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Texas A&M Transportation Institute

Implementing Rubblization and Drainage Improvement Techniques on Severely Distressed Concrete Pavements: Technical Report

Implementation Report Report 5-4687-03-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
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16. Abstract

Rubblization of old concrete pavement has not been widely used in Texas. In this implementation study, a review was made of Texas experience with this approach including both successes and failures. The lessons learned were incorporated into workshop materials developed as part of this study. A review was also completed on the recommended pavement evaluation procedures developed in the original 0-4687 project. These were updated and demonstrated on three sections, which are under consideration for rubblization, in the Beaumont, Dallas, and Paris Districts. The design recommendations for each are presented in this report.

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IMPLEMENTING RUBBLIZATION AND DRAINAGE IMPROVEMENT TECHNIQUES ON SEVERELY DISTRESSED CONCRETE PAVEMENTS: TECHNICAL REPORT

by

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). 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 FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Tom Scullion, P.E. #62683.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors thank Dr. Dar-Hao Chen formally of TxDOT who was the project director. Melissa Benavides provided support in processing the data collected on the Beaumont sections. The staff of various districts also helped greatly; in particular, many thanks to Wade Blackmon of the Paris District and Boon Thian of Dallas. This work was funded was an implementation study by TxDOT's RTI division where Joe Adams was the project administrator.

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CHAPTER 1. INTRODUCTION

Rehabilitation of concrete pavements is a major issue within the Texas Department of Transportation (TxDOT). TxDOT has many miles of old jointed and continuously reinforced concrete pavement (CRCP) that are approaching the end of their service life. Black topping and white topping can be used to gain additional life, but these treatments are often impacted by reflection cracking. In many instances, the existing concrete pavement is structurally deteriorated so that simple overlays will not provide adequate performance. TxDOT needs good alternatives for rehabilitating these pavements. In the last 20 years, slab fracturing techniques have become popular, such as crack and seat, break and seat, and rubblization. This report presents findings from the implementation project 5-4687-03, a TxDOT-sponsored project investigating rubblization as rehabilitation options for concrete pavements.

Rubblization requires special equipment to reduce the concrete to fragments having the same textural and gradation characteristics as large aggregate flexible base. The key issue here is that the fractured concrete is left in place and used as a new base in the rehabilitated pavement structure. The rubblization equipment has been used widely around Texas, but the vast majority of these projects has been for remove and replace. Rubblization is the most expensive of the three slab-fracturing techniques (more than crack and seat or break and seat), but it is gaining popularity among many departments of transportation (DOTs) as it is judged the most effective at developing uniform pavement support and minimizing reflection cracking.

With rubblization as per TxDOT specification 3038, the concrete must be broken into fist sized pieces that can be compacted to form a hard-durable base. The maximum size of particles anywhere within the existing concrete must be less than 9 in. TxDOT specs call for smaller particles at the top of the slab. Another key requirement is that the existing steel within the slab must be debonded from the concrete making it easy to remove if need be.

Two primary pieces of equipment are available for rubblization, and both are permitted to be used in TxDOT specifications. As shown in Figure 1, the resonant breaker method used by Resonant Machines, Inc. (RMI) employs a high-frequency, low-amplitude tamper to fracture the pavement. More details of the equipment are available on the company's website (*1*). The other common rubblizing equipment is the multi-head breaker (MHB) used by Antigo Construction as shown in Figure 2. This equipment uses 12 drop hammers that impact the pavement to accomplish rubblization. More details of this equipment are available at Antigo's website (*2*). The end result of both machines is to reduce the concrete to a very high quality base layer. Both sets of equipment normally target one lane mile for rubblization in one day. The RMI is reported to provide a more uniform slab fracturing with depth, whereas the Antigo unit can change the drop heights, so it can impart a lower impact if less fracturing is required. No matter what, both units have to meet the fracturing specified in the prevailing specification.

Both companies (RMI and Antigo) have many years of experience on a range of concrete rubblization projects around the world. Working with prime contractors, they will establish a construction schedule that will fit the project's needs primarily in terms of traffic handling. In extreme cases when roadways must be open during the daytime, all the work can be scheduled at night, including rubblization and asphalt overlays.

Figure 1. Resonant Machines Inc's Breaker.

Figure 2. Antigo's Multi Head Breaker (MHB).

Figure 3 shows the required steps in any successful rubblization slide. This in an important figure that presents the key steps that should be followed in all rubblization projects.

- Evaluate project to determine if it is a good candidate
- Install drainage system (if needed)
- Remove existing HMA overlay (a must)
- Saw-cut adjacent sections (Exit/On Ramps)
- Develop a different design for underpasses
- Rubblize Test Strip and validate meeting specifications
- Rubblize Pavement
- Cut and remove exposed steel
- Remove and replace weak areas (if needed)
- Compact rubblized concrete
- Place
  - A) HMA leveling course and structural HMA overlay, or
  - B) Bond Breaker and new CRCP Pavement

Figure 3. Key Steps in the Evaluation and Design of Any Rubblization Candidate.

Full details are provided on each of these steps in the workshop materials that were also developed as part of study 5-4687-03, a summary of the required steps will be described below. The first step is to determine if the deteriorated concrete pavement is a good candidate for rubblization. As will be demonstrated in the case studies, this involves testing with ground penetrating radar (GPR) and falling weight deflectometer (FWD). The key requirement is to have reasonable support directly below the existing concrete slab, without which the slab cannot be adequately broken. The support is judged by the dynamic cone penetrometer (DCP) testing of the 6 to 12 in. of material under the slab; Figure 4 presents the proposed criteria. These recommendations were initially proposed by Marshall Thompson for the Illinois DOT (*3*, *4*), and they were subsequently modified and validated for use in Texas in study 0-4687-2 (*5*).

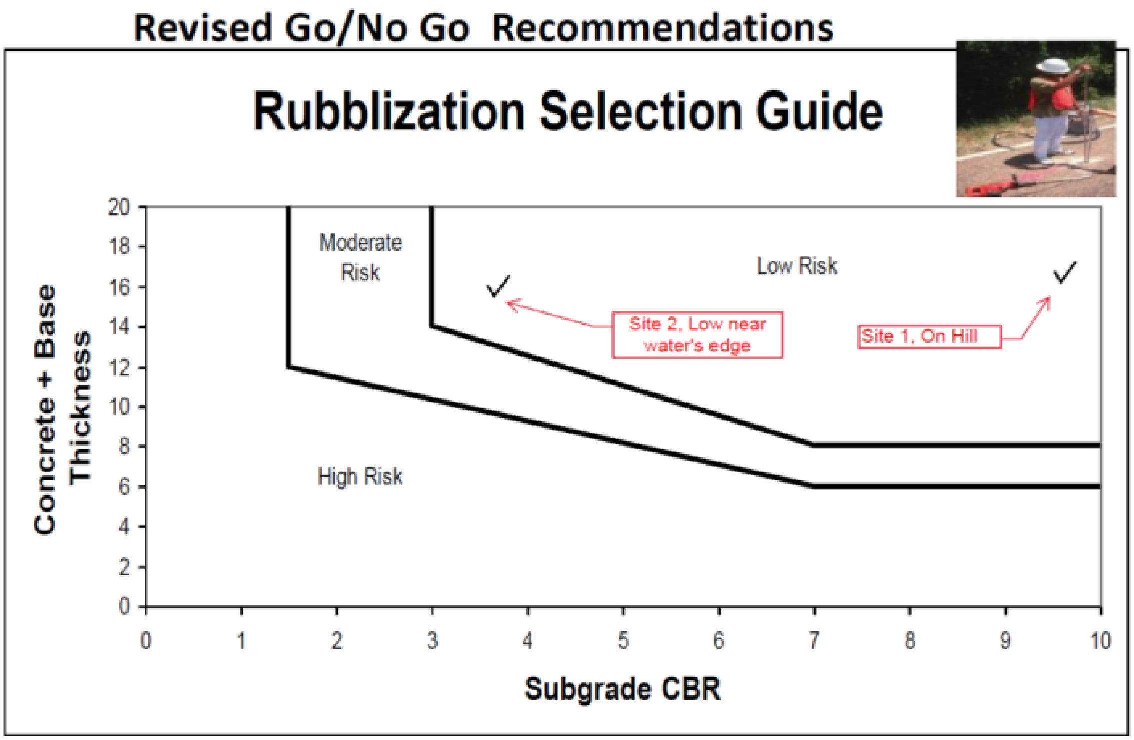


Figure 4. DCP Criteria to Evaluating the Risk Associated with Rubblization Based on Base Support as Measured by the DCP.

If moisture is present at joints or voided locations under the slab, it must be removed prior to rubblization. This can only be achieved by installing edge drains and creating adequate ditch depths to vent any moisture. All the rubblized sections in Louisiana installed edge drains. This historically has been a big problem in Texas, as often the ditches on Texas highways are not adequate to drain edge drains without substantial ditch work. This is often challenging.

For any areas that are not to be rubblized such as entrance and exit ramps, it is necessary to saw cut a joint between the two sections. At all underpasses, most probably an alternative procedure will be required to prevent bridge clearance problems. In other DOTs, the saw and seal technique is often used for 100 ft before and after the underpass.

The key step when initiating the rubblization is as per specification to establish a test strip and validate that the correct breakage pattern is being achieved. If not, the inspector should work with the contractor to normally slow down the operation or get more passes over the slab, or in the case of the MHB, increase the drop height.

As discussed throughout this workshop, the amount of remove and replace is dependent upon the base beneath the existing pavement. The old 9-6-9 jointed concrete pavement (JCP) are not good candidates, and in those cases upward of 15 to 20 percent of the concrete can the estimated to require full depth replacement. On new concrete pavements with reasonable bases that quantity, the amount of full depth repair to less than 5 percent.

Figure 5 demonstrates the economics of the cost effectiveness of rubblization.

Figure 5. Example of a Rubblized Surface Plus Cost Estimates.

The cost of simple rubblization is relatively inexpensive at around $2.50 per sq. yard. Once it is rubblized, it will cost another $4 to $5 to pick up, haul off, and dispose of the broken concrete. If the work includes building a new pavement on the site, then the cost of importing new base material will be around $15 per sq. yard.

This makes little economic sense to researchers. Removing and replacing appears to be a substantial waste of time and money. The unknown in the decision-making process is the quality of the rubblized concrete. Based on the data collected in Texas, the broken concrete will have much higher in place moduli values than traditional flexible base. In addition, as measured under the FWD, the modulus of the rubblized concrete appears to increase with time and no doubt the concrete particles start re-cementing together.

The one factor that controls the cost of rubblization in Texas is the type of coarse aggregate in the existing concrete. Limestone is relatively easy to rubblize, but river gravel is very hard to break and very hard on the equipment. The cost per square yard will largely be a function of how tough the coarse aggregate is.

The benefits of rubblization have been well documented in Louisiana where it is known to save both time and money. The Louisiana Department of Transportation and Development engineers claim that this technique, which has been widely used, is four times faster than remove, replace, and reconstruct. Cost savings of at least 33 percent have also been achieved when compared to reconstruction (*6*).

With the documented savings in time and money reported by the surrounding state DOTs, it is worth discussing why rubblization techniques have not been widely adopted in Texas. There are some good reasons, and these are described in Figure 6.

- **We have mostly CRCP (claimed cannot be rubblized – not true)**
- **Early failures with Rubblization Projects in Texas (true)**
  - **Problems with old 9 - 6 – 9 pavements**
  - **Need better up front evaluation procedures**
- **Where/When/How to install permanently operating Edge Drains**
  - **Sometime tough to get water out**
- **Raises the road**
  - **Issues with bridge clearances**
- **Concrete preferred on high volume roadways**
  - **Not an issue as you can put concrete on top of rubblized layer**
- **Turning strong Concrete into weak Flexible base not a good idea**
  - **Rubblized concrete much better than Flexible base**

Figure 6. Problems Found with Rubblization Implementation in Texas.

The vast majority of the rubblization pavements around the United States has been badly deteriorated JCP. Texas does not have too many jointed pavements. A decision was made by TxDOT's management in the 1980s to promote the use of CRCP and address several of the initial design flaws with the first generation of these pavements, namely restricting the aggregate type, providing for an asphalt base, and having concrete shoulders. CRCP essentially does not deteriorate to the same extent as jointed pavements found around the United States. Often these pavements require a simple hot mix asphalt (HMA) overlay to substantially extend their lives. It was also falsely stated that CRCP could not be successfully rubblized; this is not the case.

The biggest concern with rubblization in Texas was the poor performance of the first few projects attempted in the 1990s. Texas has many miles of old thickened edge jointed pavements constructed from 1920 to 1940. These are known as the 9-6-9 pavements, often only 18- to 20-ft wide. The edges are 9 in. thick and reinforced; and the center of the slab is only 6 in. thick. The biggest problem is that these 9-6-9 pavements were constructed on a select fill layer that was often low plasticity index sand. Over the years, this sand has been contaminated with the clay materials it is sitting on. Rubblization is only effective when the concrete slab is sitting on something solid so that it can be fractured. Basically 9-6-9 pavements are not good candidates for rubblization. When this work was started in the 1990s, TxDOT did not have a good procedure for evaluating candidate projects to determine if rubblization is even feasible. This was developed as part of research study 0-4687; this is the criteria described earlier and summarized in Figure 4.

Other issues revolve on the ability to put in edge drains on Texas highways because of the inadequacy of the existing ditches. This was the case with the success in Louisiana whose pavements are built up on substantial embankment. Meetings were held to attempt to do similar construction on IH 10 in the Beaumont District but that was abandoned when the DOT found that it would be extremely difficult to drain trapped water from under the slab because of the lack of ditches.

Project 5-4687-03 was an implementation project aimed at finalizing the candidate evaluation process and demonstrating the process on candidate sections nominated by the districts. The TTI researchers completed evaluation in three districts:

- Beaumont District (US 96).
- Dallas District (US 175).
- Paris District (US 75).

In each case non-destructive testing and DCP testing was completed. A structural design was proposed using TxDOT’s Flexible Pavement System (FPS 21) structural design program. Details of each of these evaluations is presented in the following three chapters of this report.

CHAPTER 2. US 75 DESIGN RECOMMENDATIONS

EXECUTIVE SUMMARY

Researchers propose that the Paris District place **<u>7 inches</u>** of HMA over the rubblized concrete on the test section on US 75. The top 2 inches should be a performance mix from the TxDOT spec such as a stone matrix asphalt (SMA) or a Superpave mix (district preference). The lower 5 inches can be an Item 341 mix (again district preference).

In this design, researchers proposed that the 18 kip equivalent single axle loads (ESALs) over 20 years will be 62.7 million ESALs in the design lane. This is based on the ADT estimates of 51,417 (current) and 76,403 (20 years), with 20 percent trucks.

The modulus of the base and subgrade layers for this section were set at 40 ksi and 8 ksi, respectively, based on the DCP data collected in the recent pavement evaluation.

The modulus of the rubblized concrete layer was set at 500 ksi. The rationale for this value is described in the following supporting documentation

The predicted time to first overlay for the section is 12 years.

All life estimates are based on the successful installation of edge drains to remove the trapped subsurface water.

SUPPORTING DOCUMENTATION

Figure 7, Figure 8, and Figure 9 show the input values used within FPS 21 to arrive at the design HMA thickness.

Figure 10 shows the acceptable designs that will meet the input time to first overlay of 10 years. The 7 inches of HMA design was selected for further evaluation.

Figure 11 shows the proposed design and the overlay required (2 inches) in year 12 to achieve the 20-year design life.

Figure 12 and Figure 13 show both the mechanistic check and the Texas Triaxial check for the as-designed pavement structure; the proposed design had no problem passing both the design checks.

Figure 14 shows a photo of the flexible base under the slab on US 75. The base is fairly good quality material. The problem with the base is that it is saturated with water entering the pavement at the lane/shoulder longitudinal joint. Work is underway to install edge drains to remove this trapped water. No pavement design will work without a successful installation of an operational drain.

Figure 15 shows DCP data from two locations tested in the areas proposed for the rubblization test section. An access hole was drilled through the concrete slab, and penetration testing started at the top of the base. The two graphs show the California Bearing Ratio plots with depth. The worst results were from location #66. The tables of numbers show the depth below the surface and the modulus value predicted from the DCP data using the procedures documented in TxDOT pavement design manual. The base is typically running around 40 ksi, and the lowest value in the subgrade was 8 ksi. These values were used in the FPS 21 design. These values are conservative, as once the base is drained, it is anticipated that these values will increase.

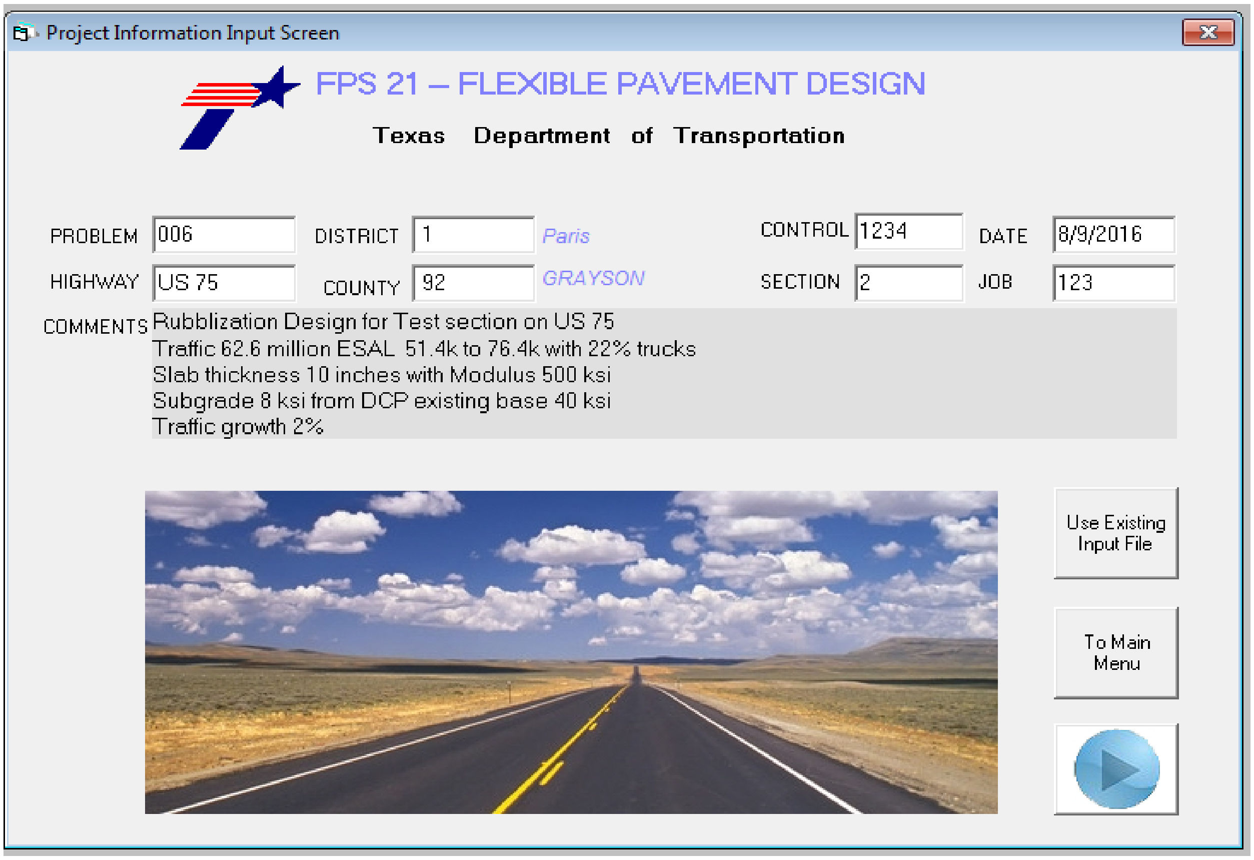


Figure 7. Screen 1 in FPS for US 75 Rubblization Design.

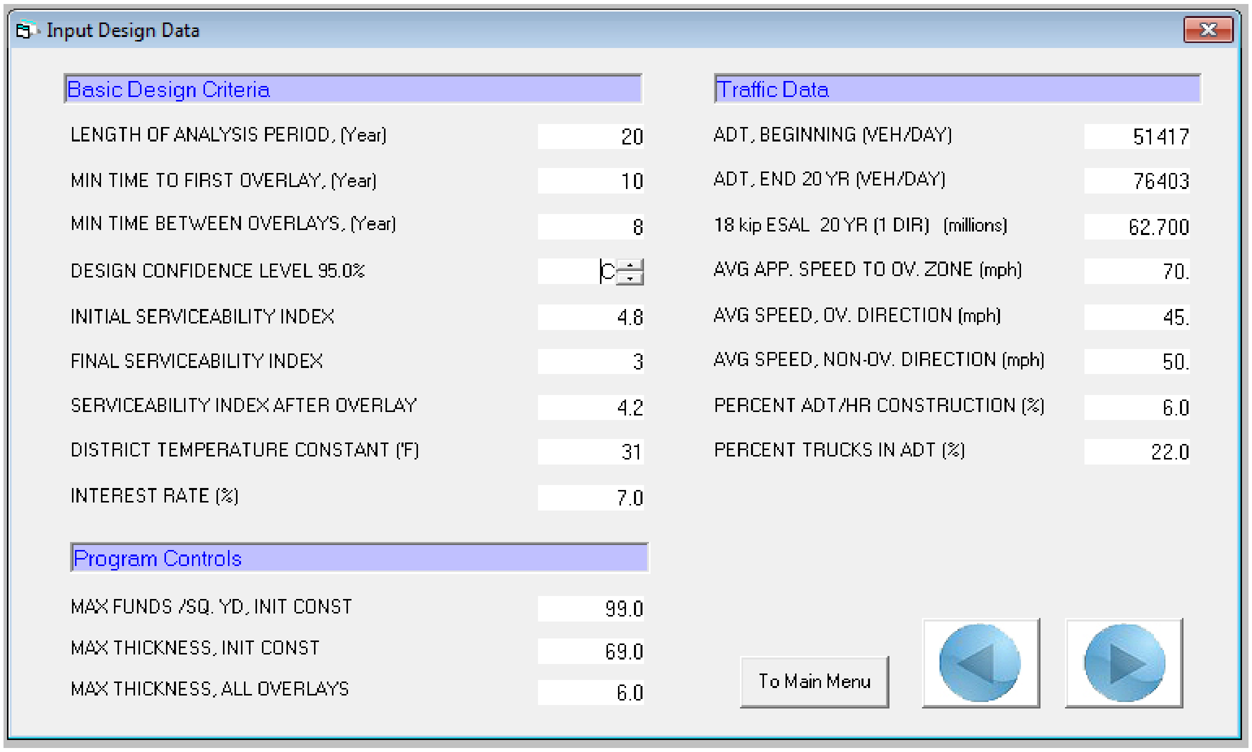


Figure 8. Screen 2 in FPS for US 75 Rubblization Design.

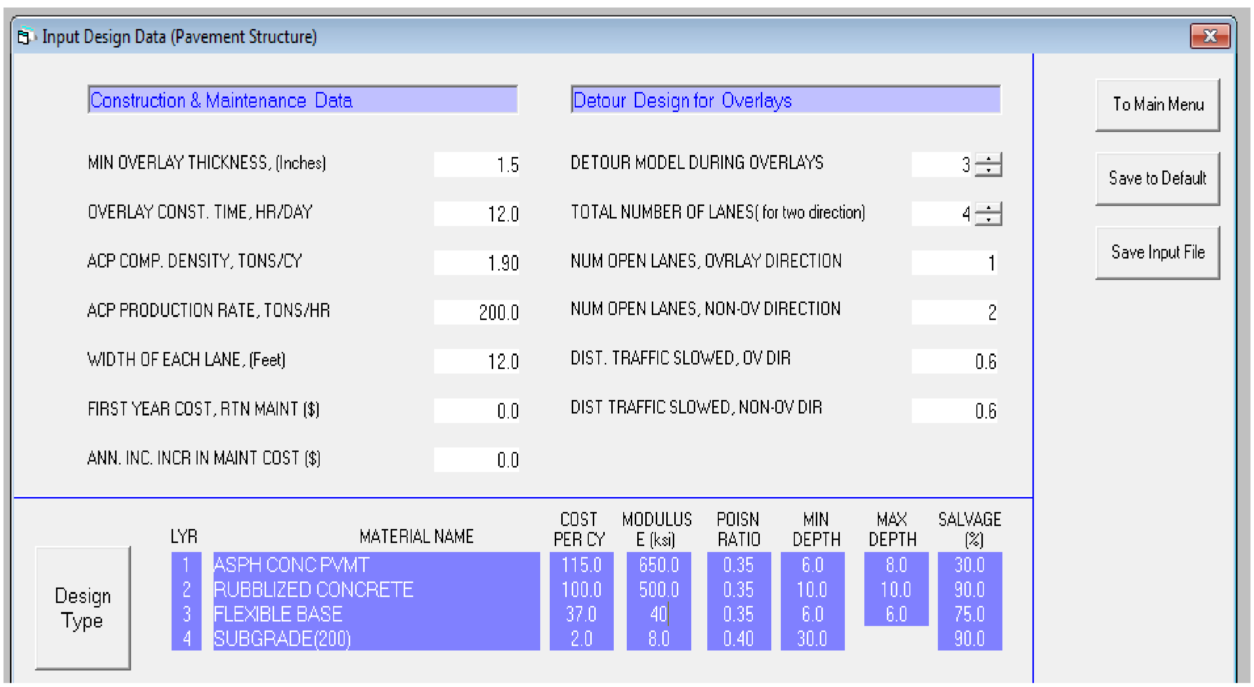


Figure 9. Screen 3 in FPS for US 75 Rubblization Design.

Figure 10. HMA Design Options.

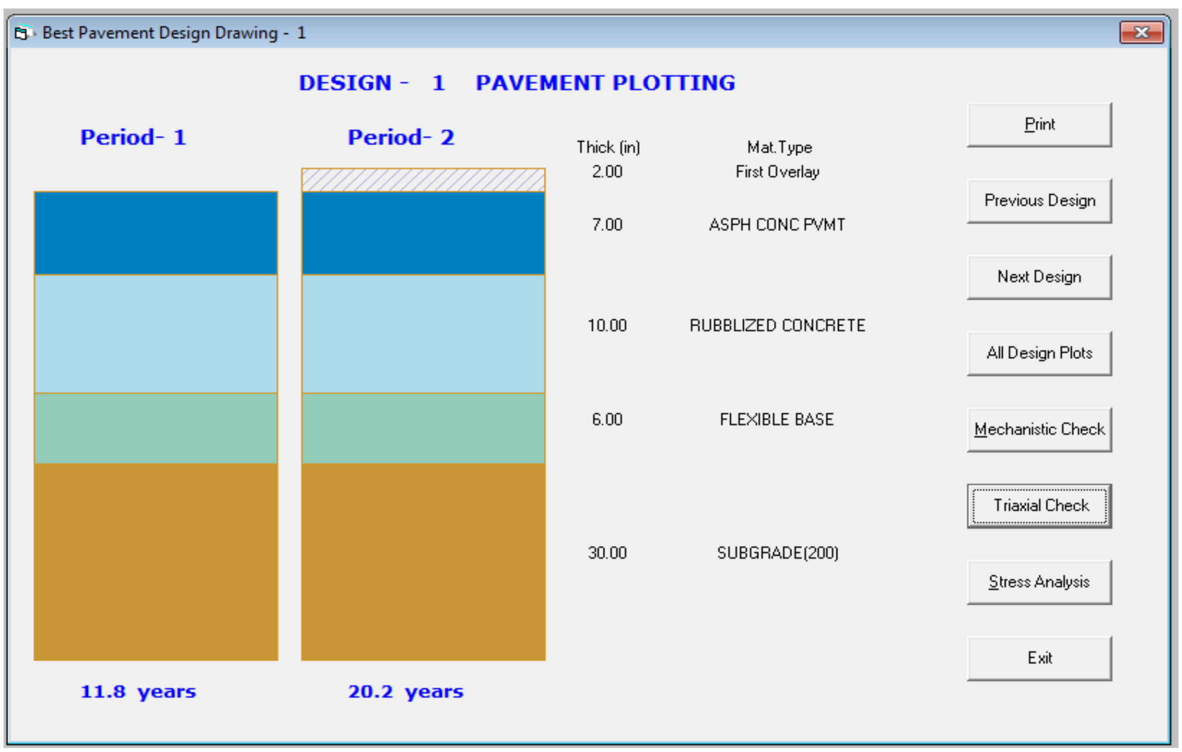


Figure 11. Proposed Pavement Design for US 75.

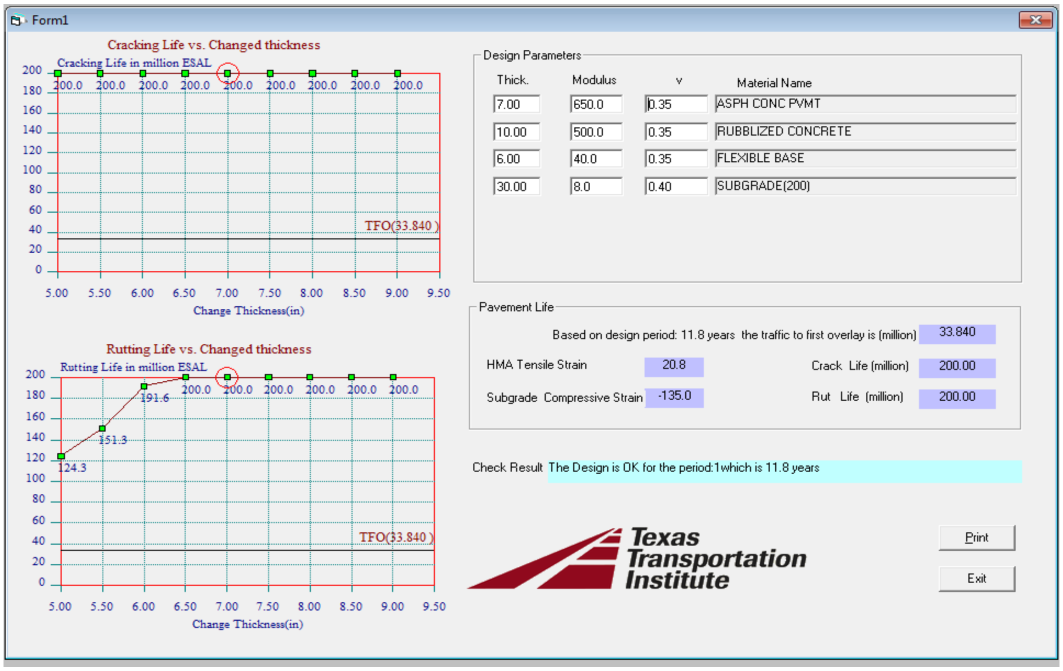


Figure 12. Mechanistic Check for US 75.

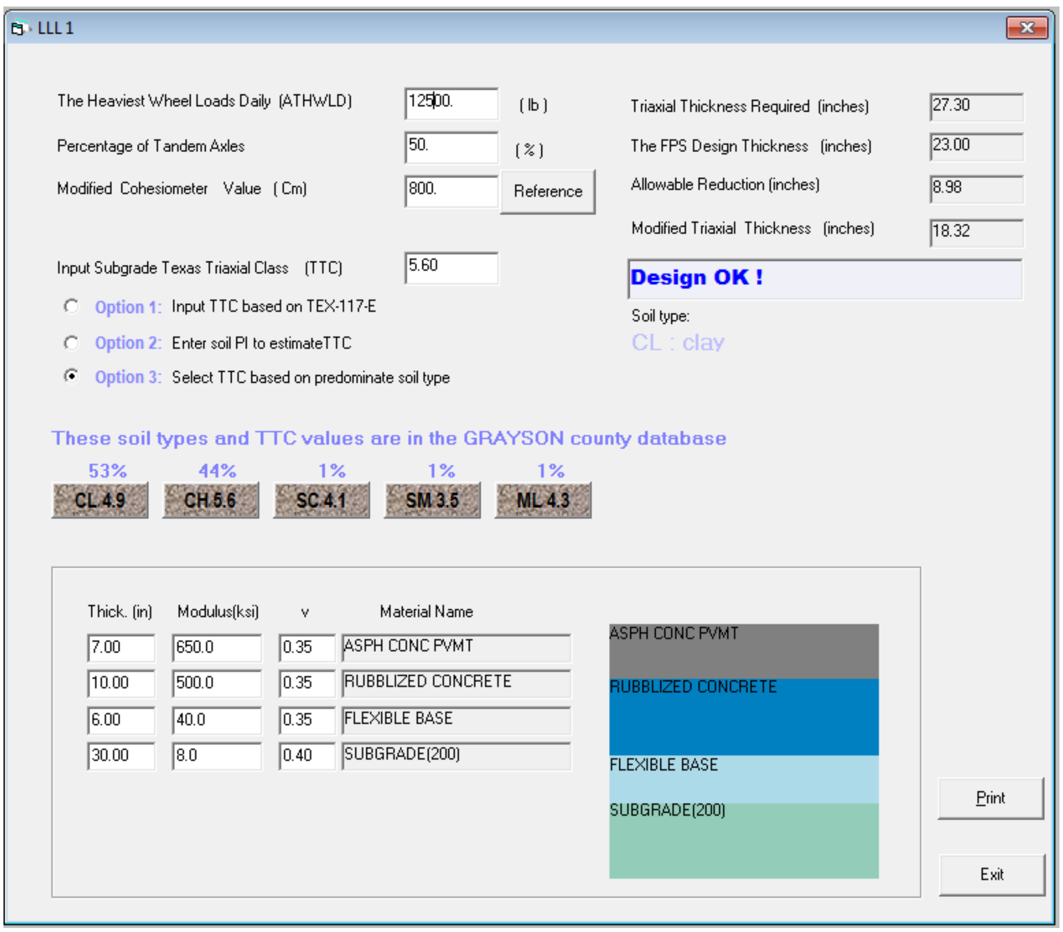
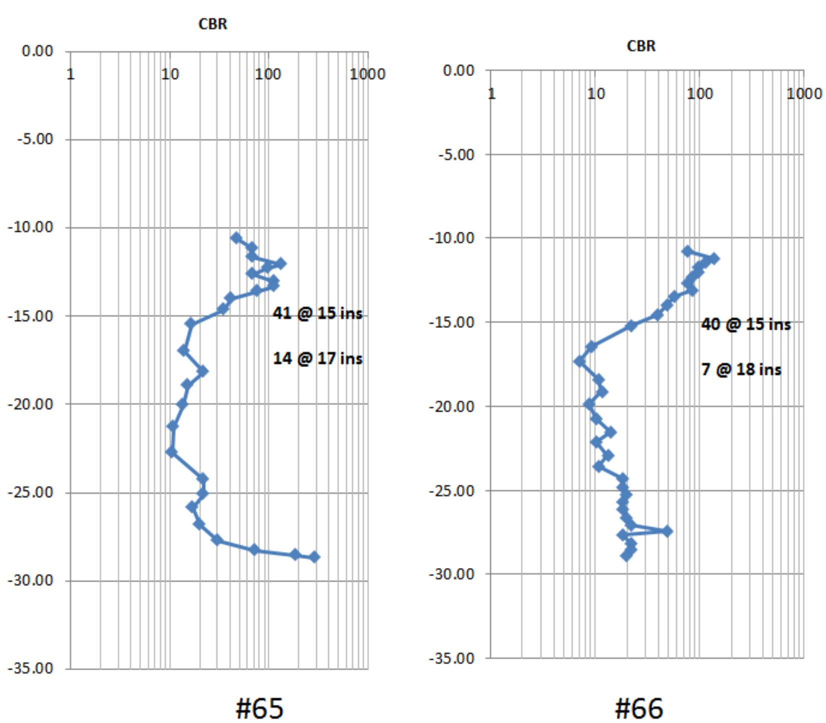


Figure 13. Texas Triaxial Check for US 75.

Figure 14. Existing Base on US 75 (Good Quality).



E (ksi)	depth (ins)
40.69917	-11.1811
58.69576	-11.4173
52.55563	-11.6929
47.7585	-12.0079
47.7585	-12.3228
43.89191	-12.6772
40.69917	-13.0709
43.89191	-13.4252
33.72182	-13.937
30.4343	-14.5276
26.70584	-15.2362
18.51761	-16.4173
10.52292	-17.2835
8.852423	-18.3858
11.68892	-19.1339
12.15082	-19.8425
10.19292	-20.748
11.26696	-21.5354
13.84723	-22.126
11.26696	-22.9134
13.22123	-23.5433
11.68892	-24.2914
16.24905	-24.7638
16.24905	-25.2362
17.29477	-25.6693

Figure 15. DCP Data on Base and Subgrade (Stiff Layer Encountered 30 Inches Down).

CHAPTER 3. US 96 DESIGN RECOMMENDATIONS

EXECUTIVE SUMMARY

Researchers propose that the Beaumont District place **4 inches** of HMA over the rubblized concrete on US 96 (CSJ-0064-08-057), north of Jasper. The top 2 inches should be a performance mix from the TxDOT spec such as an SMA. The lower 2 inches can be an Item 341 Type C mix. Alternatively, 2.5 inches of SMA over 1.5 inches of Item 341 Type D will also be acceptable.

Consideration should be given to by plan note restricting the amount of RAP in the Item 341 mix to no more than 15 percent and eliminating the use of RAS.

For the design lane traffic, the 18 kip ESALs over 20 years is 6.88 million ESALs. This is based on the ADT estimates of 11,400 (current) and 15, 800 (20 years), with 13.1 percent trucks. The traffic information was provided by TxDOT (see Figure 16).

The modulus of the existing treated base and subgrade layers for this section were set at 50 ksi and 29 ksi, respectively. They were based on the FWD data collected immediately after 4.5-inch HMA overlay for the first rubblization section constructed in 2010. The modulus of the rubblized concrete layer was set at 151 ksi. The rationale for these values are described in the following supporting documentation

The FPS 21 predicted time to first overlay for the section is 16 years.

SUPPORTING DOCUMENTATION

Figure 17, Figure 18, and Figure 19 show the input values used within FPS 21 to arrive at the design HMA thickness.

Figure 20 shows the acceptable designs that will meet the input time to first overlay of 16 years. The 4 inches of HMA design was selected for further evaluation.

Figure 21 shows the proposed design and the overlay required (2 inches) in year 16 to achieve the 20-year design life.

Figure 22 shows the mechanistic design check for as designed pavement structure. The proposed design had no problem passing mechanistic design check.

Figure 23 and Figure 24 show FWD testing on top of rubblized concrete (rubble) and conditions on one of the worst joints during rubbilization in July 2010. Figure 25 illustrates the comparisons of FWD maximum deflections (normalized to 9000 lb) between those from on top of rubblized concrete (rubble) and immediately after a 4.5-inch HMA overlay. Significant deflection reductions were observed. Figure 26 shows the backcalculated modulus values from 2010 (immediately after the 4.5-inch HMA overlay). Those backcalculated modulus values were used in this FPS 21 design. Researchers believe they are reasonable conservative design values.

Figure 27 shows the backcalculated modulus values from 2015 (after about 5 years of trafficking). The modulus of the rubblized concrete is excessively high at over 1600 ksi. The very high values indicate that the rubblized concrete layer is partially fractured and then it is re-cementing together. The modulus of the rubblized concrete layer increased over 10 times (from 151 ksi to 1688 ksi). The road was rubblized with the resonant breaker equipment in 2010. The performance has been excellent for this 3-mile-long section as it does not have a single crack in it and it continues to carry heavy logging truck traffic.

TRAFFIC ANALYSIS FOR HIGHWAY DESIGN

Beaumont District — February 20, 2018

Description of Location	Average Daily Traffic 2018	Average Daily Traffic 2038	Base Year Dir Dist %	Base Year K Factor	Percent Trucks ADT	Percent Trucks DHV	ATHWLD	Percent Tandem Axles in ATHWLD	Total Number of Equivalent 18k Single Axle Load Applications One Direction Expected for a 20 Year Period (2018 to 2038): Flexible Pavement	SN	Rigid Pavement	SLAB
US 96 Section 2 From Hi-Truitt Rd. To US 190 Jasper County	11,400	15,800	58 - 42	11.3	13.1	7.9	11,800	60	6,880,000	3	10,034,000	8"

Data for Use in Air & Noise Analysis

Vehicle Class	Base Year % of ADT	Base Year % of DHV
Light Duty	86.9	92.1
Medium Duty	1.1	0.7
Heavy Duty	12.0	7.2

Description of Location	Average Daily Traffic 2018	Average Daily Traffic 2048	Base Year Dir Dist %	Base Year K Factor	Percent Trucks ADT	Percent Trucks DHV	ATHWLD	Percent Tandem Axles in ATHWLD	Total Number of Equivalent 18k Single Axle Load Applications One Direction Expected for a 30 Year Period (2018 to 2048): Flexible Pavement	SN	Rigid Pavement	SLAB
US 96 Section 2 From Hi-Truitt Rd. To US 190 Jasper County	11,400	18,000	58 - 42	11.3	13.1	7.9	11,800	60	11,155,000	3	16,268,000	8"

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Serial Number 84704

Figure 16. Forecast Traffic for US 96 (Provided by TxDOT).

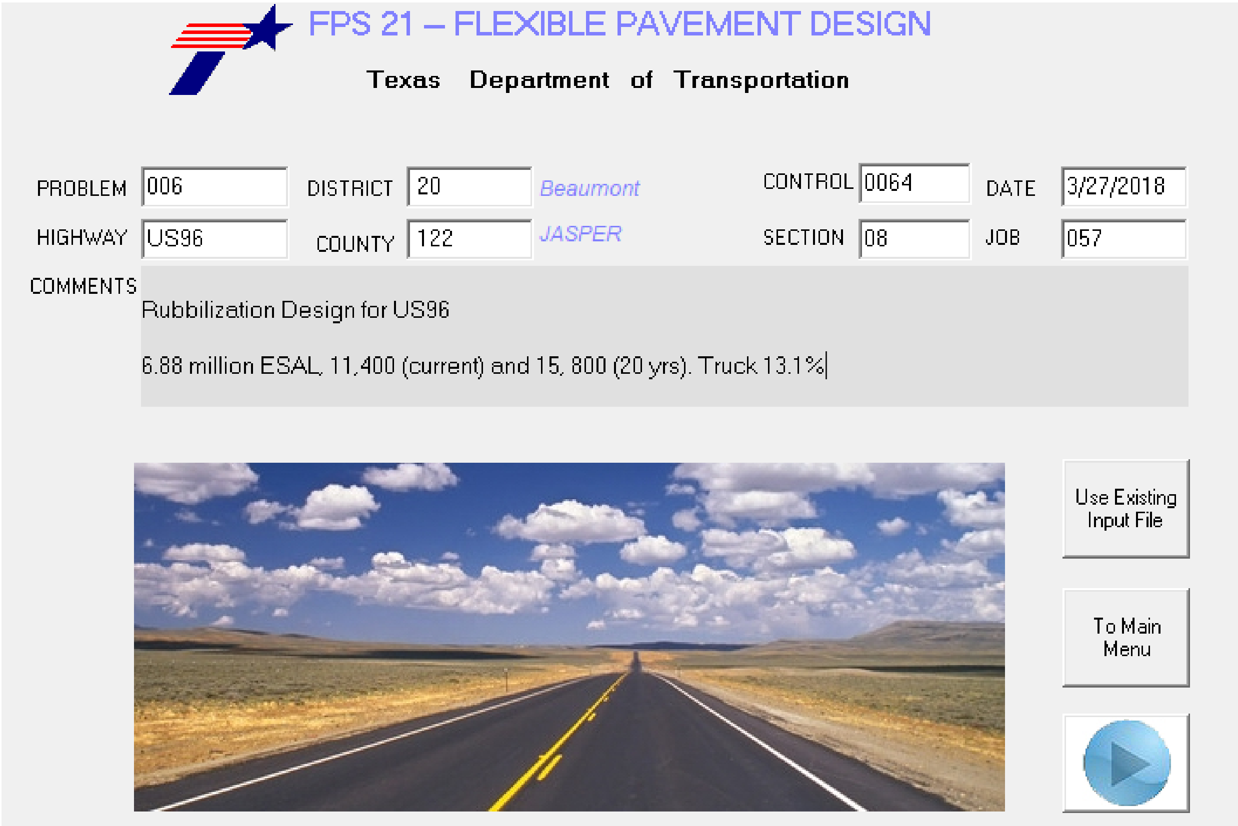

Figure 17. Screen 1 in FPS for US 96 Rubblization Design.

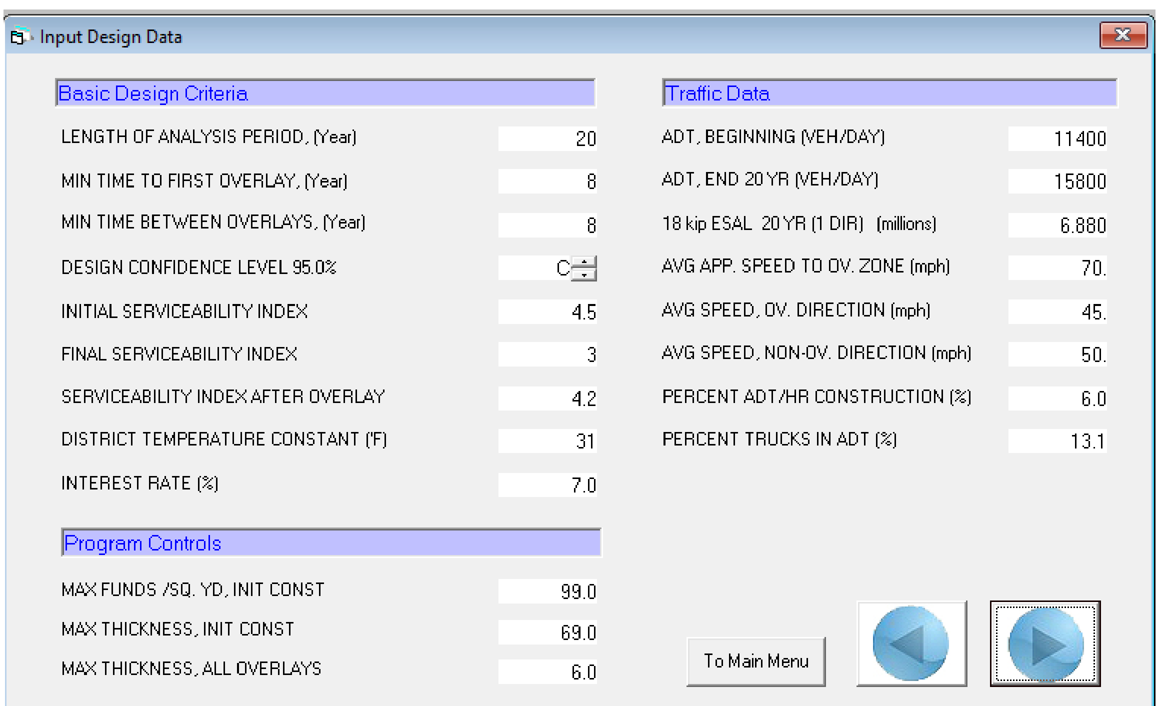

Figure 18. Screen 2 in FPS for US 96 Rubblization Design.

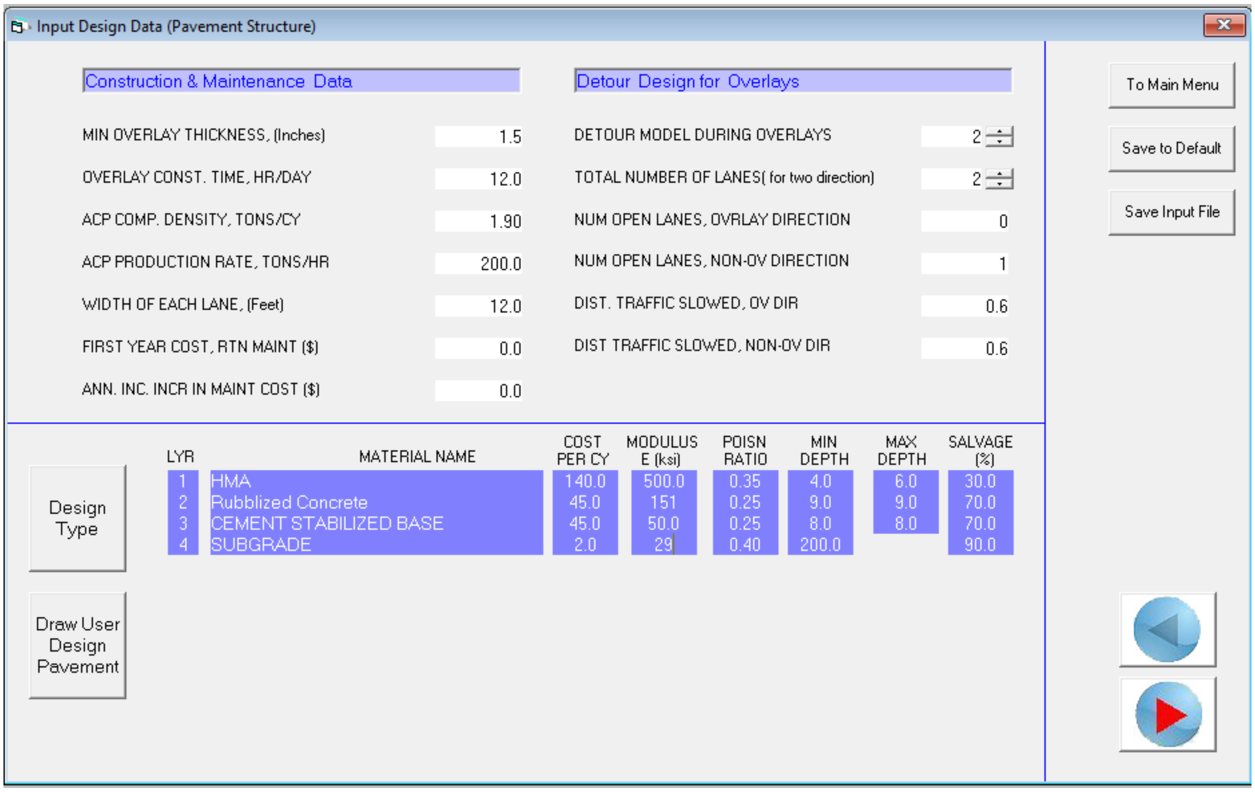

Figure 19. Screen 3 in FPS for US 96 Rubblization Design.

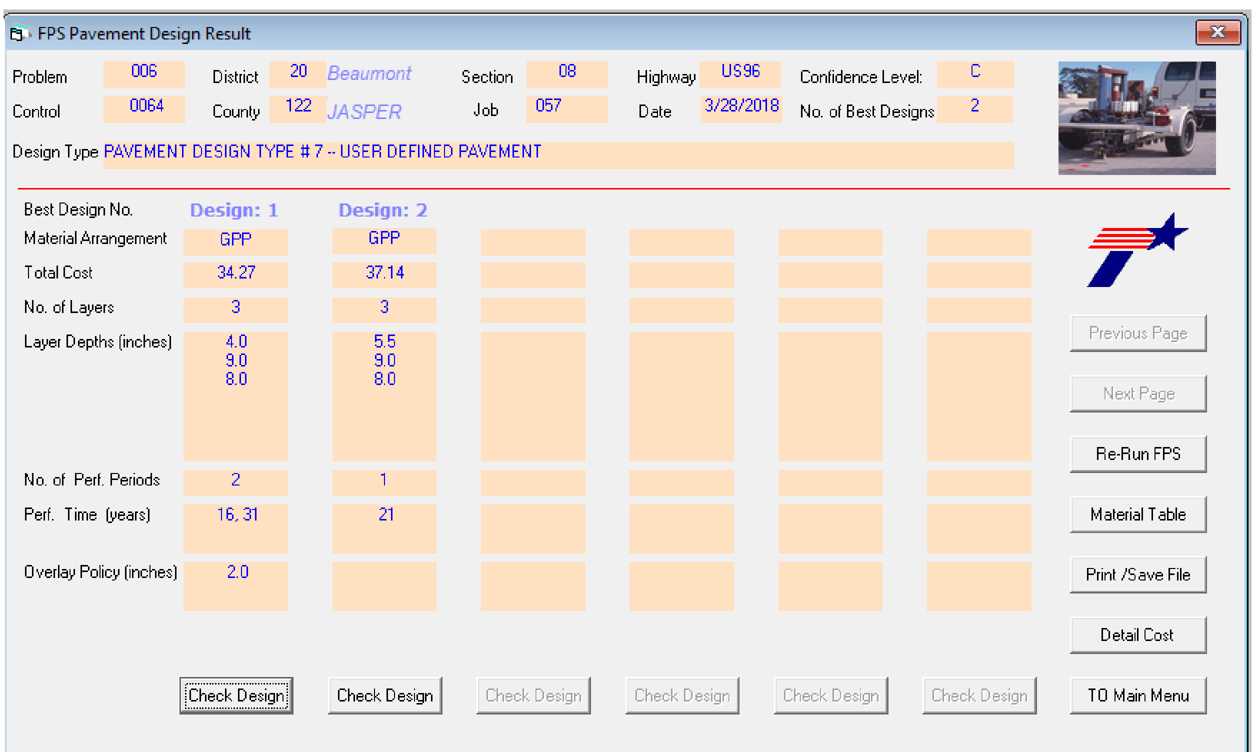

Figure 20. HMA Design Options.

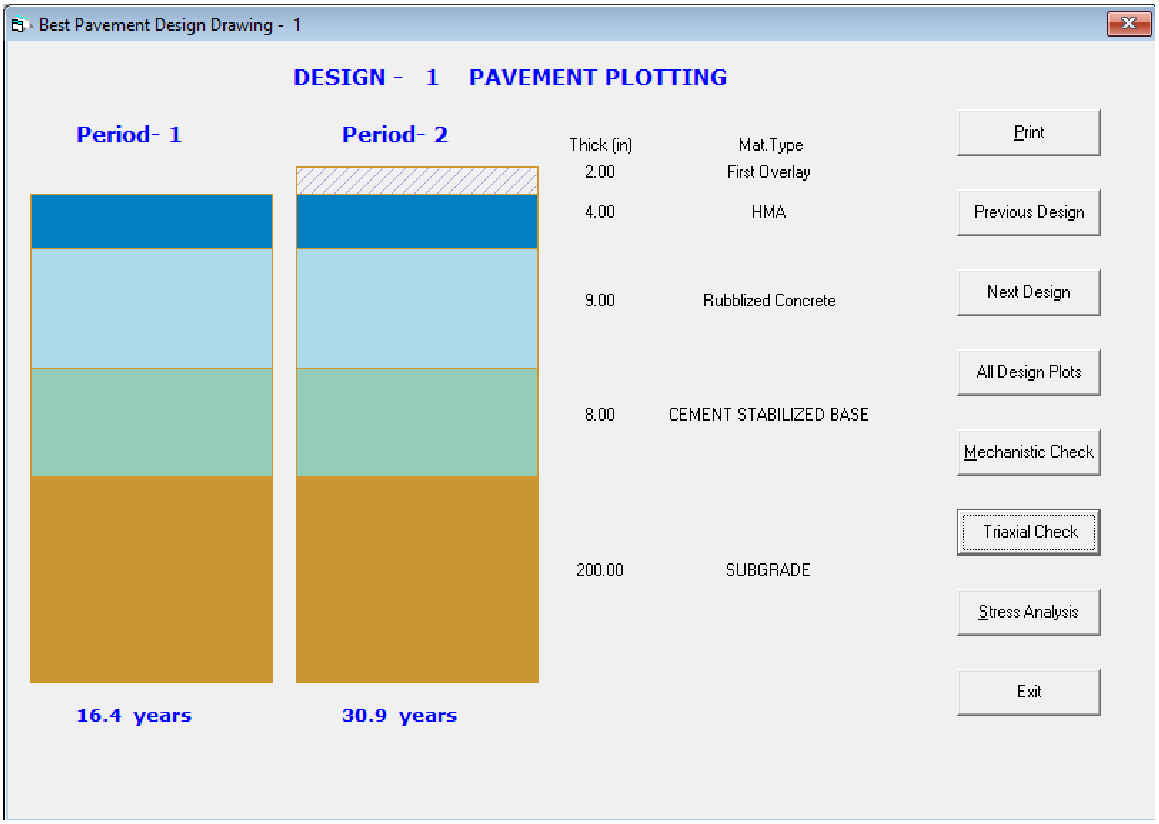

Figure 21. Proposed Pavement Design for US 96.

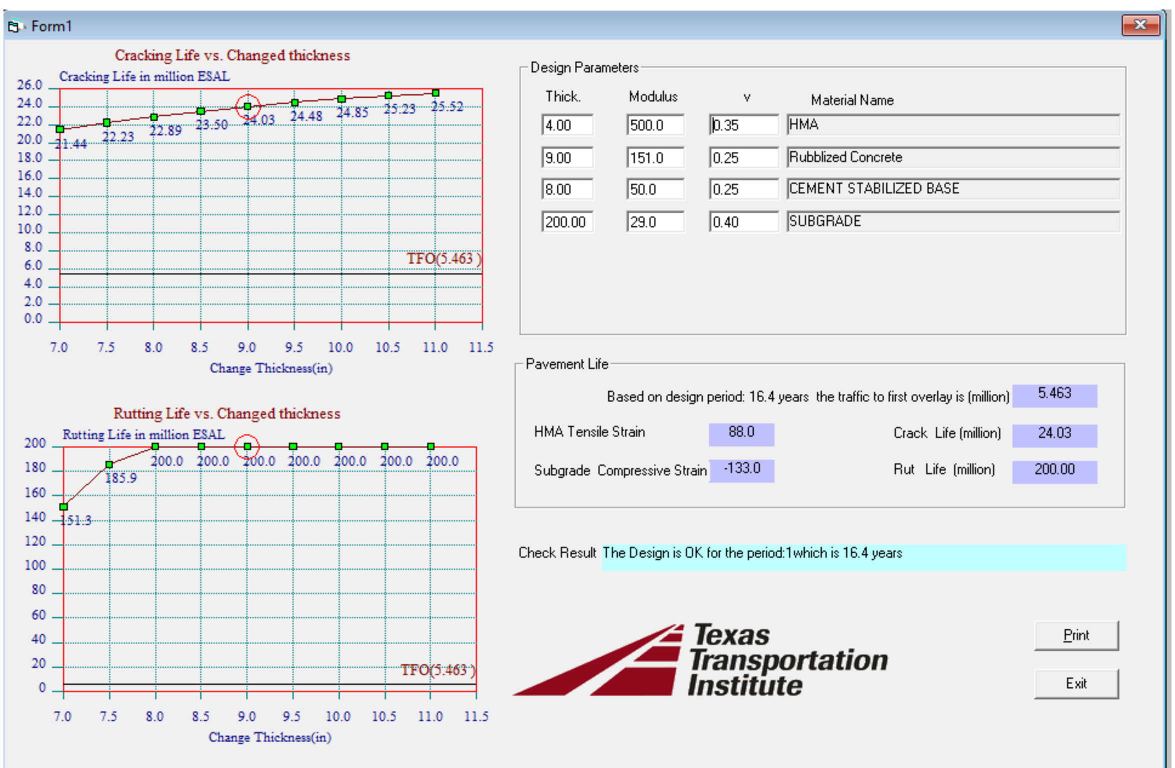

Figure 22. Mechanistic Check for US 96.

Figure 23. FWD Testing on Top of Rubblized Concrete (Rubble).

Figure 24. Rubblized (rubble) Concrete Conditions on One of the Worst Joints.

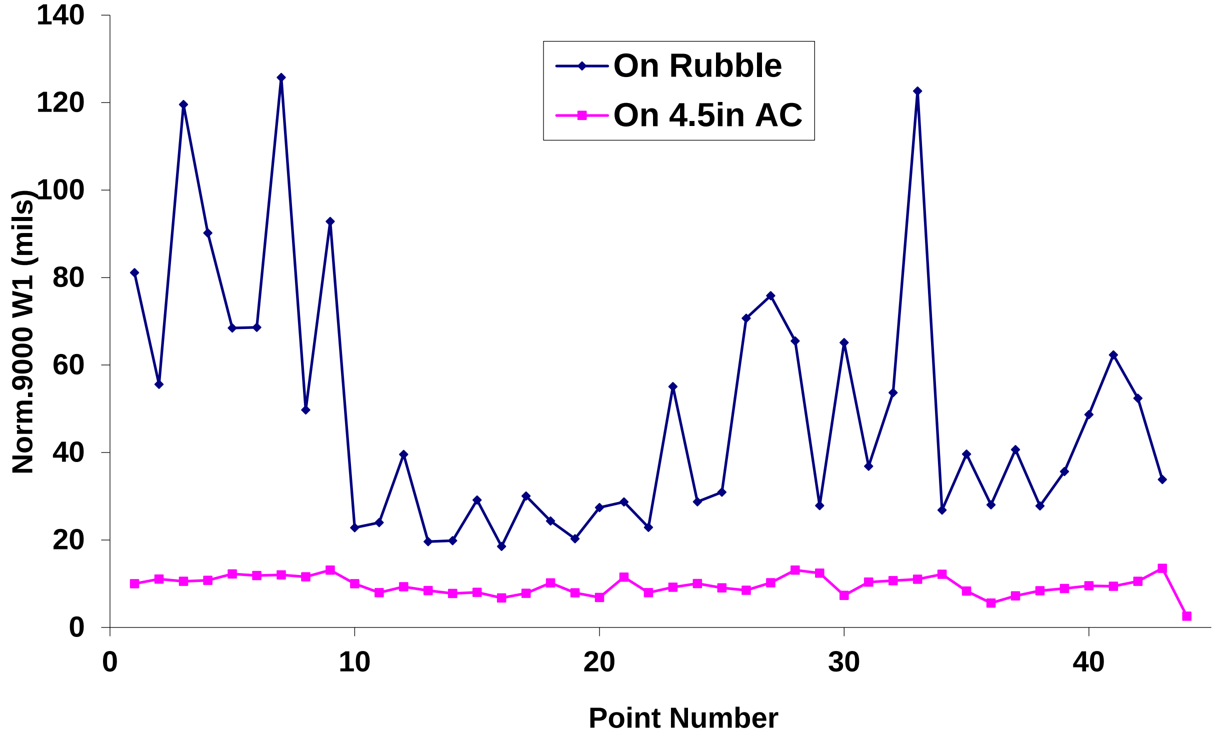

Figure 25. Comparisons of the FWD Deflections between 1) on Top of Rubblized (Rubble) Concrete and 2) on Top of 4.5-Inch HMA Overlay.

File Font Color Exit

On top of HMA over rubblized PCC (2010)

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.1)

	Thickness (in)	MODULI RANGE (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	4.50	160,000	720,000	H1: v = 0.35
Base:	9.00	100,000	2,000,000	H2: v = 0.25
Subbase:	8.00	50,000	50,000	H3: v = 0.25
Subgrade:	200.00 (User Input)	15,000		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
0.000	7,618	8.46	5.60	3.02	1.86	1.21	0.90	0.74	238.5	100.0	50.0	23.3	8.94	85.8 *
0.020	7,499	9.20	5.98	2.91	1.54	0.98	0.78	0.62	160.0	100.0	50.0	25.6	15.80	63.9 *
0.039	7,344	8.39	5.06	2.55	1.41	0.86	0.64	0.50	163.4	100.0	50.0	29.3	14.06	70.3 *
0.058	7,273	8.67	5.42	2.59	1.36	0.85	0.66	0.54	160.0	100.0	50.0	28.3	16.60	62.4 *
0.077	7,193	9.86	6.26	3.07	1.66	1.00	0.74	0.59	160.0	100.0	50.0	22.9	20.67	67.5 *
0.096	7,126	9.40	5.84	3.05	1.73	1.06	0.77	0.60	160.0	100.0	50.0	22.7	16.06	76.0 *
0.116	6,995	9.45	5.73	2.74	1.50	0.93	0.69	0.53	160.0	100.0	50.0	24.5	19.16	68.7 *
0.135	7,030	9.05	5.89	3.00	1.62	0.96	0.72	0.58	160.0	100.0	50.0	23.6	18.58	67.8 *
0.154	6,963	9.94	6.12	2.70	1.37	0.78	0.56	0.45	160.0	100.0	50.0	25.7	29.05	58.5 *
0.173	7,011	7.66	4.89	2.42	1.31	0.75	0.50	0.35	181.3	100.0	50.0	30.7	18.97	65.8 *
0.192	6,979	6.20	3.67	1.51	0.84	0.54	0.40	0.29	212.0	128.3	50.0	42.8	17.99	57.4 *
0.212	6,879	7.01	4.30	2.06	1.07	0.63	0.45	0.37	185.9	106.9	50.0	35.6	18.14	60.4 *
0.231	6,895	6.45	3.70	1.69	0.86	0.52	0.39	0.28	196.6	122.2	50.0	40.7	19.70	57.1 *
0.250	7,030	6.03	3.14	1.55	0.97	0.67	0.51	0.35	233.2	129.7	50.0	43.2	5.17	97.5 *
0.269	6,943	6.02	4.41	2.74	1.74	1.19	0.94	0.74	681.8	111.2	50.0	22.7	5.31	106.4 *
0.289	6,975	5.14	3.37	2.16	1.53	1.13	0.88	0.67	720.0	169.4	50.0	26.9	2.82	104.1 *
0.308	6,995	6.17	3.95	2.35	1.58	1.10	0.81	0.59	628.2	100.0	50.0	26.2	1.68	93.9 *
0.327	6,899	7.93	4.78	2.17	1.10	0.61	0.44	0.34	160.0	100.0	50.0	33.3	24.34	57.9 *
0.346	6,931	6.17	3.70	1.95	1.20	0.82	0.64	0.47	394.7	100.0	50.0	32.9	5.07	98.2 *
0.365	6,983	5.22	2.83	1.50	0.98	0.73	0.62	0.47	458.5	125.9	50.0	41.9	6.81	148.2 *
0.384	6,868	8.79	6.27	3.81	2.59	1.87	1.53	1.20	281.4	100.0	50.0	14.3	5.26	160.1 *
0.404	6,844	6.11	4.06	2.44	1.64	1.22	0.99	0.77	709.9	102.7	50.0	23.7	3.97	208.5 *
0.423	6,895	7.16	4.84	2.69	1.64	1.08	0.83	0.67	311.8	100.0	50.0	23.6	8.17	90.1 *
0.415	6,804	7.76	5.23	2.83	1.69	1.15	0.86	0.67	227.4	100.0	50.0	22.2	9.30	93.1 *
0.397	6,800	7.06	4.52	2.48	1.59	1.08	0.80	0.59	301.9	100.0	50.0	24.6	5.47	98.7 *
0.396	6,824	6.63	4.33	2.33	1.41	0.95	0.73	0.56	346.7	100.0	50.0	27.1	6.90	96.0 *
0.416	6,776	7.65	5.19	2.94	1.87	1.31	1.04	0.85	283.3	100.0	50.0	20.0	5.71	121.4 *
0.435	6,633	9.94	6.66	3.61	2.24	1.51	1.11	0.87	160.0	100.0	50.0	15.8	12.40	101.7 *
0.454	6,852	9.43	6.17	3.07	1.74	1.07	0.80	0.61	160.0	100.0	50.0	21.1	17.74	75.5 *
0.474	6,987	5.60	3.53	1.88	1.10	0.70	0.50	0.38	629.2	100.0	50.0	33.3	12.56	77.6 *
0.493	6,844	7.95	5.16	2.99	2.04	1.46	1.11	0.87	275.3	100.0	50.0	19.1	3.97	129.4 *
0.512	6,830	8.10	5.35	3.00	1.94	1.33	0.98	0.77	226.2	100.0	50.0	20.0	6.34	106.3 *
0.531	6,816	8.24	5.54	3.01	1.83	1.19	0.85	0.66	189.8	100.0	50.0	21.2	10.79	87.4 *
0.551	6,820	8.99	6.09	3.18	1.76	0.98	0.65	0.47	160.0	100.0	50.0	22.1	21.90	65.3 *
0.570	6,840	6.38	3.87	1.89	1.03	0.62	0.44	0.34	228.4	113.0	50.0	37.7	14.55	65.9 *
0.589	6,840	4.22	2.15	1.07	0.58	0.39	0.29	0.22	263.0	212.7	50.0	70.9	5.54	61.0 *
0.608	6,764	5.56	3.23	1.57	0.87	0.58	0.41	0.32	263.8	131.1	50.0	43.7	9.71	67.0 *
0.627	6,804	6.48	3.91	1.85	1.00	0.69	0.55	0.47	236.9	107.8	50.0	35.9	9.87	64.3 *
0.647	6,848	6.90	4.27	2.28	1.44	1.01	0.79	0.65	308.2	100.0	50.0	26.8	5.61	115.3 *
0.666	6,689	7.10	4.28	2.11	1.19	0.77	0.59	0.46	202.0	100.0	50.0	31.1	10.81	72.9 *
0.685	6,713	6.94	4.32	2.18	1.22	0.80	0.59	0.46	229.8	100.0	50.0	30.3	11.22	71.8 *
0.704	6,649	8.13	4.43	1.93	0.99	0.57	0.42	0.33	160.0	100.0	50.0	33.3	26.29	58.5 *
0.723	6,633	10.60	7.01	3.49	1.75	0.94	0.71	0.60	160.0	100.0	50.0	19.4	31.21	59.8 *
0.743	6,891	2.08	1.58	1.30	1.01	0.79	0.63	0.50	720.0	2000.0	50.0	41.1	5.67	105.4 *
Mean:		7.41	4.70	2.45	1.44	0.94	0.71	0.55	286.6	151.4	50.0	29.1	12.41	78.0
Std. Dev:		1.72	1.21	0.64	0.41	0.30	0.24	0.19	173.1	285.9	0.0	10.0	7.46	21.0
Var Coeff(%):		23.21	25.73	26.18	28.69	31.72	33.74	34.93	60.4	188.9	0.0	34.5	60.13	26.9

Figure 26. Backcalculated Modulus Values for Rubblized Layer on US 96 Beaumont District (Immediately after 4.5-Inch AC Overlay-2010).

On top of HMA over rubblized PCC about 5 yrs old (2015)

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 6.1)

	Thickness (in)	MODULI RANGE (psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	4.50	340,000	720,000	H1: v = 0.35
Base:	9.00	100,000	2,000,000	H2: v = 0.25
Subbase:	8.00	50,000	50,000	H3: v = 0.25
Subgrade:	200.00 (User Input)	15,000		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
0.000	9,684	3.42	2.60	2.19	1.84	1.50	1.26	1.02	720.0	2000.0	50.0	31.5	8.45	113.6 *
0.020	9,648	3.57	2.52	2.18	1.88	1.54	1.30	1.06	720.0	2000.0	50.0	31.0	9.37	114.8 *
0.040	9,609	3.40	2.40	2.10	1.81	1.46	1.24	1.05	720.0	2000.0	50.0	32.3	9.97	300.0 *
0.061	9,557	3.54	2.67	2.23	1.96	1.62	1.29	0.99	720.0	2000.0	50.0	29.8	9.03	82.5 *
0.080	9,521	3.14	2.06	1.72	1.45	1.15	0.92	0.77	720.0	2000.0	50.0	40.6	8.04	300.0 *
0.100	9,521	3.86	2.64	2.09	1.72	1.33	1.06	0.77	541.8	2000.0	50.0	33.2	4.44	76.8 *
0.121	9,497	2.98	1.86	1.41	1.09	0.80	0.61	0.40	546.0	2000.0	50.0	58.4	4.70	64.7 *
0.140	9,505	2.67	1.67	1.32	1.04	0.82	0.66	0.49	720.0	2000.0	50.0	60.2	8.10	76.3 *
0.565	9,458	2.54	1.51	1.11	0.85	0.64	0.42	0.37	637.8	2000.0	50.0	81.1	5.52	62.0 *
0.588	9,434	2.68	1.85	1.46	1.16	0.92	0.82	0.62	720.0	2000.0	50.0	52.4	9.19	300.0 *
0.610	9,458	4.17	2.19	1.35	0.92	0.58	0.41	0.33	340.0	553.5	50.0	74.6	2.32	66.2 *
0.636	9,418	2.40	1.39	1.02	0.81	0.57	0.41	0.36	703.8	2000.0	50.0	88.9	7.32	71.4 *
0.657	9,481	4.30	2.96	2.28	1.82	1.39	1.10	0.83	366.9	2000.0	50.0	30.9	2.64	88.5 *
0.678	9,485	5.67	3.55	2.00	1.36	0.98	0.76	0.57	720.0	182.1	50.0	43.2	4.75	120.2 *
0.697	9,418	4.20	2.64	1.74	1.32	0.98	0.76	0.61	587.9	637.9	50.0	45.9	5.50	112.5
0.715	9,458	4.42	2.78	1.74	1.33	1.00	0.81	0.61	720.0	457.9	50.0	44.8	6.72	300.0 *
0.734	9,402	4.56	3.02	2.09	1.57	1.19	0.96	0.75	340.0	1153.9	50.0	36.5	4.71	103.5 *
0.747	9,366	3.59	2.13	1.56	1.22	0.93	0.67	0.65	340.0	2000.0	50.0	50.7	4.54	79.2 *
1.346	9,323	3.83	2.74	2.07	1.77	1.37	1.07	0.86	563.7	2000.0	50.0	31.5	4.17	103.5 *
1.363	9,402	4.19	2.83	1.99	1.59	1.25	1.01	0.78	340.0	1961.5	50.0	34.9	5.36	92.0 *
1.388	9,315	3.87	2.62	1.90	1.50	1.15	0.93	0.74	366.1	2000.0	50.0	37.5	4.10	106.2 *
1.411	9,402	4.50	3.02	2.08	1.60	1.20	0.95	0.72	340.0	1227.6	50.0	36.2	4.28	89.9 *
1.434	9,255	3.75	2.42	1.62	1.23	0.89	0.67	0.50	607.9	790.9	50.0	49.3	3.85	82.4
1.458	9,366	2.49	1.63	1.21	0.96	0.74	0.58	0.48	720.0	2000.0	50.0	67.0	7.63	109.4 *
1.486	9,239	3.43	2.24	1.48	1.17	0.86	0.68	0.50	350.4	2000.0	50.0	51.5	4.87	115.7 *
1.511	9,279	3.20	1.83	1.36	1.04	0.76	0.59	0.44	373.1	2000.0	50.0	61.8	5.58	79.7 *
1.689	9,267	3.57	2.37	1.92	1.61	1.31	1.10	0.89	720.0	2000.0	50.0	33.4	7.51	110.6 *
1.907	9,251	2.83	1.80	1.37	1.10	0.83	0.66	0.48	717.3	2000.0	50.0	54.8	6.18	72.7 *
2.102	9,311	2.98	2.46	2.14	1.81	1.46	1.20	0.95	720.0	2000.0	50.0	33.3	11.60	99.2 *
Mean:		3.58	2.36	1.75	1.40	1.08	0.86	0.68	576.0	1688.5	50.0	46.8	6.22	97.6
Std. Dev:		0.75	0.52	0.38	0.35	0.31	0.27	0.22	163.7	585.3	0.0	16.2	2.31	33.4
Var Coeff(%):		20.97	22.05	21.55	24.77	28.40	31.65	32.68	28.4	34.7	0.0	34.5	37.12	34.2

Figure 27. Backcalculated Modulus Values for Rubblized Layer on US 96 Beaumont District (after about 5 Years of Trafficking-2015).

CHAPTER 4. US 175 DESIGN RECOMMENDATIONS

EXECUTIVE SUMMARY

Rolling Deflectometer, GPR, and DCP testing and field coring were conducted on the JCP on US 175 south of Dallas in the northbound lanes from Mabank to Kemp. As described below, two sections were thought good candidates for rubblization. The first is extensively patched with a very low pavement score, and the second has extensive longitudinal cracking. Researchers hoped that each test section would be 1000 ft long.

The patched section has substantial undersealing with Uratek, this being a weak foam. Discussions were held with the rubblization vendors. They claimed it can still be rubblized but the foam may slow production (may not be too critical for a 1000-ft test section). Both vendors (RMI and Antigo Construction) claim they have rubblized many miles of concrete pavement in Dallas for removal.

Both test sections are feasible but the section with the highest probability of success would be Section 2 because there is no Uratek.

If the district agrees to proceed with construction of either section, then researchers propose that the district place **4 inches** of HMA over the rubblized concrete. The top 2 inches should be a performance mix from TxDOT's spec such as an SMA or a Superpave mix (district preference). The lower 2 inches can be an Item 341 mix (again district preference).

In this design, it is proposed that the 18 kip ESALs over 20 years will be 5.3 million ESALs in the design lane. This is based on the TxDOT's ADT estimates of 16,300 (current) and 22,600 (20 years), with 7.6 percent trucks.

The modulus of the old asphalt base and subgrade layers for this section were set at 50 ksi and 6 ksi, respectively, based on the DCP data collected in the recent pavement evaluation.

The modulus of the rubblized concrete layer was set at 200 ksi. The rationale for this value is described in the following supporting documentation.

The predicted time to first overlay for the section is 15 years.

All testing indicated that there is no drainage problem along this highway, so no edge drains will be required.

Rolling deflectometer data were collected on the entire project. In addition to the rubblization test sections, the Dallas District should also consider an engineered HMA overlay for the not badly distressed sections of this jointed concrete pavement.

SUPPORTING DOCUMENTATION

Figure 28 and Figure 29 show the sites of the proposed rubblization test sections. The first is about 2 miles north of Mabank. It is extensively patched because of cracking and roughness. This patching gives the section a very low Pavement Management Information System score. About 0.5 miles farther north just after the first bridge, the roadway has numerous wide longitudinal cracks. The patched and cracked sections are long, so it should be straightforward to select a 500- to 1000-ft rubblization test section.

Figure 30 shows rolling deflection data over the proposed Section 2. The deflections in the upper plot are relatively low indicating that the slabs have a reasonable foundation layer and no excessively weak support that would be problematic for rubblization.

Figure 31 shows the DCP for Section 2. The DCP in Section 1 was better. In Section 2, the computed layer modulus was found to be fairly low, 25 inches below the surface at 6 ksi. This value was used in the pavement design.

Figure 32 shows the soil pulled from Section 1; both sites were similar. This was classified as a tan sandy clay, which is better than most soils on projects managed by the Kaufman Area Office.

Figure 33, Figure 34, and Figure 35 show the input values used within FPS 21 to arrive at the design HMA thickness.

Figure 36 shows the acceptable designs that will meet the input time to first overlay of 15 years. The 4 inches of HMA design with 12 inches of rubblized concrete was selected for further evaluation.

Figure 37 shows the proposed design and the overlay required (2 inches) in year 16 to achieve the 20-year design life.

Figure 38 and Figure 39 show both the mechanistic check and the Texas Triaxial check for the as-designed pavement structure; the proposed design had no problem passing both of the design checks.

Figure 40 shows the results from a previous national study showing what moduli values can be anticipated for fractured concrete. The top graph shows the values found by the research team. The range they reported was from 200 to 700 ksi. The biggest challenge in performing this pavement design is to arrive at a reasonable conservative design value for the rubblized concrete on US 175.

Figure 28. Rubblization Candidate Section 1 about 2 Miles North of Mabank.

Figure 29. Candidate Section 2 on US 175 about 2.5 Miles North of Mabank.

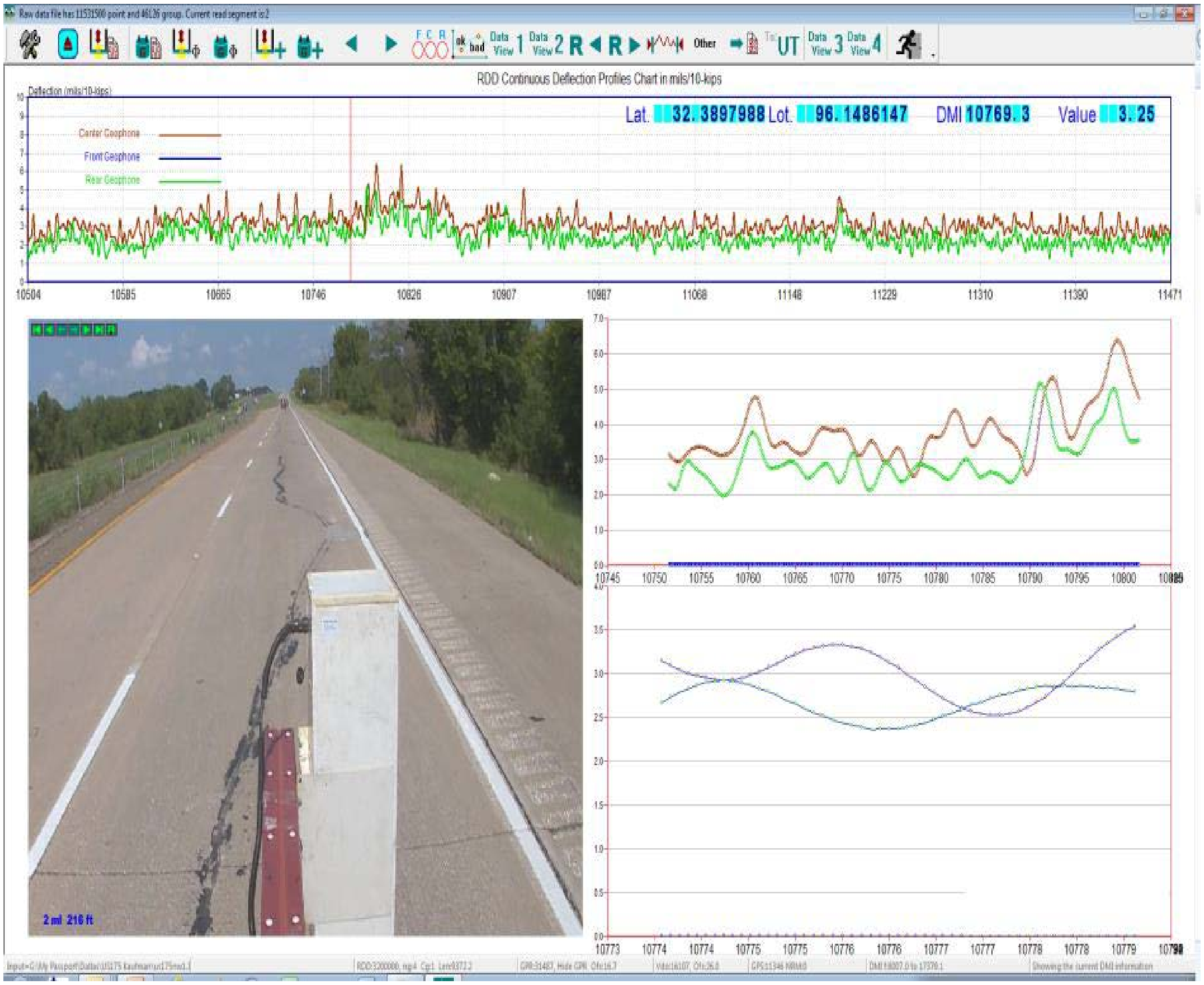

Figure 30. Rolling Deflectometer from Section 2, Very Low Deflections.

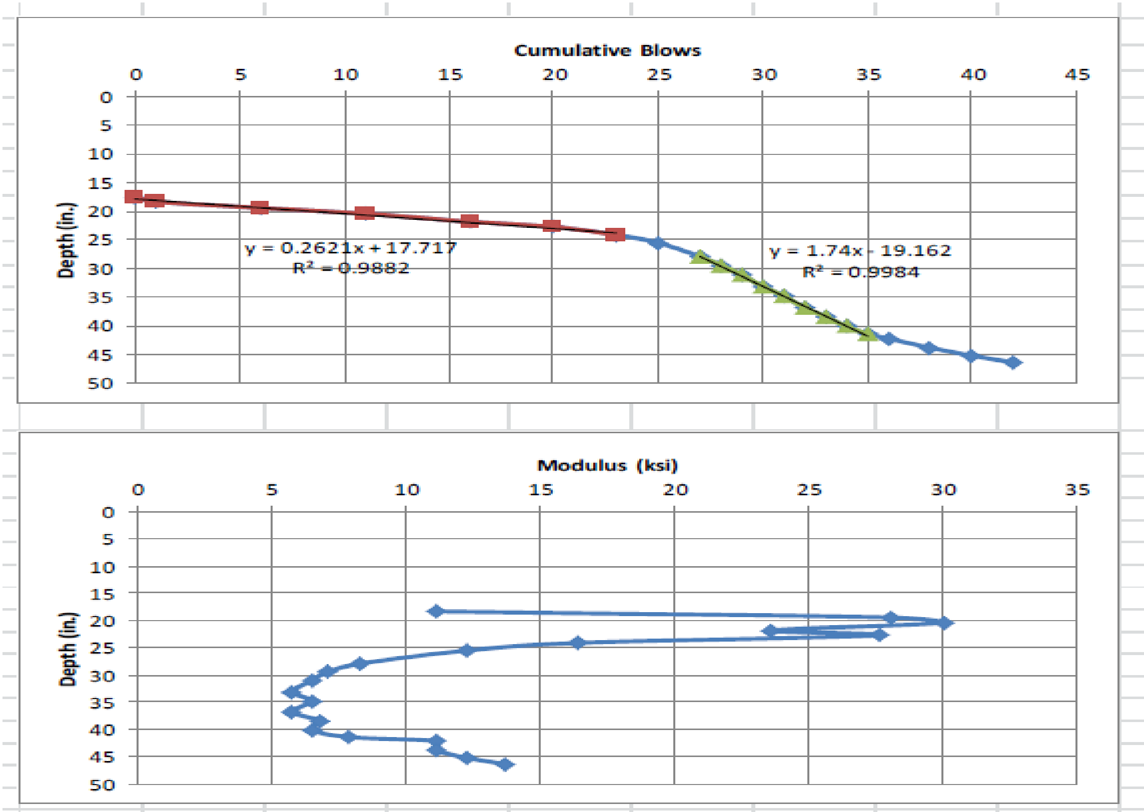

Figure 31. DCP Data from Section 2, Weak Subgrade at a Depth of 25 Inches below the Surface.

Figure 32. The Subgrade on Each Site Was Found to be a Tan Sandy Clay.

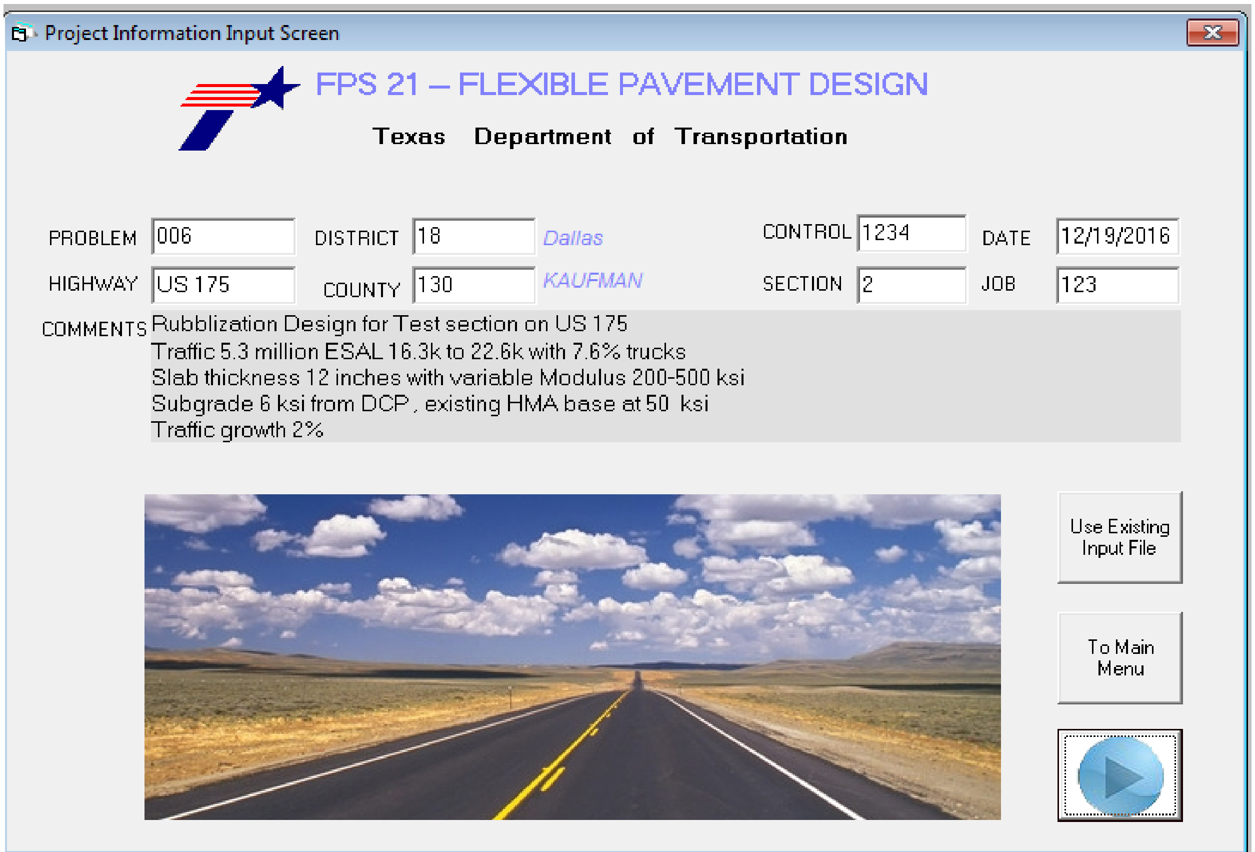

Figure 33. Screen 1 in FPS for US 175 Rubblization Design.

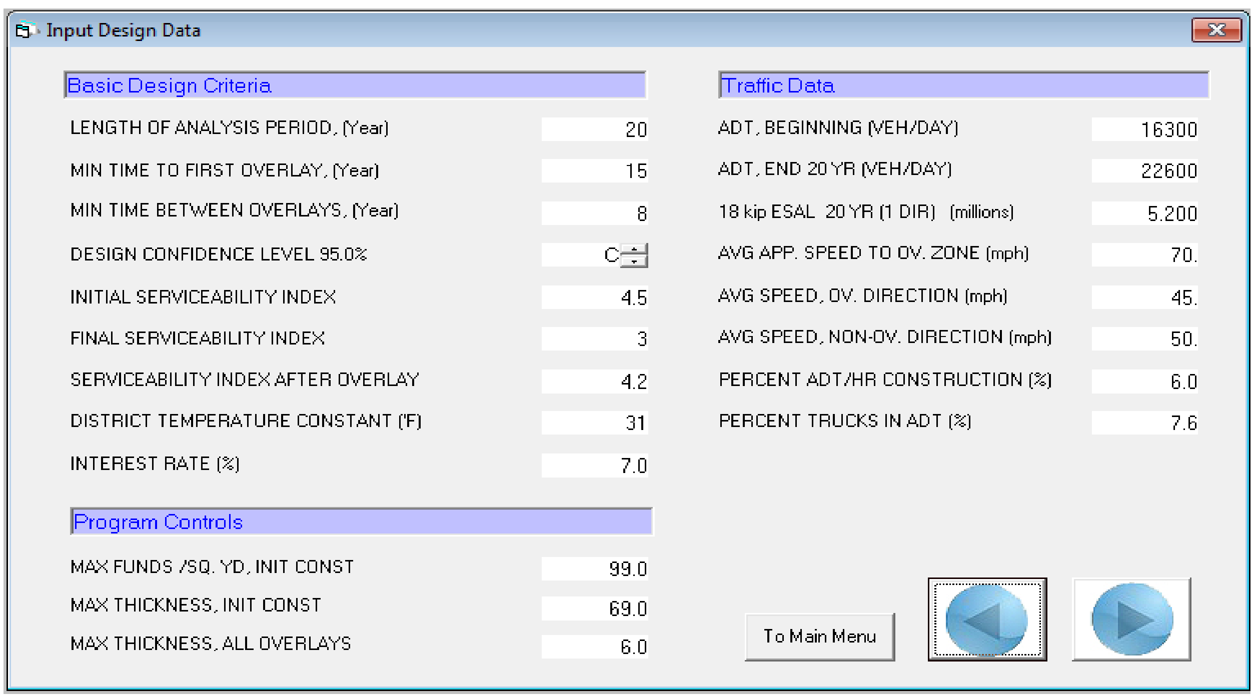

Figure 34. Screen 2 in FPS for US 175 Rubblization Design.

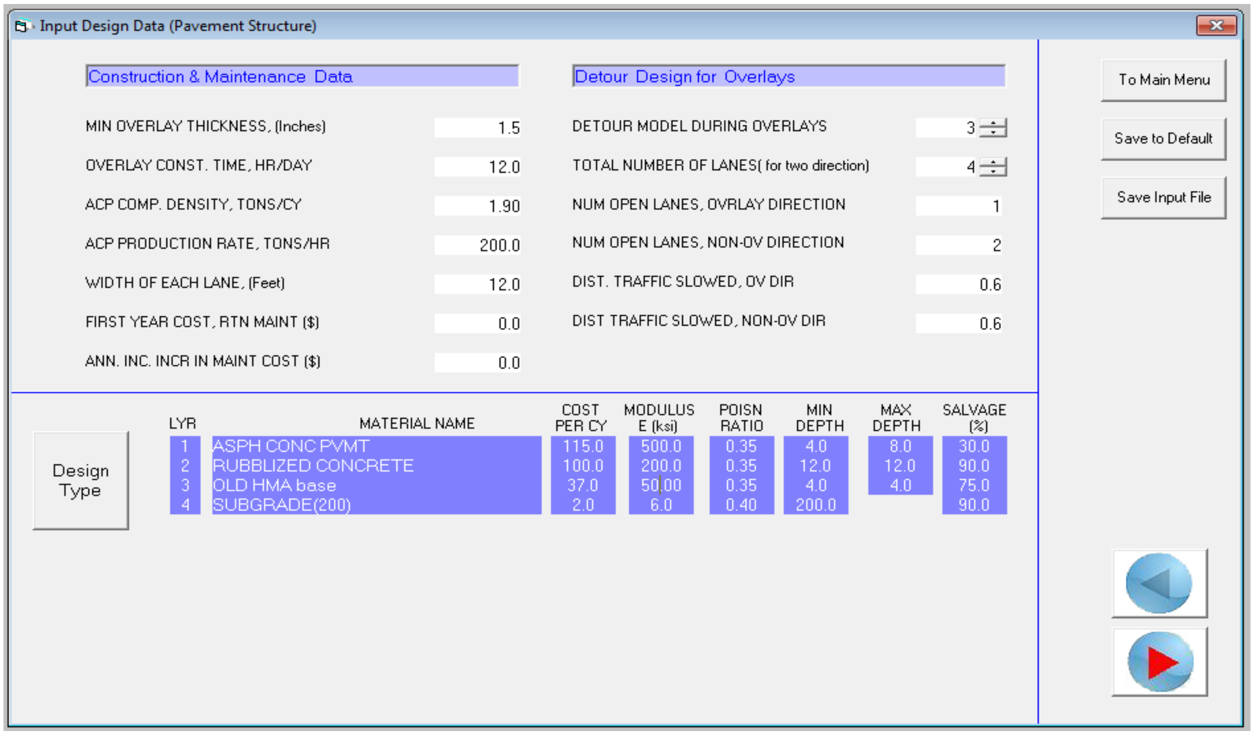

Figure 35. Screen 3 in FPS for US 175 Rubblization Design.

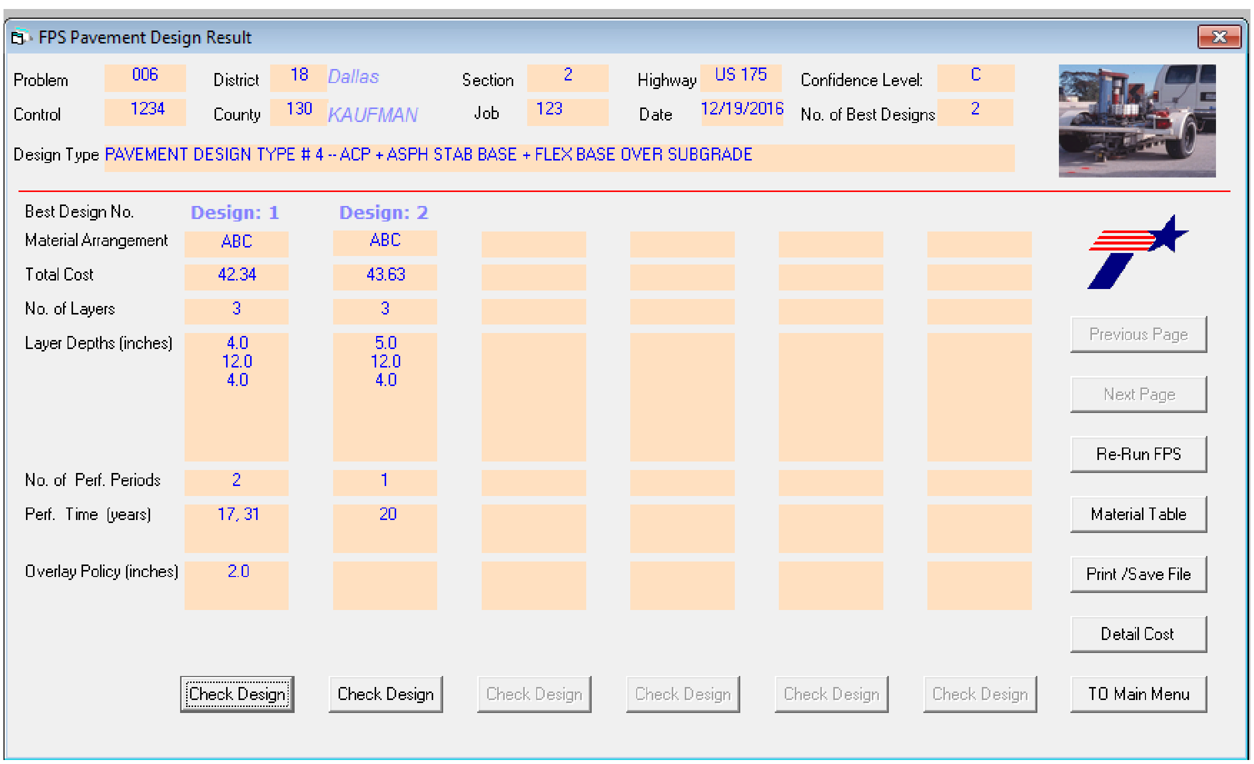

Figure 36. HMA Design Options.

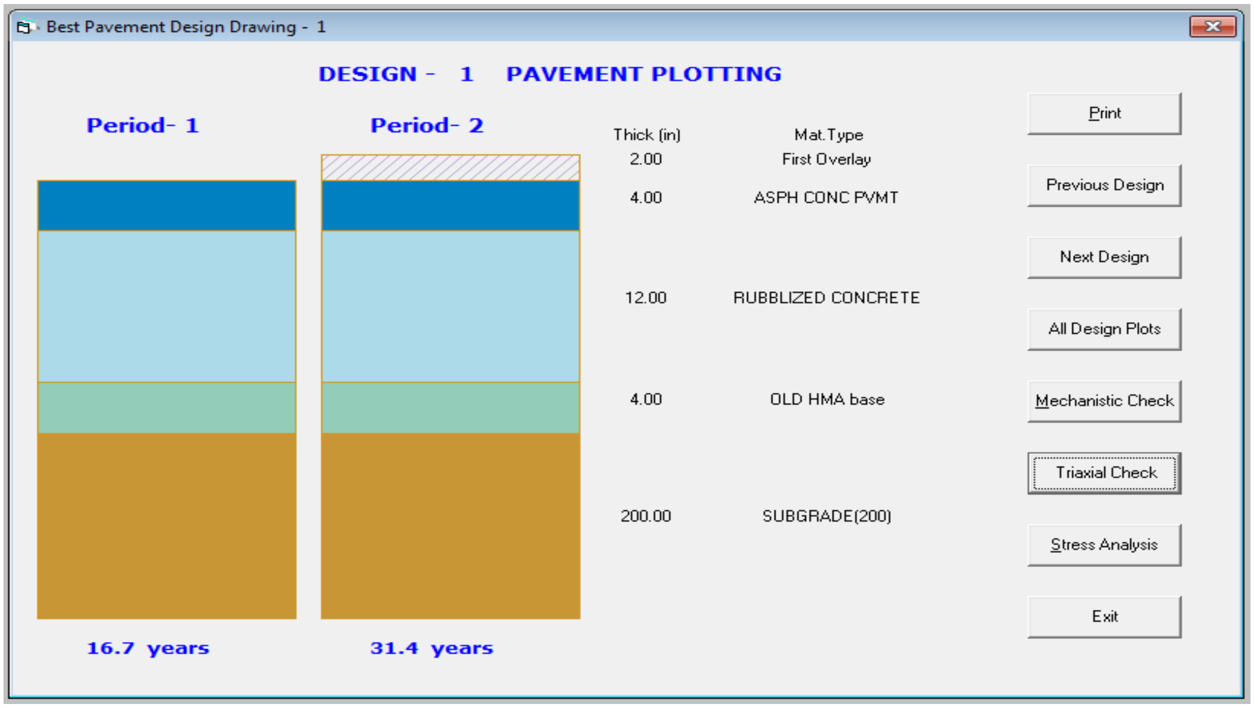

Figure 37. Proposed Pavement Design for US 175.

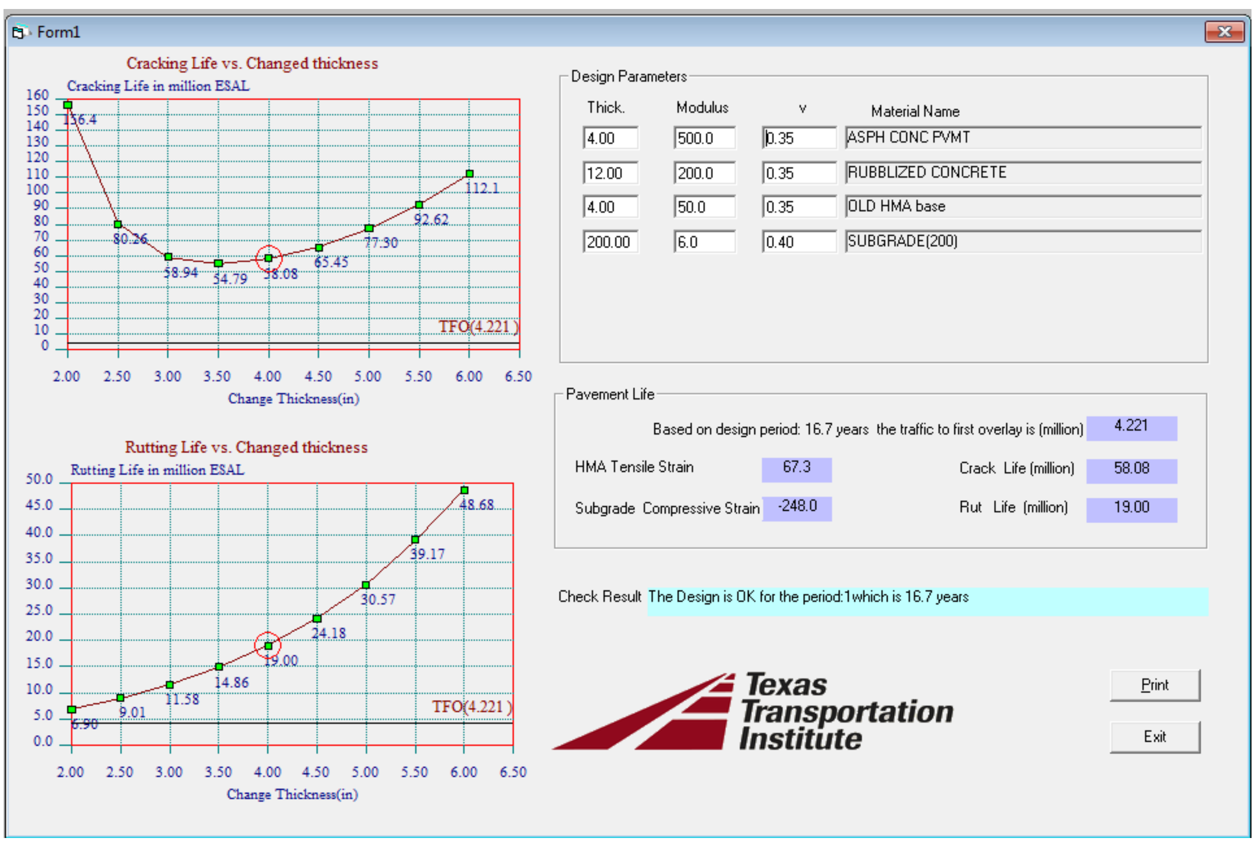

Figure 38. Mechanistic Check for US 175, No Problems.

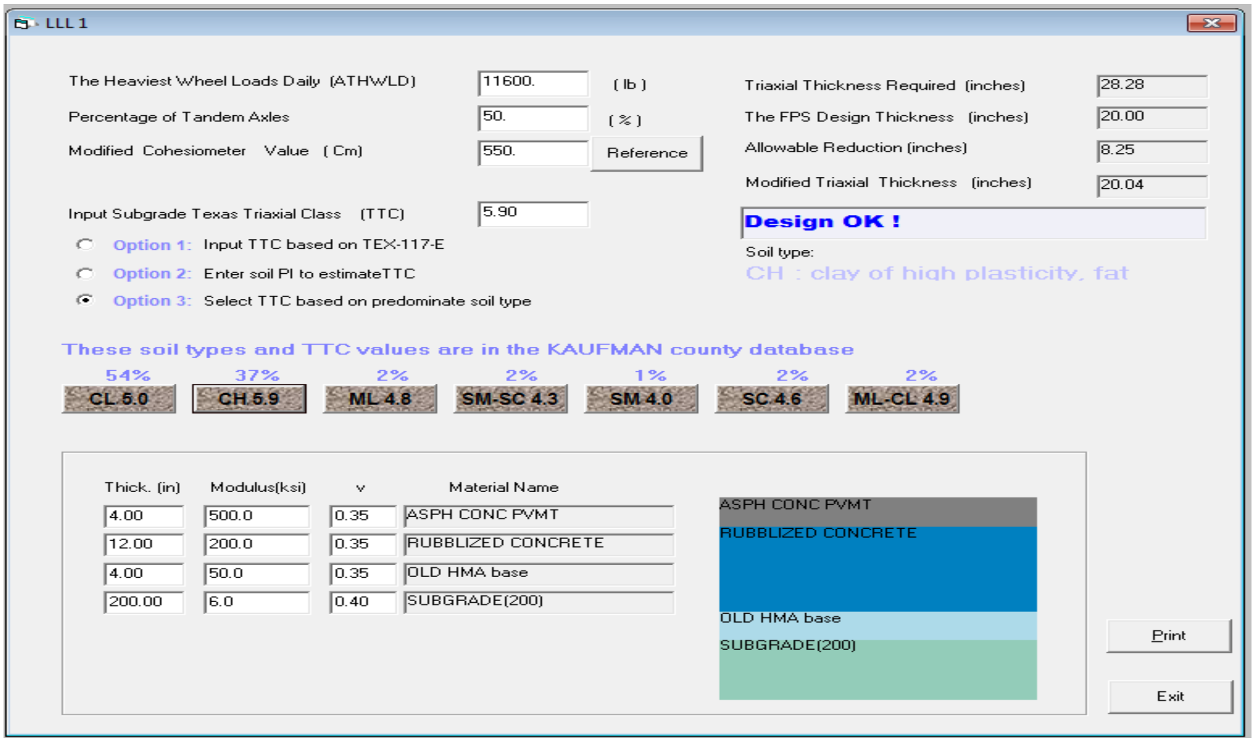

Figure 39. Texas Triaxial Check for US 175.

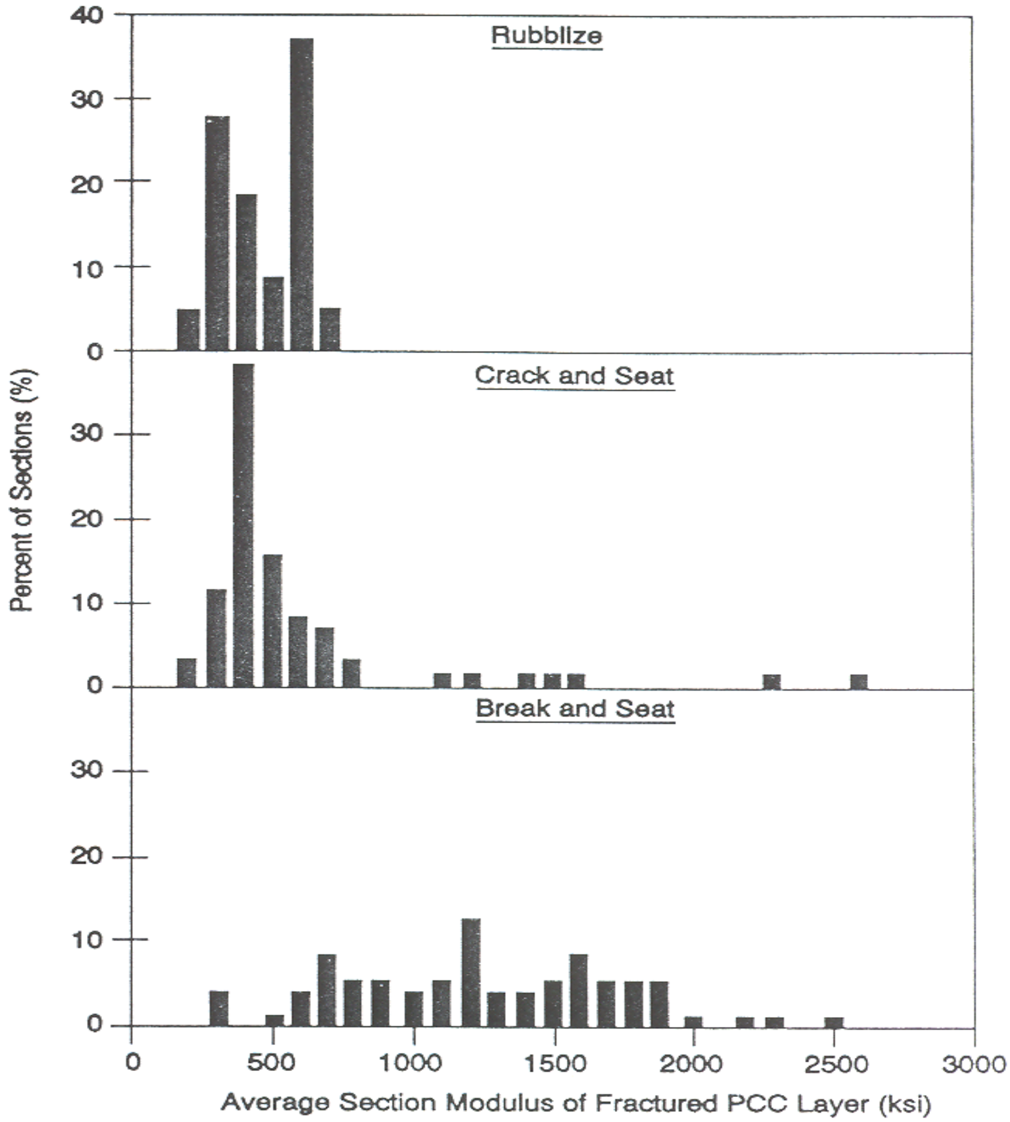

Figure 40. National Study Recommendation on Moduli of Rubblized Layers.

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