COLORADO
Department of Transportation
Region 2

Region 2 Materials Unit
5615 Wills Blvd
Pueblo, CO 81008
(719) 562-5532

PROJECT INFORMATION:
PCN: 23558/23559
PRJ: FBR R200-266/FBR R200-267
LOC: US 24 & CO 9 Locations

February 1, 2021

TO: Cynthia Bailey
FROM: Jeri Mero
SUBJECT: Pavement Justification Report

This project will consist of the replacement of 6 structures along US 24 in Fremont and Park Counties and three structure along CO 9 in Teller and El Paso Counties. Improvements will consist of the replacement of the structure and associated roadway work. At this time, it is understood that a determination has not been made if a bridge or culvert will replace the existing structures. The recommendations contained herein will be suitable for each option.

Table 1 and 2 consists of a detailed list of structure locations and approximate milepost along US 24 and CO 9. As this project will consist of approach work adjacent to existing Hot Mix Asphalt Pavement, a Life-Cycle Cost Analysis comparing Asphalt to Concrete was not performed. Instead, an alternate to utilize Hot Mix Asphalt (HMA) is being recommended. This is in accordance with the 2021 CDOT Pavement Design Manual, Section 13.2.

At this time, it is understood that the project will utilize the Design/Build alternative project delivery method. It is understood the CDOT Region 2 North and South Program will produce 30% plans for advertisement of the RFP. The recommendations supplied herein could be considered final if the project scope and assumptions above do not change significantly.

Table 1: US 24 Structure Replacement Locations

R2B2 Phase I - US 24 Locations					
Subaccount No.	Structure Name	Approximate MP	AADTT	Drivability Life	Pavement Distress
23558	I-13-G	227.095	130	8	Moderate Transverse Cracking
23558	H-13-N	240.686	240	4	Moderate Transverse Cracking
23558	I-15-T	271.691	300	3	Low Transverse Cracking
23558	I-15-AO	271.9	300	3	Low Transverse Cracking
23559	I-13-H	229.468	130	8	Moderate Transverse Cracking
23559	I-17-X	295.442	900	12	High Transverse Cracking

Table 2: CO 9 Structure Replacement Locations

R2B2 Phase I - SH 9A &C Locations					
Subaccount No.	Structure Name	Approximate MP	AADTT	Drivability Life	Pavement Distress
23558	J-15-G	15.97	100	8	Moderate Transverse Cracking
23558	J-14-C	20.107	100	7	Moderate Transverse Cracking
2355	G-12-C	71.445	130	9	Moderate Transverse Cracking
23559	P-19-G (Minor)	1.74	13	5	Moderate Transverse Cracking

Traffic data used in the analysis is from the Division of Transportation Development based on 2019 published volumes. The soil classification used for design was obtained from geotechnical reports submitted to CDOT from Yeh and Associates, Inc. The preliminary soil survey consisted of coring through the existing pavement and retrieving bulk samples from auger cuttings. The pavement recommendations contained in this memorandum were made based on a component analysis of the materials encountered during the preliminary soil survey, as well as a visual survey of the existing roadway distresses. Tables 3 and 4 detail the soil survey information provided to CDOT from Yeh and Associates, Inc.

Table 3: US 24 Soil Profile Information

R2B2 Phase I - US 24 Soil Profile Data			
Subaccount No.	Structure Name	Soil Profile Classification	R-Value
23558	I-13-G	A-6 (6)	7
23558	H-13-N	A-2-6 (1)	19
23558	I-15-T	A-1-b (0)	74
23558	I-15-AO	A-2-6 (0)	14
23559	I-13-H	A-4 (0)	29
23559	I-17-X	A-1-b (0)	76

Table 4: CO 9 Soil Profile Information

R2B2 Phase I – CO 9 Soil Profile Data			
Subaccount No.	Structure Name	Soil Profile Classification	R-Value
23558	J-15-G	A-1-b (0)	19
23558	J-14-C	A-2-4 (0)	36
23558	G-12-C	A-2-6 (0)	12
23559	P-19-G (Minor)	A-6 (7)	11

Recommendations

Based on the results of the pavement analysis, Region 2 Materials recommends the new construction for the approaches and/or the reconstruction of the roadway over the culvert consist of the following:

New Pavement Section for Approaches and Reconstruction
The new pavement section to be used for this project should consist of 6" HMA over 6" ABC Class 6. The entire pavement section should consist of HMA Grade SX (75) PG 58-28.

Tie-In Pavement Section

The tie-in pavement section to be used for the bridge replacements along US 24 and CO 9 should consist of 1.5” mill and fill. The entire tie-in pavement section should consist of HMA Grade SX (75) PG 58-28.

Applicable project special provisions for use on this project will be provided. In addition, a copy of the index of standard special provisions with applicable materials specifications for this project highlighted will also be provided.

Jeri Mero

cc: Jody Pieper
Jennifer Sparks
Scott Dalton
Patrick Vigil

Pavement Stabilization Data
(To be included in project plans)

US 24 & CO 9				
Design Parameters				
	Tie-In		Rebuild	
Design Life (Years)	10		20	
Heavy Trucks (Initial)	130		100	
Heavy Trucks (Cumulative):	326,600		588,864	
Operational Speed (MPH):	65		65	
Subgrade Classification	A-6		A-6	
Subgrade Resilient Modulus (psi)	7,247		7,247	
Effective Binder Content (%):	10.7		10.7	
Voids (%):	5.5		5.5	
Re-Construction Total Pavement Thickness (in):	-		6	
Milling Thickness (in):	-		-	
Overlay Thickness (in):	1.5		-	
HMA Grading (Top/Bottom):	SX		SX	
HMA Design Gyrations (Top/Bottom):	75		75	
HMA Grading (top lift)	PG 58-28		PG 58-28	
HMA Grading (bottom lift)	-		-	
Distress Prediction Summary				
	Target	Predicted	Target	Predicted
Terminal IRI (in/mile):	200	120.23	200	159.29
Reliability (%):	95	100	95	99.95
Permanent Deformation (in):	0.8	0.22	0.85	0.30
Reliability (%):	95	100	95	100
AC Total Fatigue Cracking(%)	35	0.11	-	-
Reliability (%):	50	100	-	-
AC Total Transverse Cracking (ft/mile):	2500	242.26	-	-
Reliability (%):	95	100	-	-
Permanent Deformation - AC Only (in):	0.65	0.11	0.8	0.16
Reliability (%):	95	100	95	100
AC Bottom-Up Fatigue Cracking (%)	25	0	25	10.77
Reliability (%):	50	100	95	100
AC Thermal Cracking (ft/mile)	1500	1	1500	111.98
Reliability (%):	50	100	95	100
AC Top-Down Fatigue Cracking (ft/mile):	3000	449.62	3000	469.99
Reliability (%):	95	100	95	100

New Pavement Thickness Design Output

Design Inputs

Design Life: 20 years
Design Type: FLEXIBLE

Base construction: May, 2021
Pavement construction: June, 2021
Traffic opening: September, 2021

Climate Data Sources (Lat/Lon): 37.954, -107.901

Design Structure

Layer type	Material Type	Thickness (in)
Flexible	R3 Level 1 SX(75) PG 58-28 United	6.0
NonStabilized	Crushed gravel	6.0
Subgrade	A-6	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	10.7
Air voids (%)	5.5

Traffic

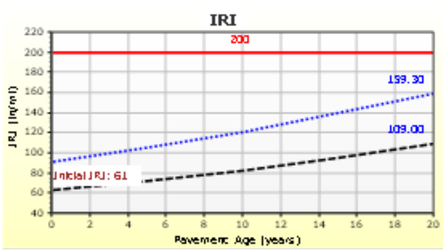
Age (year)	Heavy Trucks (cumulative)
2021 (initial)	130
2031 (10 years)	326,600
2041 (20 years)	765,524

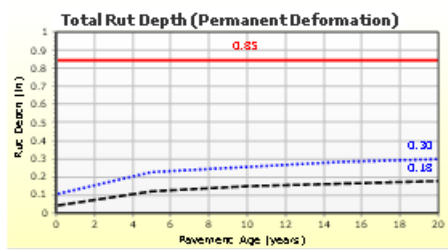
Design Outputs

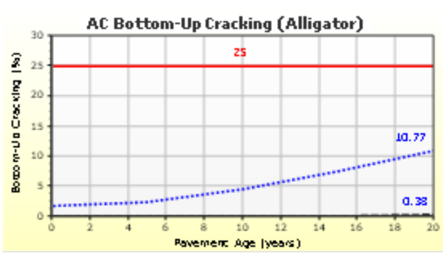
Distress Prediction Summary

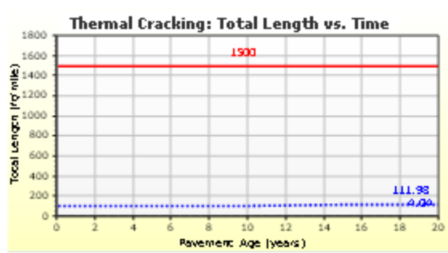
Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	200.00	159.29	95.00	99.85	Pass
Permanent deformation - total pavement (in)	0.85	0.30	95.00	100.00	Pass
AC bottom-up fatigue cracking (% lane area)	25.00	10.77	95.00	100.00	Pass
AC thermal cracking (ft/mile)	1500.00	111.98	95.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	3000.00	469.99	95.00	100.00	Pass
Permanent deformation - AC only (in)	0.80	0.16	95.00	100.00	Pass

Distress Charts





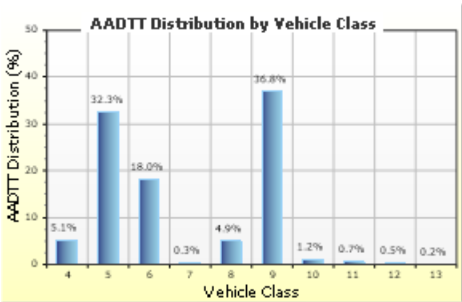


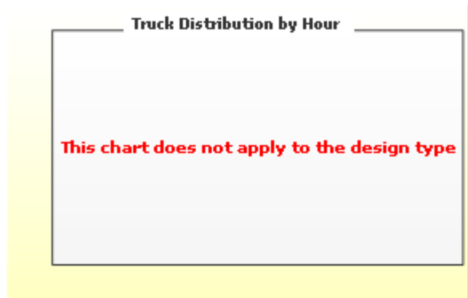


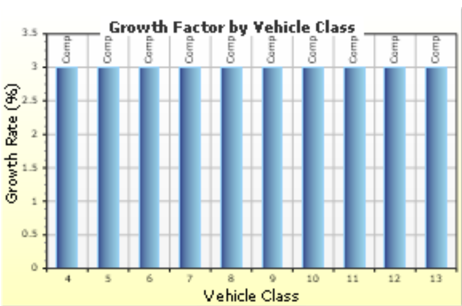
Traffic Inputs

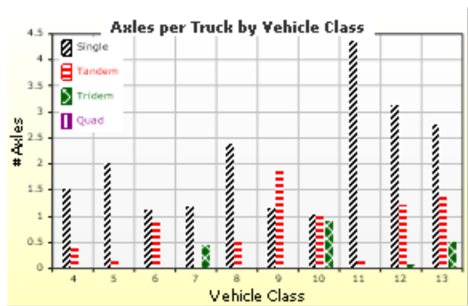
Graphical Representation of Traffic Inputs

Initial two-way AADTT:	130	Percent of trucks in design direction (%):	60.0
Number of lanes in design direction:	1	Percent of trucks in design lane (%):	100.0
		Operational speed (mph)	65.0

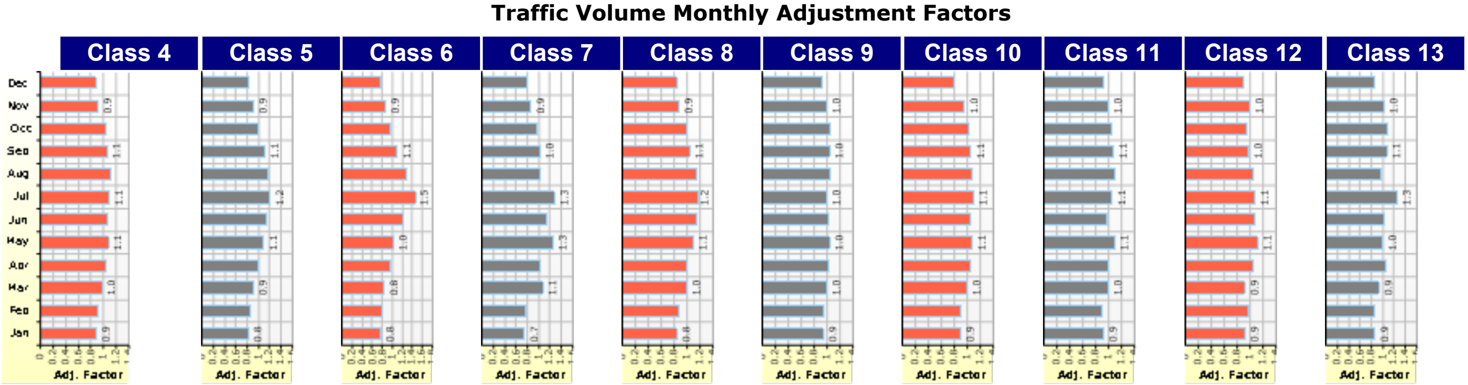








Traffic Volume Monthly Adjustment Factors



Tabular Representation of Traffic Inputs

Volume Monthly Adjustment Factors

Level 3: Default MAF

Month	Vehicle Class									
	4	5	6	7	8	9	10	11	12	13
January	0.9	0.8	0.8	0.7	0.8	0.9	0.9	0.9	0.9	0.9
February	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	0.8
March	1.0	0.9	0.8	1.1	1.0	1.0	1.0	1.0	0.9	0.9
April	1.0	1.0	0.9	1.0	1.0	1.0	1.1	1.0	1.0	1.1
May	1.1	1.1	1.0	1.3	1.1	1.0	1.1	1.1	1.1	1.0
June	1.1	1.1	1.2	1.1	1.1	1.0	1.1	1.0	1.1	1.0
July	1.1	1.2	1.5	1.3	1.2	1.0	1.1	1.1	1.1	1.3
August	1.1	1.2	1.3	1.0	1.1	1.0	1.1	1.1	1.1	1.0
September	1.1	1.1	1.1	1.0	1.1	1.0	1.1	1.1	1.0	1.1
October	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	1.1
November	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0
December	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.9	0.9	0.9

Distributions by Vehicle Class

Vehicle Class	AADTT Distribution (%) (Level 3)	Growth Factor	
		Rate (%)	Function
Class 4	5.1%	3%	Compound
Class 5	32.3%	3%	Compound
Class 6	18%	3%	Compound
Class 7	0.3%	3%	Compound
Class 8	4.9%	3%	Compound
Class 9	36.8%	3%	Compound
Class 10	1.2%	3%	Compound
Class 11	0.7%	3%	Compound
Class 12	0.5%	3%	Compound
Class 13	0.2%	3%	Compound

Truck Distribution by Hour does not apply

Axle Configuration

Traffic Wander	
Mean wheel location (in)	18.0
Traffic wander standard deviation (in)	10.0
Design lane width (ft)	12.0

Axle Configuration	
Average axle width (ft)	8.5
Dual tire spacing (in)	12.0
Tire pressure (psi)	120.0

Average Axle Spacing	
Tandem axle spacing (in)	51.6
Tridem axle spacing (in)	49.2
Quad axle spacing (in)	49.2

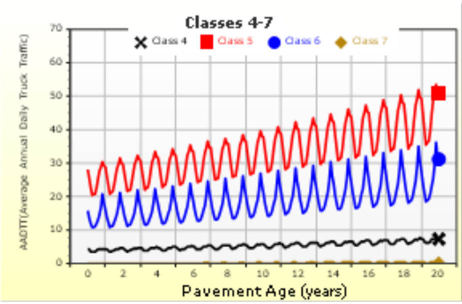
Wheelbase does not apply

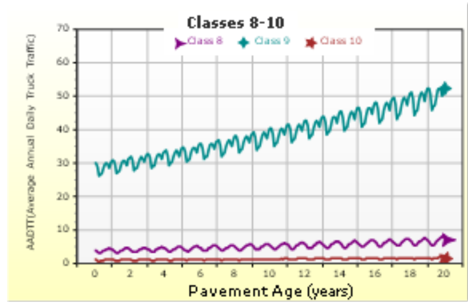
Number of Axles per Truck

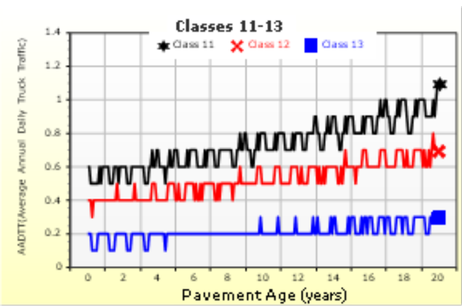
Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.53	0.45	0	0
Class 5	2.02	0.16	0.02	0
Class 6	1.12	0.93	0	0
Class 7	1.19	0.07	0.45	0.02
Class 8	2.41	0.56	0.02	0
Class 9	1.16	1.88	0.01	0
Class 10	1.05	1.01	0.93	0.02
Class 11	4.35	0.13	0	0
Class 12	3.15	1.22	0.09	0
Class 13	2.77	1.4	0.51	0.04

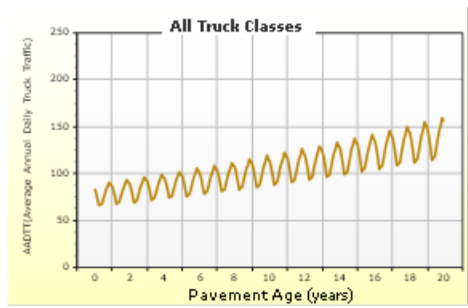
AADTT (Average Annual Daily Truck Traffic) Growth

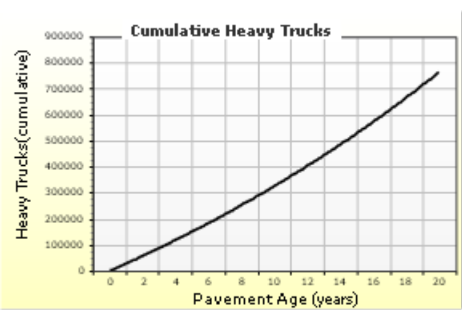
*** Traffic cap is not enforced**







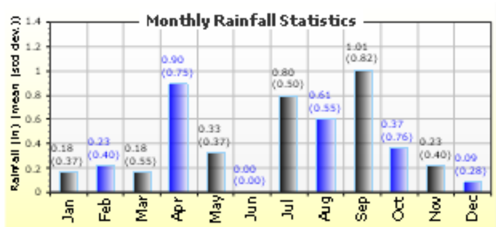




Climate Inputs

Climate Data Sources:

Climate Station Cities:	Location (lat lon elevation(ft))
TELLURIDE, CO	37.95400 -107.90100 9078

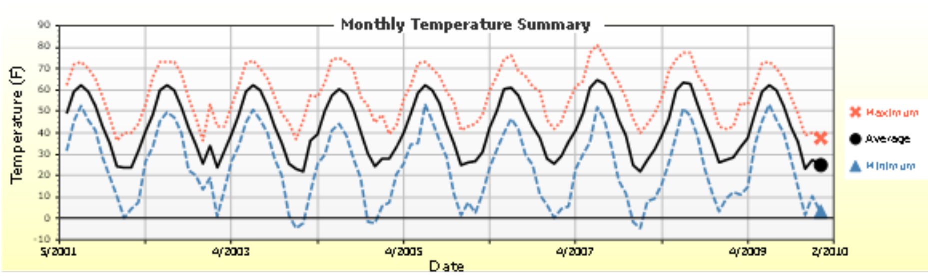


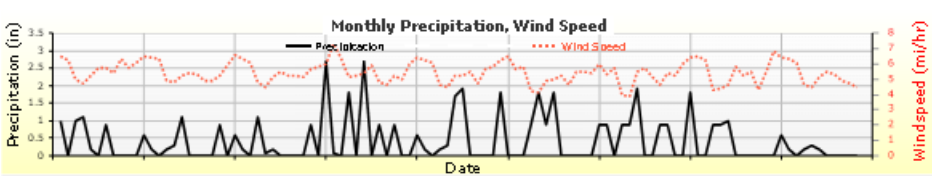
Annual Statistics:

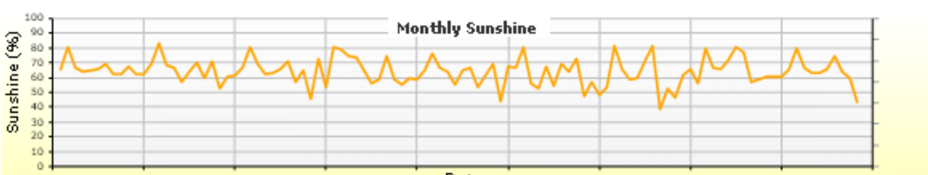
Mean annual air temperature (ºF)	42.82
Mean annual precipitation (in)	4.96
Freezing index (ºF - days)	661.24
Average annual number of freeze/thaw cycles:	74.85

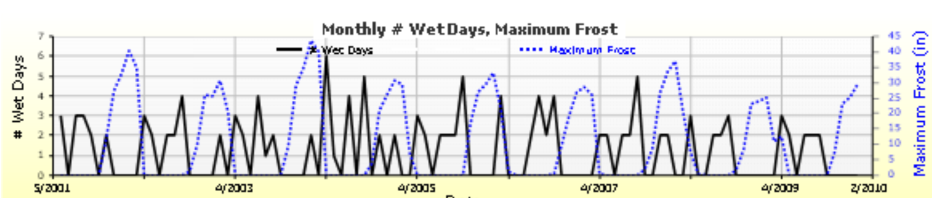
Water table depth (ft) 10.00

Monthly Climate Summary:

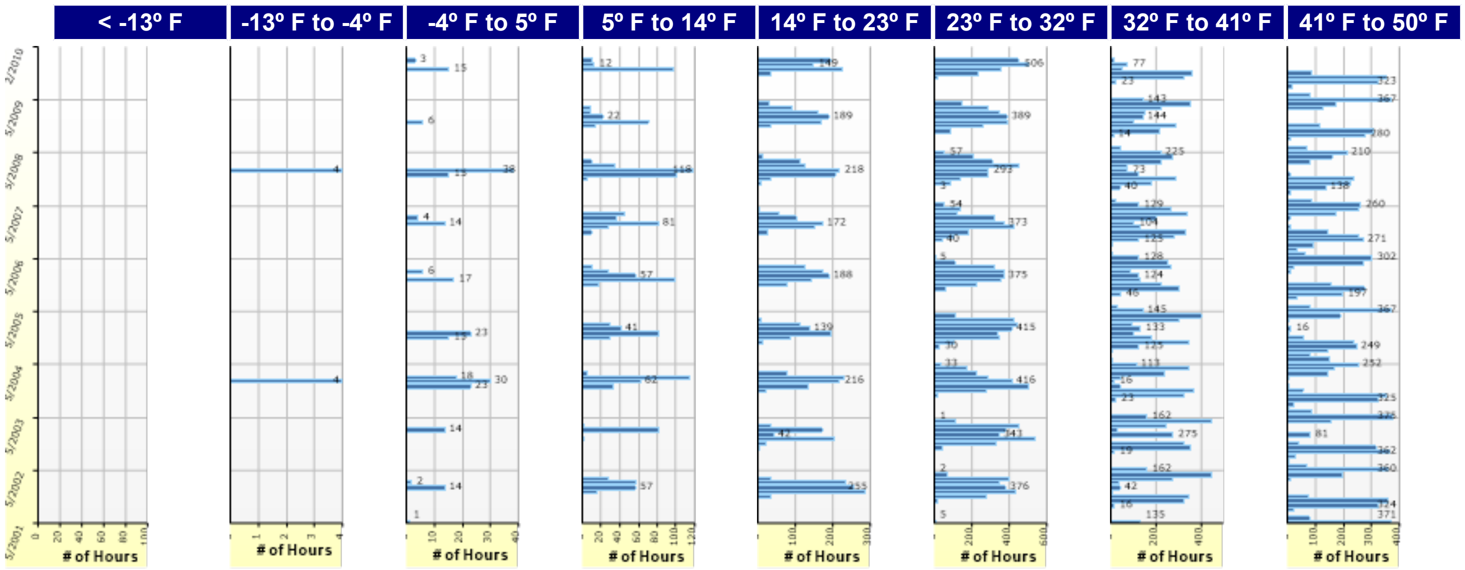


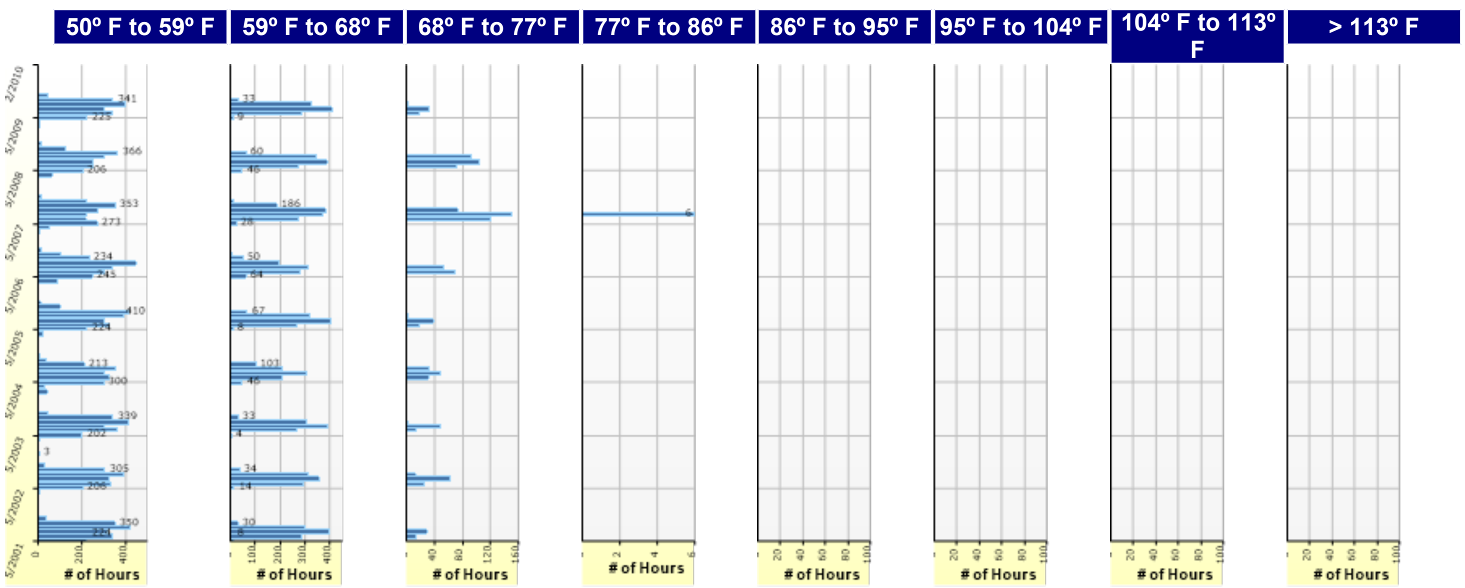






Hourly Air Temperature Distribution by Month:





Design Properties

HMA Design Properties

Use Multilayer Rutting Model	False
Using G* based model (not nationally calibrated)	False
Is NCHRP 1-37A HMA Rutting Model Coefficients	True
Endurance Limit	-
Use Reflective Cracking	True

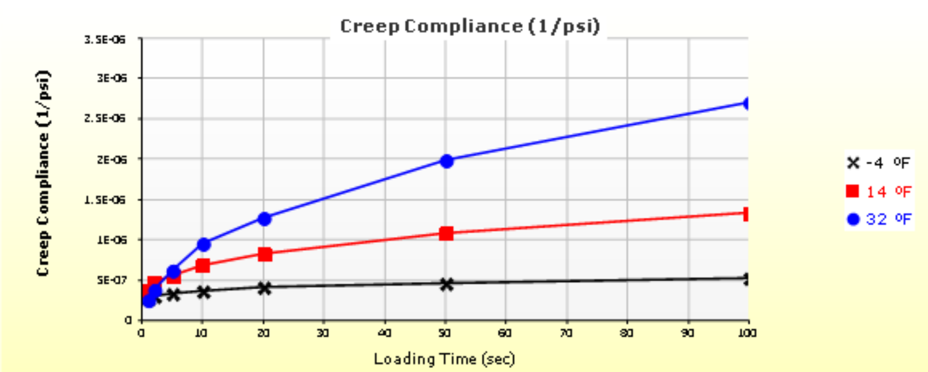
Structure - ICM Properties	
AC surface shortwave absorptivity	0.85

Layer Name	Layer Type	Interface Friction
Layer 1 Flexible : R3 Level 1 SX (75) PG 58-28 United	Flexible (1)	1.00
Layer 2 Non-stabilized Base : Crushed gravel	Non-stabilized Base (4)	1.00
Layer 3 Subgrade : A-6	Subgrade (5)	-

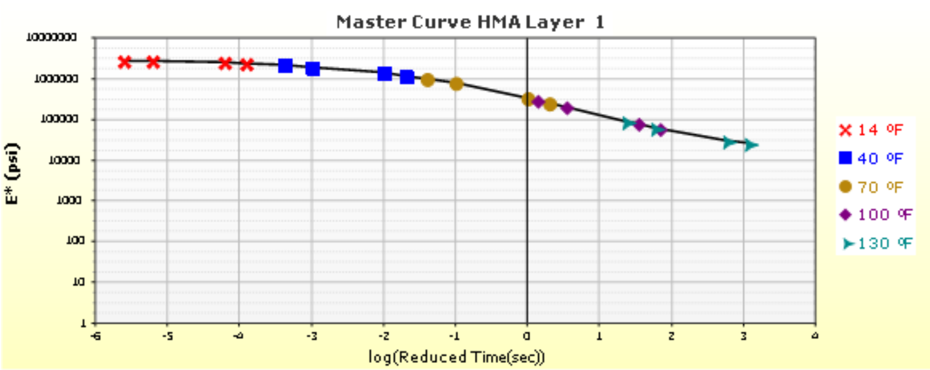
Thermal Cracking (Input Level: 1)

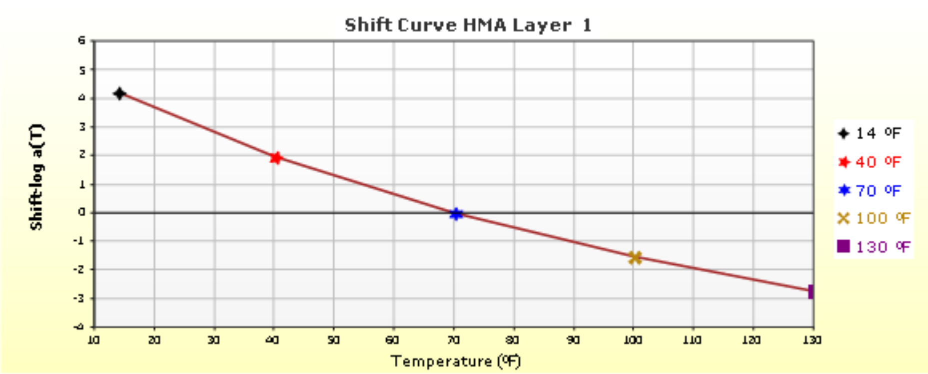
Indirect tensile strength at 14 ºF (psi)	555.90
Thermal Contraction	
Is thermal contraction calculated?	True
Mix coefficient of thermal contraction (in/in/ºF)	-
Aggregate coefficient of thermal contraction (in/in/ºF)	5.0e-006
Voids in Mineral Aggregate (%)	16.2

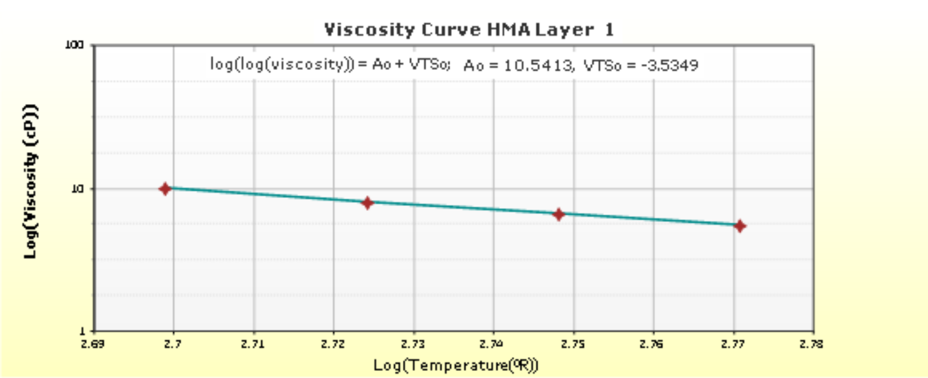
	Creep Compliance (1/psi)		
Loading time (sec)	-4 ºF	14 ºF	32 ºF
1	2.78e-007	3.91e-007	2.65e-007
2	3.11e-007	4.79e-007	3.91e-007
5	3.48e-007	5.57e-007	6.33e-007
10	3.74e-007	6.94e-007	9.55e-007
20	4.22e-007	8.31e-007	1.28e-006
50	4.63e-007	1.08e-006	1.99e-006
100	5.28e-007	1.35e-006	2.72e-006



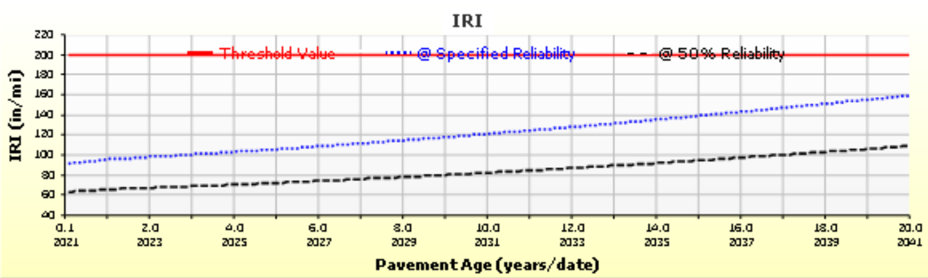
HMA Layer 1: Layer 1 Flexible : R3 Level 1 SX(75) PG 58-28 United

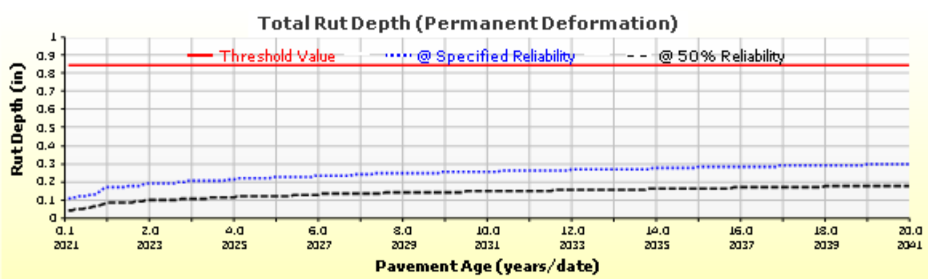


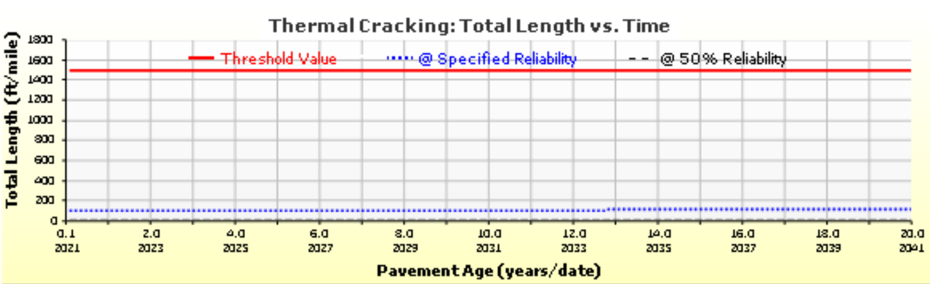


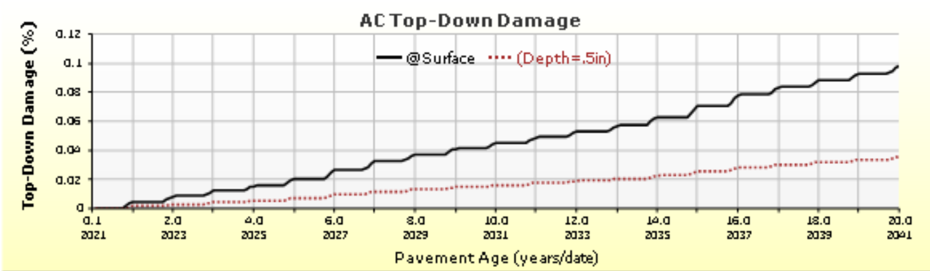


Analysis Output Charts

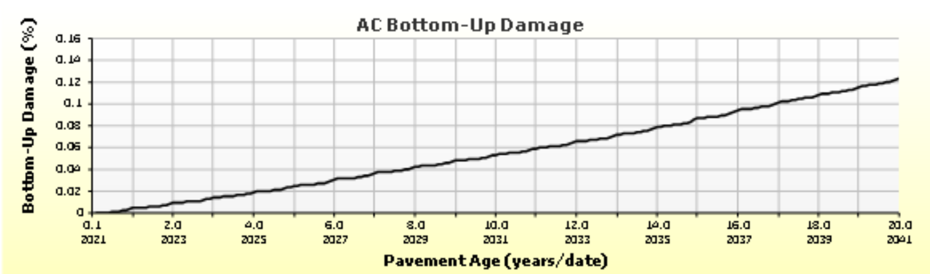




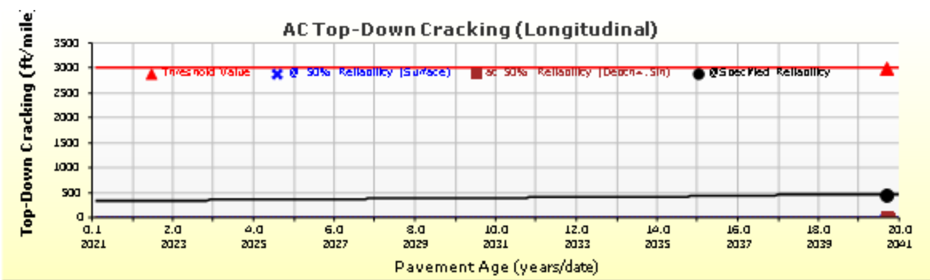




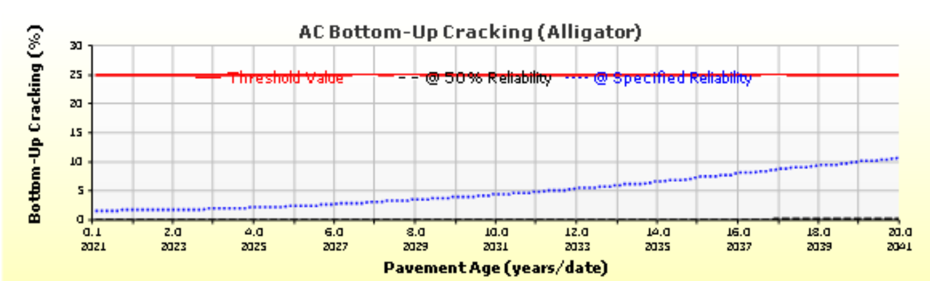
AC Top-Down Damage
@Surface
(Depth=.5in)
Top-Down Damage (%)
Pavement Age (years/date)



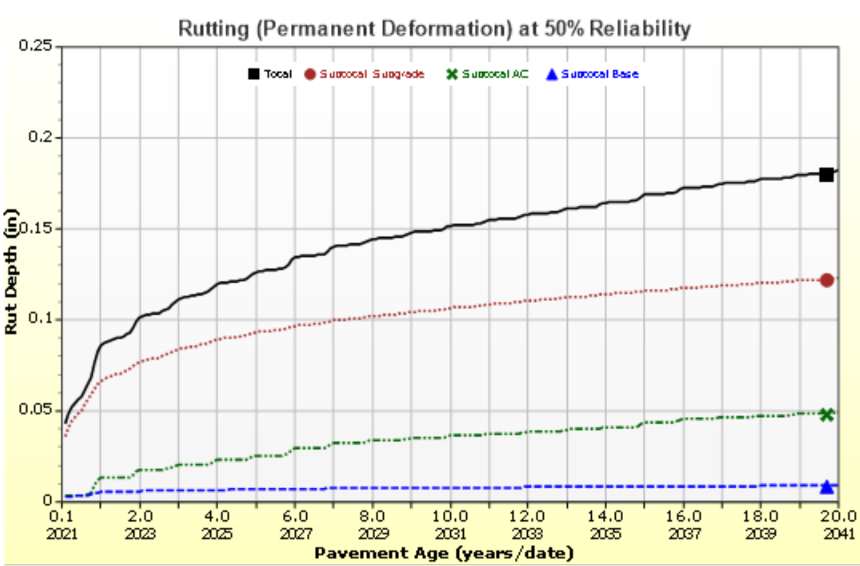
AC Bottom-Up Damage
Bottom-Up Damage (%)
Pavement Age (years/date)

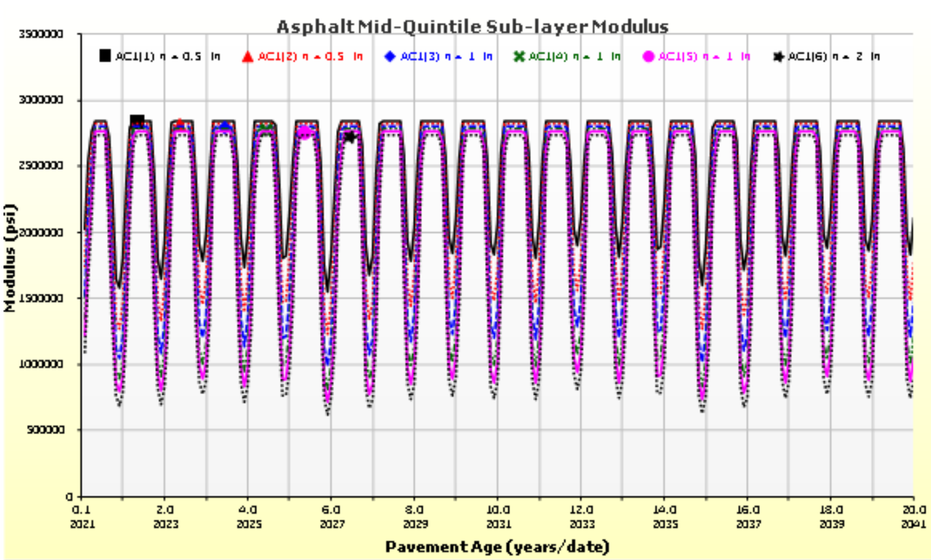


AC Top-Down Cracking (Longitudinal)
Threshold Value
Top-Down Cracking (ft/mile)
Pavement Age (years/date)

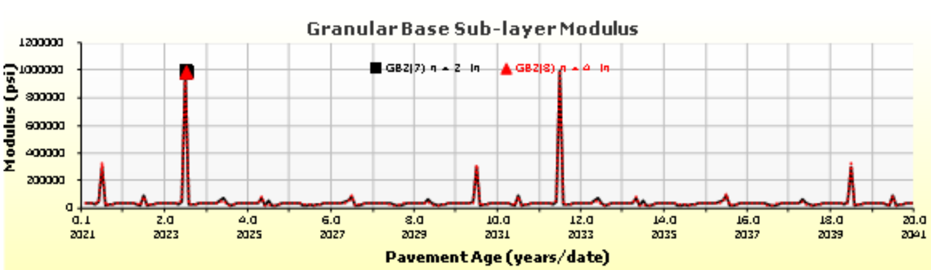


AC Bottom-Up Cracking (Alligator)
Threshold Value
@ 50% Reliability
@ Specified Reliability
Bottom-Up Cracking (%)
Pavement Age (years/date)

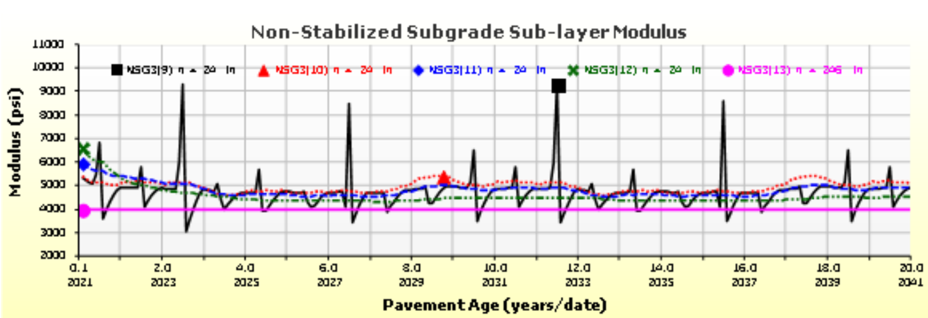

Rutting (Permanent Deformation) at 50% Reliability
Total
Subtotal Subgrade
Subtotal AC
Subtotal Base
Rut Depth (in)
Pavement Age (years/date)



Asphalt Mid-Quintile Sub-layer Modulus
AC1(1) h = 0.5 in
AC1(2) h = 0.5 in
AC1(3) h = 1 in
AC1(4) h = 1 in
AC1(5) h = 1 in
AC1(6) h = 2 in
Modulus (psi)
Pavement Age (years/date)



Granular Base Sub-layer Modulus
GB2(7) h = 2 in
GB2(8) h = 4 in
Modulus (psi)
Pavement Age (years/date)



Non-Stabilized Subgrade Sub-layer Modulus
NSG3(9) h = 24 in
NSG3(10) h = 24 in
NSG3(11) h = 24 in
NSG3(12) h = 24 in
NSG3(13) h = 246 in
Modulus (psi)
Pavement Age (years/date)

Layer Information

Layer 1 Flexible : R3 Level 1 SX(75) PG 58-28 United

Asphalt		
Thickness (in)	6.0	
Unit weight (pcf)	145.0	
Poisson's ratio	Is Calculated?	True
	Ratio	-
	Parameter A	-1.63
	Parameter B	3.84E-06

Asphalt Dynamic Modulus (Input Level: 1)

T (ºF)	0.5 Hz	1 Hz	10 Hz	25 Hz
14	2067099	2488999	2785899	2873299
40	930800	1472800	2008399	2196999
70	207600	439600	838700	1039200
100	52500	101200	215300	291900
130	24100	35400	60900	78900

Asphalt Binder

Temperature (ºF)	Binder Gstar (Pa)	Phase angle (deg)
136.4	2227.6	80
147.2	1068.2	82
158	540.1	84

General Info

Name	Value
Reference temperature (ºF)	70
Effective binder content (%)	10.7
Air voids (%)	5.5
Thermal conductivity (BTU/hr-ft-ºF)	0.67
Heat capacity (BTU/lb-ºF)	0.23

Identifiers

Field	Value
Display name/identifier	R3 Level 1 SX(75) PG 58-28
Description of object	Mix ID # FS1918
Author	CDOT
Date Created	4/3/2013 12:00:00 AM
Approver	CDOT
Date approved	4/3/2013 12:00:00 AM
State	Colorado
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 1	SX
User defined field 2	
User defined field 3	
Revision Number	0

Layer 2 Non-stabilized Base : Crushed gravel

Unbound	
Layer thickness (in)	6.0
Poisson's ratio	0.35
Coefficient of lateral earth pressure (k0)	0.5

Modulus (Input Level: 3)

Analysis Type:	Modify input values by temperature/moisture
Method:	Resilient Modulus (psi)

Resilient Modulus (psi)
25000.0

Use Correction factor for NDT modulus?	-
NDT Correction Factor:	-

Identifiers

Field	Value
Display name/identifier	Crushed gravel
Description of object	Default material
Author	AASHTO
Date Created	1/1/2011 12:00:00 AM
Approver	
Date approved	1/1/2011 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 1	
User defined field 2	
User defined field 3	
Revision Number	45

Sieve

Liquid Limit	6.0
Plasticity Index	1.0
Is layer compacted?	False

	Is User Defined?	Value
Maximum dry unit weight (pcf)	False	127.2
Saturated hydraulic conductivity (ft/hr)	False	5.054e-02
Specific gravity of solids	False	2.7
Water Content (%)	False	7.4

User-defined Soil Water Characteristic Curve (SWCC)	
Is User Defined?	False
af	7.2555
bf	1.3328
cf	0.8242
hr	117.4000

Sieve Size	% Passing
0.001mm	
0.002mm	
0.020mm	
#200	8.7
#100	
#80	12.9
#60	
#50	
#40	20.0
#30	
#20	
#16	
#10	33.8
#8	
#4	44.7
3/8-in.	57.2
1/2-in.	63.1
3/4-in.	72.7
1-in.	78.8
1 1/2-in.	85.8
2-in.	91.6
2 1/2-in.	
3-in.	
3 1/2-in.	97.6

Layer 3 Subgrade : A-6

Unbound	
Layer thickness (in)	Semi-infinite
Poisson's ratio	0.35
Coefficient of lateral earth pressure (k0)	0.5

Modulus (Input Level: 3)

Analysis Type:	Modify input values by temperature/moisture
Method:	Resilient Modulus (psi)

Resilient Modulus (psi)
7247.0

Use Correction factor for NDT modulus?	-
NDT Correction Factor:	-

Identifiers

Field	Value
Display name/identifier	A-6
Description of object	Default material
Author	AASHTO
Date Created	1/1/2011 12:00:00 AM
Approver	
Date approved	1/1/2011 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 1	
User defined field 2	
User defined field 3	
Revision Number	5

Sieve

Liquid Limit	33.0
Plasticity Index	16.0
Is layer compacted?	False

	Is User Defined?	Value
Maximum dry unit weight (pcf)	False	107.9
Saturated hydraulic conductivity (ft/hr)	False	1.95e-05
Specific gravity of solids	False	2.7
Water Content (%)	False	17.1

User-defined Soil Water Characteristic Curve (SWCC)	
Is User Defined?	False
af	108.4091
bf	0.6801
cf	0.2161
hr	500.0000

Sieve Size	% Passing
0.001mm	
0.002mm	
0.020mm	
#200	63.2
#100	
#80	73.5
#60	
#50	
#40	82.4
#30	
#20	
#16	
#10	90.2
#8	
#4	93.5
3/8-in.	96.4
1/2-in.	97.4
3/4-in.	98.4
1-in.	99.0
1 1/2-in.	99.5
2-in.	99.8
2 1/2-in.	
3-in.	
3 1/2-in.	100.0

Calibration Coefficients

AC Fatigue

AC Fatigue	
$N_f = 0.00432 * C * \beta_{f1} k_1 \left(\frac{1}{\varepsilon_1}\right)^{k_2 \beta_{f2}} \left(\frac{1}{E}\right)^{k_3 \beta_{f3}}$	k1: 0.007566
	k2: 3.9492
$C = 10^M$	k3: 1.281
	Bf1: 130.3674
$M = 4.84\left(\frac{V_b}{V_a + V_b} - 0.69\right)$	Bf2: 1
	Bf3: 1.217799

AC Rutting

$$\frac{\varepsilon_p}{\varepsilon_r} = k_z \beta_{r1} 10^{k_1} T^{k_2 \beta_{r2}} N^{k_3 \beta_{r3}}$$

$$k_z = (C_1 + C_2 * depth) * 0.328196^{depth}$$

$$C_1 = -0.1039 * H_a^2 + 2.4868 * H_a - 17.342$$

$$C_2 = 0.0172 * H_a^2 - 1.7331 * H_a + 27.428$$

Where:

$H_{ac} = total\ AC\ thickness(in)$

$\varepsilon_p = plastic\ strain(in/in)$

$\varepsilon_r = resilient\ strain(in/in)$

$T = layer\ temperature(°F)$

$N = number\ of\ load\ repetitions$

AC Rutting Standard Deviation	0.1414 * Pow(RUT,0.25) + 0.001	
AC Layer	K1:-3.35412 K2:1.5606 K3:0.3791	Br1:4.3 Br2:1 Br3:1

Thermal Fracture

$$C_f = 400 * N\left(\frac{\log C / h_{ac}}{\sigma}\right)$$

$$\Delta C = (k * \beta t)^{n+1} * A * \Delta K^n$$

$$A = 10^{(4.389 - 2.52 * \log(E * \sigma_m * n))}$$

C_f = observed amount of thermal cracking(ft/500ft)
k = refression coefficient determined through field calibration
$N()$ = standard normal distribution evaluated at()
σ = standard deviation of the log of the depth of cracks in the pavments
C = crack depth(in)
h_{ac} = thickness of asphalt layer(in)
ΔC = Change in the crack depth due to a cooling cycle
ΔK = Change in the stress intensity factor due to a cooling cycle
A, n = Fracture parameters for the asphalt mixture
E = mixture stiffness
σ_M = Undamaged mixture tensile strength
β_t = Calibration parameter

Level 1 K: 6.3	Level 1 Standard Deviation: 0.1468 * THERMAL + 65.027
Level 2 K: 0.5	Level 2 Standard Deviation: 0.2841 * THERMAL + 55.462
Level 3 K: 6.3	Level 3 Standard Deviation: 0.3972 * THERMAL + 20.422

CSM Fatigue

$$N_f = 10^{\left(\frac{k_1 \beta_{c1} \left(\frac{\sigma_s}{M_r}\right)}{k_2 \beta_{c2}}\right)}$$

N_f = number of repetitions to fatigue cracking
σ_s = Tensile stress(psi)
M_r = modulus of rupture(psi)

k1: 1	k2: 1	Bc1: 0.75	Bc2:1.1

Subgrade Rutting

$$\delta_a(N) = \beta_{s_1} k_1 \varepsilon_v h \left(\frac{\varepsilon_0}{\varepsilon_r}\right) \left| e^{-\left(\frac{\rho}{N}\right)^\beta} \right|$$

δ_a = permanent deformation for the layer
N = number of repetitions
ε_v = average veritcal strain(in/in)
$\varepsilon_0, \beta, \rho$ = material properties
ε_r = resilient strain(in/in)

Granular		Fine	
k1: 2.03	Bs1: 0.22	k1: 1.35	Bs1: 0.37
Standard Deviation (BASERUT) 0.0104 * Pow(BASERUT,0.67) + 0.001		Standard Deviation (BASERUT) 0.0663 * Pow(SUBRUT,0.5) + 0.001	

AC Cracking

AC Top Down Cracking

$$FC_{top} = \left(\frac{C_4}{1 + e^{(C_1 - C_2 * log_{10}(Damage))}}\right) * 10.56$$

c1: 7	c2: 3.5	c3: 0	c4: 1000

AC Cracking Top Standard Deviation

200 + 2300/(1+exp(1.072-2.1654*LOG10 (TOP+0.0001)))

AC Bottom Up Cracking

$$FC = \left(\frac{6000}{1 + e^{(C_1 * C_1' + C_2 * C_2' log_{10}(D * 100))}}\right) * \left(\frac{1}{60}\right)$$

$$C_2' = -2.40874 - 39.748 * (1 + h_{ac})^{-2.856}$$

$$C_1' = -2 * C_2'$$

c1: 0.021	c2: 2.35	c3: 6000

AC Cracking Bottom Standard Deviation

1 + 15/(1+exp(-3.1472-4.1349*LOG10 (BOTTOM+0.0001)))

CSM Cracking

$$FC_{ctb} = C_1 + \frac{C_2}{1 + e^{C_3 - C_4(Damage)}}$$

C1: 0	C2: 75	C3: 5	C4: 3

CSM Standard Deviation

CTB*1

IRI Flexible Pavements

C1 - Rutting
C2 - Fatigue Crack
C3 - Transverse Crack
C4 - Site Factors

C1: 50	C2: 0.55	C3: 0.0111	C4: 0.02

Tie-In Pavement Thickness Design Output

US 24_CO 9_Tie In

File Name: C:\Users\merojj\Documents\23558_23559 - R2B2 Phase I and II\US 24\US 24_CO 9_Tie In.dgpx

Design Inputs

Design Life: 10 years
Design Type: ACC_ACC

Existing construction: May, 2021
Pavement construction: June, 2021
Traffic opening: September, 2021

Climate Data Sources (Lat/Lon): 37.954, -107.901

Design Structure

Layer type	Material Type	Thickness (in)
Flexible (OL)	SX(75) PG 58-28	1.5
Flexible (existing)	Default asphalt concrete	6.0
Subgrade	A-6	12.0
Subgrade	A-6	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	10.7
Air voids (%)	5.5

Traffic

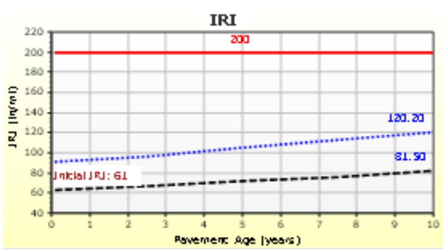
Age (year)	Heavy Trucks (cumulative)
2021 (initial)	130
2026 (5 years)	151,255
2031 (10 years)	326,600

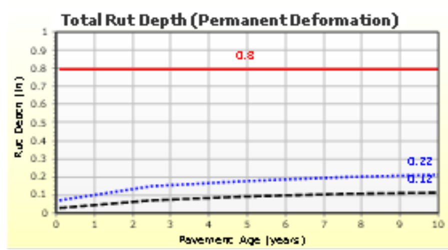
Design Outputs

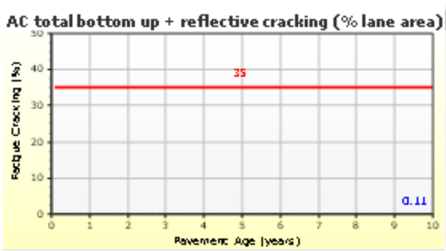
Distress Prediction Summary

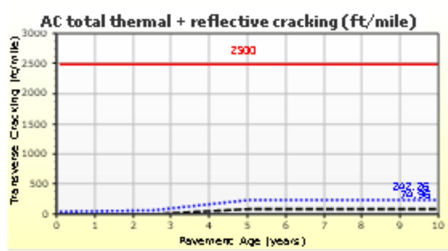
Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	200.00	120.23	95.00	100.00	Pass
Permanent deformation - total pavement (in)	0.80	0.22	95.00	100.00	Pass
AC total fatigue cracking: bottom up + reflective (% lane area)	35.00	0.11	50.00	100.00	Pass
AC total transverse cracking: thermal + reflective (ft/mile)	2500.00	242.26	95.00	100.00	Pass
Permanent deformation - AC only (in)	0.65	0.11	95.00	100.00	Pass
AC bottom-up fatigue cracking (% lane area)	25.00	0.00	50.00	100.00	Pass
AC thermal cracking (ft/mile)	1500.00	1.00	50.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	3000.00	449.62	95.00	100.00	Pass

Distress Charts





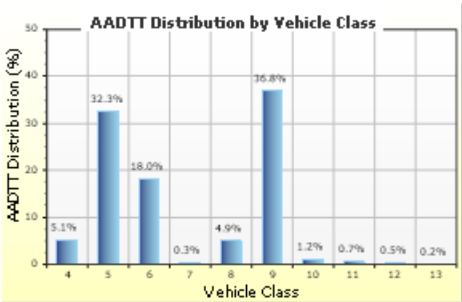


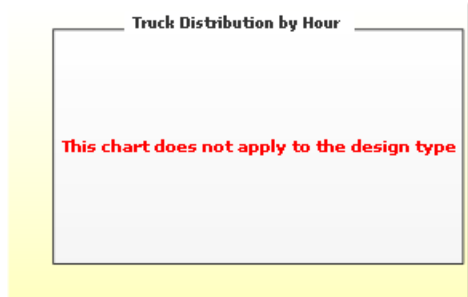


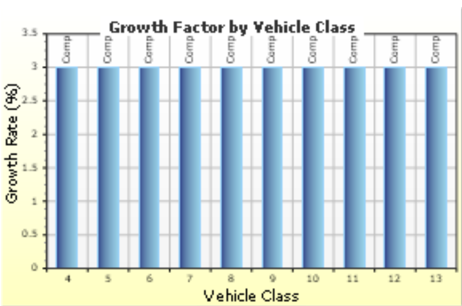
Traffic Inputs

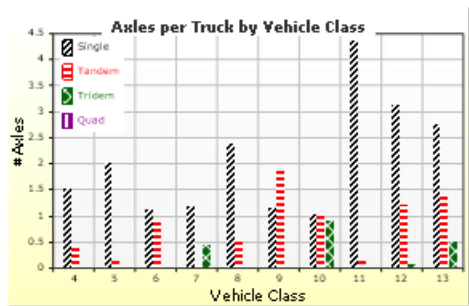
Graphical Representation of Traffic Inputs

Initial two-way AADTT:	130	Percent of trucks in design direction (%):	60.0
Number of lanes in design direction:	1	Percent of trucks in design lane (%):	100.0
		Operational speed (mph)	65.0

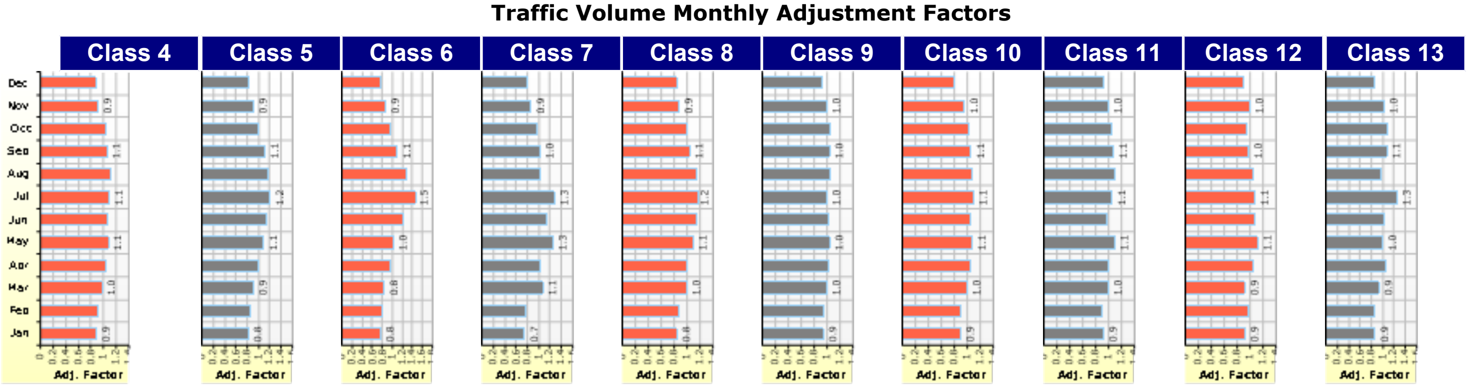








Traffic Volume Monthly Adjustment Factors



Tabular Representation of Traffic Inputs

Volume Monthly Adjustment Factors

Level 3: Default MAF

Month	Vehicle Class									
	4	5	6	7	8	9	10	11	12	13
January	0.9	0.8	0.8	0.7	0.8	0.9	0.9	0.9	0.9	0.9
February	0.9	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	0.8
March	1.0	0.9	0.8	1.1	1.0	1.0	1.0	1.0	0.9	0.9
April	1.0	1.0	0.9	1.0	1.0	1.0	1.1	1.0	1.0	1.1
May	1.1	1.1	1.0	1.3	1.1	1.0	1.1	1.1	1.1	1.0
June	1.1	1.1	1.2	1.1	1.1	1.0	1.1	1.0	1.1	1.0
July	1.1	1.2	1.5	1.3	1.2	1.0	1.1	1.1	1.1	1.3
August	1.1	1.2	1.3	1.0	1.1	1.0	1.1	1.1	1.1	1.0
September	1.1	1.1	1.1	1.0	1.1	1.0	1.1	1.1	1.0	1.1
October	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	1.1
November	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0
December	0.9	0.8	0.8	0.8	0.8	0.9	0.8	0.9	0.9	0.9

Distributions by Vehicle Class

Vehicle Class	AADTT Distribution (%) (Level 3)	Growth Factor	
		Rate (%)	Function
Class 4	5.1%	3%	Compound
Class 5	32.3%	3%	Compound
Class 6	18%	3%	Compound
Class 7	0.3%	3%	Compound
Class 8	4.9%	3%	Compound
Class 9	36.8%	3%	Compound
Class 10	1.2%	3%	Compound
Class 11	0.7%	3%	Compound
Class 12	0.5%	3%	Compound
Class 13	0.2%	3%	Compound

Truck Distribution by Hour does not apply

Axle Configuration

Traffic Wander	
Mean wheel location (in)	18.0
Traffic wander standard deviation (in)	10.0
Design lane width (ft)	12.0

Axle Configuration	
Average axle width (ft)	8.5
Dual tire spacing (in)	12.0
Tire pressure (psi)	120.0

Average Axle Spacing	
Tandem axle spacing (in)	51.6
Tridem axle spacing (in)	49.2
Quad axle spacing (in)	49.2

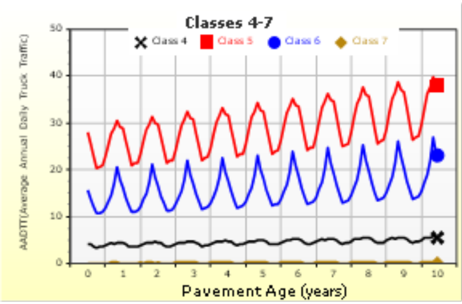
Wheelbase does not apply

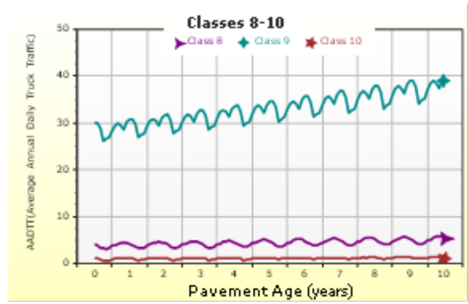
Number of Axles per Truck

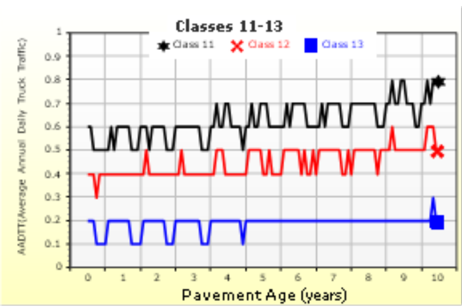
Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.53	0.45	0	0
Class 5	2.02	0.16	0.02	0
Class 6	1.12	0.93	0	0
Class 7	1.19	0.07	0.45	0.02
Class 8	2.41	0.56	0.02	0
Class 9	1.16	1.88	0.01	0
Class 10	1.05	1.01	0.93	0.02
Class 11	4.35	0.13	0	0
Class 12	3.15	1.22	0.09	0
Class 13	2.77	1.4	0.51	0.04

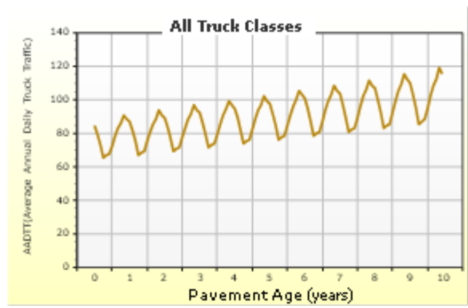
AADTT (Average Annual Daily Truck Traffic) Growth

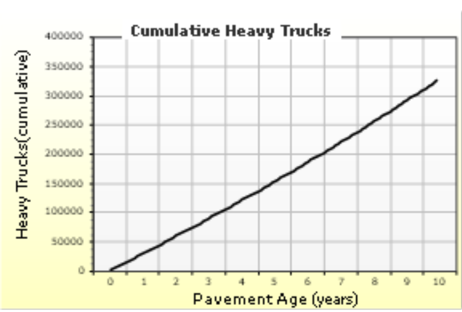
*** Traffic cap is not enforced**







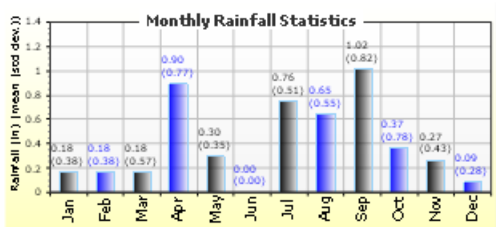




Climate Inputs

Climate Data Sources:

Climate Station Cities:	Location (lat lon elevation(ft))
TELLURIDE, CO	37.95400 -107.90100 9078

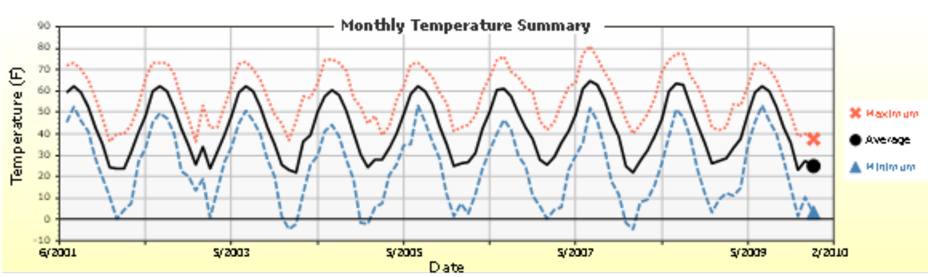


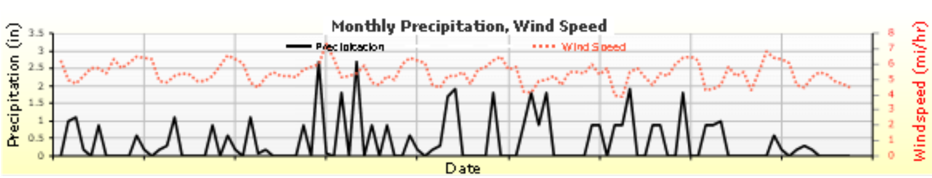
Annual Statistics:

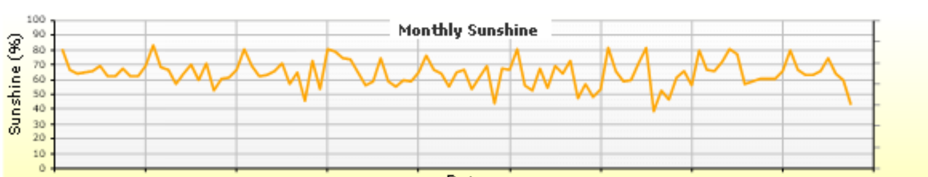
Mean annual air temperature (ºF)	43.02
Mean annual precipitation (in)	4.97
Freezing index (ºF - days)	664.35
Average annual number of freeze/thaw cycles:	74.72

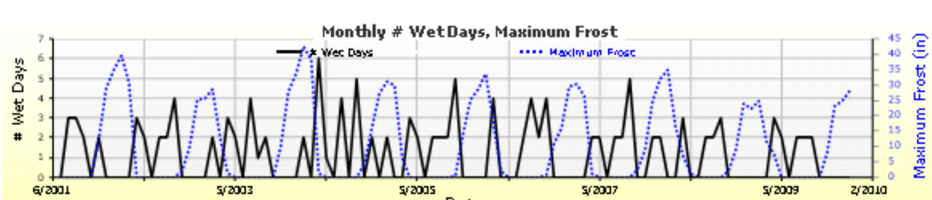
Water table depth (ft) 10.00

Monthly Climate Summary:

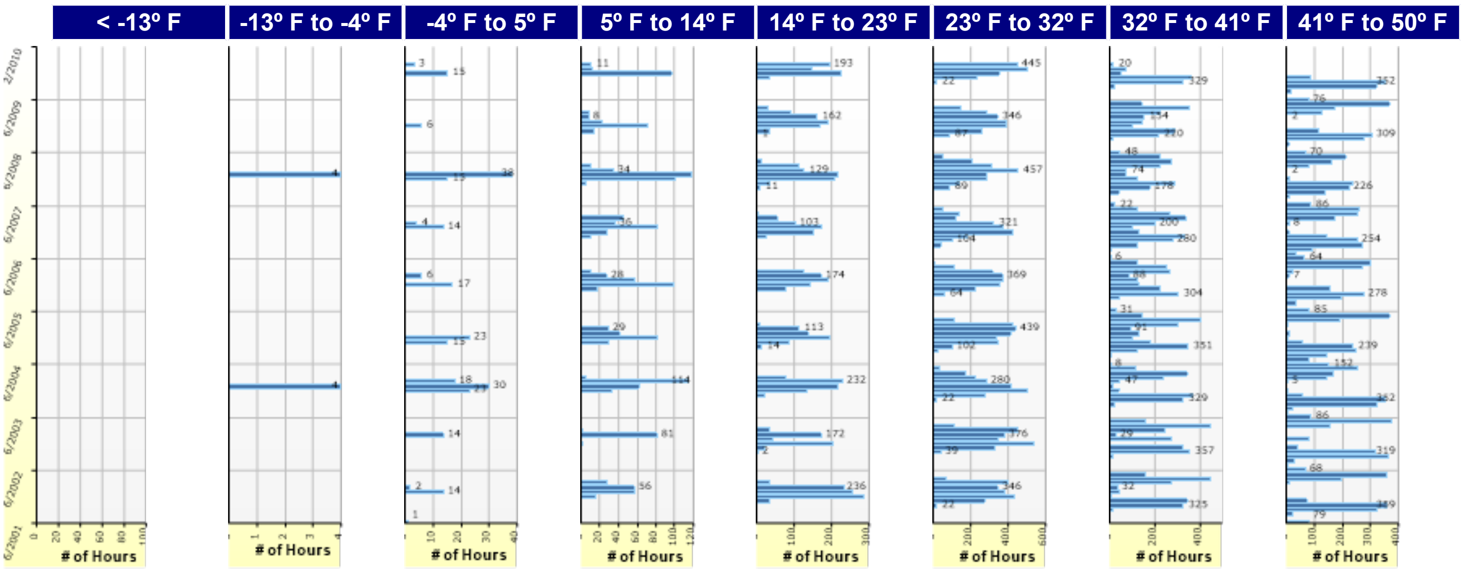


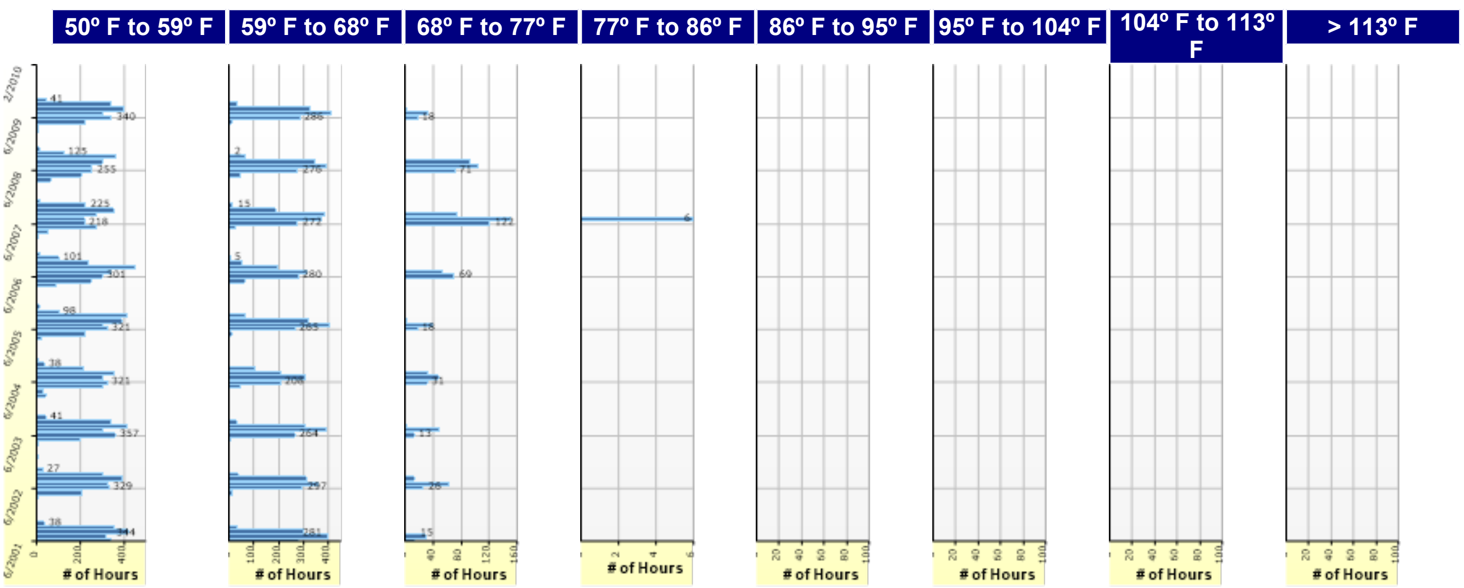






Hourly Air Temperature Distribution by Month:





Design Properties

HMA Design Properties

Use Multilayer Rutting Model	False
Using G* based model (not nationally calibrated)	False
Is NCHRP 1-37A HMA Rutting Model Coefficients	True
Endurance Limit	-
Use Reflective Cracking	True

Layer Name	**Layer Type**	**Interface Friction**
Layer 1 Flexible : SX(75) PG 58-28	Flexible (1)	1.00
Layer 2 Flexible : Default asphalt concrete(existing)	Flexible (1)	1.00
Layer 3 Subgrade : A-6	Subgrade (5)	1.00
Layer 4 Subgrade : A-6	Subgrade (5)	-

Structure - ICM Properties	
AC surface shortwave absorptivity	0.85

HMA Rehabilitation (Input Level: 2)

Milled thickness (in)	1.50
Fatigue cracking (%)	0.00 (Low)
Transverse cracking (ft/mile)	100.00 (Low)
Total rut depth (in)	-

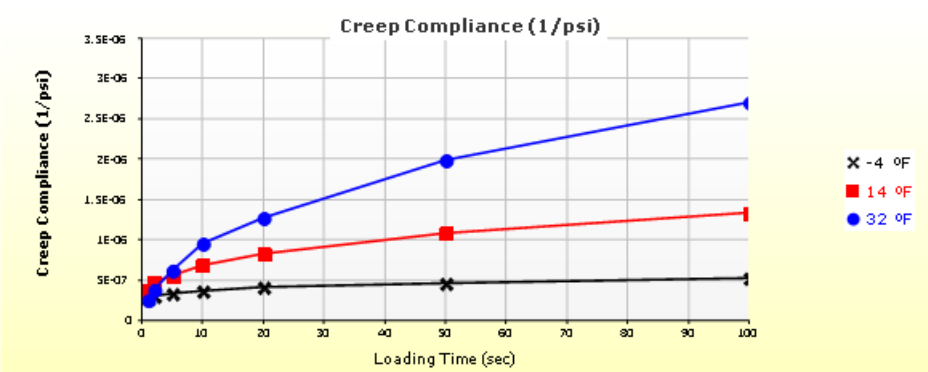
Layer Name	**Layer Type**	**Rut Depth (in)**
Layer 1 Flexible : SX(75) PG 58-28	Flexible (1)	-
Layer 2 Flexible : Default asphalt concrete(existing)	Flexible (1)	0.10
Layer 3 Subgrade : A-6	Subgrade (5)	0.00
Layer 4 Subgrade : A-6	Subgrade (5)	0.00

Thermal Cracking (Input Level: 1)

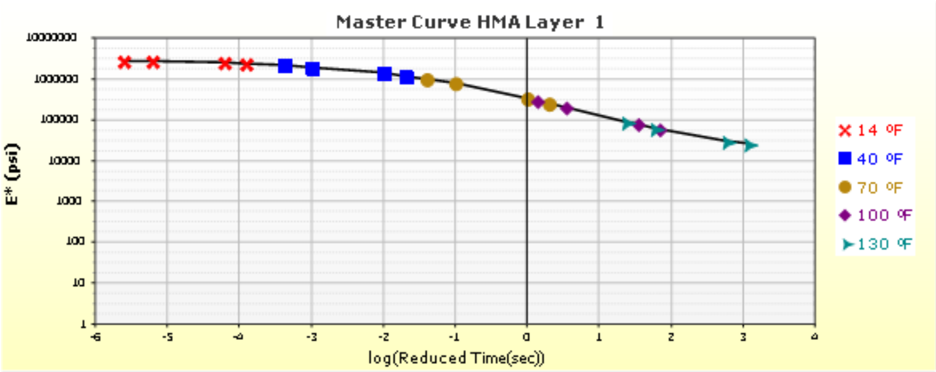
Indirect tensile strength at 14 ºF (psi)	555.90

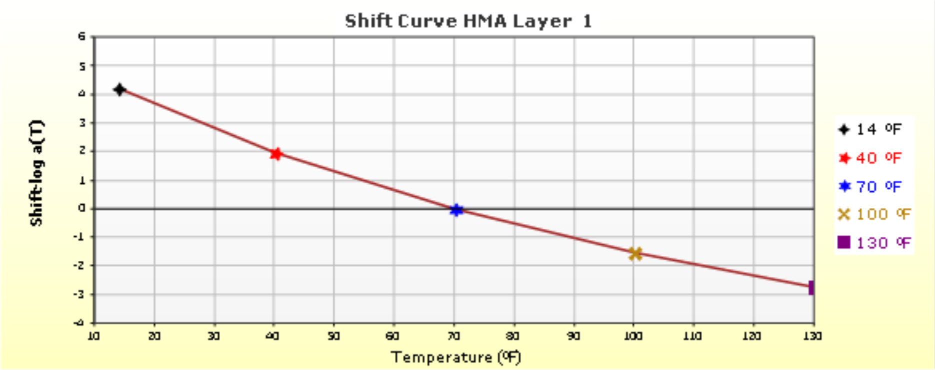
Thermal Contraction	
Is thermal contraction calculated?	True
Mix coefficient of thermal contraction (in/in/ºF)	-
Aggregate coefficient of thermal contraction (in/in/ºF)	5.0e-006
Voids in Mineral Aggregate (%)	16.2

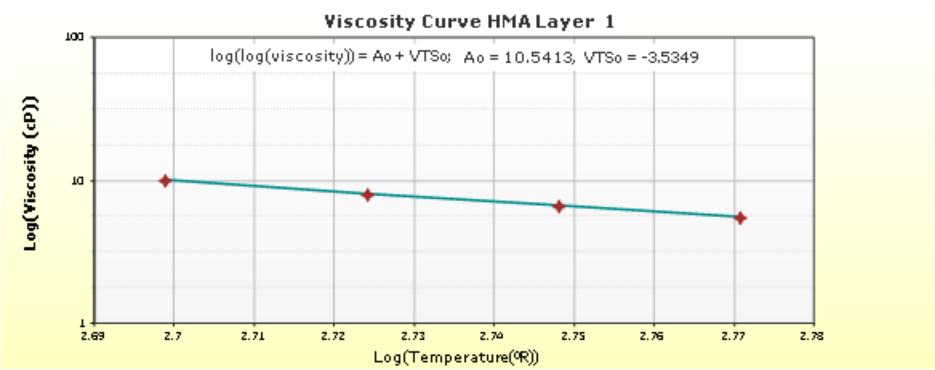
	Creep Compliance (1/psi)		
Loading time (sec)	**-4 ºF**	**14 ºF**	**32 ºF**
1	2.78e-007	3.91e-007	2.65e-007
2	3.11e-007	4.79e-007	3.91e-007
5	3.48e-007	5.57e-007	6.33e-007
10	3.74e-007	6.94e-007	9.55e-007
20	4.22e-007	8.31e-007	1.28e-006
50	4.63e-007	1.08e-006	1.99e-006
100	5.28e-007	1.35e-006	2.72e-006



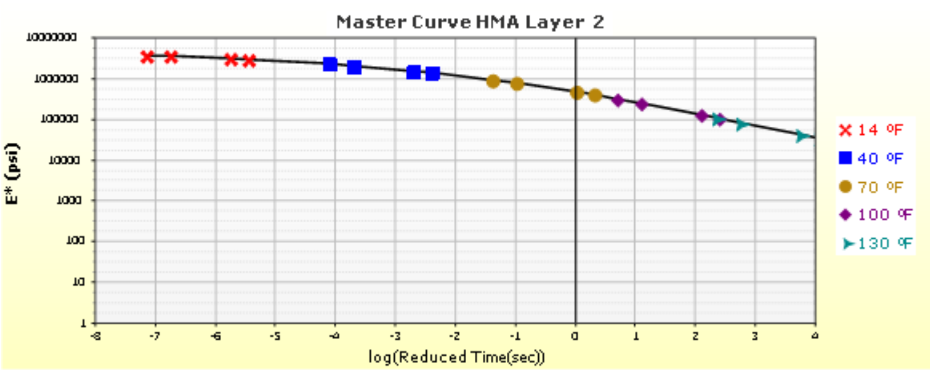
HMA Layer 1: Layer 1 Flexible : SX(75) PG 58-28

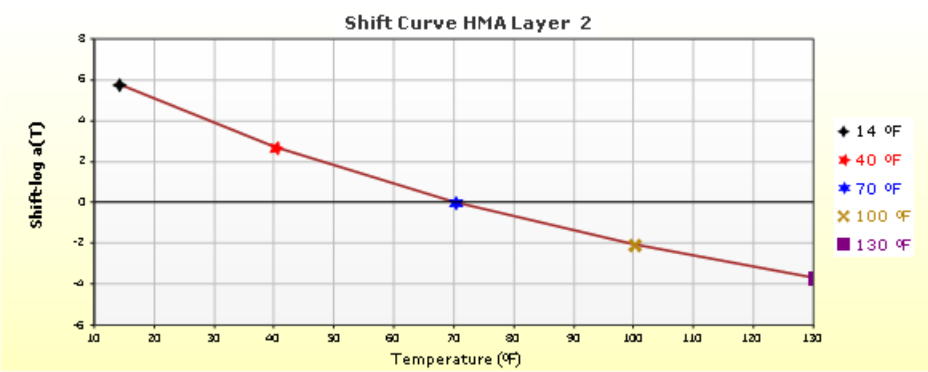


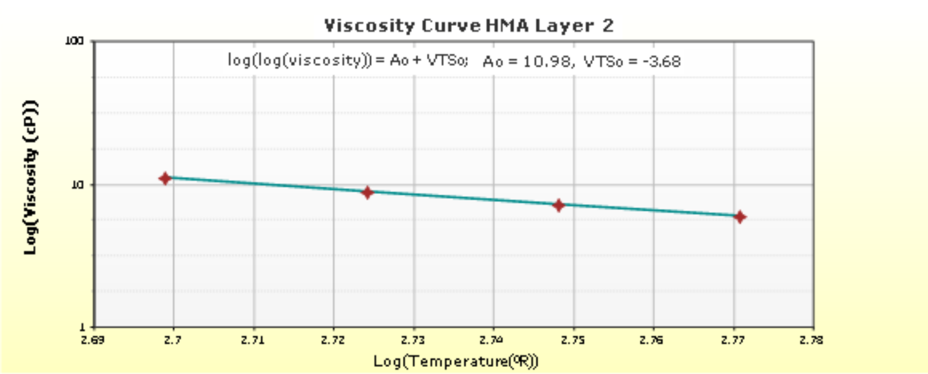




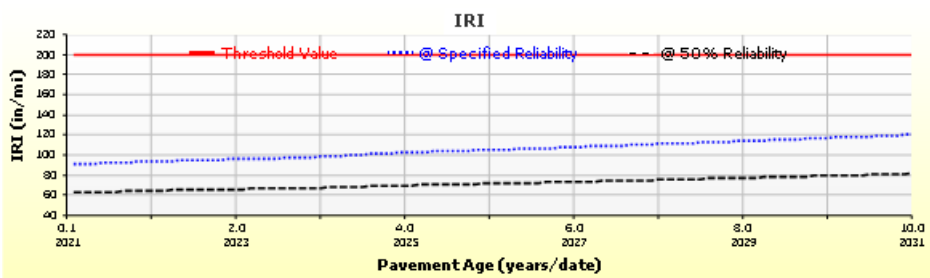
HMA Layer 2: Layer 2 Flexible : Default asphalt concrete(existing)

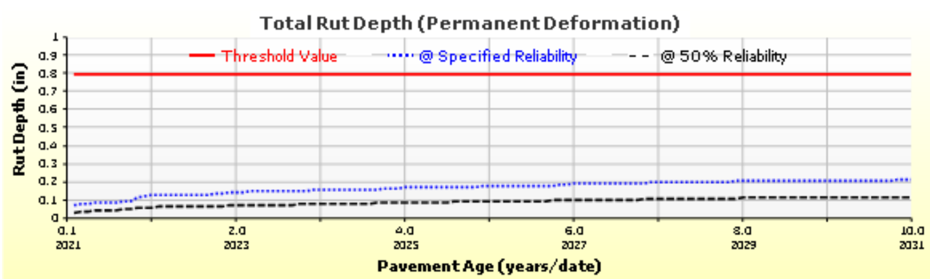


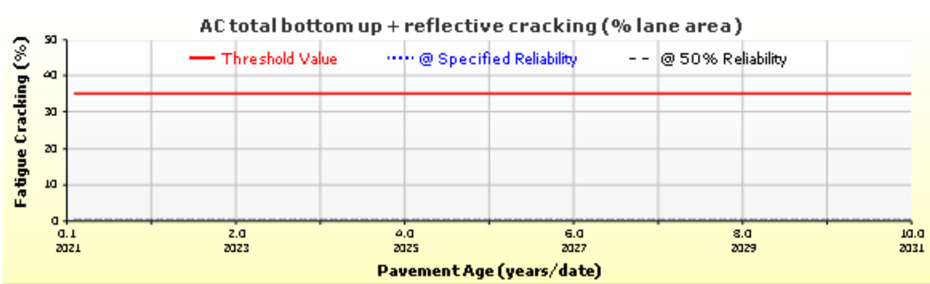


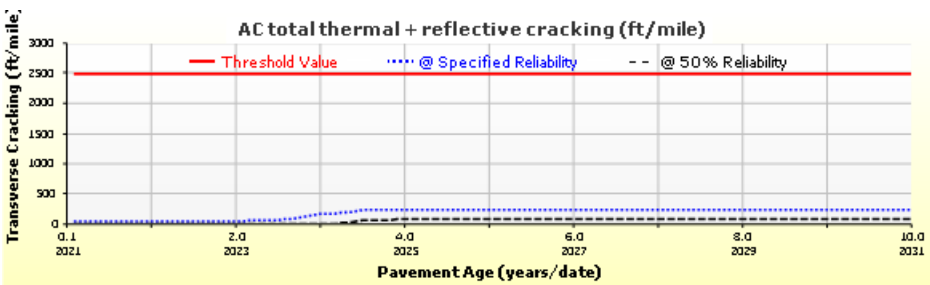


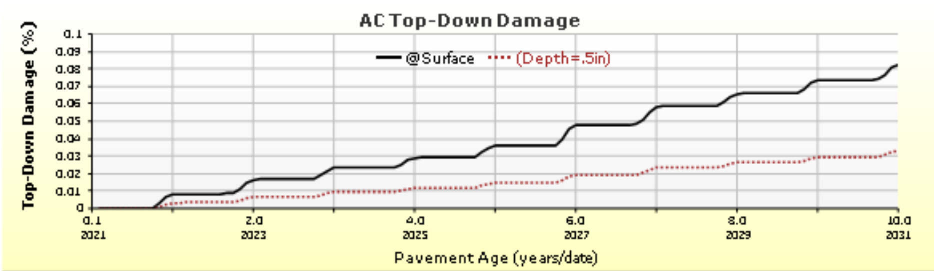
Analysis Output Charts

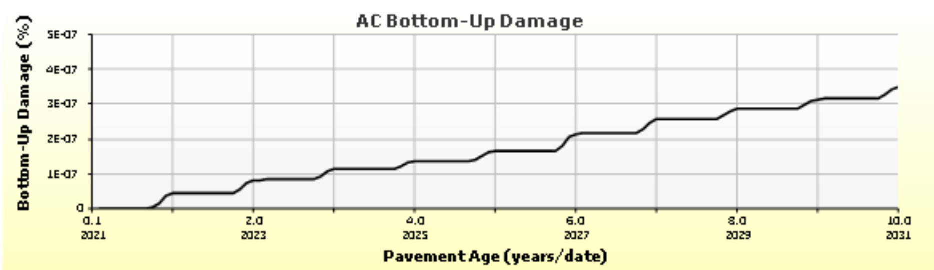


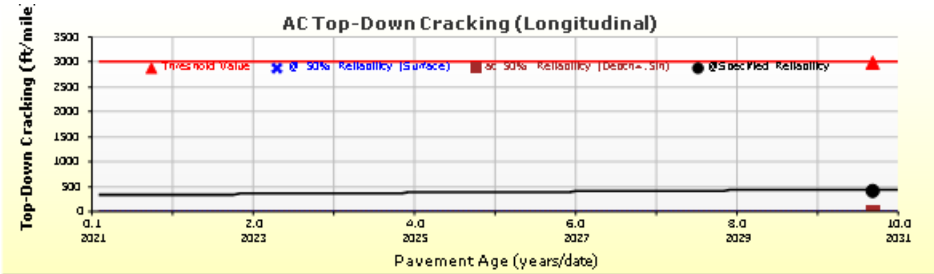


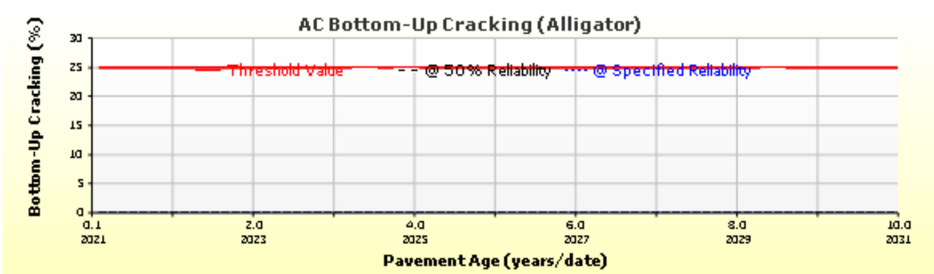


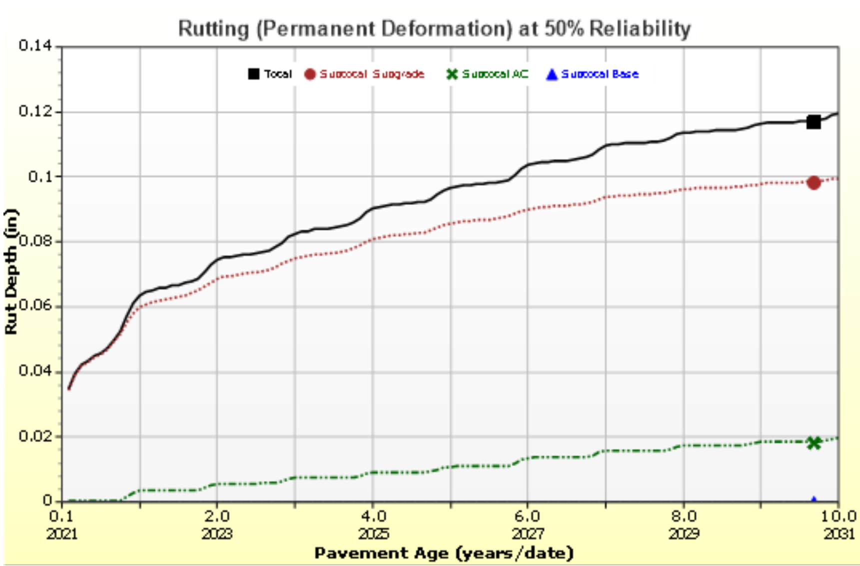


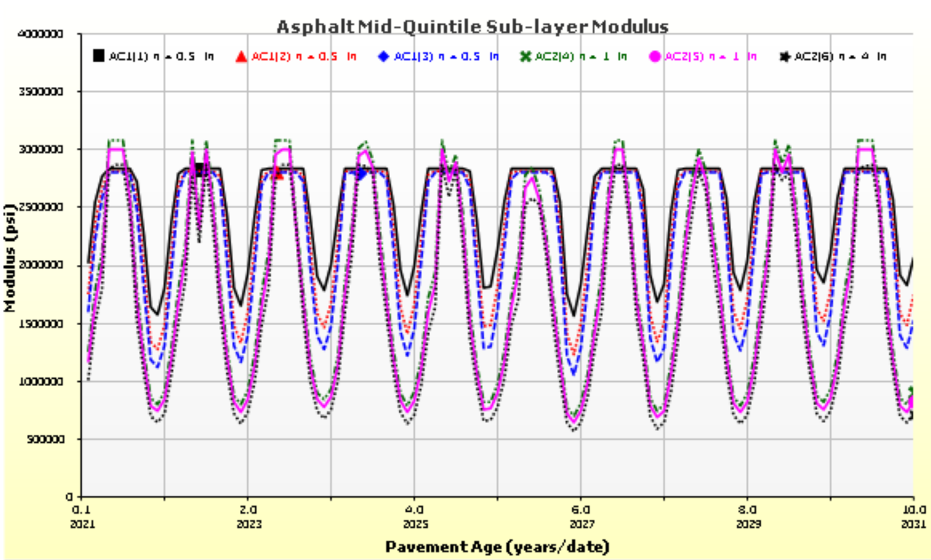

AC Top-Down Damage
@Surface
(Depth=.5in)
Top-Down Damage (%)
Pavement Age (years/date)

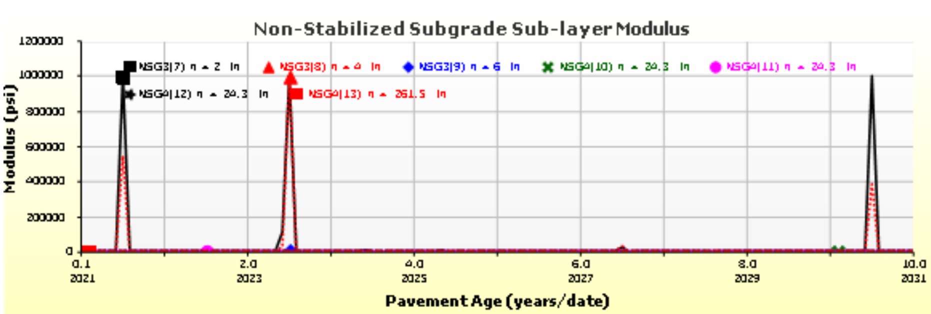

AC Bottom-Up Damage
Bottom-Up Damage (%)
Pavement Age (years/date)


AC Top-Down Cracking (Longitudinal)
Top-Down Cracking (ft/mile)
Pavement Age (years/date)


AC Bottom-Up Cracking (Alligator)
Threshold Value
@ 50% Reliability
@ Specified Reliability
Bottom-Up Cracking (%)
Pavement Age (years/date)


Rutting (Permanent Deformation) at 50% Reliability
Total
Subtotal Subgrade
Subtotal AC
Subtotal Base
Rut Depth (in)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.1
2021
2.0
2023
4.0
2025
6.0
2027
8.0
2029
10.0
2031
Pavement Age (years/date)


Asphalt Mid-Quintile Sub-layer Modulus
AC1(1) n = 0.5 In
AC1(2) n = 0.5 In
AC1(3) n = 0.5 In
AC2(4) n = 1 In
AC2(5) n = 1 In
AC2(6) n = 4 In
Modulus (psi)
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
0.1 2021
2.0 2023
4.0 2025
6.0 2027
8.0 2029
10.0 2031
Pavement Age (years/date)


Non-Stabilized Subgrade Sub-layer Modulus
NSG3(7) n = 2 In
NSG3(8) n = 4 In
NSG3(9) n = 6 In
NSG4(10) n = 24.3 In
NSG4(11) n = 24.3 In
NSG4(12) n = 24.3 In
NSG4(13) n = 261.5 In
Modulus (psi)
1200000
1000000
800000
600000
400000
200000
0
0.1 2021
2.0 2023
4.0 2025
6.0 2027
8.0 2029
10.0 2031
Pavement Age (years/date)

Layer Information

Layer 1 Flexible : SX(75) PG 58-28

Asphalt		
Thickness (in)	1.5	
Unit weight (pcf)	145.0	
Poisson's ratio	Is Calculated?	True
	Ratio	-
	Parameter A	-1.63
	Parameter B	3.84E-06

Asphalt Dynamic Modulus (Input Level: 1)

T (ºF)	0.5 Hz	1 Hz	10 Hz	25 Hz
14	2067099	2488999	2785899	2873299
40	930800	1472800	2008399	2196999
70	207600	439600	838700	1039200
100	52500	101200	215300	291900
130	24100	35400	60900	78900

Asphalt Binder

Temperature (ºF)	Binder Gstar (Pa)	Phase angle (deg)
136.4	2227.6	80
147.2	1068.2	82
158	540.1	84

General Info

Name	Value
Reference temperature (ºF)	70
Effective binder content (%)	10.7
Air voids (%)	5.5
Thermal conductivity (BTU/hr-ft-ºF)	0.67
Heat capacity (BTU/lb-ºF)	0.23

Identifiers

Field	Value
Display name/identifier	SX(75) PG 58-28
Description of object	Mix ID # FS1918
Author	CDOT
Date Created	4/3/2013 12:00:00 AM
Approver	CDOT
Date approved	4/3/2013 12:00:00 AM
State	Colorado
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 1	SX
User defined field 2	
User defined field 3	
Revision Number	0

Layer 2 Flexible : Default asphalt concrete(existing)

Asphalt		
Thickness (in)	6.0	
Unit weight (pcf)	150.0	
Poisson's ratio	Is Calculated?	False
	Ratio	0.35
	Parameter A	-
	Parameter B	-

Asphalt Dynamic Modulus (Input Level: 3)

Gradation	Percent Passing
3/4-inch sieve	100
3/8-inch sieve	77
No.4 sieve	60
No.200 sieve	6

Asphalt Binder

Parameter	Value
Grade	Superpave Performance Grade
Binder Type	64-22
A	10.98
VTS	-3.68

General Info

Name	Value
Reference temperature (ºF)	70
Effective binder content (%)	11.6
Air voids (%)	7
Thermal conductivity (BTU/hr-ft-ºF)	0.67
Heat capacity (BTU/lb-ºF)	0.23

Identifiers

Field	Value
Display name/identifier	Default asphalt concrete
Description of object	
Author	
Date Created	10/29/2010 12:00:00 AM
Approver	
Date approved	10/29/2010 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 1	
User defined field 2	
User defined field 3	
Revision Number	25

Layer 3 Subgrade : A-6

Unbound	
Layer thickness (in)	12.0
Poisson's ratio	0.35
Coefficient of lateral earth pressure (k0)	0.5

Modulus (Input Level: 3)

Analysis Type:	Modify input values by temperature/moisture
Method:	Resilient Modulus (psi)

Resilient Modulus (psi)
7247.0

Use Correction factor for NDT modulus?	-
NDT Correction Factor:	-

Identifiers

Field	Value
Display name/identifier	A-6
Description of object	Default material
Author	AASHTO
Date Created	1/1/2011 12:00:00 AM
Approver	
Date approved	1/1/2011 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 1	
User defined field 2	
User defined field 3	
Revision Number	5

Sieve

Liquid Limit	33.0
Plasticity Index	16.0
Is layer compacted?	False

	Is User Defined?	Value
Maximum dry unit weight (pcf)	False	107.9
Saturated hydraulic conductivity (ft/hr)	False	1.95e-05
Specific gravity of solids	False	2.7
Water Content (%)	False	17.1

User-defined Soil Water Characteristic Curve (SWCC)	
Is User Defined?	False
af	108.4091
bf	0.6801
cf	0.2161
hr	500.0000

Sieve Size	% Passing
0.001mm	
0.002mm	
0.020mm	
#200	63.2
#100	
#80	73.5
#60	
#50	
#40	82.4
#30	
#20	
#16	
#10	90.2
#8	
#4	93.5
3/8-in.	96.4
1/2-in.	97.4
3/4-in.	98.4
1-in.	99.0
1 1/2-in.	99.5
2-in.	99.8
2 1/2-in.	
3-in.	
3 1/2-in.	100.0

Layer 4 Subgrade : A-6

Unbound	
Layer thickness (in)	Semi-infinite
Poisson's ratio	0.35
Coefficient of lateral earth pressure (k0)	0.5

Modulus (Input Level: 3)

Analysis Type:	Modify input values by temperature/moisture
Method:	Resilient Modulus (psi)

Resilient Modulus (psi)
7247.0

Use Correction factor for NDT modulus?	-
NDT Correction Factor:	-

Identifiers

Field	Value
Display name/identifier	A-6
Description of object	Default material
Author	AASHTO
Date Created	1/1/2011 12:00:00 AM
Approver	
Date approved	1/1/2011 12:00:00 AM
State	
District	
County	
Highway	
Direction of Travel	
From station (miles)	
To station (miles)	
Province	
User defined field 1	
User defined field 2	
User defined field 3	
Revision Number	5

Sieve

Liquid Limit	33.0
Plasticity Index	16.0
Is layer compacted?	False

	Is User Defined?	Value
Maximum dry unit weight (pcf)	False	107.9
Saturated hydraulic conductivity (ft/hr)	False	1.95e-05
Specific gravity of solids	False	2.7
Water Content (%)	False	17.1

User-defined Soil Water Characteristic Curve (SWCC)	
Is User Defined?	False
af	108.4091
bf	0.6801
cf	0.2161
hr	500.0000

Sieve Size	% Passing
0.001mm	
0.002mm	
0.020mm	
#200	63.2
#100	
#80	73.5
#60	
#50	
#40	82.4
#30	
#20	
#16	
#10	90.2
#8	
#4	93.5
3/8-in.	96.4
1/2-in.	97.4
3/4-in.	98.4
1-in.	99.0
1 1/2-in.	99.5
2-in.	99.8
2 1/2-in.	
3-in.	
3 1/2-in.	100.0

Calibration Coefficients

AC Fatigue	
$N_f = 0.00432 * C * \beta_{f1} k_1 \left(\frac{1}{\varepsilon_1}\right)^{k_2 \beta_{f2}} \left(\frac{1}{E}\right)^{k_3 \beta_{f3}}$	k1: 0.007566
	k2: 3.9492
$C = 10^M$	k3: 1.281
	Bf1: 130.3674
$M = 4.84\left(\frac{V_b}{V_a + V_b} - 0.69\right)$	Bf2: 1
	Bf3: 1.217799

AC Rutting

$$\frac{\varepsilon_p}{\varepsilon_r} = k_z \beta_{r1} 10^{k_1} T^{k_2 \beta_{r2}} N^{k_3 \beta_{r3}}$$
$$k_z = (C_1 + C_2 * depth) * 0.328196^{depth}$$
$$C_1 = -0.1039 * H_a^2 + 2.4868 * H_a - 17.342$$
$$C_2 = 0.0172 * H_a^2 - 1.7331 * H_a + 27.428$$

Where:
H_{ac} = total AC thickness(in)

ε_p = plastic strain(in/in)
ε_r = resilient strain(in/in)
T = layer temperature(°F)
N = number of load repetitions

AC Rutting Standard Deviation	0.1414 * Pow(RUT,0.25) + 0.001	
AC Layer	K1:-3.35412 K2:1.5606 K3:0.3791	Br1:4.3 Br2:1 Br3:1

Thermal Fracture

$$C_f = 400 * N\left(\frac{\log C / h_{ac}}{\sigma}\right)$$
$$\Delta C = (k * \beta t)^{n+1} * A * \Delta K^n$$
$$A = 10^{(4.389 - 2.52 * \log(E * \sigma_m * n))}$$

C_f = observed amount of thermal cracking(ft/500ft)
k = refression coefficient determined through field calibration
$N()$ = standard normal distribution evaluated at()
σ = standard deviation of the log of the depth of cracks in the pavments
C = crack depth(in)
h_{ac} = thickness of asphalt layer(in)
ΔC = Change in the crack depth due to a cooling cycle
ΔK = Change in the stress intensity factor due to a cooling cycle
A, n = Fracture parameters for the asphalt mixture
E = mixture stiffness
σ_M = Undamaged mixture tensile strength
β_t = Calibration parameter

Level 1 K: 1.5	
Level 2 K: 0.5	
Level 3 K: 1.5	

CSM Fatigue

$$N_f = 10^{\left(\frac{k_1 \beta_{c1}\left(\frac{\sigma_s}{M_r}\right)}{k_2 \beta_{c2}}\right)}$$

N_f = number of repetitions to fatigue cracking
σ_s = Tensile stress(psi)
M_r = modulus of rupture(psi)

k1: 1	k2: 1	Bc1: 0.75	Bc2:1.1

Subgrade Rutting

$$\delta_a(N) = \beta_{s_1} k_1 \varepsilon_v h \left(\frac{\varepsilon_0}{\varepsilon_r}\right) \left| e^{-\left(\frac{\rho}{N}\right)^\beta} \right|$$

δ_a = permanent deformation for the layer
N = number of repetitions
ε_v = average veritcal strain(in/in)
$\varepsilon_0, \beta, \rho$ = material properties
ε_r = resilient strain(in/in)

Granular		Fine	
k1: 2.03	Bs1: 0.22	k1: 1.35	Bs1: 0.37
Standard Deviation (BASERUT) 0.0104 * Pow(BASERUT,0.67) + 0.001		Standard Deviation (BASERUT) 0.0663 * Pow(SUBRUT,0.5) + 0.001	

AC Cracking

AC Top Down Cracking

$$FC_{top} = \left(\frac{C_4}{1 + e^{(C_1 - C_2 * log_{10}(Damage))}}\right) * 10.56$$

AC Bottom Up Cracking

$$FC = \left(\frac{6000}{1 + e^{(C_1 * C_1' + C_2 * C_2' log_{10}(D * 100))}}\right) * \left(\frac{1}{60}\right)$$

$$C_2' = -2.40874 - 39.748 * (1 + h_{ac})^{-2.856}$$

$$C_1' = -2 * C_2'$$

AC Top Down Cracking				AC Bottom Up Cracking		
c1: 7	c2: 3.5	c3: 0	c4: 1000	c1: 0.021	c2: 2.35	c3: 6000

AC Cracking Top Standard Deviation	AC Cracking Bottom Standard Deviation
200 + 2300/(1+exp(1.072-2.1654*LOG10 (TOP+0.0001)))	1+15 /(1+exp(-3.1472-4.1349*LOG10 (BOTTOM+0.0001)))

CSM Cracking

$$FC_{ctb} = C_1 + \frac{C_2}{1 + e^{C_3 - C_4(Damage)}}$$

C1: 0	C2: 75	C3: 5	C4: 3

CSM Standard Deviation

CTB*11

IRI Flexible Pavements

C1 - Rutting
C2 - Fatigue Crack
C3 - Transverse Crack
C4 - Site Factors

C1: 50	C2: 0.55	C3: 0.0111	C4: 0.02

Reflective Cracking

$$\Delta C = k_1 \Delta_{bending} + k_2 \Delta_{shaering} + k_3 \Delta_{thermal}$$

$$\Delta D = \frac{C_1 k_1 \Delta_{bending} + C_2 k_2 \Delta_{shearing} + C_3 k_3 \Delta_{thermal}}{h_{OL}}$$

$$\Delta_{Bending} = A(SIF)_B^n$$

$$\Delta_{Shearing} = A(SIF)_S^n$$

$$\Delta_{Thermal} = A(SIF)_T^n$$

$$D = \sum_{i=1}^{N} \Delta D$$

$$RCR = \left(\frac{100}{C4 + e^{C5 \log D}}\right) * EX\_CRK$$

Where

ΔC = Crack length increment, in

ΔD = Incremental damage ratio

$k_1, k_2, k_3, C_1, C_2, C_3, C_4, C_5$ = Calibration factors (local and global)

$\Delta_{bending}, \Delta_{shearing}, \Delta_{thermal}$ = Crack length increments caused by bending, shearing, and thermal loading

A, n = HMA material fracture properties

N = Total number of days

$(SIF)_B, (SIF)_S, (SIF)_T$ = Stress intensity factors caused by bending, shearing, and thermal loading

D = Damage ratio

h_{OL} = Overlay thickness, in

RCR = Cracks in the underlying layers reflected, %

EX_CRK = Transverse cracking in underlying pavement layers, ft/mile (transverse cracking)
Alligator cracking in underlying pavement layers, % lane area (alligator cracking)

Pavement Type	Distress Type	k1	k2	k3	C1	C2	C3	C4	C5	Standard Deviation
AC over AC	Transverse	0.012	0.005	1	3.22	25.7	0.1	133.4	-72.4	70.98 * Pow (TRANSVERSE,0.2994) + 30.12
AC over AC	Fatigue	0.012	0.005	1	0.38	1.66	2.72	105.4	-7.02	1.1097 * Pow (FATIGUE,0.6804) + 1.23

Preliminary Soil Survey Boring Logs
(Provided by Yeh and Associates, Inc.)

<u>CDOT Region 2 Bridge Bundle</u>
220-063
Pavement Boring Summary
US 24 and CO 9

Bridge	Roadway	Boring ID	AC Thickness (in.)	Project Coordinates		Elevation (ft)
				Northing	Easting	
I-17-X (MP 295.45)	US 24	P-1	10	382795.221	157833.055	7030.5
		P-2	8	382936.533	157670.305	7042.0
I-15-AO (MP 271.9)	US 24	P-1	9	406539.948	1070443.869	8441.0
		P-2	8.5	406830.737	1070002.972	8421.5
I-15-T (271.291)	US 24	P-1	8.5	405904.497	1071141.345	8472.0
		P-2	11	405384.782	1071144.330	8495.5
H-13-N (MP 240.686)	US 24	P-1	9.5	1436903.518	2925288.260	8828.5
		P-2	9	1436694.485	2924806.507	8828.9
I-13-H (MP 229.468)	US 24	P-1	9.5	402283.147	882423.869	8987.5
		P-2	7.5	401910.031	882002.775	8993.0
I-13-G (MP 227.095)	US 24	P-1	7	398499.311	871735.300	9125.5
		P-2	8.5	398406.691	871171.013	9130.0
G-12-C (MP 71.445)	CO 9	P-1	6.5	1205804.318	2185416.009	10392.5
		P-2	8	--	--	10390.0
J-14-C (MP 20.107)	CO 9	P-1	7.5	324170.443	997093.849	8299.5
		P-2	9	324346.637	996585.515	8285.5
J-15-G (MP 15.97)	CO 9	P-1	6	305376.924	1005897.440	8002.5
		P-2	7.5	305373.961	1005390.940	8020.0

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Project:	CDOT Region 2 Bridge Bundle
Project Number:	220-063

Legend for Symbols Used on Borehole Logs

Sample Types

Bulk Sample of auger/odex cuttings	Rock core	Modified California Sampler (2.5 inch OD, 2.0 inch ID)	Standard Penetration Test (ASTM D1586)

Drilling Methods

CORING	HOLLOW-STEM AUGER

Lithology Symbols (see Boring Logs for complete descriptions)

Asphalt	Cobbles and gravel	USCS Fat/High Plasticity Clay	USCS Lean/Low Plasticity Clay
Fill	Fill with Clay as major soil	Fill with Gravel as major soil	USCS Clayey Gravel
USCS Silty, Clayey Gravel	USCS Poorly-graded Gravel	USCS Poorly-graded Gravel with Clay	Low Plasticity Gravelly Clay
USCS Silt	USCS Low Plasticity Organic silt or clay	High Plasticity Sandy Clay	Poorly-graded Sandy Gravel
Low Plasticity Sandy Clay	USCS Clayey Sand	USCS Silty Sand	USCS Poorly-graded Sand

Cobbles and gravel	Diorite	Gneiss	Granite
Limestone	Sandstone	Shale	Weathered Bedrock

Lab Test Standards

Moisture Content	ASTM D2216
Dry Density	ASTM D7263
Sand/Fines Content	ASTM D421, ASTM C136, ASTM D1140
Atterberg Limits	ASTM D4318
AASHTO Class.	AASHTO M145, ASTM D3282
USCS Class.	ASTM D2487

(Fines = % Passing #200 Sieve
Sand = % Passing #4 Sieve, but not passing #200 Sieve)

Other Lab Test Abbreviations

pH	Soil pH (AASHTO T289-91)
S	Water-Soluble Sulfate Content (AASHTO T290-91, ASTM D4327)
Chl	Water-Soluble Chloride Content (AASHTO T291-91, ASTM D4327)
S/C	Swell/Collapse (ASTM D4546)
UCCS	Unconfined Compressive Strength (Soil - ASTM D2166, Rock - ASTM D7012)
R-Value	Resistance R-Value (ASTM D2844)
DS (C)	Direct Shear cohesion (ASTM D3080)
DS (phi)	Direct Shear friction angle (ASTM D3080)
Re	Electrical Resistivity (AASHTO T288-91)
PtL	Point Load Strength Index (ASTM D5731)

Notes

1. Visual classifications are in general accordance with ASTM D2488, "Standard Practice for Description and Identification of Soils (Visual-Manual Procedures)".
2. "Penetration Resistance" on the Boring Logs refers to the uncorrected N value for SPT samples only, as per ASTM D1586. For samples obtained with a Modified California (MC) sampler, drive depth is 12 inches, and "Penetration Resistance" refers to the sum of all blows. Where blow counts were > 50 for the 3rd increment (SPT) or 2nd increment (MC), "Penetration Resistance" combines the last and 2nd-to-last blows and lengths; for other increments with > 50 blows, the blows for the last increment are reported.
3. The Modified California sampler used to obtain samples is a 2.5-inch OD, 2.0-inch ID (1.95-inch ID with liners), split-barrel sampler with internal liners, as per ASTM D3550. Sampler is driven with a 140-pound hammer, dropped 30 inches per blow.
4. "ER" for the hammer is the Reported Calibrated Energy Transfer Ratio for that specific hammer, as provided by the drilling company.

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Project Name: CDOT Region 2 Bridge Bundle	PAGE 1 of 1
Project Number: 220-063	Boring No.: **I-17-X P-1**

Boring Began: 9/3/2020
Boring Completed: 9/3/2020
Drilling Method(s): Coring / Solid-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 9.3 ft
Ground Elevation: 7030.5
Coordinates: N: 382795.2 E: 157833.1
Location: US 24, westbound turn lane
Logged By: B. Lykins
Final By: J. McCall

Weather Notes: Sunny, 78F
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
7030							**0.0 - 0.8 ft. ASPHALT** (10 inches).									
				20-23	43		**0.8 - 8.5 ft. Poorly graded SAND with gravel (SP)**, reddish brown with gray, moist, loose to dense.	3.1		34.0	56.2	9.8				
	5			15-16-20	36											
7025																
				5-3-3	6											
				50:3"	50:3"		**8.5 - 9.3 ft. COBBLES and GRAVEL**, gray with reddish brown, very dense, granite fragments.									
7020							Bottom of Hole at 9.3 ft.									
7015																
7010																

Yeh and Associates, Inc.
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Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063 | Boring No.: **I-17-X P-2**

Boring Began: 9/3/2020
Boring Completed: 9/3/2020
Drilling Method(s): Coring / Solid-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.5 ft
Ground Elevation: 7042
Coordinates: N: 382936.5 E: 157670.3
Location: US 24, eastbound turn lane
Logged By: B. Lykins
Final By: J. McCall

Weather Notes:
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Blows per 6 in	Penetration Resistance	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
				0.0 - 0.7 ft. ASPHALT (8 inches).									
7040		14-12	26	**0.7 - 3.5 ft. Poorly graded GRAVEL with sand (GP)**, reddish brown, moist, medium dense.									
	5	4-3-6	9	**3.5 - 10.5 ft. Poorly graded SAND with gravel (SP)**, dark brown to reddish brown, moist, loose to medium dense.	1.2		25.0	64.3	10.7				
7035		3-3-2	5										
	10	6-3-4	7										

Bottom of Hole at 10.5 ft.

7030

7025

7020

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Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063 | Boring No.: **I-15-AO P-1**

Boring Began: 10/6/2020
Boring Completed: 10/6/2020
Drilling Method(s): Coring / Solid-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 4.3 ft
Ground Elevation: 8441
Coordinates: N: 406539.9 E: 1070443.9
Location: US 24, westbound outside lane
Logged By: B. Lykins
Final By: J. McCall

Weather Notes: Sunny, 75F
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
							0.0 - 0.8 ft. ASPHALT (9 inches).									
8440				16-11	27		**0.8 - 4.0 ft. Clayey SAND with gravel (SC) (Fill)**, black and reddish brown, moist, medium dense, contains milled asphalt material.	7.4		21.0	46.5	32.5				
				50:3"	50:3"		**4.0 - 4.3 ft. GRANITE**, gray with pink, slightly weathered, very hard.									
							Bottom of Hole at 4.3 ft.									
8435							Auger refusal at 4' (granite bedrock)									
8430																
8425																
8420																

Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063 *Boring No.:* **I-15-AO P-2**

Boring Began: 10/7/2020
Boring Completed: 10/7/2020
Drilling Method(s): Coring / Solid-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 7.5 ft
Ground Elevation: 8421.5
Coordinates: N: 406830.7 E: 1070003.0
Location: US 24, eastbound outside lane
Logged By: B. Lykins
Final By: J. McCall

Weather Notes: Sunny, 52F
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
							0.0 - 0.7 ft. ASPHALT (8.5 inches).									
8420				12-9	21		**0.7 - 7.5 ft. Clayey SAND with gravel (SC) (Fill)**, reddish brown to dark brown, moist, medium dense.									
	5			15-12-11	23			3.1		21.0	57.5	21.5				
8415				6-2-2	4											

Bottom of Hole at 7.5 ft.

Auger refusal at 7' (cobbles)

8410

8405

8400

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Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063 *Boring No.:* **I-15-T P-1**

Boring Began: 10/5/2020
Boring Completed: 10/5/2020
Drilling Method(s): Coring / Solid-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.5 ft
Ground Elevation: 8472
Coordinates: N: 405904.5 E: 1071141.3
Location: US 24, westbound outside lane
Logged By: B. Lykins
Final By: J. McCall

Weather Notes: Sunny, 64F
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Blows per 6 in	Penetration Resistance	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Liquid Limit	Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
				0.0 - 0.7 ft. ASPHALT (8.5 inches).									
8470		15-15	30	**0.7 - 3.5 ft. Poorly graded SAND with clay and gravel (SP-SC) (Fill)**, brown to dark brown, moist, medium dense.									
	5	6-9-6	15	**3.5 - 6.5 ft. Silty SAND with gravel (SM) (Fill)**, black, moist, medium dense.	6.3		22.0	63.0	15.0	NV	NP	A-1-b (0) SM	
8465		4-4	8	**6.5 - 8.5 ft. Poorly graded SAND with clay and gravel (SP-SC) (Fill)**, dark brown, moist, loose.									
	10	1-1-2	3	**8.5 - 10.5 ft. Silty SAND with gravel (SM) (Fill)**, black, moist, loose.									

Bottom of Hole at 10.5 ft.

8460

8455

8450

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Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063

Boring No.: **I-15-T P-2**

Boring Began: 10/5/2020
Boring Completed: 10/5/2020
Drilling Method(s): Coring / Solid-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 3.1 ft
Ground Elevation: 8495.5
Coordinates: N: 405384.8 E: 1071144.3
Location: US 24, eastbound outside lane
Logged By: B. Lykins
Final By: J. McCall

Weather Notes: Sunny, 55F
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
8495							**0.0 - 0.9 ft. ASPHALT** (11 inches).									
				12-20	32		**0.9 - 2.5 ft. Silty, clayey SAND (SC-SM)**, brown to dark brown, moist, medium dense.	5.6	124.7	21.0	61.7	17.3	28	7	A-2-4 (0) SC-SM	
				50:1"	50:1"		**2.5 - 3.1 ft. GRANITE**, reddish tan, slightly weathered, very hard.									

Bottom of Hole at 3.1 ft.

Auger refusal at 3' (granite bedrock)

8490

8485

8480

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Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063

Boring No.: **H-13-N P-1**

Boring Began: 9/28/2020
Boring Completed: 9/28/2020
Drilling Method(s): Coring / Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.5 ft
Ground Elevation: 8828.5
Coordinates: N: 1436903.5 E: 2925288.3
Location: US 24, westbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 60s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Blows per 6 in	Penetration Resistance	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Liquid Limit	Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
				0.0 - 0.8 ft. ASPHALT (9.5 inches).									
		5-3	8	**0.8 - 2.0 ft. Silty SAND (SM) (Fill)**, brown, moist, loose.									
8825				**2.0 - 4.0 ft. Sandy lean CLAY (CL) (Fill)**, light brown, moist, medium stiff.									
	5	7-7	14	**4.0 - 7.0 ft. Poorly graded SAND (SP) with silt (Fill)**, brown, moist, medium dense.	3.4	102.6		93.4	6.6	NV	NP	A-1-b (0)	S/C=-1.9%
		5-6-8	14	**7.0 - 8.0 ft. Organic CLAY (OL)**, black, moist, stiff.									
8820				**8.0 - 9.0 ft. Poorly graded GRAVEL with sand (GP)**, gray-brown, moist, medium dense.									
	10	5-9-12	21	**9.0 - 10.5 ft. Poorly graded SAND with gravel (SP)**, dark brown, moist to wet, medium dense.									
8815				Bottom of Hole at 10.5 ft.									
8810													
8805													

Yeh and Associates, Inc. Geotechnical • Geological • Construction Services	Project Name: CDOT Region 2 Bridge Bundle	PAGE 1 of 1
	Project Number: 220-063	Boring No.: **H-13-N P-2**

Boring Began: 9/28/2020	**Total Depth: 10.5 ft**	Weather Notes: Clear, 60s
Boring Completed: 9/28/2020	Ground Elevation: 8828.94	Inclination from Horiz.: Vertical
Drilling Method(s): Coring / Hollow-Stem Auger	Coordinates: N: 1436694.5 E: 2924806.5	
	Location: US 24, eastbound outside lane	Night Work: ☐
Driller: Vine Laboratories		
Drill Rig: CME 750X Buggy	Logged By: C. Wallace	
Hammer: Automatic (hydraulic), ER: 80%	Final By: J. McCall	

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
				0.0 - 0.8 ft. ASPHALT (9 inches).									
		5-4	9	**0.8 - 4.0 ft. Clayey GRAVEL with sand (GC) (Fill)**, yellowish brown, moist, loose.	7.8		56.0	21.7	22.3	28	12	A-2-6 (0) GC	
8825	5	8-27-8	35	**4.0 - 5.5 ft. Poorly graded SAND with gravel (SP) (Fill)**, brown, moist, dense.									
				5.5 - 7.0 ft. Sandy lean CLAY (CL), dark brown to black, low plasticity, moist, medium stiff.									
		7-15-15	30	**7.0 - 10.5 ft. Silty SAND with gravel (SM)**, yellowish brown, moist to wet, medium dense.									
8820	10	4-5-12	17										
8815				Bottom of Hole at 10.5 ft.									
8810													
8805													

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Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063

Boring No.: **I-13-H P-1**

Boring Began: 9/24/2020
Boring Completed: 9/24/2020
Drilling Method(s): Coring / Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.5 ft
Ground Elevation: 8987.5
Coordinates: N: 402283.1 E: 882423.9
Location: US 24, westbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 60s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
							0.0 - 0.8 ft. ASPHALT (9.5 inches).									
				3-5	8		**0.8 - 2.0 ft. Silty SAND (SM) (Fill)**, black to light gray, moist, loose.	7.2		0.0	62.1	37.9	29	4	A-4 (0) SM	
8985							**2.0 - 10.5 ft. Silty SAND with gravel (SM)**, light gray with gray-brown, moist, loose to medium dense.									
	5			2-2-2	4											
							- calcareous below 6'.									
8980				4-7-5	12											
	10			5-11-16	27											

Bottom of Hole at 10.5 ft.

8975
8970
8965

Yeh and Associates, Inc. Geotechnical • Geological • Construction Services	*Project Name:* CDOT Region 2 Bridge Bundle	*PAGE 1 of 1*
	Project Number: 220-063	*Boring No.:* **I-13-H P-2**

Boring Began: 9/24/2020
Boring Completed: 9/24/2020
Drilling Method(s): Coring / Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.5 ft
Ground Elevation: 8993
Coordinates: N: 401910.0 E: 882002.8
Location: US 24, eastbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 70s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Blows per 6 in	Penetration Resistance	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Liquid Limit	Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
	0			**0.0 - 0.6 ft. ASPHALT** (7.5 inches).									
		3-4	7	**0.6 - 4.0 ft. Silty SAND with gravel (SM) (Fill)**, light gray to brown, moist, loose.									
8990													
	5	3-3-5	8	**4.0 - 10.0 ft. Silty CLAY (CL-ML)**, light gray, moist, medium stiff.	15.0		1.0	6.8	92.2	25	6	A-4 (4) CL-ML	
8985		4-6-6	12										
	10	3-4-6	10	**10.0 - 10.5 ft. Sandy lean CLAY (CL)**, gray, low plasticity, moist, stiff, siltstone gravel in shoe.									
				Bottom of Hole at 10.5 ft.									
8980													
8975													
8970													

Yeh and Associates, Inc.
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Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063

Boring No.: **I-13-G P-1**

Boring Began: 9/24/2020
Boring Completed: 9/24/2020
Drilling Method(s): Coring / Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.0 ft
Ground Elevation: 9125.5
Coordinates: N: 398499.3 E: 871735.3
Location: US 24, westbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 60s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
9125	0			**0.0 - 0.6 ft. ASPHALT** (7 inches).									
				0.6 - 7.0 ft. Clayey SAND with gravel (SC) (Fill), brown, moist, very loose to loose.									
		3-4	7										
		2-2	4		18.6	100.2	29.0	29.7	41.3	41	17	A-7-6 (3) SC	S/C=0.3%
9120	5												
		3-6	9	**7.0 - 10.0 ft. Sandy lean CLAY with gravel (CL)**, brown, moist, stiff to very stiff.									
		7-13	20										
9115	10			Bottom of Hole at 10.0 ft.									
9110													
9105													

Yeh and Associates, Inc.
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Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063 *Boring No.:* **I-13-G P-2**

Boring Began: 9/23/2020
Boring Completed: 9/23/2020
Drilling Method(s): Coring / Solid-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.0 ft
Ground Elevation: 9130
Coordinates: N: 398406.7 E: 871171.0
Location: US 24, eastbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 60s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Blows per 6 in	Penetration Resistance	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Liquid Limit	Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
				0.0 - 0.7 ft. ASPHALT (8.5 inches).									
		3-3	6	**0.7 - 8.0 ft. Gravelly lean CLAY with sand (CL) (Fill)**, brown to light brown, moist, medium stiff.									
		2-2	4		15.8	108.4	32.0	17.1	50.9	35	16	A-6 (5) CL	S/C=0%
9125	5												
		2-2	4										
				8.0 - 10.0 ft. Sandy lean CLAY with gravel (CL), dark brown to black, moist, medium stiff, rich in organic material.									
		2-2	4										
9120	10			Bottom of Hole at 10.0 ft.									
9115													
9110													

Yeh and Associates, Inc.
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Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063

Boring No.: **G-12-C P-1**

Boring Began: 9/22/2020
Boring Completed: 9/22/2020
Drilling Method(s): Coring / Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.5 ft
Ground Elevation: 10392.5
Coordinates: N: 1205804.3 E: 2185416.0
Location: State Highway 9, northbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 50s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
							0.0 - 0.6 ft. (6.5 inches).									
				8-6	14		**0.6 - 10.5 ft. Clayey SAND with gravel (SC) (Fill)**, brown to dark brown, moist, loose to medium dense.	8.0		37.0	48.2	14.8	28	10	A-2-4 (0) SC	
10390																
	5			4-4-2	6											
10385				3-5-5	10											
	10			3-5-8	13											

Bottom of Hole at 10.5 ft.

10380

10375

10370

BORING LOG 2019 - SPT CDOT STYLE 220-063 R2 BRIDGE BUNDLE FIXED FORMATTING 12-11-2020.GPJ 2019 YEH COLORADO TEMPLATE.GDT 2019 YEH COLORADO LIBRARY.GLB 1/12/21

Yeh and Associates, Inc.
Geotechnical • Geological • Construction Services

Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063 *Boring No.:* **G-12-C P-2**

Boring Began: 9/22/2020
Boring Completed: 9/22/2020
Drilling Method(s): Coring / Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.5 ft
Ground Elevation: 10390
Coordinates:
Location: State Highway 9, southbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Cloudy, 50s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels:

Symbol	▽		
Depth	7.0 ft	-	-
Date	9/22/20	-	-

Elevation (feet)	Depth (feet)	Blows per 6 in	Penetration Resistance	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Liquid Limit	Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
				0.0 - 0.7 ft. ASPHALT (8 inches).									
		8-12	20	**0.7 - 7.0 ft. Clayey SAND with gravel (SC) (Fill)**, dark brown to black, moist, medium dense, granite gravels, very coarse gravel.									
10385	5	2-2-2	4		3.4		24.0	56.9	19.1				
	▽	1-2-2	4	**7.0 - 8.0 ft. Poorly graded GRAVEL with sand (GP)**, brown, wet, loose.									
10380	10	3-2-2	4	**8.0 - 10.5 ft. Clayey SAND with gravel (SC)**, dark gray, wet, loose, rootlets.									

Bottom of Hole at 10.5 ft.

10375

10370

Yeh and Associates, Inc. Geotechnical • Geological • Construction Services	Project Name: CDOT Region 2 Bridge Bundle	PAGE 1 of 1
	Project Number: 220-063	Boring No.: **J-14-C P-1**

Boring Began: 9/30/2020
Boring Completed: 9/30/2020
Drilling Method(s): Coring / Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 75 Truck
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.5 ft
Ground Elevation: 8299.5
Coordinates: N: 324170.4 E: 997093.8
Location: State Highway 9, northbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 60s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
							0.0 - 0.6 ft. ASPHALT (7.5 inches).									
				3-4	7		**0.6 - 7.0 ft. Silty SAND with gravel (SM) (Fill)**, dark brown, moist, loose to medium dense, increasing gravel with depth.									
8295	5			1-2-4	6			7.4		25.0	53.5	21.5	24	3	A-1-b (0) SM	
				3-5-6	11		**7.0 - 9.0 ft. Poorly graded SAND with gravel (SP) (Fill)**, yellow and gray, moist, medium dense.									
8290	10			2-1-1	2		**9.0 - 10.5 ft. Silty SAND with gravel (SM) (Fill)**, dark brown, moist, very loose.									

Bottom of Hole at 10.5 ft.

8285
8280
8275

BORING LOG 2019 - SPT CDOT STYLE 220-063 R2 BRIDGE BUNDLE FIXED FORMATTING 12-11-2020.GPJ 2019 YEH COLORADO TEMPLATE.GDT 2019 YEH COLORADO LIBRARY.GLB 1/12/21

Yeh and Associates, Inc.
Geotechnical • Geological • Construction Services

Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063 *Boring No.:* **J-14-C P-2**

Boring Began: 9/29/2020
Boring Completed: 9/29/2020
Drilling Method(s): Coring / Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.5 ft
Ground Elevation: 8285.8
Coordinates: N: 324346.6 E: 996585.5
Location: State Highway 9, southbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 60s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
8285							**0.0 - 0.8 ft. ASPHALT** (9 inches).									
				4-5	9		**0.8 - 4.0 ft. Clayey SAND (SC) (Fill)**, brown, moist, loose.	18.5	111.4	3.0	51.3	45.7	30	12	A-6 (2) SC	
	5			2-3-2	5		**4.0 - 10.5 ft. Silty SAND (SM) (Fill)**, brown to black, moist, very loose to loose, micaceous, organics.									
8280																
				2-1-2	3											
	10			1-1-1	2											
8275							Bottom of Hole at 10.5 ft.									
8270																
8265																

Yeh and Associates, Inc.
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Project Name:	CDOT Region 2 Bridge Bundle
Project Number:	220-063
Boring No.:	**J-15-G P-1**

Boring Began: 10/1/2020
Boring Completed: 10/1/2020
Drilling Method(s): Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.5 ft
Ground Elevation: 8002.5
Coordinates: N: 305376.9 E: 1005897.4
Location: State Highway 9, southbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 40s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifi-cations	Field Notes and Other Lab Tests
							0.0 - 0.5 ft. ASPHALT (6 inches).									
				3-4	7		**0.5 - 6.0 ft. Silty SAND (SM) (Fill)**, dark brown, moist, loose, micaceous.									
8000																
	5			1-1-1	2			10.1		6.0	62.8	31.2	28	2	A-2-4 (0) SM	
							6.0 - 9.0 ft. Clayey SAND (SC) (Fill), brown, moist, loose.									
7995				2-2-4	6											
	10			3-4-5	9		**9.0 - 10.5 ft. Silty SAND with gravel (SM) (Fill)**, brown, moist, loose.									
							Bottom of Hole at 10.5 ft.									
7990																
7985																
7980																

Yeh and Associates, Inc.
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Project Name: CDOT Region 2 Bridge Bundle

Project Number: 220-063 *Boring No.:* **J-15-G P-2**

Boring Began: 10/1/2020
Boring Completed: 10/1/2020
Drilling Method(s): Hollow-Stem Auger
Driller: Vine Laboratories
Drill Rig: CME 750X Buggy
Hammer: Automatic (hydraulic), ER: 80%

Total Depth: 10.5 ft
Ground Elevation: 8020
Coordinates: N: 305374.0 E: 1005390.9
Location: State Highway 9, northbound outside lane
Logged By: C. Wallace
Final By: J. McCall

Weather Notes: Clear, 60s
Inclination from Horiz.: Vertical
Night Work: ☐

Groundwater Levels: Not Observed			
Symbol			
Depth	-	-	-
Date	-	-	-

Elevation (feet)	Depth (feet)	Sample Type/Depth	Drilling Method	Soil Samples: Blows per 6 in	Soil Samples: Penetration Resistance	Lithology	Material Description	Moisture Content (%)	Dry Density (pcf)	Gravel Content (%)	Sand Content (%)	Fines Content (%)	Atterberg Limits: Liquid Limit	Atterberg Limits: Plasticity Index	AASHTO & USCS Classifications	Field Notes and Other Lab Tests
							0.0 - 0.6 ft. ASPHALT (7.5 inches).									
				5-6	11		**0.6 - 10.5 ft. Silty SAND (SM) (Fill)**, dark brown to black, dry to moist, very loose to loose, micaceous.	9.0		5.0	67.2	27.8	26	3	A-2-4 (0) SM	
8015	5			1-2-3	5											
				1-1-2	3											
8010	10			1-1-1	2											

Bottom of Hole at 10.5 ft.

8005

8000

Summary of Laboratory Test Results

Project No: 220-063 Project Name: CDOT Region 2 Bridge Bundle Date: 01-08-2021

Sample Location			Natural Moisture Content (%)	Natural Dry Density (pcf)	Gradation			Atterberg			pH	Water Soluble Sulfate (%)	Water Soluble Chloride (%)	Resistivity (ohm-cm)	Swell (+) / Collapse (-) (% at Load in psf)	Unconf. Comp. Strength (psi)	R-Value	Classification	
Boring No.	Depth (ft)	Sample Type			Gravel > #4 (%)	Sand (%)	Fines < #200 (%)	LL	PL	PI								AASHTO	USCS
G-12-C P-1	1.0	MC	8		37.0	48.2	14.8	28	18	10								A-2-4 (0)	SC
G-12-C P-1/P-2	2.5	BULK	7.8		23.0	51.5	25.5	31	19	12		0.009	0.0116				12	A-2-6 (0)	SC
G-12-C P-2	4.0	SPT	3.4		24.0	56.9	19.1												
H-13-N P-1	4.0	MC	3.4	102.6		93.4	6.6	NV	NP	NP					-1.9 @ 200			A-1-b (0)	
H-13-N P-1/P-2	2.5	BULK	6.7		5.0	61.0	34.0	30	13	17		0.091	0.0039				19	A-2-6 (1)	SC
H-13-N P-2	1.0	MC	7.8		56.0	21.7	22.3	28	16	12								A-2-6 (0)	GC
I-13-G P-1	4.0	MC	18.6	100.2	29.0	29.7	41.3	41	24	17					0.3 @ 200			A-7-6 (3)	SC
I-13-G P-2	4.0	MC	15.8	108.4	32.0	17.1	50.9	35	19	16					0 @ 200			A-6 (5)	CL
I-13-G-P-1/P-2	2.5	BULK	15.9		10.0	33.7	56.3	34	19	15		0.008	0.0127				7	A-6 (6)	CL
I-13-H P-1	1.0	MC	7.2		0.0	62.1	37.9	29	25	4								A-4 (0)	SM
I-13-H P-1/P-2	2.5	BULK	9.3		8.0	47.3	44.7	29	23	6		1.473	0.0075				29	A-4 (0)	SM
I-13-H P-2	4.0	SPT	15		1.0	6.8	92.2	25	19	6								A-4 (4)	CL-ML
I-15-AO P-1	1.0	MC	7.4		21.0	46.5	32.5												
I-15-AO P-1/P-2	2.5	BULK	6.8		14.0	64.5	21.5	32	19	13		0.006	0.0259				14	A-2-6 (0)	SC
I-15-AO P-2	4.0	SPT	3.1		21.0	57.5	21.5												
I-15-T P-1	4.0	SPT	6.3		22.0	63.0	15.0	NV	NP	NP								A-1-b (0)	SM
I-15-T P-1/P-2	2.5	BULK	2.6		22.0	60.0	18.0	23	21	2		0.006	0.0264				74	A-1-b (0)	SM
I-15-T P-2	1.0	MC	5.6	124.7	21.0	61.7	17.3	28	21	7								A-2-4 (0)	SC-SM
I-17-X P-1	1.0	MC	3.1		34.0	56.2	9.8												
I-17-X P-1/P-2	2.5	BULK	1.4		18.0	65.8	16.2	24	22	2		0.004	0.0130				76	A-1-b (0)	SM

Yeh and Associates, Inc.
Geotechnical • Geological • Construction Services

Colorado Springs Lab

Summary of Laboratory Test Results

Project No: 220-063 Project Name: CDOT Region 2 Bridge Bundle Date: 01-08-2021

Sample Location			Natural Moisture Content (%)	Natural Dry Density (pcf)	Gradation			Atterberg			pH	Water Soluble Sulfate (%)	Water Soluble Chloride (%)	Resistivity (ohm-cm)	Swell (+) / Collapse (-) (% at Load in psf)	Unconf. Comp. Strength (psi)	R-Value	Classification	
Boring No.	Depth (ft)	Sample Type			Gravel > #4 (%)	Sand (%)	Fines < #200 (%)	LL	PL	PI								AASHTO	USCS
I-17-X P-2	4.0	SPT	1.2		25.0	64.3	10.7												
J-14-C P-1	4.0	SPT	7.4		25.0	53.5	21.5	24	21	3								A-1-b (0)	SM
J-14-C P-1/P-2	2.5	BULK	8.7		14.0	56.5	29.5	25	20	5		0.048	0.0223				36	A-2-4 (0)	SC-SM
J-14-C P-2	1.0	MC	18.5	111.4	3.0	51.3	45.7	30	18	12								A-6 (2)	SC
J-15-G P-1	4.0	SPT	10.1		6.0	62.8	31.2	28	26	2								A-2-4 (0)	SM
J-15-G P-1/P-2	2.5	BULK	7.1		11.0	64.6	24.4	26	22	4		0.008	0.0533				19	A-1-b (0)	SM
J-15-G P-2	1.0	MC	9		5.0	67.2	27.8	26	23	3								A-2-4 (0)	SM