Using Foamed Asphalt as a Stabilizing Agent in Full Depth Reclamation of Route 8 in Belgrade, Maine

Final Report

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Submitted by

Brian Marquis, Dale Peabody and Rajib Mallick

Maine Department of Transportation &
Worcester Polytechnic Institute
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Abstract

This paper documents the construction of a full depth reclamation project in Belgrade, Maine along Rt. 8 that used foamed asphalt as a stabilizing agent. This includes the steps involved to design a foamed asphalt mix, construction of the foamed asphalt sections and a preliminary evaluation of the application. During the mix design process the use of the foamed asphalt laboratory equipment is important to optimizing the design as proper asphalt-water ratios are determined to maximize performance. Preliminary evaluation using Falling Weight Deflectometer data reveals the structural capacity of foamed asphalt sections are greater than typical full depth reclamation sections. Long term evaluation of performance is planned.

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Introduction

Maine has a variety of soil types throughout the state. Most of these soil types degrade rapidly and have poor stability. To eliminate the cost of supplying quality road base material from a distant source and increase the stability of existing soils, the Maine Department of Transportation (MDOT) has been requiring contractors to rehabilitate roads using the full depth reclamation process.

Full depth reclamation involves milling the existing bituminous pavement plus a portion of the base material. The milled material is then graded and compacted. Traffic can use the roadway until a bituminous base and wearing surface is applied.

In addition to using full depth reclaimed material, MDOT has been experimenting with adding a number of stabilizing agents to virgin or recycled base materials to increase stability. Some of the stabilizing agents include cement, emulsion and calcium chloride.

Foamed asphalt is another stabilizing agent. This is a mixture of air, water and hot asphalt. Cold water is introduced to hot asphalt causing the asphalt to foam and expand by more than 10 times its original volume. During this foaming action the asphalt has a reduced viscosity making it much easier to mix with aggregates. A specialized piece of equipment mills the existing bituminous pavement and base material and introduces foamed asphalt all in one process. The material is then graded and compacted. Traffic can operate on the stabilized base until a hot mix asphalt base and wearing surface is applied.

This paper will describe the steps involved to design a foamed asphalt mix, preparation of the roadway, and evaluation of the experimental application.

Preliminary Data Collection

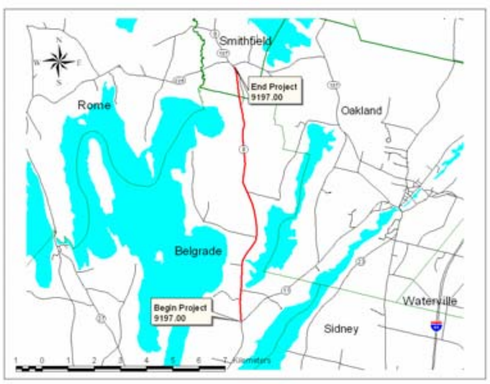


Figure 1. Location Map

Federal project number STP-9197(00)X on State Route 8 between the towns of Belgrade and Smithfield was selected for Foamed Asphalt stabilization. This is a Highway Improvement project beginning at the intersection of State Route 11 in Belgrade and extending northerly 10.15 km (6.31 mi). This project has a high occurrence of frost deformation with rut depths of 18 mm (0.7 in) in areas and IRI values as high as 3.17 m/km (201 in/mi). Sections of the project were built to state standards and are scheduled for resurfacing only. Other sections are scheduled for either Full Reconstruction, Full Depth Reclamation with Variable Depth Gravel or Full Depth Reclamation with Foamed Asphalt.

To determine the structural condition of the project and potential test site locations for Foamed Asphalt stabilization, MDOT collected Falling Weight Deflectometer (FWD) data on July 24, 2000. In addition to FWD data, power augers were used to ascertain existing pavement and gravel thickness.

Table 4 contains results of FWD data that was processed using DARWin Pavement Design Analysis System. DARWin uses FWD deflections, pavement depth, and gravel depth to determine Subgrade Resilient Modulus, Existing Pavement Modulus, and Existing Structural Number for each test location. A Future Traffic Structural Number is calculated using the formula or Nomograph from the 1993 copy of AASHTO's Guide for Design of Pavement Structures, page II-32, Figure 3.1, and the following data:

(1) a future 18-kip ESAL value for a 20-year design period, W_{18}, of 970,900
(2) a reliability value, R, of 95%
(3) a standard deviation, S_o, of 0.45
(4) the effective subgrade resilient modulus, M_R, at each station and
(5) a design serviceability loss, ΔPSI, of 2.0

Figure 2. Sampling Existing Roadway Material

This number is used to design a road to withstand the projected level of axle load traffic.

Using the Existing Structural Number, SN_{eff}, Future Structural Number, SN_f, and Pavement Layer Coefficient of 0.44, a Recommended Pavement Depth, D_{ol}, can be calculated using the formula: $D_{ol} = (SN_f - SN_{eff}) / 0.44$

Areas that will be considered for asphalt stabilization should have a D_{ol} greater than 100 mm since the full depth reclamation areas will be paved with a total of 100 mm of hot mix asphalt. Based on Recommended Pavement Thickness data from table 4 and a pavement condition survey of the project, eight areas were selected for foamed asphalt stabilization. They are located at stations 1+400 to 1+490, 1+640 to 2+680, 3+527 to 3+600, 3+700 to 3+820, 4+000 to 4+130, 4+900 to 6+445, 6+525 to 6+860 and 7+600 to 9+520.

Samples of the existing asphalt concrete and base material are required to develop a Foamed Asphalt Mix Design. To accomplish this, test pits were excavated at station 3+080, 5+476 and 8+682. In addition, bituminous core samples were cut at offsets of 0.5, 1.5 and 2.4 meters (1.6, 4.9 and 7.9 feet) at each test pit location to determine uniformity of bituminous asphalt thickness; results indicate the asphalt concrete was relatively uniform across the roadway. Roughly 140 kg (300 lb) of bituminous asphalt and base material were sampled from each test pit. The samples were crushed to a minus 51 mm (2 in) size. Using this material plus FWD information, a Foamed Asphalt Mix Design was developed by engineers at Worcester Polytechnic Institute (WPI) and AA Loudon and Partners (South Africa).

Foamed Asphalt Mix Design

The process of producing foamed asphalt consists of combining hot liquid asphalt binder with cold atomized water under pressure. The process results in the formation of "foam" by the expansion of the asphalt-water mix, and hence provides a significantly increased volume. This increased volume and the considerable reduction of viscosity of the asphalt binder helps in improved coating of a large number of fine aggregates including mineral filler. This provides a uniform mix with stone-on-stone contact in coarse aggregates particles, as well as a significant amount of time during which the mix remains workable in the field.

The performance of foamed asphalt mix is significantly affected by the quality of the foam. The foam properties are defined in terms of expansion ratio and half-life. Before embarking on the fieldwork it is necessary to assure that the optimum proportion is selected, such that the resulting foam has all the desirable qualities that are needed to produce a pavement with good performance. Therefore, at the mix design stage it is crucial to determine the optimum proportion of water and asphalt. The laboratory foamed asphalt plant, shown here, is an absolutely necessary piece of equipment during mix design. The foamed asphalt plant was obtained through a partnership with the University of New Hampshire Recycled Materials Resource Center, Worcester Polytechnic Institute and MDOT. It provides the mix designers a way to produce foam in the laboratory - safely and easily, in exactly the same way as it is done in the field. In fact, the same pressure equipment and nozzles that are used in the laboratory plant are used in the field equipment. Mix designers can combine asphalt and water in different proportions and evaluate the resulting foam properties. The mix design procedure is fairly straightforward. With a single demonstration users should be able to determine the optimal foaming characteristics of a specific grade/type of asphalt as well as prepare the samples of varying foamed asphalt contents necessary in the mix design. Foaming occurs when water and air combine to create atomized water, and is mixed with hot asphalt in the expansion chamber.

Figure 3. Laboratory Foamed Asphalt Plant

Set-up of the equipment is very clear-cut. It requires the operator to fill an internal water tank (pressurized when in use), and provide a minimum of 8 bars of air pressure. Its electrical system can be configured several ways but it will most likely require two new outlets to be installed (220v). A Hobart 220 quart mixer is supplied with the unit and is very user friendly. Once connections are made to power and air, and the system is pressurized, asphalt needs to be added to the heating chamber. The asphalt is usually pre-heated until it becomes fluid and then poured into the chamber.

The material is dried and batched out to the desired blend ratios. Optimum moisture content of aggregate blend needs to be determined. The aggregates are mixes with the required amount of moisture, taking into consideration the extra water coming from the foamed asphalt. If needed, lime and cement are also added. This material is placed in the mixing bowl.

Once the connections are made, the operator can run the equipment for a few seconds and prepare a spreadsheet to control the amount of water and time needed to let the asphalt flow from the kettle. The controls are all pre-set and with the push of a button, the process begins. The asphalt and atomized air combine in the expansion chamber and the foamed asphalt is pumped into the mixing bowl. The process stops when the timer cut off (based on % asphalt desired) and the mixer can be turned off within a minute. This process is repeated several times, usually four, depending on the desired asphalt percentages.

After adding the foamed asphalt to the aggregate, mix samples are compacted (6 at each asphalt percentage). Following compaction, the samples are conditioned at 40°C for 72 hours, after which 3 samples of each asphalt content are submerged in water (maintained at 25°C) for 24 hours. All of the samples are subsequently tested at a temperature of 25°C for strength and/or modulus. Dry, wet and retained strength and/or moduli are determined. Optimum percentage of foamed asphalt is determined from strength and/or modulus versus asphalt percent curves; generally the percent corresponding to the peak value(s) is selected.

Sampling

Three test pits were excavated, and pavement core samples were taken to determine the uniformity of the pavement thickness. The results of investigation in sample pits showed (Figure 2) an upper HMA layer of 50 mm to 200 mm, of which the thickness in excess of 100 mm were mostly from patchings. The underlying gravel base course layer was identified as A-1-b type, the upper portion of which consisted of asphalt stabilized layer. Underlying the gravel layer was a silty clay subgrade (A-4), with boulders with diameter between 100 mm and more than 300 mm. Approximately 140 kg of Reclaimed Asphalt Pavement (RAP) and base material were sampled and transported to the laboratory for mix design. The RAP was crushed to a maximum aggregate size of minus 50 mm.

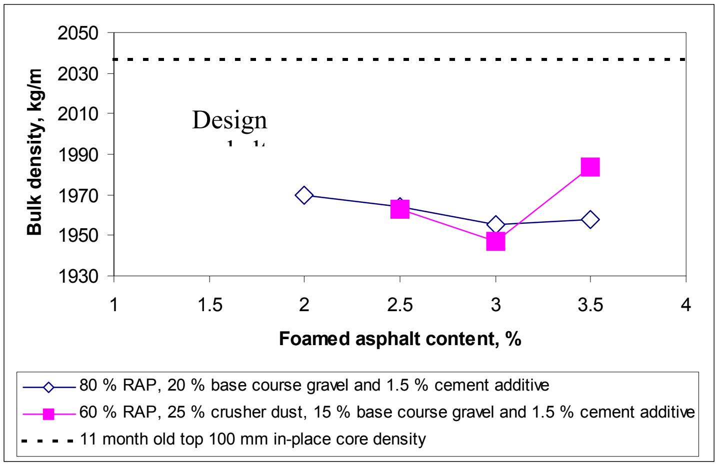
Optimum foamed asphalt content

The original mix design was conducted using only in-place materials, by blending 80 % RAP with 20 % base course gravel. A PG 64-28 binder was used for making the foamed asphalt. At a temperature of 165^{o}C, the optimum water content was determined to be 3 %, which yielded foamed asphalt with an expansion ratio of 11 and half-life of 8.5 seconds.

The 80 % RAP-20% gravel blend was mixed with 2 to 3.5 % foamed asphalt binder in 0.5 % increments, and 1.5 % cement. The cement was added to provide an additional amount of fine materials and help in the dispersion of the foamed asphalt. 100 mm diameter samples were compacted using 50 gyrations in a Superpave gyratory compactor. The samples were placed in an oven for curing at 40^{o}C for 72 hours, after which they were conditioned to 25^{o}C, and tested for bulk density, resilient modulus and tensile strength. Some samples were soaked in water at 25^{o}C for 24 hours, and then tested for soaked tensile strength.

At this time, discussions with ME DOT personnel resulted in a plan for placement of a 50 mm thick crusher dust layer on the surface before reclamation. This was decided to improve the existing shape of the road, provide adequate fines and to help avoid getting in contact with fairly large boulders in the subgrade during reclamation. To determine the optimum foamed asphalt content, mix design was conducted using 60 % RAP, 25 % crusher dust and 15 % base course gravel along with 1.5 % cement. The final structure proposed for rehabilitation is shown in Figure 2.

The results of mix design are shown in Figures 3, 4 and 5. The optimum foamed asphalt content was determined to be 2.5 %. The bulk densities for both blends (with and without crusher dust) are almost the same, although the resilient modulus and soaked tensile strengths were significantly lower for the blend with the crusher dust. However, the crusher dust blend was still pursued, since the soaked tensile strength values were found to be above 200 kPa.



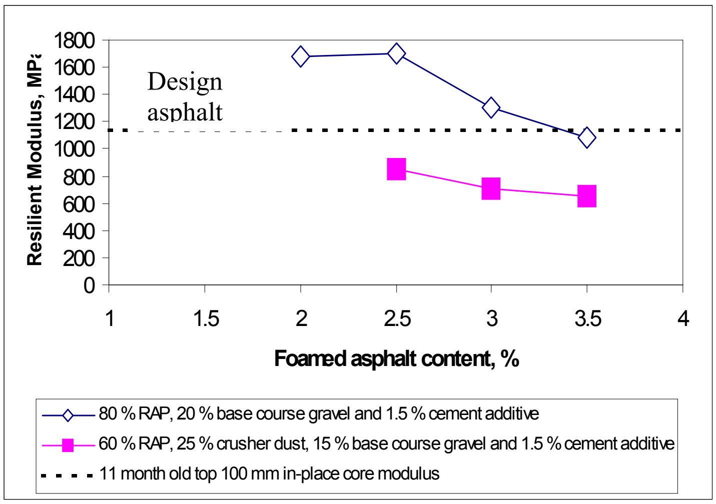


Figure 5. Plot Foamed Asphalt Content versus Resilient Modulus.

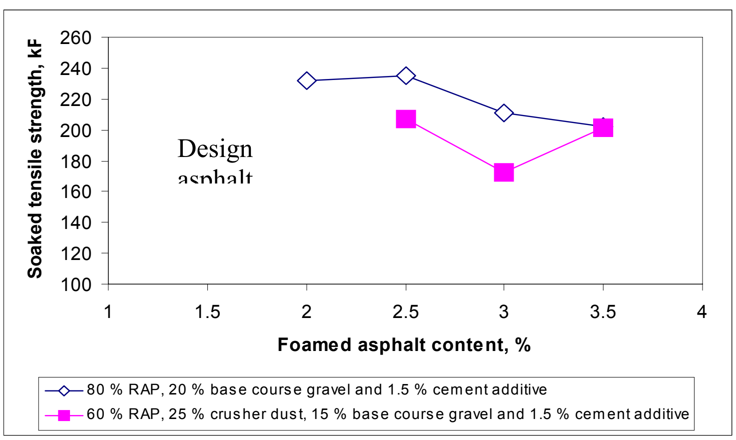


Figure 6. Plot of Foamed Asphalt Content versus Soaked Tensile

Construction

Hot Mix Asphalt Overlay

Areas that were built to state standards or were structurally sound, as determined by FWD data analysis, were treated with variable depth 9.5 mm Hot Mix Asphalt (HMA) Shim and 40 mm of 12.5 mm HMA Surface mix (Figure 2). These areas are located between Stations 1+160 to 1+400, 2+680 to 2+795, 4+380 to 4+900, 6+860 to 7+600 and 9+520 to 11+280.

Full Depth Reconstruction

Full Depth Reconstructed areas require excavating the existing roadway and placing 650 mm of Aggregate Subbase Course Gravel, 60 mm of 12.5 mm HMA Base and 40 mm of HMA Surface (Figure 3). This includes regrading of the inslope and backslope to specified tolerances. A majority of these sections include superelevated curves. These sections are located between stations 1+490 and 1+640, 3+460 and 3+527, 3+600 and 3+700 plus 4+130 and 4+205.

Full Depth Rehabilitation with Variable Depth Gravel

In areas scheduled for Full Depth Rehabilitation with Variable Depth Gravel, the entire depth of existing pavement plus approximately 25 mm (1 in) of underlying gravel were pulverized to a minus 51 mm (2 in) size. The material was then shaped and compacted to the cross-slope and grade shown on the plans. Extra material was added as necessary to restore the cross-slope and/or grade (Figure 4).

The recycled base was then surfaced with 60 mm of 12.5 mm HMA Base and 40 mm of 12.5 mm HMA Surface.

Full Depth Rehabilitation with Foamed Asphalt

A 50 mm (2 in) layer of crusher dust was applied to the roadway in areas requiring foamed asphalt. The crusher dust, entire depth of existing pavement plus approximately 50 mm (2 in) of underlying gravel were then pulverized to a minus 51mm (2 in) material using a Wirtgen Model WR 2500 milling machine without foamed asphalt chambers. The stabilized material was then shaped and compacted to the cross-slope and grade shown on the plans (Figure 5). It was necessary to pulverize the roadway prior to stabilizing due to the difficulty of consistently metering Portland Cement on an uneven roadway with wheel ruts as deep as 18 mm (0.7 in) in some areas. With the roadway graded uniformly, a tractor equipped with a spreader can be used to evenly distribute Portland Cement across the roadway directly ahead of the stabilizing unit.

Figure 7. Foamed Asphalt Full Depth Reclamation Construction

A Wirtgen Model WR 2500 equipped with foamed asphalt chambers was used to introduce foamed asphalt to the recycled material. This unit has a 2.4 m (96 in) wide cutter capable of working the soil to a depth of 20 inches. Material size, asphalt and water injection rate and depth of cut are hydraulically adjustable. The stabilizing process involves a train of vehicles all linked to the WR 2500. A 10 000 L asphalt tanker capable of maintaining asphalt temperatures at 180ºC ± 5ºC is attached to the front of the unit and a water truck is attached to the rear. Asphalt and water are supplied to the WR 2500 by flexible pipe. As the unit reclaims material, asphalt and water are introduced to mixing chambers creating asphalt foam. This foaming action increases volume and reduces viscosity of the asphalt, making it easier to mix with reclaimed material. Portland Cement and crusher dust were introduced to the reclaimed material to increase surface area for the expanded asphalt.

Figure 8 Compaction of Full Depth Reclamation Layer

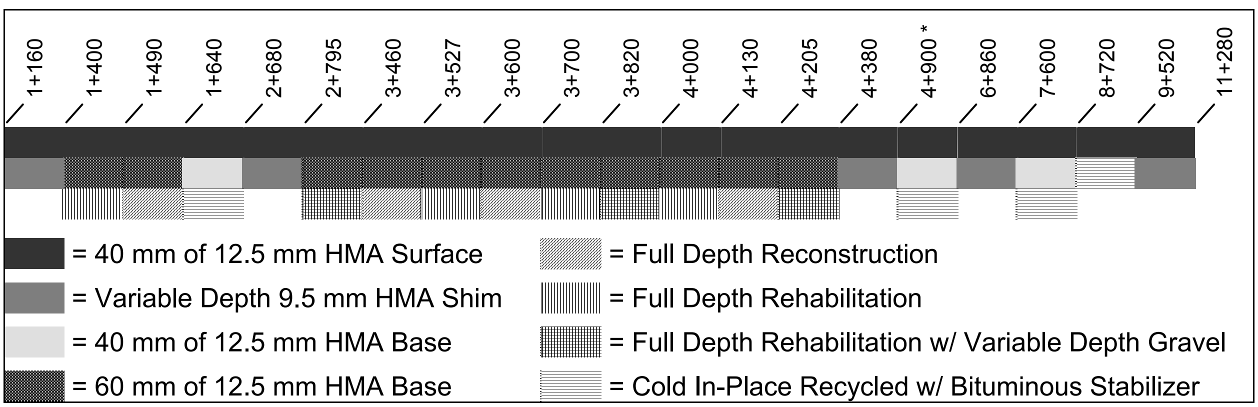
Prior to construction it was determined that one tanker of asphalt would stabilize roughly one kilometer of recycled base. It was also determined that it would be difficult to stop operations and move the unit to stabilize four small sections between stations 1+400 to 1+490, 3+527 to 3+600, 3+700 to 3+820 and 4+000 to 4+130. Because of this a decision was made to consolidate the eight Foamed Asphalt sections into three sections between stations 1+640 to 2+680, 4+900 to 6+860 and 7+600 to 9+520.

The first section to be stabilized is from station 1+640 to 2+680. Three passes

of the WR 2500 were necessary to stabilize the entire width of the roadway. Two passes set at a width of 2.4 m (8 ft) and one pass set at 2.1 m (7 ft). To incorporate Type II Portland Cement into the foamed asphalt, one bag of cement was placed on the roadway every 5.2 m (17 ft) for the 2.4 m (8ft) wide configuration and one bag every 6 m (20 ft) for the 2.1 m (7 ft) configuration. A tractor, equipped with a spreader set at a depth of 6 mm (0.25 in), was used to distribute the cement evenly. Each bag of cement was opened and dumped on the road ahead of the spreader. The spreader evenly dispersed the cement directly ahead of the WR 2500.
The asphalt stabilized reclaimed material is compacted with a vibratory pad foot soil compactor a minimum of 3 passes. The material is shaped to the cross-slope and grade shown on the plans and compacted with a vibratory steel drum roller to a minimum density of 98% of the target density as determined by a control section. After compaction, the roadway surface is treated with a light application of water and rolled with pneumatic-tired rollers to create a close-knit texture.

Figure 9. Completed Foamed Asphalt Layer

All foamed asphalt treated reclaim areas include crusher dust with the exception of an area between stations 6+335 and 6+525. This area was scheduled for untreated full depth rehabilitation and was located between two foamed asphalt treated sections. A decision was made to treat this area with bituminous asphalt rather than stop, move the train of equipment ahead 80 meters, and start up again.
After a minimum of 36 hours curing time, the stabilized base was very stable and looked very much like pavement (see photo at right). A 40 mm layer of 12.5 mm HMA Base and 40 mm of 12.5 mm HMA Surface were placed on the stabilized base. Another experimental section between stations 8+720 and 9+520 were treated with 40 mm of HMA surface only, omitting the HMA Base course.



** No crusher dust between stations 6+445 and 6+525*

Figure 10. Project Treatment by Section (not to scale).

Project Evaluation

This project will be evaluated for a period of five years. Performance of each test section will be compared to a control section. Data collection will include FWD deflections to monitor changes in structural integrity of the recycled and stabilized base. Surface evaluations will include roughness, rutting, and cracking. Three areas were demarcated for evaluation, one control and two test sections. In addition to evaluating the control and test sections, a visual evaluation of the project will be conducted in late winter/early spring of each year to locate areas that have frost movement. The control section is located between stations 3+700 and 3+870. The subbase consists of full depth reclaimed material. Caution was taken to select an area that has no variable depth gravel added to the recycled subbase. The surface is paved with 60 mm of 12.5 mm HMA Base and 40 mm of 12.5 mm HMA Surface. Test Section One is located between stations 4+980 and 5+180. The subbase is treated with foamed asphalt. The surface is paved with 40 mm of 12.5 mm HMA Base and 40 mm of 12.5 mm HMA Surface.

Figure 11. Cores Taken from Project

Test Section Two is located between stations 9+100 and 9+300. This section consists of foamed asphalt stabilized subbase and is surfaced with 40 mm of HMA Surface with no HMA Base.
Three 150 mm (6 in) diameter cores were extracted from each test section on September 27, 2001 to determine resilient modulus values of the foamed asphalt treated base. Core number 2 was destroyed during extraction from the core bit. The remaining cores were intact and very stable. Depth of treatment varies from 165 to 202 mm. Tests will be completed at Worchester Polytechnic Institute using ASTM D 4123 test method. Table 1 contains core locations and descriptions.
An attempt was made to extract a core of full depth reclaim base material from the Control Section for resilient modulus tests. The bit used to extract the reclaimed material was designed to cut asphalt and wouldn't cut the unstabilized reclaimed base. In addition, water that was used to cool the bit contaminated the reclaim material by increasing the natural water content. Results of the Resilient Modulus core values will be included in the First Interim Report.

Table 1. Core Locations

Core	Station	Offset	Test Section	Depth Below Finished Grade
1	9+277	1.8 m Left	Section 2	0-40 mm HMA Surface, 40 - 236 mm Stabilized Base
2	9+177	1.8 m Right	Section 2	0 - 52 mm HMA Surface, 52 - 230 mm Stabilized Base
3	9+216	1.8 m Right	Section 2	0 - 40 mm HMA Surface, 40 - 233 mm Stabilized Base
4	5+141	1.8 m Left	Section 1	40 - 90 mm HMA Base*, 90 - 255 mm Stabilized Base
5	5+090	1.8 m Right	Section 1	40 - 80 mm HMA Base*, 80 - 270 mm Stabilized Base
6	5+031	1.8 m Left	Section 1	40 - 78 mm HMA Base*, 78 - 280 mm Stabilized Base

** Core cut before application of HMA Surface*

Table 2 contains a Cost Summary for each treatment. As expected the HMA Overlay has the lowest cost and Full Depth Reconstruction has the highest cost.

The Full Depth Reclamation without Stabilizer and Asphalt Stabilized Base without HMA Base are very similar in costs. Evaluation of these sections over the five-year period will determine which treatment is most cost effective.

Table 2. Treatment cost summary (cost per square meter)

Treatment	40 mm HMA Surface	Shim[1]	40 mm HMA Base	60 mm HMA Base	CIPR	VDG[2]	Excavation	ASCG[3]	Stabilized Subbase	Total Cost
HMA Overlay	3.42	2.93								6.35
FDR	3.42			5.13	1.33					9.88
FDR + VDG	3.42			5.13	1.33	5.04				14.92
Full Construction	3.42			5.13			5.04	8.29		21.88
Stabilized Base w/HMA Base	3.42		3.42						8.32	15.16
Stabilized Base wo/HMA Base	3.42								8.32	11.74

1 Average depth of 35 mm

2 Variable Depth Gravel (average depth of 360 mm)
3 Aggregate Subbase Course Gravel (650 mm depth)

Sections treated with Full Depth Reclaimed material plus Variable Depth Gravel and Asphalt Stabilized Base with HMA Base are also similar in costs. Once again evaluation of these sections will determine which treatment is most cost effective.

A Theoretical Structural Number (TSN) was calculated for each treatment using FWD data from Table 4 and the following equations:

HMA Overlay (Shim):
$TSN = SN_e + (D_{sh} * C_{sh}) + (D_s * C_s)$
Full Depth Reclamation:
$TSN = (D_{pg} - D_c) * C_g + D_c * C_c + D_b * C_b + D_s * C_s$
Full Depth Reclamation with Variable Depth Gravel:
$TSN = (D_{pg} - D_c) * C_g + D_c * C_c + D_g * C_g + D_b * C_b + D_s * C_s$
Full Depth Reconstruction:
$TSN = D_g * C_g + D_b * C_b + D_s * C_s$
Foamed Asphalt Stabilized Base:
$TSN = (D_{pg} - D_c) * C_g + D_f * C_f + D_b * C_b + D_s * C_s$
Foamed Asphalt Stabilized Base without HMA Base:
$TSN = (D_{pg} - D_c) * C_g + D_f * C_f + D_s * C_s$
where
SN_e = Existing structural number
D_{ep} = Depth of existing pavement
C_{ep} = Layer coefficient of existing pavement
D_{pg} = Depth of combine pavement and gravel
C_g = Layer coefficient of Subbase Gravel, ASCG or VDG = 0.09
D_{sh} = Depth of HMA Shim (used an average of 35 mm)
C_{sh} = Layer coefficient of HMA Shim = 0.35
D_s = Depth of HMA Surface
C_s = Layer coefficient of HMA Surface = 0.44
D_c = Depth of Cold In-Place material
C_c = Layer coefficient of Cold In-Place material = 0.14
D_b = Depth of HMA Base
C_b = Layer coefficient of HMA Base = 0.40
D_g = Depth of ASCG or VDG (used an average of 360 mm for VDG)
D_f = Depth of Foamed Asphalt Stabilized Base
C_f = Layer coefficient of Foamed Asphalt Stabilized Base = 0.34

A Theoretical Structural Number for each station is included in Table 4. The following table contains a summary of Theoretical Structural Numbers.

Table 3. Summary of Theoretical Structural Number by Treatment

Treatment	COUNT Stations	MIN	MAX	AVE	STD DEV
HMA Overlay	32	91	135	111	11
Full Depth Reclamation	4	79	85	81	3
Full Depth Reclamation w/ VDG*	10	111	134	118	11
Full Depth Reconstruction	5	100	100	100	0
Asphalt Stabilized Base	42	128	150	135	7
Asphalt Stabilized Base wo/ HMA Base	8	118	118	118	0

** Lowest possible SN with 0 mm Variable Fill = 79, Highest SN with 400 mm Variable Fill = 137*

According to data in Table 3, sections treated with Full Depth Reclamation had the lowest Structural Numbers and sections with Asphalt Stabilized Base and HMA Base had the highest. Sections treated with Full Depth Reclamation with Variable Depth Gravel have the second highest average TSN at 135. Using an average of 360 mm of Variable Depth Gravel could be contributing to the high Structural Numbers when many stations could have a thinner layer of gravel. HMA Overly and Full Depth Reconstruction have similar Structural numbers.

Another column was added to Table 4 revealing the Structural Deficiency of a treatment if the Theoretical Structural Number fell below the Future Structural Number. All sections treated with Full Depth Recycled material had Structural Deficiencies ranging from 33 to 59 mm indicating an additional 75 to 134 mm (Structural Deficiency divided by a HMA layer coefficient of 0.44) of HMA would be necessary to increase the Theoretical Structural Number to meet the Future Structural Number. All Full Depth Reconstructed sections had Structural Deficiencies between 17 and 34 mm. Most of the Variable Depth Gravel sections also had Structural Deficiencies ranging from 7 to 32 mm. A number of HMA Overlay areas had deficiencies ranging from 3 to 25. There were also a few areas of Foamed Asphalt with deficiencies ranging between 2 and 6 mm. All sections of Foamed Asphalt base with no HMA base had Theoretical Structural Numbers higher than Future Structural Numbers. Future monitoring of these areas should determine if the correct treatment was used at each station.

FWD readings will be recorded in June 2002 on the same stations as in Table 4. Those readings will be compared to the Theoretical Structural Number as well as the Future Structural Number in Table 4 to confirm accuracy of the TSN calculations and monitor each treatment for structural integrity.

TABLE 4

Falling Weight Deflectometer Data Analysis

Station	Existing Structural Number (mm)	Future Traffic Structural Number (mm)	Overlay Structural Number (Existing - Future)[1]	Recommended Pavement Thickness (mm)[2]	Proposed Treatment[3]	Actual Treatment[3]	Existing Pavement Modulus (kPa)	Subgrade Resilient Modulus (kPa)	Pavement Depth (mm)[4]	Combined Pavement /Gravel Depth (mm)	Theoretical Structural Number	Structural Deficiency (Future - Theoretical)
1+200	91	110	**-19**	43	S	S	1,058,788	29,209	115	370	121	
1+300	78	127	**-49**	**111**	S	S	669,772	18,594	115	370	**108**	19
1+400	78	118	**-40**	91	**F**	C	684,935	23,808	**115**	370	**85**	33
1+500	74	123	**-49**	**111**	R	R	567,269	20,684	115	370	**100**	23
1+600	75	117	**-42**	95	R	R	600,136	24,290	115	370	**100**	17
1+700	71	122	**-51**	**115**	**F**	**F**	505,444	21,358	115	370	134	
1+800	64	109	**-45**	**102**	**F**	**F**	712,967	29,891	175	300	128	
1+900	78	115	**-37**	84	**F**	**F**	1,271,638	25,769	175	300	128	
2+000	71	126	**-55**	**125**	**F**	**F**	955,056	19,422	175	300	128	
2+100	67	127	**-60**	**136**	**F**	**F**	816,415	18,931	**175**	300	128	
2+200	73	117	**-44**	100	**F**	**F**	1,059,350	24,017	175	300	128	
2+300	67	118	**-51**	**116**	**F**	**F**	800,236	23,812	175	300	128	
2+400	85	108	**-23**	52	**F**	**F**	270,671	31,075	42	550	150	
2+500	107	102	5	-	**F**	**F**	525,949	36,816	42	550	150	
2+600	87	102	**-15**	34	**F**	**F**	289,751	36,789	42	550	150	
2+700	94	99	**-5**	11	S	S	359,685	39,352	**42**	550	124	
2+800	88	109	**-21**	48	V	V	297,887	29,664	42	550	134	
2+900	97	116	**-19**	43	V	V	397,293	24,927	42	550	134	
3+000	96	120	**-24**	55	V	V	385,126	22,186	42	550	134	
3+100	48	140	**-92**	**209**	V	V	299,189	13,688	85	300	**111**	29
3+200	57	128	**-71**	**161**	V	V	502,452	18,153	85	300	**111**	17
3+300	57	143	**-86**	**195**	V	V	503,355	12,975	**85**	300	**111**	32
3+400	59	126	**-67**	**152**	V	V	555,210	19,210	85	300	**111**	15
3+500	75	120	**-45**	**102**	R	R	1,136,041	22,617	85	300	**100**	20
3+600	60	118	**-58**	**132**	**F**	C	572,075	23,637	85	300	**79**	39
3+700	60	126	**-66**	**150**	R	R	578,136	19,080	62	300	**100**	26
3+800	62	117	**-55**	**125**	**F**	C	629,693	24,324	62	300	**79**	38
3+900	55	139	**-84**	**191**	V	V	457,993	13,997	**62**	300	**111**	28
4+000	76	118	**-42**	95	V	V	1,153,720	23,744	62	300	**111**	7
4+100	55	138	**-83**	**189**	**F**	C	444,789	14,560	62	300	**79**	59
4+200	52	134	**-82**	**186**	R	R	387,092	15,816	62	300	**100**	34

[1] Bold numbers represent areas of inadequate existing pavement thickness

[2] Bold numbers represent areas requiring > 100 mm of HMA to meet future design requirements

[3] C = Full Depth Rehabilitation, F = Foamed Asphalt, F2 = Foamed Asphalt without HMA Base, R = Full Depth Reconstruction, S = Shim, V = "C" + Variable Depth Gravel

[4] Bold numbers indicate auger locations to determine existing pavement and gravel depths

4+300	59	139	**-80**	**182**	V	V	547,386	13,983	62	300	**111**	28
4+400	61	102	**-41**	93	S	S	619,464	36,820	62	300	**91**	11

TABLE 4 continued

Falling Weight Deflectometer Data Analysis

Station	Existing Structural Number (mm)	Future Traffic Structural Number (mm)	Overlay Structural Number (Existing - Future)[1]	Recommended Pavement Thickness (mm)[2]	Proposed Treatment[3]	Actual Treatment[3]	Existing Pavement Modulus (kPa)	Subgrade Resilient Modulus (kPa)	Pavement Depth (mm)[4]	Combined Pavement /Gravel Depth (mm)	Theoretical Structural Number	Structural Deficiency (Future - Theoretical)
4+500	64	103	**-39**	89	S	S	687,265	35,569	130	300	**94**	9
4+600	67	106	**-39**	89	S	S	787,896	32,398	130	300	**97**	9
4+700	64	104	**-40**	91	S	S	691,277	34,261	130	300	**94**	10
4+800	67	100	**-33**	75	S	S	815,761	38,786	130	300	**97**	3
4+900	58	131	**-73**	**166**	**F**	**F**	510,198	17,073	130	300	**128**	3
5+000	58	134	**-76**	**173**	**F**	**F**	533,764	15,915	**130**	300	**128**	6
5+100	56	133	**-77**	**175**	**F**	**F**	481,052	16,189	130	300	**128**	5
5+200	56	130	**-74**	**168**	**F**	**F**	463,898	17,592	130	300	**128**	2
5+300	78	128	**-50**	**114**	**F**	**F**	1,270,802	18,359	130	300	128	
5+400	63	126	**-63**	**143**	**F**	**F**	671,161	19,071	130	300	128	
5+500	62	130	**-68**	**155**	**F**	**F**	650,133	17,663	130	300	**128**	2
5+600	80	120	**-40**	91	**F**	**F**	405,810	22,508	75	450	141	
5+700	73	134	**-61**	**139**	**F**	**F**	302,554	16,040	75	450	141	
5+800	82	115	**-33**	75	**F**	**F**	442,205	25,268	75	450	141	
5+900	81	122	**-41**	93	**F**	**F**	417,200	21,368	75	450	141	
6+000	68	140	**-72**	**164**	**F**	**F**	245,008	13,734	75	450	141	
6+100	71	136	**-65**	**148**	**F**	**F**	280,620	15,077	**75**	450	141	
6+200	75	125	**-50**	**114**	**F**	**F**	330,193	19,667	75	450	141	
6+300	79	113	**-34**	77	**F**	**F**	389,879	26,586	75	450	141	
6+400	82	102	**-20**	45	**F**	**F**	430,367	36,169	75	450	141	
6+500	76	128	**-52**	**118**	V	**F**	342,931	18,143	75	450	141	
6+600	82	107	**-25**	57	**F**	**F**	431,282	31,441	95	450	141	
6+700	89	102	**-13**	30	**F**	**F**	566,214	36,628	95	450	141	
6+800	91	94	**-3**	7	**F**	**F**	599,892	46,129	95	450	141	
6+900	96	99	**-3**	7	S	S	713,220	39,499	95	450	126	
7+000	98	106	**-8**	18	S	S	741,283	32,382	**95**	450	128	
7+100	88	92	**-4**	9	S	S	541,234	49,722	95	450	118	
7+200	97	103	**-6**	14	S	S	716,696	35,002	95	450	127	

[1] Bold numbers represent areas of inadequate existing pavement thickness
[2] Bold numbers represent areas requiring > 100 mm of HMA to meet future design requirements
[3] C = Full Depth Rehabilitation, F = Foamed Asphalt, F2 = Foamed Asphalt without HMA Base, R = Full Depth Reconstruction, S = Shim, V = "C" + Variable Depth Gravel
[4] Bold numbers indicate auger locations to determine existing pavement and gravel depths

7+300	76	131	**-55**	**125**	S	S	346,843	16,873	95	450	**106**	25
7+400	91	108	**-17**	39	S	S	589,596	30,936	95	450	121	
7+500	92	94	**-2**	5	S	S	1,127,286	46,006	195	370	122	
7+600	96	104	**-8**	18	**F**	**F**	1,262,438	34,592	195	370	134	
7+700	78	121	**-43**	98	**F**	**F**	690,647	21,927	195	370	134	
7+800	82	117	**-35**	80	**F**	**F**	798,939	24,114	195	370	134	
7+900	88	109	**-21**	48	**F**	**F**	959,529	30,253	**195**	370	134	

TABLE 4 continued

Falling Weight Deflectometer Data Analysis

Station	Existing Structural Number (mm)	Future Traffic Structural Number (mm)	Overlay Structural Number (Existing - Future)[1]	Recommended Pavement Thickness (mm)[2]	Proposed Treatment[3]	Actual Treatment[3]	Existing Pavement Modulus (kPa)	Subgrade Resilient Modulus (kPa)	Pavement Depth (mm)[4]	Combined Pavement /Gravel Depth (mm)	Theoretical Structural Number	Structural Deficiency (Future - Theoretical)
8+000	88	109	**-21**	48	**F**	**F**	982,660	30,275	195	370	134	
8+100	89	101	**-12**	27	**F**	**F**	996,392	37,547	195	370	134	
8+200	93	102	**-9**	20	**F**	**F**	1,144,276	36,001	195	370	134	
8+300	80	120	**-40**	91	**F**	**F**	744,188	22,456	195	370	134	
8+400	88	115	**-27**	61	**F**	**F**	986,728	25,371	195	370	134	
8+500	81	109	**-28**	64	**F**	**F**	765,680	30,167	140	370	134	
8+600	88	111	**-23**	52	**F**	**F**	984,229	28,277	140	370	134	
8+700	82	105	**-23**	52	**F**	**F**	796,212	33,706	140	370	134	
8+800	85	118	**-33**	75	**F**	**F2**	862,439	23,756	140	370	118	
8+900	83	115	**-32**	73	**F**	**F2**	811,414	25,680	140	370	118	
9+000	89	104	**-15**	34	**F**	**F2**	1,022,001	33,966	140	370	118	
9+100	76	110	**-34**	77	**F**	**F2**	626,210	29,437	**140**	370	118	
9+200	80	117	**-37**	84	**F**	**F2**	721,260	24,260	140	370	118	
9+300	87	107	**-20**	45	**F**	**F2**	937,290	31,458	140	370	118	
9+400	95	101	**-6**	14	**F**	**F2**	1,213,640	37,428	140	370	118	
9+500	77	99	**-22**	50	**F**	**F2**	654,924	40,043	140	370	118	
9+600	73	114	**-41**	93	S	S	447,865	26,224	50	400	**103**	11
9+700	83	92	**-9**	20	S	S	644,644	48,976	50	400	113	
9+800	76	116	**-40**	91	S	S	489,690	24,886	50	400	**106**	10
9+900	77	115	**-38**	86	S	S	520,490	25,497	**50**	400	**107**	8
10+000	79	114	**-35**	80	S	S	567,056	26,260	50	400	**109**	5
10+100	76	111	**-35**	80	S	S	493,055	28,229	50	400	**106**	5
10+200	76	111	**-35**	80	S	S	500,460	28,330	50	400	**106**	5
10+300	69	121	**-52**	**118**	S	S	368,592	21,995	50	400	**99**	22

[1] Bold numbers represent areas of inadequate existing pavement thickness
[2] Bold numbers represent areas requiring > 100 mm of HMA to meet future design requirements
[3] C = Full Depth Rehabilitation, F = Foamed Asphalt, F2 = Foamed Asphalt without HMA Base, R = Full Depth Reconstruction, S = Shim, V = "C" + Variable Depth Gravel
[4] Bold numbers indicate auger locations to determine existing pavement and gravel depths

10+400	72	120	**-48**	**109**	S	S	427,550	22,639	78	400	**102**	18
10+500	71	119	**-48**	**109**	S	S	403,515	22,717	78	400	**101**	18
10+600	82	117	**-35**	80	S	S	618,226	24,305	78	400	**112**	5
10+700	83	113	**-30**	68	S	S	655,303	26,963	**78**	400	113	
10+800	83	101	**-18**	41	S	S	635,212	37,666	78	400	113	
10+900	85	108	**-23**	52	S	S	690,009	30,624	78	400	115	
11+000	84	107	**-23**	52	S	S	681,637	31,589	78	400	114	
11+100	105	108	**-3**	7	S	S	599,744	30,548	52	520	135	
11+200	97	107	**-10**	23	S	S	472,039	31,725	52	520	127	
11+400									**52**	520		

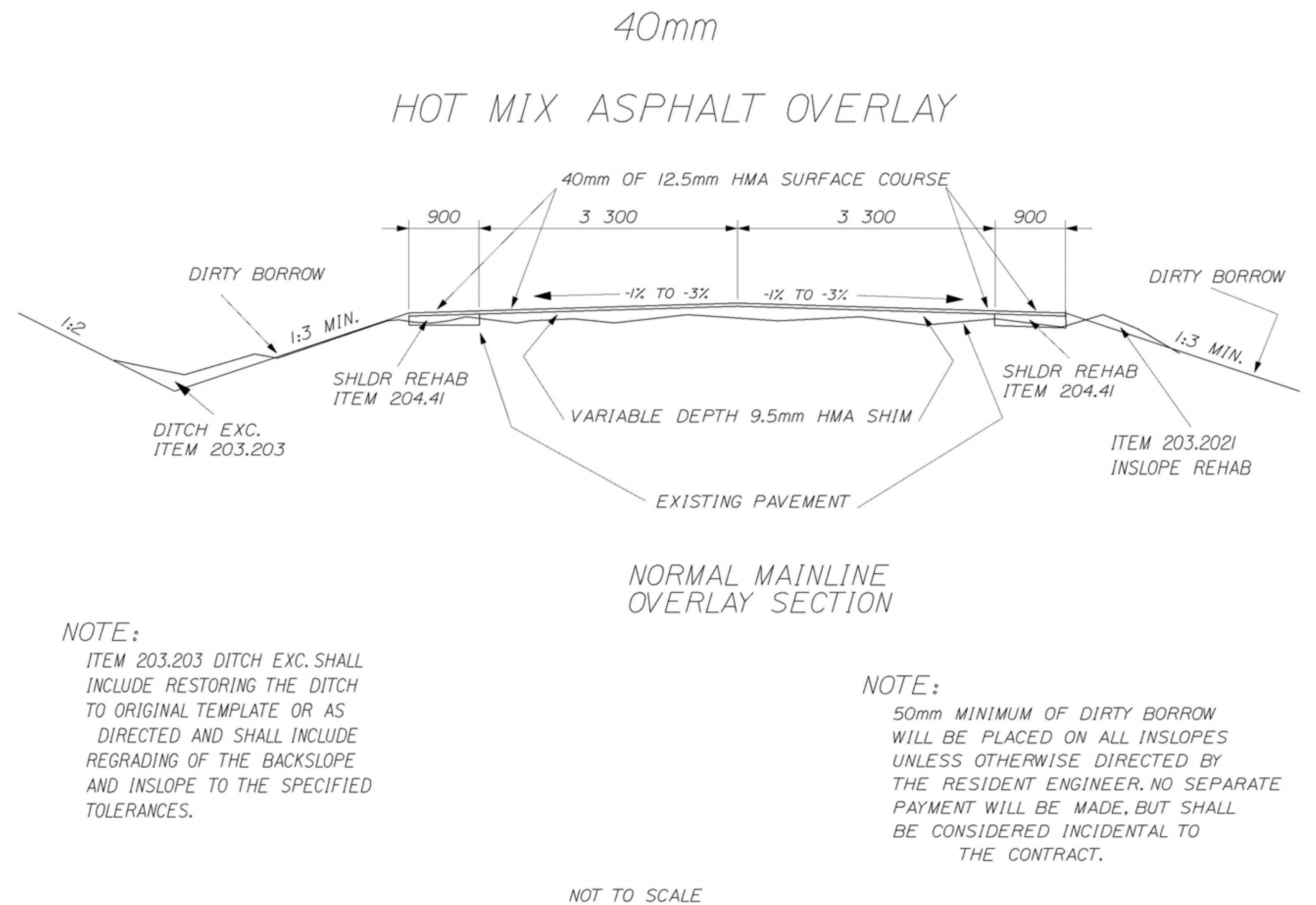


Figure 12. Typical Hot Mix Asphalt Overlay.

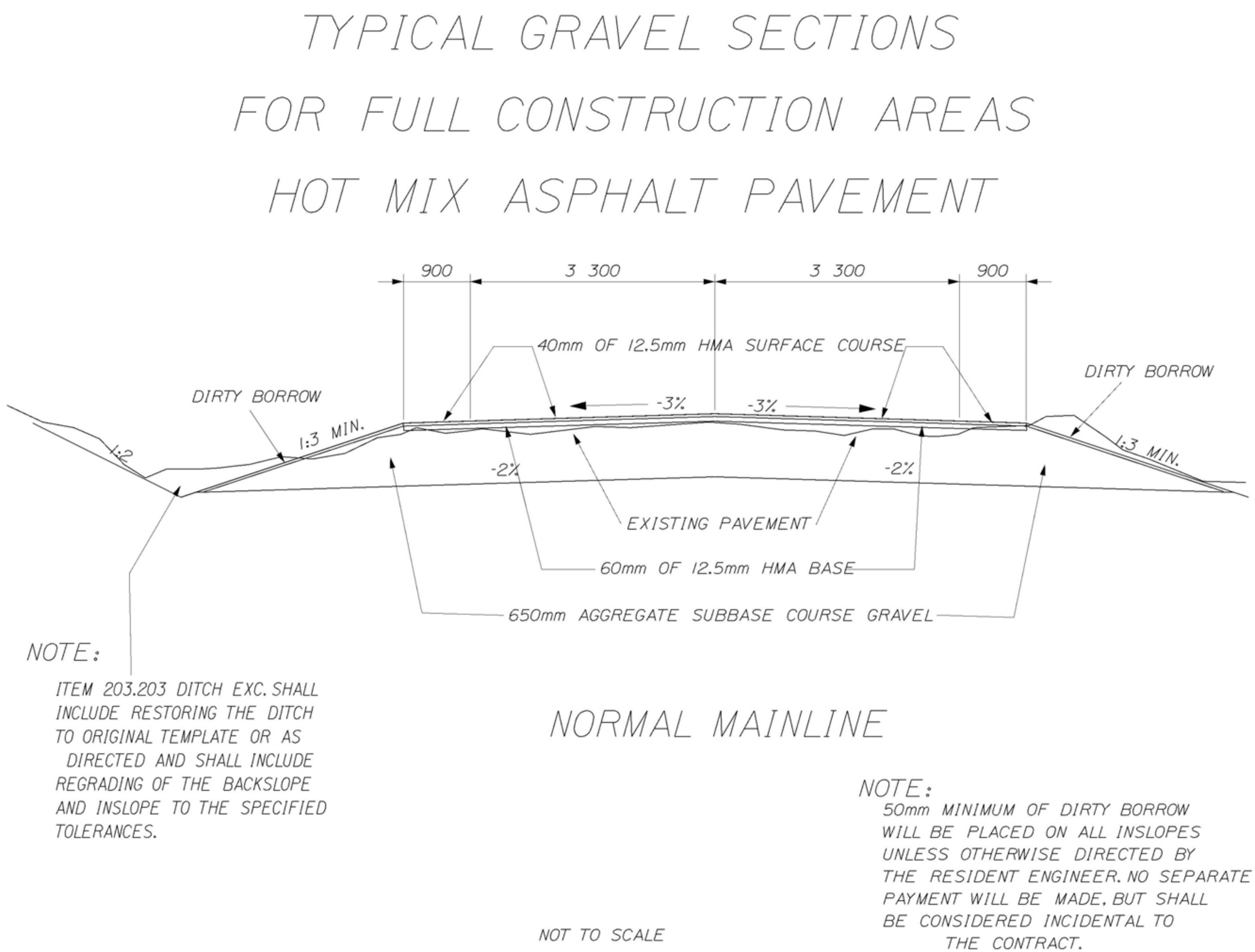


Figure 13. Typical Full Depth Reconstruction.

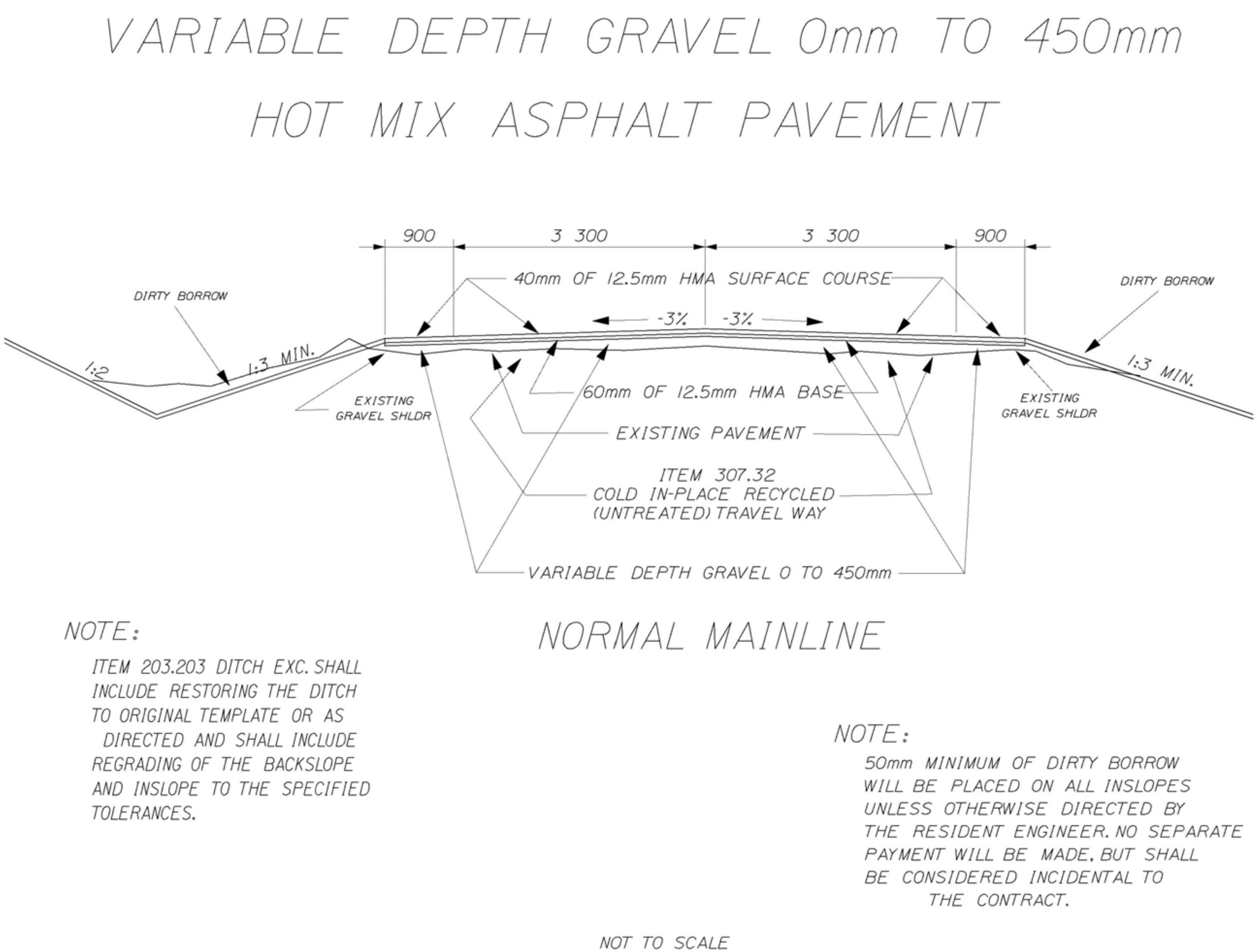


Figure 14. Typical Full Depth Rehabilitation with Variable Depth Gravel.

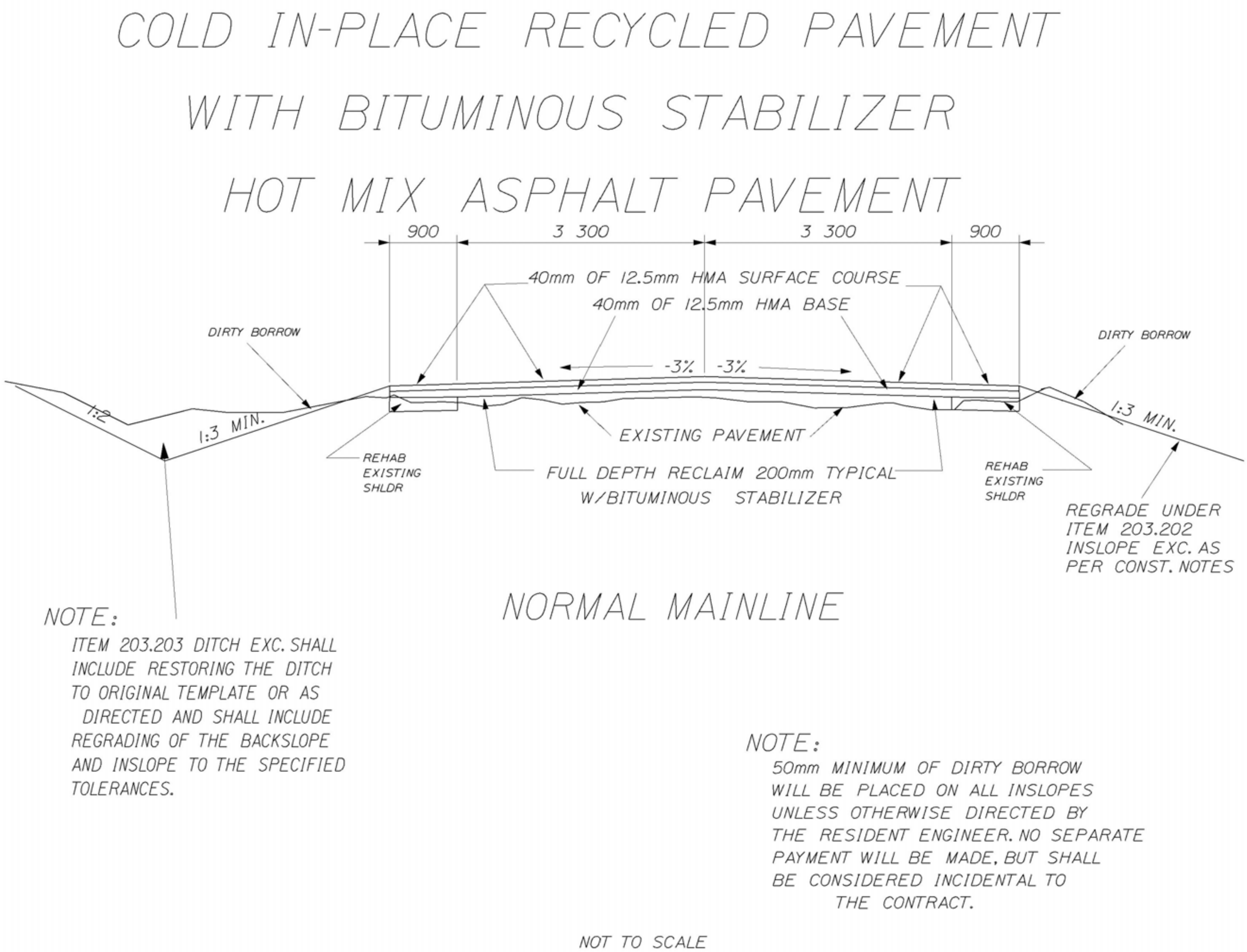


Figure 15. Typical Full Depth Rehabilitation with Foamed Asphalt Stabilized Base.