Ration Values
Highway/Road:  FM 1155 NB          Pavement:        2.50           421,600   421,600  5,500,000    H1:    v = 0.35
                                   Base:            7.50           200,000  7,000,000              H2:    v = 0.20
                                   Subbase:         0.00                                           H3:    v= 0.00
                                   Subgrade:      290.00 (by DB)        20,000                     H4:    v= 0.40
------------------------------------------------------------------------------------------------------------------------
          Load   Measured Deflection (mils):                       Calculated Moduli values (ksi):          Absolute  Dpth to
 Station  (lbs)    R1     R2     R3     R4     R5     R6     R7    SURF(E1) BASE(E2) SUBB(E3) SUBG(E4)  ERR/Sens  Bedrock
------------------------------------------------------------------------------------------------------------------------
   500    9,060   8.44   7.26   6.66   5.83   4.86   3.96   3.32    421.6    5657.5      0        8.2      1.51      300
  3500    9,291   8.26   8.28   8.22   6.2    4.21   2.66   2.32    421.6    2394.9      0       10.8     11.78     150.4
  3750    9,148   7.01   6.21   5.38   4.45   3.44   2.59   2.02    421.6    3926.1      0       13        2.05      300
  6253    9,029   8.17   7.12   5.88   4.65   3.46   2.51   1.89    421.6    2102.2      0       13.2      1.96      300
  6449    9,009  12.67  12.62  12.35   6.63   5.31   4.21   3.32    421.6     926.7      0        8        9.84     113.1
  7452    8,917   7.84   6.46   5.13   3.93   2.89   2.13   1.68    421.6    1694.6      0       15.6      0.47      300
  7758    9,052   7.06   6.33   5.32   4.28   3.25   2.39   1.81    421.6    3092.4      0       13.9      2.48      300
  8009    9,128   6.41   6.39   5.44   4.39   3.38   2.54   2.01    421.6    4427.5      0       12.8      4.9       300
  8249    8,850   7      6.63   5.73   4.65   3.54   2.62   2.07    421.6    3597.2      0       12.1      4.05      300
------------------------------------------------------------------------------------------------------------------------
Mean:                8.1    7.48   6.68   5      3.82   2.85   2.27    421.6    3091        0       11.9      4.34      300
Std. Dev:            1.85   2.03   2.33   0.96   0.81   0.72   0.62      0      1475.8      0        2.5      3.93     117.8
Var Coeff (%):      22.87  27.21  34.93  19.19  21.11  25.4   27.33      0        47.7      0       21.3     90.55      44.2
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Table D.4. FWD Results for FM 1155 with Thick ACP over JCP.

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                                          TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT)                   (Version 6.0)

District:   Bryan                                                    MODULI RANGE (psi)
County:     Washington                            Thickness (in)  Minimum   Maximum              Poisson Ration Values
Highway/Road:  FM 1155 NB          Pavement:        8.00           160,000   720,000  5,500,000    H1:    v = 0.35
                                   Base:            7.50           100,000   500,000               H2:    v = 0.20
                                   Subbase:         0.00                                           H3:    v= 0.00
                                   Subgrade:      144.80 (by DB)        20,000                     H4:    v= 0.40
------------------------------------------------------------------------------------------------------------------------
          Load   Measured Deflection (mils):                       Calculated Moduli values (ksi):          Absolute  Dpth to
 Station  (lbs)    R1     R2     R3     R4     R5     R6     R7    SURF(E1) BASE(E2) SUBB(E3) SUBG(E4)  ERR/Sens  Bedrock
------------------------------------------------------------------------------------------------------------------------
  4753    8,925  14.81  13.13  10.88   8.6    6.34   4.34   3.22    633.7     100        0        5.1      3.62     118.4
  5000    9,096  11.08   9.05   7.38   5.87   4.52   3.53   2.89    496.4     300.1      0        7.1      0.63     248
------------------------------------------------------------------------------------------------------------------------
Mean:               12.95  11.09   9.13   7.24   5.43   3.94   3.06    565.1     200        0        6.1      2.13     160.3
Std. Dev:            2.64   2.88   2.47   1.93   1.29   0.57   0.23     97.1     141.5      0        1.4      2.11      56.7
Var Coeff   (%):    20.37  26.01  27.11  26.7   23.7   14.6    7.64     17.2      70.7      0       23.4     99.4       35.4
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After studying FWD results in the field, researchers performed DCP tests at selected locations to verify whether adequate subgrade support exists. These data are used in the rubblization selection chart developed by the Illinois DOT. The DCP data allow for evaluation of two governing parameters:

- *Support immediately beneath the slab*: If there is inadequate support immediately beneath the slab, rubblization may not be feasible. To evaluate the project for this parameter, the concrete thickness versus the CBR of the base layer immediately beneath the slab is plotted. In instances where the DCP data did not reveal a clear layer distinction, a dummy base layer value of 6 inches was assigned.

- *Support at deeper depths into the subgrade*: Even if support is sufficient immediately beneath the slab for concrete breakage, weak soils deeper in the pavement can create problems. Shear failures can occur particularly with the resonant breaker equipment due to the multiple passes required over the rubblized pavement to break the entire pavement width. To evaluate this parameter, the combined thickness of the concrete and base is plotted against the CBR value of the first 6 inches of subgrade.

Table D.5 summarizes the DCP results for use in the Illinois DOT rubblization selection chart. Figure D.4 shows the DCP data in this chart. The DCP data, in conjunction with the IDOT criteria, indicate:

- The location at DCP 1 is of questionable suitability for rubblization due to marginal support immediately beneath the slab.
- The locations represented by DCP tests 2, 3, and 4 are suitable for rubblization.
- At the location of DCP 5, support is inadequate for rubblization; the concrete may not break. Additionally, due to the poor support, even if the concrete does break, if the resonant breaker was used, the multiple passes may result in shear failure of the subgrade.
- At the locations of DPC 6 and 7, the project is marginally suitable for rubblization. This is because although reasonable support exists immediately beneath the slab, the subgrade quality quickly deteriorates with depth. Again, depending on equipment used, shear failure in the subgrade could occur from loading stresses from the construction equipment.

Table D.5. Summary DCP Results for FM 1155.

DCP Test Location	Concrete Thickness (in)	Base Thickness (in)	CBR Values		Subgrade Modulus from FWD (ksi)	Location (feet north from RM 631 on FM 912)	Comment
			Base	Subgrade			
1	7.5	6*	5.5	3.8	8.2	500	~ 2.5" ACP over JCP
2	8.5	6*	66	133.0	12.7	1002	
3	7.4	4.3	15.5	7.5	10.1	3006	
4	7.0	6*	15.8	12.6	5.3	3260	
5	7.0	6*	3	2.6	7.1	5000	~ 8" ACP over JCP**
6	7.1	5.9	9.0	2.2	8.9	6750	
7	7.4	4.1	8.5	2.4	7.7	7257	

*Assigned to 6 inches because no clear base layer boundary observed in DCP data

**FWD indicates JCP either severely deteriorated or perhaps replaced with CTB

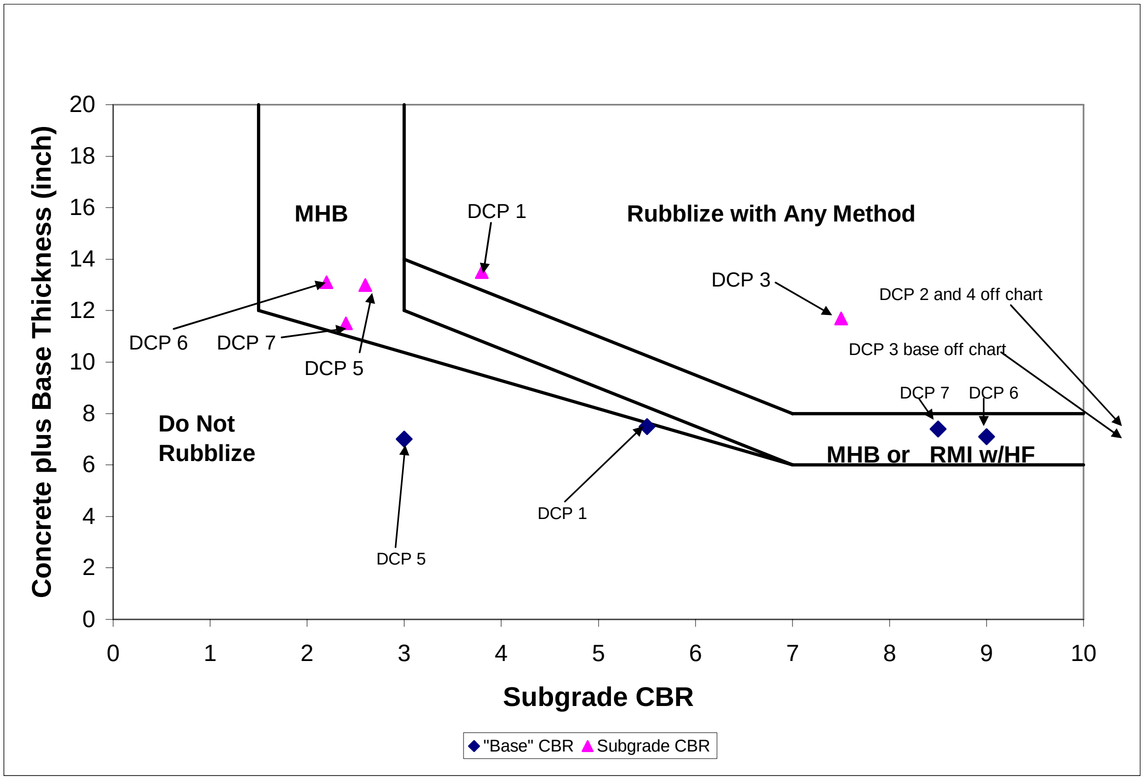

Figure D.4. DCP Results from FM 1155 on IDOT Rubblization Selection Chart.

Because the DCP testing is spot-specific, efforts were made to use the FWD data to better partition the project into limits where rubblization may be an option. To accomplish this segmenting, the minimum recommended subgrade CBR that would enable the concrete to be broken was read from Figure D.4. For the concrete thickness on FM 1155 (~7.5 inches), a subgrade CBR of approximately 6 would be required. Next, a relationship between the FWD and average CBR of the top 12 inches of subgrade was evaluated, as shown in Figure D.5. With all the data, a poor fit exists. When the two outliers are trimmed, as shown in Figure D.6, a better fit exists. The data in Figure D.5 indicate a minimum backcalculated modulus of approximately 7.5 is needed; the trimmed data in Figure D.6 indicate a backcalculated subgrade modulus of approximately 8.5 is necessary. The two methods of analysis are in reasonable agreement with each other, and it seems reasonable that for analysis purposes, the minimum required backcalculated subgrade modulus can be estimated as approximately 8.

Figure D.7 shows the backcalculated subgrade modulus with distance for the project. Using the approximate minimum subgrade CBR of 8, rubblization may not be feasible for approximately one third of the project. With the FWD analysis in conjunction with the DCP analysis, the greatest risk of encountering problems if rubblization is attempted exists between 4580 to 5250 feet north of RM 631 on FM 912.

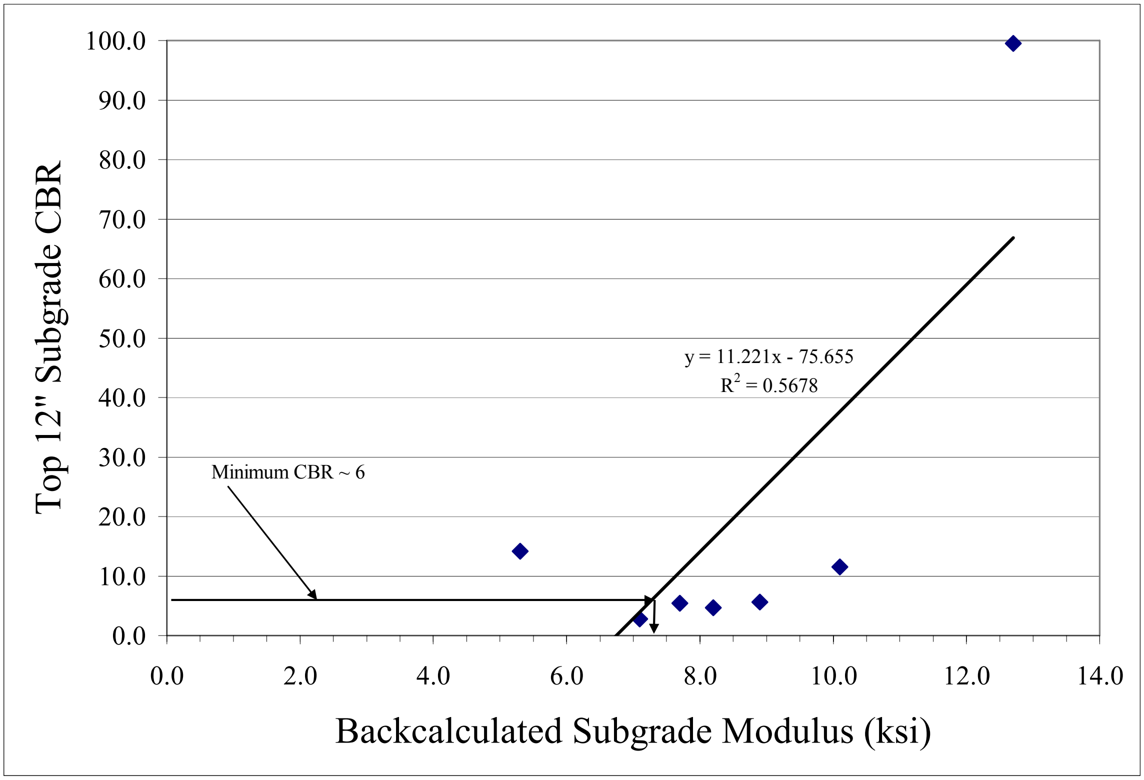

Figure D.5. Subgrade CBR vs. Subgrade Modulus for FM 1155.

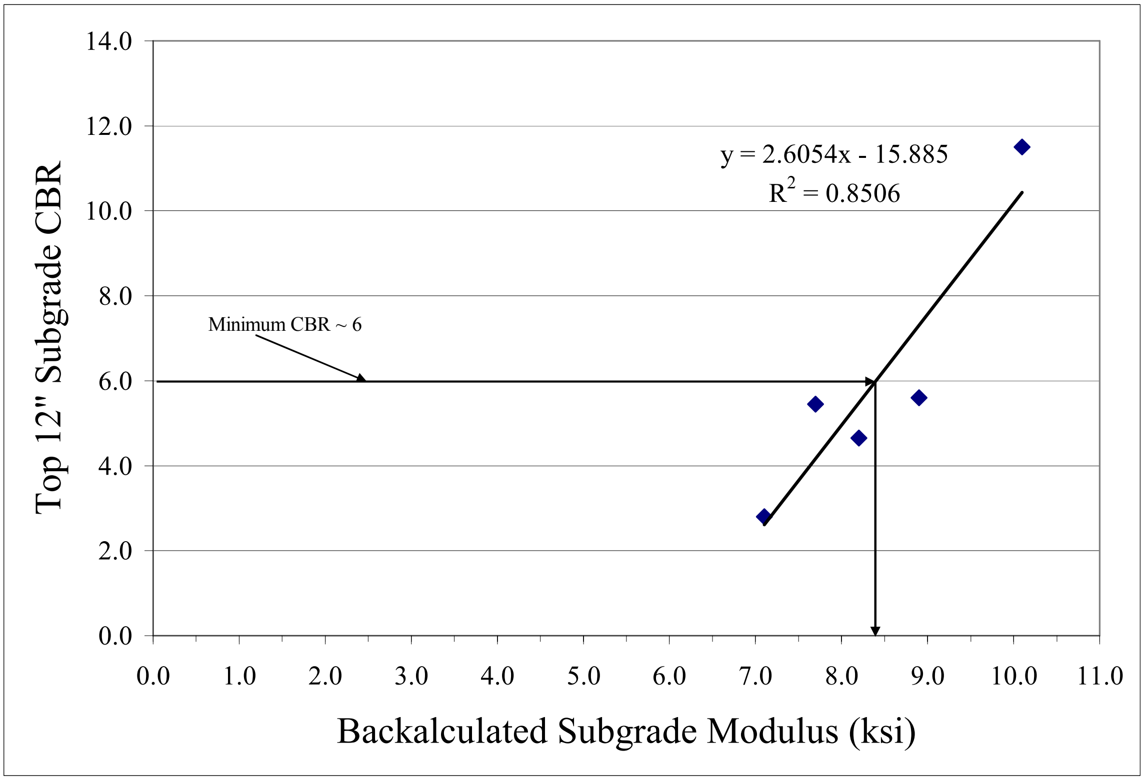

Figure D.6. Subgrade CBR vs. Subgrade Modulus with Trimmed Data for FM 1155.

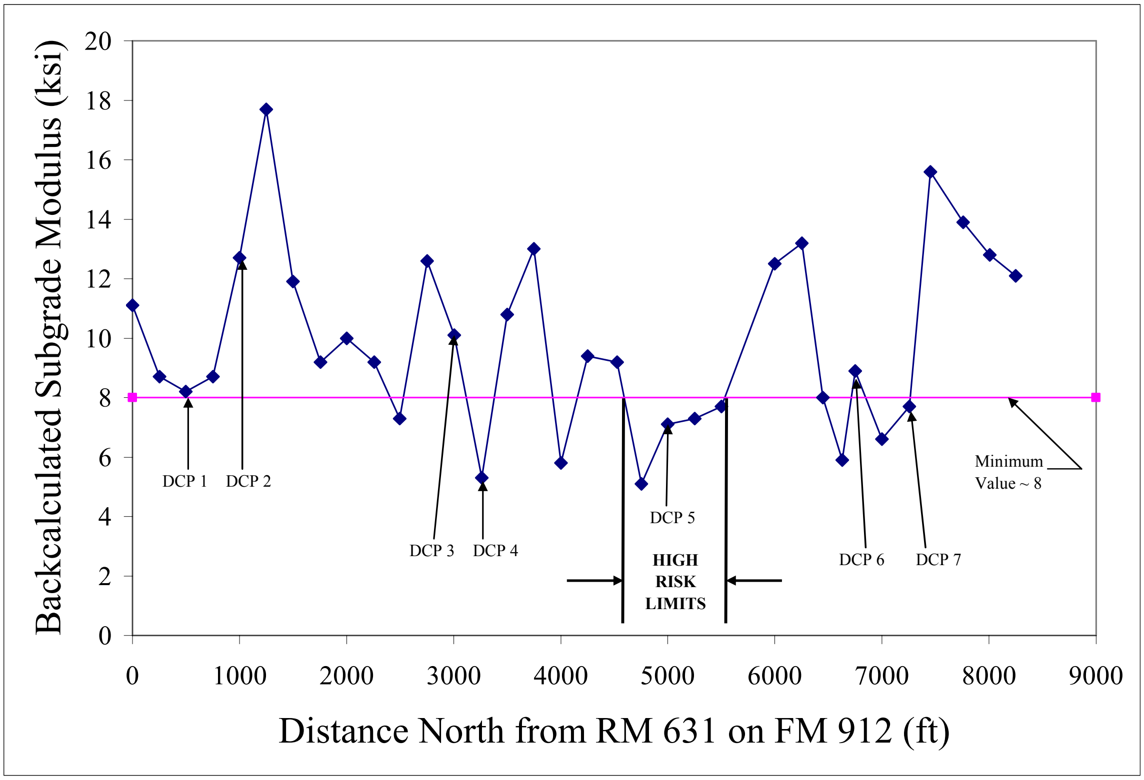

Figure D.7. FM 1155 Backcalculated Subgrade Modulus with Distance (NB Direction).
Note: Zero Distance is at RM 631 on FM 912.

RECOMMENDATION

Based upon the results presented and discussed above, the majority of the JCP on FM 1155 is of marginal suitability for rubblization. Using RM 631 on FM 912 as the zero distance point, the data indicate the following:

- The first 1000 feet are of questionable suitability for rubblization.
- From 1000 to 4550 feet, the project should be suitable for rubblization.
- From 4550 to 5250 feet, the subgrade support is likely too poor to support rubblization operations. A core should be taken at 5000 feet to verify the pavement structure.
- From 5250 feet to the end of the JCP, the project is marginally suitable for rubblization.
- Given the soil conditions, the multi-head breaker likely is the safest equipment to use if rubblization is attempted.