“ An Overview of Pavement Durability Cracking Distress in Pavement Systems”

by

Dr.M.W.Witczak

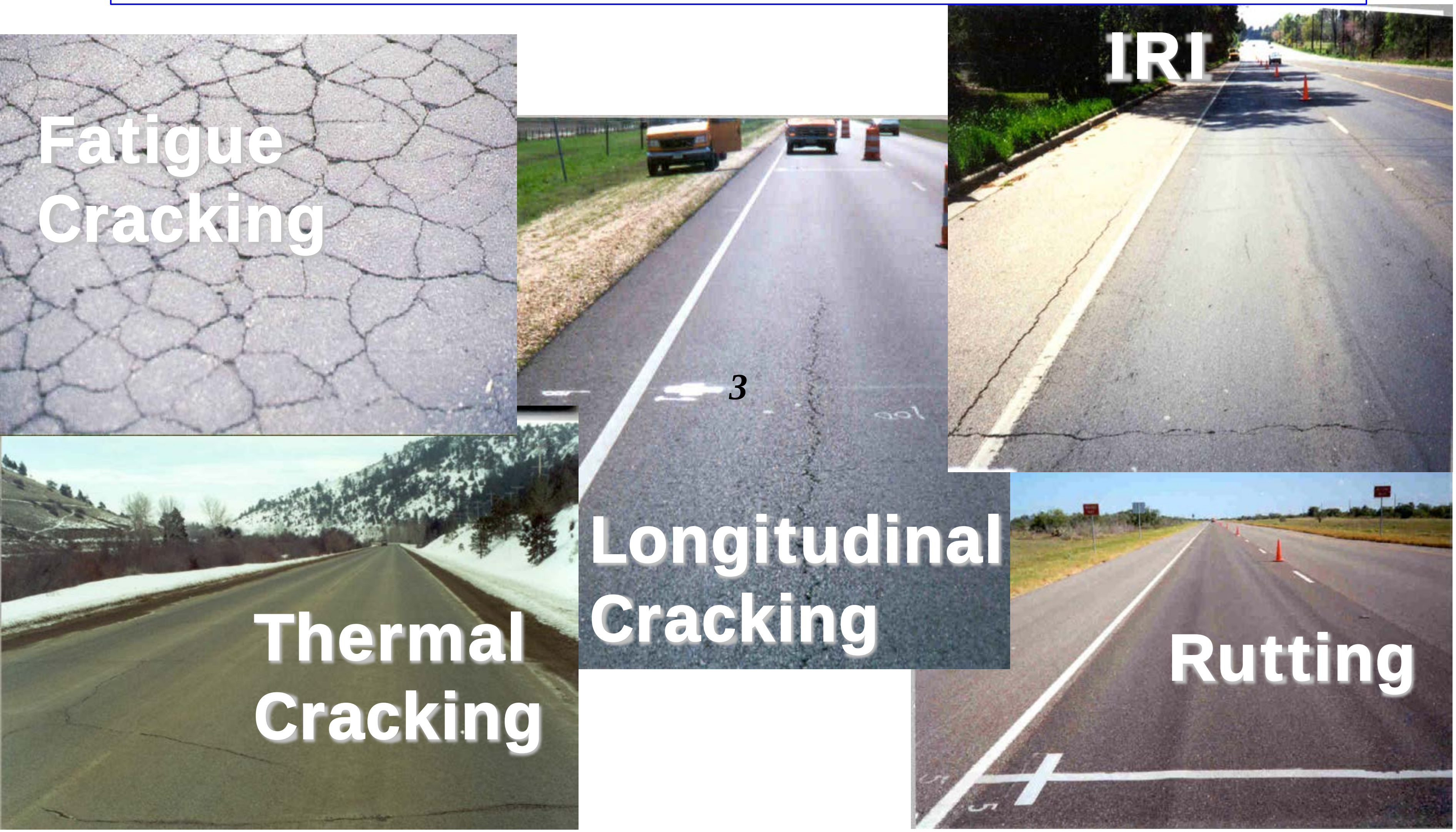
Emeritus Professor University of Maryland
Emeritus Professor Arizona State University
Partner, ZW Consultants LLC

11th Arizona Pavements/Materials Conference

19-20 November 2014
Phoenix, Arizona

AASHTO MEPDG DESIGN GUIDE PROCEDURE

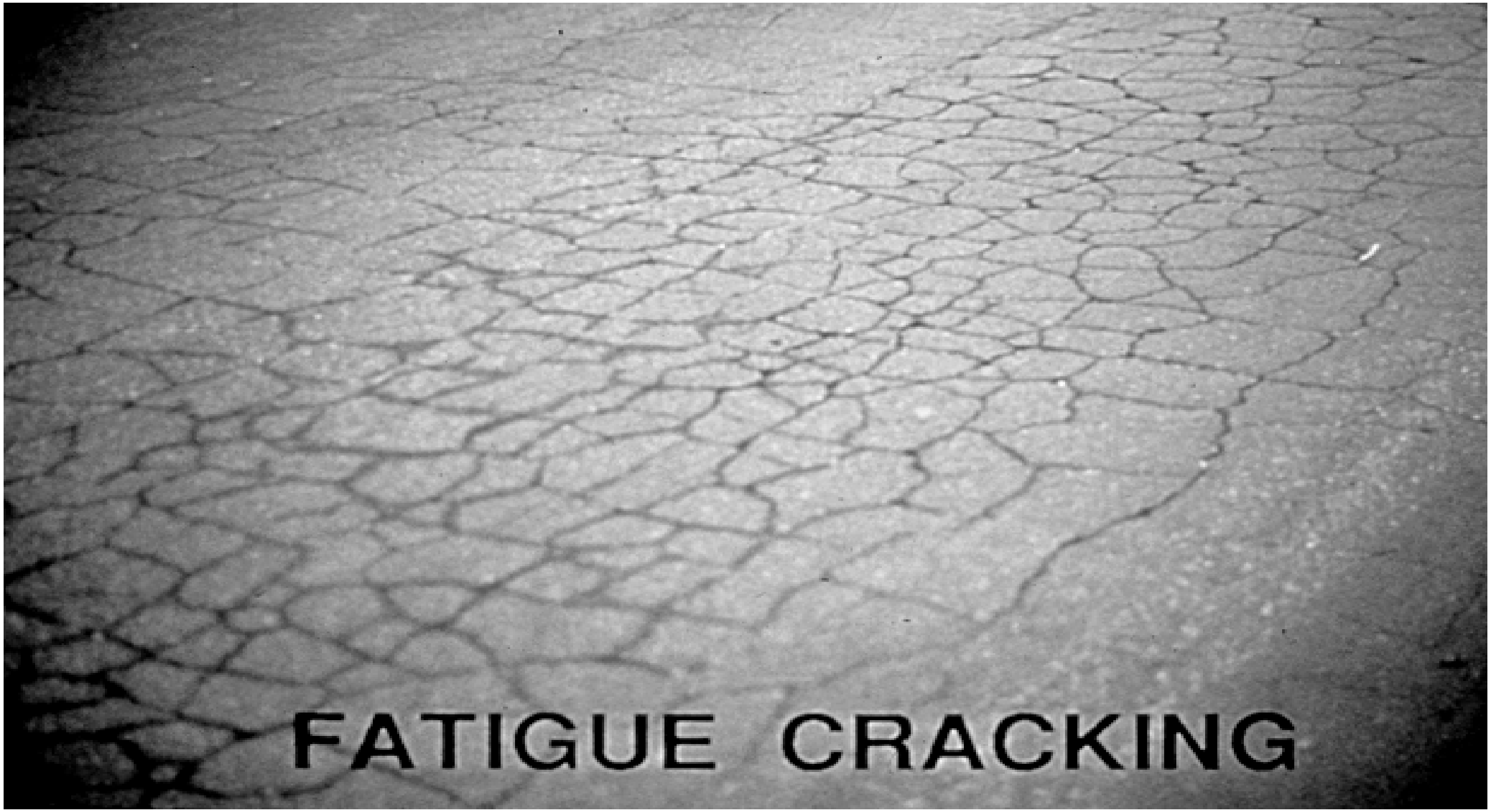
AASHTO MEPDG Predicted Distresses



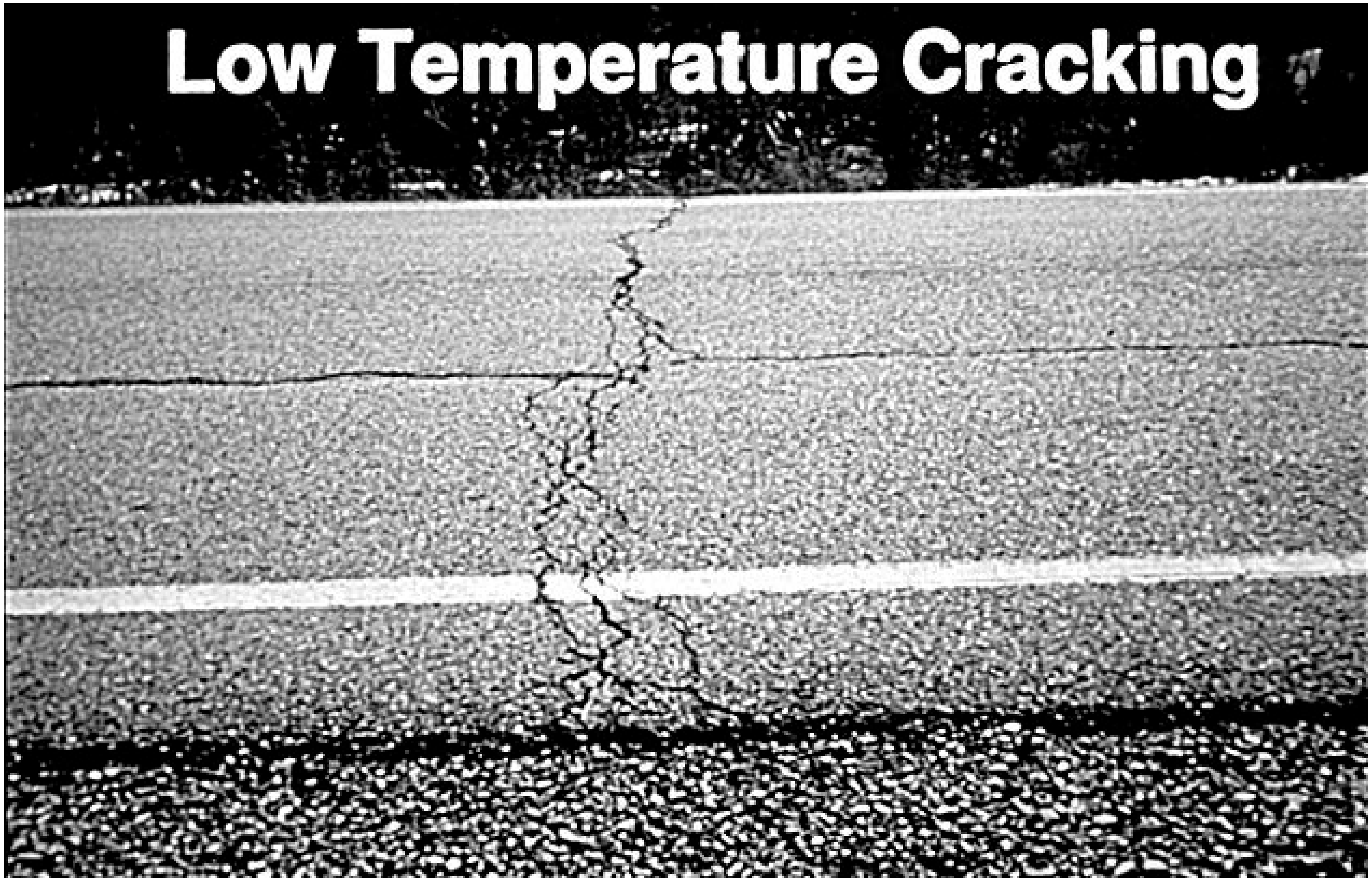
What a 2 Billion ESAL Highway Looks Like (Before Opened To Normal Traffic)

Severely Rutted Pavement!!

Severely Fatigue Cracked

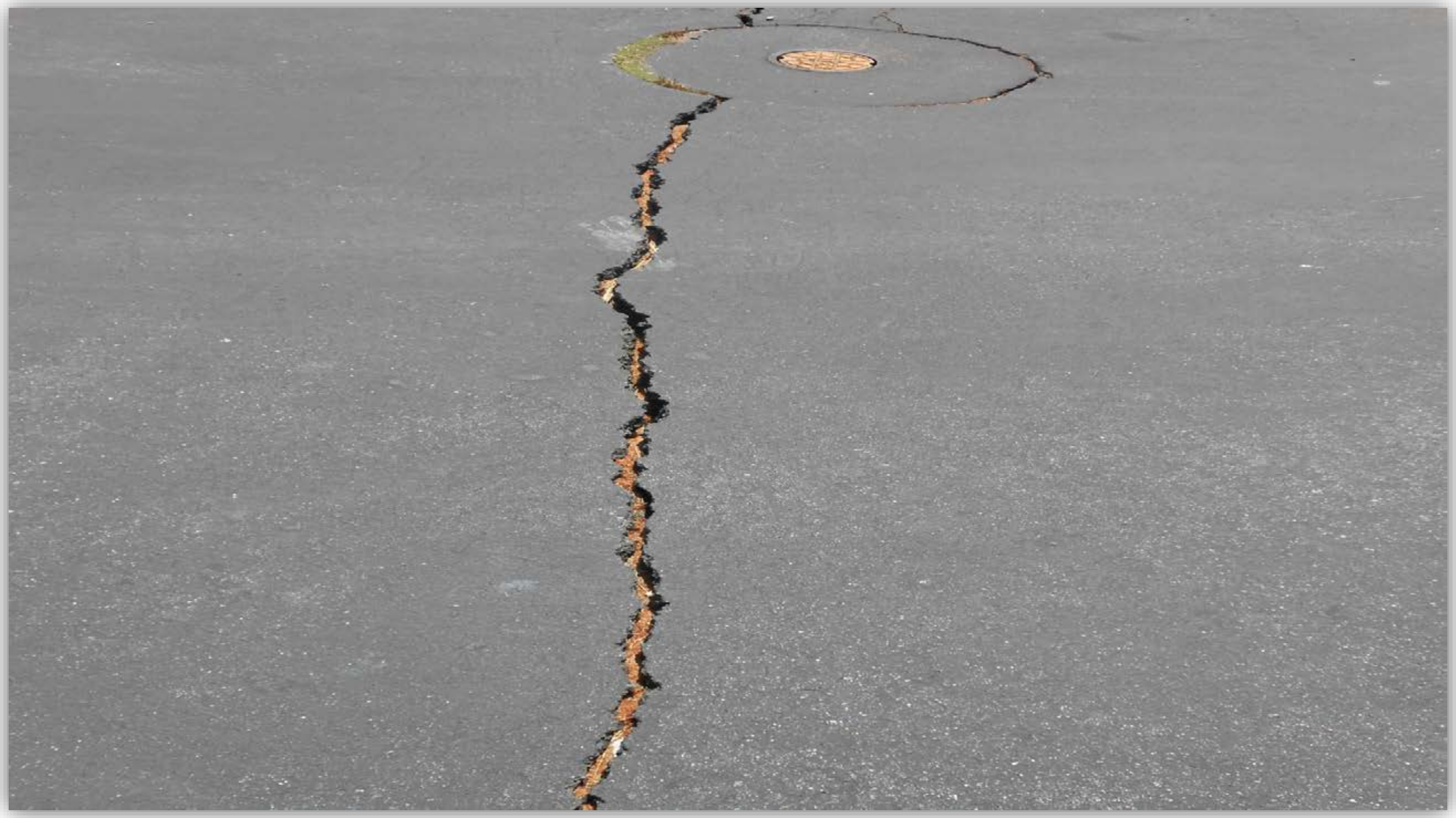


Thermal Cracking



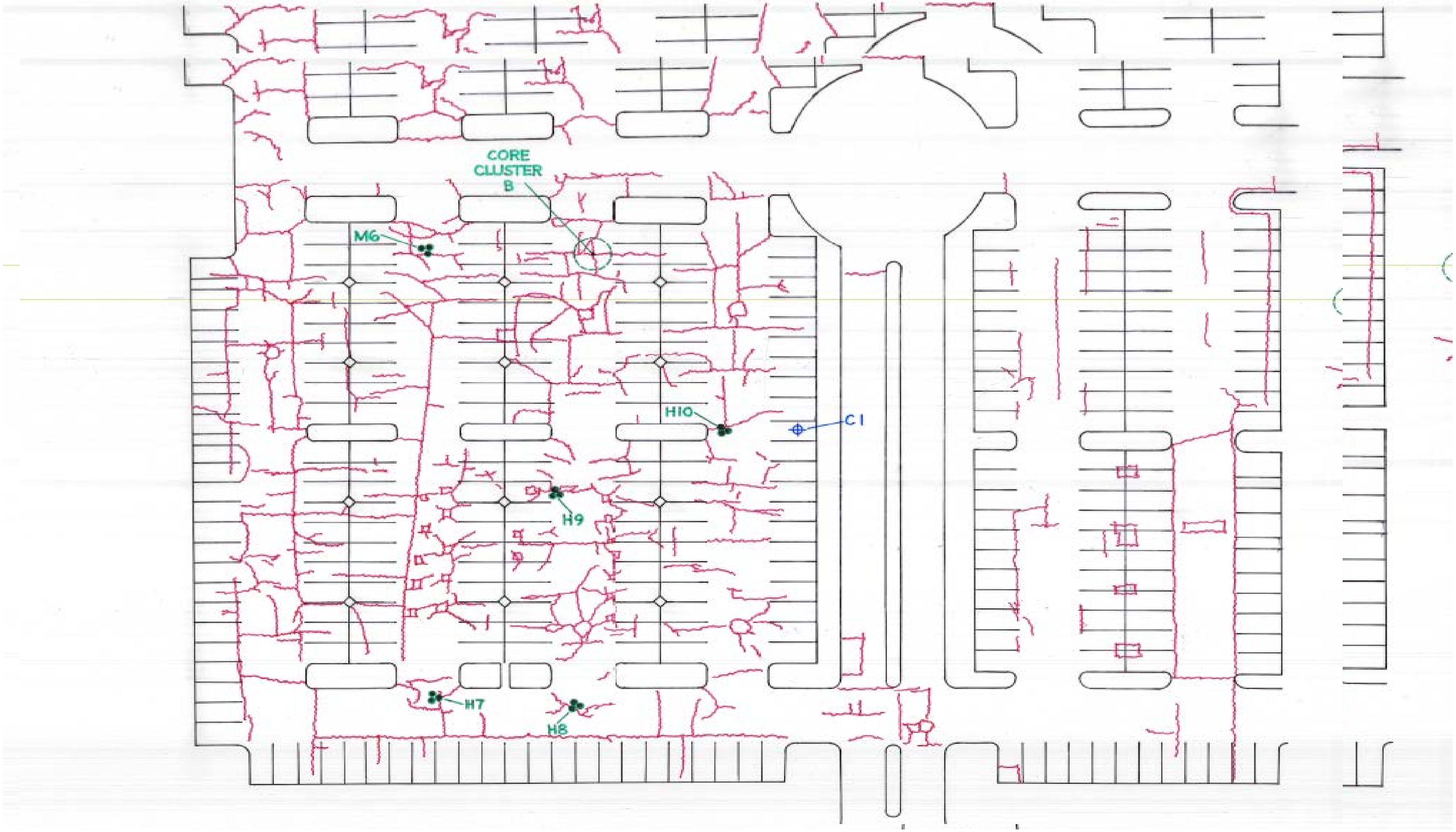
HMA Cracking Due To Durability / Shrinkage

Durability Cracking in Residential Streets



Durability Cracking in Residential Streets

Durability Cracking in Parking Lot Pavements


CORE
CLUSTER
B
M6
H10
C1
H9
H7
H8

The Impact Of Top Down Durability Cracking May Lead To:

Full Destruction of Load Carrying Ability of Pavement Structure

Some Aspects of Durability Cracking

- ***The Profession currently has a Much Better Technical Level of Understanding / Design Methodologies to Accommodate:***
    - ***Pavement Rutting***
    - ***Fatigue Cracking***
    - ***Thermal Fracture***

Compared to our Understanding and Ability to Eliminate Durability Cracking

Some Aspects of Durability Cracking

- ***There is <u>NO</u> Difference in the Future Performance of a Pavement System Possessing Full Depth Cracking Caused By:***
  - ***Structural (Load) Induced Cracking OR***
  - ***Durability (Non Load) Induced Cracking***

Both Cracking Forms <u>Destroy</u> the Structural Integrity of the Pavement System and Will Lead to the Necessity to Have Major Reconstruction of the Entire Pavement Structure

Some Aspects of Durability Cracking

- ***Major Causes of Durability Cracking***

    - ***Mix Design / Construction Considerations (eg Low AC% / High Va%)***

    - ***Construction Related Issues***
        - *Excessive Short Term Binder Stiffness (Gb*)*
        - *Lack of Specification for Actual In-Situ Binder Stiffness*

Some Aspects of Durability Cracking

- ***All Durability Distress is Greatly Enhanced in Frequency and Severity through Extremely Abnormal Environmental Conditions of:***
  - ***High Annual Temperatures and /or***
  - ***High Annual Rainfall***

Some Fundamentals of Mix Design Practice

Fundamental World Philosophy of Asphalt Mixture Design

- ***"Always Use as Much Asphalt as the Mix will Tolerate and still be Stable to Resist Rut Deformation and Shear"***

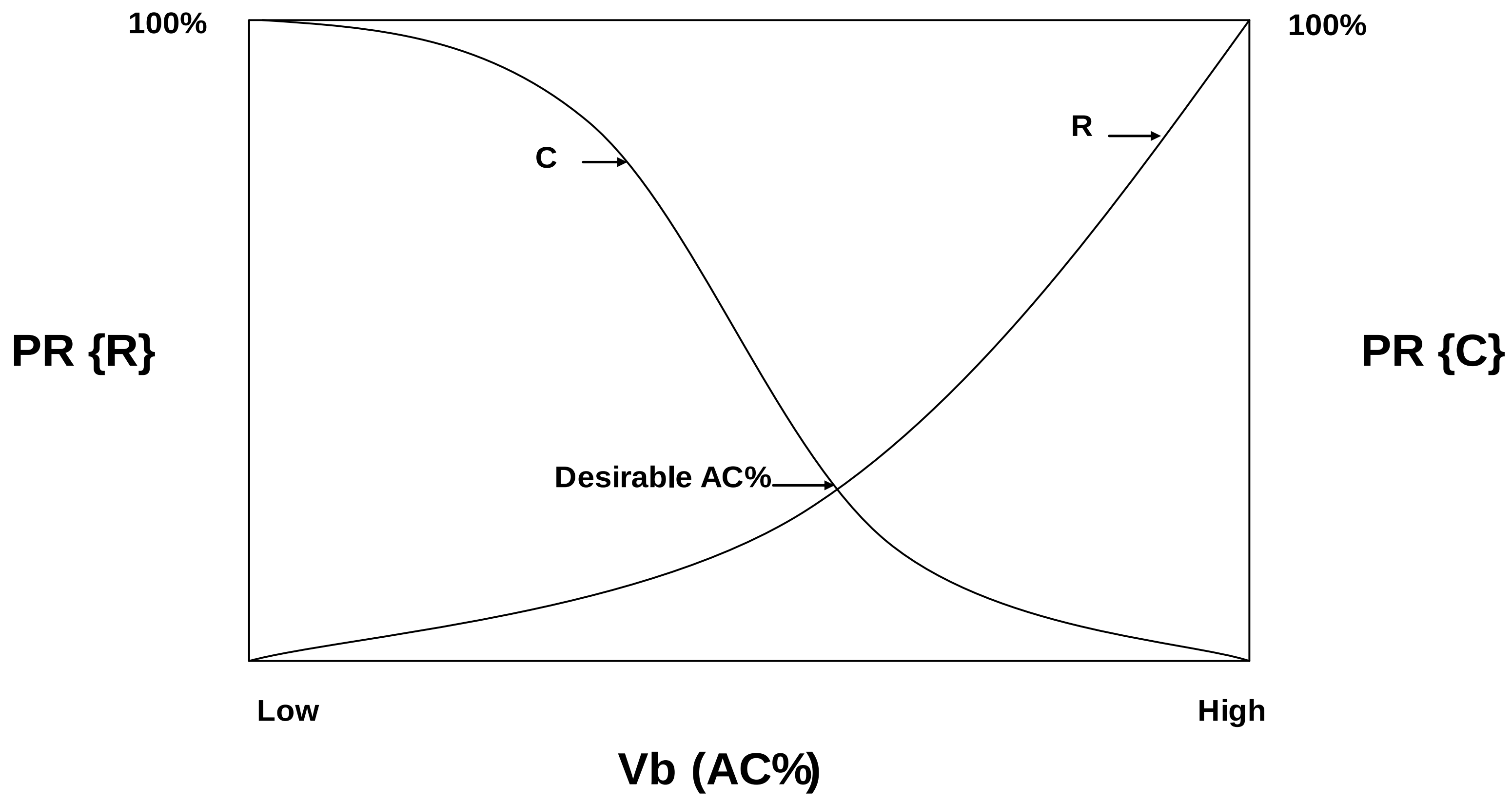
Contributing Mix Factors of Distress

- ***AC Distress Modes***
  - *Moisture Susceptibility*
  - *Raveling*
  - *Thermal Fracture*
  - *Alligator Fatigue Fracture*
  - *Longitudinal Fatigue Fracture*
  - *Block Cracking*
  - *Ageing*
- ***Major Contributing Factors***
  - *Low Vb (AC%)*
  - *High Va%*

Contributing Mix Factors of Distress

- ***AC Distress Modes***
  - ***Rutting***
  - ***Shoving***
- ***Major Contributing Factors***
  - ***High Vb (AC%)***
  - ***Low Va%***

Impact of Vb (AC%) Upon Distress



Principle of TAI MS-2 Mix Design Procedure

- *TAI Marshall followed process of classical, historical USACE procedure until approximately 15+ years ago*
- *At that time , an important addition to the procedure was made by TAI.*
- *It added a minimum Vb criteria to ensure that enough asphalt was always added to the mix to properly coat all aggregate particles with the proper film thickness to resist common durability problems associated with*
    - *Moisture Susceptibility (Stripping)*
    - *Raveling*
    - *Excessive Field Aging*
    - *Significantly Enhance Fracture Resistance of Mix*

TAI MS-2 Minimum Vb

– Min VMA @ Va% (Selected in Marshall)

Dnom	Va=3	Va=4	Va=5
#4	16	17	18
½"	13	14	15
¾"	12	13	14
1"	11	12	13
1 ½"	10	11	12
2"	9.5	10.5	11.5

TAI MS-2 Minimum Vb

– Recognize Vb(min)= VMA(min)-Va

Dnom	Va=4	Va=6	Va=8
#4	13	13	13
½”	10	10	10
¾”	9	9	9
1”	8	8	8
1 ½”	7	7	7
2”	6.5	6.5	6.5

First Major Conclusion

- –Regardless of Va Selected in Marshall
- –Min Vb = f(Dnom)

Dnom	MinVb
#4	13
½”	10
¾”	9
1”	8
1 ½”	7
2”	6.5

Second Major Conclusion

– Since VMA=Va + Vbeff
– Min VMA = f(Dnom & Va Marshall))

		Min VMA for VA% Marshall		
Dnom	MinVb	Va=4%	Va=6%	Va=8%
#4	13	17	19	21
½”	10	14	16	18
¾”	9	13	15	17
1”	8	12	14	16
1 ½”	7	11	13	15
2”	6.5	10.5	12.5	14.5

Third Major Conclusion

– Min Vfa = f(Dnom & Va-Marshall)

		Min Vfa @ Va% Selected in Marshall		
Dnom	MinVb	Va=4%	Va=6%	Va=8%
#4	13	77	69	62
½”	10	71	63	56
¾”	9	69	60	53
1”	8	67	58	51
1 ½”	7	64	55	47
2”	6.5	62	52	45

INTRODUCTION OF THE AC MIX DESIGN WINDOW

TYPICAL AC SPECIFICATIONS (MAY OR MAY NOT BE PRESENT)

Mix Properties

- ***Stability (Min)***
- ***Flow (Min – Max)***
- ***Stiffness (Min)*****
- ***Retained Stability (Min)*****

Mix Volumetrics

- ***Va% (Min – Max)***
- ***Vma% (Min)***
- ***Vfb% (Min – Max)***

TYPICAL AC SPECIFICATIONS (MAY OR MAY NOT BE PRESENT)

Gravimetric Properties

- ***AC% (Min – Max)*****
- ***Dust/Binder Ratio(Min – Max)*****
- ***Knowledge of Gb and Gsb Allows Conversion of Gravimetric to Volumetric Properties***

Mandatory to Include TAI MS-2 Criterion

Dnom Controls Vbeff (Min)

Concept of "Mix Design Window"

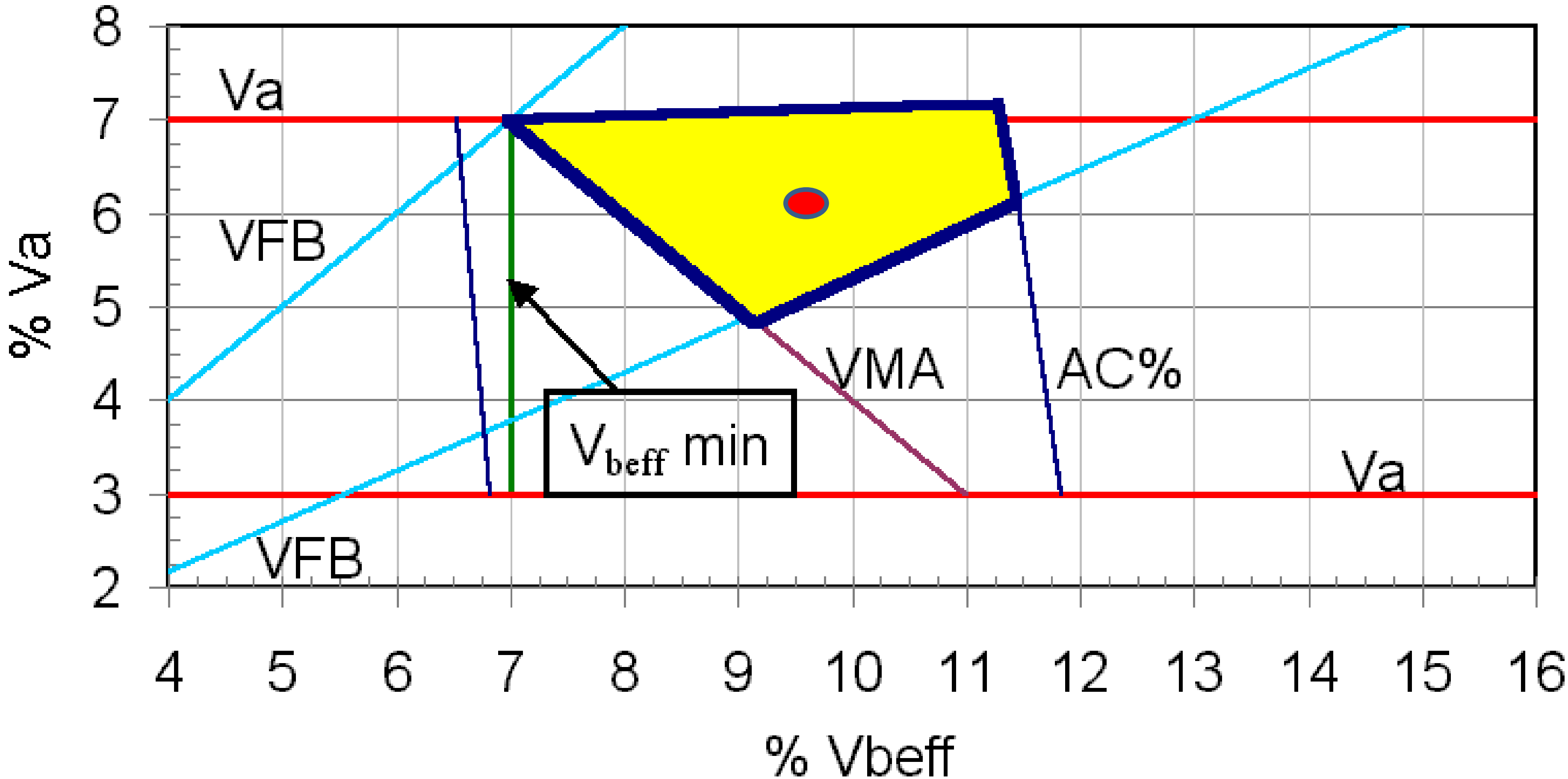
Develop a graphical Picture , called a

"MIX DESIGN WINDOW"

Window is Formed by Superimposing all Specification Volumetric Criterion On Plot of :

Vbeff (x-axis) and Va% (y-axis)

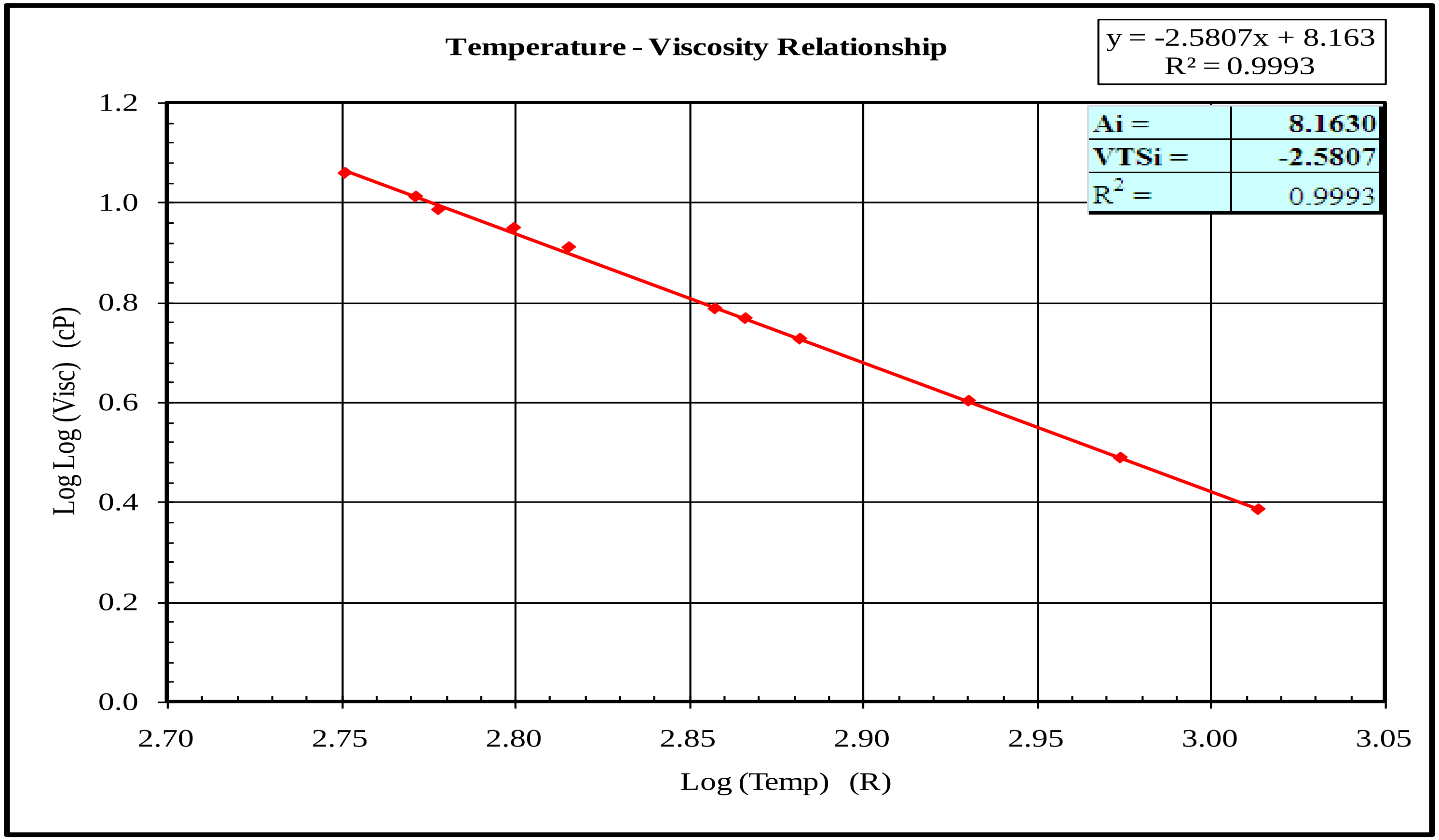
The AC Mix Design Window



IMPACT OF EXCESSIVE HMA MIX (BINDER) AGEING

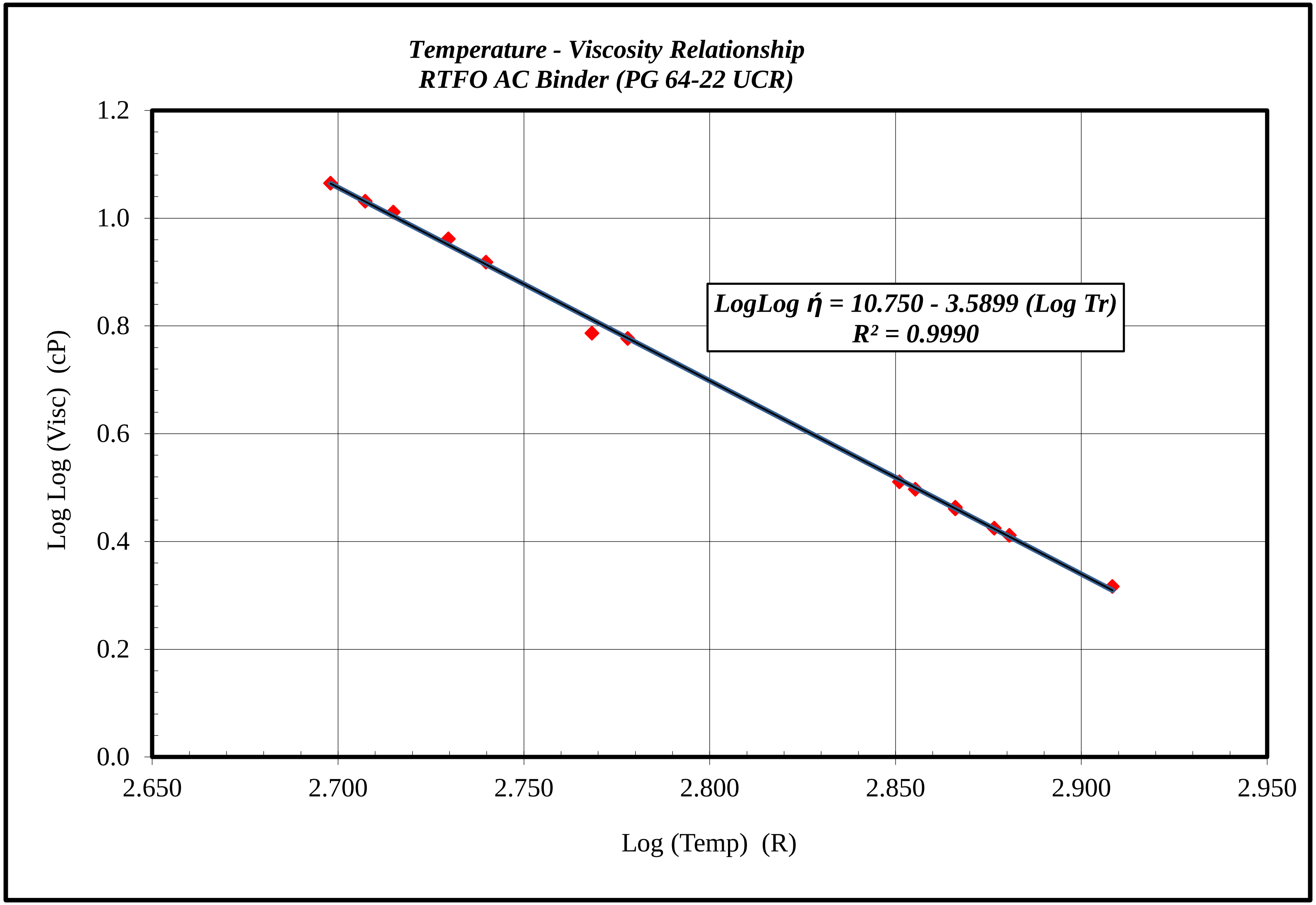
ASTM A_i-VTS_i Viscosity Model

$\log \log \eta = A + VTS \log T_R$



Developing the Ai-VTSi Parameters

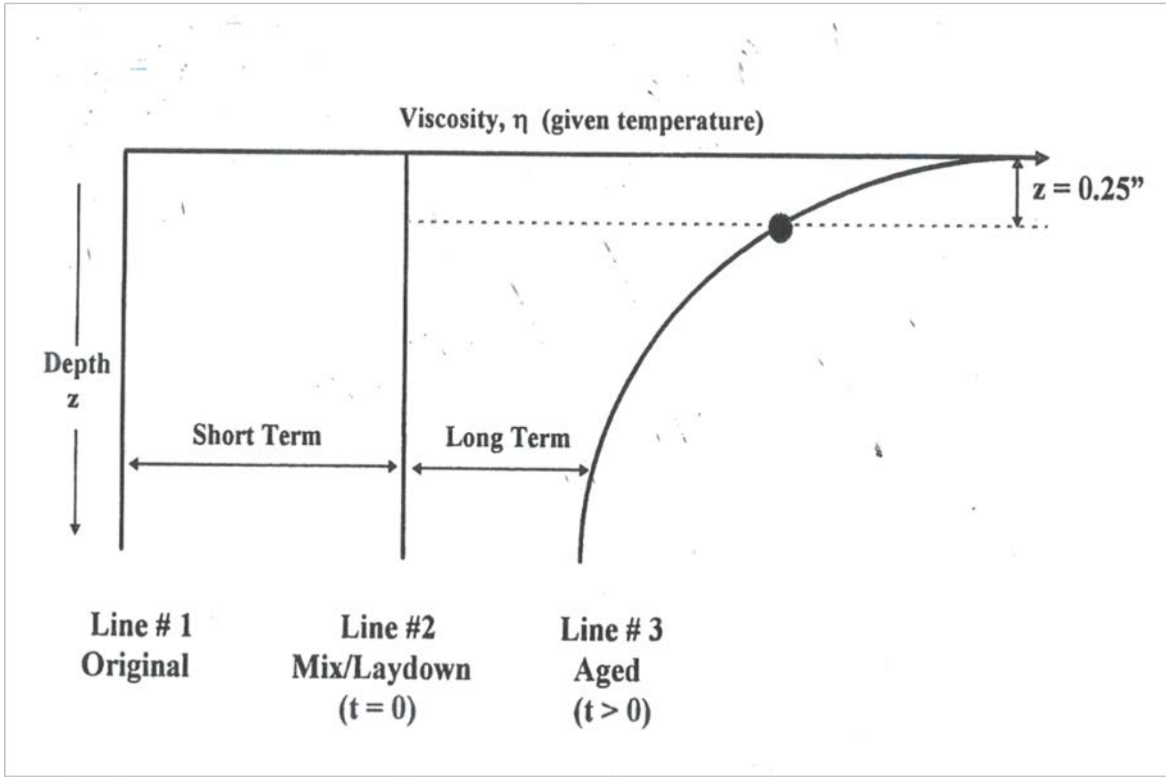
Test	*Temp (C)*	*Temp (F)*	*Temp (R)*	*Log Temp (R)*	*Penetration (.1mm)*	*Viscosity (Poise)*	*Viscosity (cP)*	*LogLog Visc*
Penetration	*4.0*	*39.2*	*498.9*	*2.698*	*2.50*	*4.00E+09*	*4.00E+11*	*1.065*
Penetration	*10.0*	*50.0*	*509.7*	*2.707*	*6.00*	*5.56E+08*	*5.56E+10*	*1.031*
Penetration	*15.0*	*59.0*	*518.7*	*2.715*	*9.90*	*1.80E+08*	*1.80E+10*	*1.011*
Penetration	*25.0*	*77.0*	*536.7*	*2.730*	*30.80*	*1.40E+07*	*1.40E+09*	*0.961*
Penetration	*32.0*	*89.6*	*549.3*	*2.740*	*74.80*	*1.90E+06*	*1.90E+08*	*0.918*
Penetration								
Softening Point, F	*52.7*	*126.9*	*586.6*	*2.768*		*13,000*	*1.30E+06*	*0.786*
Softening Point, F								
Absolute Visc, P	*60.0*	*140.0*	*599.7*	*2.778*		*9566*	*9.57E+05*	*0.777*
Absolute Visc, P								
Kinematic Visc, cst	*135.0*	*275.0*	*734.7*	*2.866*		*782.00*	*8.04E+02*	*0.463*
Kinematic Visc, cst								
Dynamic Visc, cSt	*121.1*	*250.0*	*709.7*	*2.851*		*1690.00*	*1.74E+03*	*0.511*
Dynamic Visc, cSt	*125.0*	*257.0*	*716.7*	*2.855*		*1338.00*	*1.38E+03*	*0.497*
Dynamic Visc, cSt	*135.0*	*275.0*	*734.7*	*2.866*		*748.50*	*7.69E+02*	*0.460*
Dynamic Visc, cSt	*145.0*	*293.0*	*752.7*	*2.877*		*441.40*	*4.54E+02*	*0.424*
Dynamic Visc, cSt	*148.9*	*300.0*	*759.7*	*2.881*		*369.00*	*3.79E+02*	*0.411*
Dynamic Visc, cSt	*176.7*	*350.1*	*809.8*	*2.908*		*114.70*	*1.18E+02*	*0.316*


Temperature - Viscosity Relationship
RTFO AC Binder (PG 64-22 UCR)
LogLog ή = 10.750 - 3.5899 (Log Tr)
R² = 0.9990
Log Log (Visc) (cP)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2.650
2.700
2.750
2.800
2.850
2.900
2.950
Log (Temp) (R)

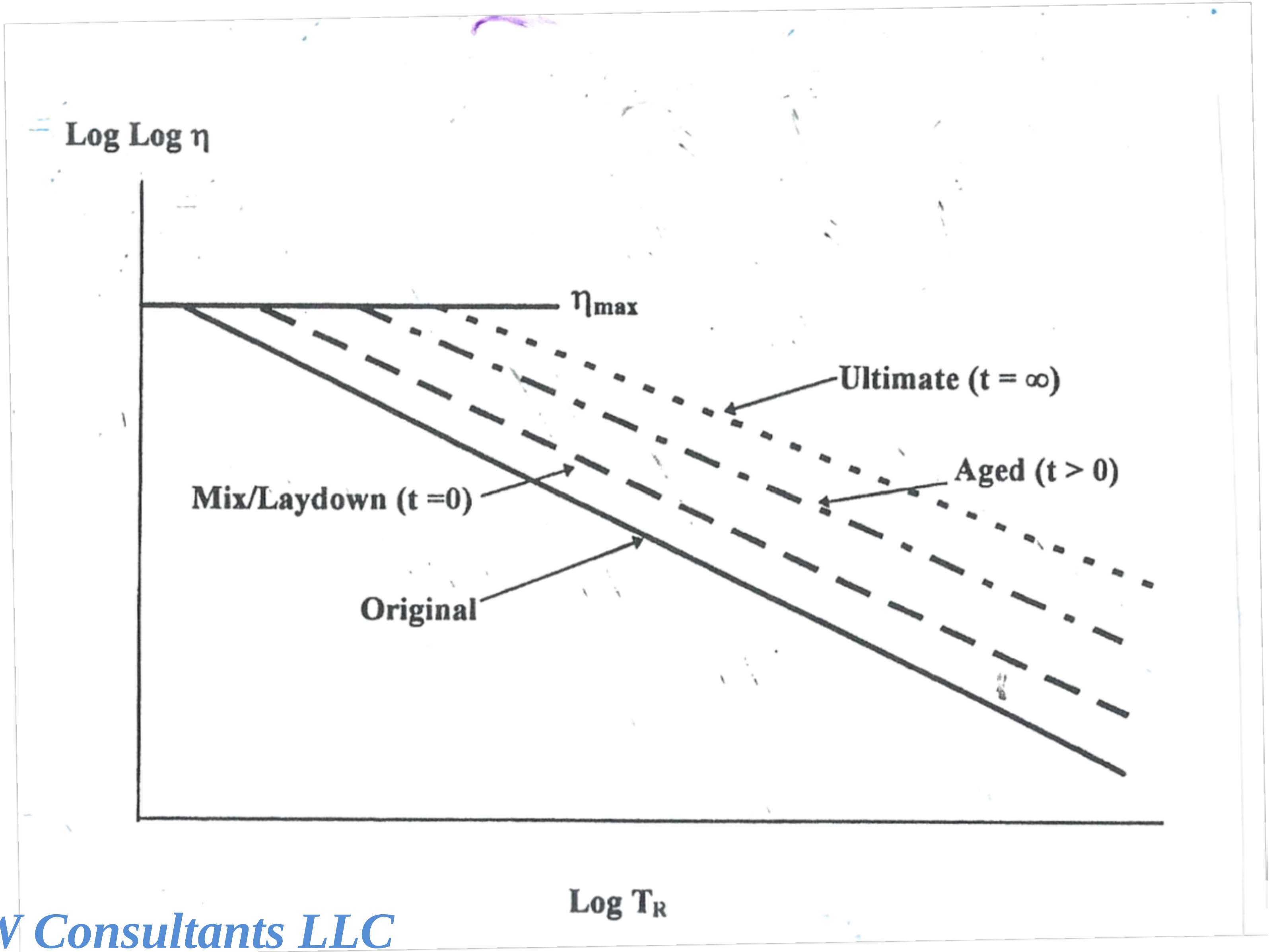
AASHTO MEPDG Global Aging System (Witczak-Mirza Model)

- *Includes 3 Major Models*
  - *Original to Mix / Laydown Model*
  - *Surface Aging Model*
  - *Viscosity Depth Model*

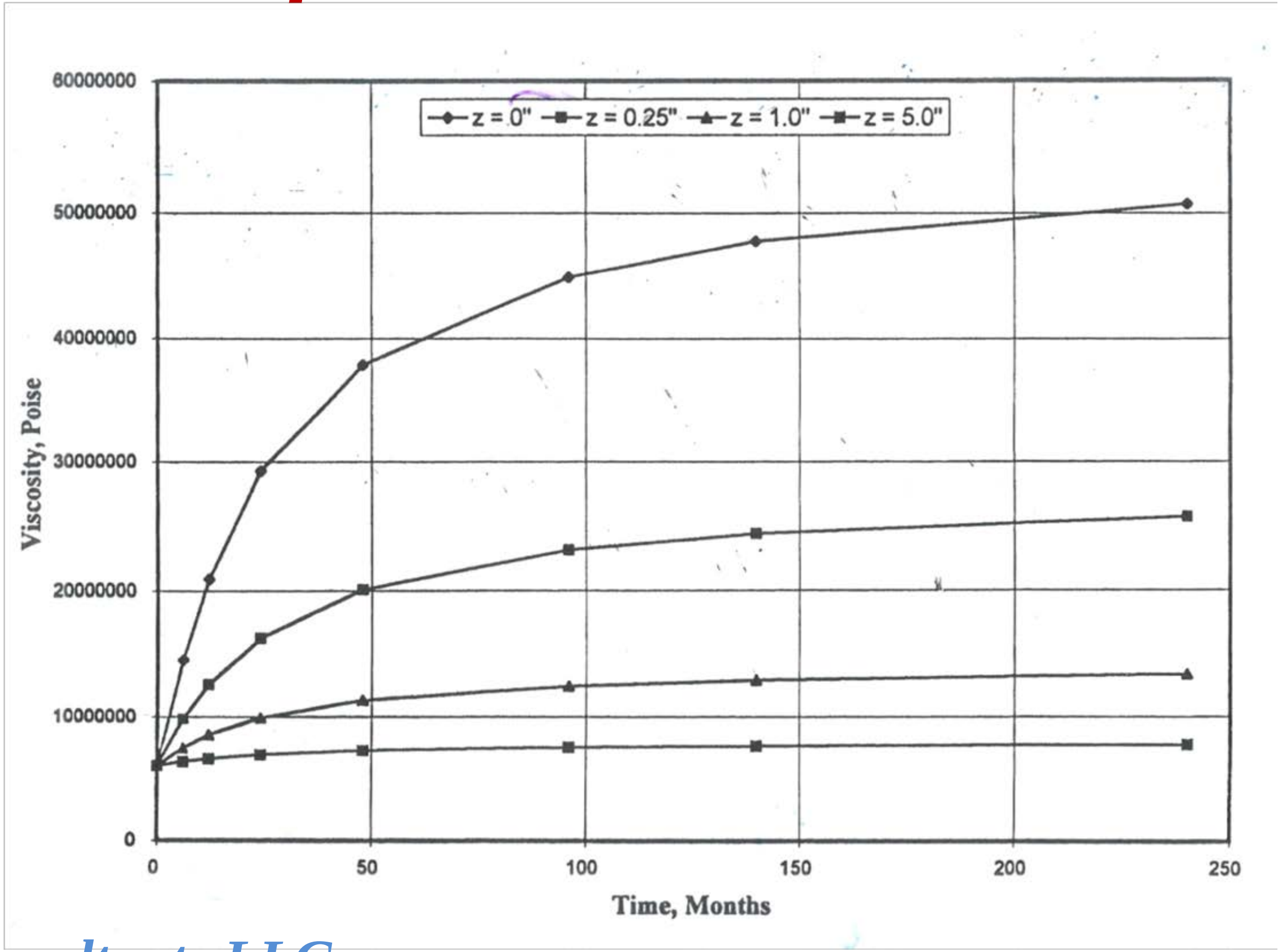
Phases of AC Viscosity Aging



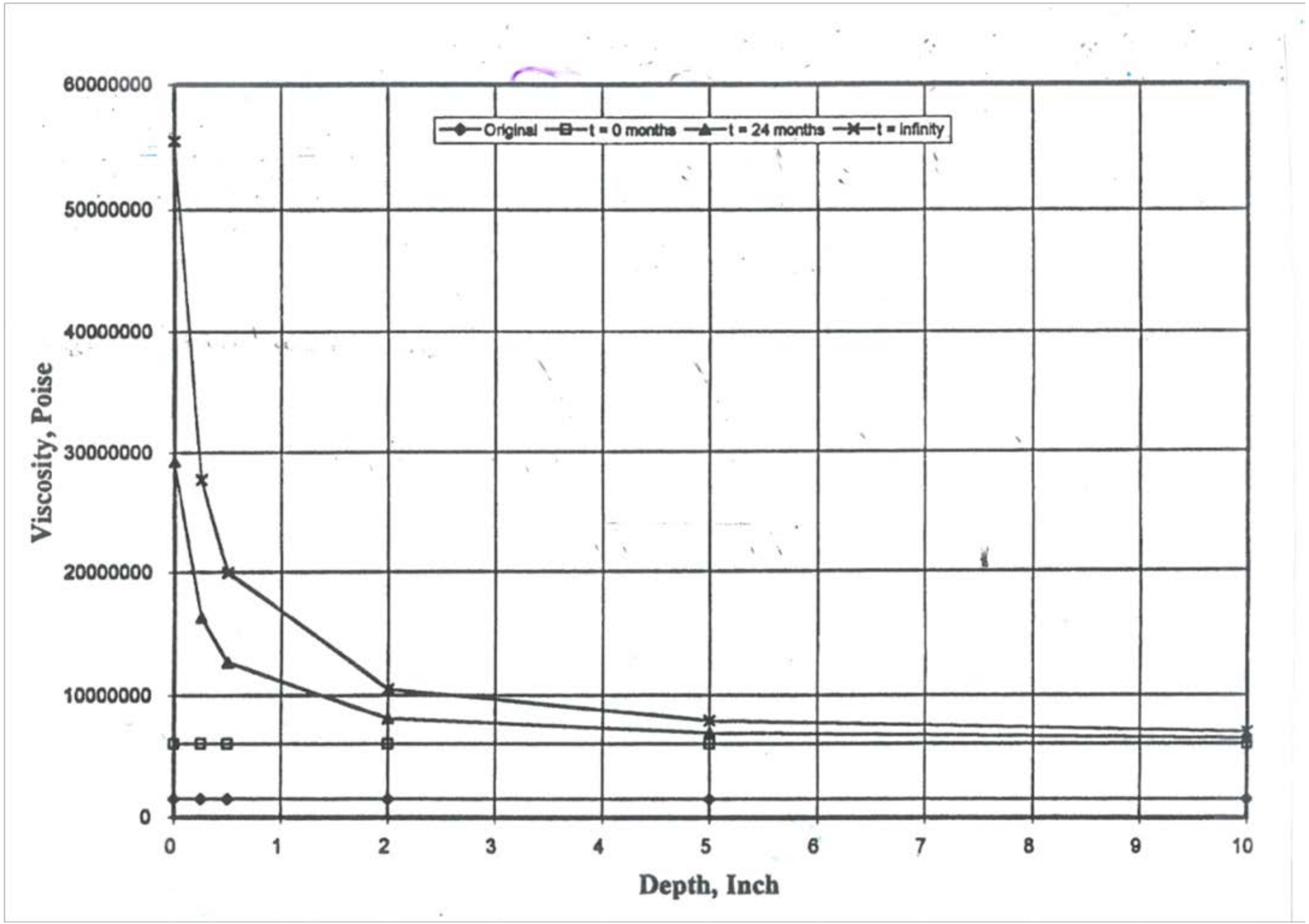
Viscosity Changes at Various Aging Stages



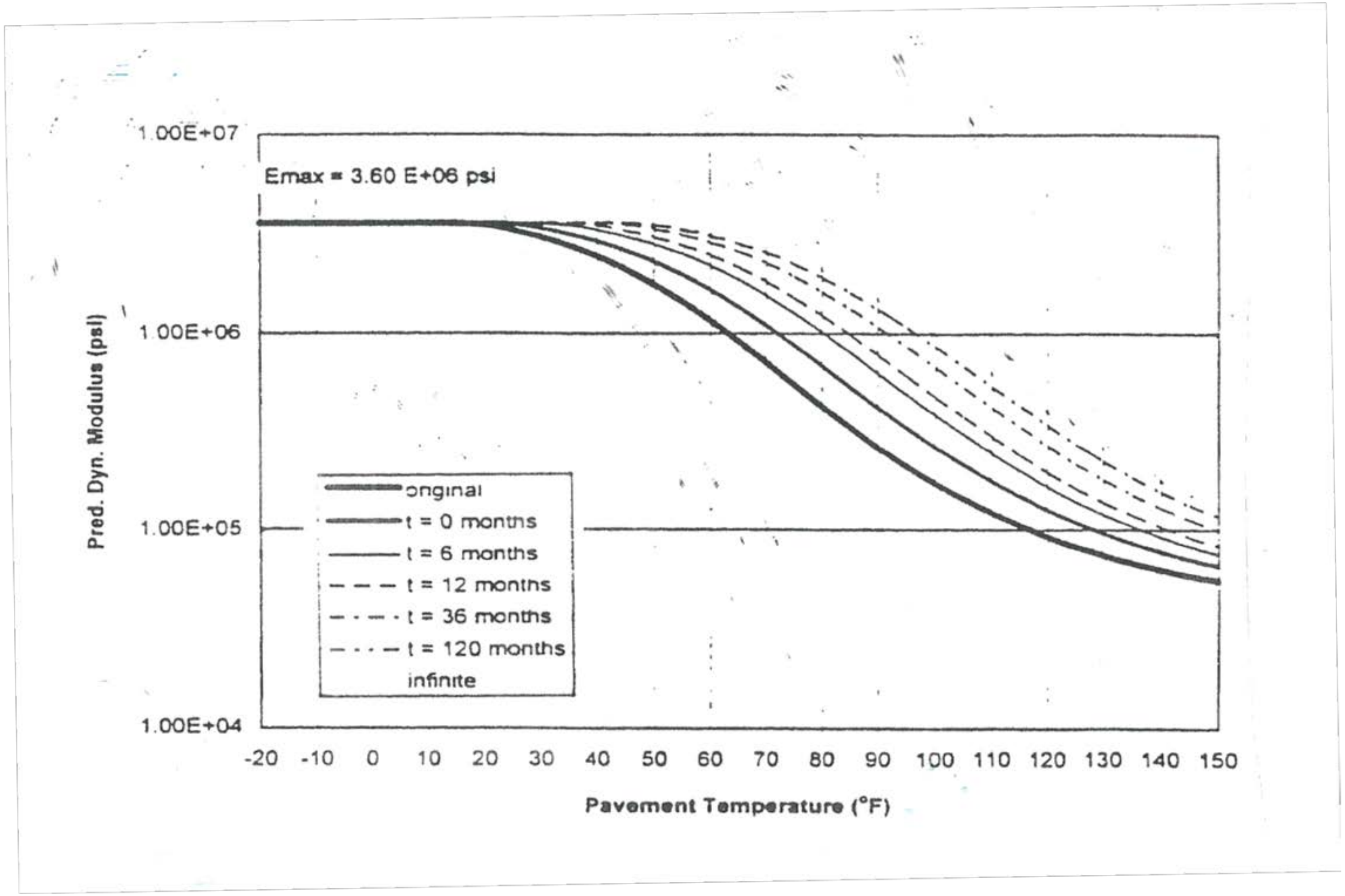
Long Term Field Aging as a Function of the Depth Within the Pavement



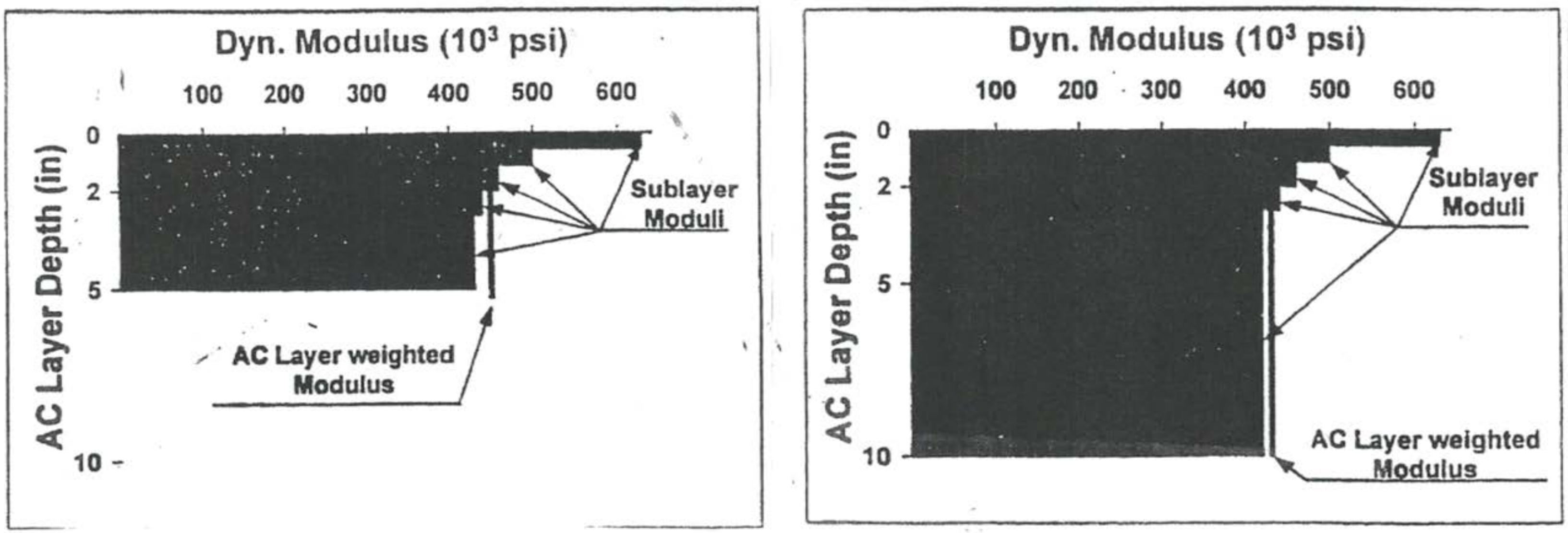
Viscosity Depth Relationships at Various Aging Times



Impact of Aging Upon E* Master Curves



Distribution of E* with Depth Within a Pavement Layer



(Pav. Temperature: 21.1 C [70 F]; MAAT = 4.4 C [40 F]; Asphalt AC-5; Mix Age: 24 months)

Possible Ways to Have Excessive AC Mix Aging in the Mix-Laydown Process

Possible and Very Practical Ways of Occurrence:

1. *Very High Temperatures during the Plant Mixing operations*
2. *Too Long a Mixing Time during the Plant Mixing operations*
3. *Reheating of Mix Several Times after Cooling Down*
4. *Extended Period of Mix Storage in Silos*
5. *Deficiencies from Target Mix Volumetrics (low AC%; and High Air Voids)*

Major Consideration for the Pavement Community in the Greater Phoenix and Arizona Community

- ***Seriously Consider / Fund a Joint Research Program to:***

  "Eliminate Durability Cracking in HMA Pavement Systems in the Southwest United States"

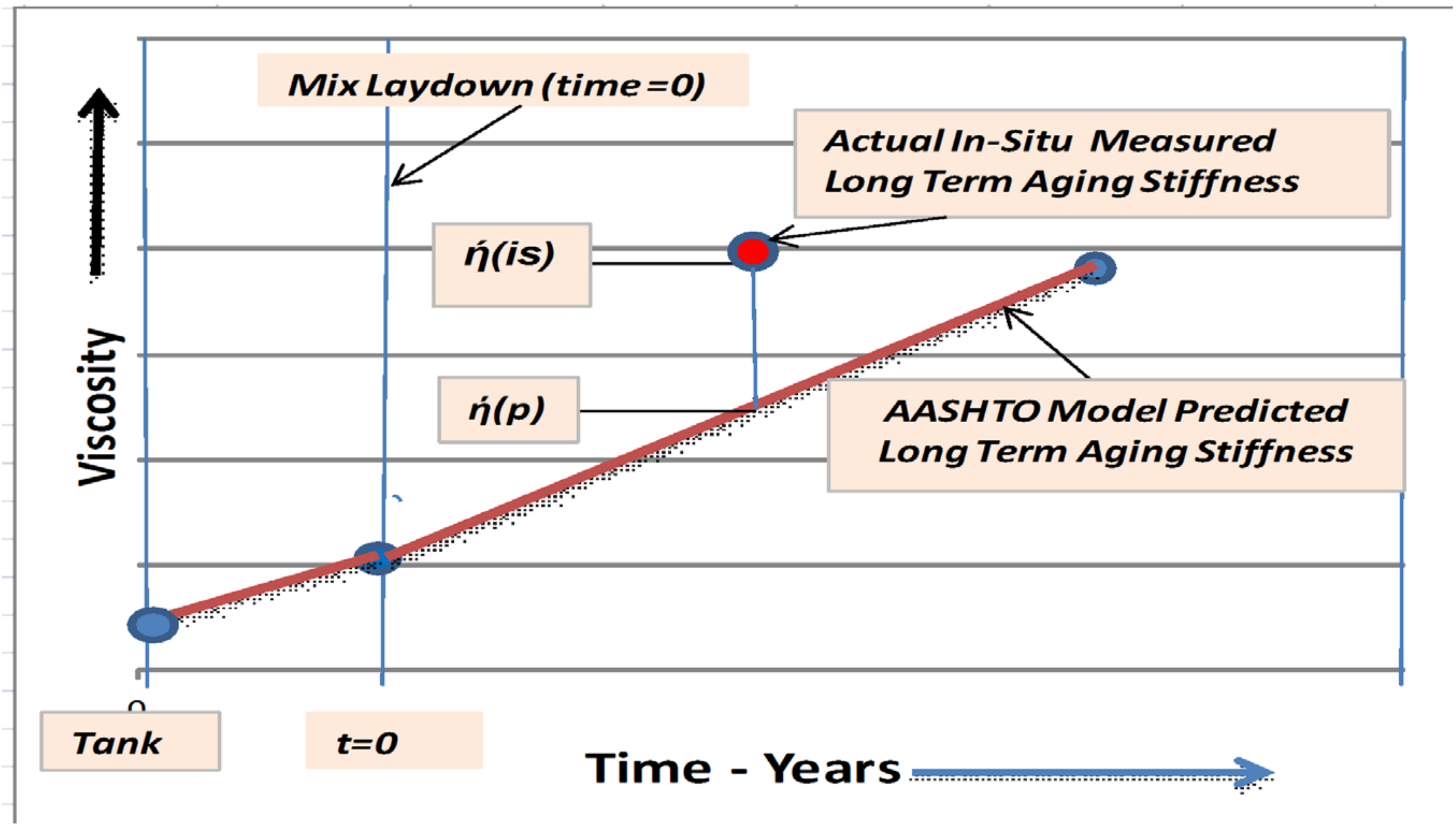
  Multi Agency Involvement

  Economic benefits of Project are Potentially Enormous

Some Background Fundamentals of Project Scope / Analysis

- ***AASHTO MEPDG Already Has Excellent :Typical Properties of Ai – VTSi Parameters of a Wide Range of AC Grades***
  - ***Pen Graded AC Binders***
  - ***Visc Graded Binders***
  - ***PG Graded Binders***
- ***Ai – VTSi Parameters Exist for Following Consistency Conditions***
  - ***Virgin (Tank) Conditions***
  - ***RTFO (Short Term: Mix Laydown) Conditions***
- ***This Information , along with AASHTO Ageing Models, would allow for Forensic Study capability on Actual Projects all over the SW Region***

Basis of Research Analysis for Durability Study



Research Study Basis Using Stiffness (Viscosity) Ratio

- ***For any Given Temperature, Depth, Ageing Time and Environmental Location, the Ratio of the AC Binder Viscosity (ή) or Stiffness (G*), for the Actual In-Situ Measurement to that of the Predicted Value is a Direct Indicator of the Probability of Having Durability Cracking***

- ***If the Ratio ((ήis)/(ήp)) is***

    - ***Ratio is << 1; No Durability Cracking Should Be Present***
    - ***Ratio is = 1 ; Aging is under Normal (Typical) Conditions***
    - ***Ratio is >> 1: Durability Cracking Becomes Very likely as Ratio Increases***

Summary and Conclusions

- ***Current State of Knowledge is Excellent to Eliminate / Minimize Major Pavement related Distresses of:***
  - ***Repeated Load HMA Fatigue Cracking***
  - ***Rutting / Permanent deformation in HMA***
  - ***Surface Rutting Caused by Subgrade Repetitive Shear Deformations***
  - ***Thermal Fracture***
  - ***Moisture Related Distress***

Summary and Conclusions

- ***The Elimination of Durability Related Cracking in AC Layers is Currently the Most Salient (Major) Distress in the Southwest Region of the US that we DO NOT Presently Have a Fundamental Design Methodology or Procedure to Design Against***

- ***AC Durability Cracking (in my Opinion) is the Most Critical Distress that Has Enormous Economic Implications in the Future Maintenance / Rehabilitation of:***

  Primary State / County Highways
  Urban (Residential) Styreet networks
  Private / Industrial Parking facilities

Summary and Conclusions

- ***A Comprehensive , Multi-Agency Project, Based Upon Principles Found in the New AASHTO Design Guide, that is Dedicated to the Elimination of Durability Cracking in AC Pavement Systems is NECESSARY and would Result in an Enormous Benefit / Cost Ratio for a Major Region of the US.***

- ***The Study should Focus on:***
    - ***Defining Limiting Long Term HMA / AC Binder Ageing Stiffness to Values that will not be Conducive to Developing Durability Cracking in the High Temperature Southwest US.***
    - ***Identify Specification Limits (Badly Needed) on AC Binder Stiffness (Consistency) Values Immediately After the Construction Mix/Laydown Process***

The Trip Down The Long Road