SPRINGVILLE PERFORMANCE EVALUATION & PAVEMENT DESIGN FOR MINOR COLLECTORS

Project ID: CEEn_2018CPST_013

As performed by

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A Capstone Project Completion Report

Submitted to

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Executive Summary

PROJECT TITLE: Springville Performance Evaluation & Pavement Design for Minor Collectors

PROJECT ID: CEEn_2018CPST_013

PROJECT SPONSOR: City of Springville

TEAM NAME: MagiCAP

A recently completed study of pavement performance in Springville City indicated that minor collectors were failing prematurely. The client contracted with MagiCAP to evaluate selected sections of minor collectors to determine the cause(s) of premature failure.

The scope of work for this project included traffic counts and ESAL estimations, frost heave surveying, asphalt coring and testing, and base material excavation and testing to determine the cause(s) of pavement failure. A mechanistic-empirical (ME) analysis was conducted to evaluate the performance of the existing pavement, and to prescribe a new design for future construction of minor collectors. New pavement designs were created that consist of a cement-treated base (CTB) layers with an overlying asphalt layer. Further analysis is recommended for road construction using standard base, subbase and subgrade layers.

This study will help Springville City identify areas where pavement construction can be improved. The combined approach of laboratory testing and ME analyses will point out which failure mechanisms can be mitigated by more careful quality assurance and quality control procedures, and which mechanisms are due to inadequate design.

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Introduction

A recently completed study of pavement performance in Springville City by Infrastructure Research, LLC indicates that minor collectors are failing prematurely (Guthrie, Waters and Stevens 2018). An evaluation of selected minor collectors was needed to determine the cause(s) of premature failure. Phases of this project consisted of data collection and field-work, laboratory experimentation, and post-processing of the collected data. Potential causes of failure were identified, and new pavement designs were prescribed to improve longevity and performance.

Two assumptions were used for assessment and design purposes. First, it was assumed that premature failures were a result of deviations of the construction specifications for minor collectors from current American Society for Testing and Materials (ASTM) and American Association of State Highway and Transportation Officials (AASHTO) standards. Second, it was assumed that the standard for minor collectors was insufficient for the loads and weathering to which these specific streets were subjected.

Based on the study above, Springville City contains many minor collectors in varying states of deterioration. The study indicated that some of the tested road segments contained layers that performed below standard engineering practices. Suggestions for layer thicknesses and the use of cement-treated base (CTB) layers were set forth. In order to verify these results, a mechanistic-empirical (ME) analysis was performed to determine the layer thicknesses associated with a CTB layer for a new pavement design.

The same five streets that were used in the previously completed study were used for this analysis. This allowed for greater consistency in understanding the properties of various minor collectors throughout Springville City. The locations of the five studied streets are summarized in Table 1. These locations were chosen to better understand the West, Northeast, and Southeast regions of the city. Of the five locations, sections 193 and 873 were selected to perform a frost heave analysis, coring, and excavation.

Table 1: Street Locations and PASER Values (Guthrie et al. 2018)

Geographic Region	Segment Number	Location	Pavement Age (yr.)	Average PASER Value
West	1483	550 N, 750 to 800 W	11	5.0
	1053	550 W, 300 to 400 S	10	3.3
Southeast	1085	900 S, 1600 to 1650 E	20	10.0
	193	800 E, 800 to 900 S	21	2.5
Northeast	873	400 E, 1000 to 1050 N	5	4.0

Premature failure of streets throughout Springville poses a serious concern for the safety of Springville citizens and a substantial financial burden. These minor collectors are intended to last approximately 20 years. However, some streets reach unacceptable quality in a fraction of that time, resulting in the need to rehabilitate and replace roads at a faster rate. Knowing why some roads outperform others is extremely valuable for the city of Springville to improve their infrastructure, save money for their residents, and ultimately increase the level of safety of their roads.

The main deliverable for this project is the ME analysis of the Springville minor collector structural performance. Using the dynamic cone penetrometer (DCP) data from the study previously performed by

Infrastructure Research, LLC, a computer software package (KENPAVE) was used to assess the capacity of the roads in their as-built conditions. The results indicated that the base and subbase materials were providing insufficient strength and stiffness for the actual ESAL demands. Additional simulations were run to determine pavement designs that would withstand a lifetime ESAL load of 1,000,000. Based on these simulations, the specification of a CTB layer overlying the subgrade was designed. Design calculations were made in KENPAVE for permutations of asphalt layers between 3-6 in. (using 0.5 in. increments), and CTB course of 6-12 in. (using 2 in. increments), and between CTB 7-day unconfined compressive strengths (UCS) of 400, 450 and 500 psi. Moduli of elasticity were estimated for the subgrade (6 and 15 ksi), asphalt (430 ksi), and CTB (550.9 ksi, 568.8 ksi, and 586.6 ksi).

Assumptions & Limitations

This capstone project follows the work of a preliminary study performed by Infrastructure Research, LLC (Guthrie et al. 2018) and will aim to identify the nature of the failure mechanisms of minor collectors throughout Springville City. The comprehensiveness of this study is limited by the small sample size of pavements being analyzed and the assumption that they are representative of all minor collectors throughout the city. In order to best represent the pavements in Springville City, sample segments were chosen in the North, South, East, and West sections of the city. Budgeting and time constraints only permitted core samples to be obtained from sections 193 and 873. The assumption was made that the pavement segments sampled would provide a representative description of their failure methods.

Preliminary tests and visuals recorded by Infrastructure Research, LLC, indicated that the base materials used in the construction of the minor collectors were weaker than the underlying subbase materials. This assumption was used throughout the entire analysis. Excavation beneath the asphalt layers revealed that the DCP estimates for layer thicknesses were accurate. Due to that accuracy, it was assumed that modulus values obtained from the DCP tests were also accurate.

A 24-hour traffic study of the streets in question was performed in order to make estimations of the lifetime equivalent single axle loads (ESAL) on these pavements. It is understood that typical traffic studies will be performed on a 48-hour schedule; however, due to time constraints 24-hour counts were used to make lifetime ESAL estimations. Comparisons between the results of the traffic survey and a professional survey conducted by Horrocks Engineers in 2016 were analyzed. The results of the 24-hour counts were 67% of the professional survey. It was thus determined that the Horrocks study was more conservative and their counts were used for the ESAL estimations.

Traffic Study

Procedures

A 24-hour traffic study was conducted on the five minor collectors in Springville that had previously undergone (DCP) and pavement surface evaluation and rating (PASER) testing. Cameras were placed at strategic locations on each street to record the cars that passed. Those cameras were placed on a Tuesday evening and recovered Thursday afternoon, in January. The 24-hour count was done for that Wednesday. The scope of the traffic study was limited in three ways. First, although it did not snow during the study, the winter weather likely reduced the number of trips that were made. Second, a full 24-hour count was only performed on the street that had the highest traffic count during peak hours between 7-9 a.m., 10-12 p.m., and 4-7 p.m. The street was segment 873. Third, the specific day may not have been a representative sample of the annual average daily traffic (AADT).

The AADTs were used to estimate the daily estimated single axle load (ESAL), which was used to generate a yearly ESAL for each roadway. Those ESAL values were used to estimate the lifetime ESALs for each roadway based on the number of years of service through 2018, when the DCP analysis was performed. Knowing the lifetime ESALs estimates would indicate if the load on each roadway was higher than those used in the design. Growth rates of 2%, 4%, and 6% were used to determine the lifetime ESALs 20, 30, and 40 years into the future.

Due to the limitations of this study, the Springville City Transportation Master Plan was used to compare this study's estimate to a more in-depth analysis. The AADT given for segment 873 was higher than the estimated value. An ESAL comparison was performed with both values to highlight the difference. The street with the highest AADT was used to determine the design lifetime ESAL of minor collectors since it represents the largest likely load that any of the minor collectors will feel; roadways with a lower ESAL should last longer based on the lower trafficking.

Results

The observed ESAL values were compared against the estimated allowable ESALs as proposed by Guthrie et al. (2018), as shown in Table 2. Subgrade moduli were estimated based on location (West or East) and were used to make estimations on the number of allowable ESALs prior to failure of the respective layer. Table 2 provides evidence across all the segments tested that the base material governs the design life of the pavement.

Table 2: Allowable ESAL Values Per Segment (Guthrie et al. 2018)

Geographic Region	Segment Number	Estimated Number of ESALs for Protection of Indicated Layer		
		Base	Subbase	Subgrade
West	1483	**20,900**	**334,400**	4,155,900
	1053	**114,600**	3,156,100	8,798,600
Southeast	1085	2,927,600	10,002,700	22,443,200
	193	**195,300**	901,300	3,139,200
Northeast	873	870,100	7,784,500	86,953,900

Estimated lifetime ESAL values experienced by each pavement segment are reported in Table 3 below. Many of the pavement segments have not yet surpassed their limiting layer's allowable number of ESALs.

However, pavement segment 1438 is limited significantly by its base material. In only 11 years of service life, this pavement has already surpassed its allowable ESAL. Pavement failure at only 50% of the design life will lead to early and extensive repair and/or reconstructive costs. A better-quality base material would improve the number of allowable ESALs substantially.

Table 3: Lifetime Allowable ESALs

Geographic Region	Segment Number	Pavement Age in 2018 (yr)	Actual Lifetime ESAL (2% Growth)	Actual Lifetime ESAL (4% Growth)	Actual Lifetime ESAL (6% Growth)
West	1438	11	**24,615**	**21,845**	19,514
	1053	10	27,077	24,238	21,821
Southeast	1085	20	59,750	49,276	41,320
	193	21	19,638	16,072	13,392
Northeast	873	5	139,089	87,985	82,533

Table 4 shows the projected 20-year ESAL on these same pavement segments as if they were constructed new in 2019. These projections were made using 2%, 4%, and 6% growth rates. By accounting for future growth, there are three pavement segments that would experience failure, or have high risk of failure, in the base material after 20 years (segments 1438, 1053, and 873). Comparing the results of the traffic study with the estimated allowable ESALs of Table 2, it is suggested that the current design specification of the base material is not adequate for the current and future ESALs on minor collectors in the city of Springville.

Table 4: Estimated Allowable ESALs

Geographic Region	Segment Number	Pavement Age in 2019 (yr)	20-year projected ESAL (2% Growth)	20-year projected ESAL (2% Growth)	20-year projected ESAL (2% Growth)
West	1438	0	**60,013**	**74,412**	**93,087**
	1053	0	71,335	88,449	**110,648**
Southeast	1085	0	90,561	112,288	140,470
	193	0	28,675	35,555	44,478
Northeast	873	0	640,224	**793,825**	**993,057**

Frost Heave

Background

In climates subject to sub-freezing temperatures, frost heaving is a major cause of premature roadway failure. Throughout the year, water can percolate through the void spaces in the asphalt and make its way to the base, subbase, and subgrade layers below. As temperatures descend below 0 °C (32 °F), the lenses of water freeze and expand, exerting stresses and strains on the pavement layers. A quantifiable measure of frost heave at the site locations was desired to better understand the susceptibility of these pavements to these stresses.

Procedures

The magnitude of frost heave was determined by in-field surveys at two of the specified locations. The Northeast and Southeast locations were strategically chosen based on the results from a moisture susceptibility test performed by Guthrie et al. in 2018. These results are shown in Table 5 below.

Table 5: CBR Conditions for Road Segments (Guthrie et al. 2018)

Geographic Region	Segment Number	Water Ingress (in.^{3})	Test Location	CBR of Base Material	Change in CBR	Percent Change in CBR (%)
West	1483	1.3	2A	58	-7	-11
			2B	51		
	1053	1.0	2A	51	1	2
			2A	52		
Southeast	1085	1.4	2B	54	-10	-19
			2A	44		
	193	10.7	2A	61	-38	-62
			2B	23		
Northeast	873	0.0	2A	90	-3	-4
			2B	87		

As can be seen in Table 5 the Northeast pavement section (segment 873) did not allow any water ingress during 30 minutes of soaking. The Southeast pavement (segment 193) allowed 10.7 cubic inches of water during this same soaking period. Pavement segment 873 exhibited little change in California Bearing Ratio (CBR) after the soak test, while segment 193 exhibited over 60% change. Observations at both sites with respect to frost heaving were desired to quantitatively compare the effects of frost heave across these two pavement sections.

The amount of frost heave was estimated by two in-field surveys: one conducted in the middle of winter after three consecutive days with minimum temperatures below freezing, and the other performed in spring after three consecutive days with minimum daily temperatures above freezing. P-K nails (Magnails) were driven into the pavement at the sites of previous DCP testing to mark the locations where elevations would be surveyed. Nearby fire hydrants were established as relative datums and a survey level and grade rod were used to obtain relative elevations of the P-K nails in winter and spring. Frost heave was then estimated as the difference between the winter and spring elevations. Due to unreliable measurements and large estimations for frost heave after the first spring survey, each site was surveyed again in the spring in order to validate the results of the first spring survey.

Results

The results of the frost heave survey were less reliable than desired. The raw data from the field survey at sites 873 and 193 are reported in Table 9 and Table 10 in Appendix B. The most reliable estimation for frost heave of 0.648 in. comes from measurements obtained at segment 873 at the location of the center DCP test site. It was assumed that this estimation would represent the minimum amount of frost heave at the other locations surveyed. This assumption was made because pavement segment 873 allowed very little water ingress in comparison to segment 193. The two segments also have similar quantity of fines passing the No. 200 sieve; therefore, the effect of frost heave was assumed to be just as, or more, damaging in other locations as at segment 873. The estimated 0.648 in. is the smallest observed heave of all points and it was therefore assumed that the other points would heave at least as much as this minimum value.

Inaccuracies in the frost heave measurements were likely due to instrumentation and operator error. The winter survey was conducted prior to sunrise and the spring survey was performed after sunset. These poor lighting conditions contributed to the lack of precision. Another source of error may be the long distances between the level station and the control point. Fire hydrants were located near the site, though not at close proximity with the survey points. The long distances to the control point may have amplified inaccuracies.

The survey, while not precise, did provide evidence that frost heave does indeed occur as part of the yearly cycle of freezing and thawing in these roads. Careful observance of gradation specifications can help mitigate the effects of yearly frost heaving.

Coring, Marshall Stability, and Flow

Procedures

4 in. asphalt core samples from segments 873 and 1438 were obtained from the southbound wheel path. These 4 in. cores were obtained using a hitch mounted KOR-IT coring machine. The 4 in. coring bit was mounted to the machine and penetrated the full depth of the asphalt layer, to the interface of the asphalt and base layer. Three (3) 4 in. cores were taken in a tangent circle pattern such that the extents of the three (3) 4 in. cores would fit within a 12 in. diameter coring bit. During the extraction of the asphalt cores at the site 1438, two distinct asphalt layers were observed. The first layer was assumed to be a 3 in. thick overlay constructed within the year prior to the study. The bottom layer of original pavement was measured as 4 in. thick. These two layers were distinct in that there was no adhesion between them, and a separate core was obtained for each respective layer. Upon removal, the cores were placed in independently labeled plastic bags and transported back to the laboratory at Brigham Young University to undergo ASTM D6927, the standard test method for Marshall Stability and Flow of asphalt mixtures.

Standard procedures for ASTM D6927 were followed. The 4 in. coring bit produced asphalt samples of average diameter 3.75 in., and these cores were trimmed to an average height of 2.5 in. As the cores for the site 1438 were separated as a top and bottom layer, the team separated the samples from site 873 into the top 3 in. and the bottom 4 in. ASTM D6927 recommends that the test be performed three separate times for each asphalt core sample. While the team did obtain three samples at each location, only two samples could be tested for site 873 because one of the samples became stuck in the coring bit and could not be dislodged.

A metal pan was set on the scale, and the scale was tared. Specimens were then weighed in the pan. After weighing, the specimen's height was measured using a digital micrometer, taking four (4) measurements, equally spaced around the circumference of the specimen. Each specimen was labeled and then placed in the 60°C (140°F) distilled water bath. A timer was set for 30 minutes. At the expiration of 30 minutes, specimens were removed from the bath and again towel-dried. Each specimen was placed into the testing head of the Marshall stability and flow machine. The machine was set to a strain rate of 2 in./minute, and each specimen was loaded until a peak loading could be observed. Peak loads and their corresponding displacements were recorded.

Results

Results from the Marshall Flow and Stability test are summarized in Table 15 in Appendix B. Only three (3) stability and flow tests yielded usable numerical results. One sample was stuck in the coring bit, and the results from the top layer core at N1 were unusable because the compression loading machine reached its maximum limit before the test was completed. Notwithstanding the fewer data points at site 873, it can be seen from Table 15 that this pavement segment is stiffer and more consistent than the pavement at site 193. The average stability of the top layer was only 793 lbs., whereas the average bottom layer stability was 2529 lbs. From these results it can clearly be seen that the top layer of asphalt was not placed to the same specification as the bottom layer.

Excavation and Gradations

Procedures

Excavation was performed beneath the 12 in. asphalt core so that gradation curves could be obtained for the base, subbase, and subgrade materials. Upon removal of the cores, manual digging, and material removal was performed using a digging bar, post-hole digger, and hand trowel. The aim of the excavation was to obtain separate samples for the base, subbase, and subgrade materials. To accomplish this aim, the required digging depths were approximated from the study performed by Infrastructure Research, LLC (Guthrie et al. 2018). Approximate layer thicknesses are reported in Table 6 below. These values were used to excavate to the assumed depths for each layer. When digging depths approached these layers, changes in material composition and coloration were noted to demarcate the transition to the next layer.

Table 6: Road Segment Layer Properties (Guthrie et al. 2018)

Geographic Region	Segment Number	Average Layer Thickness (in.)			Average CBR		
		Asphalt	Base	Subbase	Base	Subbase	Subgrade
West	1483	2.8	8.8	10.0	47	35	13
	1053	3.6	10.3	-	81	112	-
Southeast	1085	6.2	6.1	-	86	164	-
	193	7.2	6.8	5.5	68	80	24
Northeast	873	5.0	9.3	8.5	93	137	46

Segment 193 had no significant change in composition or coloration that could be noted. The distinction between the layers on this segment were therefore based on the depths of the approximate layer thicknesses reported in Table 6 above. These samples were brought back to the laboratory where they were dried in ovens at 60 °C (140 °F).

Gradations were completed on the base material from both segment 193 and 873. A preliminary dry sieve with approximately 11 lbs. (5,000 g.) of each material was performed using sieve sizes described in Table 11, Table *12*, Table *13*, and Table *14* in Appendix B. To get a more accurate gradation report for each sample, the sieved soil was then washed, dried, and reweighed.

Due to the time constraints of the project, gradation curves were only generated for the base material of segments 873 and 193. It was shown in the earlier study by Infrastructure Research, LLC (Guthrie et al. 2018) that the base material is the limiting layer in the design strength of the tested road segments. As such, it was determined that the base material would be the best material on which to perform the particle size distribution analysis.

Results

The results of the base material dry sieve and washed sieve from segments 873 and 193 are provided in Table 11, Table *12*, Table *13*, and Table *14* in Appendix B. The particle size distribution curve for the dry sieve of segments 873 and 1483 are shown in Figure 1 and Figure *2*, respectively. The construction specifications for the city of Springville are provided in Table 7, and follow the guidelines for roadway construction outlined in the APWA Manual of Standard Specifications. It was assumed for this analysis that the Superpave, 1" maximum nominal aggregate (SP-1) design was the prescribed design of the investigated minor collectors. It can be seen from Table 7 that the maximum permissible percentage of fines passing the No. 200 is between 1-7%. By comparison, the washed sieve analysis demonstrates that both segments contained approximately 14% fines passing the No. 200. This is more than double the permissible quantity.

Table 7: Springville City Roadway Construction Gradation Specifications for SP-1 as per the Manual of Standard Specifications

Sieve	Percent Passing by Weight
1.5"	100
1"	90-100
3/4"	<90
1/2"	-
3/8"	-
No. 4	-
No. 8	19-45
No. 200	1-7

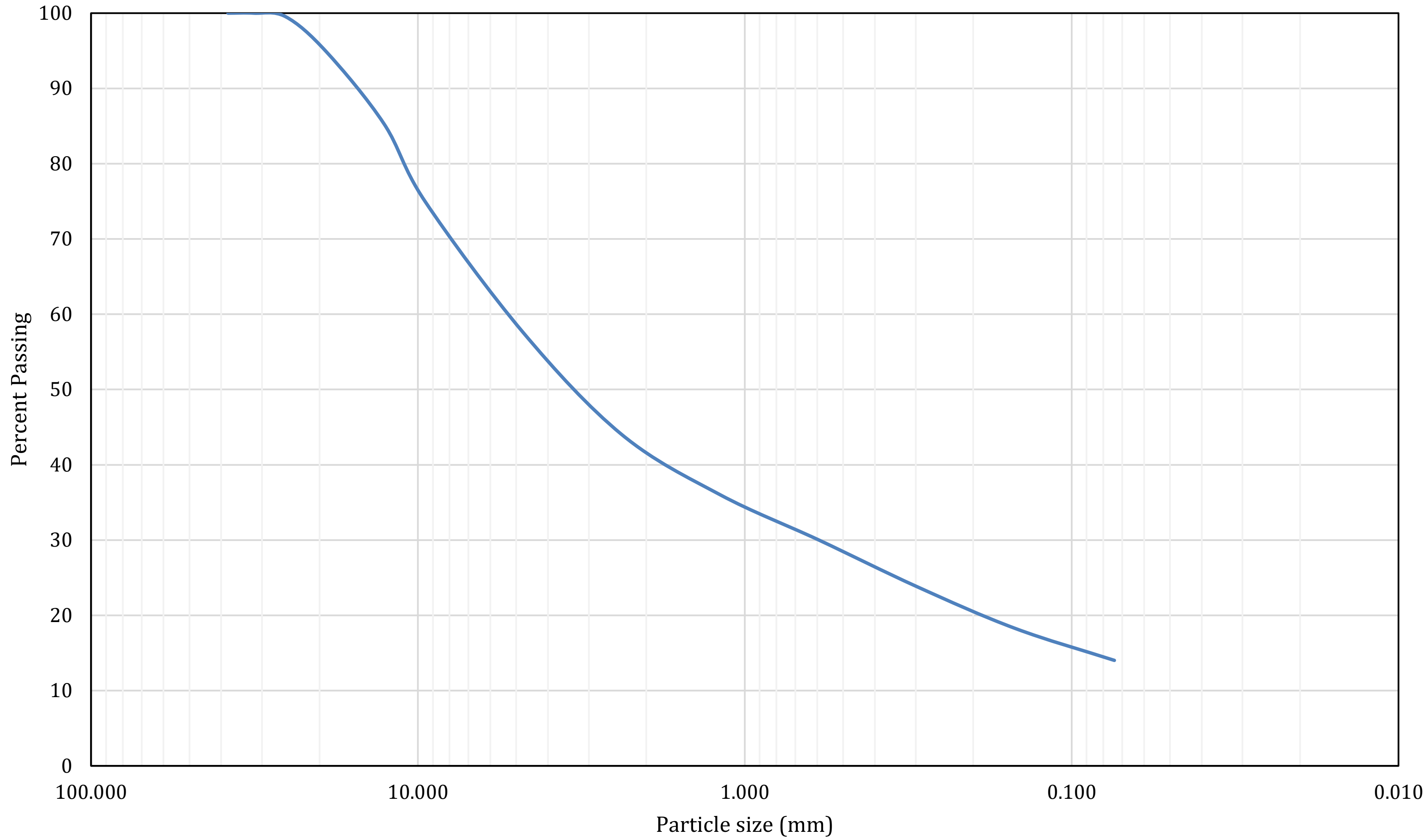

Figure 1: Particle size distribution for Segment 873.

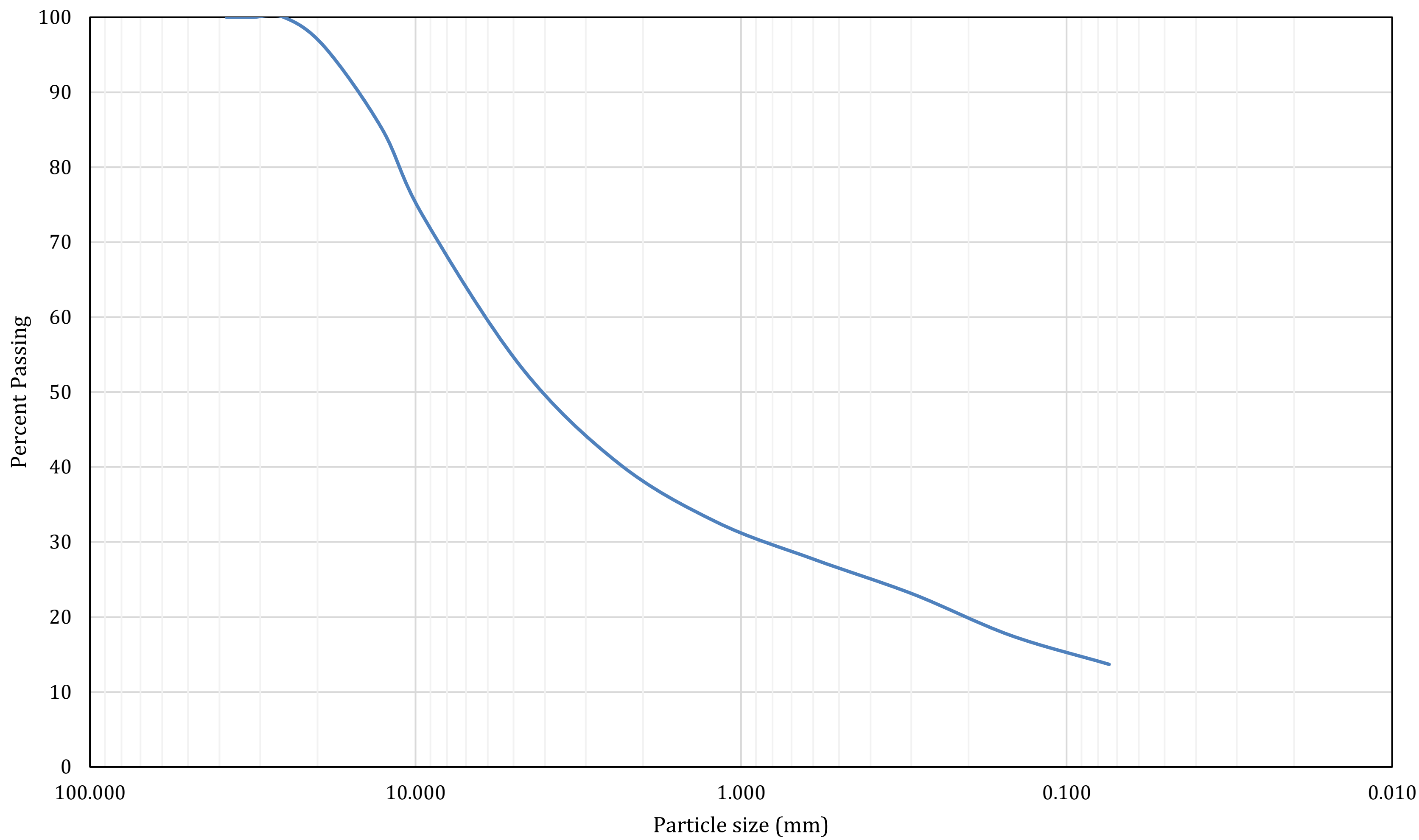

Figure 2: Particle size distribution for Segment 193.

Mechanistic-Empirical Analyses

Procedures

As indicated in Guthrie et al. (2018), a ME analysis was advised to determine possible pavement thicknesses. For the capstone Scope of Work, the analysis was performed to determine pavement thicknesses as well as to verify the preliminary work done.

The ME analysis consisted of two parts: 1) mechanistically determine stresses and strains on pavement designs using a software package titled KENPAVE and 2) empirically determine ESAL passes by using transfer functions set forth in an article by Guthrie, Crane and Eggett (2009), which would indicate failure in specific layers of the pavement design.

Using KENPAVE, existing pavement specifications for Springville City were analyzed, as well as new pavement designs consisting of asphalt thicknesses from 3 in. to 6 in. were used, incremented at 0.5 in. For each asphalt thickness, a CTB layer thickness of 6 in., 8 in., 10 in., or 12 in. was used. In addition to those layer thicknesses, 7-day UCS values for the CTB layers were assumed to be 400, 450 and 500 psi. Per Infrastructure Research, LLC (Guthrie et al. 2018), subgrade moduli of elasticity were assumed to be 6 ksi for the West side of Springville, and 15 ksi for the East side of Springville. After performing the flow and stability analysis, an asphalt modulus of elasticity was determined from Figure 7.13 in *Pavement Analysis and Design* (Huang 294), attached in Appendix B as Figure 11. This method used the Marshall Stability, in pounds, and estimated the modulus of elasticity and a structural layer coefficient, a_1. Per Dr. Guthrie, the Northeast cores were used as the baseline Marshall stability, with an assumed stability of 2000 lbs. Using the assumed stability, a modulus of elasticity of 430,000 psi and a structural layer coefficient of 0.42. Using these parameters, 168 pavement designs were completed.

With the completion of the designs, the associated stresses and strains were imported into a spreadsheet designed specifically for this project. The transfer function method used was the Uzan method, as determined in Guthrie et al. (2009). This method utilized empirical coefficients, mechanistically determined tensile stresses, and the 7-day UCS values for the CTB layers. Using the imported data, as well as the transfer functions, the number of ESAL passes to failure were determined for fatigue cracking in the asphalt, deformation (rutting) in the asphalt, and fatigue cracking in the CTB layer.

Results

Each pavement design, with its associated UCS value, geographic location, and the number of ESAL passes to failure were plotted in Figure 3, Figure *4*, Figure *5*, Figure *6*, Figure *7* and Figure *8*. A recommended value of 1,000,000 ESALs was used as the threshold for adequate pavement design. Designs that did not meet this threshold were not plotted. Two specific parameters change with each figure. First, figures are separated into East and West segments. Second, the 7-day UCS values change. Designs for the West side of Springville are represented in Figure 3, Figure *4* and Figure *5*. Designs for the East side of Springville are represented in Figure 6, Figure *7* and Figure *8*. For the given designs, the associated ESAL passes to failure are listed above the pavement design.

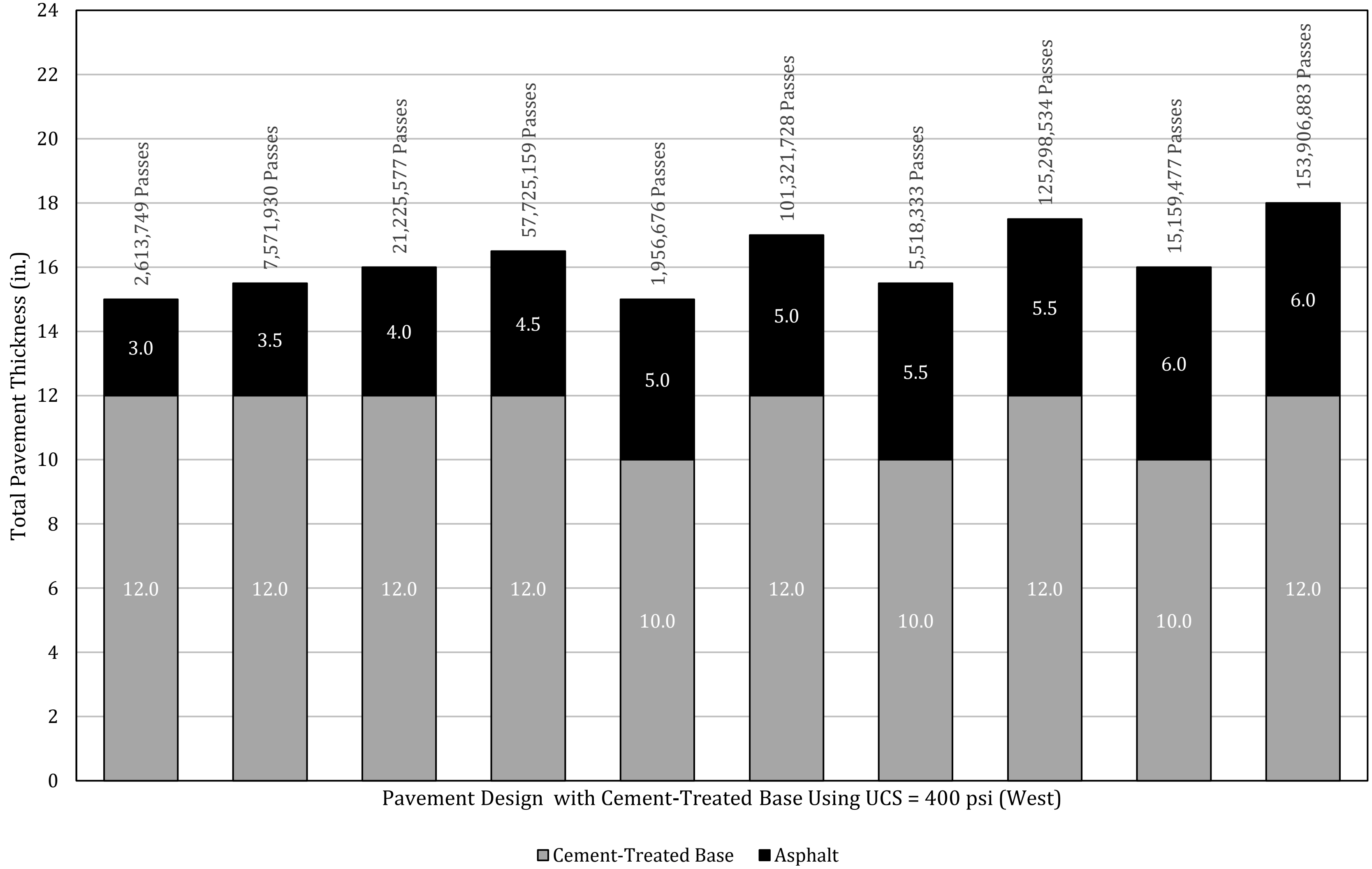

Figure 3: Pavement design for a 7-day UCS of 400 psi (West)

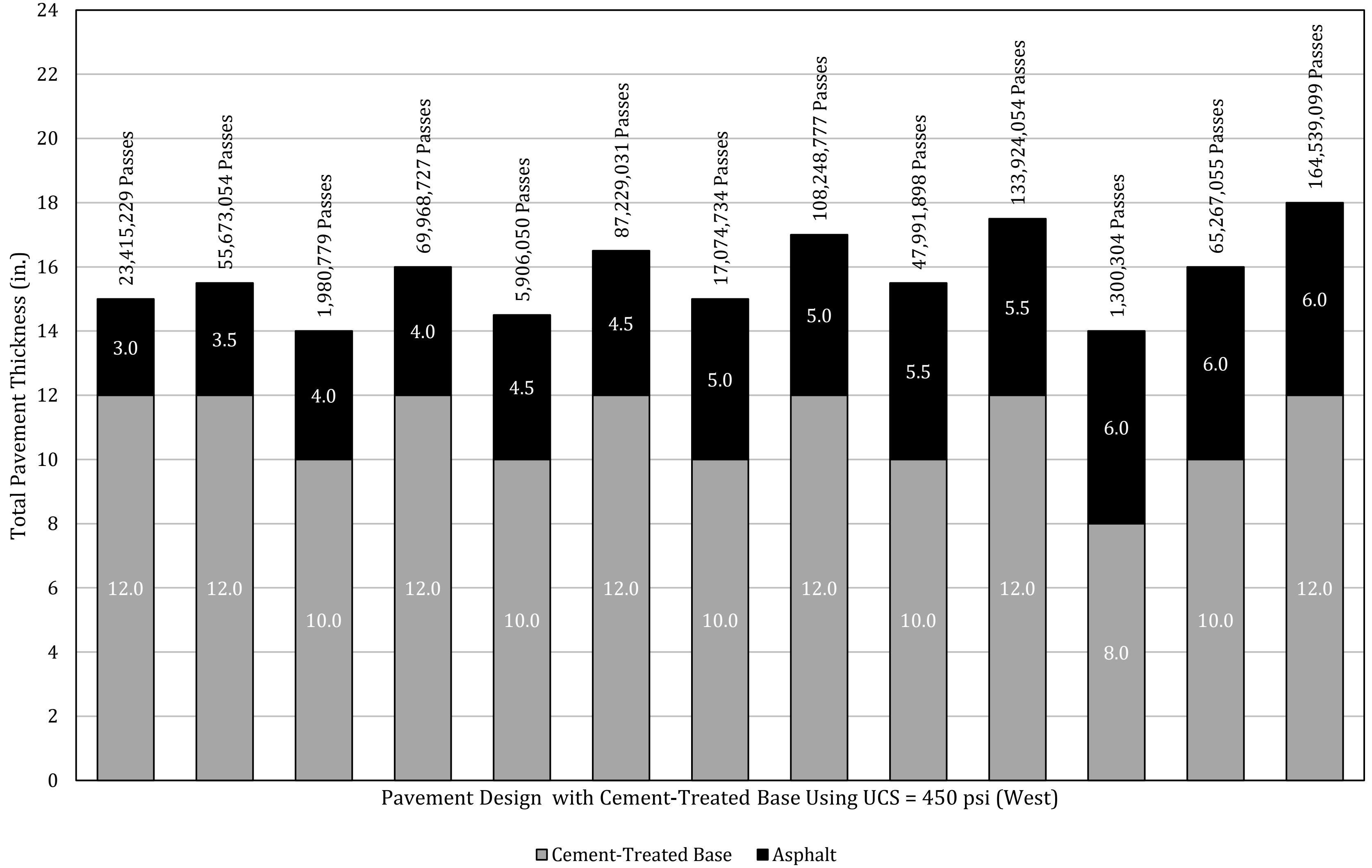

Figure 4: Pavement design for a 7-day UCS of 450 psi (West)

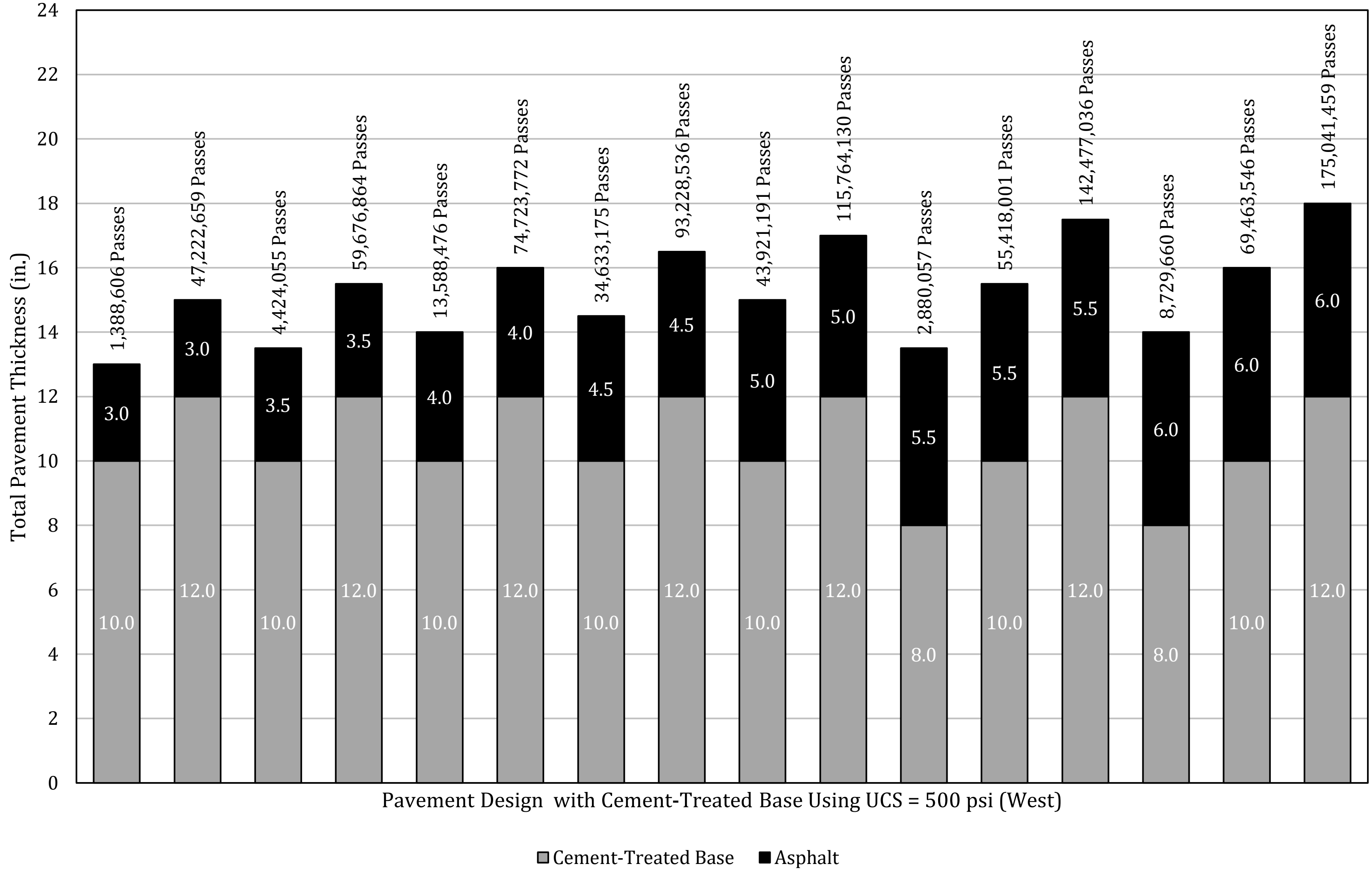

Figure 5: Pavement design for a 7-day UCS of 500 psi (West)

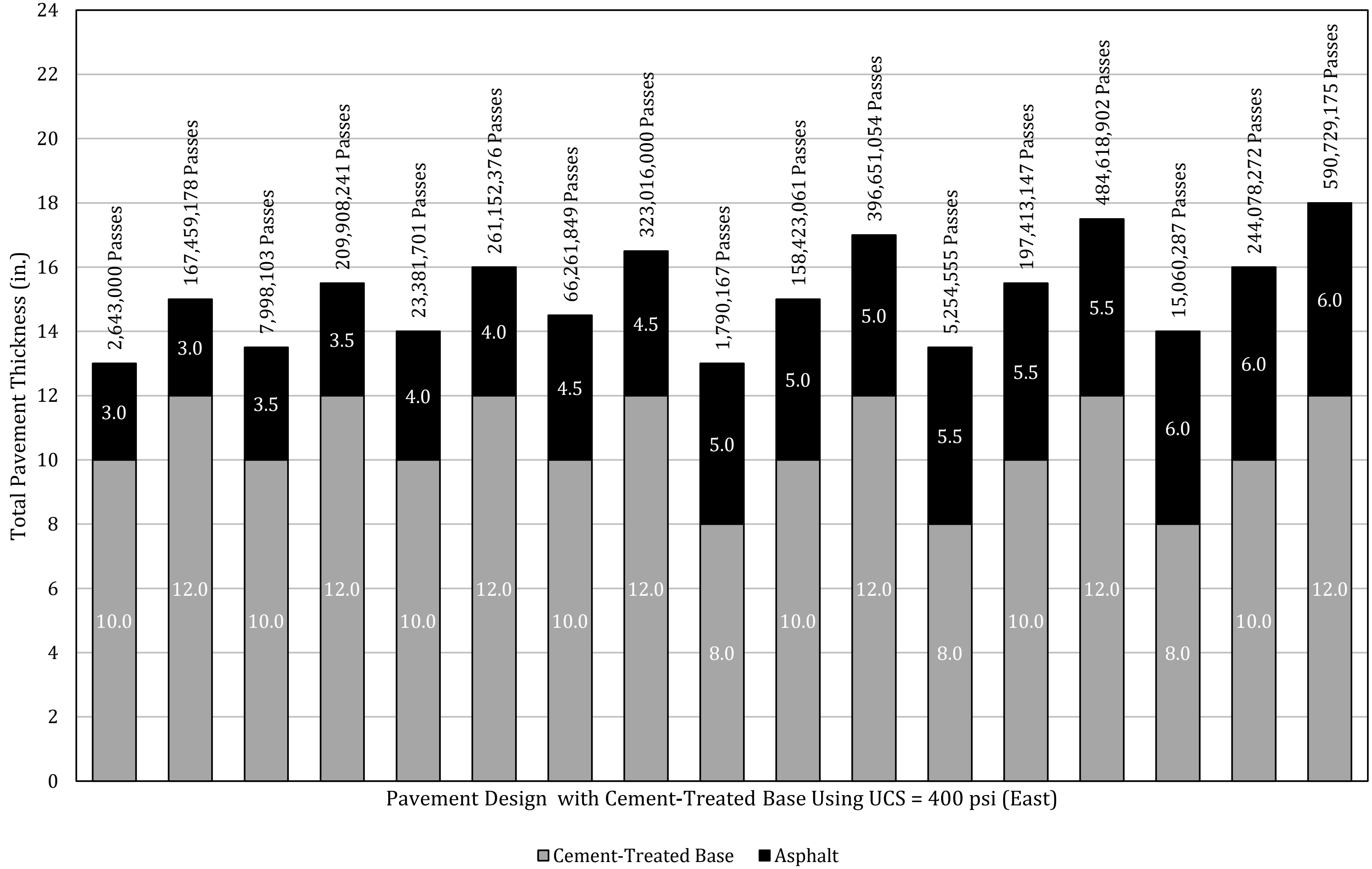

Figure 6: Pavement design for a 7-day UCS of 400 psi (East)

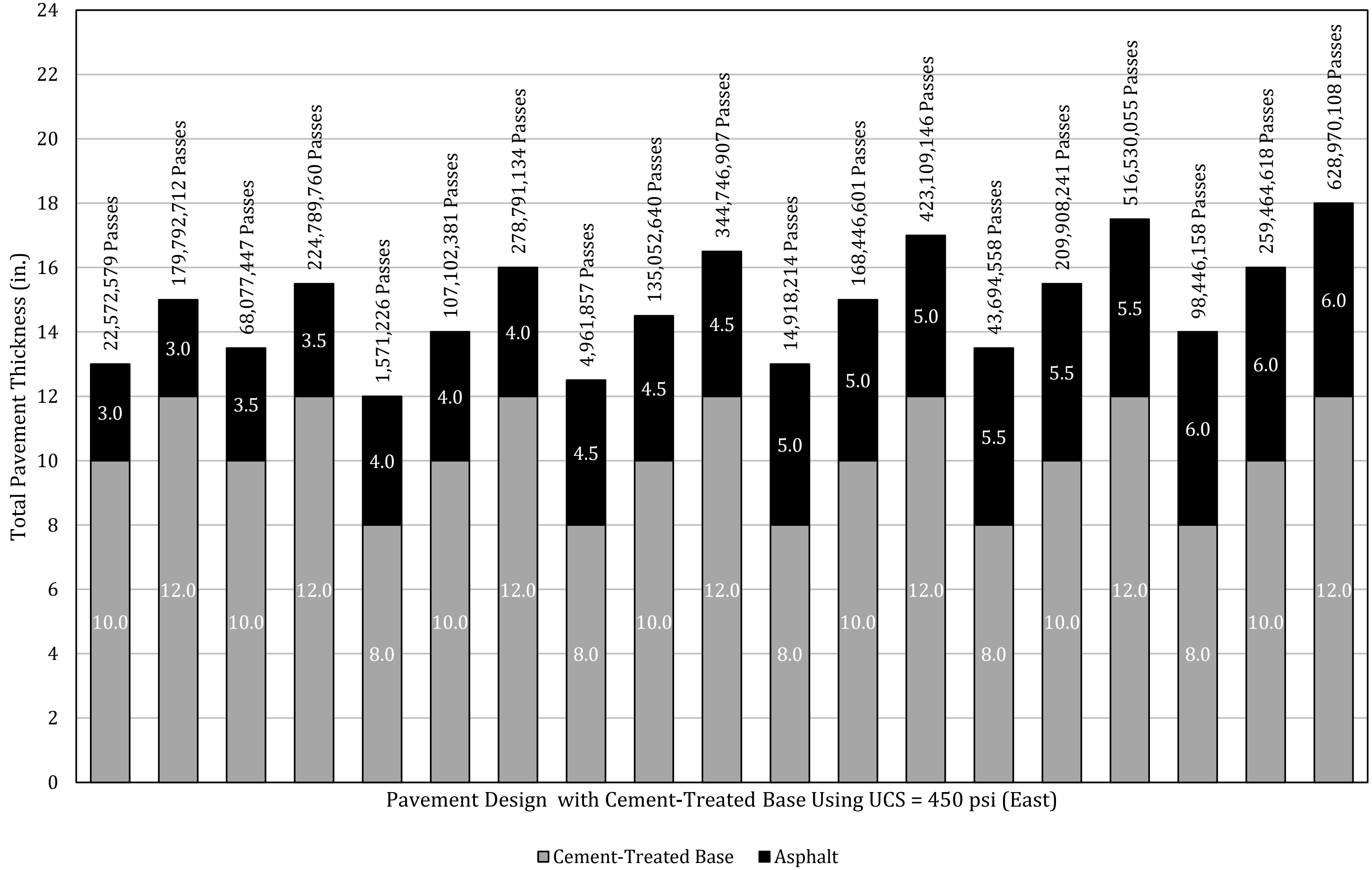

Figure 7: Pavement design for a 7-day UCS of 450 psi (East)

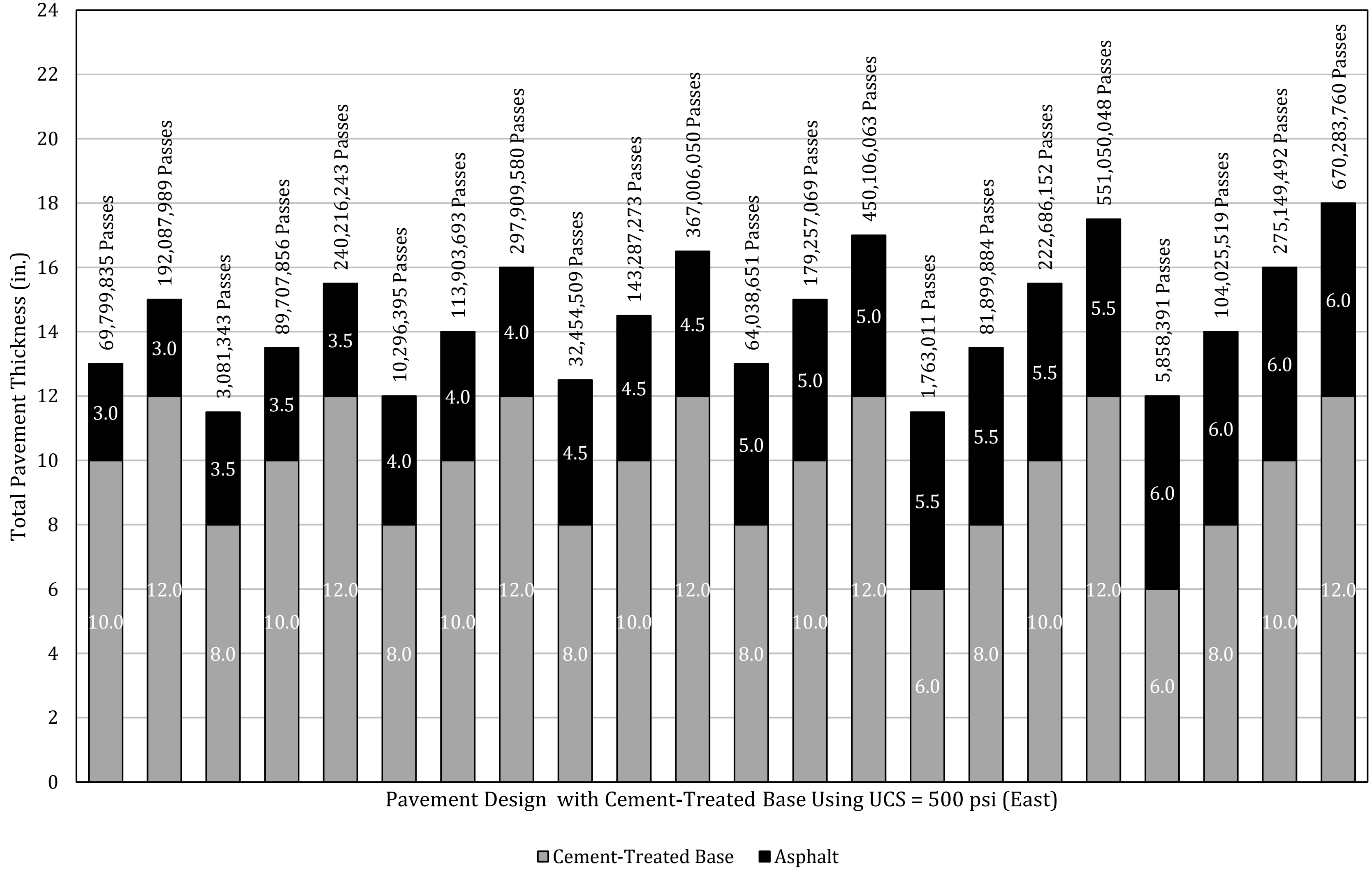

Figure 8: Pavement design for a 7-day UCS of 500 psi (East)

If a Full-Depth Reclamation (FDR) is desired, a recommended maximum of 8 in. of CTB should be used. However, for new construction, a CTB layer can be used from 6 to 12 in. A maximum of 12 in. is listed in this report. Each of the above figures lists all possible combinations of asphalt on CTB that surpass 1,000,000 ESALs.

Based on this project, 1,000,000 ESAL passes constitute the threshold for an adequate design. Table 8 has the tabulated values for every pavement design, with adequate designs marked in green.

Table 8: Mechanistic-Empirical Analysis Results

Asphalt Thickness (in)	CTB Thickness (in)	UCS 400 psi		UCS 450 psi		UCS 500 psi	
		West	East	West	East	West	East
3.0	6.0	0	45	2	374	12	2,424
3.0	8.0	104	15,920	907	134,035	6,180	883,297
3.0	10.0	22,659	2,643,000	200,681	22,572,579	1,388,606	69,799,835
3.0	12.0	2,613,749	167,459,178	23,415,229	179,792,712	47,222,659	192,087,989
3.5	6.0	1	186	8	1,535	55	9,935
3.5	8.0	393	55,882	3,421	469,009	23,240	3,081,343
3.5	10.0	72,837	7,998,103	642,455	68,077,447	4,424,055	89,707,856
3.5	12.0	7,571,930	209,908,241	55,673,054	224,789,760	59,676,864	240,216,243
4.0	6.0	4	725	35	5,983	237	38,658
4.0	8.0	1,419	187,697	12,299	1,571,226	83,300	10,296,395
4.0	10.0	225,498	23,381,701	1,980,779	107,102,381	13,588,476	113,903,693
4.0	12.0	21,225,577	261,152,376	69,968,727	278,791,134	74,723,772	297,909,580
4.5	6.0	17	2,706	145	22,284	970	143,687
4.5	8.0	4,886	593,838	42,292	4,961,857	286,047	32,454,509
4.5	10.0	674,674	66,261,849	5,906,050	135,052,640	34,633,175	143,287,273
4.5	12.0	57,725,159	323,016,000	87,229,031	344,746,907	93,228,536	367,006,050
5.0	6.0	67	9,700	567	79,690	3,776	512,892
5.0	8.0	15,840	1,790,167	136,739	14,918,214	922,396	64,038,651
5.0	10.0	1,956,676	158,423,061	17,074,734	168,446,601	43,921,191	179,257,069
5.0	12.0	101,321,728	396,651,054	108,248,777	423,109,146	115,764,130	450,106,063
5.5	6.0	249	33,501	2,114	274,611	14,047	1,763,011
5.5	8.0	49,698	5,254,555	427,997	43,694,558	2,880,057	81,899,884
5.5	10.0	5,518,333	197,413,147	47,991,898	209,908,241	55,418,001	222,686,152
5.5	12.0	125,298,534	484,618,902	133,924,054	516,530,055	142,477,036	551,050,048
6.0	6.0	893	111,840	7,567	914,627	50,160	5,858,391
6.0	8.0	151,390	15,060,287	1,300,304	98,446,158	8,729,660	104,025,519
6.0	10.0	15,159,477	244,078,272	65,267,055	259,464,618	69,463,546	275,149,492
6.0	12.0	153,906,883	590,729,175	164,539,099	628,970,108	175,041,459	670,283,760

As expected, as asphalt and CTB thicknesses increase, the amount of ESAL passes allowed also increases. In addition, as the 7-day UCS values increase, the ESAL passes increase. Although all designs in green will be adequate, the most cost-effective designs are desired. Based on the data in Table 8, minimum recommended pavement thicknesses, with associated ESAL passes to failure are shown in Figure 9 and Figure *10*.

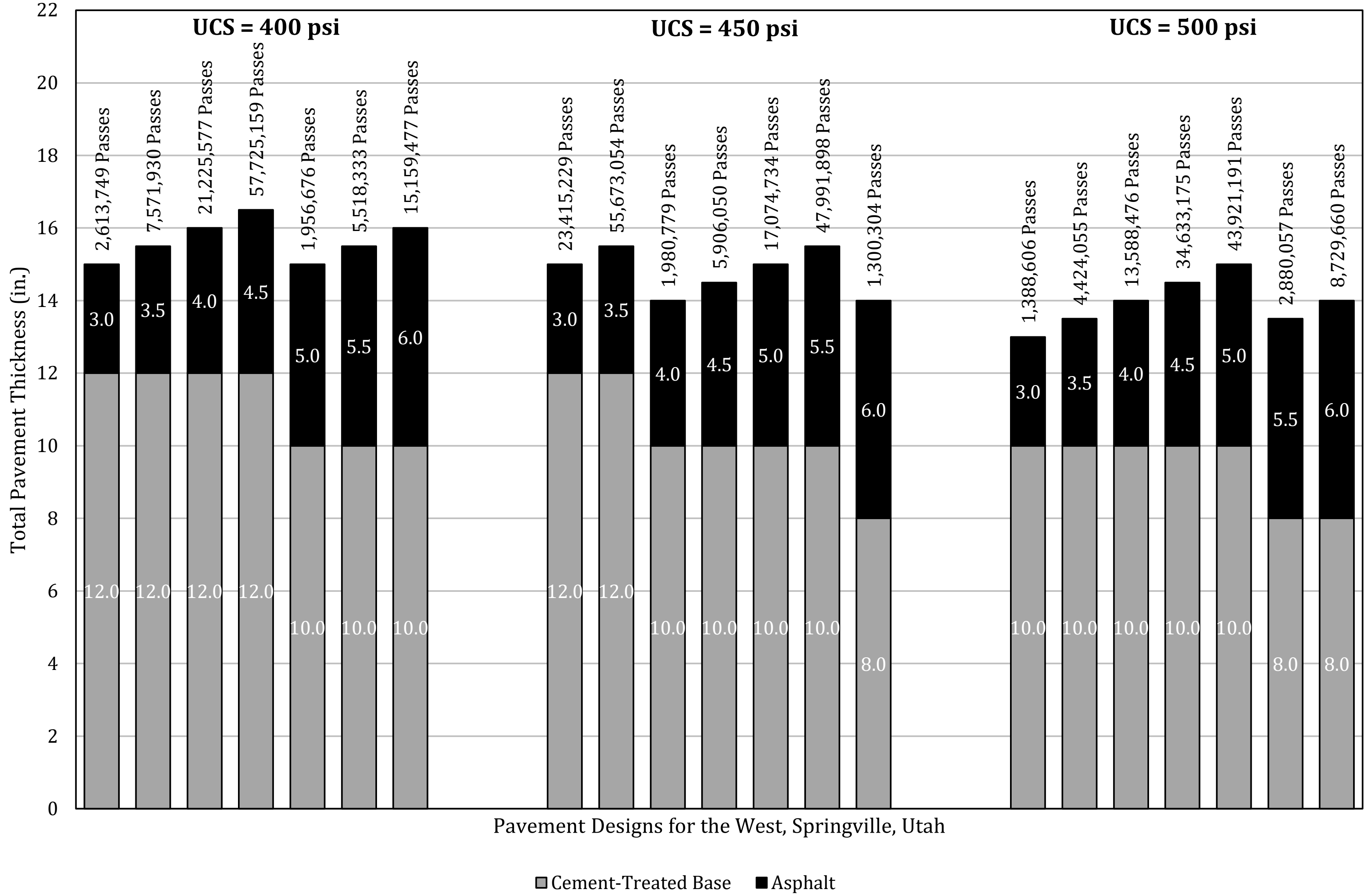

Figure 9: Pavement design of the West section of Springville.

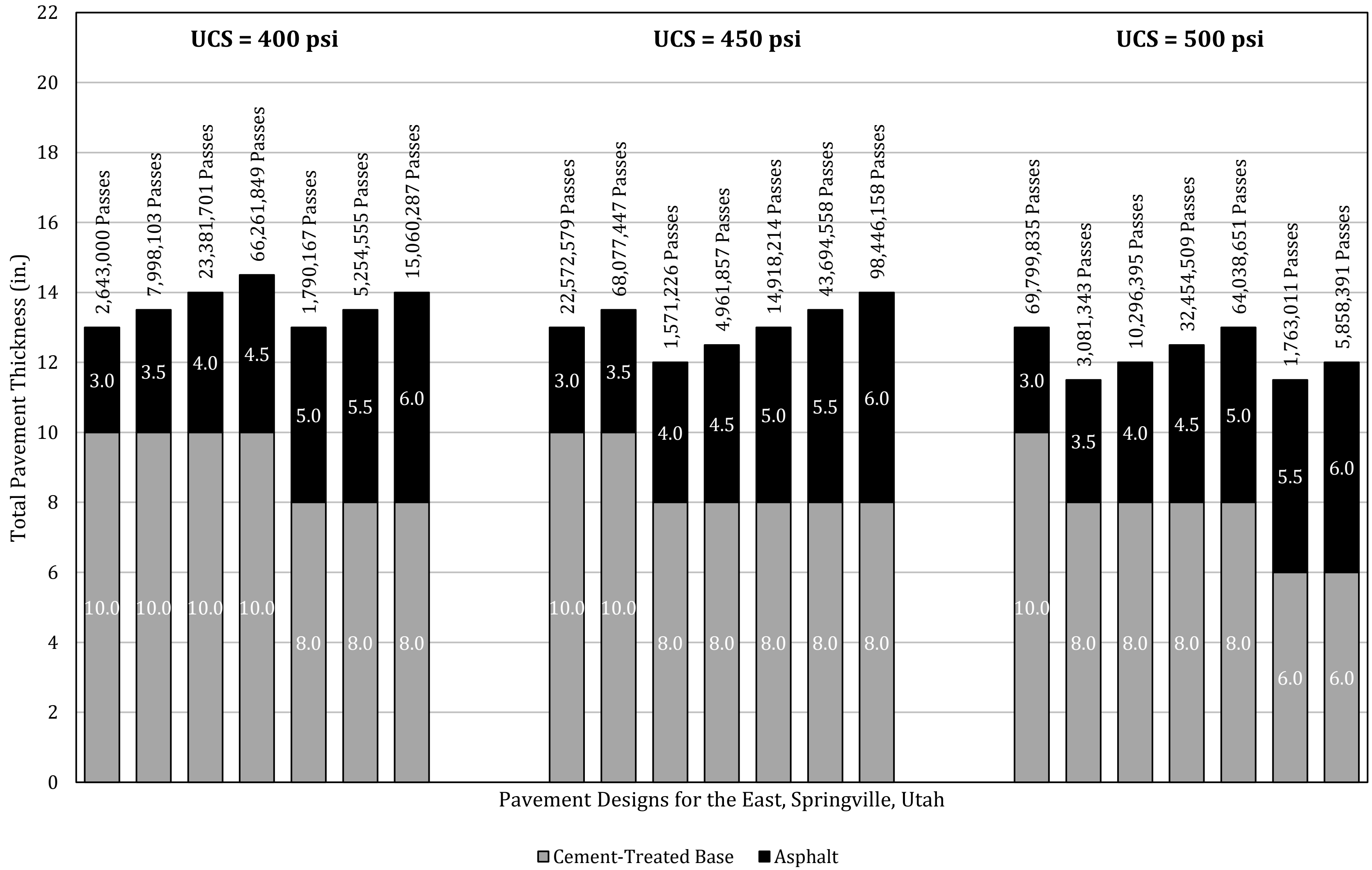

Figure 10: Pavement design of the East section of Springville.

Based on the criteria that the pavement design must withstand 1,000,000 ESAL passes, seven (7) pavement designs were chosen for each of the 7-day UCS values. Even though each design is considered adequate by the above criteria, the recommended 7-day UCS value would be 500 psi, since it allows the shallowest pavement designs, with the least amount of asphalt. As is viewed in the above figures, the 500 psi UCS allows for the thinnest asphalt design on the thinnest CTB layers, typically resulting in a 2 in. reduction in CTB on both the West and East sides of Springville. This is highly recommended for construction located on the West side of Springville City, where the subgrade has a modulus of elasticity of approximately 6 ksi. The stronger CTB layer will help protect the subgrade as well as provide a strong base for the asphalt layer. However, if 500 psi is not desired, designs have been submitted for the remaining UCS values.

Conclusions

Minor collectors in Springville City are failing prematurely. This has been determined by Infrastructure Research, LLC. Per the study performed in 2018, and with gradation data from this project, it was determined that the base materials used in the construction of many of the minor collectors contained large quantities of fines. The presence of so many fines severely weakened the base material, making it more susceptible to freeze/thaw cycles. Improved specifications for base materials should be instituted to ensure that fine quantities remain at a minimum. In addition, to ensure stronger base materials, improved Quality Control and Quality Assurance, as well as LA Abrasion testing (ASTM C131 & AASTHO T96) should be instituted during road construction.

In addition to the field and laboratory testing, ME analyses were performed to determine pavement designs that would improve pavement lifespans. Moduli of elasticity were determined from field and laboratory testing for asphalt and base materials. However, assumed values for subgrade moduli were determined by Infrastructure Research, LLC, which determined the weakest modulus for the geographic regions (East and West). Using these parameters, designs were calculated for varying asphalt thicknesses. In addition, it was recommended that for CTB layers, a UCS of 500 psi be used. This will ensure that the CTB layer has adequate strength to protect the underlying subgrade and strength to support the overlaying asphalt layer. However, if 500 psi is not desired, pavement designs for lower UCS values have been submitted, with pavement thicknesses, and allowable ESAL passes to failure.

After careful review of the Marshall Stability test, it is recommended that the asphalt modulus of elasticity be a minimum of 430,000 psi. If a lower modulus is used, the pavement designs listed above will not be applicable.

One other issue encountered throughout this project was a lack of records of the studied roads. This made it difficult to determine the intended designs of the segments studied. Additionally, depths, thicknesses, and characteristics of both pavement and base materials could not be compared to the original design specifications. All future projects should maintain a detailed record of these values to ensure future analysis can be done.

These recommendations just described are based off of testing done on two segments on the Northeast and Southeast sides of Springville. Further analysis of minor collectors on the West side of Springville City is recommended to ensure that the suggested design will be adequate. Additional frost heave analysis is also recommended to determine the level at which this process contributed to road deterioration. Results from either of these analyses could help determine if a uniform minor collector design is adequate, or if an East and West side design would be more appropriate.

The population of Springville is estimated to grow by nearly 75% between now and 2040. This rapid growth will place an even greater strain on the existing infrastructure that is already underperforming. If the current design specifications are used, new roads will still be likely to fail much sooner than the design life. The recommended new pavement designs, along with best practice maintenance, will allow Springville City to meet the increasing demands. Meeting those demands will ultimately increase the level of safety for residents and reduce the cost of constant rehabilitation and rebuild.

Appendix A

Aleczander N. Escamilla

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EDUCATION

Brigham Young University — **Provo, UT**
B.S. Civil Engineering; Minor: Business Management — Apr 2020

- GPA: 3.94/4.00; ACT: 29/36 (92nd percentile)
- Harvard Business School Peek Weekend Ambassador
- Marigold N. Saunders merit-based scholarship and W. Don Budge Civil Engineering merit-based scholarship recipient

EXPERIENCE

PricewaterhouseCoopers — **Dallas, TX**
Start Advisory Intern — Jun 2018 – Jul 2018

- Created a best-in-class client deliverable that visually connects PwC's service offerings to their 6 FY19 platforms
- Enhanced the ability of sales teams to bring the One Firm methodology to the client
- Developed strong relationships while balancing multiple projects and allowed for greater focus on high impact work

Brigham Young University — **Provo, UT**
Research Assistant in Department of Civil and Environmental Engineering — Oct 2016 – Present

- Perform 20+ unconstrained shear testing using a Universal Testing Machine to determine effectiveness of geogrid
- Work directly with a Master's student to publish a thesis through BYU and in an academic journal
- Work independently and collaboratively on preparing, compacting, and testing 20+ different soil samples

W.W. Clyde & Co. — **Orem, UT**
Engineer Intern — May 2017 – Dec 2017

- Drove over $60,000 in savings on a $19 M project by finding value engineering opportunities
- Created a production schedule using Excel in order to keep the project profitable and to meet established goals
- Verified accuracy of reported quantities for payment and created 15+ submittals for various project phases
- Managed the purchasing and supervised the installation of 3,000+ yards of storm drain
- Identified design deficiencies and worked with owners, designers, and subcontractors to correct them

Intertek PSI — **Oklahoma City, OK**
Engineer Intern — May 2016 – Aug 2016

- Supervised the pouring and performed quality control testing of concrete on 20+ projects, often between 1 am-6 am
- Ran a variety of lab tests including Atterberg Limits, California Bearing Ratios, Proctors, and Resistivities
- Demonstrated ability to learn and fill multiple roles including as a driller's assistant, boring twenty 15-45 foot deep holes
- Certified American Concrete Institute 1 technician with only a few days of training

Brigham Young University — **Provo, UT**
Residence Assistant — Jan 2016 – Apr 2016

- Helped create and supervise a healthy community directly with 38 residents and upwards of 150 indirectly
- Planned, organized, and ran 4 events to encourage development of healthy life habits available to hundreds of students
- Met weekly with about 20 residents to lead discussions on community standards and life skills

SERVICE AND LEADERSHIP

Cougar Consulting Group — **Provo, UT**
Engagement Manager and Founding Team Member — Mar 2018 – Present

- Developed a quantifiable, data-driven strategy to determine an international office location for a fast-growing SAAS client

Engineers Mean Business Club — **Provo, UT**
Treasurer and former Vice President of Events — Jan 2017 – Present

- Planned, organized, and coordinated events that would increase members professional networks and their business skills
- Worked directly with professionals in engineering, entrepreneurship, tech, and others to inspire club members

American Society of Civil Engineers BYU Student Chapter — **Provo, UT**
President, Concrete Canoe Team Member, and Heavy Civil Construction Management Case Competitor — Aug 2017 – Present

- Coordinate the efforts of 14 other officers to provide service, leadership, and networking opportunities to over 200 students
- Authored and presented a non-technical paper that won 1st place overall at the ASCE Rocky Mountain Conference
- Helped build a canoe made out of concrete that not only floats but is used for several different races against other schools
- Led a team of 6 to analyze, schedule, bid, and present a construction management case competition in 24 hours

The Church of Jesus Christ of Latter-day Saints — **Oaxaca, Mexico**
Bilingual Service Representative — Aug 2013 – Jul 2015

- Coordinated the daily efforts of over 30 other representatives to improve the lives of the people in Oaxaca
- Organized and presented weekly and bi-monthly leadership training conferences that focused on interpersonal skills
- Adapted to an international environment by working with local leaders and immersing myself in the culture

PERSONAL

- Starting to learn Finnish
- Inner tube water polo goalie

CRAIG STAPLES, EIT

469 Wymount Terrace, Provo, UT 84604 ♦ 530-635-4475 ♦ castaples14@gmail.com

APR 2019 EXPECTED — **Brigham Young University** — **Provo, UT**
BS CIVIL ENGINEERING — 3.83 GPA — Civil Engineering Scholarship — ASCE National Member

KEY UNIVERSITY COURSE WORK:

Elementary Soil Mechanics	Statics and Dynamics	Geomatics and GIS	Hydrology
Structural Analysis	Differential Equations	Reinforced Concrete	Foundations

EXPERIENCE

JAN 2018- PRESENT — **Brigham Young University Civil Engineering Department** — **Provo, UT**
RESEARCH ASSISTANT

- Conduct research analyzing the effects of geogrid on base materials
- Results show that base materials are strengthened with the addition of geogrid

APR 2018- DEC 2018 — **Acute Engineering Inc.**
STUDENT ENGINEER

- Designed structural members for over 100 residential homes
- Redesigned the structural analysis spreadsheet for Acute practices to calculate wind loads per ASCE 7-10

AUG 2017- APR 2018 — **Brigham Young University Civil Engineering Department** — **Provo, UT**
SOIL MECHANICS LABORATORY INSTRUCTOR

- Guided 7 students on a weekly basis through real-world laboratory exercises
- Critiqued weekly technical writing on laboratory group reports and gave quality feedback
- Assisted students during weekly office hours with university soil mechanics coursework

MAY 2017- AUG 2017 — **RB&G Engineering** — **Provo, UT**
LABORATORY TECHNICIAN

- Sampled, tested and provided quality assurance work on 300+ soil samples
- Completed rice, gyratory, Marshall, and burnoff tests on 300+ asphalt samples
- Performed slump, air and compressive tests for airport hangars at the Salt Lake City International Airport

VOLUNTEER/SERVICE

APR 2017- APR 2018 — **BYU American Society of Civil Engineers (ASCE)** — **Provo, UT**
CLUB SECRETARY

- Documented weekly officer meeting minutes with assignment follow up
- Conducted weekly club meetings for 250+ students

SEPT 2011-2013 — **The Church of Jesus Christ of Latter-day Saints** — **Paris, France**
VOLUNTEER REPRESENTATIVE

- Trained 6 missionaries in essential French speaking, teaching, and planning skills
- Prepared weekly trainings for 8 missionaries during a two-month period

SKILLS AND ACHIEVEMENTS

- Fundamentals of Engineering Exam (Passed March 15, 2018)
- Computer skills:
  - Excel (including VBA)
  - AutoCAD, Revit
  - ArcMap/GIS
  - Google Docs and Sheets
  - Microsoft Word, PowerPoint, Photo shop
- OSHA 10 Hour Trained
- Eagle Scout, Boy Scouts of America

Paul JW Andersen, EIT

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385-207-9395 * paolo.andersen@gmail.com

Education

Brigham Young University — Apr 2019
BS Civil & Environmental Engineering; Minor: Business Management — Provo, UT

- 3.79 cumulative GPA, member of Tau Beta Pi Engineering Honor Society
- Relevant Coursework: Design of Wood Structures, Foundation Design, Advanced Foundation Design, Seepage & Slope Stability, Structural Steel Design, Reinforced Concrete Design, Geotechnical Engineering, Geology for Engineers, Fluid Mechanics, etc.

Work Experience

Brigham Young University — May 2018 - Present
Field Research Assistant to Dr. Kyle Rollins — Provo, UT

- Collaborated with professors from BYU and Università di Bologna, in a ground improvement study using rammed aggregate piers to mitigate liquefaction potential in susceptible soils (sponsored by Geopier Foundation)
- Assisted with field testing at site in Bondeno, Italy and post-experiment data analytics using Excel and VBA

Acute Engineering — Nov 2017 – Jan 2019
Structural Engineering Intern — Orem, UT

- Provided light-frame engineering in accordance with ASCE 7-10, NDS, SDPWS, IBC, IRC and local code
- Institutionalized universal shallow foundation details for projects outside of Utah County

South Valley Sewer District — Jun 2017 - Aug 2017
Wastewater Engineer Intern — Bluffdale, UT

- Reviewed and revised all sewage plans with district and staff engineers for all new construction projects within the largest utility district in Utah
- Programmed with VBA to reduce regular data entry project time from 15 hours to 1 hour

Qualtrics, LLC. — Dec 2016 - Nov 2017
Project Manager — Provo, UT

- Managed research studies across numerous industries, utilizing Qualtrics software and strategic sampling

Product Specialist — Sep 2013 - Dec 2016

- Provided customer service to companies such as Bain & Co., Google, PWC, Allianz, etc.
- Promoted internally resulting in a doubling of personal hourly pay (starting $8/hr., end $17.50/hr.)

Carescape Sprinkler and Landscape Gurus — Jun 2013 - Sep 2013
Operations Manager — Heber City, UT

- Led team of 4 and managed plans, materials, equipment to efficiently install automated home irrigation systems
- Operated heavy equipment such as trenchers, skidsteers and excavators safely

Volunteer and Other Experience

The Church of Jesus Christ of Latter-day Saints — Mar 2011 - Mar 2013
Full-time Representative — Southern Italy and Malta

- Developed leadership, training, public speaking, and managerial skills while providing full-time volunteer service
- Coordinated efforts of 26-50 volunteers spread across the regions of Calabria and Sicily

BYU Y-Serve: Self Help Homes — Jan 2015 - Apr 2016
Program Director — Heber City & Elk Ridge Utah

- Collaborated with constructional professionals to provide skill training to volunteers, resulting in our program's community contact receiving the Community Service Provider of the year award from BYU

Utah's Hogle Zoo — Jun 2016
Animal care intern — SLC, UT

- Selected as hoof-stock caretaker, responsible for husbandry of 4 giraffes, 3 zebras and 2 ostriches

Other Skills & Courses Taken

- Software: Basic knowledge of Autodesk's CAD and Revit, VBA Programming, Microsoft Office
- Language: Fluency in Italian

Appendix B

Frost Heave survey raw results:

Table 9: Frost Heave Measurements for Segment 873

Site Location:	400 E, 1000-1050 N, Springville UT		
Survey ID	Winter Elevation (ft)	Spring Elevation (ft)	Frost Heave (in.)
FH1	100	100	
SN1	99.065	99.142	N/A
SN2	97.655	97.59	0.648
SN3	97.115	96.853	4.920

Table 10: Frost Heave Measurements for Segment 193

Site Location:	800 E, 800-850 S, Springville UT		
Survey ID	Winter Elevation (ft)	Spring Elevation (ft)	Frost Heave (in.)
FH1	100	100	
SN1	94.862	94.6	3.144
SN2	95.565	95.318	2.964
SN3	96.541	96.259	3.384

Results from dry and washed sieve analysis are as follows:

Table 11: Gradation Values for Segment 873, Pre-Wash

Team:	MagiCAP
City, State:	Springville, Utah
Site Location:	NE Base Pre-Wash
Date Sampled:	3/27/2019
Date Tested:	3/29/2019
Technician:	Craig, Alec, Paul
Sample:	Base
Sample Weight (g)	4965.9

Sieve Opening	Quantity Retained (g)	Quantity Passing (g)	Percent Passing	Percent Retained
1 1/2	0.0	4965.9	100.0	0.0
1 1/4	0.0	4965.9	100.0	0.0
1	54.9	4911.0	98.9	1.1
3/4	350.2	4560.8	91.8	8.2
1/2	573.0	3987.8	80.3	19.7
3/8	469.3	3518.5	70.9	29.1
4	939.7	2578.8	51.9	48.1
8	758.6	1820.2	36.7	63.3
16	477.8	1342.4	27.0	73.0
30	340.9	1001.5	20.2	79.8
50	338.5	663.0	13.4	86.6
100	349.3	313.7	6.3	93.7
200	168.2	145.5	2.9	97.1
Pan	141.0			

Total (g):	4961.4	
Percent Change:	0.1%	Decrease

Table 12: Gradation Values for Segment 873, Post-Wash

Team:	MagiCAP
City, State:	Springville, Utah
Site Location:	NE Base Post-wash
Date Sampled:	3/27/2019
Date Tested:	3/29/2019
Technician:	Craig, Alec, Paul
Sample:	Base
Sample Weight (g)	4953.9

Sieve Opening	Quantity Retained (g)	Quantity Passing (g)	Percent Passing	Percent Retained
1 1/2	0.0	4953.9	100.0	0.0
1 1/4	0.0	4953.9	100.0	0.0
1	23.1	4930.8	99.5	0.5
3/4	231.4	4699.4	94.9	5.1
1/2	473.4	4226.0	85.3	14.7
3/8	508.4	3717.6	75.0	25.0
4	866.3	2851.3	57.6	42.4
8	670.3	2181.0	44.0	56.0
16	396.4	1784.6	36.0	64.0
30	297.0	1487.6	30.0	70.0
50	308.6	1179.0	23.8	76.2
100	274.1	904.9	18.3	81.7
200	210.6	694.3	14.0	86.0
Pan	694.3			

Total (g):	4953.9	
Percent Change:	0.2%	Decrease

Table 13: Gradation Values for Segment 193, Pre-Wash

Team:	MagiCAP
City, State:	Springville, Utah
Site Location:	SE Base Pre-Wash
Date Sampled:	3/28/2019
Date Tested:	4/1/2019
Technician:	Alec/Paul
Sample:	Base
Sample Weight (g)	5003.8

Sieve Opening	Quantity Retained (g)	Quantity Passing (g)	Percent Passing	Percent Retained
1 1/2	0.0	5003.8	100.0	0.0
1 1/4	0.0	5003.8	100.0	0.0
1	0.0	5003.8	100.0	0.0
3/4	221.7	4782.1	95.6	4.4
1/2	540.8	4241.3	84.8	15.2
3/8	581.3	3660.0	73.1	26.9
4	1051.8	2608.2	52.1	47.9
8	741.4	1866.8	37.3	62.7
16	461.0	1405.8	28.1	71.9
30	296.2	1109.6	22.2	77.8
50	226.7	882.9	17.6	82.4
100	318.7	564.2	11.3	88.7
200	293.8	270.4	5.4	94.6
Pan	266.9			

Total (g):	5000.3	
Percent Change:	0.1%	Decrease

Table 14: Gradation Values for Segment 193, Post-Wash

Team:	MagiCAP
City, State:	Springville, Utah
Site Location:	SE Base Post-Wash
Date Sampled:	3/28/2019
Date Tested:	4/13/2019
Technician:	Paul
Sample:	Base
Sample Weight (g)	5000.1

Sieve Opening	Quantity Retained (g)	Quantity Passing (g)	Percent Passing	Percent Retained
1 1/2	0.0	5000.1	100.0	0.0
1 1/4	0.0	5000.1	100.0	0.0
1	0.0	5000.1	100.0	0.0
3/4	196.8	4803.3	96.1	3.9
1/2	544.8	4258.5	85.2	14.8
3/8	577.6	3680.9	73.6	26.4
4	1008.3	2672.6	53.5	46.5
8	647.3	2025.3	40.5	59.5
16	392.0	1633.3	32.7	67.3
30	249.9	1383.4	27.7	72.3
50	229.9	1153.5	23.1	76.9
100	275.2	878.3	17.6	82.4
200	194.3	684.0	13.7	86.3
Pan	684.0			

Total (g):	5000.1	
Percent Change:	0.1%	Decrease

Table 15: Marshall Flow and Stability

Core Location		Core Layer	Core Weight (lbs.)	Core Density (pcf)	Average Core Height (in.)	Flow (in.)	Stability (lbs.)	Stability Adjustment Factor	Adjusted Stability (lbs.)	Average Stability Top (lbs.)	Average Stability Bottom (lbs.)	Average Stability Total (lbs.)
NE	N1	Top	2.1445	142.2	2.359	Error	Error	-	-	2414	1677	2046
		Bottom	2.3130	142.1	2.547	24.0	1520	0.97	1474			
	N2	Top	2.4905	155.9	2.500	19.8	2414	1.00	2414			
		Bottom	2.3810	156.9	2.375	16.4	1725	1.09	1880			
SE	S1	Top	2.0445	128.0	2.500	28.7	796	1.00	796	793	2529	1661
		Bottom	2.2240	135.8	2.563	32.2	3010	0.96	2890			
	S2	Top	2.0240	127.5	2.484	23.1	687	1.01	694			
		Bottom	2.2555	136.9	2.578	29.2	2138	0.95	2036			
	S3	Top	1.9840	121.9	2.547	24.4	917	0.97	889			
		Bottom	2.1990	140.3	2.453	28.9	2583	1.03	2660			

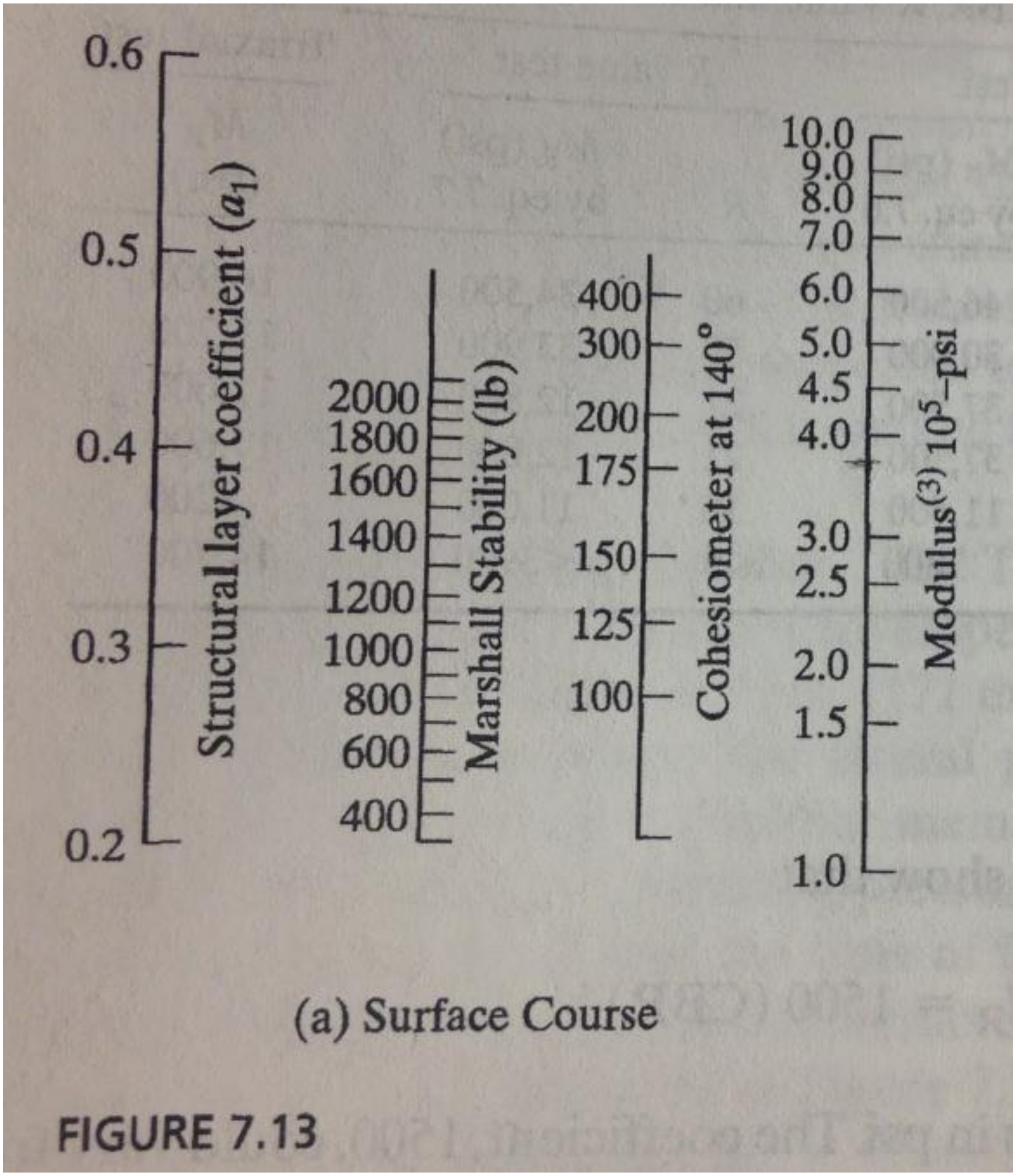

Figure 11: Figure to determine modulus of elasticity for asphalt layer, based on Marshall Stability (Huang 2003).

ASTM Test Standards for Laboratory Work

The following ASTM Standards will be followed for laboratory work:

ASTM D1883 – 16 (California Bearing Ratio)

ASTM C131 & AASTHO T96 (LA Abrasion Test)

ASTM D698 (Standard Proctor Test)

ASTM D1557 (Modified Proctor Test)

ASTM C 136 (Sieve Analysis of Fine and Coarse Aggregates)

ASTM D1074 (Uniaxial Compressive Strength of asphalt)

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- Guthrie, W. Spencer, Tenli Waters, and Robert Stevens. "Performance Evaluation and Pavement Design for Minor Collectors in Springville City."
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- Springville City Transportation Master Plan : https://www.springville.org/wp-content/uploads/2016/10/Springville-TMP-Report-2016-09-30.pdf