WELCOME TO THE

PvD

AASHTOWare Pavement

ME Design

WEBINAR

- This Webinar is being presented from a computer with a resolution of 1280 X 1024.
- Using a similar setting on your machine may improve your viewing experience.
- The webinar will start at 10:00am Central/11:00am Eastern

Top-Down Cracking Enhancement Released in Version 2.6.0

25 June 2020

TDC Enhancement Released with Version 2.6.0

Moderator:

- John Donohue, Missouri Department of Transportation; Chair

Presenters:

- Harold Von Quintus, ARA
- Wouter Brink, ARA,
- Chad Becker, ARA

Presentation will be available for viewing on the ME-Design Resource website: http://www.me-design.com

Process for Enhancing the Software:

1. Suggested revisions are received from users and AASHTO members.

2. Pavement ME Design Task Force monitors on-going/completed NCHRP, FHWA, and pool fund projects applicable to the MEPDG.

3. Pavement ME Design Task Force members review and prioritize all potential suggested revisions and enhancements.

Pavement ME Task Force Members

1. John Donahue, P.E.; Missouri DOT, Chairperson
2. Ryan Fragapane, AASHTO Project Manager
3. Clark Morrison, P.E., North Carolina DOT, Vice-Chair
4. Felix Doucet; Quebec Transportation
5. Robert Shugart, P.E.; Alabama DOT
6. David Holmgren, P.E.; Utah DOT
7. Patrick Bierl, P.E.; Ohio DOT
8. Jeff Neal, P.E.; Kansas DOT,
9. Tara Liske; TAC Liaison
10. Tom Yu, P.E.; FHWA Liaison
11. Travis Tackett; Florida DOT; T&AA Liaison

TDC Enhancement Released with Version 2.6.0

- Phones are being muted.
- Please post your questions in the Q&A box. This can be accessed by clicking on the Webex Q&A button.
- The presenters will answer all questions at the end of the webinar/demonstration as time permits.
- Questions not answered because of time, will be responded to separately.

TDC Enhancement Released with Version 2.6.0

Before we get started:

Poll 1: Questions 1 and 2

TDC Enhancement Released with Version 2.6.0

Outline of todays webinar:

1. Introduction
2. Additional Inputs and Outputs
3. Key Points and Methodology
4. Calibration
5. Examples

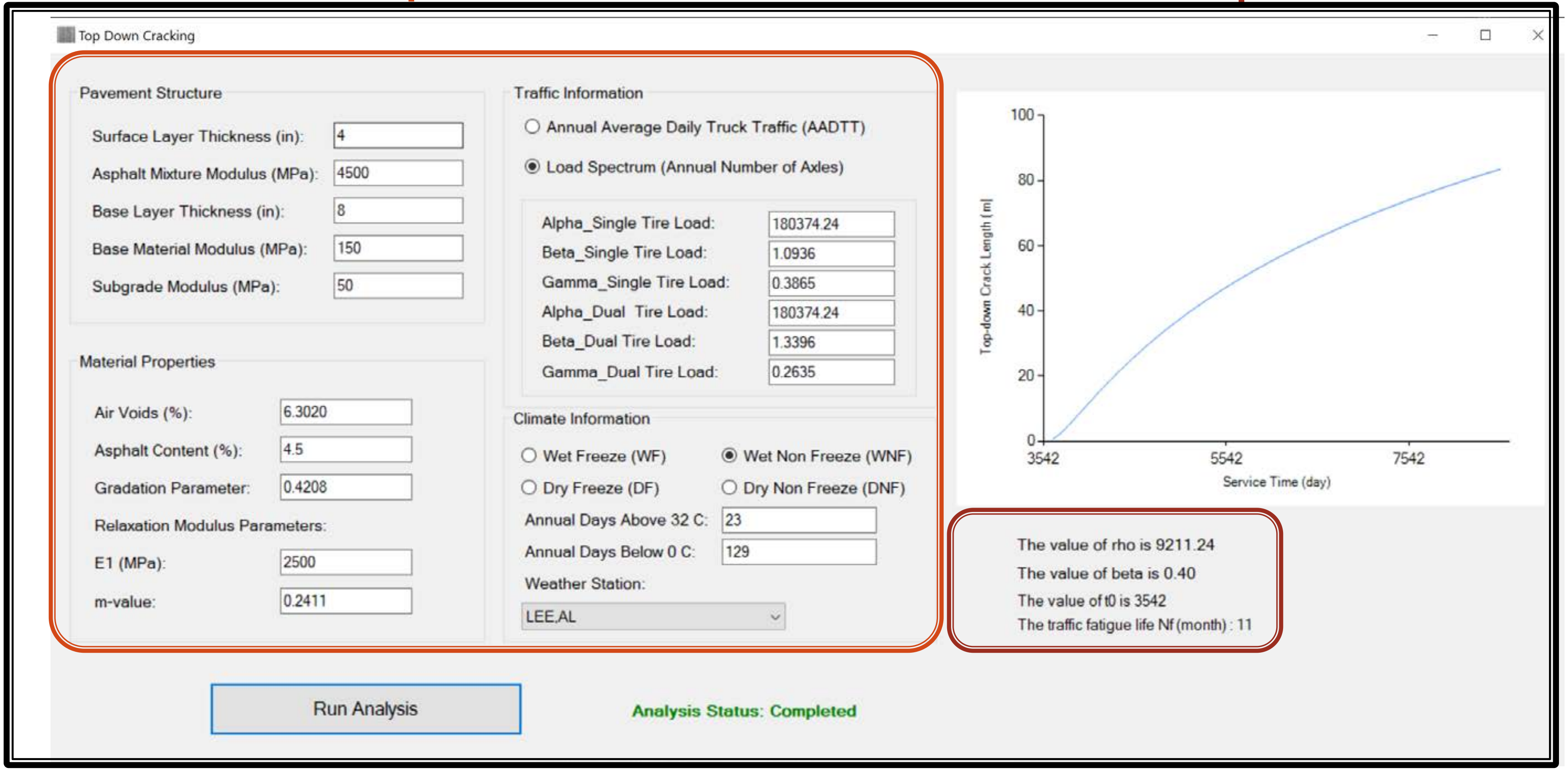
Note: The 3rd Edition of the Manual of Practice is integrated in Version 2.6.0.

NCHRP 1-52 Top-Down Cracking (TDC) Model

- Title: A Mechanistic-Empirical Model for Top-Down Cracking of Asphalt Pavement Layers
- Agency: Texas A&M Transportation Institute; The Texas A&M University System
- Authors:
  - Robert L. Lytton, P.I.
  - Xue Luo
  - Meng Ling
  - Yu Chen
  - Sheng Hu
  - Fan GU

NCHRP 1-52 Software Program

Inputs Outputs



NCHRP 1-52 TDC Model

- As a reminder, current model in PMED:
  - Fatigue strength, bending beam based, like the bottom-up alligator fatigue cracking model.
- NCHRP 1-52 model integrated in PMED:
  - Fracture mechanics based, similar to the transverse and reflection cracking model.

NCHRP 1-52 TDC Model

Staff:

- Engineers: Dinesh Ayalla, Wouter Brink
- Software: Brendan Neunaber, Yanbin Zhang.

SME:

- Robert Lytton, P.E.

NCHRP 1-52 TDC Model

- In addition, the LTPP program and database are a valuable source of data that make the model enhancements possible.
- A thank you to all of the agencies that invested their time, resources, and funds into the LTPP program, as well as a thank you to FHWA for setting up and administering the program and database.

Outline

1. Introduction
2. Additional Inputs and Outputs
3. Key Points and Methodology
4. Calibration
5. Examples

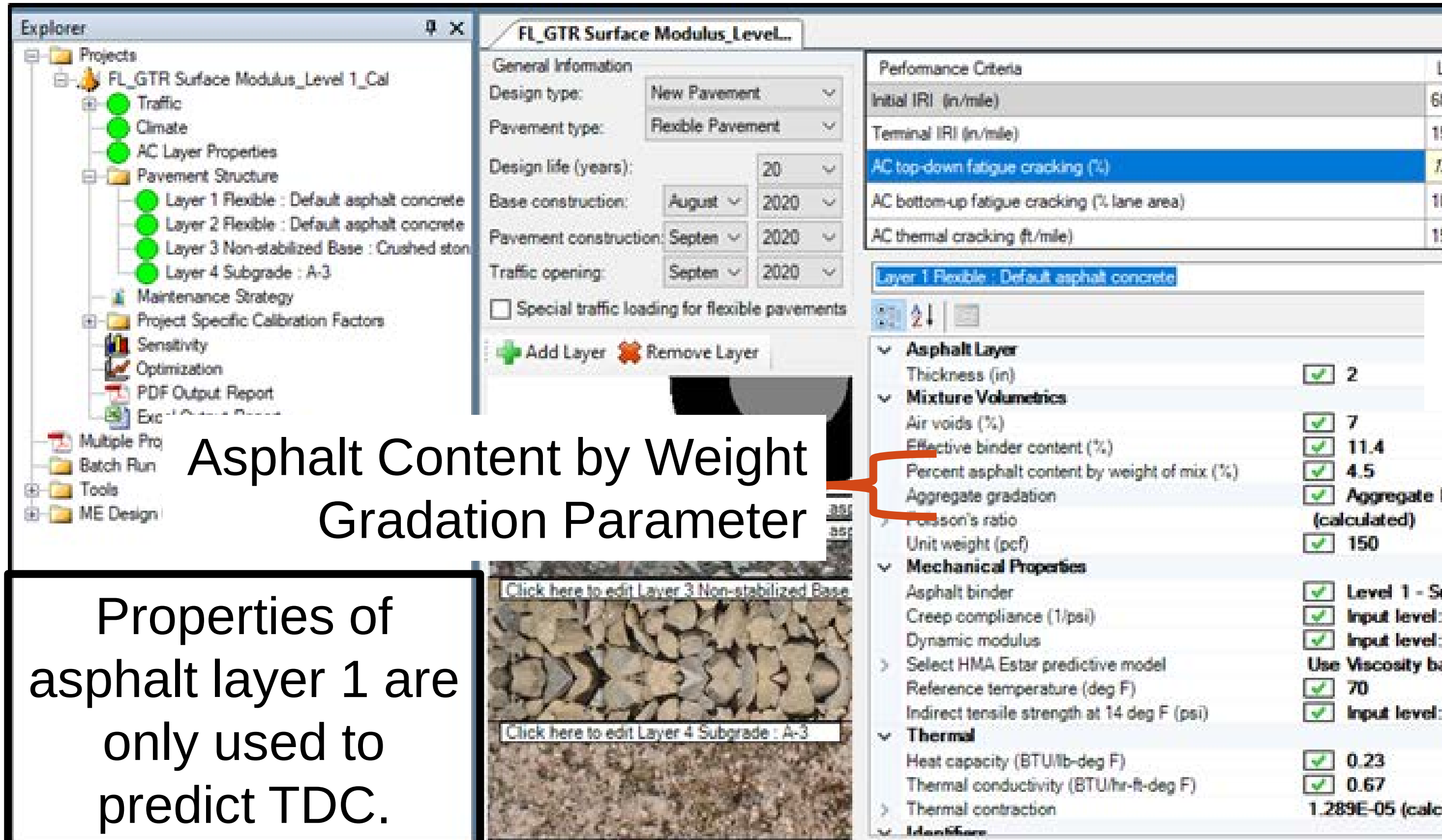
What different inputs are needed and what new outputs can be reviewed relative to TDC for design?

Additional Inputs and Outputs

- Added or New Inputs
  1. Asphalt Content by Weight
  2. Gradation Parameter

- Added or New Outputs
  1. Crack Depth over Time
  2. Area of Cracking over Time

New Asphalt Mixture Inputs

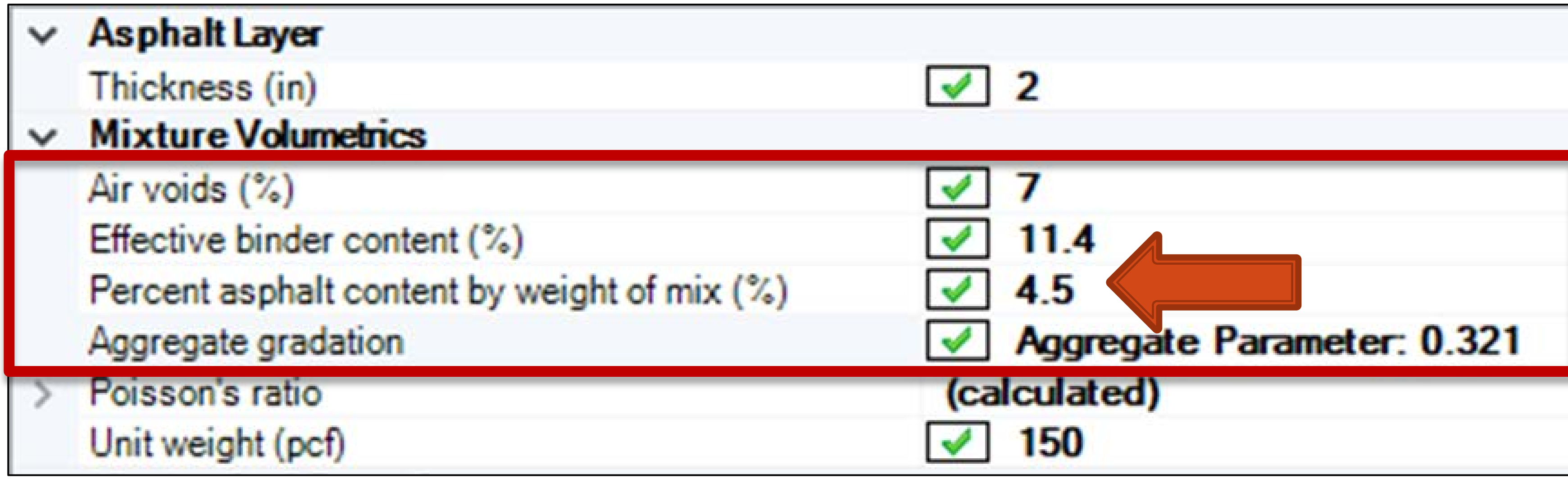


Under Mix Volumetrics

Asphalt Content by Weight
Gradation Parameter

Properties of asphalt layer 1 are only used to predict TDC.

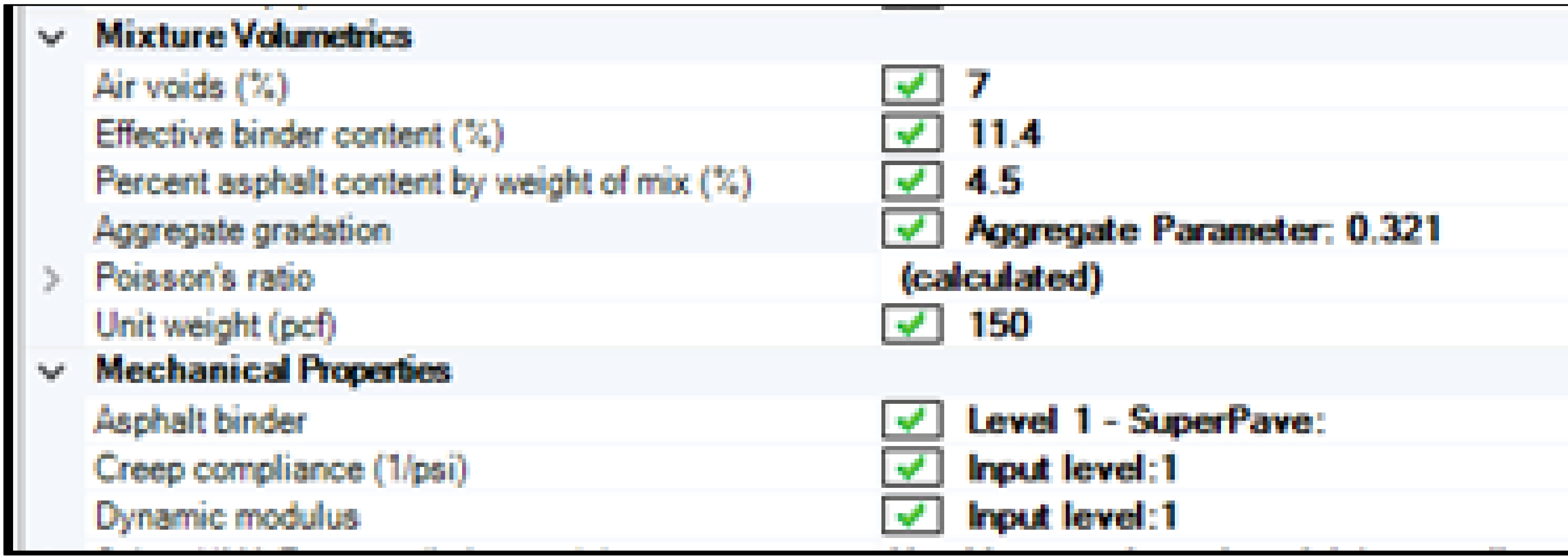
Asphalt Content by Total Weight



User needs to ensure the percent asphalt content by total weight is compatible with the percent effective asphalt content by volume, air voids, and gradation.

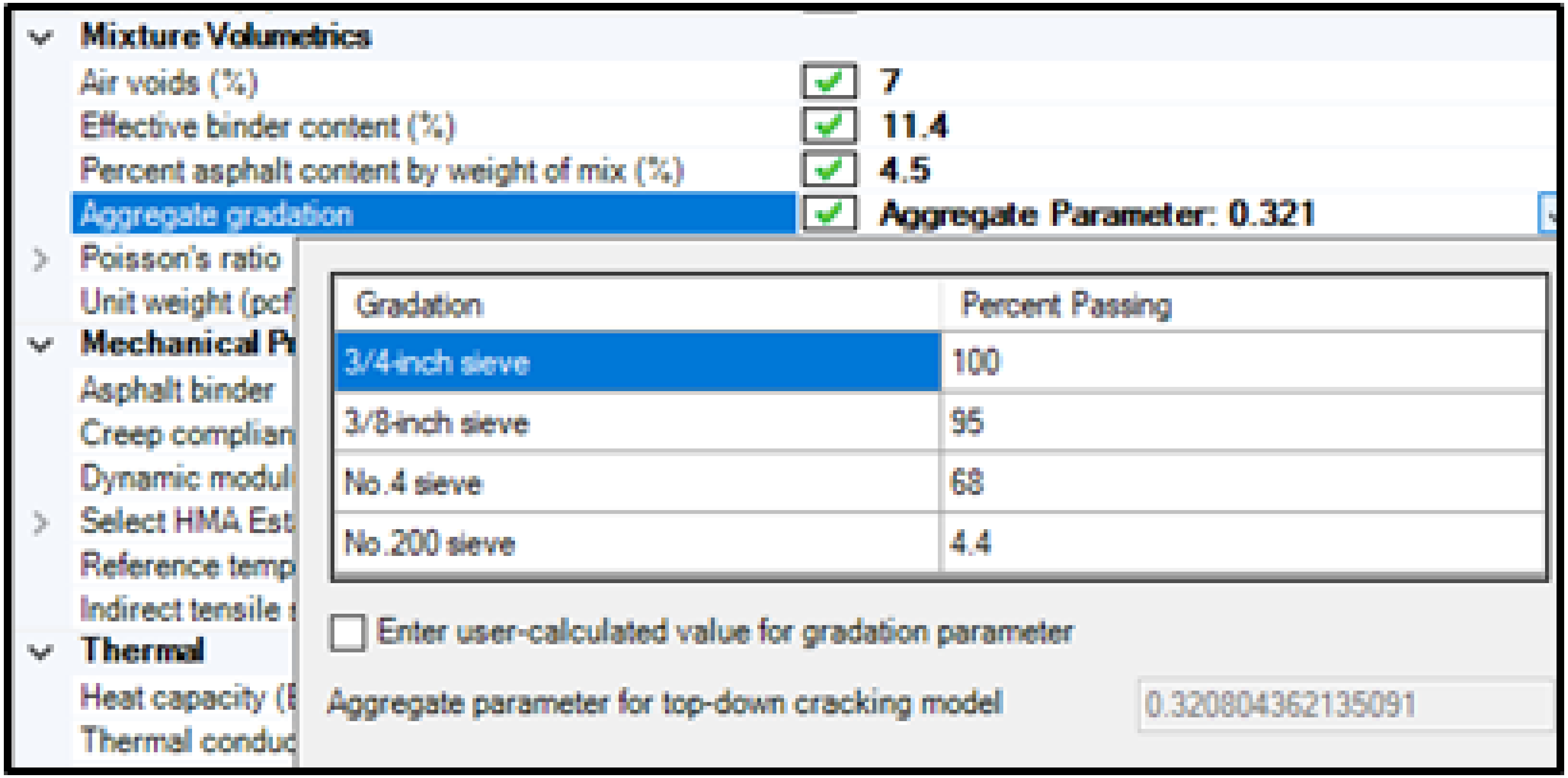
Gradation Parameter

- Gradation parameter is calculated from the gradation.
- Gradation/sieve sizes are now entered under Mixture Volumetrics screen.



Sieve sizes are now entered under the Mixture Volumetric property screen.

Gradation Parameter



No additional inputs are needed; the gradation parameter is calculated from the current sieve sizes.

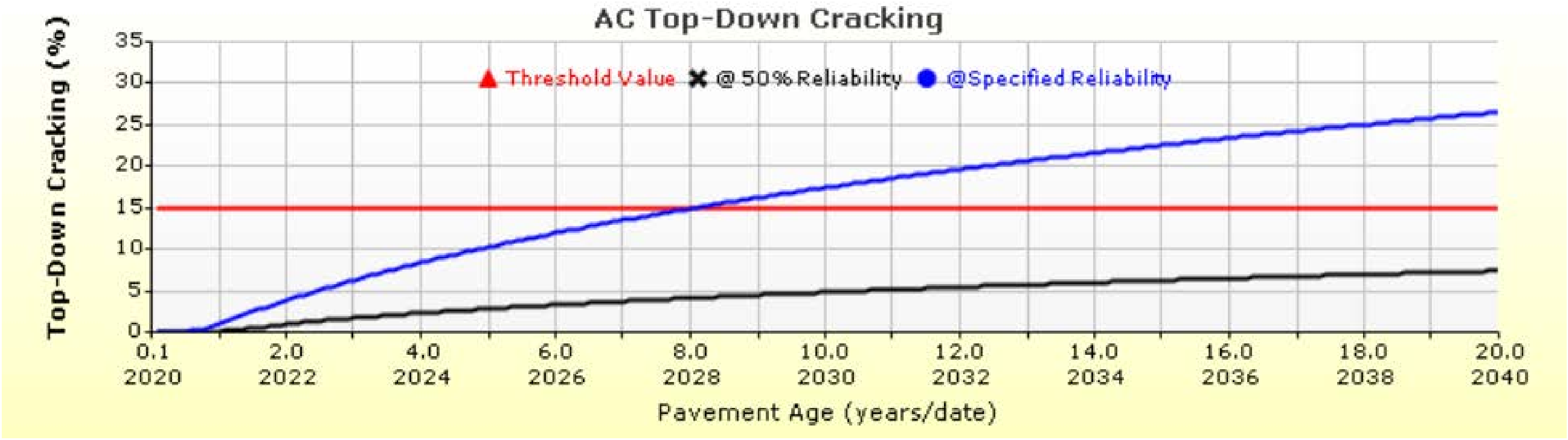
TDC Outcome

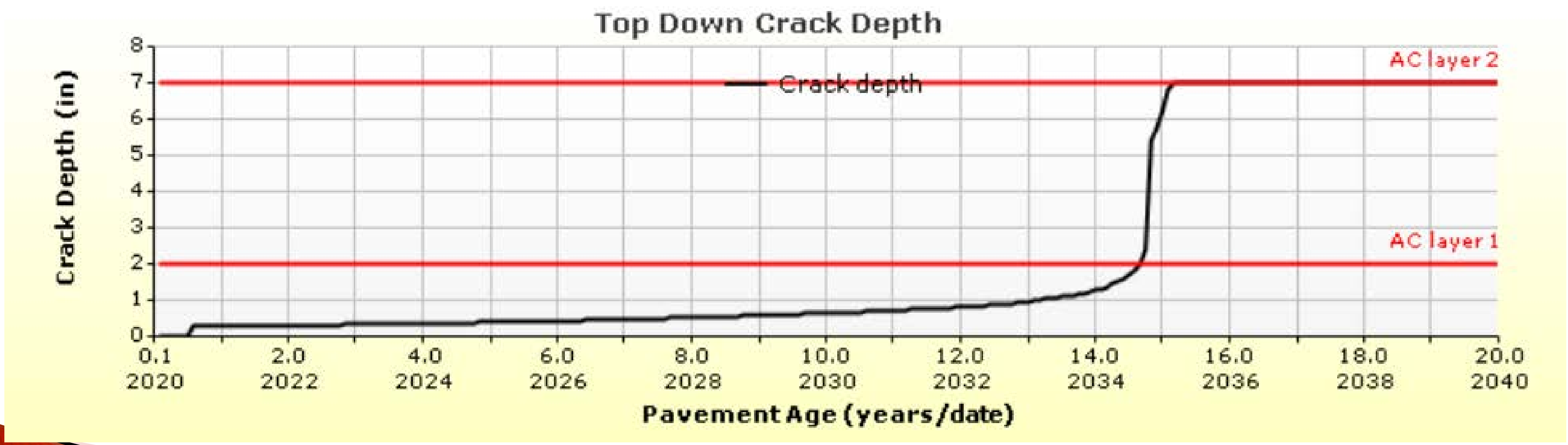
Distress Prediction Summary					
Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	150.00	144.94	90.00	92.64	Pass
Permanent deformation - total pavement (in)	0.50	0.22	90.00	100.00	Pass
AC bottom-up fatigue cracking (% lane area)	15.00	1.45	90.00	100.00	Pass
AC thermal cracking (ft/mile)	1500.00	2930.50	90.00	16.90	Fail
AC top-down fatigue cracking (%)	15.00	26.55	90.00	69.47	Fail
Permanent deformation - AC only (in)	0.50	0.01	90.00	100.00	Pass

TDC Prediction:

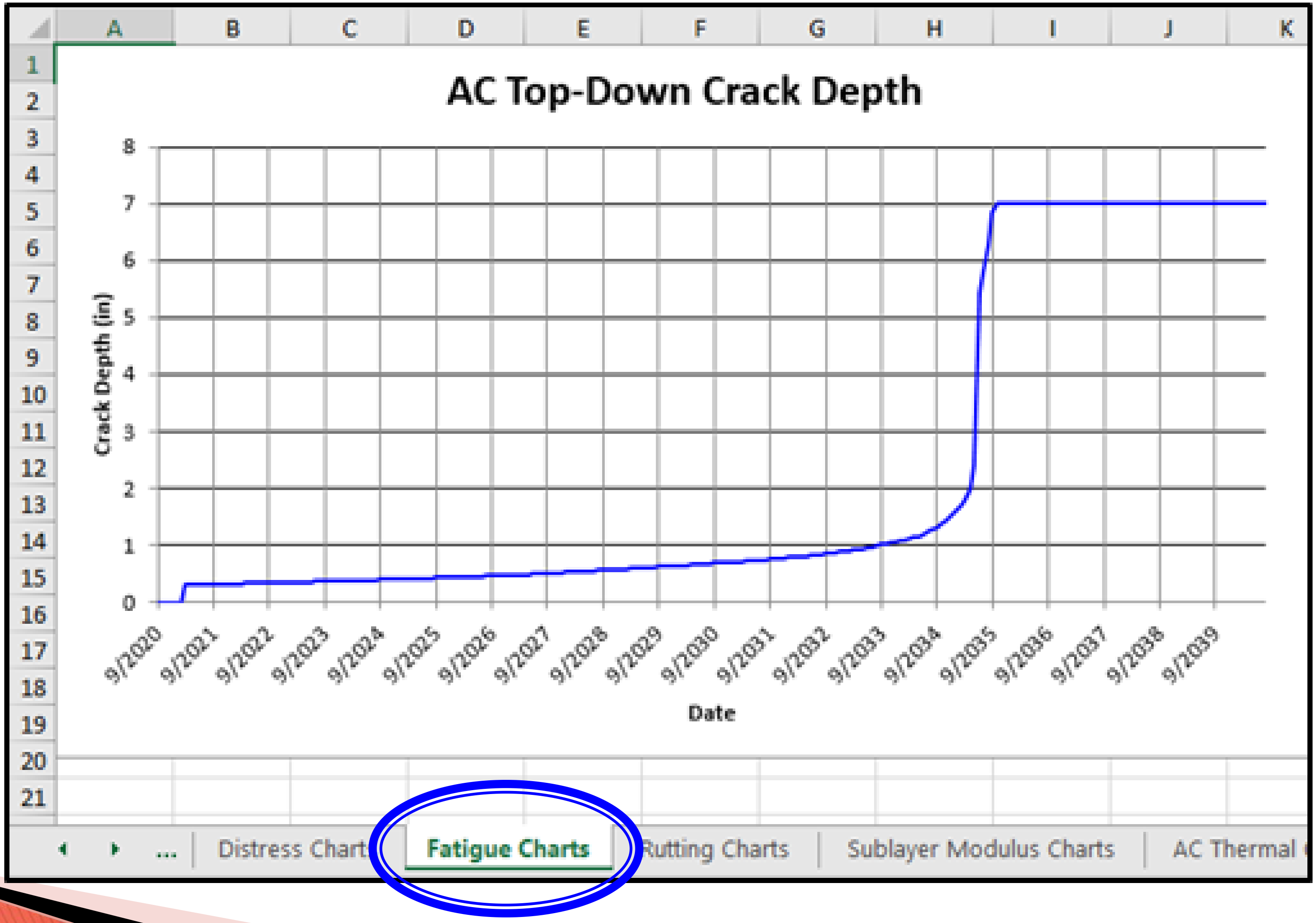
- Version 2.5.5 and earlier – feet per mile.
- Version 2.6.0 – percent total lane area

TDC Outcome; PDF Report





TDC Outcome; Excel Spreadsheet



Outline

1. Introduction
2. Additional Inputs and Outputs
3. Key Points and Methodology
4. Calibration
5. Examples

How TDCs are predicted and are there differences between the NCHRP 1-52 software and the features included in the PMED software?

AASHTOWare Pavement ME Design AASHTO

TDC Prediction Model

NCHRP 1–52 TDC model features and MEPDG revisions.

NCHRP 1-52 Feature	Pavement ME Design
1. TDC assumed to be longitudinal cracks in wheel path.	TDC not restricted to only longitudinal cracks.
2. Crack length or wheel path length (length per 300 meters) was the outcome and included in the calibration.	Percent total lane area with TDC was added and included in the calibration.

This revision was defined through calibration using LTPP sites.

TDC Prediction Model

NCHRP 1-52 TDC model features and MEPDG revisions.

NCHRP 1-52 Feature	Pavement ME Design
3. Only applicable to new flexible pavement design.	Applicable to all design strategies.
4. Limited to a 3-layer system: AC over granular base, on subgrade.	Decision functions or rules included converting multiple-layer system to a 3-layer system.
5. Reliability is not considered in the procedure.	Reliability is considered; standard deviation equation was derived.

TDC Prediction Model

NCHRP 1-52 TDC model features and MEPDG revisions.

NCHRP 1-52 Feature	Pavement ME Design
6. Includes ability to consider single tires.	Default distribution between single and dual tires added.
7. Crack propagation calculated.	Crack propagation was added, but only for TDC.
8. Does not predict crack severity but crack width.	Crack width added to predict crack depth.

Crack width was not included in the calibration.

TDC Prediction Model

NCHRP 1-52 TDC model features and MEPDG revisions.

NCHRP 1-52 Feature	Pavement ME Design
9. Temperature gradient only needed for depth of crack propagation.	Temperature gradient considered through entire pavement structure.
10. The thicker the AC layer, the lower the TDC prediction and the longer the time before TDC occurs. More TDC for the thinner structures.	TDC is more dependent on AC mixture properties, than on the structural layer properties. For thin asphalt layers difficult to determine where cracks initiated.

TDC Prediction Model

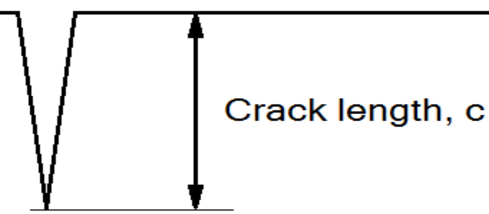
NCHRP 1–52 TDC model features and MEPDG revisions.

NCHRP 1-52 Feature	Pavement ME Design
11. The time to surface-initiated cracks is much later in life of AC pavement (after 10 years) for many conditions.	Longitudinal cracks predicted shortly after construction under certain conditions.
12. All computations are in SI units. Inputs include a mix of English and SI units.	One set of units as inputs, but computations are made in SI and English units.

TDC Prediction Model, NCHRP 1-52

- Fracture mechanics based model to calculate incremental crack length (depth) due to repetitive traffic loads using Paris' law.
- Two part prediction methodology: crack initiation and propagation.
- Calculate stress intensity factors due to single and dual tire loads and growth of crack length for each month in pavement design life.

Crack geometry is important.



- Terminology: Crack length vs. crack depth
- Crack width defines crack depth.

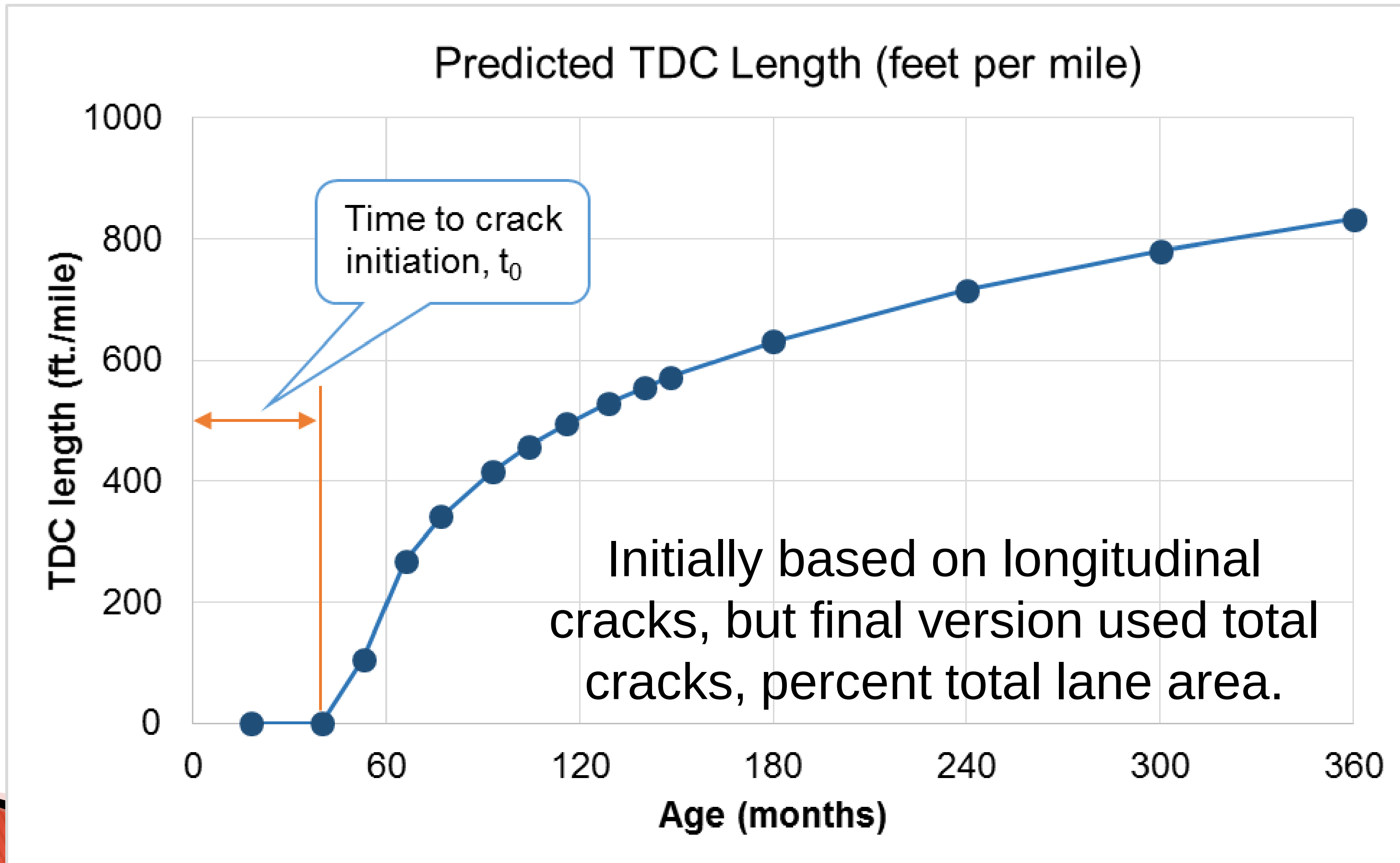
TDC Prediction Model, NCHRP 1-52

Crack Initiation:

- Crack initiation – Depth of crack is 7.5 mm (0.3 in).
- Time to crack initiation, t_0 – Calculated from regression equation as a function of AADTT, climatic data and asphalt material properties
- Number of months to failure, N_f – Time required (in months) for crack to grow from 7.5 mm to 40 mm
- N_f is used to determine scale (maximum TDC length) and shape (rate of growth of TDC) of top-down cracking distress curve.

TDC Prediction Model, NCHRP 1-52

Crack initiation defined from the LTPP test sections; t_0 was back-casted for each LTPP site with TDC.



TDC Prediction Model, NCHRP 1-52

Time to crack initiation t_0 (calculated in days):

$$t_0 = \frac{\boldsymbol{K_{L1}}}{1 + e^{\boldsymbol{K_{L2}} 100(a_0/2A_0) + \boldsymbol{K_{L3}}(HT) + \boldsymbol{K_{L4}}(LT) + \boldsymbol{K_{L5}}(Log_{10}AADTT)}}$$

$a_0/2A_0$ = Energy parameter.
HT = Annual number of days above 32ºC.
LT = Annual number of days below 0ºC.
K_{L1},K_{L2},K_{L3},K_{L4},K_{L5} = Calibration coefficients.

$$a_{0/2A_0} = 0.1796 + 1.5x10^{-5}E_1 - 0.69m - 7.169x10^{-4}H_a$$

E_1, m= Relaxation modulus power law function parameters for aged asphalt.
H_a = Total asphalt layer thickness.

TDC Prediction Model, NCHRP 1-52

- Crack depth tied to crack width at surface.
- Crack severity included in the LTPP database, but not crack width.


TDC Prediction Model, NCHRP 1-52

Crack Propagation:

1. Similar to reflection cracking and transverse cracking prediction models.
2. Except the formation of micro-cracks and crack propagation is modeled using a modified Paris law.

$$\frac{dc}{dN} = A'(J_R)^{n'}$$

C = Crack length or depth, dc is the change or growth in crack depth.
N = Number of load cycles.
J_R = Pseudo J-integral.
A', n' = Fracture properties of the asphalt mixture.

TDC Prediction Model, NCHRP 1-52

Pseudo J-integral is defined as the increment in dissipated work per unit crack surface area and related to the stress intensity factors.

$$J_R = \frac{1-\mu^2}{E_R}\left(K_I^2 + K_{II}^2\right) + \frac{1+\mu}{E_R}K_{III}^2$$

μ = Poisson's ratio.
E_R = Representative elastic modulus.
K_I = Stress intensity factor in mode I, opening model..
K_{II} = Stress intensity factor in mode II, in-plane shear.
K_{III} = Stress intensity factor in model III, out-of-plane shear.

TDC Prediction Model, NCHRP 1-52

Asphalt mixture fracture parameters.

$$n' = -9.00498 + 1.0627\varphi + \frac{2.8713}{m} - 40.8788\left(\frac{1}{E_1}\right) + 18.868\frac{P_b}{V_a + P_b}$$

$$A' = 10^{-(1.2752n+1.713)}$$

V_a = Average air voids, percent.
P_b = Average asphalt binder by total weight of mix percent.
E_1, m= Relaxation modulus power law function parameters for aged asphalt.
φ = Shape parameter of the aggregate power law function.

TDC Prediction Model, NCHRP 1-52

Area of TDC in terms of total percent lane area is calculated using a sigmoidal function:

$$L(t) = L_{Max} e^{-\left(\frac{\boldsymbol{C_1}\rho}{t - \boldsymbol{C_3} t_0}\right)^{\boldsymbol{C_2}\beta}}$$

- L_{Max} = Maximum area of top-down cracking, percent
- t = Analysis month in days.
- t_0 = Time to crack initiation in days.
- **C_1, C_2, C_3** = Calibration coefficients.
- ρ and β = Scaling shape parameters.

TDC Prediction Model, NCHRP 1-52

Scaling shape parameters:

- ρ is a function of climatic zone and number of months to failure, N_f.

$$\rho = \alpha_2 + \alpha_1 N_f$$

- β is a function of number of months to failure, N_f.

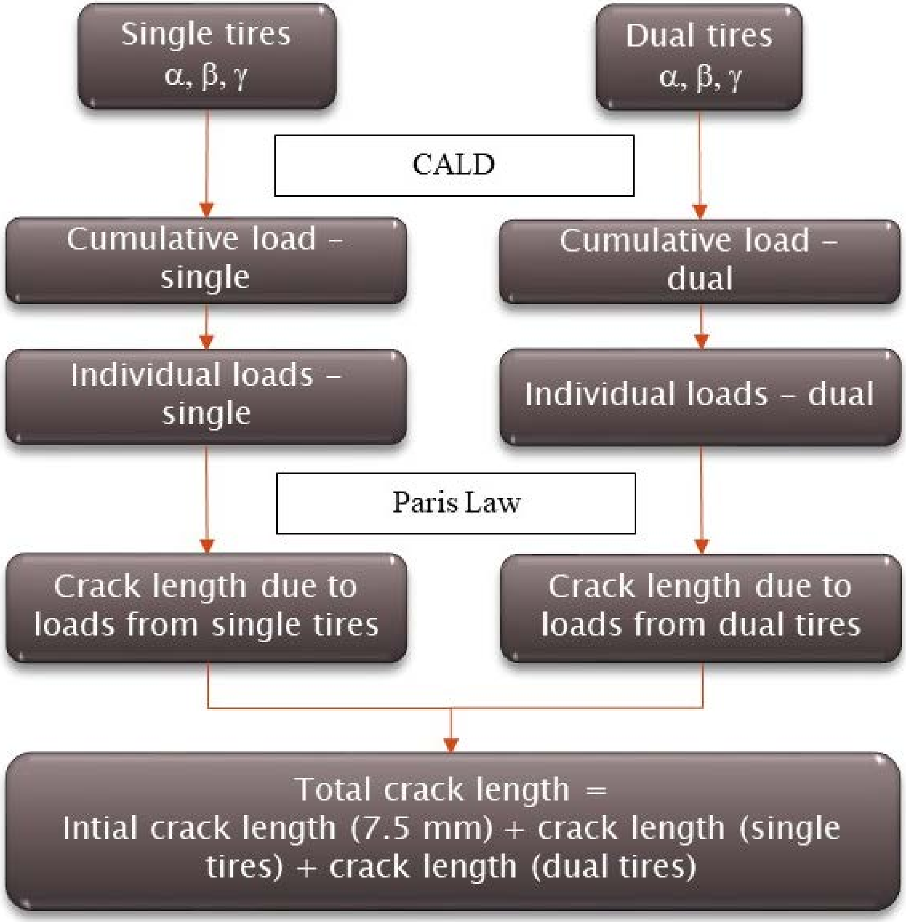
$$\beta = 0.4201\left(Log_{10} N_f\right)^{-1.2801}$$

N_f = Number of months to failure, defined at the time for the cracks to propagation to 40 mm.

α_1 and α_2 are defined by the climate.

TDC Traffic Parameters

- $AADTT_0$ (initial).
- Cumulative axle load distribution (CALD) parameters;
  Fitted curve parameters – alpha, beta and gamma for single and dual tires – ***calculated/derived from NALD inputs***.



TDC Traffic Parameters

Program assumes axles that have single tires and dual tires (via truck classification).

FHWA Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
4	Group 1	Group 3	Group 5	Group 7
5	Group 1	Group 3	Group 5	Group 7
6	Group 1	Group 4	Group 6	Group 8
7	Group 1	Group 4	Group 6	Group 8
8	Group 2	Group 4	Group 6	Group 8
9	Group 2	Group 4	Group 6	Group 8
10	Group 2	Group 4	Group 6	Group 8
11	Group 2	Group 4	Group 6	Group 8
12	Group 2	Group 4	Group 6	Group 8
13	Group 2	Group 4	Group 6	Group 8

Group	Axle Type	Tires	Tire Width (in.)
1	Single	Single	7.874
2	Single	Dual	8.740
3	Tandem	Single	7.874
4	Tandem	Dual	8.740
5	Tridem	Single	7.874
6	Tridem	Dual	8.740
7	Quad	Single	7.874
8	Quad	Dual	8.740

Axles Per Truck

Vehicle Class	Single	Tandem	Tridem	Quad
Class 4	1.62	0.39	0	0
Class 5	2	0	0	0
Class 6	1.02	0.99	0	0
Class 7	1	0.26	0.83	0
Class 8	2.38	0.67	0	0
Class 9	1.13	1.93	0	0
Class 10	1.19	1.09	0.89	0
Class 11	4.29	0.26	0.06	0
Class 12	3.52	1.14	0.06	0
Class 13	2.15	2.13	0.35	0

TDC Traffic Parameters

Cumulative axle load distribution (CALD) function

$$P(L) = \alpha e^{-e^{\beta - \gamma L}}$$

L is length of rectangular contact area, calculated as a function of tire inflation pressure, tire load and tire width.

PMED traffic inputs used to calculate CALD parameters:

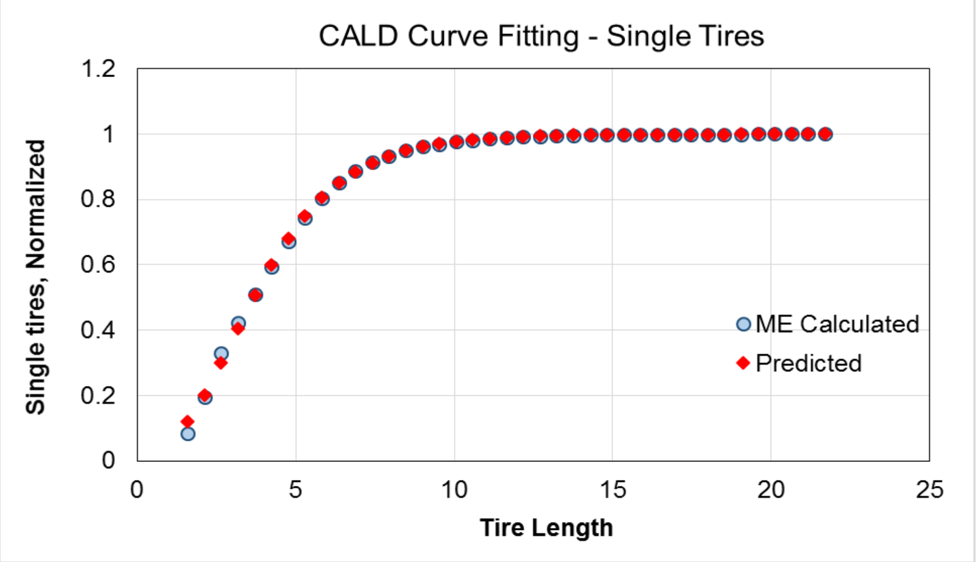
- Normalized axle load spectrum
- Truck class distribution
- Average no. of axles per truck
- Tire pressure

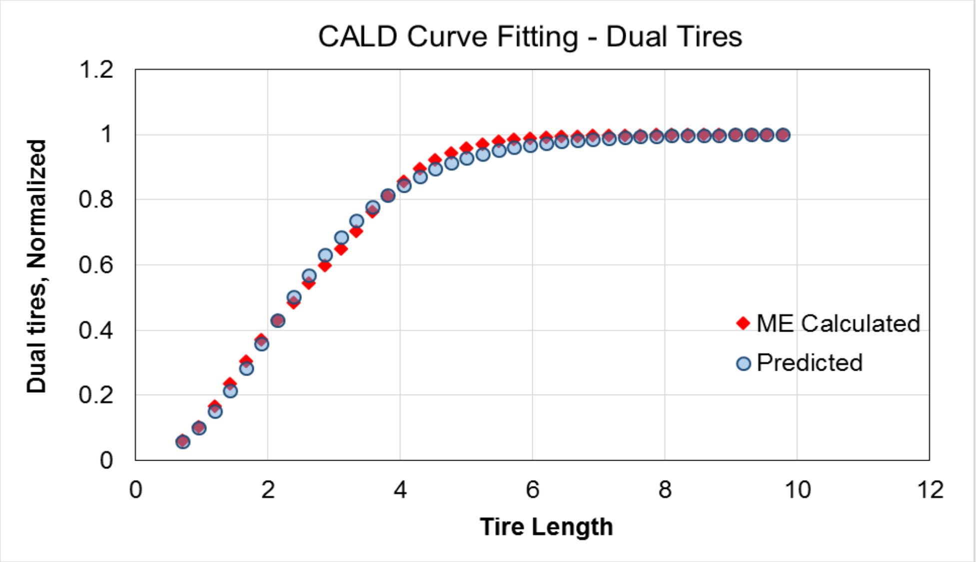
For axles with both single and dual tires.

TDC Traffic Parameters

Sample fitted curves for axle loads with single and dual tires.

No changes to traffic inputs; program assumes axles that have single tires and dual tires (via truck classification).





TDC Climate Parameters

- Hourly climatic data (HCD)
- Climatic zone (DF, DNF, WF, WNF)
- Number of days above 32°C and below 0°C

No changes required to climate inputs. Program calculates parameters needed from EICM outcome.

Climatic zone

- Existing procedure in PMED for CRCP design.
- Uses EICM data to determine climatic zone for project location.

Number of days above 32°C and below 0°C

- Calculated as average number of days with temperature above 32°C and below 0°C from hourly climatic data

TDC Structure Parameters

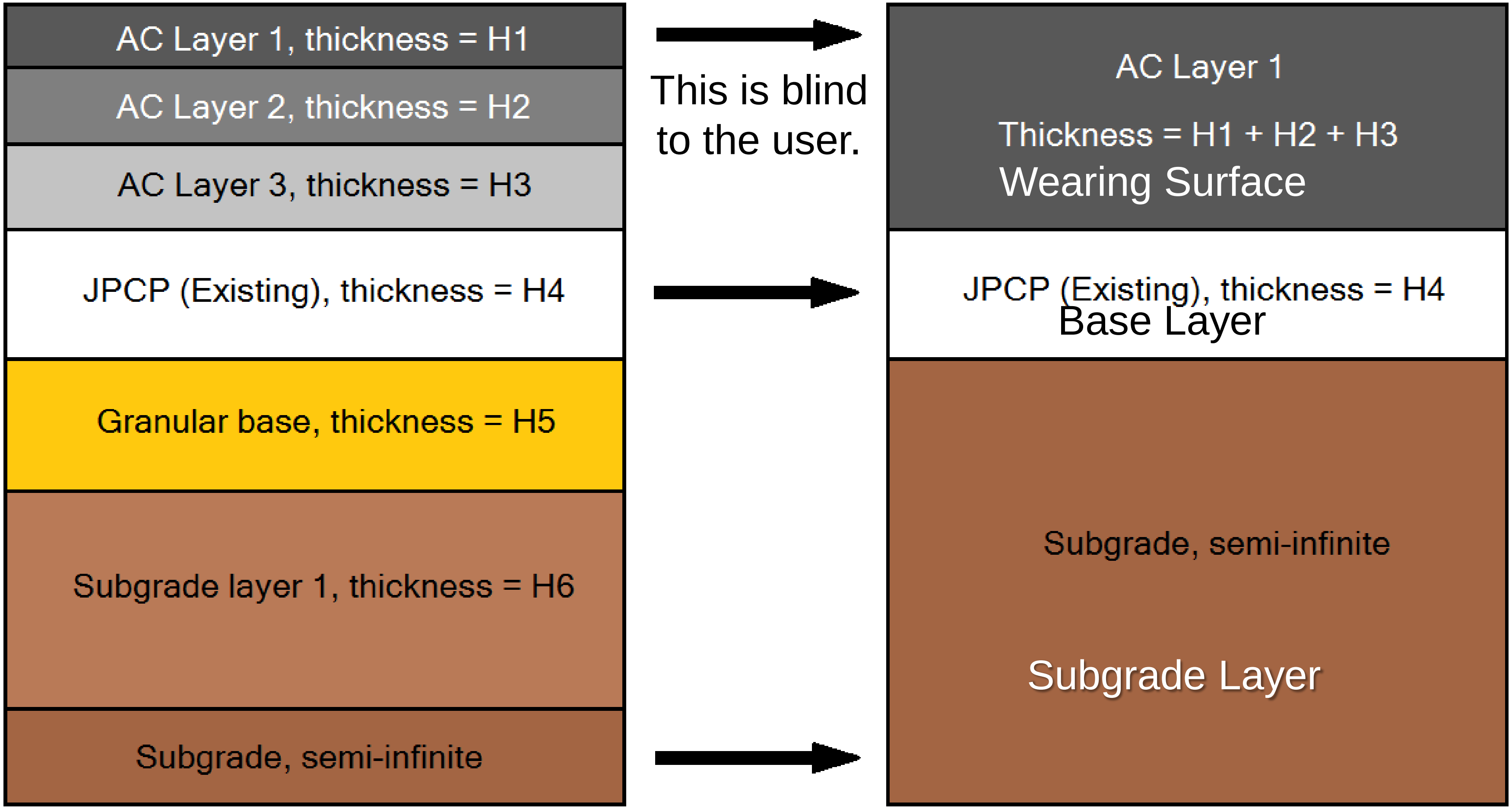
TDC: three layers simulated:

1. Asphalt layer
2. Base course
3. Subgrade

All pavements with an asphalt surface in PMED are converted to an equivalent three-layered structure:

- Cumulative layer thickness within each layer type.
- Properties for wearing surface (for multiple asphalt layers)
- Base layer modulus and thickness
- Subgrade modulus

TDC Structure Parameters



No changes required to structure. Program combines layers and calculates modulus values needed.

TDC Asphalt Layer Parameters

Asphalt layer inputs required for TDC model

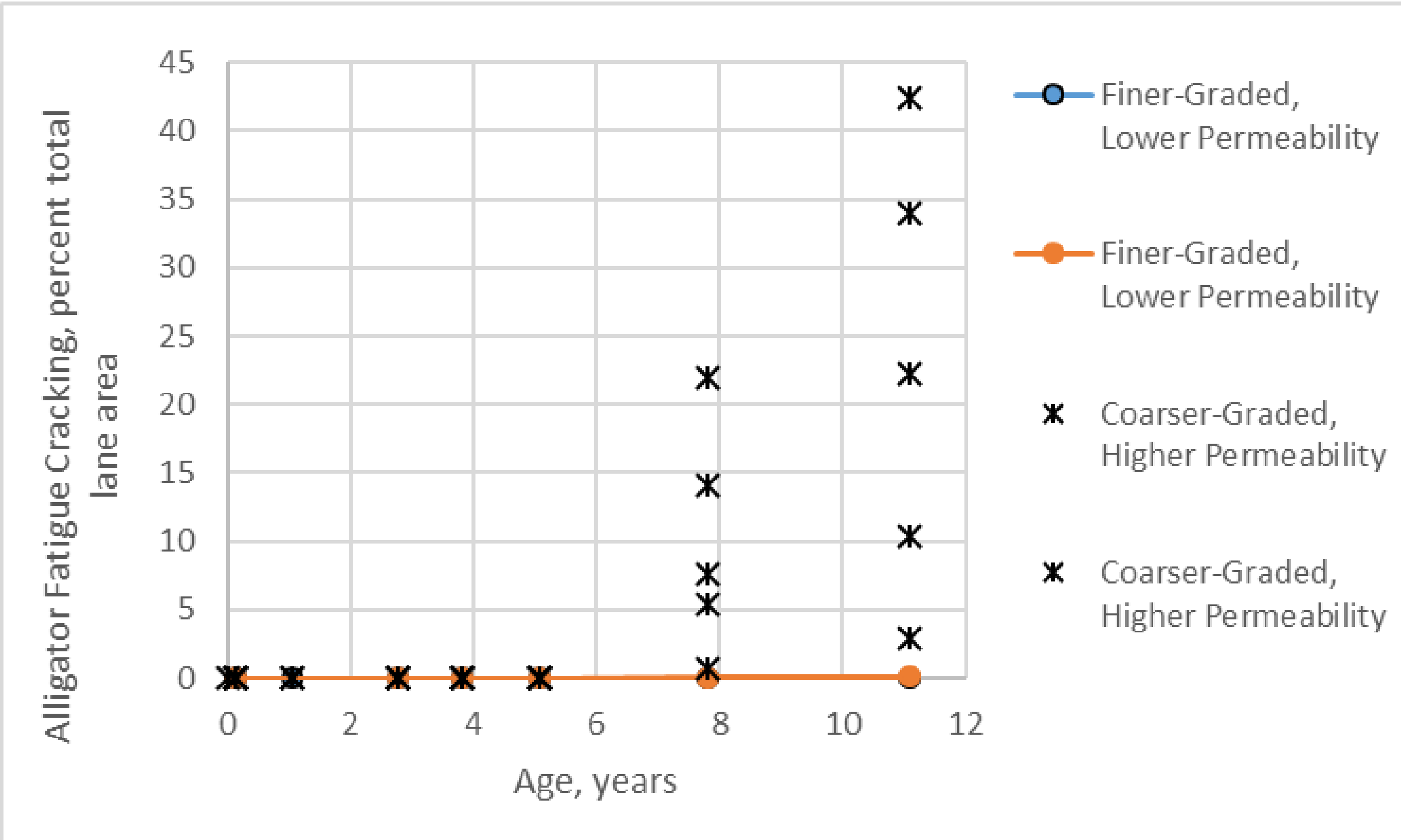
- Percent asphalt content by weight of mix, P_b
- Gradation parameter ψ from gradation Power law curve
- Representative modulus of asphalt concrete, E_R calculated at each monthly interval

Changes to Pavement ME user inputs

- P_b is added as a new mixture volumetric input for surface AC layer
- ψ is calculated from aggregate gradation inputs (or can be entered by user if calculated separately)
- AC dynamic modulus Level 1 analysis now requires gradation
- E_R is calculated internally by Pavement ME (no user input required)

TDC Asphalt Layer Parameters

Gradation: Interesting observation in the measured fatigue cracking data from some SPS-9 sections.



Outline

1. Introduction
2. Additional Inputs and Outputs
3. Key Points and Methodology
4. Calibration
5. Examples

Revision from the NCHRP 1-52 model were based on results from calibration using measured and predicted values.

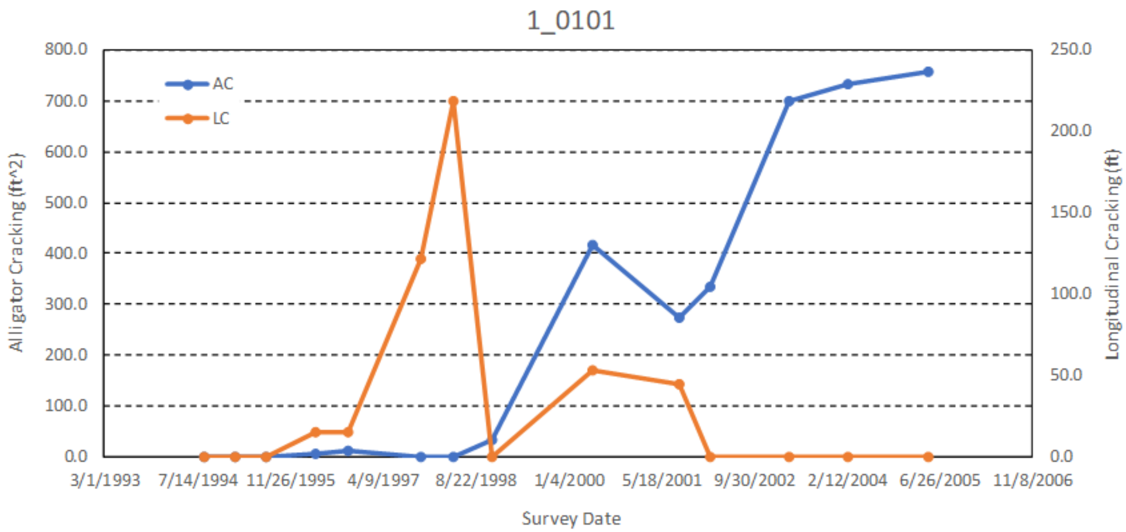
TDC Calibration

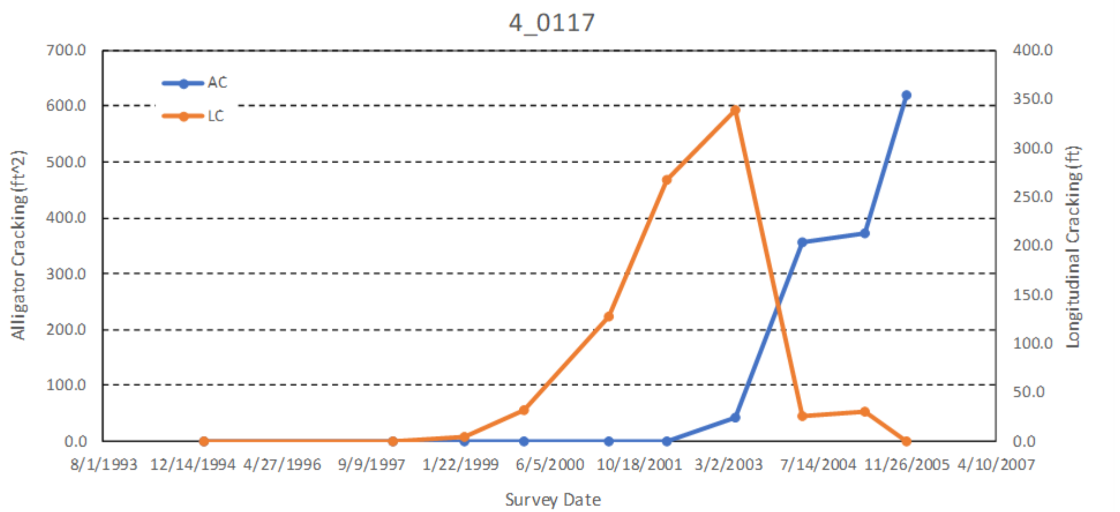
- All longitudinal cracks assumed to start at the surface; TDC(?).
- All alligator cracks assumed to start at the bottom of asphalt layer(?).

TDC Calibration

LTPP Sites: TDC or BUC?

- Longitudinal cracks increase over time but then decrease over time with an increase in alligator cracks.
- No cores available to determine where cracks initiated.

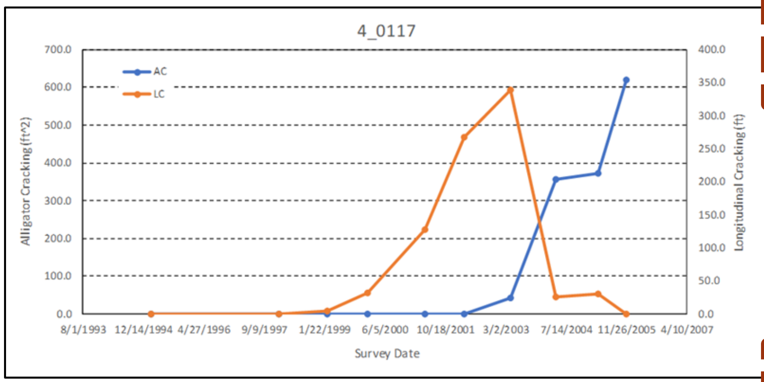




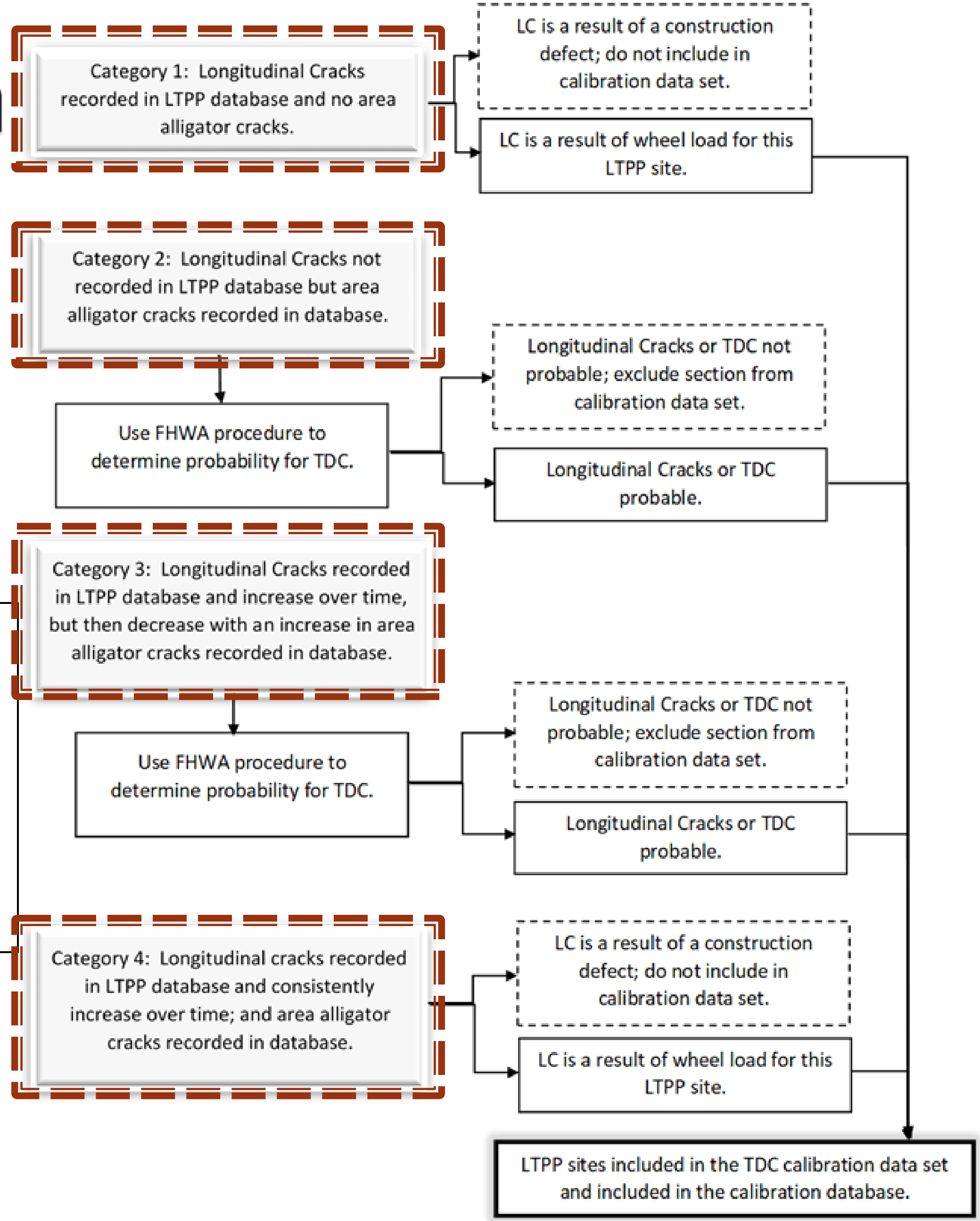
TDC Calibration

TDC Calibration

Combine area cracks with longitudinal cracks; cracking continues to increase over time.



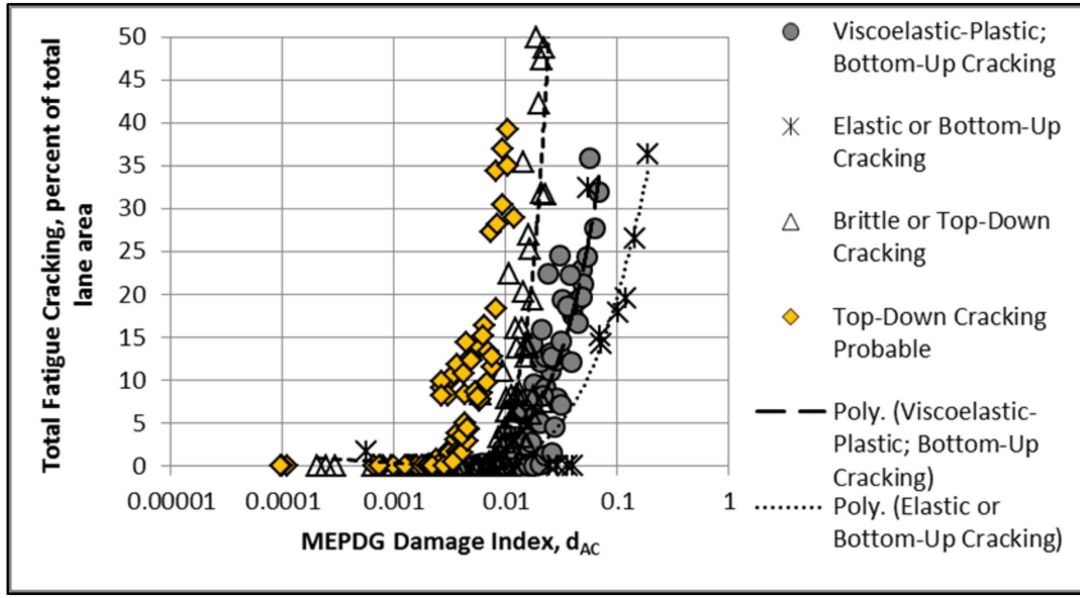
Length of wheel paths with TDC.



TDC Calibration

Separated TDC from bottom-up cracking and TDC caused by construction defects - segregation.

"Characterization Existing Asphalt Concrete Layer Damage for Mechanistic Pavement Rehabilitation Design," Report # FHWA-HRT-17-05, 2017.



$DI_{E\text{-}Ratio}$	Fatigue Cracking (Percent Total Lane Area)						
	0	0–2	2–10	10–20	20–35	35–50	> 50
Negative				Area with higher probability of TDC, debonding near the surface, or some other near surface defect.			
0–0.25							
0.25–0.5							
0.50–0.75	Area with higher probability of bottom-up cracking. All cracks have yet to reach the surface, or there is moisture damage, debonding, or other lower AC layer defects.						
> 0.75							

TDC Calibration

LTPP sites grouped into different categories for calibration.

Slow crack propagation.

Fast crack propagation.

Defect; long. segregation.

Defect; bonding deficiency.

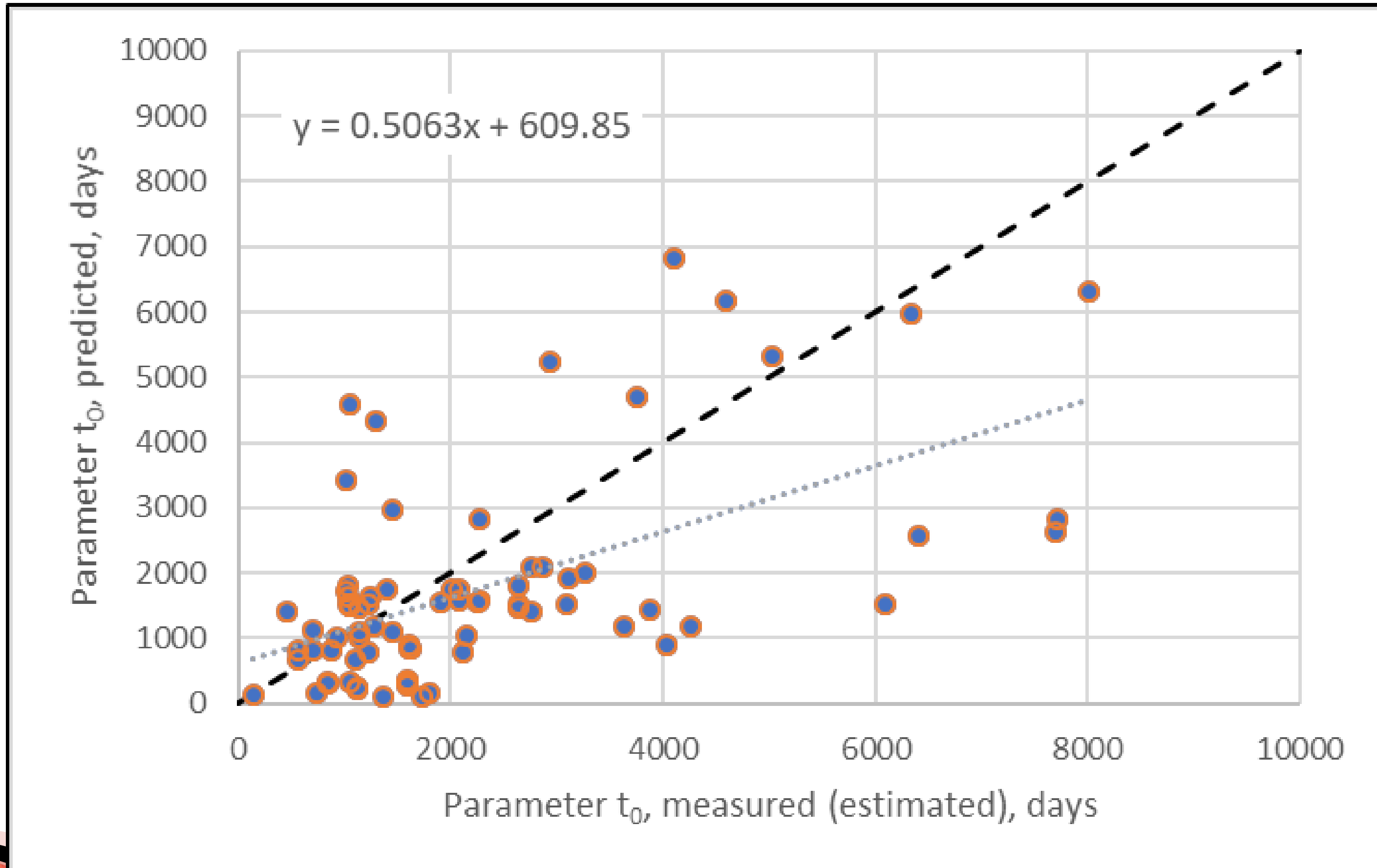
Defect; other deficiency.

Attempted to include these sites in calibration.

Attempted to exclude these sites from calibration.

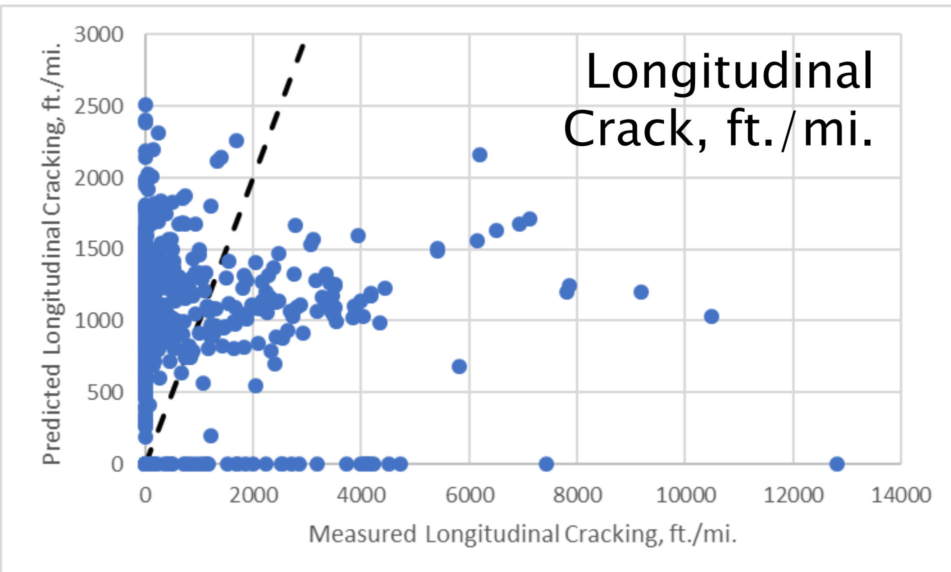
TDC Calibration

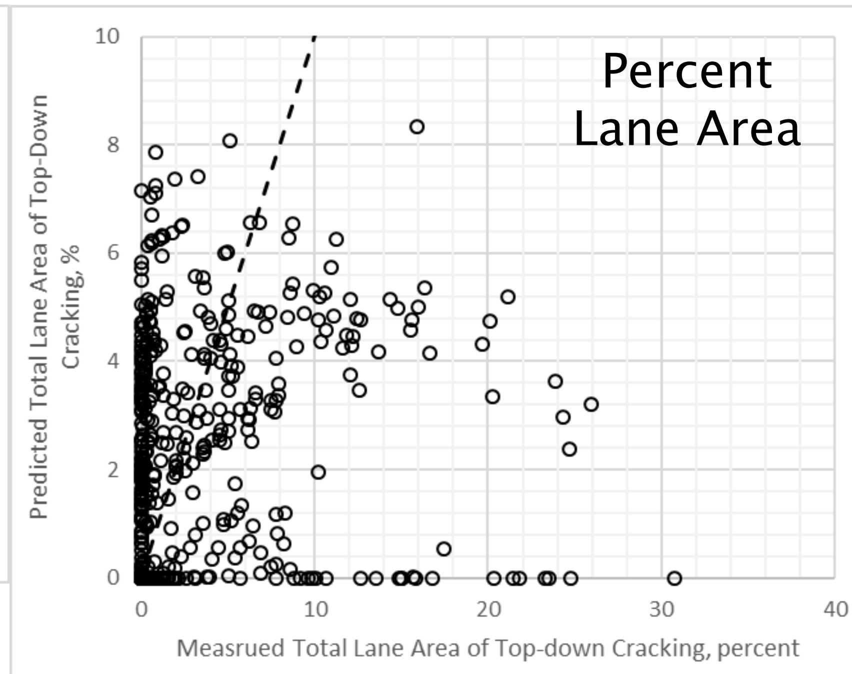
Crack initiation time was determined from LTPP sites for longitudinal or area fatigue cracks – assumed to initiate at the surface.



TDC Calibration

- Software predicts percent area of cracks, and not the length of longitudinal cracks, based on results from final calibration.





Standard deviation of residuals = 5.4 percent.

$$\sigma_{RE} = 0.3657(TDC_{Mean}) + 3.6563$$

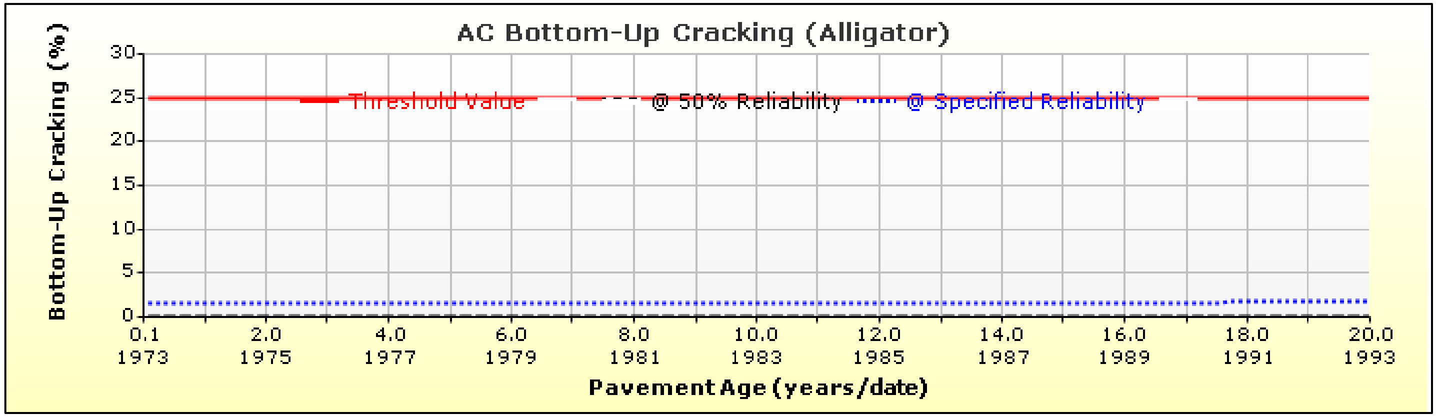
Outline

1. Introduction
2. Additional Inputs and Outputs
3. Key Points and Methodology
4. Calibration
5. Examples

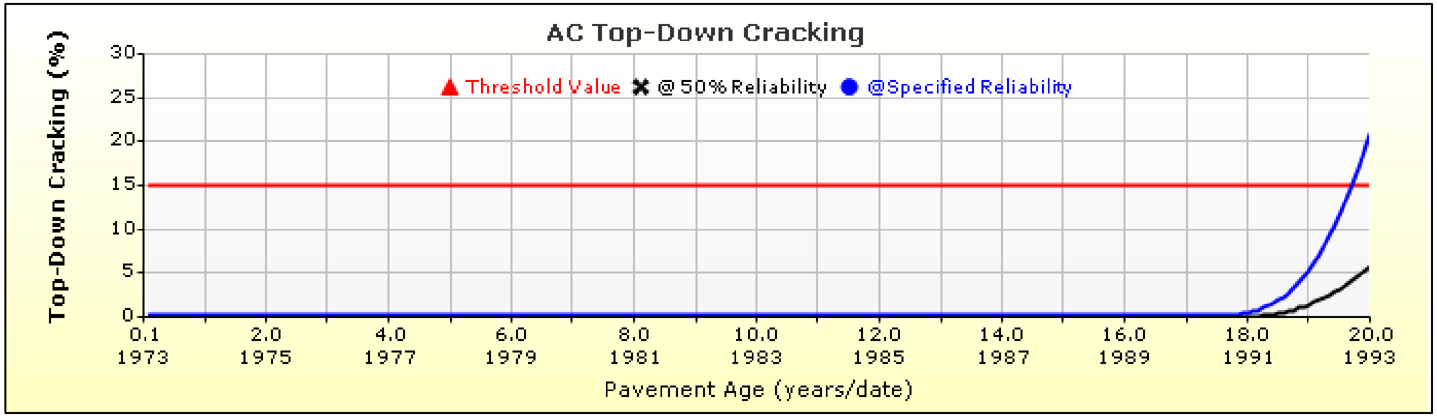
Some examples of predicted TDC with different input parameters to illustrate the impact.

Texas site with a thin asphalt wearing surface of 1.5 in. and heavier truck traffic, AADTT is 1,000.

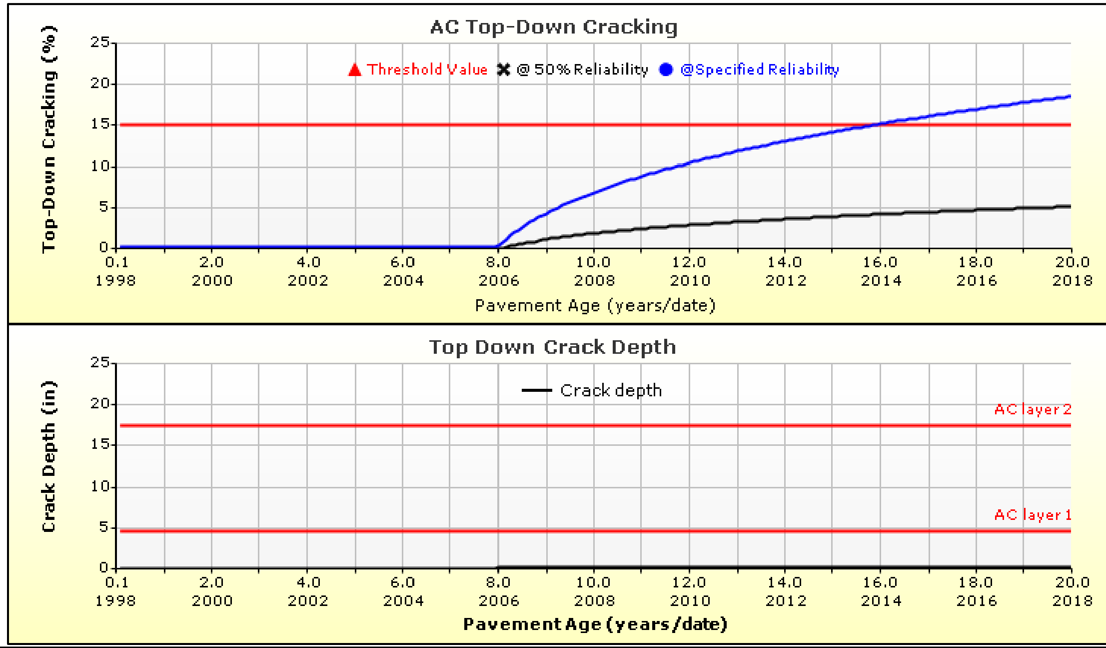
Bottom–Up fatigue cracking.



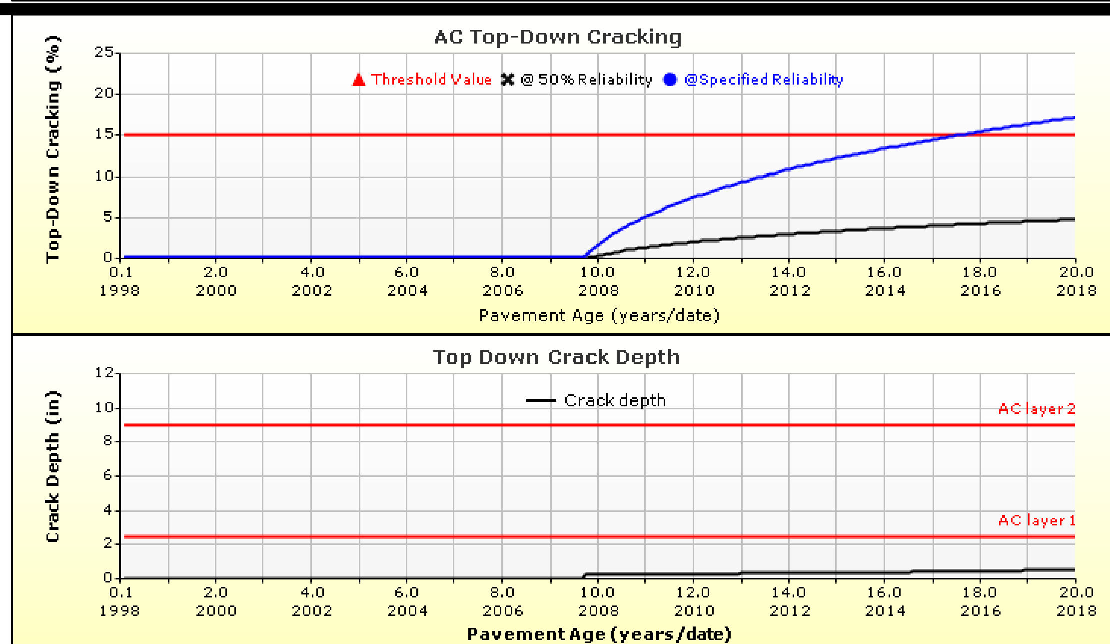
Top–Down fatigue cracking.



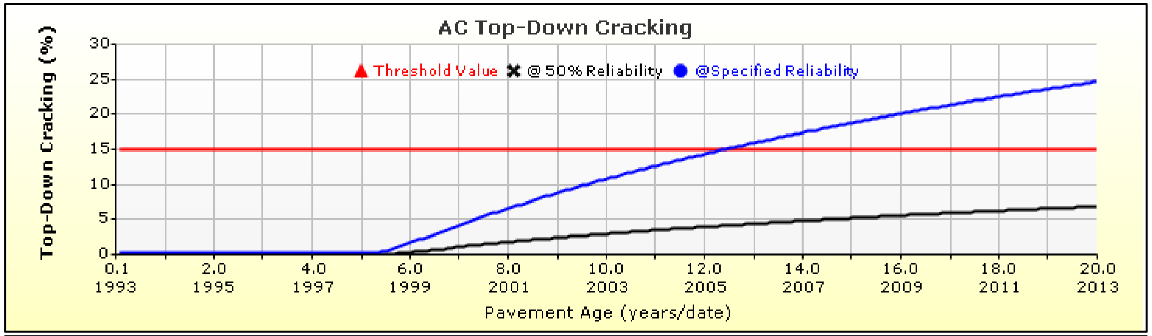
Montana site with a total asphalt layer thickness of 17.4 inches for a full-depth asphalt pavement.

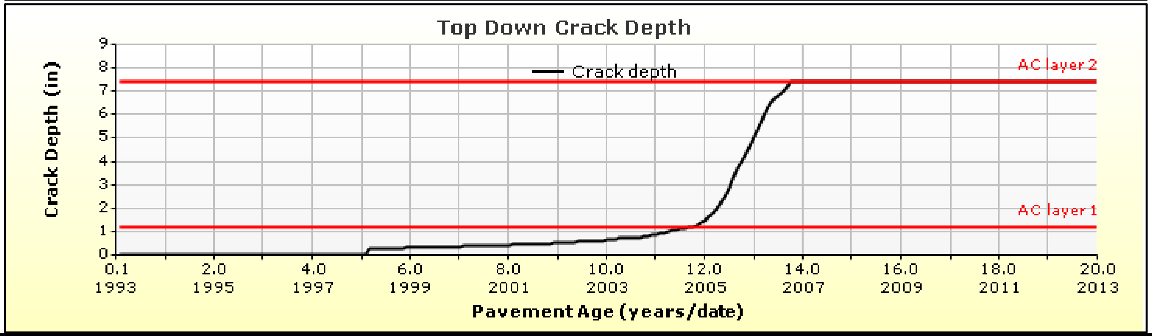


Montana site with a total asphalt layer thickness of 9.0 inches for a full-depth asphalt pavement.

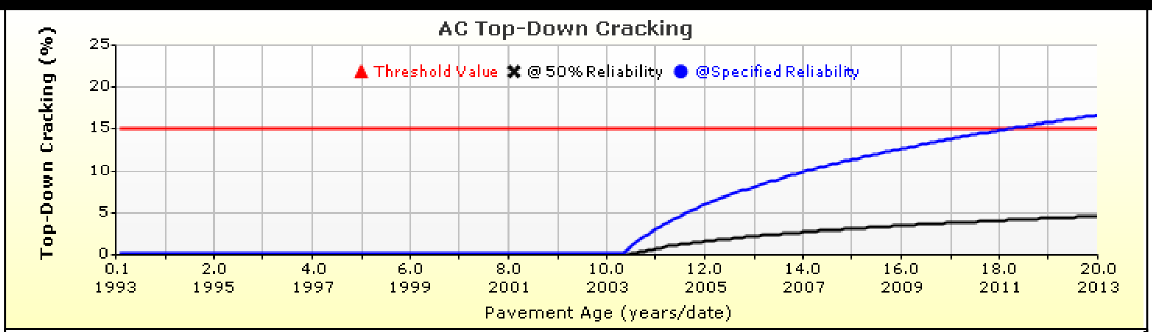


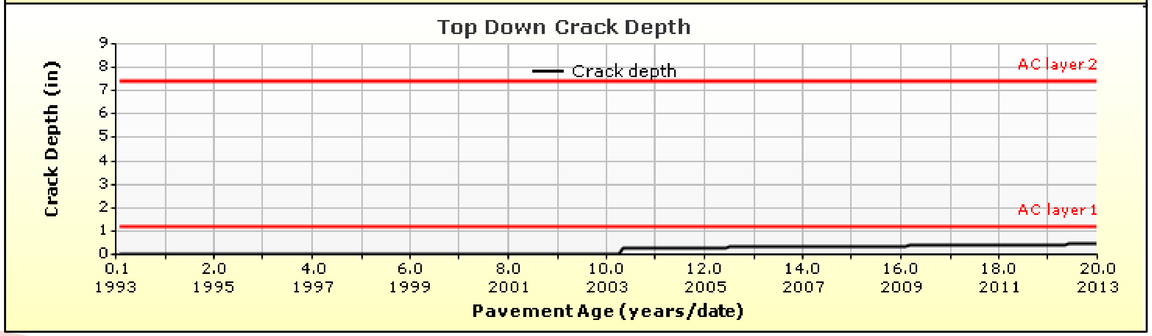
Alabama site with a very soft binder wearing surface mixture.





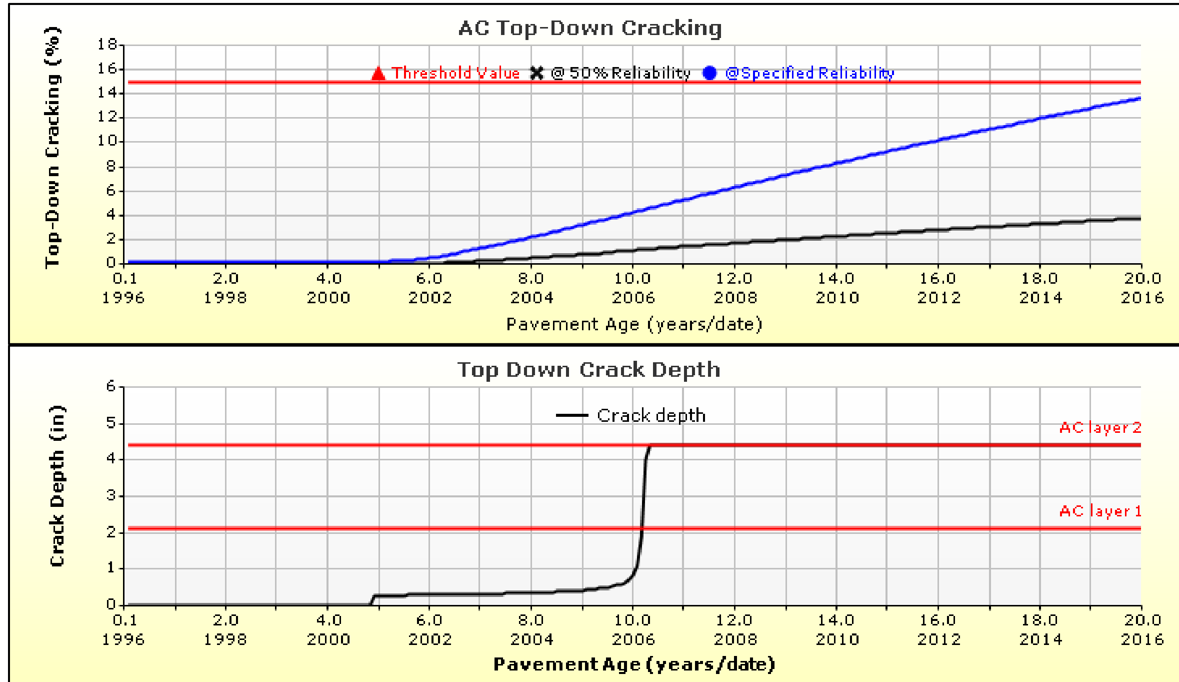
Alabama site with a very hard binder wearing surface mixture.





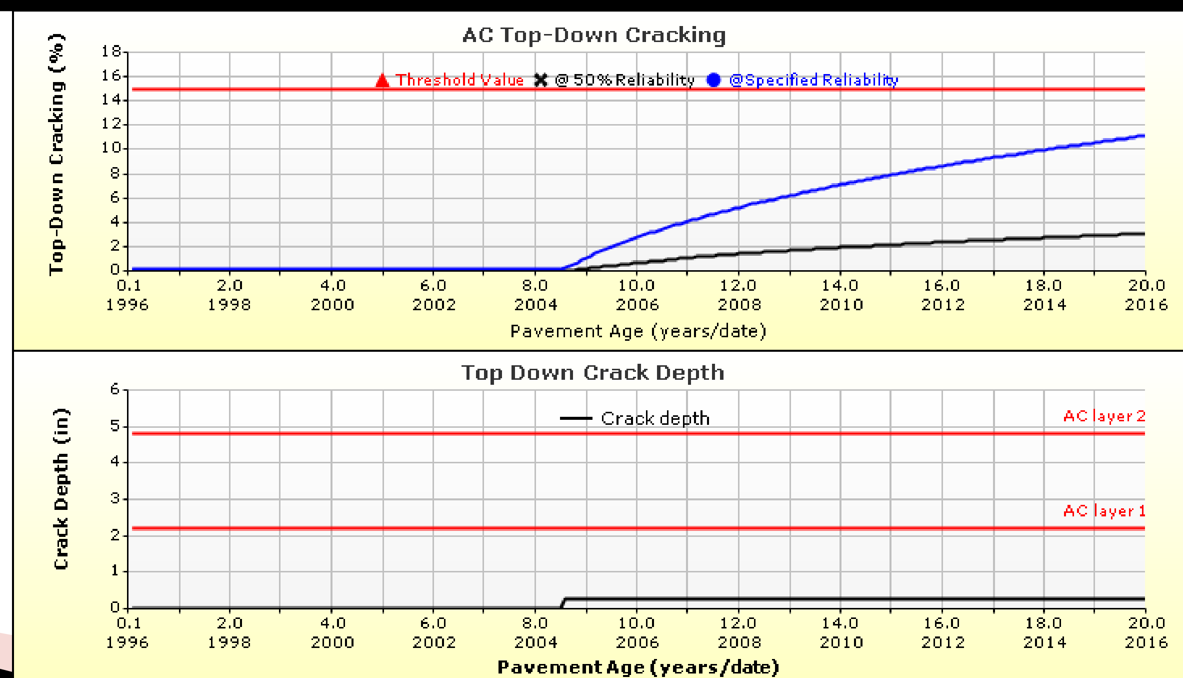
Canadian SPS-9 test section with a coarse, gap-graded asphalt surface mixture.

Gradation Parameter is 0.768 and asphalt content is 4.75%.

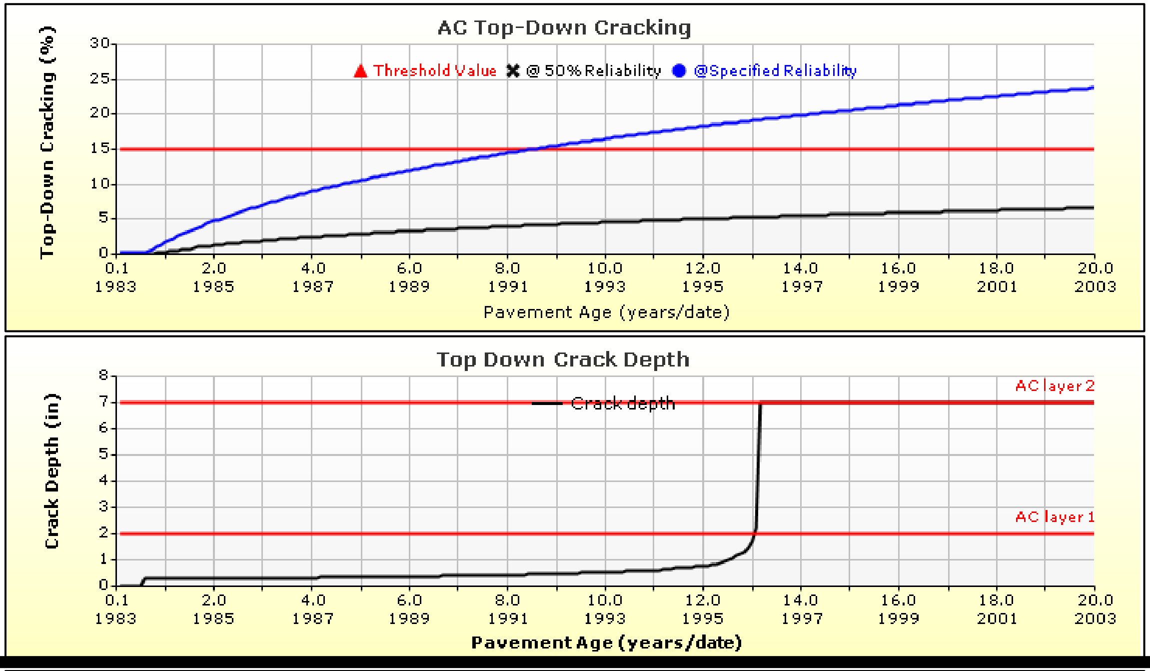


Canadian SPS-9 test section with a fine-graded asphalt surface mixture.

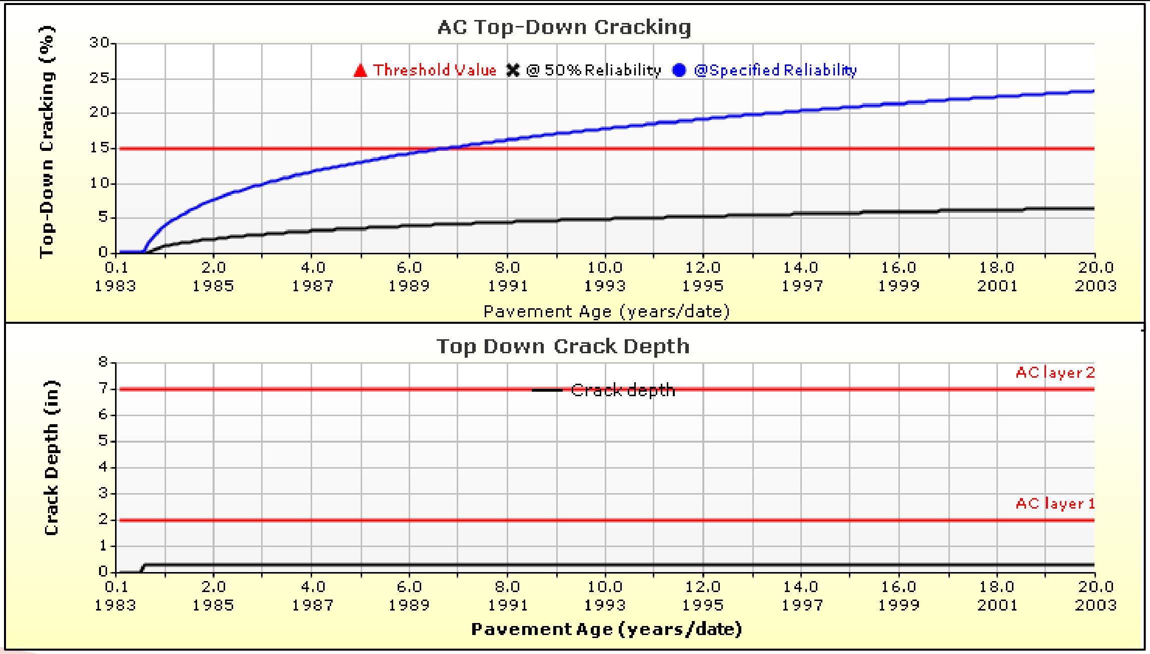
Gradation Parameter is 0.409 and asphalt content is 5.65%.



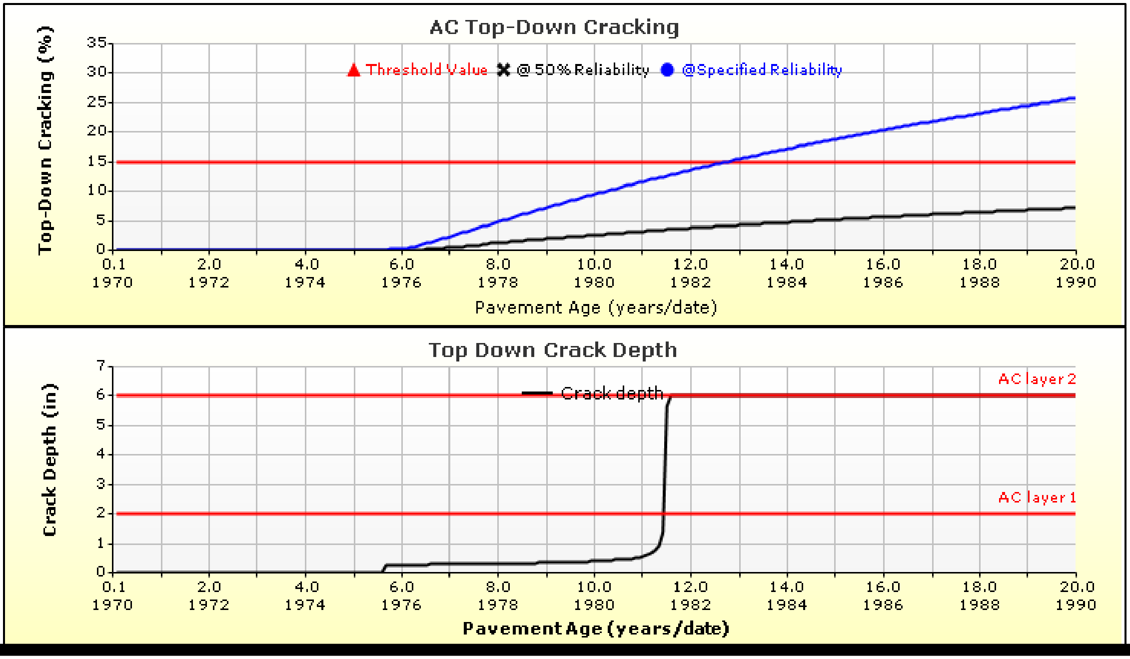
Texas site with a conventional granular base of a flexible pavement: design resilient modulus = 22,000 psi.



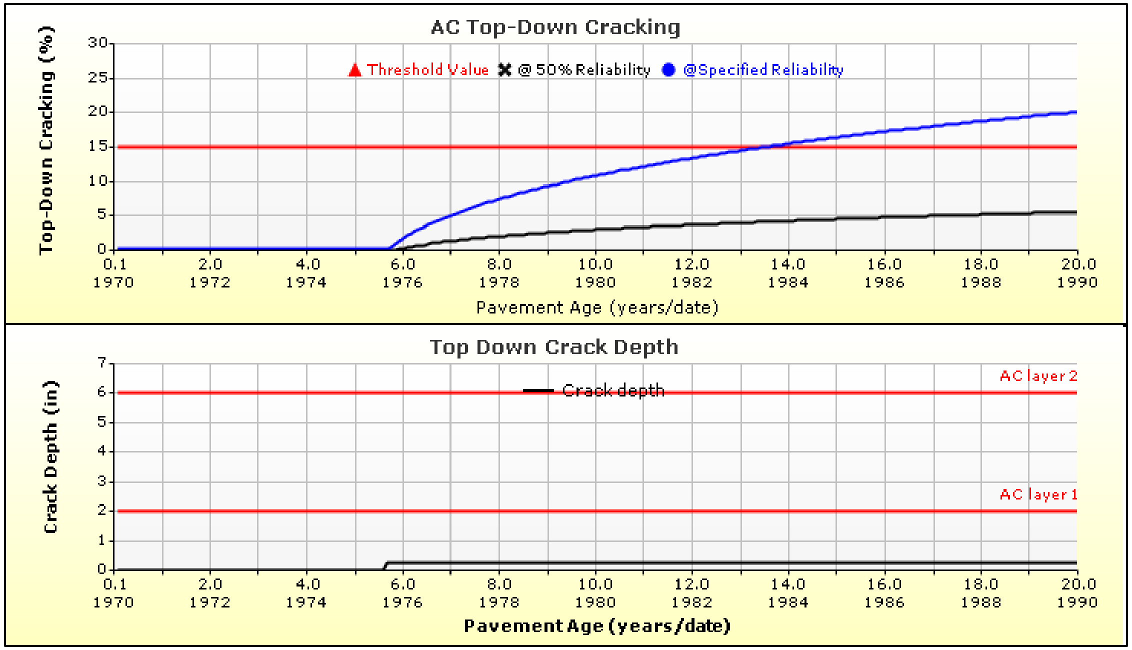
Texas Site with a stabilized base or a semi-rigid pavement: elastic modulus = 500,000 psi.



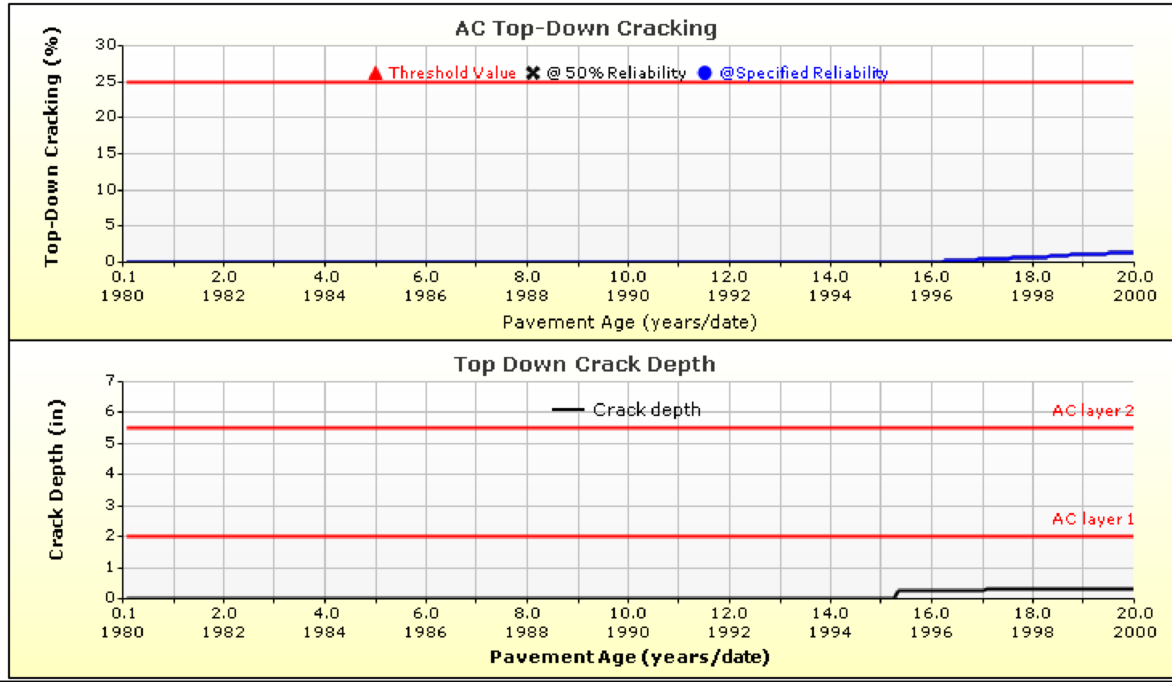
North Carolina site with a conventional flexible pavement on a weak soil or subgrade (resilient modulus is 8,000 psi); an A-6 higher plasticity soil.



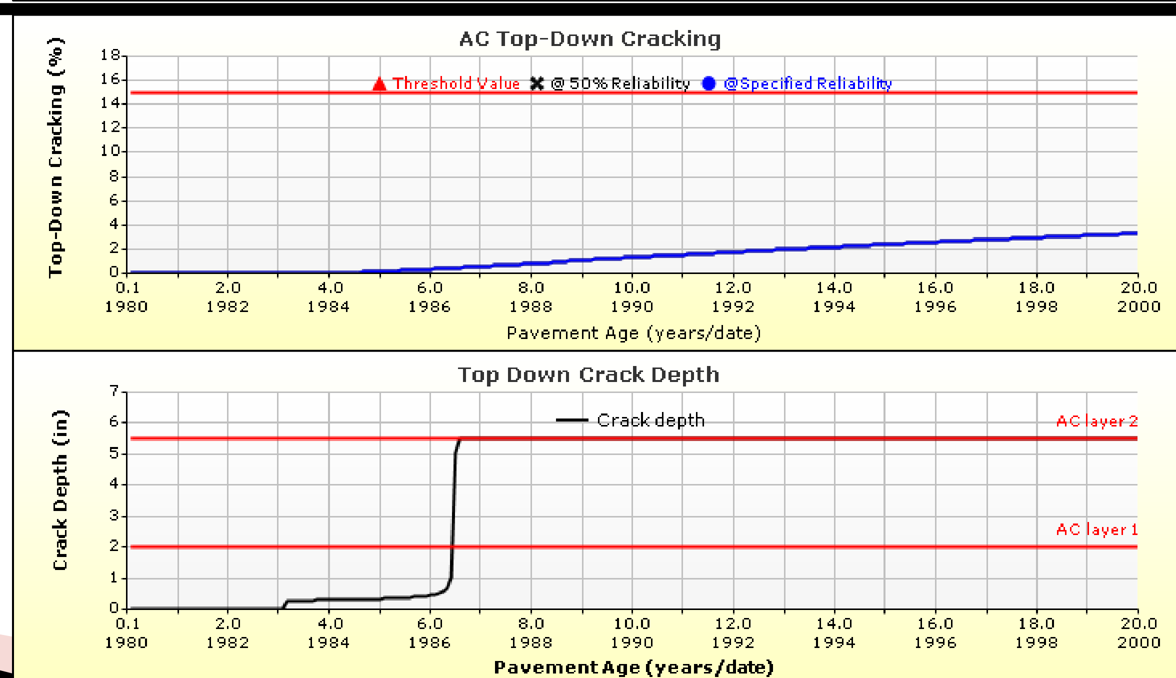
North Carolina site with a conventional flexible pavement on a strong soil or subgrade (resilient modulus is 20,000 psi); an A-1-b soil.



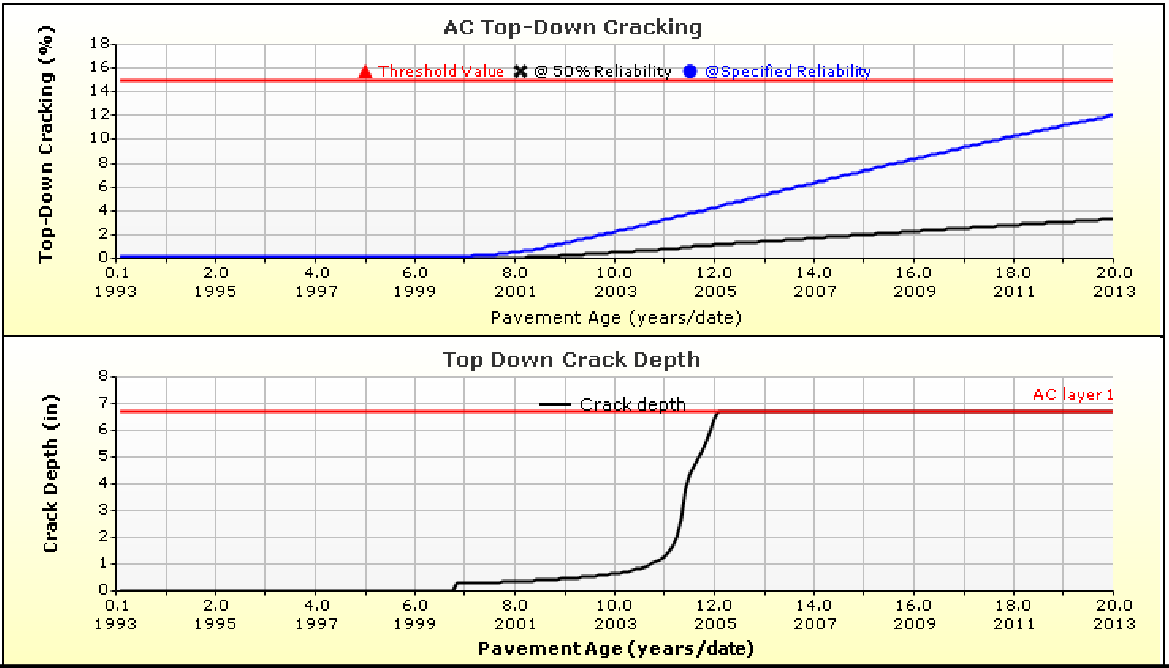
Utah site with an AADTT of 194 and a typical axle load distribution.



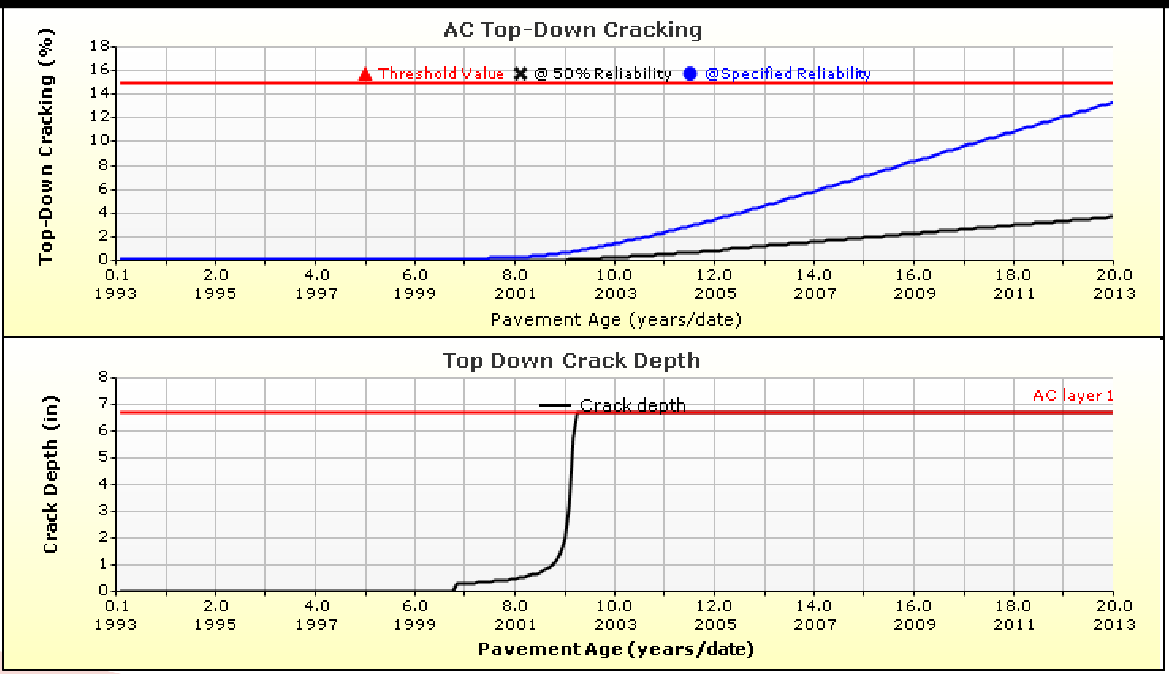
Utah site with an AADTT of 600 and a typical axle load distribution.



Arizona site with moderate truck traffic, AADDT of 1,100, and lightly loaded trucks.



Arizona site with moderate truck traffic, AADDT of 1,100, and heavily loaded trucks with overloads.



TDC Anomaly

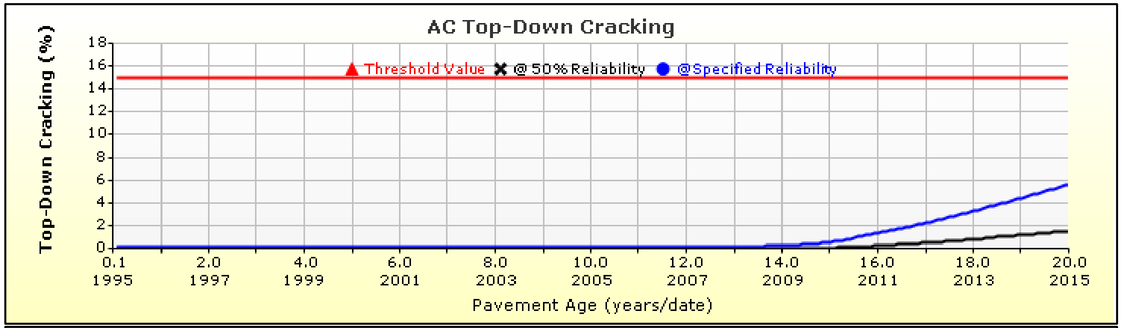
Anomaly shown in the following slide relative to the mathematical simulation for calculating crack depth.

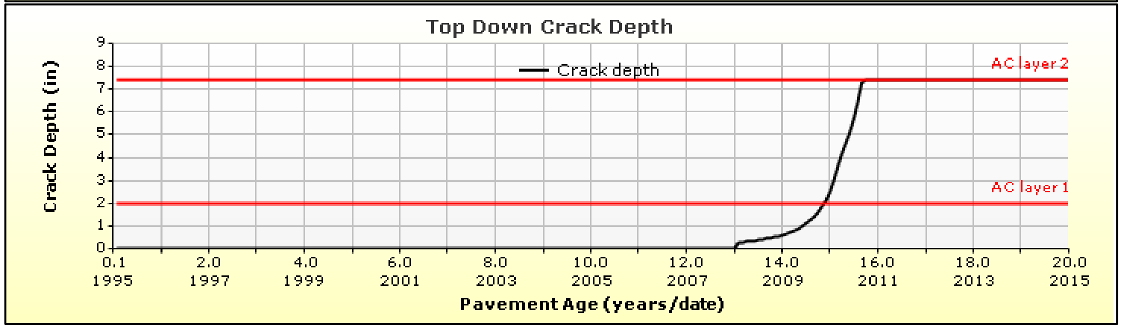
- Asphalt layers with high air voids: crack propagate through entire asphalt layer within a couple of years, even when total area of TDC is low.
- If the total area of top-down cracks are less than 2 percent, crack depth is unimportant.

TDC Anomaly

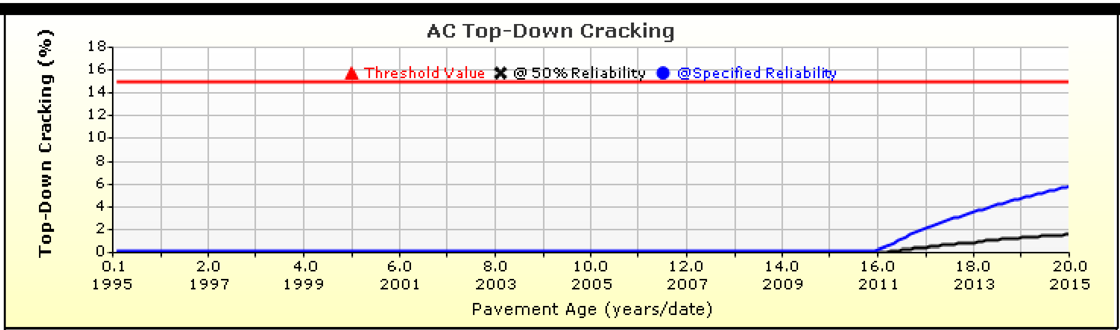
New Mexico site with high air voids; 9.9 percent.

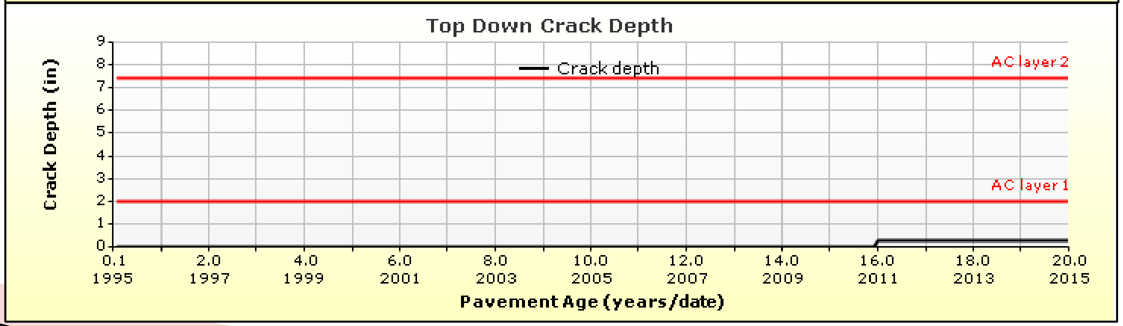
Crack propagation is unrealistic.





Same New Mexico site with low air voids; 5 percent.





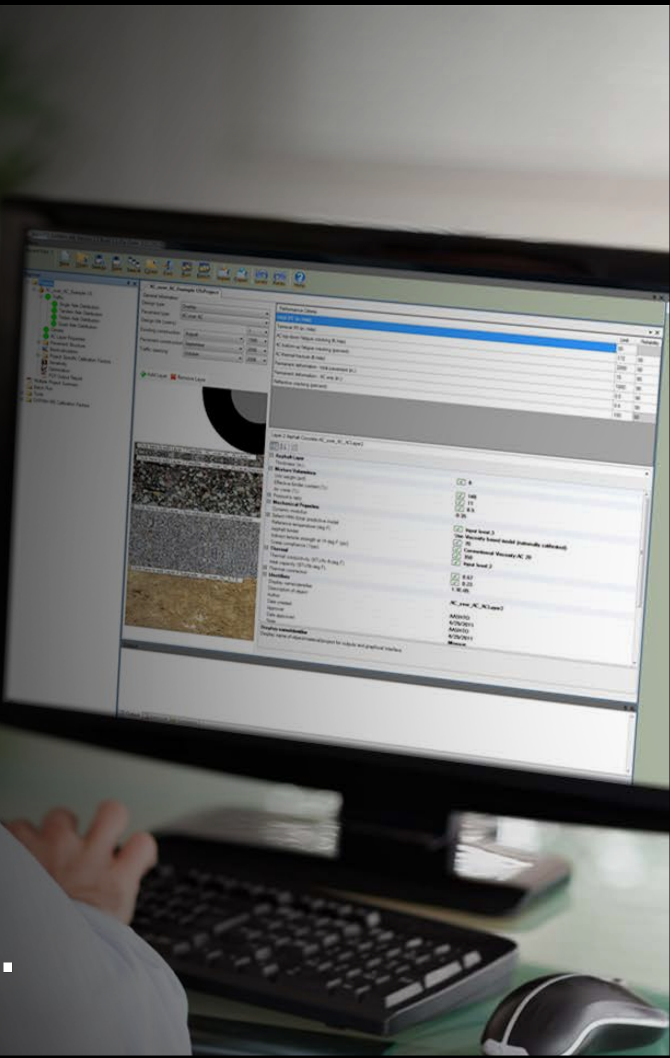
TDC Enhancement Released with Version 2.6.0

Before we end:

Poll 2: Questions 3 to 5

QUESTION AND ANSWER SESSION

We welcome comments & suggestions for future webinars; Send an email to pavementmedesign@ara.com.



Questions and Answers

Remember to visit https://engineering.stackexchange.com/questions/tagged/pavement to ask questions and participate in the Pavement ME design community.

Thank you for Attending the Webinar!

AASHTOWare Pavement ME-Design Contacts:

- Ryan Fragapane, AASHTO
  rfragapane@aashto.org
  Phone: (202) 624-3632
- Clark Morrison, NCDOT
  cmorrison@ncdot.gov

ME Design Resource Website
http://www.me-design.com

Pavement ME Design Users Group Contact:

- Christopher Wagner, FHWA
  Christopher.wagner@dot.gov
  Phone: (404) 562-3693

Help Desk, Customer Support:

PREFERRED

- Pavement ME Design Help Desk
  pavementmedesign@ara.com
- Phone: (217) 356-4500

Other ARA Staff:

- Chad Becker
  cbecker@ara.com
- Wouter Brink,
  wbrink@ara.com
- Harold Von Quintus, P.E.
  hvonquintus@ara.com

Phone: (217) 356-4500

AASHTOWare: Pavement ME Design
Top-Down Cracking Enhancement Released in Version 2.6.0

THANK YOU FOR ATTENDING THE WEBINAR

TDC Calibration

Crack initiation time was determined from LTPP sites for longitudinal or area fatigue cracks – assumed to initiate at the surface.