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GEOTECHNICAL ENGINEERING STUDY AND PAVEMENT THICKNESS DESIGN PROPOSED STATE HIGHWAY 79 WIDENING SOUTH OF BENNETT AVENUE BENNETT, COLORADO

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Apr-23-18

Prepared For:

Town of Bennett
355 4th Street
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Attention: Mr. Daymon Johnson; Public Works Director

Project No. 18-3-108

April 20, 2018

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SUMMARY

1. The subsurface conditions at the site were evaluated by drilling two exploratory borings to depths of about 10 feet below the ground surface. Boring P-1 encountered about 5.75 inches of asphalt overlying about 2.25 inches of base course. The base course was underlain by about 4.5 feet of man-placed fill consisting of lean clay with sand to clayey sand which was in turn, underlain by natural clayey soils. The natural clayey soils were underlain by natural granular soils that extended to the explored depth of about 10 feet below the existing ground surface. Boring P-2 encountered about 7 feet of man-placed fill which was underlain by natural clayey soils that extended to the explored depth of about 10 feet.

   Groundwater was not encountered in the borings at the time of drilling. The borings were immediately backfilled for safety reasons.

2. Flexible pavements should consist of a composite section consisting of 6 inches of asphalt and 12 inches of base course.

   Proper subgrade preparation is discussed herein.

PURPOSE AND SCOPE OF WORK

This report presents the results of a geotechnical engineering study and pavement thickness design for the proposed State Highway 79 Widening to be constructed south of Bennett Avenue in Bennett, Colorado. This study was performed in accordance with our Proposal No. P3-17-283 dated September 27, 2017.

A field exploration program consisting of exploratory borings was conducted to obtain information on subsurface conditions. Samples of soils obtained during the field exploration were tested in the laboratory to determine their strength, compressibility or swell characteristics, and classification. Results of the field exploration and laboratory testing were analyzed to develop recommendations for exterior flatwork areas and pavements. The results of the field exploration and laboratory testing are presented herein.

This report has been prepared to summarize the data obtained during this study and to present our conclusions and recommendations based on the proposed construction and the subsurface conditions encountered. Design parameters and a discussion of geotechnical engineering considerations related to construction of the proposed pavement areas are included in the report.

PROPOSED CONSTRUCTION

The proposed pavement widening is planned to have a total length of about 1,100 linear feet. The proposed pavement improvements will include a northbound left-turn lane onto Muegge Way as well as a median between northbound and southbound traffic. The widening will also include a right-turn lane from southbound State Highway 79 onto Muegge Way.

If the proposed construction varies significantly from that generally described above or depicted in this report, we should be notified to reevaluate the conclusions and recommendations provided herein.

SITE CONDITIONS

The site consists of a single-lane asphalt paved roadway running north and south. The site is bounded by a government building and recreation facility to the west and a vacant field to the east. The site is relatively flat and slopes gently down to the north.

SUBSURFACE CONDITIONS

The subsurface conditions at the site were evaluated by drilling two (2) exploratory borings to depths ranging from about 5 to 10 feet below the existing ground surface. The exploratory borings were drilled in the proposed pavement improvement areas.

Boring P-1 encountered about 5.75 inches of asphalt overlying about 2.25 inches of base course. The base course was underlain by about 4.5 feet of man-placed fill consisting of lean clay with sand to clayey sand which was in turn, underlain by natural clayey soils. The natural clayey soils were underlain by natural granular soils that extended to the explored depth of about 10 feet below the existing ground surface. Boring P-2 encountered about 7 feet of man-placed fill which was underlain by natural clayey soils that extended to the explored depth of about 10 feet. The natural clayey soils consisted of lean clay with sand to sandy lean clay and the granular soils consisted of clayey sand.

The man-placed fill material was fine to coarse grained with gravel, moist and brown to dark brown. The natural clayey overburden soils were fine to medium grained, slightly moist to moist and light brown. The natural granular soils were fine to coarse grained, moist, and tan. Based on sampler penetration resistance, the natural clayey overburden soils were stiff to very stiff and the natural granular soils were medium dense.

Groundwater Conditions: Groundwater was not encountered in the borings at the time of drilling. The borings were immediately backfilled for safety reasons.

LABORATORY TESTING

Laboratory testing was performed on selected soil samples obtained from the borings to determine in-situ soil moisture content and dry density, Atterberg limits, swell-consolidation characteristics, gradation, and concentration of water soluble sulfates. The results of the laboratory tests are shown to the right of the logs on Fig. 2 and summarized in Table 1. The results of specific tests are graphically plotted on Figs. 4 through 6. The testing was conducted in general accordance with recognized test procedures, primarily those of the American Society for Testing of Materials (ASTM).

Swell-Consolidation: Swell-consolidation testing was conducted on samples of the existing fill. The swell-consolidation testing was performed in order to determine the compressibility and swell characteristics of the sample under loading and when submerged in water. The samples

were prepared and placed in a confining ring between porous discs, subjected to a surcharge pressure of 200 psf, and allowed to consolidate before being submerged. The sample height was monitored until deformation practically ceased under each load increment.

Results of the swell-consolidation testing are plotted as a curve of the final strain at each increment of pressure against the log of the pressure and are presented on Fig. 4. Based on the results of swell-consolidation testing, the fill material exhibited low swell potential upon wetting at surcharge pressures of 200 psf. The fill exhibited a swell potential ranging from about 0.3% to 0.6%

Index Properties: Samples were classified into categories of similar engineering properties in general accordance with the Unified Soil Classification System. This system is based on index properties, including liquid limit and plasticity index and grain size distribution. Values for moisture content, dry density, liquid limit and plasticity index, and the percent of soil passing the U.S. No. 4 and 200 sieves are presented in Table I and adjacent to the corresponding sample on the boring logs.

GEOTECHNICAL CONSIDERATIONS

As previously discussed, site subsurface conditions generally consist of an asphalt surface overlying about 4.5 to 7 feet of man-placed fill overlying natural overburden soils. Without documentation of placement conditions, the existing fills are considered non-engineered and may be unsuitable in their current state for support of new pavements.

Existing fill materials will be the predominant subgrade material available on-site. The fill should be evaluated by proof-rolling the surface and by performing in-place moisture/density tests both at and 1-foot below pavement subgrade elevation. If the stability is adequate based on proof-rolling, and the moisture/density tests indicate the existing fill generally meets the moisture content and compaction requirements indicated in this report, the fill may be left in place. If either the stability based on proof-rolling or in-place moisture/density tests indicate the fill as unsuitable, the fill will need to be reworked to provide a suitable and stable subgrade for overlying pavements.

If the fill is found to be suitable, the upper 12 inches should be scarified, adjusted in moisture content and compacted as indicated in the Site Grading section of this report. If the fill is found to be unsuitable, the upper 2 feet should be removed and the exposed surface scarified to a

depth of 12 inches. The scarified materials should be adjusted in moisture content and compacted as indicated in the Site Grading section of this report. The subgrade should be brought to final plan elevation using materials meeting the criteria and placed as indicated in the Site Grading section of this report.

Excavated existing fills and natural soils should be suitable for use as site grading fill and may be suitable for use as structural fill beneath flatwork and pavements provided they can be properly moisture conditioned and compacted.

WATER SOLUBLE SULFATES

The concentration of water-soluble sulfates measured in a sample of the overburden soils obtained from the exploratory borings was 0.00%. This concentration of water-soluble sulfates represents a Class 0 severity exposure to sulfate attack on concrete exposed to these materials. The degree of attack is based on a range of Class 0, Class 1, Class 2, and Class 3 severity exposure as presented in ACI 201. Based on the laboratory test results, we believe special sulfate resistant cement will generally not be required for concrete exposed to the on-site soils.

Temporary Excavations: For temporary excavations that occur during site grading, the existing man-placed fills and natural soils will classify as OSHA Type C soils. All excavations should be constructed in accordance with the applicable OSHA regulations. If groundwater is encountered, the geotechnical engineer should be notified so that additional recommendations can be provided, if necessary.

Material Specifications: The following material specifications are presented for fills on the project site. A geotechnical engineer should evaluate the suitability of all proposed import fill material, if required, for the project prior to placement.

1. Fill Beneath Pavements and Flatwork: Fill placed beneath pavements and flatwork should consist of existing on-site overburden soils free of organic or deleterious substances. Imported fill, if required, should have no more than 60 percent passing the No. 200 sieve, a maximum liquid limit of 30 and a maximum plasticity index of 12. Some leniency may be granted to the criteria above if the material has less than 1/2 percent swell potential when remolded to 95 percent of the maximum dry density at the optimum

moisture content as determined by standard Proctor (ASTM D 698) under a 200 psf surcharge pressure.

2. Pipe Bedding Material: Pipe bedding material should be a free draining, coarse grained sand and/or fine gravel. The near-surface on-site soils generally consist of clay soils and sands within relatively high silt and/or clay content and are not considered suitable for pipe bedding.

3. Aggregate Base Course: Aggregate base course material should consist of crushed stone, crushed slag, recycled concrete, crushed gravel or natural gravel which conforms to CDOT Specifications for Class 6 or Class 5 criteria for aggregate base course.

4. Utility Trench Backfill: Material excavated from the utility trenches may be used for backfill provided it does not contain unsuitable material or particles larger than 4 inches.

5. Material Suitability: It is our intent to allow the on-site overburden soils to be used as fill material as discussed in Item 1 above.

   All fill material should be free of vegetation, brush, sod and other deleterious substances and should not contain rocks, debris or lumps having a diameter of more than 4 inches. Rocks, debris or lumps should be dispersed throughout the fill and "nesting" of these materials should be avoided. The geotechnical engineer should evaluate the suitability of proposed import fill materials prior to placement.

Placement and Compaction Specifications: We recommend the following compaction criteria be used on the project:

1. *Moisture Content*: Compaction of all fill materials should be compacted as outlined below with moisture contents between the optimum moisture content and 3 percentage points above optimum moisture for clayey material and within -2 to +2 percentage points of optimum for granular soils.

   The contractor should be aware that the on-site and/or imported fine-grained soils may become somewhat unstable and deform under wheel loads if placed near the upper end of the moisture range(s). Some fill instability is not a concern in deeper fills provided the

required density is achieved; instability is a concern primarily in the upper 2 to 3 feet of slab and pavement subgrade fill.

2. *Placement and Degree of Compaction*: Structural fill beneath flatwork and pavements should be placed in 6-inch to 12-inch lifts as necessary, provided proper compaction can be achieved.

The following compaction criteria should be followed during construction:

Area	Percentage of Standard Proctor Maximum Dry Density (ASTM D698/ AASHTO T-99)	Percentage of Modified Proctor Maximum Dry Density (ASTM D1557, AASHTO T-180)
Fill Less Than 8 Feet Below the Ground Surface	95	N/A
Fill More Than 8 Feet Below the Ground Surface	98	N/A
Aggregate Base Course	N/A	95

3. *Subgrade Preparation*: Areas receiving new fill should be prepared as recommended in specific sections of this report to provide a uniform base for fill placement. All other areas to receive new fill not specifically addressed herein should be scarified to a depth of at least 8 inches and recompacted to at least 95% of the standard Proctor (ASTM D 698) maximum dry density at moisture contents recommended above.

Construction Monitoring: A representative of the geotechnical engineer should observe and test fill placement. Fills beneath settlement-sensitive flatwork and pavements should be observed and tested on a full-time basis. Full time observation and testing is a critical component to reducing the risk of post-construction movement of the fills.

PAVEMENT DESIGN

A pavement section is a layered system designed to distribute concentrated traffic loads to the near surface subgrade. Performance of the pavement structure is directly related to the physical properties of the subgrade soils and traffic loadings. Soils are represented for pavement design purposes by means of a soil support value for flexible pavements. This value is empirically related to strength.

Subgrade Materials: Based on the results of the field and laboratory studies, the majority of the near-surface subgrade materials at the site classify as A-6 with group indices between 1 and 8 in accordance with the American Association of State Highway and Transportation Officials (AASHTO) classification. R-Value testing of a composite sample taken from the subgrade resulted in an R-Value of 26. In accordance with Colorado Department of Transportation (CDOT) correlation procedures, the R-Value was converted to an equivalent resilient modulus value of 8,431 psi for use in design of asphalt pavements to be constructed for the project.

Design Traffic: We understand the traffic conditions for the roadway are considered arterial. Based on the traffic data provided by the CDOT's Online Transportation Information System, we have estimated an initial two-way AADT (Annual Average Daily Traffic) value of 385 after applying a growth rate factor to the 2016 traffic data. The AADT assumptions included a 20-year design life with minimal growth in traffic volumes over the design life. If traffic loading conditions are different from those described, we should be notified to re-evaluate the recommendations presented herein.

Flexible Pavement Sections: The pavement thicknesses were determined in accordance with the 2018 M-E Pavement Design Manual. For design purposes, a reliability of 90% was assumed for all pavement areas. Flexible pavements should consist of a composite section consisting of 6 inches of asphalt and 12 inches of base course. Aggregate base course materials should meet the material and placement requirements provided in the "Site Grading" section of this report. Asphalt pavement should be placed in accordance with current CDOT standards.

Pavement Materials: The following are recommended material and placement requirements for pavement construction for this project site. We recommend that properties and mix designs for all materials proposed to be used for pavements be submitted for review to the geotechnical engineer prior to placement.

1. *Aggregate Base Course*: Aggregate base course (ABC) used beneath HMA pavements should meet the material specifications for Class 5 or Class 6 ABC stated in the current CDOT *"Standard Specifications for Road and Bridge Construction"*. The ABC should be placed and compacted as outlined in the "SITE GRADING" section of this report.

2. *Hot Mix Asphalt:* Hot mix asphalt (HMA) materials and mix designs should meet the applicable requirements indicated in the current CDOT *"Standard Specifications for Road and Bridge Construction"*. We recommend that the HMA used for this project is designed in accordance with the SuperPave gyratory mix design method. The mix should meet Grading S specifications with a SuperPave gyratory design revolution (N_{DESIGN}) of 75. A mix meeting Grading SX specification can be used for the top lift wearing course, however, this is optional. The mix design(s) for the HMA should use a performance grade (PG) asphalt binder of PG 58-28 or PG 64-22. However, we recommend the PG 58-28 binder which tends to perform better under relatively low traffic volumes. Placement and compaction of HMA should follow current CDOT standards and specifications.

Subgrade Preparation: We recommend that areas of pavement be underlain by at least 2 feet of properly moisture conditioned compacted structural fill.

The owner should be aware that partial subexcavation and replacement of existing fills will reduce but not eliminate potential movement of pavements should moisture levels change within these materials.

Prior to placing new fill or the pavement section, the entire subgrade area should be scarified to a depth of 8 inches, adjusted to a moisture content near optimum and compacted to at least 95% of the standard Proctor (ASTM D 698) maximum dry density. Fill placed beneath the pavement should meet the material and compaction requirements for structural fill presented in the "Site Grading" section of this report.

The pavement subgrade should be proofrolled with a heavily loaded pneumatic-tired vehicle. Pavement design procedures assume a stable subgrade. Areas that deform excessively under heavy wheel loads are not considered stable and should be removed and replaced to achieve a stable subgrade prior to paving. The contractor should be aware that the clay soils, including on-site and imported materials, may become somewhat unstable and deform under wheel loads if placed near the upper end of the moisture range.

Drainage: The collection and diversion of surface drainage away from paved areas is extremely important to the satisfactory performance of pavement. Drainage design should provide for the removal of water from paved areas and prevent the wetting of the subgrade soils.

DESIGN AND CONSTRUCTION SUPPORT SERVICES

Kumar & Associates, Inc. should be retained to review the project plans and specifications for conformance with the recommendations provided in our report. We are also available to assist the design team in preparing specifications for geotechnical aspects of the project, and performing additional studies if necessary to accommodate possible changes in the proposed construction.

We recommend that Kumar & Associates, Inc. be retained to provide construction observation and testing services to document that the intent of this report and the requirements of the plans and specifications are being followed during construction. This will allow us to identify possible variations in subsurface conditions from those encountered during this study and to allow us to re-evaluate our recommendations, if needed. We will not be responsible for implementation of the recommendations presented in this report by others, if we are not retained to provide construction observation and testing services.

LIMITATIONS

This study has been conducted in accordance with generally accepted geotechnical engineering practices in this area for exclusive use by the client for design purposes. The conclusions and recommendations submitted in this report are based upon the data obtained from the exploratory borings at the locations indicated on Fig. 1, and the proposed type of construction. This report may not reflect subsurface variations that occur between the exploratory borings, and the nature and extent of variations across the site may not become evident until site grading and excavations are performed. If during construction, fill, soil, rock or water conditions appear to be different from those described herein, Kumar & Associates, Inc. should be advised at once so that a re-evaluation of the recommendations presented in this report can be made. Kumar & Associates, Inc. is not responsible for liability associated with interpretation of subsurface data by others.

Swelling soils occur on this site. Such soils are stable at their natural moisture content but will undergo high volume changes with changes in moisture content. The extent and amount of perched water beneath the building site as a result of area irrigation and inadequate surface drainage is difficult, if not impossible, to foresee.

The recommendations presented in this report are based on current theories and experience of our engineers on the behavior of swelling soil in this area. The owner should be aware that

there is a risk in constructing a building in an expansive soil area. Following the recommendations given by a geotechnical engineer, careful construction practice and prudent maintenance by the owner can, however, decrease the risk of foundation movement due to expansive soils.

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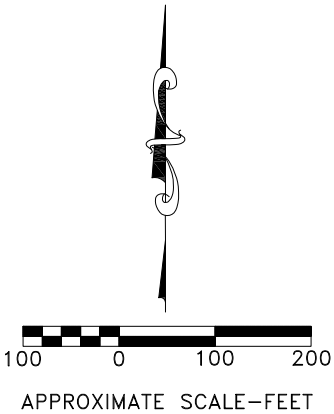

18-3-108	Kumar & Associates	LOCATION OF EXPLORATORY BORINGS	Fig. 1

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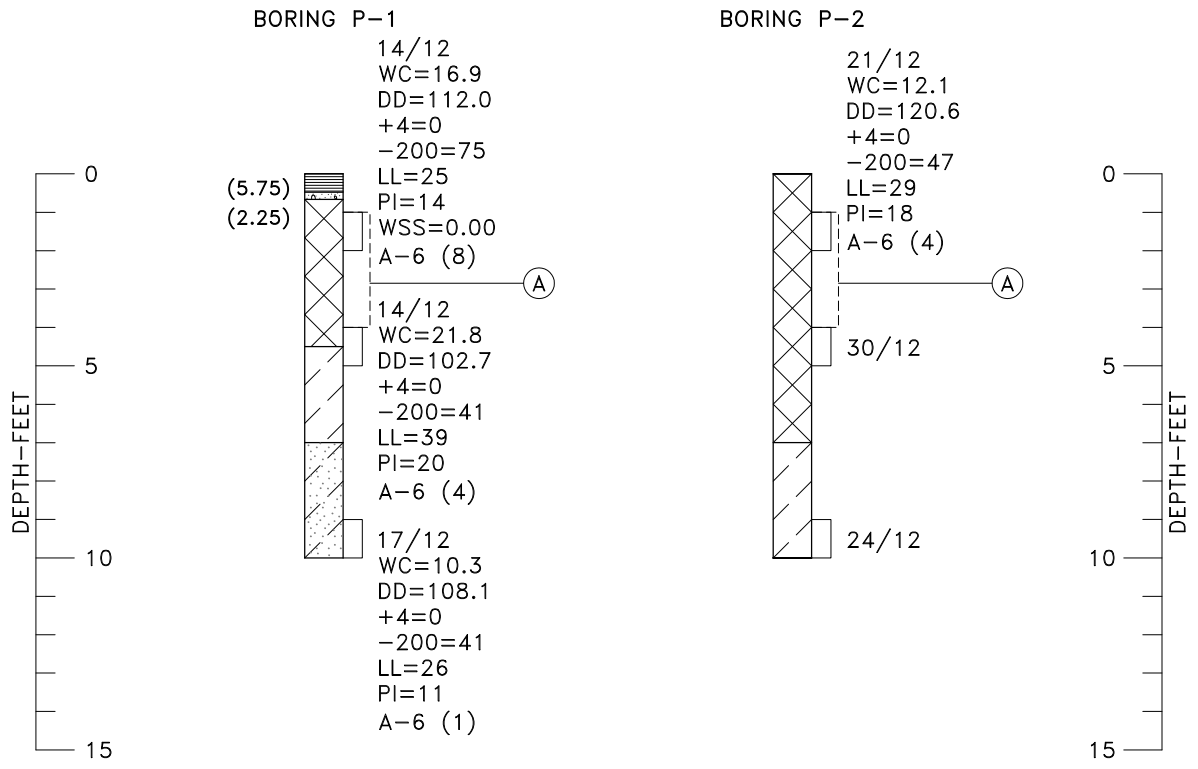

A

OMC=13.0
MDD=116.1
+4=3
-200=52
LL=33
PI=21
A-6 (5)
R=26

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18-3-108	Kumar & Associates	LOGS OF EXPLORATORY BORINGS	Fig. 2

LEGEND

(5.75) ASPHALT, THICKNESS IN INCHES SHOWN IN PARENTHESES TO LEFT OF THE LOG.

(2.25) AGGREGATE BASE COURSE, THICKNESS IN INCHES SHOWN IN PARENTHESES TO LEFT OF THE LOG.

FILL: LEAN CLAY WITH SAND (CL) TO CLAYEY SAND (SC), FINE TO COARSE GRAINED WITH GRAVEL, MOIST, BROWN TO DARK BROWN.

LEAN CLAY WITH SAND (CL) TO SANDY LEAN CLAY (CL), FINE TO MEDIUM GRAINED, STIFF TO VERY STIFF, SLIGHTLY MOIST TO MOIST, LIGHT BROWN.

CLAYEY SAND (SC), FINE TO COARSE GRAINED, MEDIUM DENSE, MOIST, TAN.

DRIVE SAMPLE, 2-INCH I.D. CALIFORNIA LINER SAMPLE.

DRIVE SAMPLE, 1 3/8-INCH I.D. SPLIT SPOON STANDARD PENETRATION TEST.

DISTURBED BULK SAMPLE.

14/12 DRIVE SAMPLE BLOW COUNT. INDICATES THAT 14 BLOWS OF A 140-POUND HAMMER FALLING 30 INCHES WERE REQUIRED TO DRIVE THE SAMPLER 12 INCHES.

NOTES

1. THE EXPLORATORY BORINGS WERE DRILLED ON FEBRUARY 20, 2018 WITH A 4-INCH DIAMETER CONTINUOUS FLIGHT POWER AUGER.
2. THE LOCATIONS OF THE EXPLORATORY BORINGS WERE MEASURED APPROXIMATELY BY PACING FROM FEATURES SHOWN ON THE SITE PLAN PROVIDED.
3. THE ELEVATIONS OF THE EXPLORATORY BORINGS WERE NOT MEASURED AND THE LOGS OF THE EXPLORATORY BORINGS ARE PLOTTED TO DEPTH.
4. THE EXPLORATORY BORING LOCATIONS SHOULD BE CONSIDERED ACCURATE ONLY TO THE DEGREE IMPLIED BY THE METHOD USED.
5. THE LINES BETWEEN MATERIALS SHOWN ON THE EXPLORATORY BORING LOGS REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN MATERIAL TYPES AND THE TRANSITIONS MAY BE GRADUAL.
6. GROUNDWATER WAS NOT ENCOUNTERED IN THE BORINGS AT THE TIME OF DRILLING.
7. LABORATORY TEST RESULTS:
   WC = WATER CONTENT (%) (ASTM D 2216);
   DD = DRY DENSITY (pcf) (ASTM D 2216);
   +4 = PERCENTAGE RETAINED ON NO. 4 SIEVE (ASTM D 422);
   -200= PERCENTAGE PASSING NO. 200 SIEVE (ASTM D 1140);
   LL = LIQUID LIMIT (ASTM D 4318);
   PI = PLASTICITY INDEX (ASTM D 4318);
   WSS = WATER SOLUBLE SULFATES (%) (CP-L 2103);
   R = HVEEM R-VALUE (AT 300 psi) (ASTM D 2844);
   A-2-6 (0) = AASHTO CLASSIFICATION (GROUP INDEX) (AASHTO M 145);
   OMC = OPTIMUM MOISTURE CONTENT (%) (ASTM D 698);
   MDD = MAXIMUM DRY DENSITY (pcf) (ASTM D 698).

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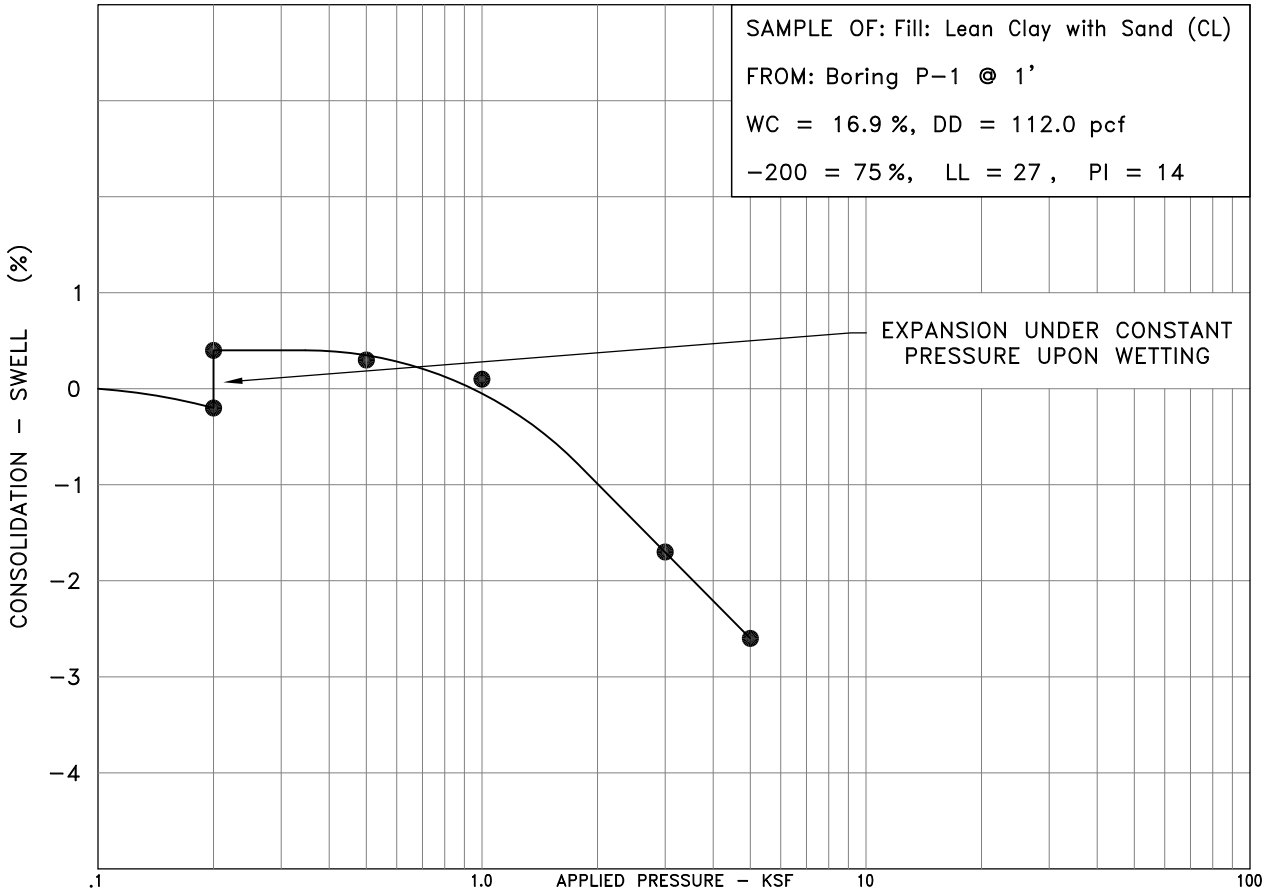

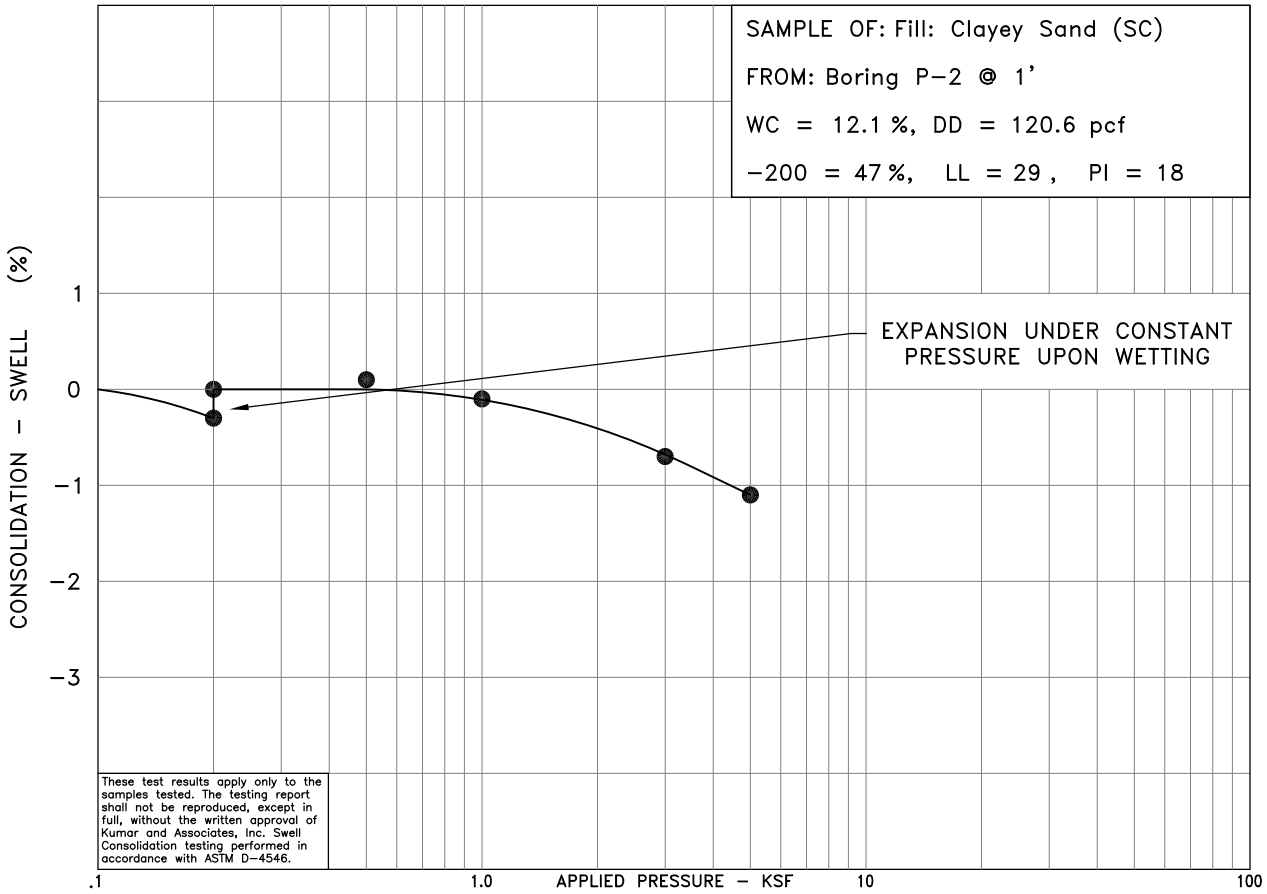

These test results apply only to the samples tested. The testing report shall not be reproduced, except in full, without the written approval of Kumar and Associates, Inc. Swell Consolidation testing performed in accordance with ASTM D-4546.

18-3-108	Kumar & Associates	SWELL-CONSOLIDATION TEST RESULTS	Fig. 4

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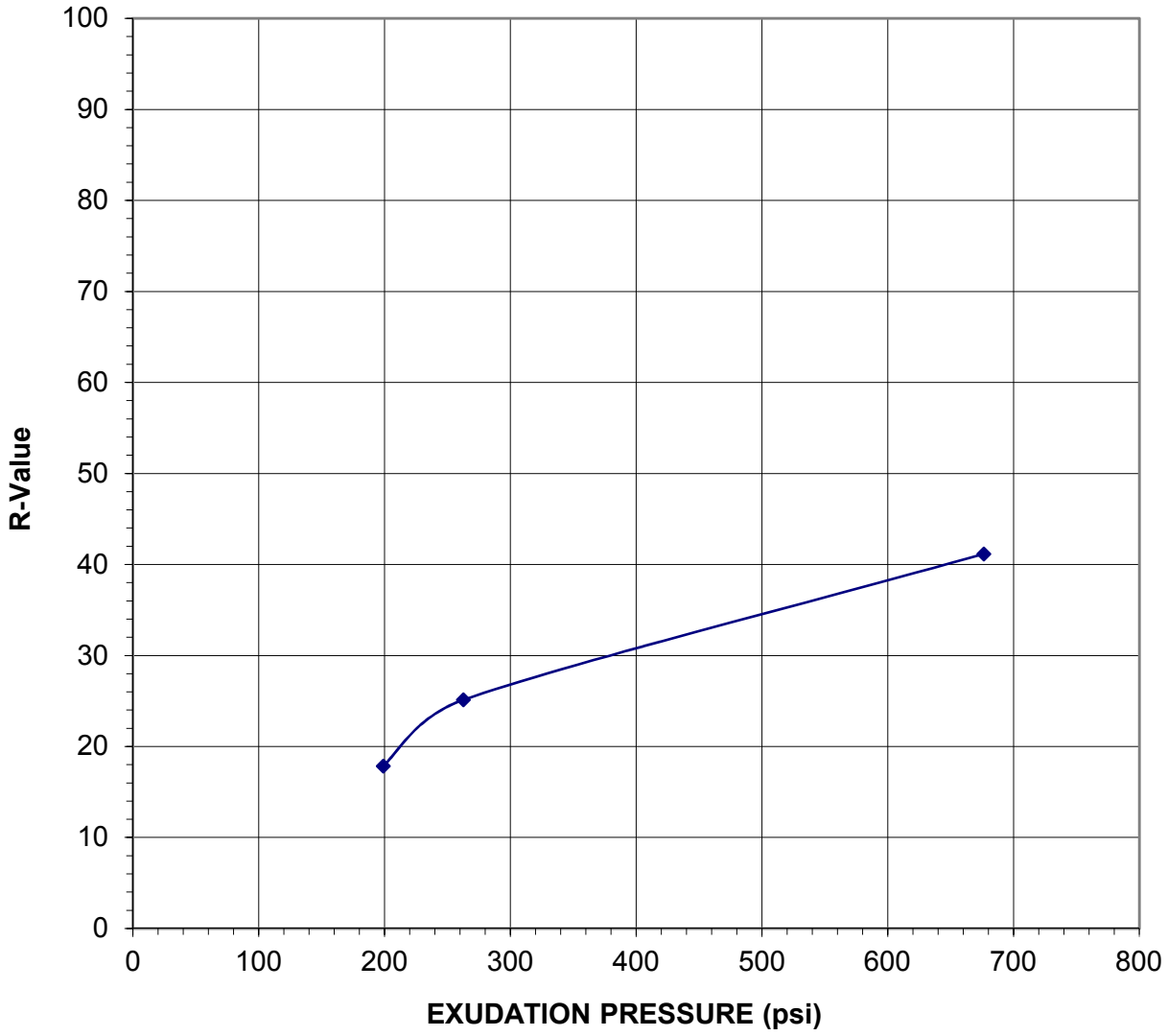
R-VALUE

TEST SPECIMEN	1	2	3	4	Rvalue @ 300 psi
MOISTURE CONTENT (%)	13.0	11.3	7.8		
DENSITY (pcf)	115.9	118.1	128.8		
EXPANSION PRESSURE (psi)	0.000	0.000	0.000		
EXUDATION PRESSURE (psi)	199	263	676		
R-VALUE	18	25	41		**26**



SOIL TYPE: **Clay**

LOCATION: **P-1 to P-2 @ 1'-4'**

DATE SAMPLED: **2/26/2018** DATE RECEIVED: **2/27/2018** DATE TESTED: **3/8/2018**

GRAVEL: **3** SAND: **45** SILT AND CLAY: **52**

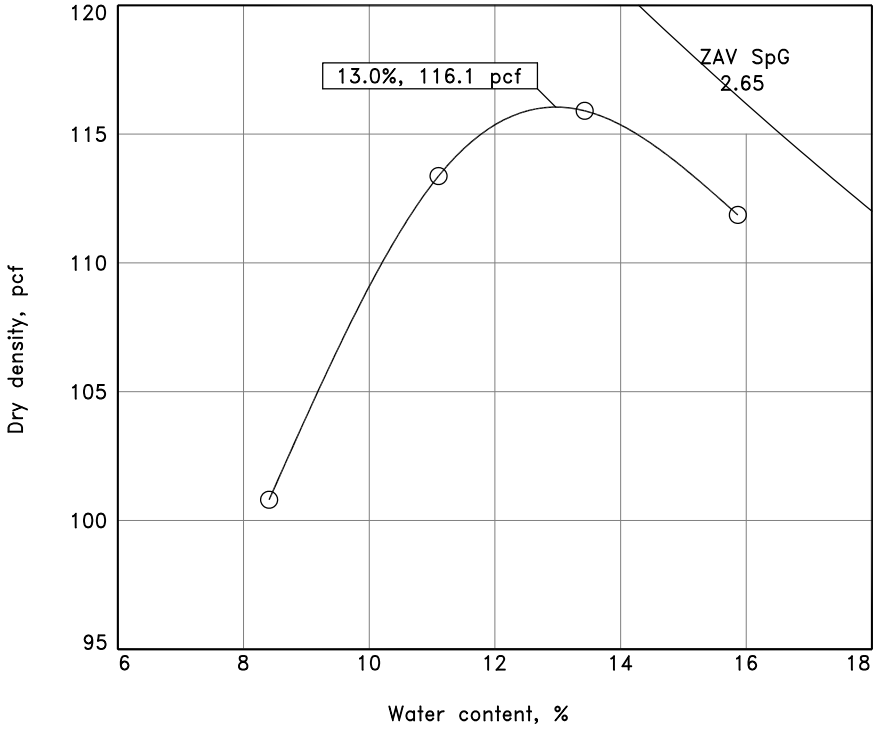
LIQUID LIMIT: **33** PLASTICITY INDEX: **21**

These test results apply to the samples which were tested. The testing report shall not be reproduced, except in full, without the written approval of Kumar & Associates, Inc. R-value performed in accordance with ASTM D2844. Atterberg limits performed in accordance with ASTM D4318. Sieve analyses performed in accordave with ASTM D422, D1140

18-3-108	KUMAR & ASSOCIATES	HVEEM STABILOMETER TEST RESULTS	Fig. 5

COMPACTION TEST REPORT

Curve No. 2029



Preparation Method	
Rammer: Wt.	5.5 lb.
Drop	12 in.
Type	manual
Layers: No.	three
Blows per	25
Mold Size	0.03322 cu. ft.
Test Performed on Material Passing	3/8 in. Sieve
%>3/8 in.	2
%<No.200	52
Atterberg (D 4318): LL	33
PI	21
NM (D 2216)	
Sp.G. (D 854)	2.65
USCS (D 2487)	CL
AASHTO (M 145)	A-6(7)
Date: Sampled	2/26/18
Received	2/27/18
Tested	3/1/18
Tested By	RK

COMPACTION TESTING DATA
ASTM D 698-12 Method B Standard

	1	2	3	4	5	6
WM + WS	3815.0	4067.2	4150.5	4122.4		
WM	2162.9	2162.9	2162.9	2162.9		
WW + T #1	781.6	791.1	818.7	723.6		
WD + T #1	735.7	731.0	744.2	650.0		
TARE #1	189.7	189.7	189.4	186.1		
WW + T #2						
WD + T #2						
TARE #2						
MOIST.	8.4	11.1	13.4	15.9		
DRY DENS.	100.8	113.4	115.9	111.9		

SIEVE TEST RESULTS
ASTM D 422 ASTM D 1140

Opening Size	% Passing	Specs.
1.5"	100	
3/4"	100	
3/8"	98	
#4	97	
#8	93	
#16	89	
#30	82	
#50	69	
#100	58	
#200	52	

TEST RESULTS

Maximum dry density = 116.1 pcf

Optimum moisture = 13.0 %

Material Description

sandy lean clay

Remarks:

Project No. 18-3-108 Client: Town of Bennett

Project: State Highway 79 Widening

○ Location: P-1 to P-2 @ 1'-4' Sample Number: 2029

Checked by: ACT

Title: Lab Supervisor

18-3-108	Kumar & Associates	MOISTURE-DENSITY RELATIONSHIPS	Fig. 6

April 18, 2018 - 08:41am
V:\Projects\2018\18-3-108 State Highway 79 Widening\Drafting\183108-06.dwg

Table I
Summary of Laboratory Test Results

Project No.: 18-3-108
Project Name: State Highway 79 Widening
Date Sampled: February 20, 2018
Date Received: February 21, 2018

Sample Location		Date Tested	Natural Moisture Content (%)	Natural Dry Density (pcf)	Gradation		Percent Passing No. 200 Sieve	Atterberg Limits		R-Value	Water Soluble Sulfates (%)	AASHTO Classification (Group Index)	Soil or Bedrock Type
Boring	Depth (Feet)				Gravel (%)	Sand (%)		Liquid Limit (%)	Plasticity (%)				
P-1	1	3/1/18	16.9	112.0	0	25	75	27	14		0.00	A-6 (8)	Fill: Lean Clay with Sand (CL)
P-1	4	3/1/18	21.8	102.7	0	59	41	39	20			A-6 (4)	Fill: Clayey Sand (SC)
P-1	9	2/28/18	10.3	108.1	0	59	41	26	11			A-6 (1)	Clayey Sand (SC)
P-2	1	2/28/18	12.1	120.6	0	53	47	29	18			A-6 (4)	Fill: Clayey Sand (SC)
P-1 to P-2	1-4	2/28/18	13.0*	116.1*	3	45	52	33	21	26		A-6 (7)	Fill: Sandy Lean Clay

* - Optimum moisture content and maximum dry density as determined by standard Proctor (ASTM D 698)

APPENDIX A
DARWIN ME™ SOFTWARE OUTPUT

Design Inputs

Design Life:	20 years	Base construction:	June, 2018	Climate Data Sources (Lat/Lon)	39.783, -104.55
Design Type:	Flexible Pavement	Pavement construction:	July, 2020		
		Traffic opening:	October, 2020		

Design Structure

Layer type	Material Type	Thickness (in)
Flexible	R2 Level 1 SX(75) PG 64-22	6.0 (Optimized)
NonStabilized	Crushed stone	12.0
Subgrade	A-2-6	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	11.8
Air voids (%)	6.9

Traffic

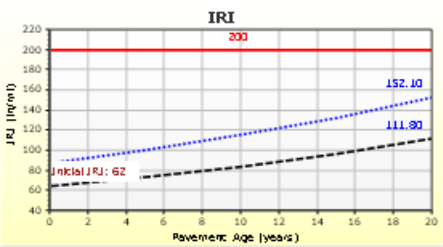
Age (year)	Heavy Trucks (cumulative)
2020 (initial)	385
2030 (10 years)	810,682
2040 (20 years)	1,860,420

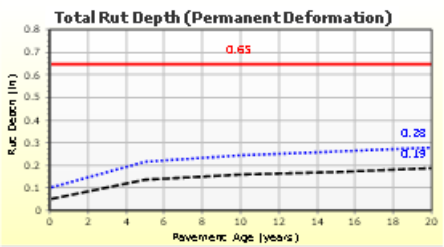
Design Outputs

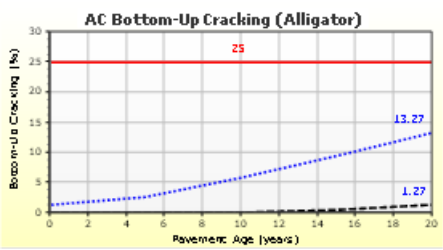
Distress Prediction Summary

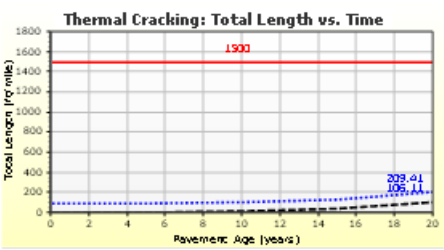
Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	200.00	152.07	90.00	99.75	Pass
Permanent deformation - total pavement (in)	0.65	0.28	90.00	100.00	Pass
AC bottom-up fatigue cracking (% lane area)	25.00	13.27	90.00	99.44	Pass
AC thermal cracking (ft/mile)	1500.00	209.41	90.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	2500.00	282.89	90.00	100.00	Pass
Permanent deformation - AC only (in)	0.50	0.13	90.00	100.00	Pass

Distress Charts







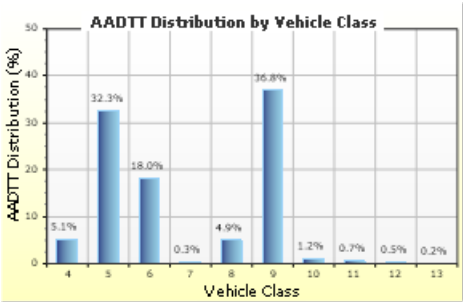


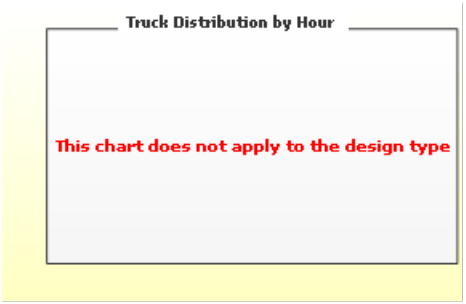
Threshold Value ····· @ Specified Reliability - - - @ 50% Reliability

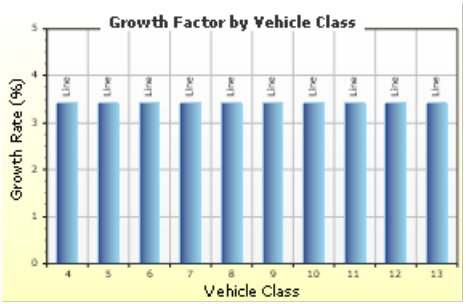
Traffic Inputs

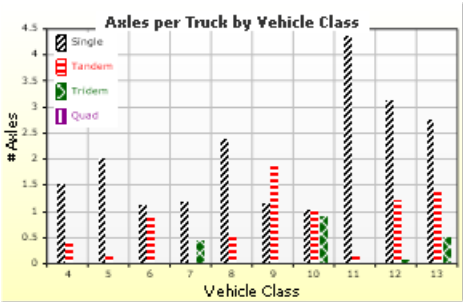
Graphical Representation of Traffic Inputs

Initial two-way AADTT:	385	Percent of trucks in design direction (%):	50.0
Number of lanes in design direction:	1	Percent of trucks in design lane (%):	100.0
		Operational speed (mph)	45.0

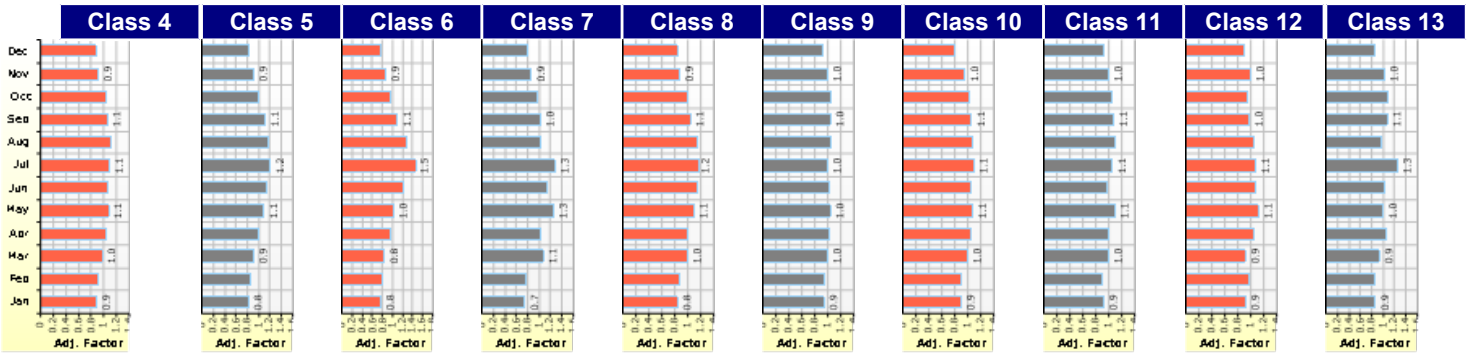








Traffic Volume Monthly Adjustment Factors



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%	3.4%	Linear
Class 5	32.3%	3.4%	Linear
Class 6	18%	3.4%	Linear
Class 7	0.3%	3.4%	Linear
Class 8	4.9%	3.4%	Linear
Class 9	36.8%	3.4%	Linear
Class 10	1.2%	3.4%	Linear
Class 11	0.7%	3.4%	Linear
Class 12	0.5%	3.4%	Linear
Class 13	0.2%	3.4%	Linear

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

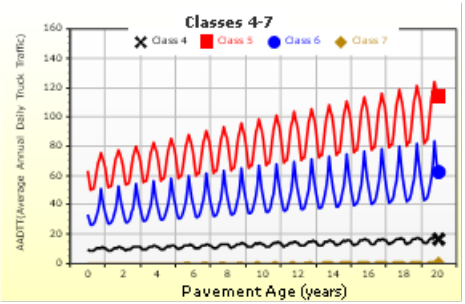
Wheelbase does not apply

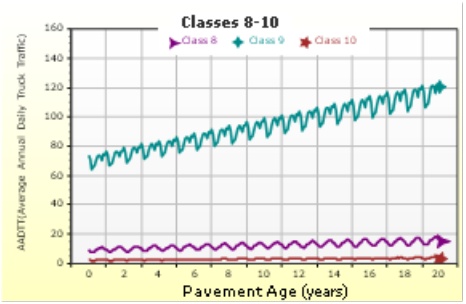
Number of Axles per Truck

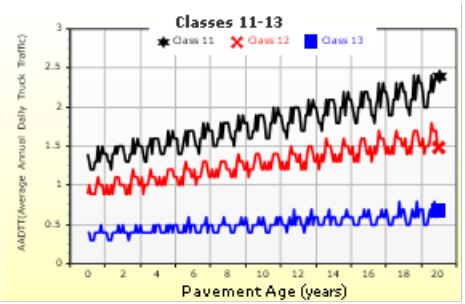
Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.53	0.45	0	0
Class 5	2.02	0.16	0.02	0
Class 6	1.12	0.93	0	0
Class 7	1.19	0.07	0.45	0.02
Class 8	2.41	0.56	0.02	0
Class 9	1.16	1.88	0.01	0
Class 10	1.05	1.01	0.93	0.02
Class 11	4.35	0.13	0	0
Class 12	3.15	1.22	0.09	0
Class 13	2.77	1.4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

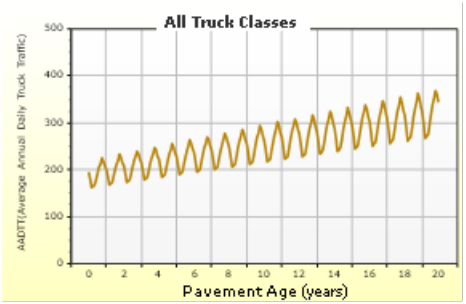
AADTT (Average Annual Daily Truck Traffic) Growth

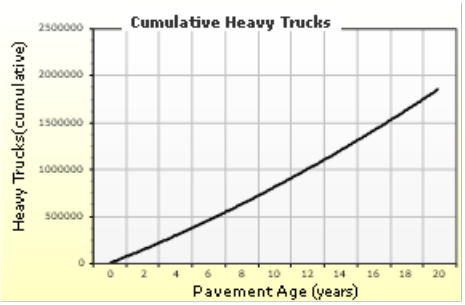
*** Traffic cap is not enforced**







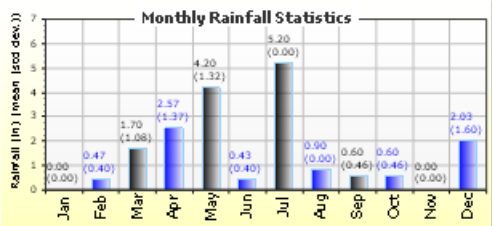




Climate Inputs

Climate Data Sources:

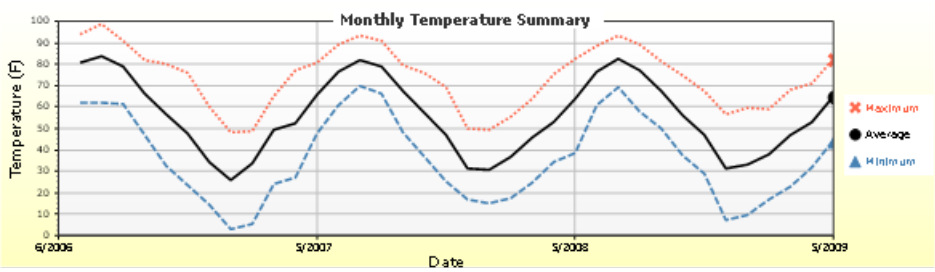
Climate Station Cities:	Location (lat lon elevation(ft))
DENVER, CO	39.78300 -104.55000 5607

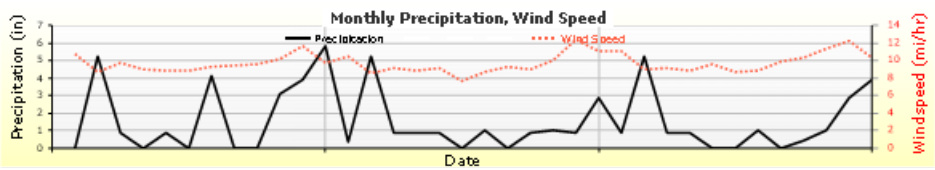


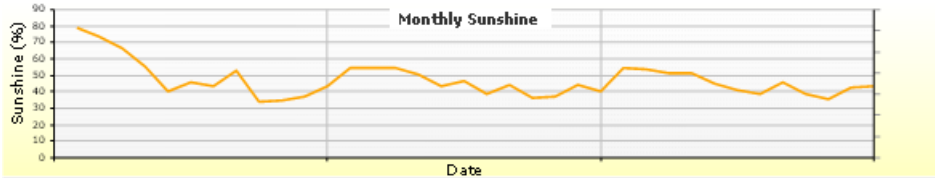
Annual Statistics:

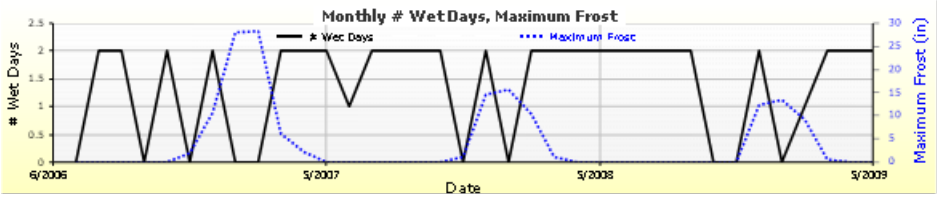
Mean annual air temperature (ºF)	56.23
Mean annual precipitation (in)	18.75
Freezing index (ºF - days)	216.14
Average annual number of freeze/thaw cycles:	51.65
Water table depth (ft)	10.00

Monthly Climate Summary:

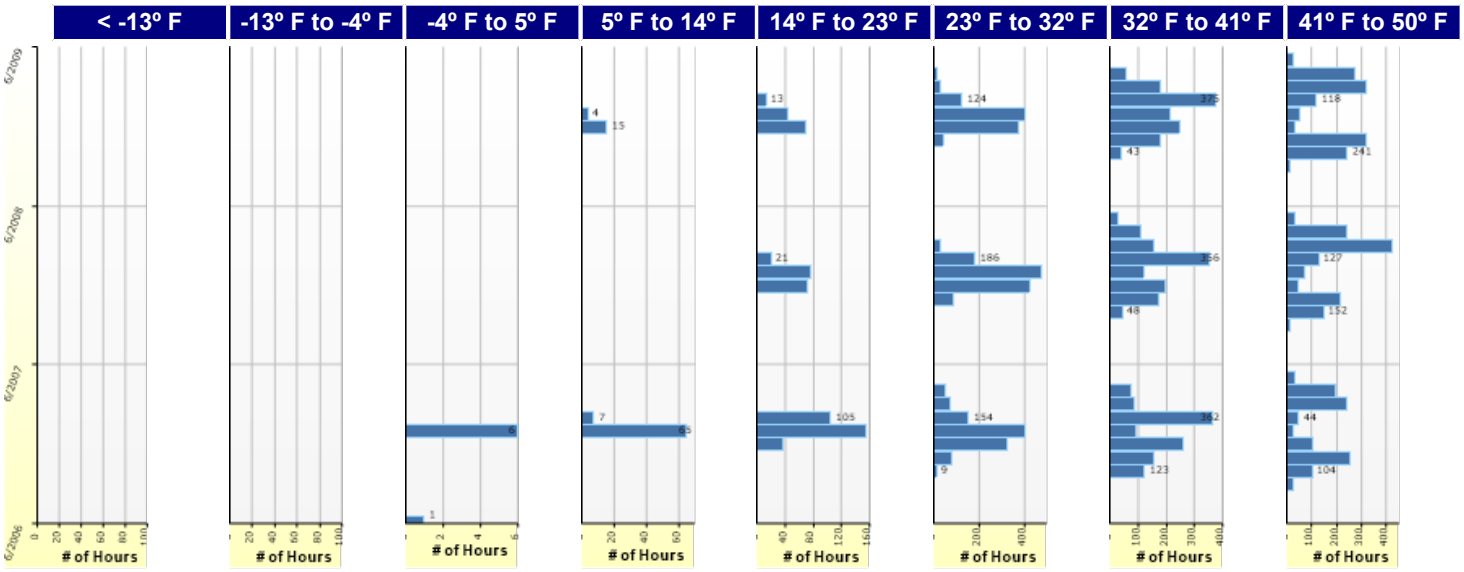


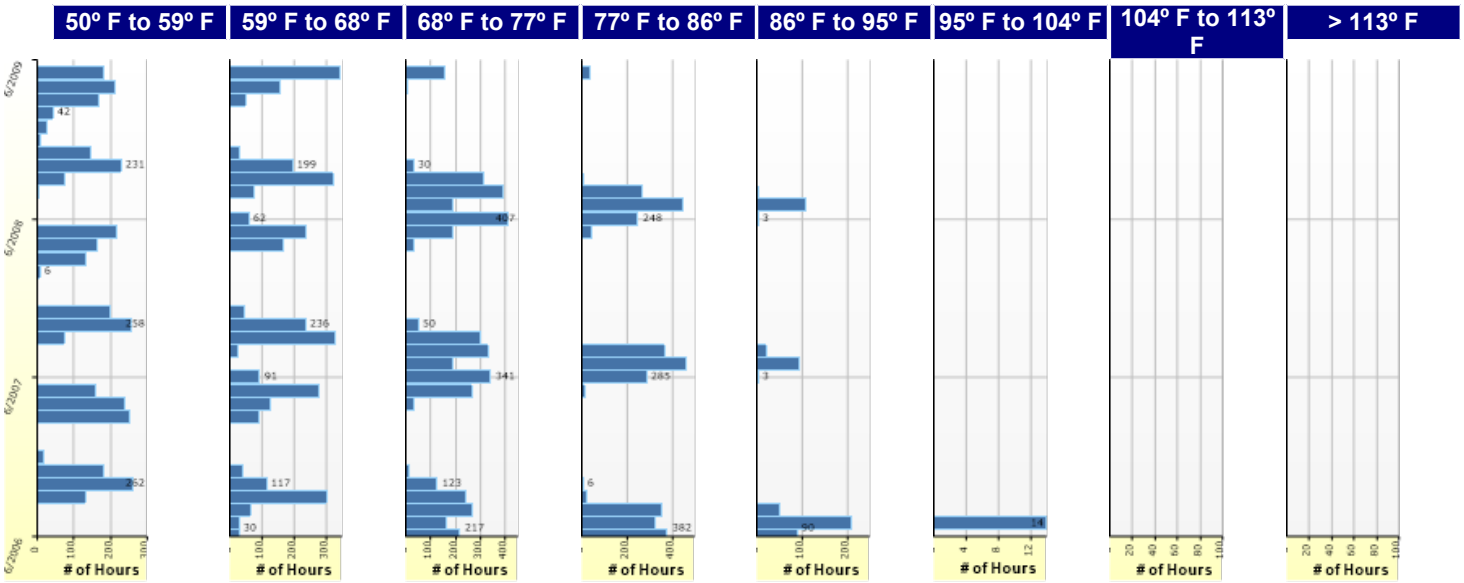






Hourly Air Temperature Distribution by Month:





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

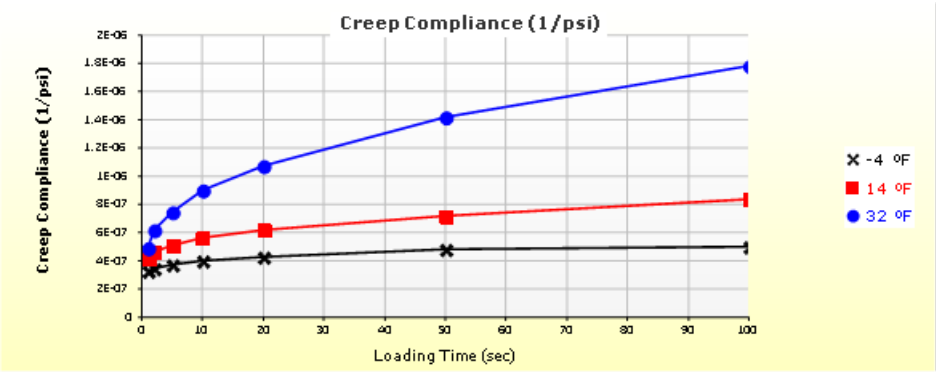
Layer Name	Layer Type	Interface Friction
Layer 1 Flexible : R2 Level 1 SX (75) PG 64-22	Flexible (1)	1.00
Layer 2 Non-stabilized Base : Crushed stone	Non-stabilized Base (4)	1.00
Layer 3 Subgrade : A-2-6	Subgrade (5)	-

Thermal Cracking (Input Level: 1)

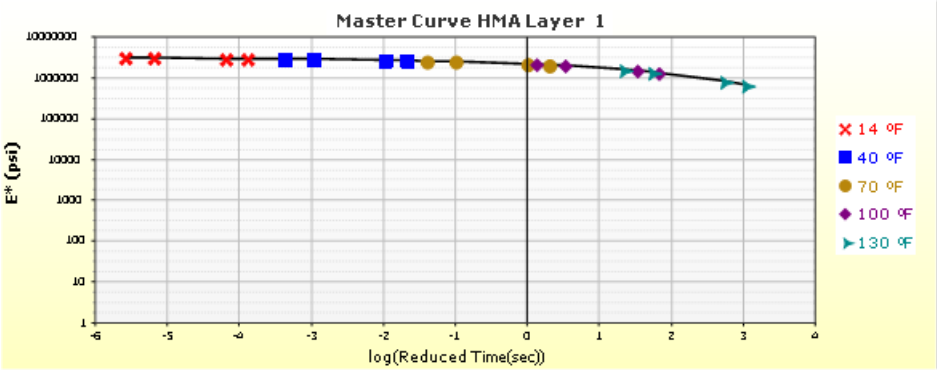
Indirect tensile strength at 14 ºF (psi)	451.00

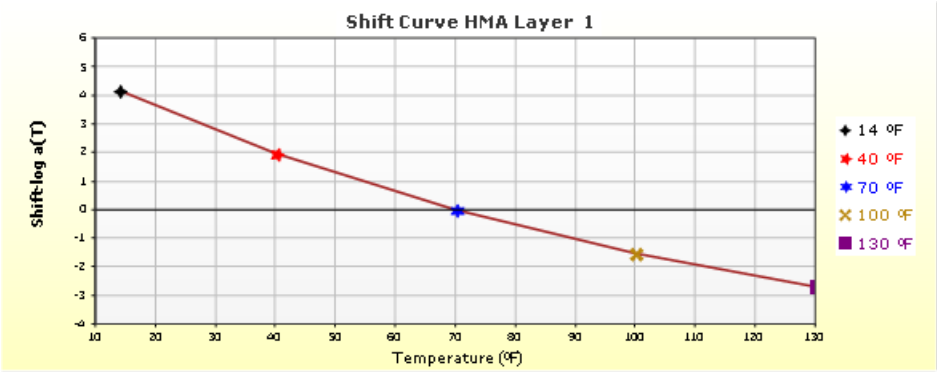
Thermal Contraction	
Is thermal contraction calculated?	True
Mix coefficient of thermal contraction (in/in/ºF)	-
Aggregate coefficient of thermal contraction (in/in/ºF)	5.0e-006
Voids in Mineral Aggregate (%)	18.7

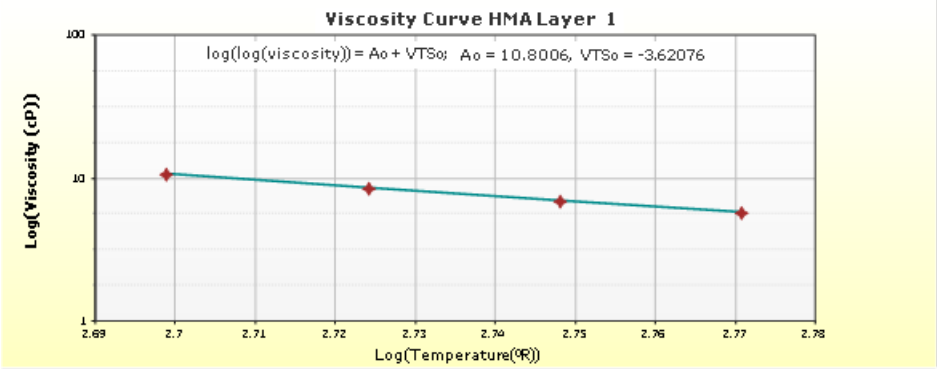
	Creep Compliance (1/psi)		
Loading time (sec)	**-4 ºF**	**14 ºF**	**32 ºF**
1	3.34e-007	4.19e-007	4.99e-007
2	3.53e-007	4.64e-007	6.19e-007
5	3.79e-007	5.15e-007	7.49e-007
10	4.05e-007	5.70e-007	9.08e-007
20	4.31e-007	6.26e-007	1.08e-006
50	4.87e-007	7.27e-007	1.43e-006
100	5.05e-007	8.41e-007	1.79e-006



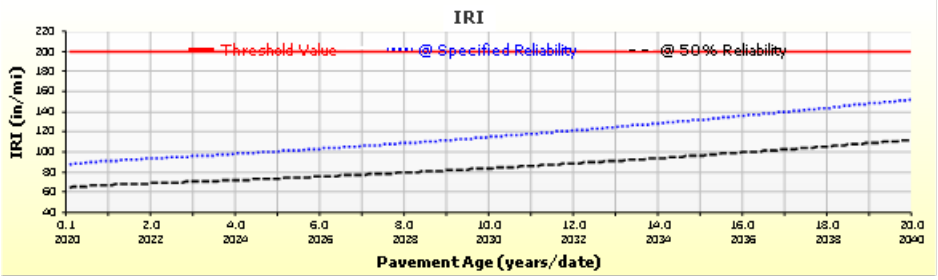
HMA Layer 1: Layer 1 Flexible : R2 Level 1 SX(75) PG 64-22

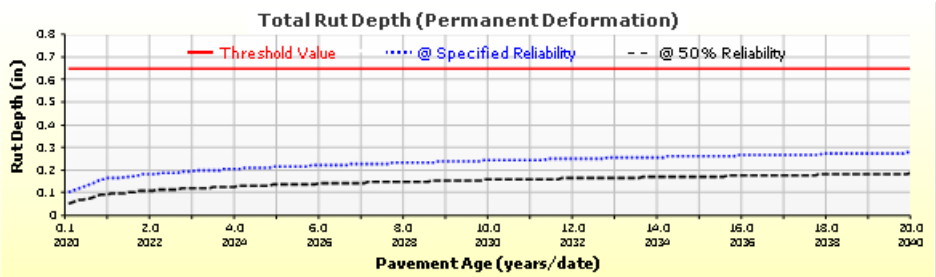


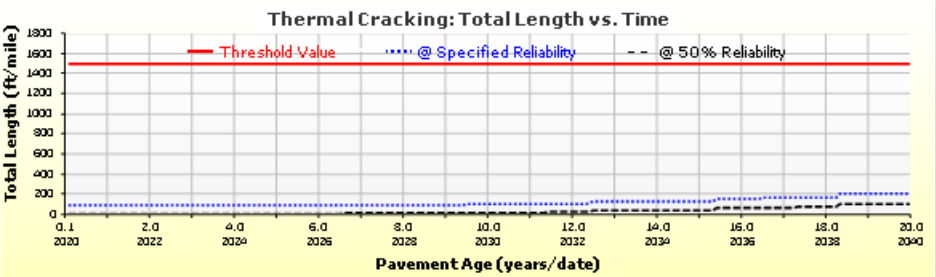


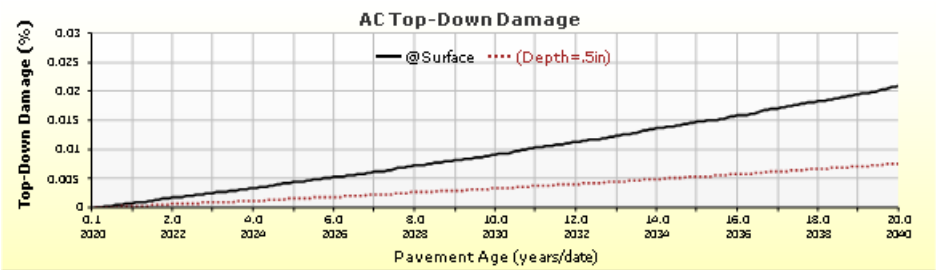


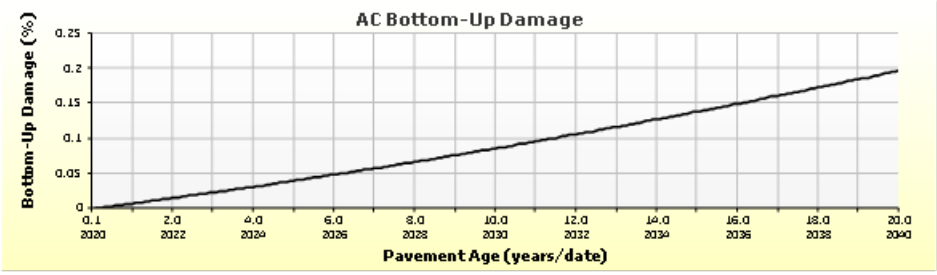
Analysis Output Charts

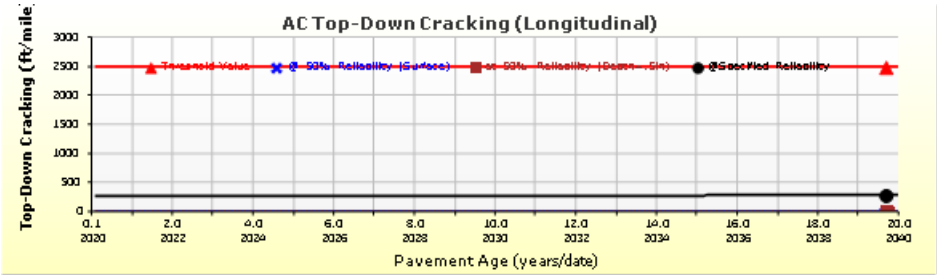


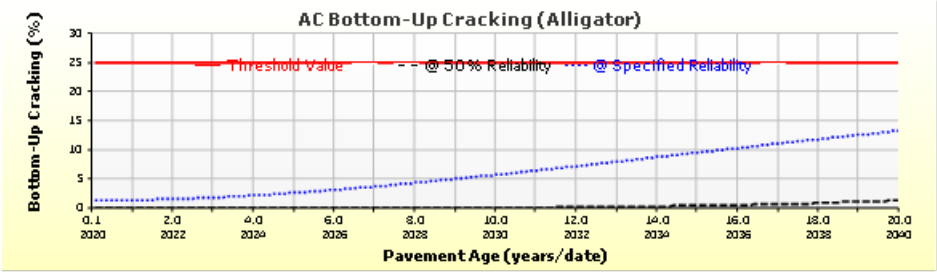


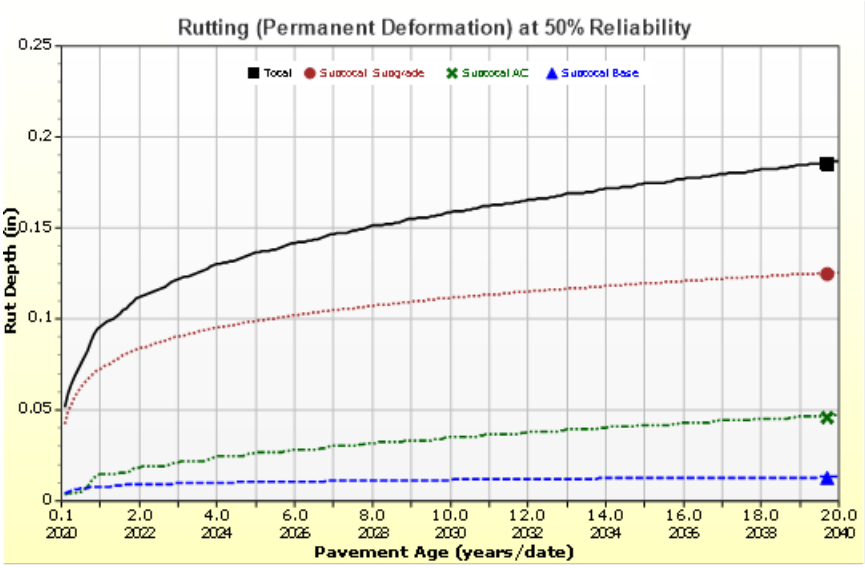


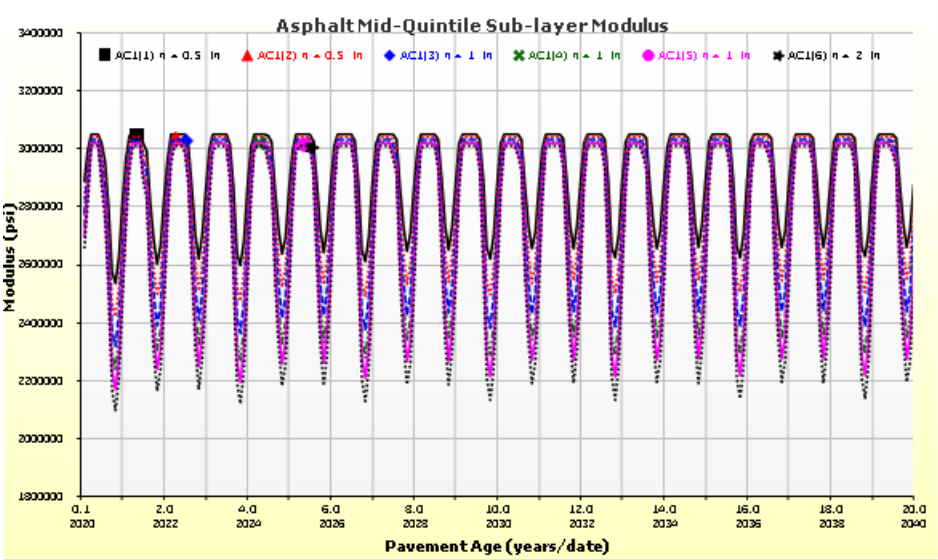

AC Top-Down Damage
@Surface
(Depth=.5in)
Top-Down Damage (%)
Pavement Age (years/date)

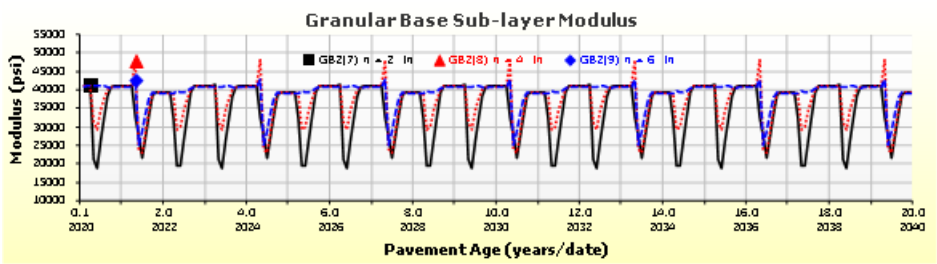

AC Bottom-Up Damage
Bottom-Up Damage (%)
Pavement Age (years/date)

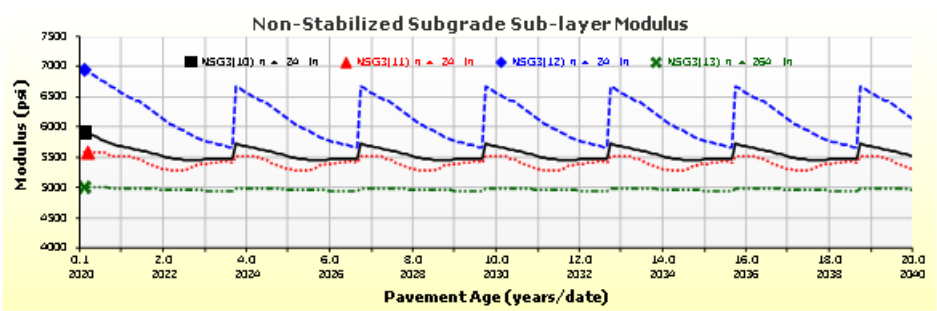

AC Top-Down Cracking (Longitudinal)
Top-Down Cracking (ft/mile)
Pavement Age (years/date)


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
Subcoal Subgrade
Subcoal AC
Subcoal Base
Rut Depth (in)
0.25
0.2
0.15
0.1
0.05
0
0.1 2020
2.0 2022
4.0 2024
6.0 2026
8.0 2028
10.0 2030
12.0 2032
14.0 2034
16.0 2036
18.0 2038
20.0 2040
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 = 1 in
AC1|4) n = 1 in
AC1|5) n = 1 in
AC1|6) n = 2 in
Modulus (psi)
3400000
3200000
3000000
2800000
2600000
2400000
2200000
2000000
1800000
0.1
2020
2.0
2022
4.0
2024
6.0
2026
8.0
2028
10.0
2030
12.0
2032
14.0
2034
16.0
2036
18.0
2038
20.0
2040
Pavement Age (years/date)


Granular Base Sub-layer Modulus
GB2|7) n = 2 in
GB2|8) n = 4 in
GB2|9) n = 6 in
Modulus (psi)
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
0.1
2020
2.0
2022
4.0
2024
6.0
2026
8.0
2028
10.0
2030
12.0
2032
14.0
2034
16.0
2036
18.0
2038
20.0
2040
Pavement Age (years/date)


Non-Stabilized Subgrade Sub-layer Modulus
NSG3|10) n = 24 in
NSG3|11) n = 24 in
NSG3|12) n = 24 in
NSG3|13) n = 264 in
Modulus (psi)
7500
7000
6500
6000
5500
5000
4500
4000
0.1
2020
2.0
2022
4.0
2024
6.0
2026
8.0
2028
10.0
2030
12.0
2032
14.0
2034
16.0
2036
18.0
2038
20.0
2040
Pavement Age (years/date)

Layer Information

Layer 1 Flexible : R2 Level 1 SX(75) PG 64-22

Asphalt		
Thickness (in)	6.0	
Unit weight (pcf)	140.5	
Poisson's ratio	Is Calculated?	False
	Ratio	0.35
	Parameter A	-
	Parameter B	-

Asphalt Dynamic Modulus (Input Level: 1)

T (ºF)	0.5 Hz	1 Hz	10 Hz	25 Hz
14	2910500	2947100	3034800	3058600
40	2620500	2695700	2882400	2934800
70	2057300	2190500	2549800	2658300
100	1334300	1500400	2017600	2195500
130	697600	836500	1365200	1584000

Asphalt Binder

Temperature (ºF)	Binder Gstar (Pa)	Phase angle (deg)
168.8	451	85
147.2	1857	81.6
158	889	83.1

General Info

Name	Value
Reference temperature (ºF)	70
Effective binder content (%)	11.8
Air voids (%)	6.9
Thermal conductivity (BTU/hr-ft-ºF)	0.67
Heat capacity (BTU/lb-ºF)	0.23

Identifiers

Field	Value
Display name/identifier	R2 Level 1 SX(75) PG 64-22
Description of object	Mix ID # 19127A
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 2	
User defined field 3	
Revision Number	0

Layer 2 Non-stabilized Base : Crushed stone

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

Modulus (Input Level: 2)

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

Resilient Modulus (psi)
27000.0

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

Identifiers

Field	Value
Display name/identifier	Crushed stone
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 2	
User defined field 3	
Revision Number	20

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
Optimum gravimetric 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-2-6

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

Modulus (Input Level: 2)

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

Resilient Modulus (psi)
8431.0

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

Identifiers

Field	Value
Display name/identifier	A-2-6
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 2	
User defined field 3	
Revision Number	0

Sieve

Liquid Limit	32.0
Plasticity Index	15.0
Is layer compacted?	False

	Is User Defined?	Value
Maximum dry unit weight (pcf)	False	121.9
Saturated hydraulic conductivity (ft/hr)	False	7.651e-06
Specific gravity of solids	False	2.7
Optimum gravimetric water content (%)	False	10

User-defined Soil Water Characteristic Curve (SWCC)	
Is User Defined?	False
af	75.5741
bf	0.9351
cf	0.4315
hr	500.0000

Sieve Size	% Passing
0.001mm	
0.002mm	
0.020mm	
#200	24.8
#100	
#80	32.4
#60	
#50	
#40	43.5
#30	
#20	
#16	
#10	59.4
#8	
#4	67.2
3/8-in.	78.8
1/2-in.	83.3
3/4-in.	90.4
1-in.	94.5
1 1/2-in.	97.7
2-in.	99.4
2 1/2-in.	
3-in.	
3 1/2-in.	99.9

Calibration Coefficients

AC Fatigue

$$N_f = 0.00432 * C * \beta_{f1} k_1 \left(\frac{1}{\varepsilon_1}\right)^{k_2 \beta_{f2}} \left(\frac{1}{E}\right)^{k_3 \beta_{f3}}$$

$$C = 10^M$$

$$M = 4.84\left(\frac{V_b}{V_a + V_b} - 0.69\right)$$

k1: 0.007566
k2: 3.9492
k3: 1.281
Bf1: 130.3674
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:

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

$\varepsilon_p = plastic\ strain\left({}^{in}/_{in}\right)$
$\varepsilon_r = resilient\ strain\left({}^{in}/_{in}\right)$
$T = layer\ temperature\left({}^{\circ}F\right)$
$N = number\ of\ load\ repetitions$

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

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

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

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

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

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

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

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

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

Subgrade Rutting

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

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

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