DARWin-ME Value Engineering Design From Concept to Construction

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DONGRE LABORATORY SERVICES

Consulting and Testing Services in Asphalt Technology

Kraton

Giving Innovators Their Edge

CAMINEROS

infrastructure transportation development

Acknowledgements

- Bethel LaPlana – DLSI
- Eugeniu Morari – DLSI
- Dr. Shane Underwood – ASU
- Mr. Harold von Quintus – ARA
- Dr. Haleh Azari – AMRL (APRIL Lab)

Outline

- What is Value Engineering Design?
  - Concept
  - Approach
  - Assumptions
- Background
  - What is HiMA?
- Design Approach
  - Objective
  - Laboratory Testing
  - Results and Discussion
  - Pavement Design Results
- Take Away Message

What is Value Engineering Design?

- Concept
  - Highly modified HiMA mixes(7.5% SBS) may be used in construction of pavements with lower layer thicknesses than those using standard modified mixes (3.0% SBS)
    - without a decrease in the resistance to fatigue and rutting and other performance characteristics

Value Engineering Example

Type of Layer	Type of Material	Standard SBS Thickness (cm)	HiMA Thickness (cm)
Asphalt pavement layer	Asphalt Concrete Standard SBS: PG 76S-22 HiMA: PG 76E-22	12.0	7.0
Cement stabilized based	Stabilized with Cement Portland	30.0	25.0
Non-stabilized layer	A-2-4	30.0	30.0
Soil	A-4	Semi-infinite	Semi-infinite

What is Value Engineering Design?

- Approach
  - Use Darwin-ME for pavement design
    - Allows use of laboratory determined damage model coefficients
      - Fatigue and rutting
    - Performance Calibrated
    - Quickly evaluate effect of thickness reduction on fatigue and rutting performance
  - Determine fatigue and rutting coefficients in the laboratory with std. lab tests
    - For both – HiMA and standard mixes

What is Value Engineering Design?

- Assumptions
  - Darwin – ME may be used to predict performance of standard and HiMA mixes using laboratory determined coefficients
    - K factors (global) rather than ß factors (local)
  - Predicted performance is conservative
  - Performance may be further calibrated using field performance data
    - ß factors

Background – what is HiMA?

- HiMA technology uses modified binders with high content of SBS polymer (>7%) to produce hot mix asphalt.
- Basic idea: the high polymer content gives a phase inversion so the binder acts more like asphalt-modified rubber than rubber-modified asphalt with much higher toughness and resilience
- The increased toughness allows for the construction of pavements with lower thickness than traditionally modified binders without a decrease in the resistance to fatigue and deformation.

Value Engineering Design Approach

- Objective
  - Determine the optimum layer thickness of the wearing course and base layers for high modulus mixes made using HiMA
    - Use Darwin-ME for pavement design
      - Mechanistic-empirical design method
      - Requires mix modulus master curve
      - Requires fatigue model coefficients – kf factors for HiMA
      - Requires rutting model coefficients – kr factors for HiMA
  - Compare HiMA layer thicknesses to those determined for standard SBS
    - Determine cost savings for a given life expectancy

DARWIN-ME Data Needs….

- Pavement Design Data for Darwin-ME
- Materials Data
  - Dynamic Modulus of mixes
    - Mix design volumetrics etc
  - Binder G* and phase angle
  - Fatigue coefficients – kf factors
    - endurance limit
  - Rutting coefficients – kr factors
- Unbound layers and subgrade soil data
- Traffic data
- Climate data
- Performance criteria

MATERIALS DATA DETAILS

- Laboratory Mix and Binder Data
  - Dynamic Modulus - AMPT Testing on Mixes
    - Test Temperatures: 10, 40, 68,100 and,130°F
    - Test Frequencies: 0.1, 1.0, 5.0 and 10 Hz
  - Binder G* and phase angle at the same temps at 10 rad/s
    - DSR testing on Binders
  - Fatigue data at one temperature 20C and 4 strain levels
    - AMPT Pull-Pull test S-VECD approach (Dr. R. Kim)
  - Rutting data
    - AMPT Flow number data at 3 temperatures
    - NCHRP 9-30A protocol – Mr. Harold von Quintus

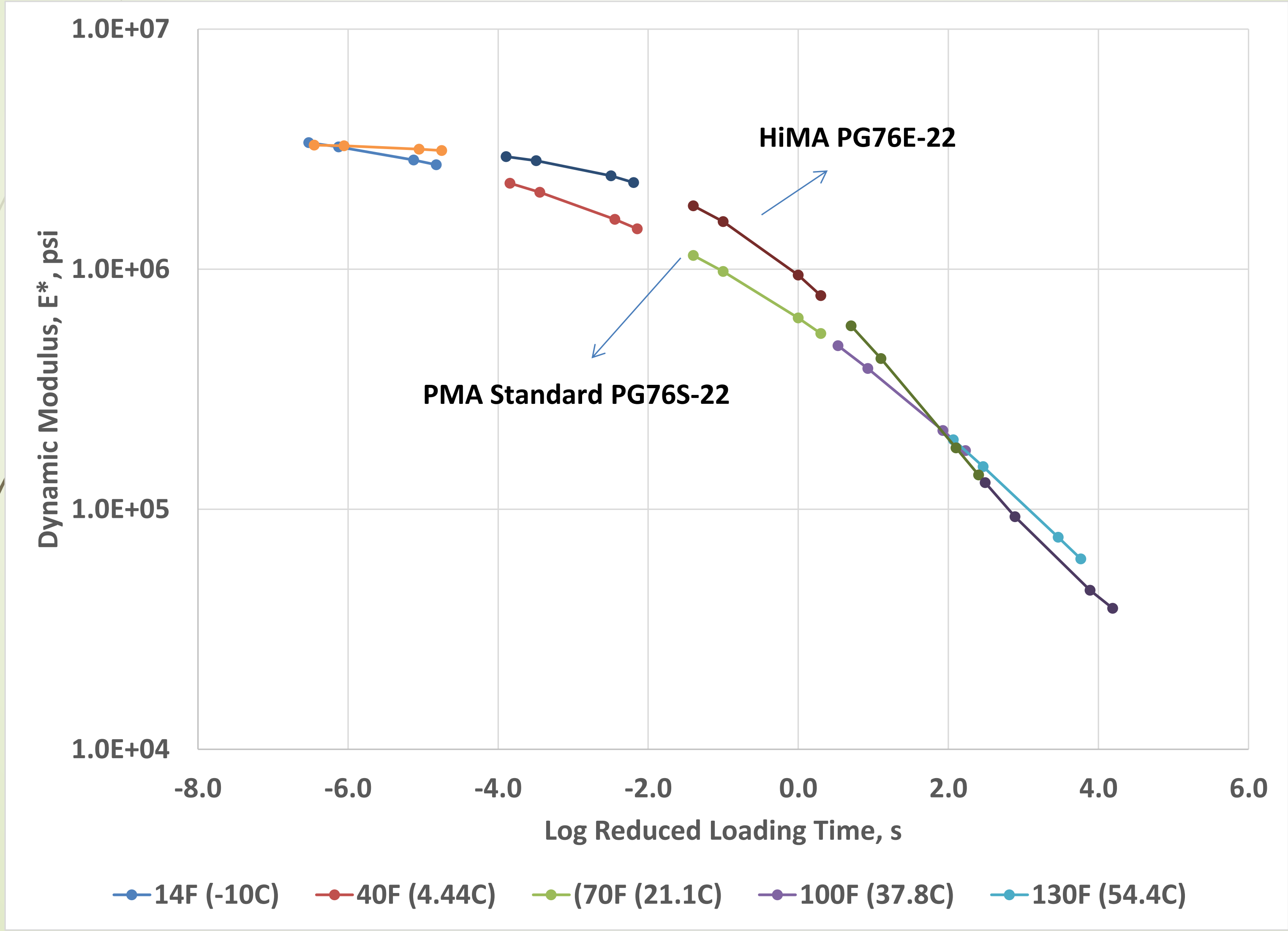
CONVENTIONAL SBS MODIFIED ASPHALT PG76S-22

- The test were done in samples containing Repsol Asphalt binder, Penetration Grade: 85/100 and PG: PG 58-28.
- The asphalt binder was modified with a standard SBS polymer (3.5%)
- Properties and PG values:
  - Softening point: 60°C
  - Elastic recovery: 85% at 25°C after the RTFO
  - Conventional or standard PG: PG 76-22
  - PG with MSCR PG: **PG 76-22S** (J_{nr} > 4kPa^{-1})

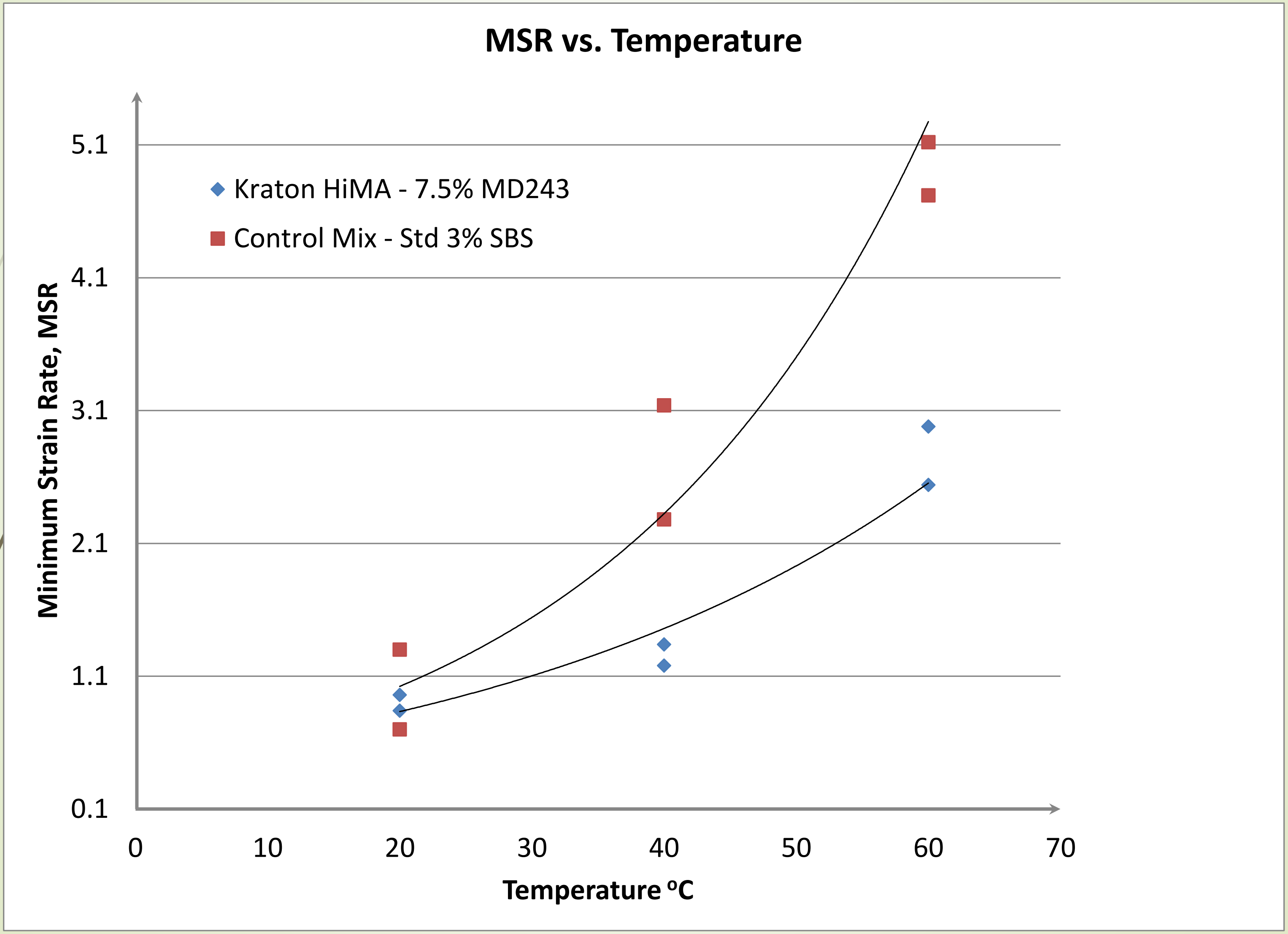
HIGHLY MODIFIED ASPHALT BINDER (HiMA) PG76E-22

- Asphalt binder: REPSOL Refinery (La Pampilla)
  - Penetration grade: 85/100, PG 58-28 (PG 62.33 – 29.88)
- Polymer type: SBS D0243 (Kraton)
  - Polymer content: 7.5%
- HiMA – Highly Modified PMA
  - Softening point, SP: 85 °C
  - Elastic recovery: 95% a 25°C after the RTFO
  - Conventional/Standard PG: PG 94-22
  - PG with MSCR : **PG76-22E** (J_{nr} = 0.1 kPa^{-1})
- The HiMA binder met the temperature and loading requirements of the project.

Dynamic Modulus Master Curves



iRLPD Method for Rutting Performance – Azari Method



Determination of CALIBRATION FACTORS/Coefficients

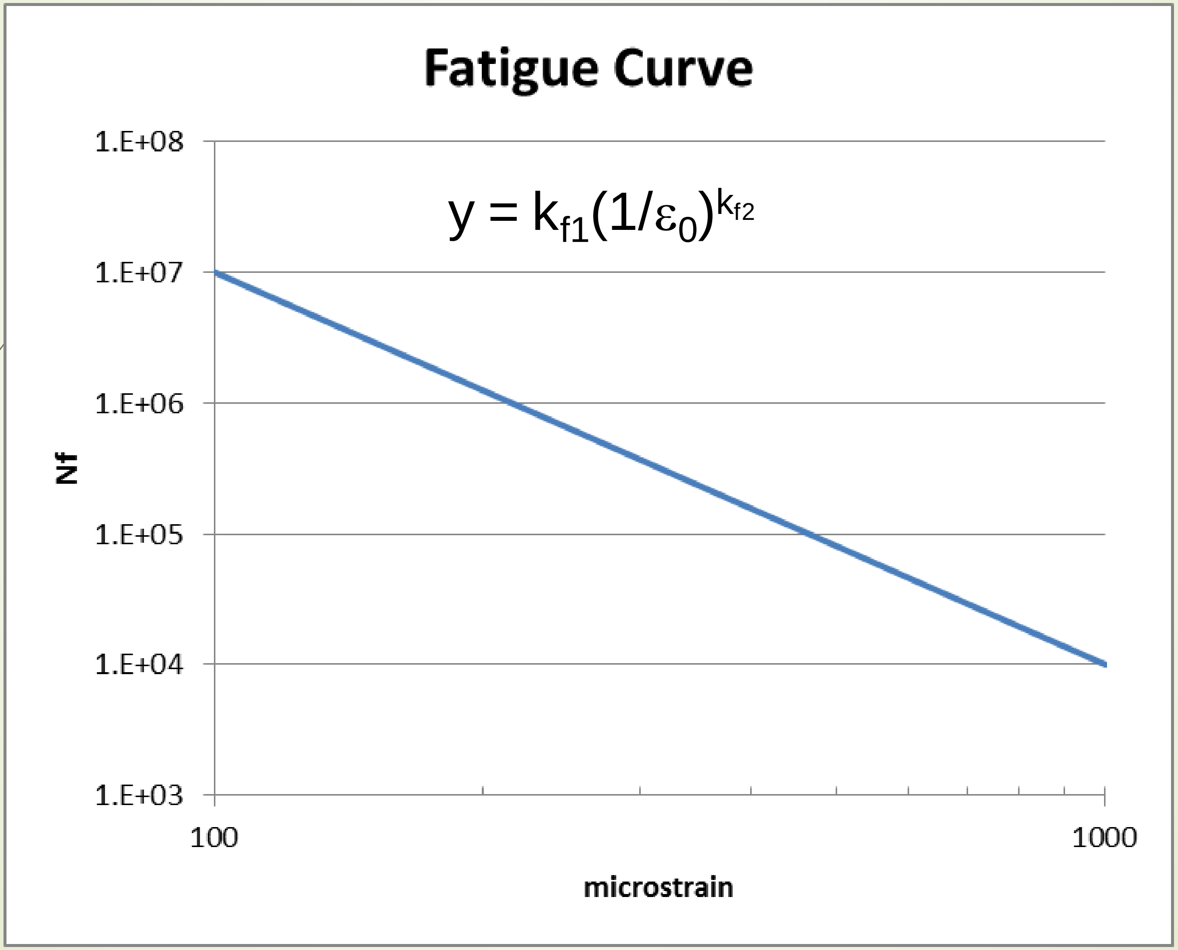
FATIGUE Model

RUTTING Model

DARWIN-ME Model– Fatigue

- $N_{f\text{-}HMA} = k_{f1}(C)(C_H)\beta_{f1}(\varepsilon_t)^{kf2\beta f2}(E_{HMA})^{kf3\beta f3}$
- Where:
- $N_{f\text{-}HMA}$ = Allowable axle load applications
- ε_t = Tensile strain
- E_{HMA} = Dynamic modulus measured in compression
- $k_{f1,f2,f3}$ = Global field calibration parameters
- $\beta_{f1,\ f2,\ f3}$ = local or mixture field calibration factors
- C = volumetrics parameter (asphalt content and air voids)
- C_H = Thickness correction term (depends on type of cracking)

Calibration Factors
Fatigue Model - Darwin - ME



$$y = k_{f1}(1/\varepsilon_0)^{k_{f2}}$$

Fatigue Calibration

- Determine N_f versus strain curve
- Fit k_{f1} and k_{f2} to curve
- Measure modulus and reverse fit k_{f3}
- Extrapolate to N_f = 50MM for endurance limit

- Options for fatigue testing:
- Standard 4 point bending beam
- NCSU S-VCED model and procedure using AMPT
- AAT S-VECD model and procedure using AMPT

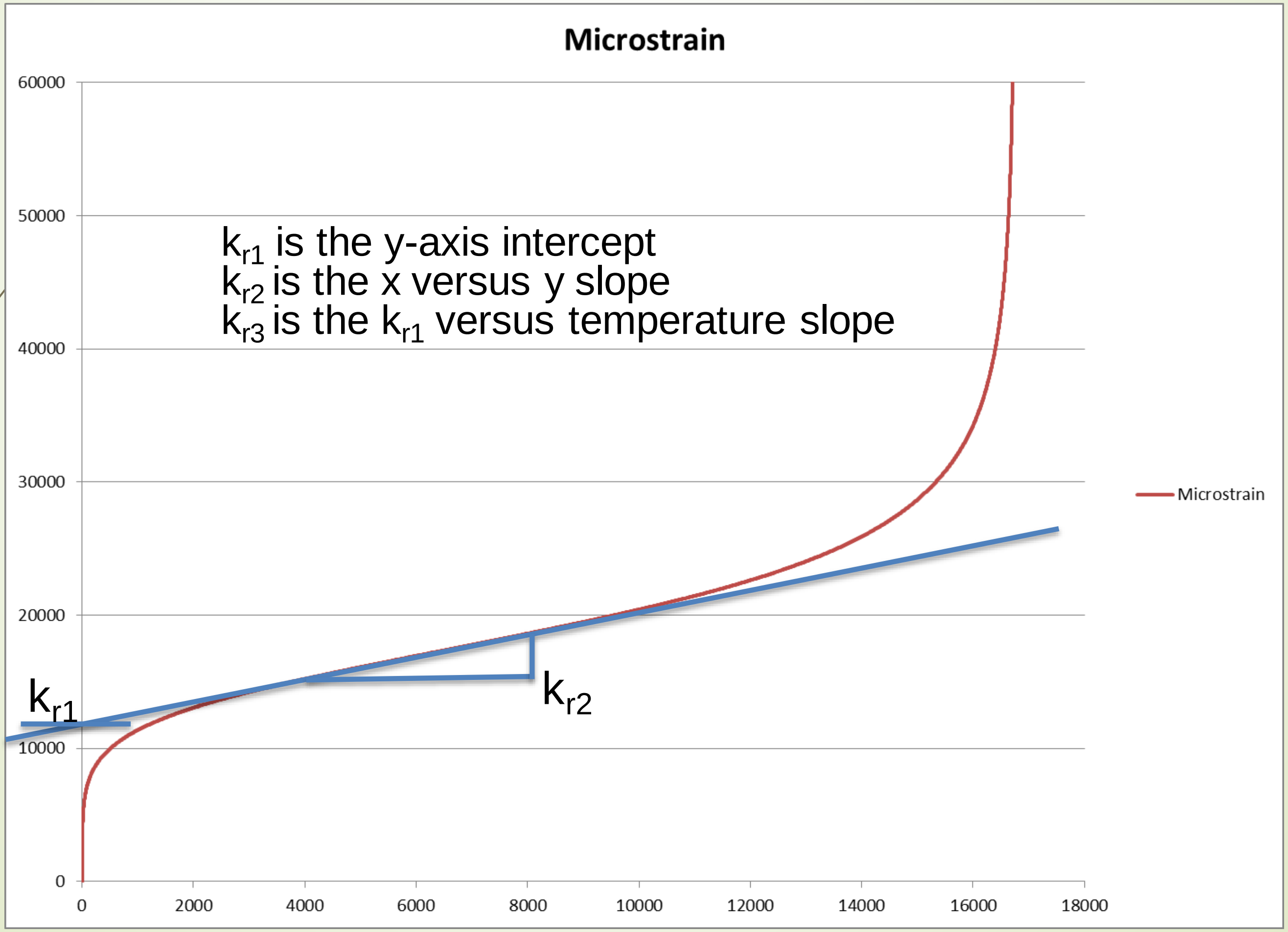
Fatigue Calibration Coefficients

Mix Type	Fatigue Factors		
	kf1	kf2	kf3
DarWin-ME - Default PG 76-22	7.57E-03	3.95	1.28
PERU Mix - Std. PMA PG 76S-22	4.10E+14	9.01	-6.6
PERU Mix - HIMA PG76E-22	4.10E+20	9.69	-7.6

DARWIN-ME Models - RUTTING

- $\Delta_{p(HMA)} = \varepsilon_{p(HMA)} h_{HMA} = \beta_{r1} k_z \varepsilon_{r(HMA)} 10^{kr1} \eta^{kr2\beta r2} \mathbf{T}^{kr3\beta r3}$
- Where:
- $\Delta_{p(HMA)}$ = Accumulated vertical plastic (permanent) deformation
- $\varepsilon_{p(HMA)}$ = Accumulated axial plastic strain
- $\varepsilon_{r(HMA)}$ = Calculated mid-depth resilient strain
- h_{HMA} = Thickness
- η = number of axle load repetitions
- **T** = pavement temperature
- k_z = depth confinement factor
- $k_{r1,r2,r3}$ = global field calibration parameters
- $\beta_{r1,r2,r3}$ = local or mixture field calibration factors

Calibration Factors
Rutting Model - Darwin - ME



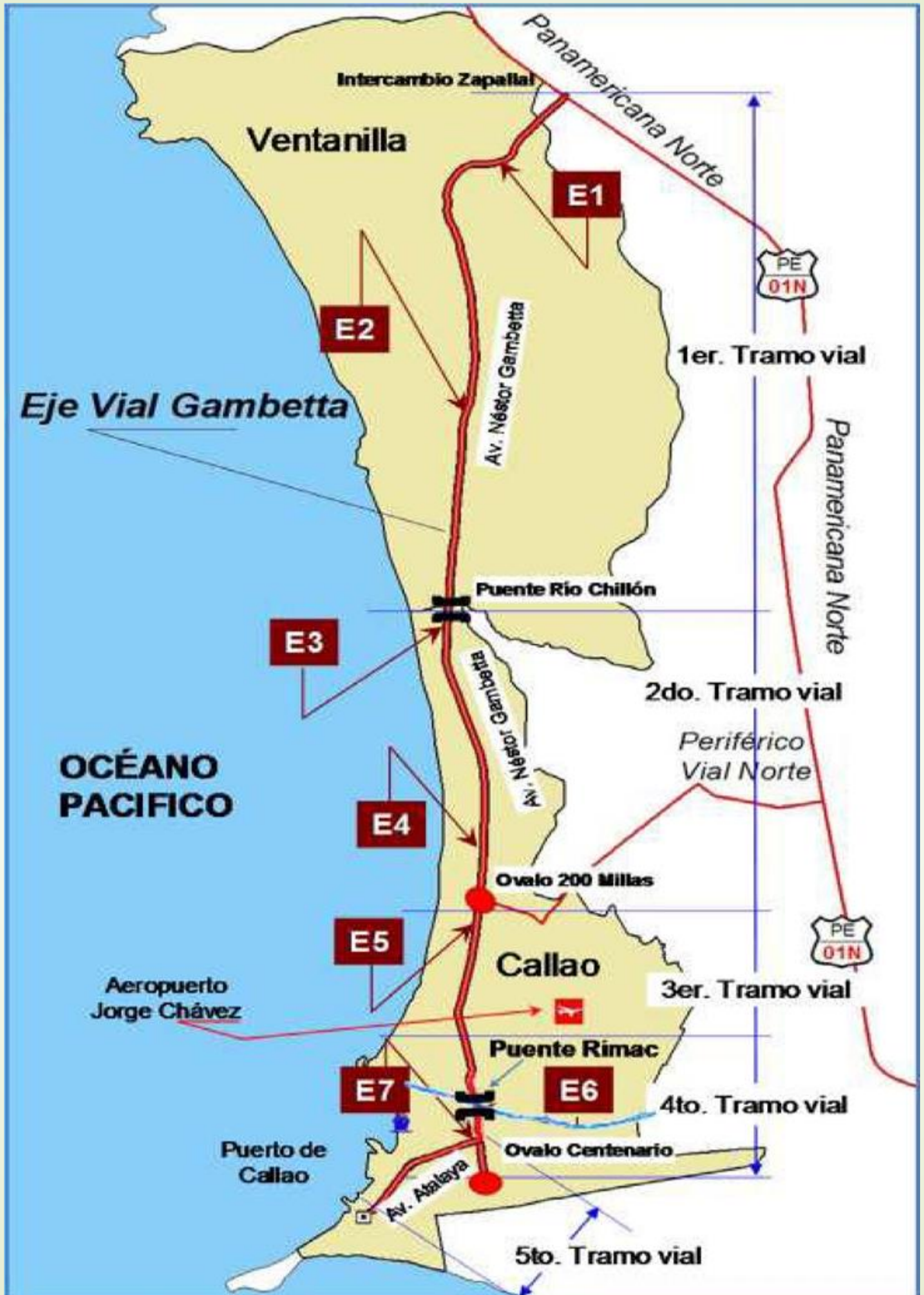
Rutting Calibration – NCHRP 9-30A Protocol

- This is the 9-30A protocol, but similar data can be generated with, e.g., Hamburg or APA
- Run AMPT Flow Number (F_n) at 3 temperatures, 70 psi load, 10 psi confinement. Temperatures are 20 °C, (LTTP 50% reliability temp -5 °C) and midpoint. Typical would be 20 °C, (64-5) = 59 °C and 39.5 °C
- k_{r1} = y axis intercept of secondary flow tangent
- k_{r2} = slope of secondary flow
- k_{r3} = slope of k_{r1} versus temperature plot

Laboratory Rutting Calibration Coefficients

Field Matched ME Design Calibration Factors (Ref. 9-30A Standard Procedure)						
Mix Type	Log10 Slope	Log10 Intercept	Rutting Calibration Factors			Comments
	µs/cycle	µs	kr1	kr2	kr3	
UnMod	DARWIN-ME Default		-3.35412	1.5606	0.4719	Global Calibration USA
PMA	DARWIN-ME Default		1.13*(-3.35412)	1.5606	0.4719	AI Report VonQuintus ER-235
Std. PMA PG76S-22	DLSI Study		-2.6000	1.3317	0.2400	DLSI Laboratory Data
HiMA PG76E-22	DLSI Study		-2.3000	0.0694	0.2200	DLSI Laboratory Data

PROJECT



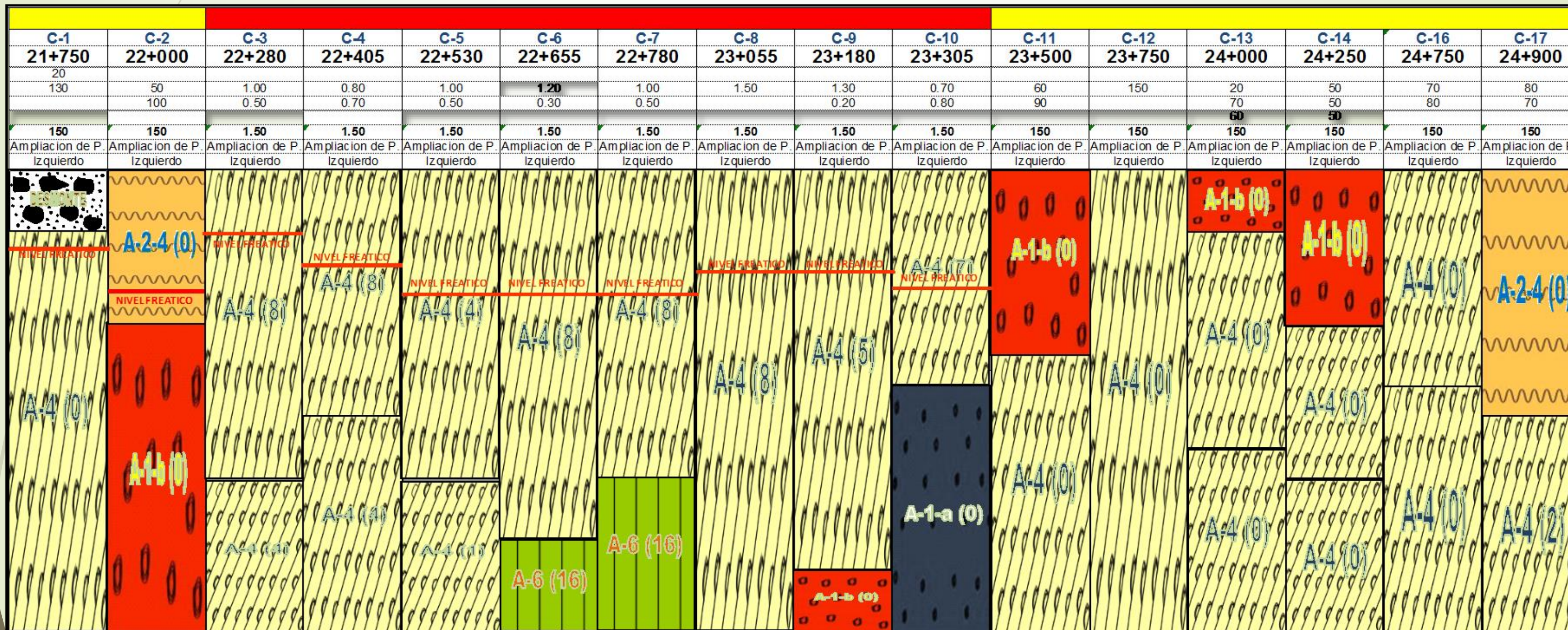
Intercambio Zapallal
Panamericana Norte
Ventanilla
E1
PE 01N
E2
Av. Néstor Gambetta
1er. Tramo vial
Eje Vial Gambetta
Panamericana Norte
Puente Río Chillón
E3
2do. Tramo vial
Av. Néstor Gambetta
Periférico Vial Norte
OCÉANO PACIFICO
E4
Ovalo 200 Millas
E5
PE 01N
Callao
3er. Tramo vial
Aeropuerto Jorge Chávez
Puente Rimac
E7
E6
4to. Tramo vial
Puerto de Callao
Ovalo Centenario
Av. Atalaya
5to. Tramo vial

TRAFFIC

- IMDA (Total) : 21,232 vpd
- IMDA (Right lane): 10,394 vpd
- IMDA (Left lane): 10,838 vpd
- Type of vehicle:
  - Light Duty Vehicle: 67.7%
  - Heavy Duty Vehicle: 32.3%
- Growth rate:
  - Light Duty Vehicle: 2.5-3.0%
  - Heavy Duty Vehicle: 3.4%
- ESALS (20 years) : 63 x10^6 Equivalent axles at 80kN

SOIL PROFILE

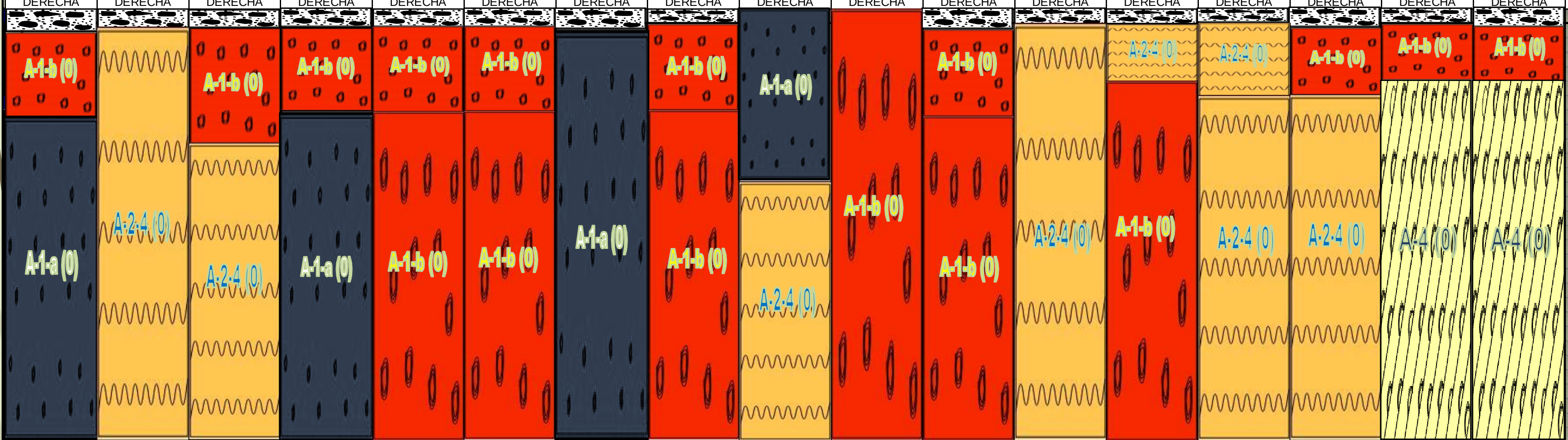
Left lane



A-1-a A-1-b A-2-4 A-4 A-6

SOIL PROFILE
Right lane

C-72	C-73	C-74	C-75	C-76	C-77	C-78	C-79	C-80	C-81	C-82	C-83	C-84	C-85	C-86	C-87	C-88
21+700	22+000	22+100	22+200	22+350	22+500	22+700	22+705	22+860	23+250	23+400	23+650	23+900	24+250	24+500	24+660	24+900
7	6	6	6	6	6	6	5			7	6	6	5	6	5	6
30	144	40	30	30	30	144	30	60	150	30	144	20	25	25	20	20
113		104	114	114	114		115	90		113		124	120	119	125	124
150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150	150
Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente	Plat. Existente
DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA	DERECHA



A-1-a A-1-b A-2-4 A-4

CLIMATIC CONDITIONS

- The climatic study used data from the CORPAC Meteorological station (Jorge Chavez airport).
- In particular, the minimum and maximum temperature values during the last 10 years (2002-2011).
- The objective of the study was to establish the required PG of the asphalt mixes.

CLIMATIC CONDITIONS

Temperatura del Aire:

Máxima (prom)	:	28.9 °C (50% Confiabilidad)
Desv. Std.	:	1.0 °C
Máxima (R=98)	:	30.9 °C (98% Confiabilidad)
Minima (prom)	:	13.6 °C (50% Confiabilidad)
Desv. Std.	:	0.7 °C
Mínima (R=98)	:	12.1 °C (98% Confiabilidad)

Temperatura máxima del pavimento (TPmax):

Latitud	:	12.00 °
T superficie	:	55.1 °C (Modelo SHRP 1999)
H	:	20 mm (Profundidad estándar de medición)
TPMAX	**:**	**53.9 °C (Modelo SHRP 1999)**
TPMAX	**:**	**57.8 °C (Modelo LTPP)**
TPMAX	**:**	**55.9 °C (Método Experimental Camineros)**
TPMAX MAX	**:**	**57.8 °C (Máximo Maximorum)**

Temperatura mínima del pavimento (TPmin):

TPMIN	**:**	**12.1 °C (Modelo Canadiense)**
TPMIN	**:**	**12.1 °C (Modelo Superpave)**

PG 58-10 (PG value according to the climatic conditions)

CLIMATIC CONDITIONS

- PG value according to the climatic conditions:

  PG 58-10
- Volume of traffic: $63x10^6$ ESAL'S (> 30 M)
- Slow and static loads (Vprom< 20 km/h)
- PG value according the volume of traffic:

  PG 58-10E (J_{nr}< 0.5 kPa^{-1})

VERIFICATION OF THE PAVEMENT DESIGN

DARWIN - ME

DARWIN-ME Designs

Type of Layer	Type of Material	Standard SBS Thickness (cm)	HiMA Thickness (cm)
Asphalt pavement layer	Asphalt Concrete Standard SBS: PG 76S-22 HiMA: PG 76E-22	12.0	7.0
Cement stabilized based	Stabilized with Cement Portland	30.0	25.0
Non-stabilized layer	A-2-4	30.0	30.0
Soil	A-4	Semi-infinite	Semi-infinite

DARWIN-ME – Pavement Structures

ALTERNATIVA ASFALTO MODIFICADO SBS ESTANDAR

CA Pol.SBS STD.	12 cm
Base Cementada Alto Módulo	30 cm
Sub-base Granular	30 cm

ALTERNATIVA ASFALTO MODIFICADO HIMA

CA Pol.SBS STD.	7 cm
Base Cementada Alto Módulo	25 cm
Sub-base Granular	30 cm

Performance Prediction DARWIN - ME

Distress Type	Distress @ Specified Reliability		
	Target	Predicted	
		CONTROL (STD. SBS)	HiMA
Terminal IRI (in./mile)	168.00	145.41	138.66
Permanent deformation - total pavement (in.)	0.75	0.72	0.55
AC bottom-up fatigue cracking (percent)	17.00	1.45	1.45
Total Cracking (Reflective + Alligator) (percent)	100.00	4.48	4.48
AC thermal fracture (ft/mile)	1000.00	27.17	27.17
AC top-down fatigue cracking (ft/mile)	2000.00	413.37	256.48
Permanent deformation - AC only (in.)	0.25	0.45	0.22

Crucial Point for DARWin ME Design

- Note that we adjusted the <u>global</u> calibration parameters in this analysis, not the <u>local</u> calibration factors.
- Local calibration requires data from actual local pavement performance and materials which we do not have.
- Consequently, we cannot do an "absolute" pavement design and predict performance.
- What we <u>can</u> do is a relative pavement design, comparing a HiMA pavement to a standard one, and give a high confidence expectation of relative performance.

Take Away Message - Findings

- Highly Modified Binders maybe used to reduce Layer Thickness
- Darwin-ME calibration factors maybe determined successfully in the Laboratory
  - AMPT Pull-Pull test and S-VECD for Fatigue Coefficients
  - NCHRP 9-30A for Rutting Coefficients

Thank You!