A Technical Memo to the

Texas Department of Transportation

Deliverable P1 Study 0-6132

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Date:	Sept 1st 2012
Subject:	Next Generation Mix Design Procedures and Recommendations for Texas (Study 0-6132)

Texas A&M Transportation Institute

BACKGROUND

- Study 0-6132 has promoted the development and implementation of the balanced mix design (BMD) approach for selecting the optimal asphalt content for all of TxDOT's hot mix asphalts (HMA), including Item 341. In this approach the engineering properties are measured in both the laboratory design and the trial batch with both the Hamburg Wheel Track test (Tex Method 242F) and the Overlay test (Tex Method 248F).
- In study 0-6132 TTI researchers used the BMD approach with mixes from seven different Districts, details of these mix designs are provided in the accompanying documentation for Product P1 of study 0-6132.
- Several full scale 1000 ft long test sections were constructed around Texas. As will be described below the most notable success was in the Laredo District where using the balanced mix design approach resulted in a savings of over $5 per ton of HMA by moving to a less expensive binder while improving the mix's overall engineering properties. No problems were encountered with constructing any of the section and the field performance to date has been excellent.
- The balanced mix design approach was also field tested in an Accelerated Pavement Testing (APT) study conducted in cooperation with the Louisiana Transportation Research Center (LTRC) at their ALF facility in Baton Rouge. Performance data confirmed the laboratory Hamburg tests relationship to field rutting and the Overlay tests relationship to reflection cracking.
- In 2012, the use of the Overlay tester has been proposed to be included in the newly updated TxDOT Stone Matrix Asphalt specifications (Draft Item 346), and for the new fine PFC (Draft Item 342), and continues to be required with the Crack Attenuating Mixes (SS 3191) and the Thin Overlay Mixes (SS 3239).
- However the Balance Mix Design approach has not been implemented for the bulk of TxDOT mixes including the Dense Graded materials, which are designed according to Item 341. This technical memorandum proposed an approach to implement the BMD within Item 341.
- In the section below the proposed modifications to the recently proposed Item 341 specification are described. An updated draft specification is provided in the accompanying documentation. The last section presents a summary of the supporting documentation. More details are available in the accompanying tech memos:
    - Laredo District (Design and Monitoring memos in accompanying folder "Product 0-6132-P1/ 1.00 in-service Hwy sections/Laredo").
    - Atlanta District (Design and Construction memos).
    - Bryan District (Design and Construction memos).
    - APT performance testing ("Product 0-6132-P1/ 2.00 APT + HMA performance testing").
- It is proposed that these recommendations be considered for an implementation project and that the proposed BMD approach should be incorporated into upcoming Item 341 projects, to be run in parallel with the current design approach.

RECOMMENDED CHANGES TO SPECIFICATIONS

As part of the P1 deliverable for study 0-6132 a draft Item 341 specification has been proposed. The tentative proposed modifications are described in this section. The draft spec is in the accompanying folder "Products 0-6132-P1/3.0 Draft Recommendations for Item 341."

The proposed changes to the recently proposed Item 341 specification, in order of importance, are described below.

Item 1 Page 11- Require the performance tests to be performed at a minimum of two different asphalt contents

Proposed Wording

"The asphalt content selected using either a) or b) above is defined as the Optimum Asphalt Content (OAC). Evaluate each mix using the Hamburg Wheel Test and the Overlay Test at the OAC and at the asphalt content corresponding to the lesser of either a target lab molded density of 1.0% higher than that used to determine the OAC or 98%."

Discussion

Implementation of any balanced mix design approach will need TxDOT to require performance tests (HWTT and OT) to be run at as a minimum two asphalt contents so that the benefits of increasing binder content can be evaluated by the contractor and District personnel. (In project 6132 a minimum of three asphalt contents were used to select the OAC, three would be preferred but two is the minimum). The major concern heard recently is that the current mixes are too dry, and consequently the proposed changes call for running the tests at a binder content higher than optimum. A 1.0% increase in density was used in the design example from Atlanta (Figure 2 below).

The use of the asphalt content at 1.0% higher lab molded density is subject to change. The initial consideration was to test at 0.5% more asphalt then optimum. However this may in some cases take the mix out of the acceptable density window specified for Texas Gyratory designs.

The Hamburg and Overlay tester results will be presented to the District by the contractor. These will be compared with the requirements for this mix and a decision will be made on the binder content to use in the trial batch. On some mixes it will become apparent that the proposed combination of materials will not meet the performance specifications. In those cases the designer will have the option of changing binder grade (Figure 1 below), using a different binder source (Figure 3), changing RAP/RAS levels, modifying the type or amount of anti-strip agent or changing gradation or aggregate sources.

<u>Item 2</u> Page 17 – Assign a mix specific or project specific OT requirements

<u>Proposed Wording</u>

"D.1.1 Overlay Test Requirements.

Use either method 1 or 2 to determine the Overlay Tester requirement.

<u>Method 1</u> Design a mix to meet the minimum requirement given below in Table 11.

Table 11 Overlay Tester Requirement

Mix Type	***Test Method***	***Minimum # of Cycles[1] In Overlay Tester, Tested @ 25°C***
Types A/B	*Tex-248-F*	*30*
Type C		*100*
Type D/F		*150*

1. May be decreased or waived when shown on the plans.

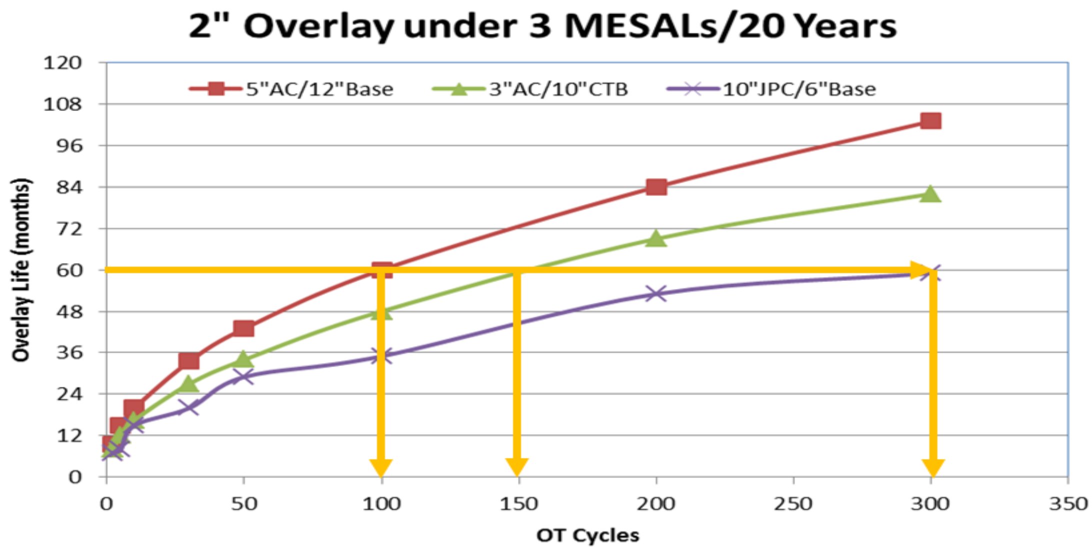
<u>Method 2</u> For DGAM, which are to be placed as overlays of 2 inch thickness or less. The Overlay Tester requirement may be computed using the Design program DCL (Design Crack Life). Select an overlay test requirement so that the predicted reflection cracking life is greater than 60 months. In no cases should the minimum number of cycles for a surface mix be less than 30 cycles.

<u>Discussion</u>

One major factor limiting the adoption of the OT for the dense graded mixes is what should be the criteria for the broad range of mixes and pavement conditions found in Texas. Several cases have been identified where dense graded mixes with low resistance to cracking have performed reasonably well in the field. The bottom line is that the required cracking resistance is project specific relating to a range of factors including mix type (base or surface), pavement condition, base type, traffic levels, climate, and others.

In the table presented above the base mixes (Types A and B) are specified to require a low number of cycles to failure in the overlay tester. Whereas the numbers required for the surfacing mixes are in line with TxDOT's current proposal for performance mixes. These are tentative at this time and subject to review and modification.

The preferred method of selecting the required OT requirement for overlays is method 2. This software is relatively simple to use and can rapidly take into consideration all of the factors impacting overlay cracking life. An example of output from this program is shown graphically in Figure A for different base types. Further discussion on the background of this approach is presented in Figures 6 through 11 at the end of this memo. Using this method the required OT cycles to failure would be calculated for each project and included in the plan notes.



<u>Figure A</u> Typical example of using TTI's Overlay Design program to estimate cracking life

The case studies described below provide some insight into the options available to improve the OT test results. This includes increasing target density (Atlanta example), changing to softer binders (Laredo example), or simply changing the source of the asphalt (Bryan example). Other options include limiting RAP/RAS usage, changing gradation, and several other options.

<u>Item 3</u> Page 39; Pay for the Aggregates and Asphalt as a separate Bid item

<u>Proposed Wording</u>

*"**Payment** The work performed and materials furnished in accordance with this Item and measured as provided under Article 5, "Measurement," will be paid for at the unit price bid for "DGAM (Asphalt)" of the binder specified and for "DGAM (Aggregate)" of the grade and surface aggregate classification specified. These prices are full compensation for surface preparation; materials including tack coat, placement, equipment, labor, tools, and incidentals."*

<u>Discussion</u>
If the performance tests are to be run at two different asphalt contents it will be critical to pay for the asphalt as a separate bid item.

<u>Item 4</u> Pages 5 – 7; - Remove the restriction on RAP/RAS percentages; Use of the performance tests will dictate the level of usage

<u>Proposed Wording</u>

"The performance test results shown in Mixture Design section will govern the amount of RAP and RAS that can be used."

Discussion

This will be one of the controversial aspects of this proposal. If the mix design is truly to be based on the results of the rutting and cracking performance tests then it is not necessary to limit the amount of RAP or RAS included in any mix. Therefore the contractors will have the incentive to actively optimize their designs. In several cases RAP/RAS contents higher than currently permitted will be allowed for none cracking critical layers.

This requirement has the following advantages:

a) It greatly simplifies the existing specifications.
b) It permits the contractors more flexibility to optimize mix designs.

Item 5 Page 19 Incorporate the Overlay Tester in the acceptance testing of the trial batch

Proposed Wording

"The trial batch mixture must also be in compliance with the Hamburg Wheel requirement in Table 10 and Overlay Test requirements from section D.1."

Discussion

As the contractor still has the option to include a Warm Mix additive into the trial batch it will be important to run both the HWTT and OT on the mix which is close to the material to be used on the project. Until further notice TxDOT currently recommended sample preparation and curing procedures must be followed to test the trial batch.

SUPPORTING DOCUMENTATION

Product P1 is being provided to TxDOT on CD with the three folders listed below that contain supporting documentation:

1.0 In-service Hwy Sections + performance Testing/Atlanta (Bryan/Laredo/Other Districts).
2.0 APT + HMA Performance testing.
3.0 New Texas HMA Draft Specification.

Figures 1 thru 5 are extracted from these tech memos and show results of using the BMD approach on TxDOT projects. Figures 6 through 12 present details of the software proposed to be used to generate project specific OT requirements.

Figure 1 Balanced Mix Design Results for a Type C Mix with RAP from the Laredo District.

Ramon J. Rodriquez from the Laredo District supported this effort and thanks are also due to the Anderson Colombia Company for placement of the control and modified mixes. The original Type C design with the PG 70-22 binder with gravel aggregates and 20% RAP, rutted 2.9 mm in the Hamburg and lasted only 38 cycles in the Overlay tester. The mix was proposed to be placed on four major highways in the Laredo District namely US 83, Loop 20, US 59, and Spur 400, all heavily trafficked highways. Of particular concern was the US 59 project that had extensive existing wheel path cracking.

Figure 1 shows the Hamburg and OT results for both the PG 70-22 and 64-22 binders for a range of different asphalt contents (lab molded densities from 96% to 98%). At the 96.5% target density the PG 64-22 binder required an increase in asphalt content of 0.2% over the PG 70-22 binder but the OT cycles increases from 38 cycles to 200 cycles. Figure 1 provides a comprehensive review of the options available to the District. If the District wished to design to 300 cycles this could have been obtained using 5.4% binder with a HWTT rut depth at 20,000 passes of 8 mm, which would correspond to a target lab molded density of 97.5%.

These results were presented to the District staff in summer 2010 with the intention of constructing a short test section with the proposed modified mix design. However, based on these results the District field changed out the PG 70-22 for the PG 64-22 on three of the projects opting for the 5.0% binder content. The US 83 was already underway and it used the PG 70-22 binder. The contractor reported that the modified design saved them at least $5 per ton.

Generating tables such as those shown in Figure 1 requires a lot of lab testing. However it must be recalled that the final mix design is not used just once. In this case it was used on three projects. It is our understanding that this mix has been continued to be produced and used on subsequent projects in the Laredo District including Loop 480.

All mixes were placed as a 2 inches thick overlay by Anderson Colombia Company late summer 2010. Following monitoring has been performed on a regular basis and no performance problems have been currently observed. The District staff are extremely happy with the performance of these sections, the Loop 20 project is just outside of the District office and it contains numerous light with heavy stop and go traffic. Monitoring of these sections will continue.

Figure 2 BMD Results for a Type C mix with RAP from the Atlanta District.

Miles Garrison of the Atlanta District lab supported this effort and thanks are also due to both Longview Asphalt and Madden Construction for placement of the control and modified mixes. The Atlanta District was used their OT device to design this mix. The original design because of the quality of the aggregates and the use of a PG 64-22 binder was thought to be reasonable. The District asked if the balanced mix design approach could further optimize the mix. This is a heavily trafficked section of US 59 and the existing hot mix was showing wheel path cracking.

Figure 2 shows that by increasing the optimum asphalt content from 5.2% to 5.5% could increase the OT cycles to failure from 250 to over 500 cycles. Two 1000-ft test sections were placed on March 26, 2010. The two year inspection of both the control and modified test sections has just been completed and no significant differences in performance were noted. Monitoring of these sections will continue.

Figure 3 Balanced Mix Design Results for a CAM Mix from the Bryan District.

Darlene Goehl of the Bryan District lab supported this effort and thanks are also due to Knife River for the placement of the modified mix. In this mix design TTI was asked to assist Knife River who had bid a CAM design project on an urban street in the Bryan District. The contractor had used the same mix on two early CAM projects with no problem meeting the CAM specification of passing the Hamburg and lasting more than 750 cycles in the OT. However Knife River's initial results were unsuccessful at arriving at a passing mix design with at the 98% target density with an HWTT rut depth of 3 mm and OT cycles to failure of around 140 cycles.

A laboratory study was undertaken at TTI and two other PG 76-22 binders were introduced into the lab design. Both of the alternative binders had no problem meeting the 750 cycles in the OT. Both the Jebro and Valero Binders worked well. A PG grading test was made on the three binders and the results are shown in the top table in Figure 3. It turned out the failing binder was graded at PG 82-22 and these properties translated to poorer performance in Overlay tester but less rutting in the Hamburg test.

Figure 3 also shows the benefits of running the performance tests at different binder contents as proposed in the BMD. At the target density of 98% lab molded density would have required 7.1% Jebro binder with a HWTT rut depth of 5.4 mm and 1000 cycles in the OT. However from the data it was found that the 6.7% binder content corresponding to the 97% target density would rut 4.3mm in the HWTT and also last more than 1000 cycles in the OT. The District instructed the contractor to change the mix design to place the mix at 6.7% binder.

Figures 4 and 5 APT Results from Louisiana LTRC-ALF Testing.

More details of the APT testing which was performed as part of Project 0-6132, can be found in the accompanying summary report "APT-ALF testing SUMMARY REPORT" or in the second year's report 0-6132-2. Two different mixes were placed using primarily the Brownwood limestone, which is a quality aggregate and a PG 76-22 binder. The lab design results are shown in Figure 4. The control mix had an OAC content of 4.3% and rutted 4.7 mm in the HWTT and lasted 90 cycles in the OT. The modified mix was designed at 5.2% binder and rutted 7.0 mm in the HWTT and lasted 600 cycles in the OT.

The mixes were placed on test strips at the Louisiana DOT's APT facility in Baton Rouge and tested under their ALF machine. Testing ran from September 2009 to June 2010. Rutting, reflection cracking, and fatigue cracking tests were conducted. The normal sequence was to place 9,750 lb on the dual wheels and complete 75,000 passes, if no distresses appeared then to increase the load to 14,600 lb and continue trafficking until failure occurred.

Summary results are shown in Figure 4. Using the channelized loading at high summer temperatures the control section rutted 7.7 mm after 75,000 load applications whereas the modified mix rutted 11.8 mm thus confirming the HWTT ranking of these materials. However in the reflection cracking test over a joint with a load transfer efficiency (LTE) of 50% the control mix cracked after 75,000 load applications, whereas no cracks were induced in the modified mix after the equivalent of over 200,000 passes at the 9,750 load level, confirming the OT ranking of these two mixes.

Figure 6 Overlay Life Prediction Software Developed in Project 0-5123.

Two factors have slowed the implementation of the Balance Mix Design concept. These are:

1) Concerns about the repeatability of the OT itself; and
2) What criteria to use for different mixes and different projects, as some mixes with low OT cycles do in some cases perform well.

Recently completed project 0-6607 has been studying the repeatability issue and has made recommendations on how to reduce the test Coefficient of Variation to less than 30%, this involved among other items increasing the number of samples from 3 to 4 and numerous other refinements to Tex Method 248 F.

The remaining major continuing concern is what criteria to use for the different mixes available to TxDOT. In many instances high resistance to both reflection and fatigue cracking is not critical if the layer will not be subjected to high tensile strains, this could be the case of an overlay on a CRCP pavement with excellent LTE or for a thin overlay added to improve skid resistance of a structurally sound flexible pavement.

In the specification discussed above two approaches have been proposed to address the target OT requirement, these being:

1) A default number of OT cycles for each mix type (this will be used for all new construction and for thin overlays to be placed over thin flexible pavements), or
2) Use of a project specific recommendations based on the overlay cracking life predicted by a simplified version of TxDOT Overlay design program (Project 4-5132) as shown in Figure 6.

What is proposed is to simplify this program so that all of the input parameters are readily available for the District designers. This program is recommended for all overlay design projects where the existing pavement has more than 2 inches of asphalt. The information will be used in the mix design phase to design a mix that passes both the current HWTT requirement and last the calculated number of cycles in the Overlay test. This could be for example 5 years without any predicted reflection cracking. The project specific number of OT cycles can be placed in plan notes for each project.

The inputs the District will require to run the program will include:

- District Number (to get default temperature data).
- County Number (to get default soils data as used in FPS).
- Pavement structure, (base type (CRCP/JCP/Flex/CTB/etc.) and the current HMA thickness [estimated]).
- Current Condition (severity of cracking).
- Joint or crack spacing for pavements with either CTB of JCP bases.
- Traffic levels (18 kip ESALs).
- Proposed thickness of overlay under consideration (the program has the capability to include 2 overlays, for example a 1 inch level up and a wearing surface).

The user will then run the program inputting different OT cycles until the target overlay cracking life is achieved (for example 5 years).

The use of the FWD will be encouraged to obtain better LTE values for more important projects (for routine use the program default LTE values will be defined based on the level of cracking). GPR will also be encouraged for those important studies to better map layer thicknesses and to manage project variability. Details of the background of this program and typical outputs are provided in Figures 7 through 12.

Figure 7 Basic Reflection Cracking Model.

The cracking model used to predict the crack growth is the accepted Paris model shown in this figure. The material properties needed are the ***A*** and ***n*** values which Dr. Zhou in recently completed study 0-6092 has correlated with the results from the overlay tester. As will be shown in Figures 8 and 9 by inputting an OT number of cycles the program can estimate these crack growth parameters for any proposed overlay material. The rate of crack growth is also dependent upon the pavements structural parameter ***K*** which is a function of the load transfer of existing cracks and joints, the overall deflection of the pavement and the typical temperature cycles experienced.

Figure 8 Lab Testing Completed in Project 0-6092 (PI Dr. F-Zhou).

In recently completed study 0-6092 independent measurements were made of both A and n and the number of OT cycles to failure on the 25 different mixes shown in this figure. These represent a range of OT values from 3 to 957. For each comparison five replicate OT samples were tested and five measurements were made of the ***A*** and ***n*** value, using the procedures defined in study 0-5123.

Figure 9 Graphical Relationship between n and A and Overlay Tester Cycles to Failure.

The graph shows both ***A*** and ***n*** value against OT number of cycles is shown in Figure 9. A reasonable R^2 value was obtained.

Figure 10 Predicted Overlay Life for Design Cases where Reflection Cracking Is a Concern.

This figure shows typical outputs from the program on the effect of changing base type (and LTE) on the predicted OT requirement to last the 5 year life with no reflection cracking. In the same District with a) a pavement with a flexible base, b) a pavement with a CTB and c) from a pavement with a jointed concrete slab, the program predicts that the different base types will require different OT requirements to withstand reflection cracking for the 60 month design period, these being 100, 150, and 300 OT cycles, respectively.

Figure 11 Predicted Overlay Life for the Same Case as Figure 10 but where the Lower Support Conditions Are Very Good.

Figure 11 shows the same predictions for two pavements with similar loads but this time with very good support conditions. One is a simulation of the CRCP pavement just overlaid on Loop 820 in the Fort Worth District, in that case the LTEs were very good (>95%) and the pavement support was excellent. The second is the analysis of the data from FM 973 in the Austin District, which just received several thin overlays. FM 973 has a thick structure with 8 inches of HMA over a very stiff mix, which the FWD computed to have a modulus value of over 100 ks, indicating excellent support. The existing pavement was also not badly cracked.

In both of these cases the program defaults to a very low OT requirement to get reasonable life for the new overlay. Because of the good support and low levels of existing cracks the overlay will not be experiencing large tensile or shear strain conditions.

Figure 12 Influence of Climate on Required OT Life.

This last figure illustrates the ability of the proposed software to include the critical importance of climate on the required OT number of cycles to achieve the required design life in the different climates found in Texas. For exactly the same pavement type , structure and loading conditions in the two extremes of the State, the program predicts different overlay test requirements. In the cold climate (Amarillo) the overlay material is predicted to require an OT life of 300 cycles, whereas in the mild Pharr District the mix will only be required to last 70 cycles for the same predicted performance life.

As shown in Figure 12, significantly higher OT test values are required for the pavement with a CTB but these are also strongly dependent on the climate.

Hamburg and OT Results for the Original Mix-Design (PG 70-22).

AC	Corresponding TGC Lab Density	VMA (≥ 13)	Hamburg (After 20 000 Passes)	Overlay (Cycles)
4.7%	96.0%	14.6	2.04 mm	24
4.8%	**96.5%**	**14.4**	**2.9 mm**	**38**
5.0%	97.0%	14.3	2.7 mm	46
5.2%	97.5%	14.4	2.9 mm	60
5.5%	98.0%	14.5	3.2 mm	73

: Hamburg and OT Results for the TTI Modified Design (PG 64-22).

AC	Corresponding TGC Lab Density	VMA	Hamburg (After 20 000 Passes)	Overlay (Cycles)
4.8%	96.0%	14.7	5.4 mm	180
5.0%	**96.5%**	**14.8**	**6.0 mm**	**200**
5.2%	97.0%	14.8	6.5 mm	219
5.4%	97.5%	14.7	8.0 mm	311
5.6%	98.0%	14.7	9.7 mm	380

Detailed Hamburg Results for the TTI Modified Design (PG 64-22).

Hamburg Passes	4.8% AC	5.0% AC	5.2% AC	5.4% AC	5.6% AC
00 000	0.0 mm	0.0 mm	0.0 mm	0.0 mm	0.0 mm
05 000	3.3 mm	3.6 mm	4.0 mm	4.5 mm	5.2 mm
10 000	4.1 mm	4.3 mm	4.7 mm	5.5 mm	6.5 mm
15 000	4.9 mm	5.3 mm	5.6 mm	6.7 mm	8.1 mm
20 000	5.4 mm	6.0 mm	6.5 mm	8.0 mm	9.7 mm
Corresponding TGC density	96.0%	96.5%	97.0%	97.5%	98.0%

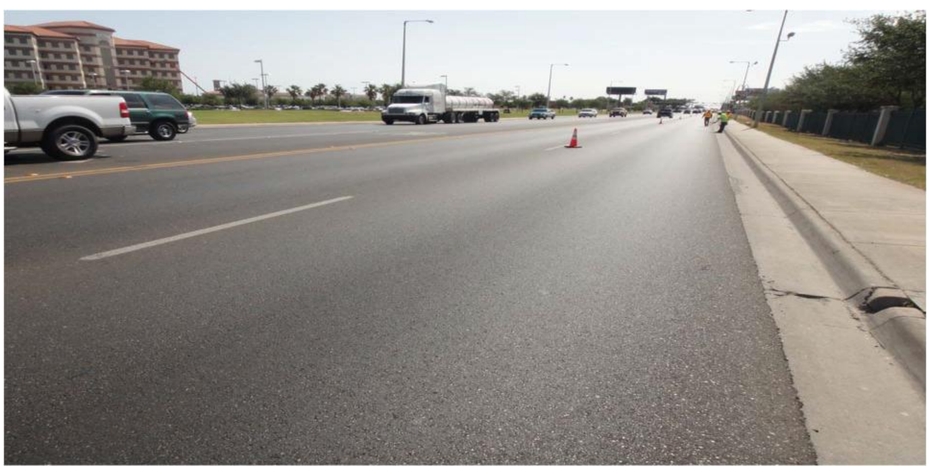


Figure 1 Balanced mix design results for a Type C mix with RAP from the Laredo District. No satisfactory results could be obtained from the PG 70-22 binder so a change was made to the PG 64-22 binder with a reported savings of $5 per ton. US 59 section after 2 year is shown above.

Test Section, HMA Mix Details, and Performance Evaluation.

Item	TTI Section 1	TTI Section 2	TTI Section 3
Designation	Control# 1	*Modified*	Control# 2
Section length	1 479 ft	*1 848 ft*	1 000 ft
HMA Mix-Design Details			
Mix Type	Type D – Fine Surface (Item 341)	*Type D – Fine Surface (Item 341)*	Type D – Fine Surface (Item 341)
Materials	PG 64-22 + Quartzite + 20% RAP	*PG 64-22 + Quartzite + 20% RAP*	PG 64-22 + Quartzite + 20% RAP
Design target AC	5.2%	*5.5%*	5.2%
Lab design TGC density	97.0%	*98.0%*	97.0%
Overlay (OT) crack testing	269 cycles	*506 cycles*	240 cycles
Hamburg @ 15 000 passes	3.1 mm	*4.1 mm*	3.4 mm

Figure 2 Balanced mix design results from the Atlanta District. Increasing the design asphalt content 0.3% doubled the OT cycles to failure. The modified mix is performing very well after 2 years of service on US 59.

Asphalt-Binder DSR and BBR Results.

#	Source	Actual Tested PG Grade	DSR (High Temp)		BBR (Lower Temp)	
			G* (kPa)	G*/Sin δ (kPa) (> 1.00)	S (MPa) (< 300)	m-value (> 0.300)
1	***Jebro PG 76-22***	***PG 76-22***	***1.41***	***1.54***	***174***	***0.325***
2	Valero PG 76-22	PG 76-22	1.55	1.61	132	0.316
3	Martin PG 76-22	PG 82-22	1.03	1.05	77	0.317

Table I-2. Hamburg and Overlay Results – Jebro PG 76-22.

#	Asphalt-Binder Content	Corresponding Lab Density	VMA (>17)	Hamburg @ 20 k (< 12.5)	Overlay Cycles (Avg.) (> 750)	Average OT Peak Loads (lb)
1	6.5%	96.5%	18.7	3.2 mm	861	600
2	***6.7%***	***97.0%***	***18.7***	***4.3 mm***	***1 000***	***774***
3	6.9%	97.5%	18.7	5.0 mm	938	640
4	7.1%	98.0%	18.7	5.4 mm	1 000	612

Table I-3. Hamburg and Overlay Results – Valero PG 76-22.

#	Asphalt-Binder Content	Corresponding Lab Density	VMA (>17)	Hamburg @ 20 k (< 12.5)	Overlay Cycles (Avg.) (> 750)	Average OT Peak Loads (lb)
1	6.5%	96.5%	19.0	4.5 mm	736	580
2	6.7%	97.5%	18.1	4.9 mm	951	630
3	6.9%	98.0%	18.1	5.7 mm	956	553
4	7.1%	98.4%	18.4	7.4 mm	1 000	563

Table I-4. Hamburg and Overlay Results – Martin PG 76-22.

#	Asphalt-Binder Content	Corresponding Lab Density	VMA (>17)	Hamburg @ 20 k (< 12.5)	Overlay Cycles (Avg.) (> 750)	Average OT Peak Loads (lb)
1	6.5%	96.7%	18.4	2.9 mm	132	815
2	6.7%	98.5%	17.2	3.6 mm	169	770
3	6.9%	98.9%	17.4	4.1 mm	173	696
4	7.1%	99.0%	17.6	4.4 mm	173	835

Figure 3 Balanced mix design results for a CAM mix from the Bryan District. Substantially different results were obtained by simply changing the source of the PG 76-22 binder.

HMA Mixes Used for ALF-APT Testing.

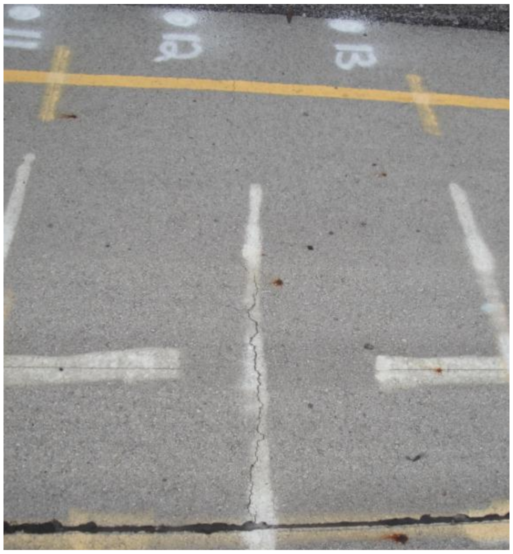
Item	TG Method	Balanced H-O Method
Mix designation	Control	Modified
Mix Type	Type C	Type C
Materials	PG 76-22 (Valero) + Limestone (Brownwood, TX)	PG 76-22 (Valero) + Limestone (Brownwood, TX)
Design OAC	4.3%	5.2%
Corresponding TGC lab density (96% ≤ TGC < 98%	96.0%	97.5%
VMA (≥ 14%)	14.0	14.2%
Hamburg rutting (≤ 12.5 mm)	4.7	7.0
Overlay crack cycles (≥ 300)	90	600
ITD (85 ≤ IDT ≤ 200 psi)	165 psi	130 psi
APT placement	Control sections	Modified sections

Summary of Lab and Field APT Test Results.

Item	Rutting		Reflective Cracking	
	Control 1	Modified 1	Control 2	Modified 2
Lab-molded (lab design) - lab	4.7 mm	7.0 mm	105 (< 300)	330 (> 300)
Plant-mix from test site - lab	2.3 mm	4.1 mm	041 (< 300)	446 (> 300)
Field APT performance after 75 000 ALF load passes	7.7 mm	11.8 mm	Cracked @ 75K	No cracking after 211K passes

Figure 4 APT results from Louisiana ALF testing.

These results verify that the OT results are good indicators of reflection cracking performance where the control mix cracked after 75,000 load applications and the modified mix lasted more than 200,000 equivalent loads. The HWTT results confirmed it ability to control rutting.



a) Initiation of reflection cracking **b) Forensic investigation of rutting**

C) Condition assessment under APT

Figure 5 APT test arrangement and photographs of pavement condition.
Details provided in "APT-ALF testing summary report."

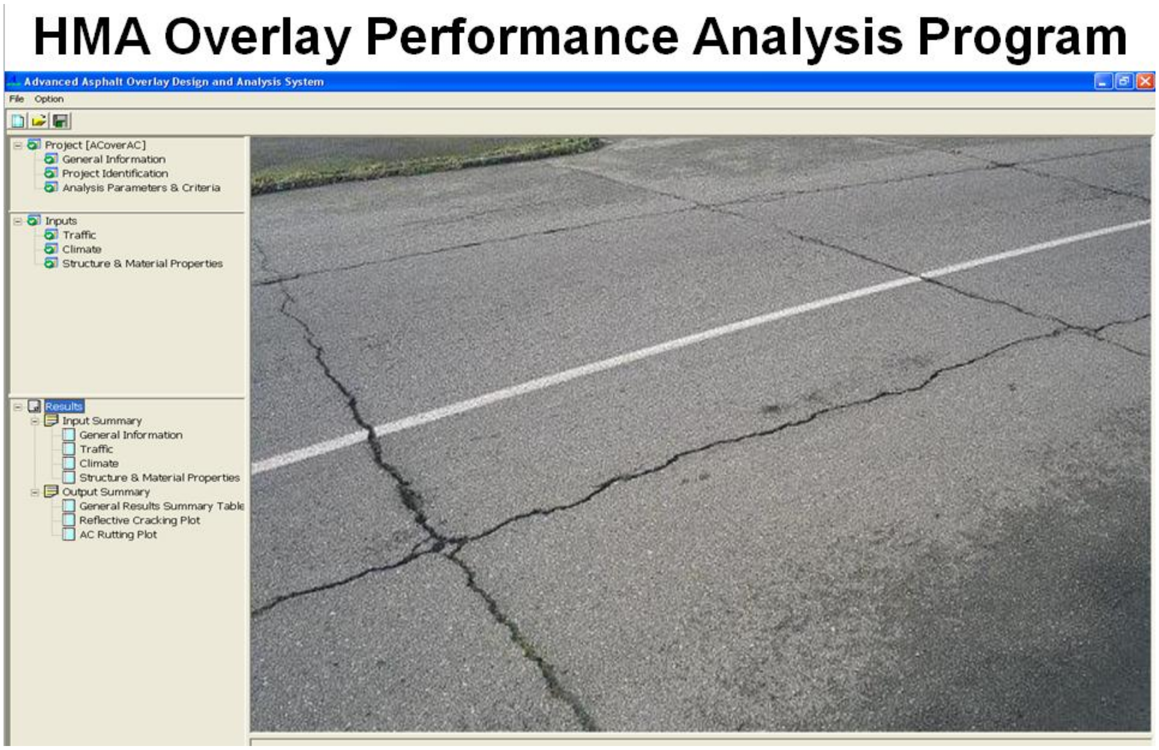


Figure 6 Overlay Life Prediction software developed in Project 5123 (PI Dr. F-Zhou).

- Reflection cracking model

$$\Delta c = A(K)^n \Delta N$$

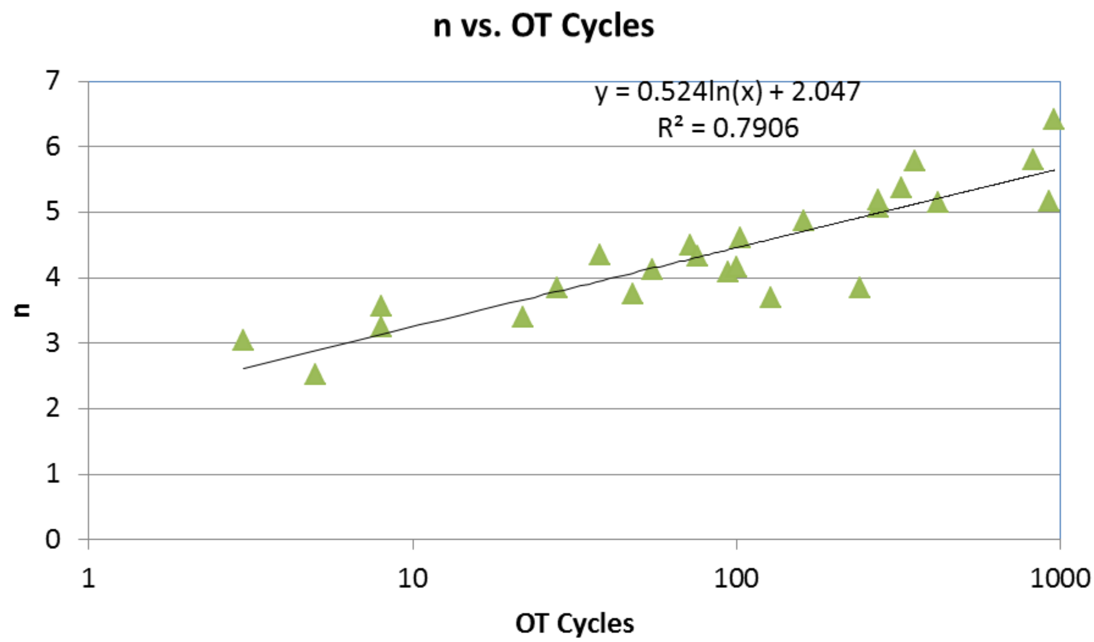
  - N= number of load repetitions
  - *A*, *n*= fracture properties of HMA mixtures
  - K= stress intensity factor (regression equations)

- Model inputs: *A* and *n* from Overlay tester

Figure 7 Basic Reflection Cracking Model, where K is a function of pavement structure, severity of damage in terms of LTE and climate.

No.	Mixes	OT Cycles @0.025"	A @0.017"	n @0.017"
1	US87 S1-RAS mix (dense-graded mix)	94	1.3677E-06	4.0833
2	US87 S2-RAS mix (dense-graded mix)	48	7.8997E-06	3.7445
3	SH143-RAP mix (dense-graded mix)	5	2.2461E-03	2.5136
4	SH359-RAP mix (dense-graded mix)	3	7.6451E-04	3.0370
5	Loop820-RAP/RAS/WMA (dense-graded mix)	8	3.9572E-05	3.2465
6	Dallas-Ty B mix (dense-graded mix)	22	6.2163E-05	3.3900
7	Dallas-Ty C mix (dense-graded mix)	128	7.9056E-06	3.7014
8	MnRoad Cell2 (Superpave mix)	356	1.1148E-08	5.7841
9	MnRoad Cell16 (Superpave mix)	100	2.4601E-06	4.1542
10	PG64-34 TamKo RAS-5.2AC	322	2.9004E-08	5.3648
11	PG58-34 TamKo RAS-5.2AC	420	1.0015E-07	5.1560
12	Odessa P. Mix S4 (dense-graded mix)	161	7.3597E-08	4.8755
13	Buda PG64-34-5% RAS mix (dense-graded mix)	72	6.6989E-07	4.4910
14	Buda PG58-34-5% RAS mix (dense-graded mix)	274	6.1648E-08	5.0803
15	NCAT N9-1 (Superpave mix)	55	8.1553E-07	4.1200
16	NCAT N9-2 (Superpave mix)	8	6.4143E-06	3.5650
17	PG64-22 15%RAP (dense-graded mix)	76	1.0020E-06	4.3220
18	PG64-28 15%RAP (dense-graded mix)	240	3.9073E-06	3.8385
19	PG64-34 15%RAP(dense-graded mix)	926	5.8813E-08	5.1721
20	Paris-PG58-34 15%RAP (dense-graded mix)	274	8.3199E-08	5.1880
21	Amarillo-20%RAP-I40 (dense-graded mix)	103	3.8371E-07	4.6076
22	SMA PG70-28 0RAP AC 6.6	827	5.1984E-09	5.7962
23	SMA PG70-28 0RAP AC 6.0	957	1.2871E-09	6.4071
24	NCAT S6-1 (Superpave mix)	28	2.6396E-06	3.8433
25	NCAT N10-1 (Superpave mix)	38	2.4574E-07	4.3536

Figure 8 Lab testing completed in Project 6092 (PI Dr. F-Zhou) to establish the relationship between OT cycles and *A* and *n* parameters.



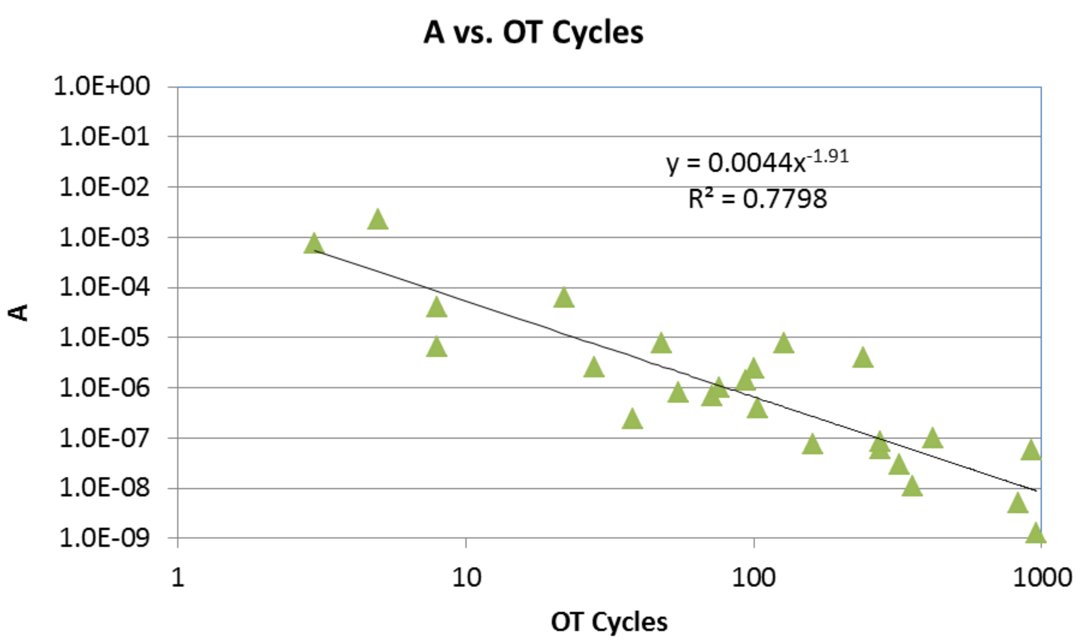


Figure 9 Graphical relationship between n and A and Overlay tester cycles to failure.

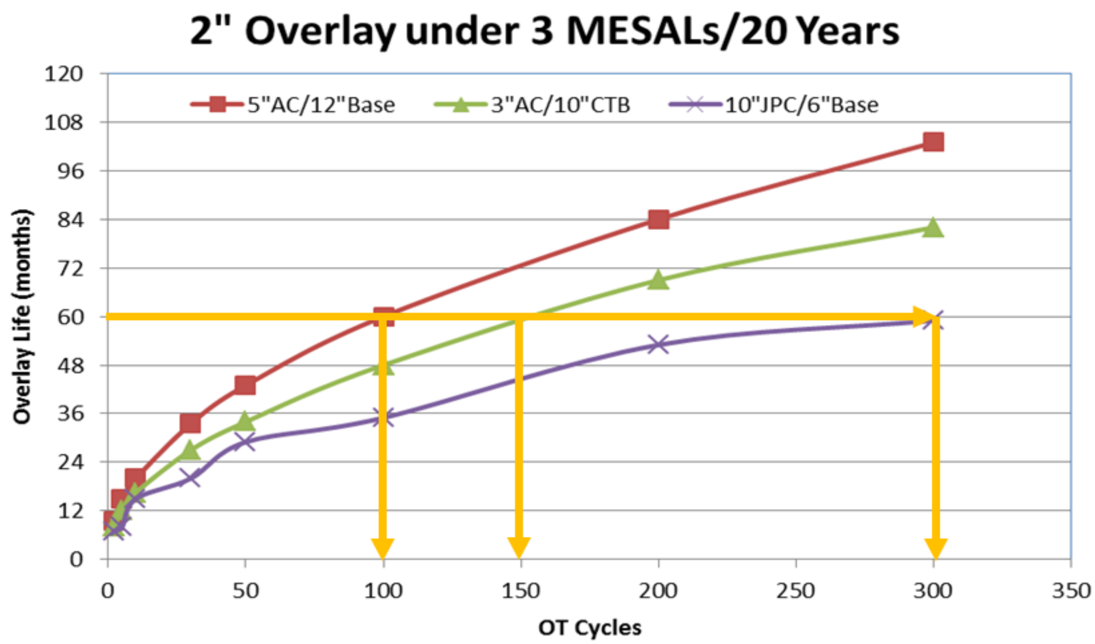


Figure 10 Predicted Overlay life for design cases where reflection cracking is a concern (for this case over the CTB the required design OT cycles to failure would be 150).

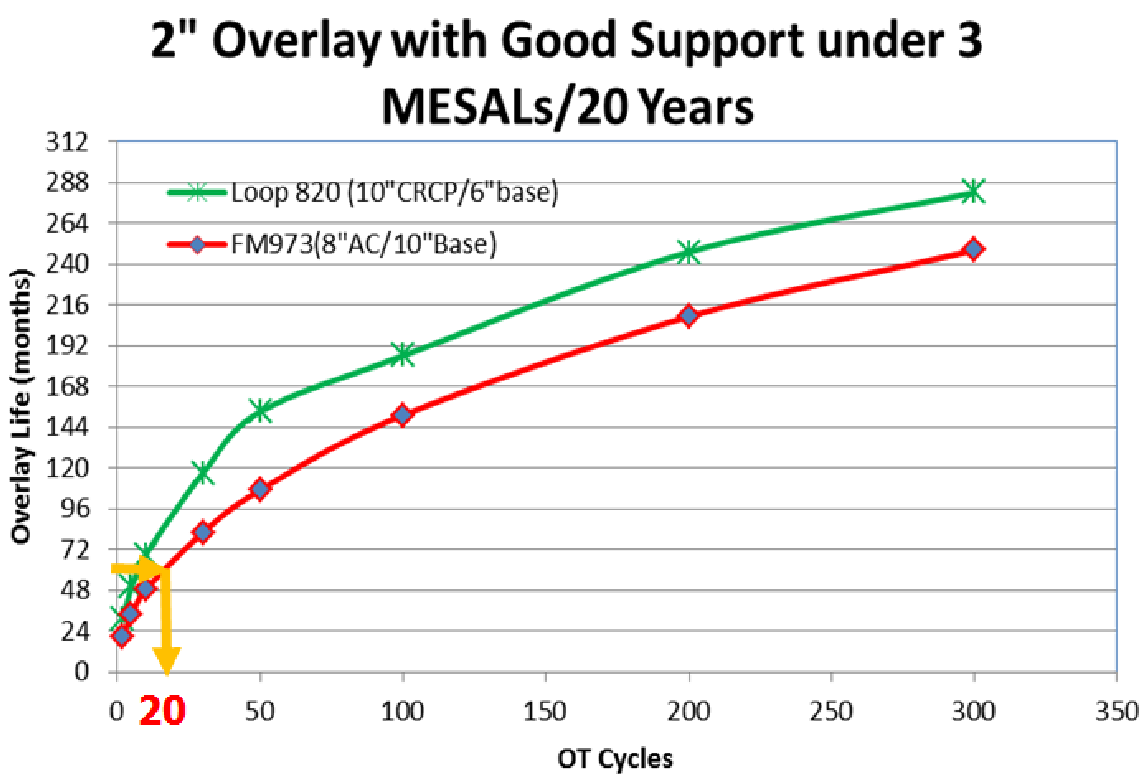
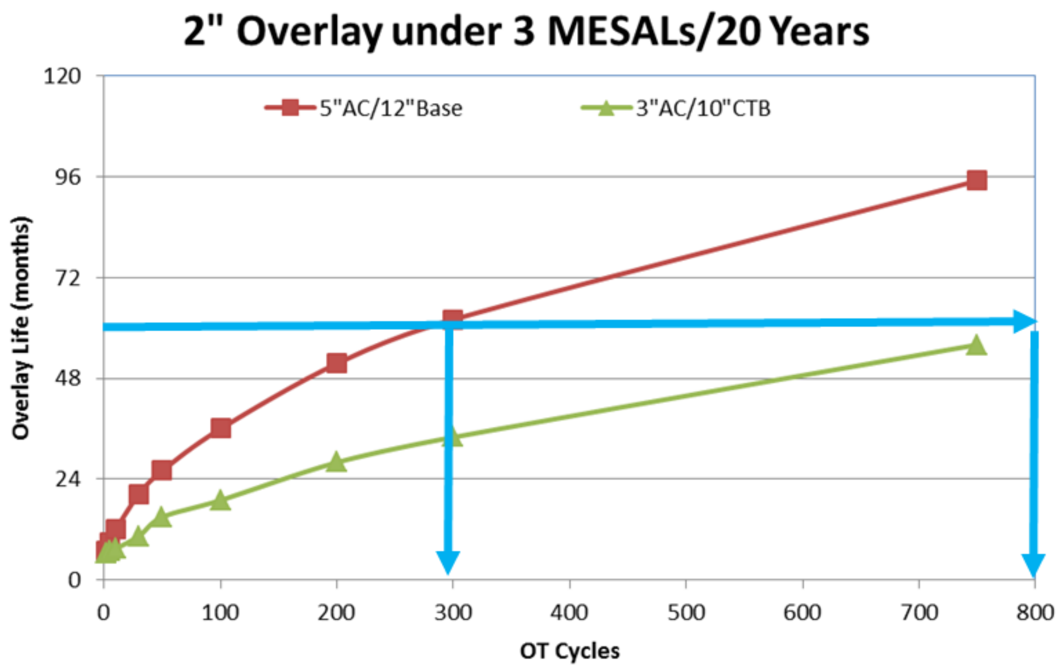


Figure 11 Predicted Overlay life for the same case as Figure 10 but where the lower support conditions are very good.

Amarillo



McAllen

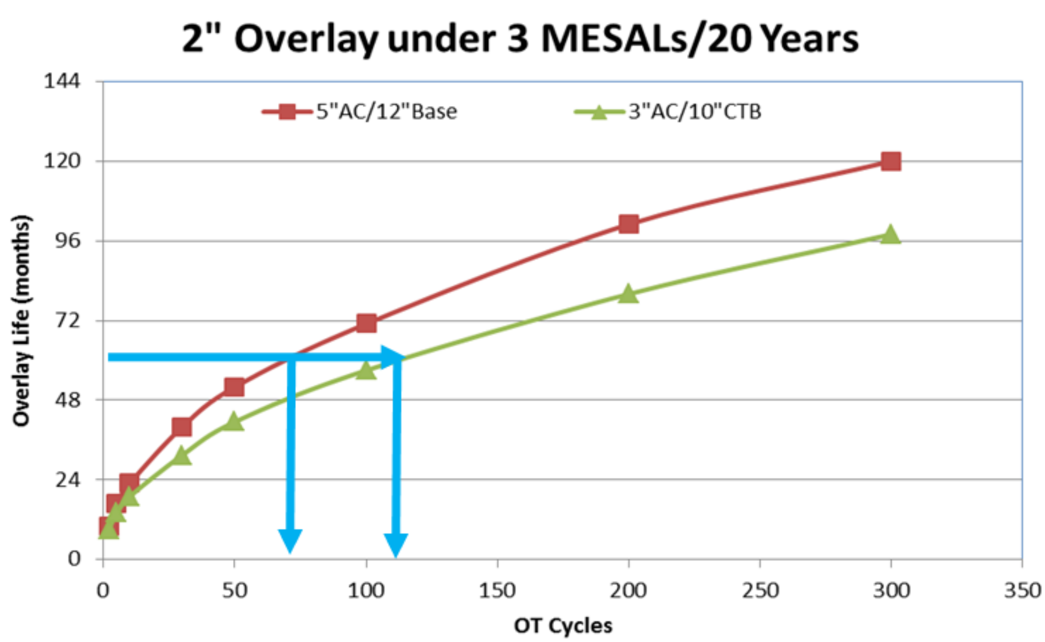


Figure 12 Influence of climate on required OT life to last 5 years. For same conditions require 70 cycles in Pharr and 300 cycles in Amarillo.