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The Characteristics of Underground Utility Repairs Made in Asphaltic Roadways – Comparing the Use of Grade D Aggregate as a Viable Backfill Option

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To the Graduate Council:

I am submitting herewith a thesis written by Susan Gail Deland entitled "The Characteristics of Underground Utility Repairs Made in Asphaltic Roadways – Comparing the Use of Grade D Aggregate as a Viable Backfill Option." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

John S. Schwartz, Baoshan Huang, Major Professor

We have read this thesis and recommend its acceptance:

Eric C. Drumm

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A Thesis
Presented for the
Master of Science
Degree
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Susan Gail DeLand
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DEDICATION

This thesis is dedicated to my loving husband, Michael DeLand, for his continual and unwavering support.

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Abstract

Given that most utilities are located beneath public right of ways, it is difficult to perform repairs to the utility without significantly disturbing the existing roadway. Currently there are several standard orders of procedure that deal with small-scale repairs on asphaltic surfaces. This study investigates the use of Grade D Aggregate as a backfill during a utility repair versus the condition of the repair. Five East Tennessee utilities provided a total of 60 utility repair locations over three years of age; 30 of which incorporated Grade D Aggregate and 30 incorporated #57 Stone.

The Tennessee Department of Transportation specifies a smoothness criterion of the roadway to regulate any deviation of the surface of the roadway greater than ¼ inch over a 12-foot span. The parameters measured during this study include smoothness, condition of the asphalt topcoat, adjacent stress cracking, depth of repair and disturbed surface area. Multiple linear regression and analysis of variance tests were used to analyze the results.

Results suggest that there is no difference between using and not using Grade D Aggregate except with failures of one inch or greater. The results also suggest that there is little to no relationship between roadway characteristics and the performance of the repair except with failures one inch or greater. There is a correlation between slope and failures that had a deviation of one inch or greater. The results suggest that Grade D Aggregate performs better when significant failures occur. Recommendations include implementation of a cutback area, development and implementation of installation

guidelines within the municipality, and implementation of a maintenance program that will address the repair cut failures in a timely manner.

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Chapter 1.0 Introduction

1.1 Utility Repair Restoration

Utilities are commonly located beneath city streets or right-of-ways. Utilities are usually located underground for aesthetics, to protect them from the affects from climate conditions, and for public safety purposes. However, within cities there are not enough unpaved areas to install all needed utilities; therefore utilities are primarily under pavement within metropolitan areas. The infrastructure in America has aged and deteriorated, most of the utilities receiving a 'C' on the ASCE Infrastructure Report Card. Therefore a sizeable portion of utilities have recently been updated or will be at some point in the near future. From Jensen (2005), "In general, the restoration of a utility cut involves a cut, excavation, repair, and compaction of backfill materials. Items of general concern in the backfilling process include backfill materials, lift thickness, placement of water content, and desired density."

A major issue facing utility providers and/or cities is the low serviceability of the asphalt after restoration of utility cuts (Zeghal 1984). The entire road has a lower life expectancy and rate of service during the remainder of its lifecycle. The cost of repairing the low service utility cuts is continually rising and is causing financial strain on utility providers and/or cities (Khogali 1999). "While the costs of utility conflicts have largely been unmeasured, the case studies show that they impose significantly unexpected costs on public projects" (Goodrum 2008).

There are three main categories of utility cut failures; settling of the cut, rising of the cut and/or adjacent settling (Schaefer 2005). “Settling of the cut resulting in vehicles hitting a low spot, as well as the collection of moisture, which can induce additional settlement. Typically, settlement is caused either by a combination of a poor compaction effort in natural soils or other backfill materials which have been or are exposed to wet or frozen conditions or the use of unsuitable backfill materials” (Schaefer 2005). Rising of the cut occurs when the water capillaries freeze and expand during the colder months. When the soil thaws the soil structure is even weaker than before freezing resulting in greater settlement (Schaefer 2005). Adjacent settling is caused when excavating the trench and the existing material adjacent to the trench causes loss of lateral support, leading to a weaker sub-base outside of the trench. Studies indicate the total affected area outside around the trench itself is two to three feet beyond the trench (Jensen 2005). There may also be formation of cracks in the distress region around the utility cut where water can enter and increase deterioration (Schafer 2005). A stretching zone, caused by an unsupported face of the utility cut, is estimated to be 3.5 ft into the pavement structure (Humphrey 1998). It is important to understand the full extent of the potential area of damage in order to accurately determine the required restoration.

Most distress appears to occur in the fill/sub-grade material (Humphrey 1998). Jensen noted the “poor performance of pavements over and around utility trenches on local and state systems often causes unnecessary maintenance problems due to improper backfill placement (e.g., under compacted, too wet, too dry).” If backfill is installed properly, a life expectancy of 15 to 20 years is estimated. In addition to proper installation of the backfill, the asphalt should be cut in a rectangular shape through its full depth to ensure total restoration of the surface (Sheflin 2002).

A study by Polvi (2002) shows that poor installation techniques and poor material quality can adversely affect the adjacent area to a repair which can contribute to further deterioration even though not evident at the time of construction. On the other hand, the study showed that if quality materials and proper installation techniques are used the repairs perform well over time. Polvi (2002) recommends stabilizing the sides of the cuts or repairing the side in the case of damage. Also, Polvi (2002) recommends proper joint sealing, material compaction, and appropriate asphalt thickness in making repairs.

Failure of the adjacent cut is often observed as degrading of the existing pavement, which results in higher repair and maintenance costs, safety issues, and poor aesthetics (Arudi 2000). The City Engineering Department of Prescott, Arizona has determined that lack of inspection results in inadequate trench restoration leading to failures (Brinkley 1990). Based on Toronto, Canada’s successful implementation of non-shrink slurry, Prescott developed a mix design to be used in their utility repairs. Their mix design incorporated Portland Cement in addition to aggregates. This provided a stable backfill and did not require additional intensive labor. However the full depth reclamation with concrete (FDR) is sensitive to the amount of water added to the mix but has many benefits. Prescott implemented the slurry as the only backfill permitted by the city and has seen promising repair performances (Brinkley 1990). A falling weight deflectometer study shows that the maximum deflection of the repair decreases with increasing slab thickness and soil modulus (Sawant 2009).

1.2 Description of Collection System Maintenance

Each municipality develops a program for dealing with the challenges of collection systems maintenance. Because wasterwater collection systems are typically buried it is difficult to ascertain the system condition and performance. One technique universally accepted is the use of Closed Circuit Televising (CCTV). This tool is simply a special camera mounted on wheels that is inserted into the sewer main then remotely controlled to relay live video data to the operator. During CCTV operation, the operator notes structural defects such as cracks, offset joints, fractures and sometimes collapses. The operator also notes maintenance conditions such as the presence of roots, water infiltration, grease and debris.

When the operator notes structural conditions of the pipe the engineer determines how to address the defect. If rehabilitation of the main line is required, there are three commonly used options to choose from: 1) Open cut replacement – this is the oldest rehabilitation method. Open cut replacement consists of physically digging down to the pipe and installing new pipe in the existing location; 2) Pipebursting – this is a fairly new product but has become a widely accepted practice. Pipebursting consists of digging an entry pit and inserting new high-density polyethylene pipe into the existing pipe using a hammerhead. The head breaks the old pipe and pushes it radially so the new pipe will have room to be inserted; and 3) Cured In Place Pipe (CIPP) – this is also a fairly new product. CIPP is made of a thick felt-like material that is impregnated with resin. The pipe is placed into the sewer main and filled with hot water that cures the resin, creating a new pipe inside of the old one. CIPP is not an option for rehabilitation if severe offsets or collapse exist within the pipe segment.

1.3 Study Objectives

This study investigates two different backfill materials used utility repairs, and compares them to the current condition of the repair. The backfill materials examined in this study are #57 Stone and Grade D Aggregate. The goal of this research is to compare the relationship of the current repair condition with the type of backfill used during construction. The data studied uses multiple linear regression and analysis of variance (ANOVA) to determine relationships between current repair conditions and repair characteristics as a function of the overall quality and rideability.

The results may be used to assist cities and municipalities with failing utility repairs in asphalt roadways to determine whether the installation of Grade D Aggregate in any quantity is beneficial to preserving the quality of utility repairs. As a study of the prolonged effects of utility repairs, the repairs in this study are more than three years of age.

Chapter 2.0 Study Area

2.1 Description of Study Area

East Tennessee is a unique area that is surrounded by two mountain ranges, has multiple waterways in the area, and a rich diverse culture. East Tennessee is made up of 33 counties with a population of 2,119,505 of 2000 and a land area of 13,558.27 square miles. The eastern area is the most densely populated area of the state with 37.25% of the state's total population. Knoxville is the largest city in the eastern area with a population of 173,890 (Wikipedia 2010). See Table 3.

This study looks at utility repairs in the following cities; Knoxville, Maryville, Oak Ridge, Farragut, and Athens. All cities have a responsibility to bring water and other resources to its citizens and also to remove the waste generated by its citizens. Transporting resources requires tremendous effort and land use. Most utilities are located underground which helps to minimize the footprint of the utility. Therefore, excavation to expose the utility is required when repairs are needed. Within larger cities a significant portion of the utilities are buried beneath roadways due to the lack of physical space. Repairs made to utilities under asphalt are treated differently than those that are not under asphalt. Unfortunately when repairs are made to utilities under asphalt the restoration is less successful.

The wastewater rehabilitation challenges faced by East Tennessee utilities are no different than any other area. Ultimately, the entire industry wants a wastewater repair that is smooth and aesthetically pleasing.

Chapter 3.0 Means and Methods

3.1 Study Design

Since the common backfill materials used for utility repair are #57 Stone and Grade D Aggregate, this study design was created to investigate existing utility repairs that incorporated these materials. A study set of 60 utility repair cuts was assembled from local utilities, 30 of which utilized Grade D Aggregate and 30 utilized #57 stone.

A field inspection form was designed to ensure all pertinent information was captured while in the field. Information collected encompassed repair dimensions, distance to nearest pavement edge, type of roadway and other information as detailed in 3.2 Data Collection. A survey plan was also developed to ensure all relevant information was gathered at each site. Surface measurements were taken parallel to the centerline at the most visibly deflected location and included measurements of the existing pavement.

Quality parameters in this study include the Tennessee Department of Transportation (TDOT) specification on smoothness, the presence of adjacent cracking, and topcoat failure. Repair characteristics and survey data were measured in the field. Repair characteristics include affected repair area, depth of repair, slope and type of street on which the repair was made. The survey data collected was a measurement of the local elevation of the surface along a tape with a local datum. This showed the smoothness of the surface.

The data collected was analyzed to show relationships between Grade D Aggregate and #57 Stone. Analytical and statistical tests were applied to the collected data to determine the relationships or disparity of the repair effectiveness of the studied materials. The strength of the respective relationships found within the data will attempt to reveal if a difference exists between the utilization of Aggregate Grade D and #57 Stone exists.

3.2 Data Collection

Each utility provided an escorted tour of all locations. The following information was received from the utilities – type of utility repaired, depth of repair, type of pipe, dimensions of pipe, repair date, specifications, and type of backfill. The following information was collected during initial site investigation – angle of cut to roadway centerline, dimensions of repair surface, and distance to the nearest pavement edge.

A data set was collected for each utility repair location included the following information –

1. Type of repair including material, pipe dimension, and utility to which the repair was made and the repair date
2. Dimensions including area of cut, depth (local manhole depth was used when repair depth was unavailable), and distance to the nearest pavement edge
3. Survey Data including surface profile measurements in which the slope and smoothness profile were assessed
4. Site Data including photographs depicting the amount of lateral cracking, top coat failure, and angle of cut to roadway centerline
5. Additional information collected for comparison purposes included specifications, type of street, and type of backfill

Surveying included placing a measuring tape along the repair at the most obvious deflected location. Surveying began one foot outside the trench and measurements were taken on the seam and at an interval that would most completely capture the data. The most common interval was one foot spacing however some intervals were two feet and one was five feet. The survey data was placed compiled to show a surface profile and a smoothness profile. See Figures 15 to 191.

The four failure categories include failure of the smoothness specification of ¼ inch deviation, a less stringent smoothness specification of ½ inch, the presence of adjacent cracking, and failure of the topcoat. Failure rates were calculated for both categories 1) Grade D Aggregate and 2) No Grade D Aggregate. See Table 4 for failure rates.

3.3 Statistical Analysis

After data collection was complete, all data gathered in the field was input to the trench database. See Tables 1 and 2. Basic analysis included categorizing failures and computing failure rates of each type of backfill. Statistical analysis included an initial normality test of the data followed by multiple linear regression and analysis of variance (ANOVA) of the following data sets -

All data – deviation sorted and categorized

Aggregate Grade D vs. # 57 Stone – deviation unsorted

Aggregate Grade D vs. # 57 Stone – deviation sorted and categorized

All data – deviation by slope

All data – deviation by type of street

All data – deviation by depth to pipe invert

All data – deviation by area of repair

The surface and smoothness profile shows the data plotted with the axes Distance (feet) and Surface Measurement (feet). Distance indicates the position along the tape or distance along the road surface and surface measurement is the measurement taken from the survey rod.

The surface profile shows the trend line for the data set that is the approximate slope (ft/ft) of the roadway. The slope range is 0.0 to .16 ft/ft along the roadway.

The smoothness profile is an enlarged view of the data set that shows the most deflected feature of the cut. TDOT Specification Subsection 407.18 of TDOTSS, 1995 states that the deviation of the surface when measured with a straight edge shall not exceed ¼ inch. From the smoothness profile, a straight edge was added to the drawing and the deviation was measured. If the deviation was greater than ¼ inch the cut was considered to have failed to meet the requirements. The failure rate for the data set is 98% where 58 out of 59 repair locations failed to meet the above requirements. One location was not surveyed due to the street having been paved before survey had taken place.

Statistical analysis was performed using the statistical computation software JMP. Initially, a normality test was completed to show if the data was normal and to what degree the normality occurred. The data was then analyzed for the following two groups 1) the presence of Grade D Aggregate and 2) the absence of Grade D Aggregate. ANOVA and the Tukey-Kramer Test were also completed for the following data groups and the respective sub-groups.

1.A The presence of Grade D Aggregate– Deviation

a. 0 to ½ inch Deviation

b. ½ inch to ¾ inch Deviation

c. ¾ inch to 1 inch Deviation

d. Over 1 inch Deviation

1.B The absence of Grade D Aggregate– Deviation

a. 0 to ½ inch Deviation

b. ½ inch to ¾ inch Deviation

c. ¾ inch to 1 inch Deviation

d. Over 1 inch Deviation

The data was then analyzed to show if relationships between the deviation and the following variables existed; and to what degree.

1. Slope (ft/ft)
2. Type of Street
3. Depth to Pipe Invert (feet)
4. Area (ft^2)

Chapter 4.0 Results

4.1 Repair Failure Rates

The failure categories in this study include failure of the smoothness specification at ¼ inch, failure of the smoothness specification at ½ inch, failure due to presence of adjacent cracking, and failure of the top asphalt layer. There was a high failure rate in the smoothness category at both the ¼ inch and ½ inch criteria. The trenches with non- Grade D Aggregate repairs performed slightly better than the Grade D Aggregate trenches in the smoothness categories and adjacent cracking. However, the asphalt topcoat failure was higher for the non-Grade D Aggregate repairs. See Table 4.

4.2 Statistical Relationships

The data was found to be not normal, therefore nonparametric statistical tests were implemented. See Figure 8 for the distribution and the fitted normal curve. The mean of the deviation is 0.071 feet with a standard deviation of 0.045 feet.

Figure 9 shows the ANOVA results for the following categories and subcategories. Categories 1.A and 1.B have a strong relationship with a correlation value of 86%.

1.A The presence of Aggregate Grade D – Deviation

   a. 0 to ½ inch Deviation
   b. ½ inch to ¾ inch Deviation
   c. ¾ inch to 1 inch Deviation
   d. Over 1 inch Deviation

1.B The absence of Aggregate Grade D – Deviation

a. 0 to ½ inch Deviation

b. ½ inch to ¾ inch Deviation

c. ¾ inch to 1 inch Deviation

d. Over 1 inch Deviation

The Tukey-Kramer Pairs test shows that all pairs are similar to at least one additional pair except for the subcategory Over 1 inch Deviation, #57 Stone. The data pairs 1.A.a & 1.B.a, 1.A.b & 1.B.b and 1.A.c & 1.B.c all had a probability 1.00 that the two pairs in each set would perform similarly. See Tables 6 - 8.

The relationships between the performance of the repair and the characteristics of the repair show little to no correlation. The following are the variables as compared to deviation and its respective relationship thereto.

Slope, Correlation of 29%

Area, 13%

Type of Street, 12%

Depth, 3%

The categories Grade D Aggregate, Over 1 inch Deviation and #57 Stone, Over 1 inch Deviation had significant differences so further analysis was conducted on these categories. Eleven of sixty sites in this study were in this category and were evenly distributed throughout the test area. The following are the variables as compared to deviation and its respective thereto.

Slope, Correlation of 55%

Depth, 16%

Area, 10%

Type of Street, 1.2%

Chapter 5.0 Discussion of Results

The data suggests that there are little to no behavioral differences between repairs using Grade D Aggregate and repairs using # 57 Stone except in the Over 1 inch Deviation category. The data also suggests that field characteristics have little to no effect in the long term except for the Over 1 inch Deviation category which suggests that a relationship with slope in this category exists. Repairs with a significant failure show Grade D Aggregate performs better than #57 Stone.

Therefore it can be inferred that the initial conditions are key to the success of the repair. As previously stated, poor installation techniques and poor material quality can adversely affect the area adjacent to the repair, which can contribute to future damage even though not evident at the time of construction. (Polvi, 2002).

Jensen (2005) noted the "poor performance of pavements over and around utility trenches on local and state systems often causes unnecessary maintenance problems due to improper backfill placement (e.g., under compacted, too wet, too dry)." There was a slight difference in the performance of the two categories however both had a high failure rate which would indicate that choosing to install Grade D Aggregate is not likely to solve long term problems.

Some utilities have implemented a repaving program to address such failures. In that, after some period of time the repair would be milled and repaved. It is also beneficial to implement a cutback standard that would address the stretching zone created through excavation. Studies indicate the total affected area around the trench is two to three feet beyond the trench (Jensen 2005). Although it is not necessary to remove three feet of asphalt outside the trench some portion of asphalt removal may be necessary to address the weakened area.

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Appendix

Appendix A – City / Municipality Information

Table 1. Trench Database – Grade D Aggregate

Address	Municipality	Pictures Taken ?	Survey Completed?	Failed Smoothness @ 1/4 inch or .02083 feet	Failed Smoothness @ 1/2 inch or .04167 feet	Failed Due to Adjacent Cracking	Top Coat Failure	Utility Type	Type of Street	Deviation (feet)	Deviation (Inch)	Angle of Cut to Roadway Centerline	Slope (ft/ft)	Installation Date	Length of Cut (feet)	Width of Cut (feet)	Area (ft^2)	Distance to the nearest pavement edge	Type of Backfill	Depth to Pipe Invert (feet)	Type of Pipe	Diameter of Pipe (inch)	Aggregate Grade D Used?
605 Gettys Lane	AUB	Y	Y	Y	Y	Y	N	Sewer	Residential	0.08	0.96	45°	0.01	October-06	30	3.5	105	Edge to Edge	Crusher Run	4	PVC	6	Y
431 Matlock Avenue	AUB	Y	Y	Y	N	N	N	Sewer	Light Highway	0.04	0.42	0°	0.04	October-06	6	4.5	27	Edge	Crusher Run	6	PVC	8 X 6	Y
1834 Timbercrest Drive	AUB	Y	Y	Y	Y	N	Y	Sewer	Residential	0.12	1.38	0°	0.03	May-05	401	5	2005	7'	Crusher Run	5	PVC	8	Y
112 Ashley Court	AUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.08	0.96	0°	0.01	October-06	80	4.5	360	Edge	Crusher Run	5.5	PVC	8	Y
410 Matlock Avenue	AUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.09	1.08	0°	0.04	October-06	33	7	231	3'	Crusher Run	6.5	PVC	8	Y
302 Dixon Avenue	AUB	Y	Y	Y	Y	N	N	Sewer	Light Highway	0.06	0.76	0°	0.01	January-01	22	4	88	7'	Crusher Run	6.65	PVC	8	Y
304 Lynn Avenue	AUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.06	0.67	0°	0.01	February-02	10	3.5	35	11'	Crusher Run	5	PVC	8	Y
1814 Adams Street	AUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.07	0.78	75	0.00	October-06	22	6.5	143	Edge to Edge	Crusher Run	4	PVC	6	Y
111 Fischer Street	AUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.05	0.54	90	0.01	October-06	Irregular		112.5	Edge	Crusher Run	8	PVC	10 X 6	Y
165 California Avenue	COR	Y	Y	Y	N	Y	N	Sewer	Residential	0.03	0.36	45°	0.10	June-05	13.5	5	67.5	6'	Crusher Run	8	PVC	8	Y
309 E. TN Avenue	COR	Y	Y	Y	Y	N	N	Sewer	Residential	0.05	0.60	0°	0.02	August-05	80	24.33	1946.4	Edge	Crusher Run	10	PVC	8	Y
237 East Drive	COR	Y	Y	Y	Y	N	N	Sewer	Residential	0.08	0.96	90	0.00	November-05	37.25	14.166	527.68	Edge	Crusher Run	7	PVC	8	Y
440 East Drive	COR	Y	N			Y	N	Sewer	Residential			90		June-06	17.083	24.16	412.73	Edge	Crusher Run	5.5	PVC	8	Y
217 East Drive	COR	Y	Y	Y	Y	N	N	Sewer	Residential	0.09	1.08	0°	0.01	November-06	24.083	11.5	276.95	Edge	Crusher Run	10	PVC	8	Y
100 Ashland Lane	COR	Y	Y	Y	Y	Y	Y	Sewer	Residential	0.05	0.60	0°	0.04	November-06	25	10	250	Edge	Crusher Run	6	PVC	8	Y
103 Emerson Circle	COR	Y	Y	Y	Y	Y	N	Sewer	Residential	0.06	0.72	0	0.01	May-07	33	8.25	272.25	Edge	Crusher Run	9	PVC	8	Y
209 Hillcrest Drive	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.05	0.54	90	0.01	April-05	Irregular		360.7	Edge to Edge	57/Pug	5	PVC	8	Y
Stanton Road	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.10	1.14	75	0.00	April-05	Irregular		168.05	Edge to Edge	57/Pug	5	PVC	8	Y
5121 Oakview Road	KUB	Y	Y	Y	N	N	N	Sewer	Residential	0.04	0.48	75	0.01	April-05	9.7	6.25	60.625	Edge	57/Pug	5.5	PVC	6	Y
3005 Conner Drive	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.06	0.72	75	0.01	April-05	10.6	8.8	93.28	Edge	57/Pug	4	PVC	6	Y
4926 Oakview Road	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.07	0.84	90	0.03	April-05	Irregular		28.25	Edge	57/Pug	7	PVC	6	Y
4942 Oakview Road	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.05	0.54	90	0.07	April-05	5	5.5	27.5	Edge	57/Pug	5	PVC	6	Y
2828 Lowe Road	KUB	Y	Y	Y	Y	Y	N	Sewer	Residential	0.05	0.60	90	0.04	April-05	8.3	10.4	86.32	Edge	57/Pug	8	PVC	6	Y
3111 Rennoc Road	KUB	Y	Y	Y	Y	Y	N	Sewer	Residential	0.08	0.96	90	0.06	April-05	17.583	7.83	137.67	Edge	57/Pug	5.5	PVC	6	Y
2857 Rennoc Road	KUB	Y	Y	Y	N	Y	Y	Sewer	Residential	0.03	0.41	90	0.00	April-05	Irregular		136.5	Edge	57/Pug	7	PVC	6	Y
3401 Kesterwood Drive	KUB	Y	Y	Y	Y	Y	N	Sewer	Residential	0.08	0.96	90	0.06	April-05	5.666	3.583	20.301	Edge	57/Pug	5.5	PVC	6	Y
5114 Robin Road	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.17	1.98	90	0.03	April-05	Irregular		159.35	Edge	57/Pug	7	PVC	6	Y
5028 Hedgewood	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.08	0.90	90	0.01	April-05	Irregular		77.5	Edge	57/Pug	8	PVC	6	Y
2933 Conner Drive	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.07	0.84	90	0.05	April-05	11	9.5	104.5	Edge	57/Pug	5	PVC	6	Y
5132 Robin Road	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.08	0.96	90	0.05	April-05	7.33	9.33	68.389	Edge	57/Pug	6	PVC	6	Y

Table 2. Trench Database – No Grade D Aggregate

Address	Municipality	Pictures Taken ?	Survey Completed?	Failed Smoothness @ 1/4 inch or .02083 feet	Failed Smoothness @ 1/2 inch or .04167 feet	Failed Due to Adjacent Cracking	Top Coat Failure	Utility Type	Type of Street	Deviation (feet)	Deviation (Inch)	Angle of Cut to Roadway Centerline	Slope (ft/ft)	Installation Date	Length of Cut (feet)	Width of Cut (feet)	Area (ft^2)	Distance to the nearest pavement edge	Type of Backfill	Depth to Pipe Invert (feet)	Type of Pipe	Diameter of Pipe (inch)	Aggregate Grade D Used?
802 Front Street	COM	Y	Y	Y	Y	N	N	Sewer	Residential	0.08		22	0.06	November-07	Irregula	1) 7 2) 5	213	Edge	57 Stone	7	PVC	8	N
610 Short Street	COM	Y	Y	Y	N	N	N	Sewer	Residential	0.04		90	0.02	February-07	Irregular		66	12'	57 Stone	5	PVC	8	N
409 South Cedar Street	COM	Y	Y	Y	Y	N	N	Sewer	Residential	0.06		0°	0.01	March-07	Irregular		166.75	4'6"	57 Stone	6	PVC	8	N
603 South Cedar Street	COM	Y	Y	Y	Y	N	N	Sewer	Residential	0.09		90	0.11	May-07	Irregular		144.75	Edge	57 Stone	6.5	PVC	8	N
1107 Everett Avenue	COM	Y	Y	N	N	N	N	Sewer	Residential	0.00		90	0.05	December-07	21	3	63	Edge	57 Stone	6	PVC	8	N
408 Keeble Street	COM	Y	Y	Y	Y	N	N	Sewer	Residential	0.08		90	0.08	July-07	14	4	56	Edge	57 Stone	7	PVC	8	N
1616 Windlau Court	COM	Y	Y	Y	Y	Y	N	Sewer	Residential	0.29		1) 0 2) 90	0.16	February-07	Irregula	1) 7 2) 5	294	1) 14 2) 0	57 Stone	6	PVC	8	N
1611 Cherry Drive	COM	Y	Y	Y	N	N	N	Sewer	Residential	0.03		90	0.02	February-07	17	4	68	Edge	57 Stone	7	PVC	8	N
1414 Wales Street	COM	Y	Y	Y	Y	Y	N	Sewer	Residential	0.06		90	0.05	July-07	Irregula	1) 3 2) 9	72	Edge	57 Stone	8	PVC	8	N
311 Lochapoka Drive	COM	Y	Y	Y	Y	Y	N	Sewer	Residential	0.05		90	0.03	May-07	18	3.5	63	Edge	57 Stone	5	PVC	8	N
312 Cunningham	COM	Y	Y	Y	Y	N	N	Sewer	Residential	0.06		0	0.02	January-07	Irregula	1) 4.5 2)	144.25	5'	57 Stone	6	PVC	8	N
1140 View Drive	COM	Y	Y	Y	Y	Y	N	Sewer	Residential	0.04		90	0.00	May-07	19	5.5	104.5	Edge	57 Stone	8	PVC	8	N
203 Waller Avenue	COM	Y	Y	Y	Y	N	N	Sewer	Residential	0.05		90	0.03	May-07	Irregula	1) 6 2) 1	194	Edge to Edge	57 Stone	9	PVC	8	N
1205 Melvin Avenue	COM	Y	Y	Y	Y	N	N	Sewer	Residential	0.12		0	0.05	July-07	12	5	60	Edge	57 Stone	7	PVC	8	N
7913 Weiblo	WKUD	Y	Y	Y	Y	Y	N	Sewer	Residential	0.18		90	0.05	October-06	22	4	88	Edge to Edge	57 Stone	6	PVC	6	N
1060 Bob Kirby Road	WKUD	Y	Y	Y	N	N	Y	Water	Light Highway	0.03		90	0.03	October-07	19	7	133	Edge to Edge	57 Stone	3.5	DI	8	N
Mabry Hood	WKUD	N	Y	Y	Y			Water	Light Highway	0.05		0	0.01	October-06	18	3	54	Edge to Edge	57 Stone	3.5	DI	8	N
Garrison	WKUD	Y	Y	Y	Y	N	N	Water	Light Highway	0.06		90	0.02	October-07	17	4	68	Edge to Edge	57 Stone	4	PVC	6	N
Chert Pit	WKUD	Y	Y	Y	Y	N	N	Water	Light Highway	0.07		0	0.07	December-06	13	5	65	3'	57 Stone	4	CI	6	N
9612 Gulfpark Drive	WKUD	Y	Y	Y	Y	Y	Y	Sewer	Residential	0.19		90	0.01	June-05	25	11	275	Edge to Edge	57 Stone	6	PVC	6	N
7319 Jenkins	WKUD	Y	Y	Y	Y	N	Y	Water	Light Highway	0.14		0	0.06	June-05	8	4	32	Edge	57 Stone	3	Galviniz	2	N
220 Wise Hills Road	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.05		90	0.03	July-06	Irregular		134.38	Edge	57 Stone	6	PVC	6	N
Wise Hills Road	KUB	Y	Y	Y	N	N	N	Sewer	Residential	0.04		90	0.14	July-06	9.5	5.7	54.15	Edge	57 Stone	5	PVC	6	N
204 Stone Road	KUB	Y	Y	Y	Y	N	N	Sewer	Light Highway	0.06		90	0.04	July-06	21.75	11.33	246.43	Edge to Edge	57 Stone	6	PVC	6	N
310 Stone Road	KUB	N	Y	Y	Y			Sewer	Light Highway	0.04		90	0.03	July-06	10.33	8	82.64	Edge	57 Stone	5	PVC	6	N
300 Stone Road	KUB	Y	Y	Y	Y	N	N	Sewer	Light Highway	0.05		90	0.02	July-06	10.33	10.08	104.13	Edge	57 Stone	4	PVC	6	N
5223 McNutt Road	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.07		90	0.07	October-05	Irregular		40.23	Edge	57 Stone	8	CIPP	8	N
801 Edwards Drive	KUB	Y	Y	Y	Y	N	N	Sewer	Residential	0.07		90	0.01	October-05	17.8	6.7	119.26	Edge	57 Stone	5	CIPP	8	N
807 Edwards Drive	KUB	Y	Y	Y	N	N	N	Sewer	Residential	0.04		90	0.08	October-05	11.8	7	82.6	Edge	57 Stone	5	CIPP	8	N
501 Tedlo Lane	KUB	Y	Y	Y	Y	N	Y	Sewer	Residential	0.05		90	0.06	October-05	10	4.5	45	Edge	57 Stone	8	CIPP	8"	N

Table 3. City / Municipality Information

City	Population	Utility Name	No. of Repairs in Study	Collection System (Miles)	Wastewater Treatment Plant Capacity (MGD)
Knoxville	173,890	KUB	23	1,320	66
Oak Ridge	27,387	COR	7	236	6.5
Maryville	23,120	COM	14	245	6.7
Farragut	17,720	WKUD	7	300	4
Athens	13,220	AUB	9	125	7.2

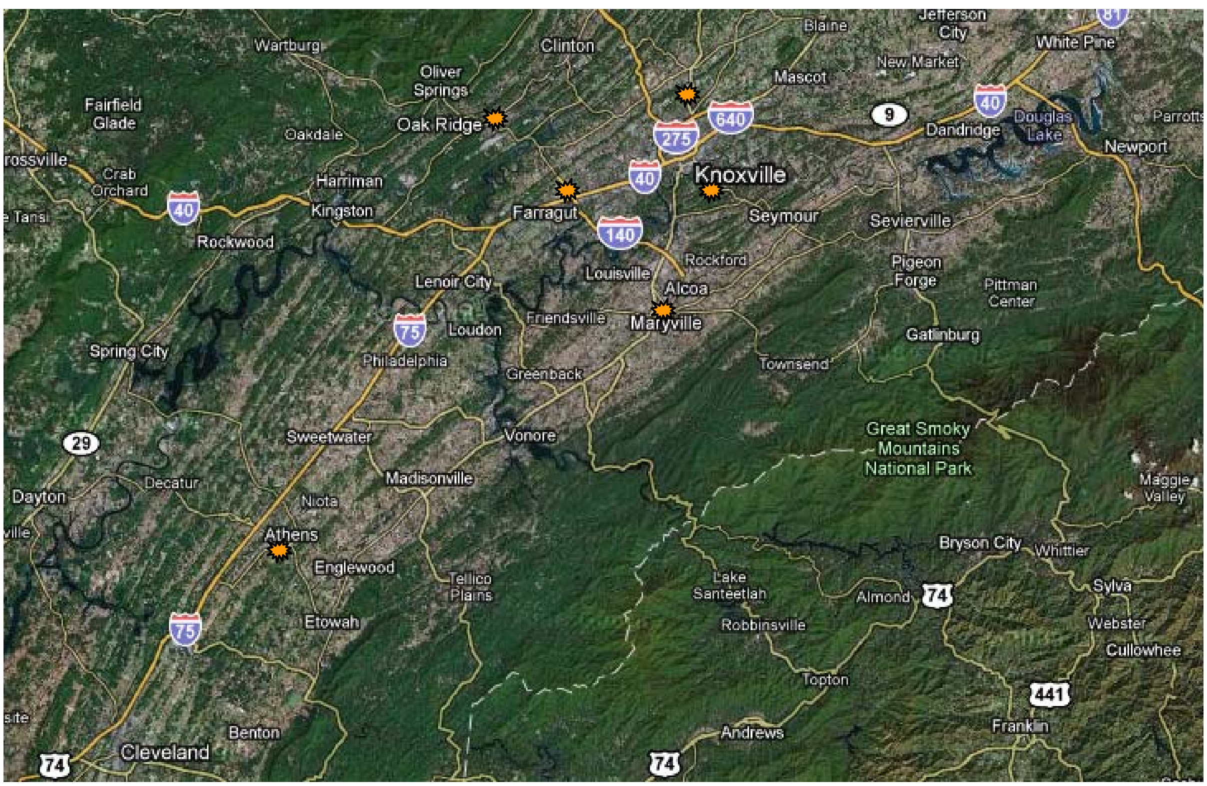

Figure 1. City / Municipality Location

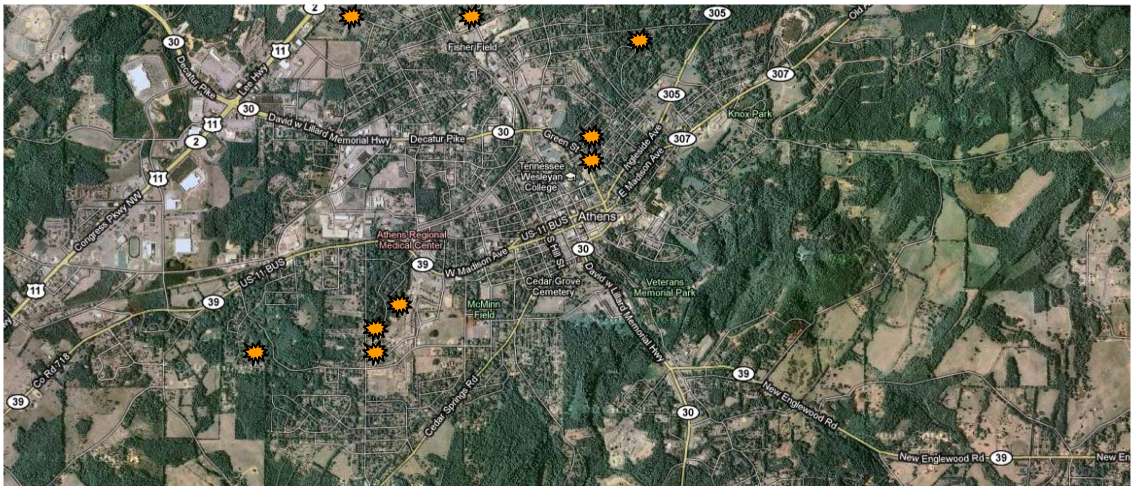

Figure 2 - Athens Utilities Board Sites

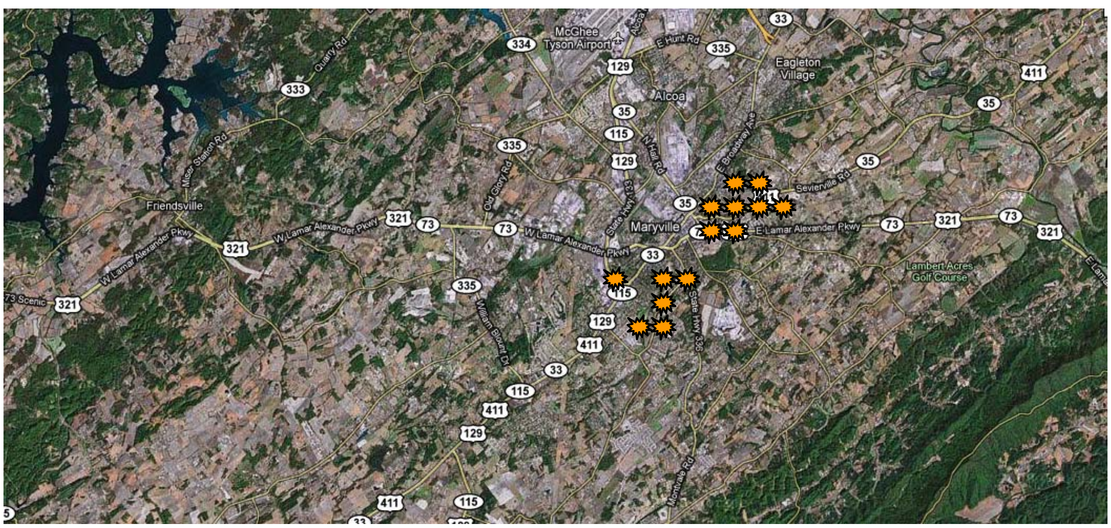

Figure 3 - City of Maryville Sites

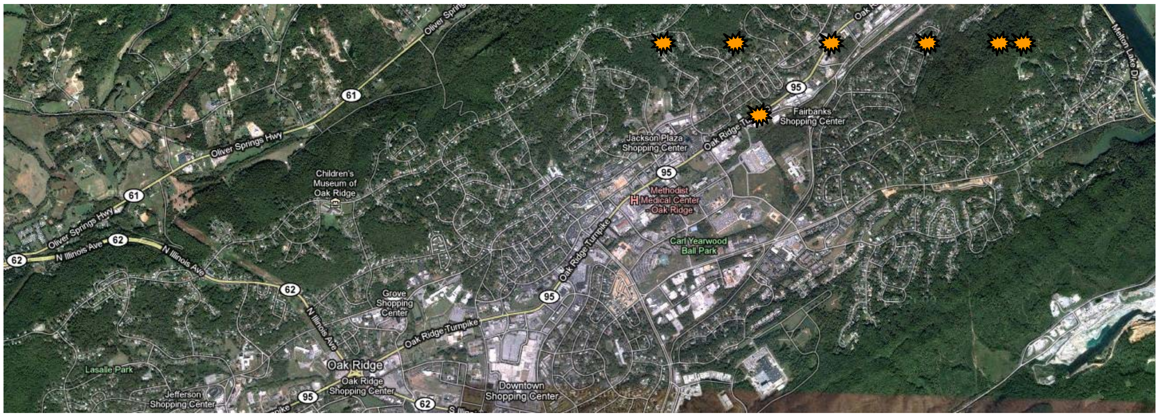

Figure 4 - City of Oak Ridge Sites

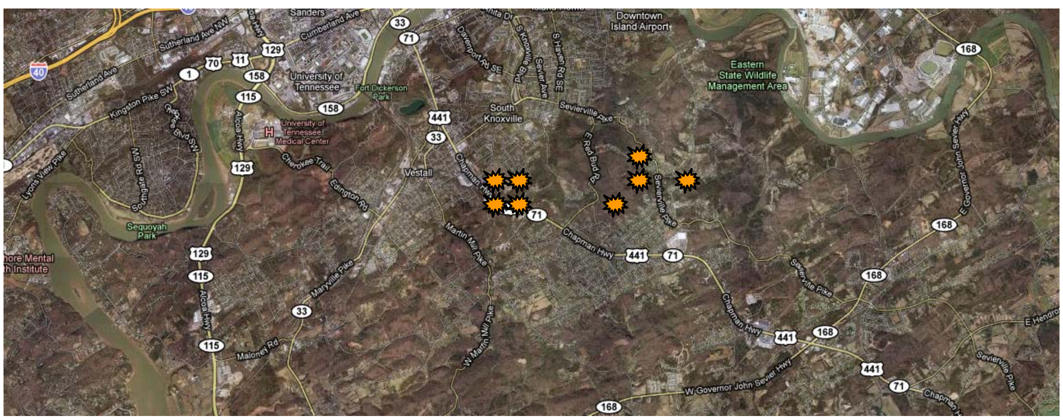

Figure 5 - Knoxville Utilities Board Sites 1

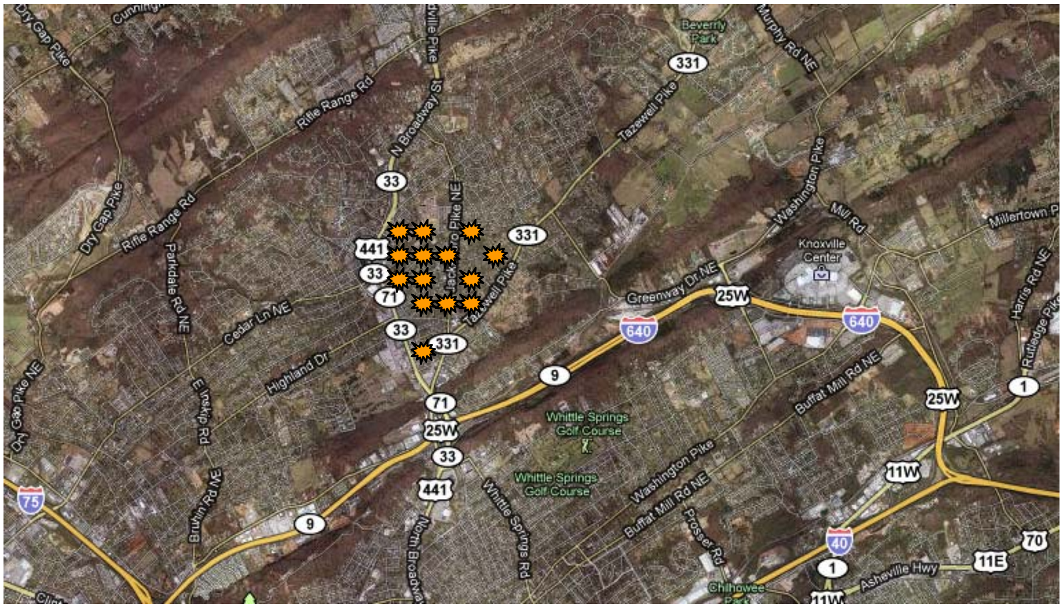

Figure 6 - Knoxville Utilities Board Sites 2


Figure 7 - West Knox Utility District

Appendix B – Results

Table 4. Failure Rates

Failure Type	Failure Rate (Percent Failed)	
	Aggregate Grade D	No Aggregate Grade D
Smoothness @ 1/4 inch deviation	100	97
Smoothness @ 1/2 inch deviation	87	80
Adjacent Cracking	30	17
Asphalt Top Layer	10	13

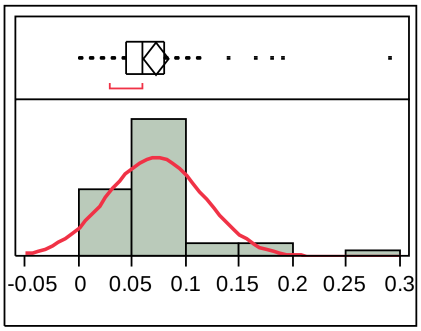

Figure 8. Distribution Deviation (feet)

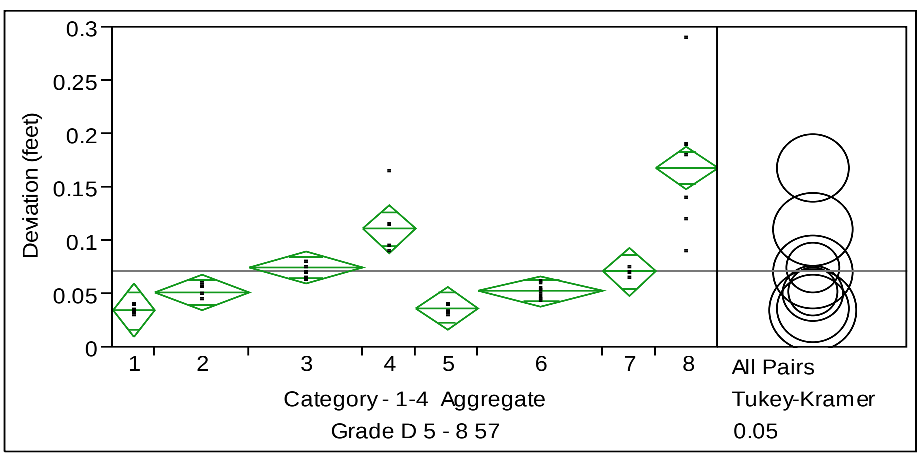

Figure 9. Oneway Analysis of Deviation (feet) By Category - 1-4 Grade D Aggregate, 5 - 8 57

Table 5. Analysis of Variance - Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
1	4	0.034750	0.01227	0.01010	0.05940
2	9	0.051222	0.00818	0.03479	0.06765
3	11	0.074818	0.00740	0.05996	0.08968
4	5	0.111000	0.01098	0.08896	0.13304
5	6	0.037083	0.01002	0.01696	0.05721
6	12	0.052583	0.00708	0.03835	0.06681
7	5	0.071000	0.01098	0.04896	0.09304
8	6	0.168333	0.01002	0.14821	0.18846

Table 6. Means Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
3.16268	0.05

Abs(Dif)-LSD	8	4	3	7	6	2	5	1
8	-0.04481	0.010335	0.054124	0.050335	0.076942	0.076204	0.086439	0.083483
4	0.010335	-0.04909	-0.00568	-0.00909	0.017103	0.016486	0.026918	0.024184
3	0.054124	-0.00568	-0.0331	-0.03804	-0.01016	-0.01129	-0.00166	-0.00525
7	0.050335	-0.00909	-0.03804	-0.04909	-0.0229	-0.02351	-0.01308	-0.01582
6	0.076942	0.017103	-0.01016	-0.0229	-0.03169	-0.03286	-0.02331	-0.02698
2	0.076204	0.016486	-0.01129	-0.02351	-0.03286	-0.03659	-0.02677	-0.03017
5	0.086439	0.026918	-0.00166	-0.01308	-0.02331	-0.02677	-0.04481	-0.04777
1	0.083483	0.024184	-0.00525	-0.01582	-0.02698	-0.03017	-0.04777	-0.05488

Table 7. Means Comparisons for all pairs using Tukey-Kramer HSD 2

Level				Mean
8	A			0.16833333
4		B		0.11100000
3		B	C	0.07481818
7		B	C	0.07100000
6			C	0.05258333
2			C	0.05122222
5			C	0.03708333
1			C	0.03475000

Table 8. Means Comparisons for all pairs using Tukey-Kramer HSD 3

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL	p-Value	Difference
8	1	0.1335833	0.0158412	0.083483	0.1836841	<.0001*	
8	5	0.1312500	0.0141688	0.086439	0.1760615	<.0001*	
8	2	0.1171111	0.0129343	0.076204	0.1580182	<.0001*	
8	6	0.1157500	0.0122706	0.076942	0.1545579	<.0001*	
8	7	0.0973333	0.0148604	0.050335	0.1443320	<.0001*	
8	3	0.0935152	0.0124551	0.054124	0.1329067	<.0001*	
4	1	0.0762500	0.0164627	0.024184	0.1283163	0.0006*	
4	5	0.0739167	0.0148604	0.026918	0.1209154	0.0002*	
4	2	0.0597778	0.0136884	0.016486	0.1030698	0.0015*	
4	6	0.0584167	0.0130630	0.017103	0.0997308	0.0011*	
8	4	0.0573333	0.0148604	0.010335	0.1043320	0.0073*	
3	1	0.0400682	0.0143289	-0.005250	0.0853860	0.1191	
4	7	0.0400000	0.0155212	-0.009089	0.0890885	0.1887	
3	5	0.0377348	0.0124551	-0.001657	0.0771264	0.0694	
7	1	0.0362500	0.0164627	-0.015816	0.0883163	0.3682	
4	3	0.0361818	0.0132365	-0.005681	0.0780447	0.1365	
7	5	0.0339167	0.0148604	-0.013082	0.0809154	0.3234	
3	2	0.0235960	0.0110304	-0.011290	0.0584817	0.4051	
3	6	0.0222348	0.0102441	-0.010164	0.0546335	0.3865	
7	2	0.0197778	0.0136884	-0.023514	0.0630698	0.8318	
7	6	0.0184167	0.0130630	-0.022897	0.0597308	0.8485	
6	1	0.0178333	0.0141688	-0.026978	0.0626448	0.9095	
2	1	0.0164722	0.0147474	-0.030169	0.0631135	0.9500	
6	5	0.0155000	0.0122706	-0.023308	0.0543079	0.9079	
2	5	0.0141389	0.0129343	-0.026768	0.0550460	0.9553	
3	7	0.0038182	0.0132365	-0.038045	0.0456810	1.0000	
5	1	0.0023333	0.0158412	-0.047767	0.0524341	1.0000	
6	2	0.0013611	0.0108216	-0.032864	0.0355865	1.0000	

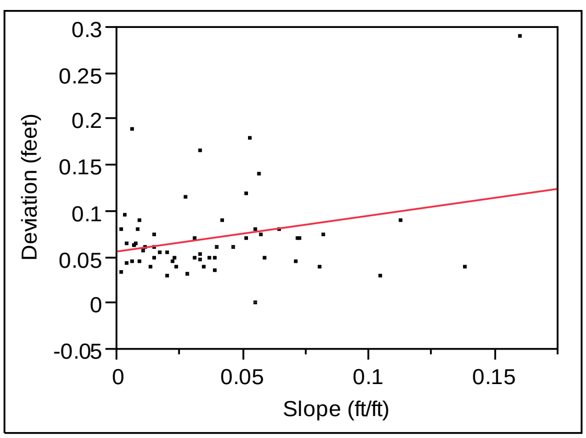

Figure 10. Bivariate Fit of Deviation (feet) By Slope (ft/ft)

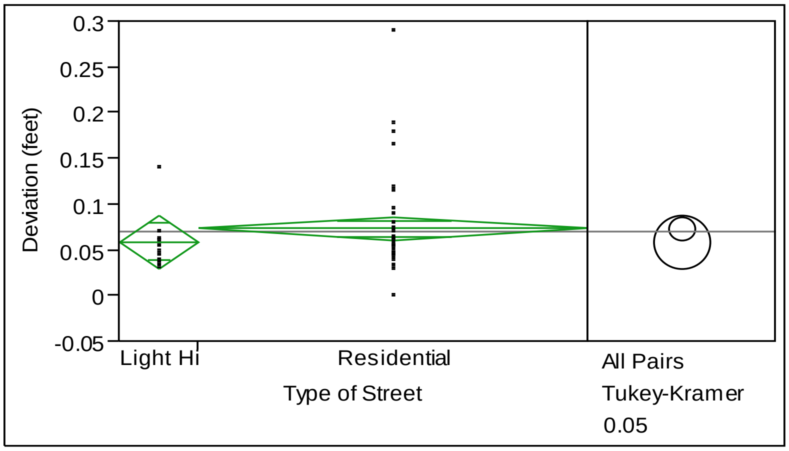

Figure 11. Oneway Analysis of Deviation (feet) By Type of Street

Table 9. t Test Type of Street

Difference	0.01454	t Ratio	0.920478
Std Err Dif	0.01580	DF	57
Upper CL Dif	0.04618	Prob > |t|	0.3612
Lower CL Dif	-0.01709	Prob > t	0.1806
Confidence	0.95	Prob < t	0.8194

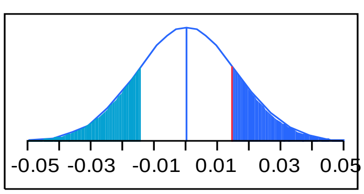

Figure 12. t Test Type of Street

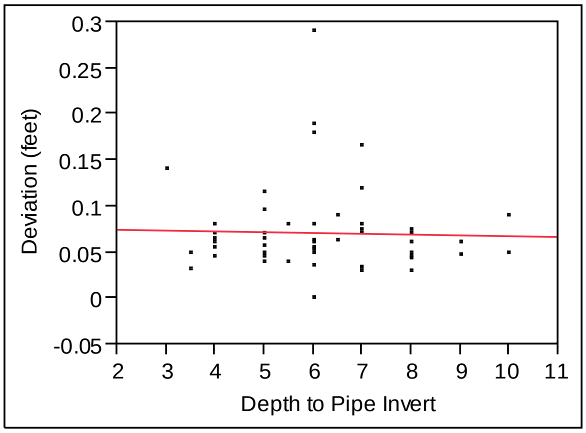

Figure 13. Bivariate Fit of Deviation (feet) By Depth to Pipe Invert

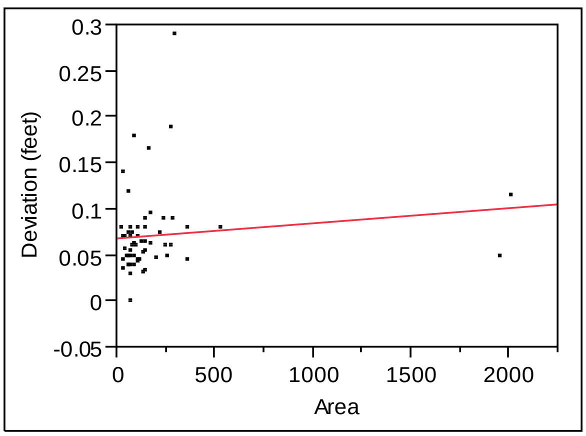

Figure 14. Bivariate Fit of Deviation (feet) By Area (ft^2)

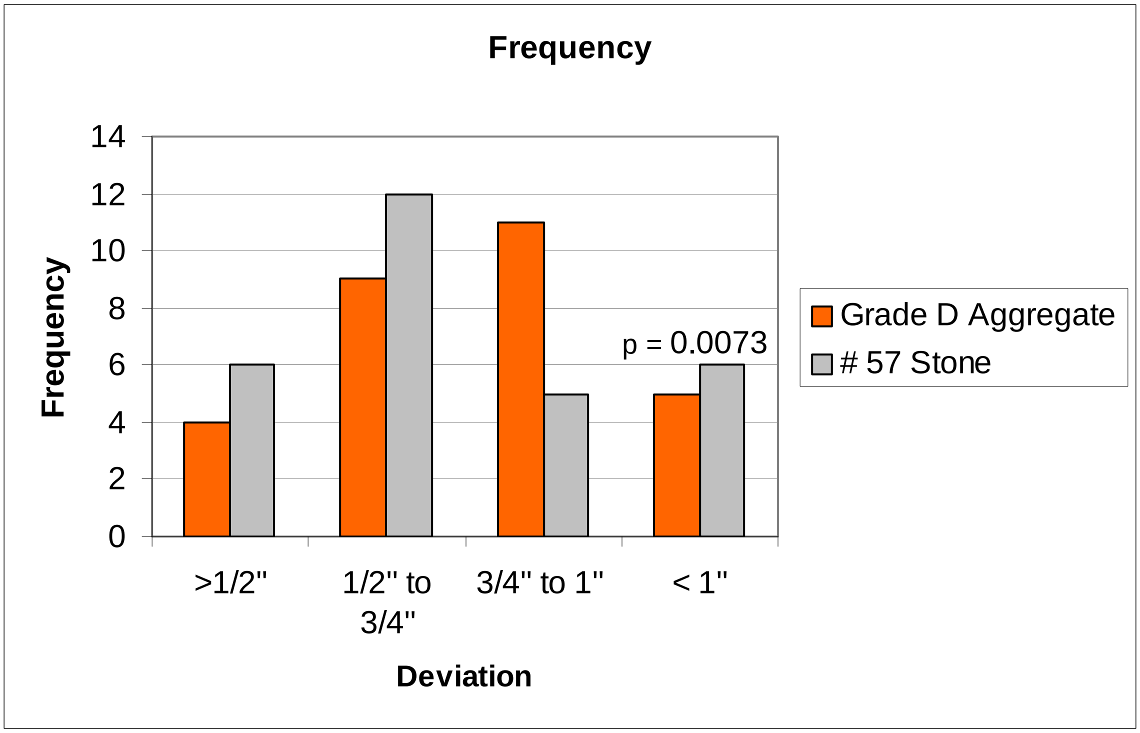

Figure 15. Frequency of Deviation (>1 inch)

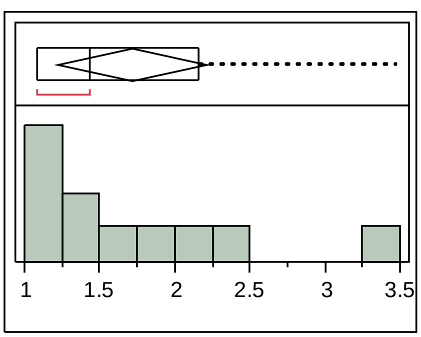

Figure 16. Distribution Deviation (> 1 inch)

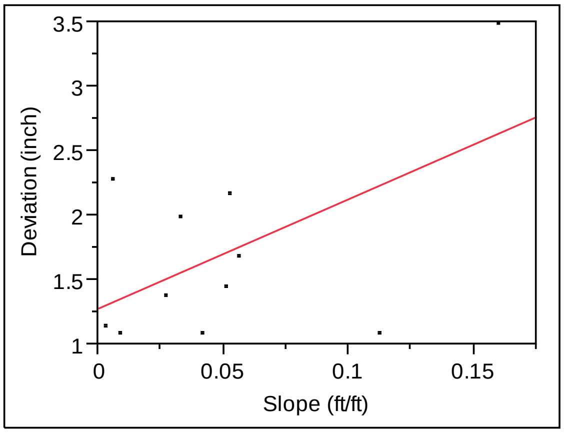

Figure 17. Bivariate Fit of Deviation (>1 inch) By Slope (ft/ft)

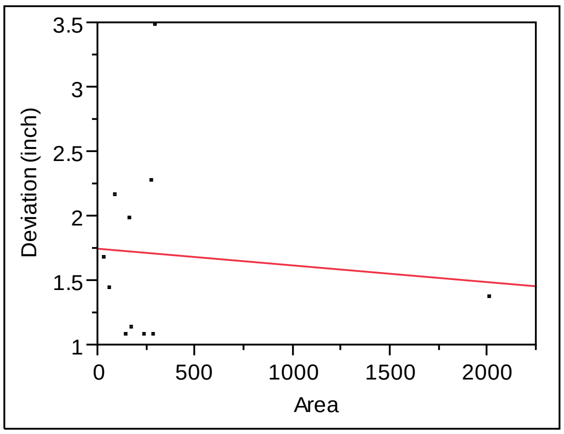

Figure 18. Bivariate Fit of Deviation (>1 inch) By Area (ft^2)

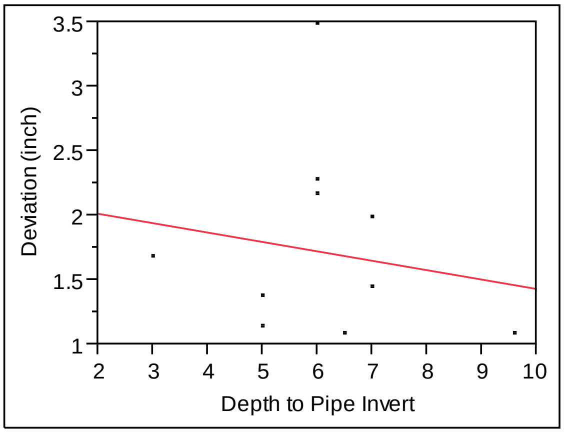

Figure 19. Bivariate Fit of Deviation (>1 inch) By Depth (ft)

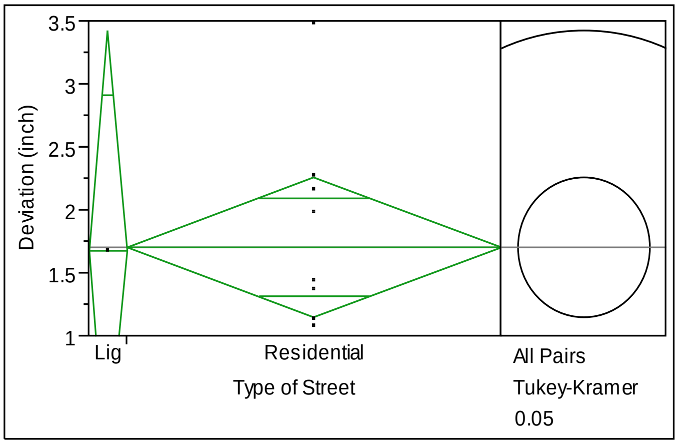

Figure 20. Oneway Analysis of Deviation (>1 inch) By Type of Street

Table 10. t Test Type of Street

Difference	0.0300	t Ratio	0.036823
Std Err Dif	0.8147	DF	9
Upper CL Dif	1.8730	Prob > |t|	0.9714
Lower CL Dif	-1.8130	Prob > t	0.4857
Confidence	0.95	Prob < t	0.5143

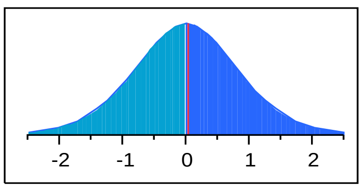

Figure 21. t Test Type of Street with Deviations >1 inch

Appendix C – Trench Details

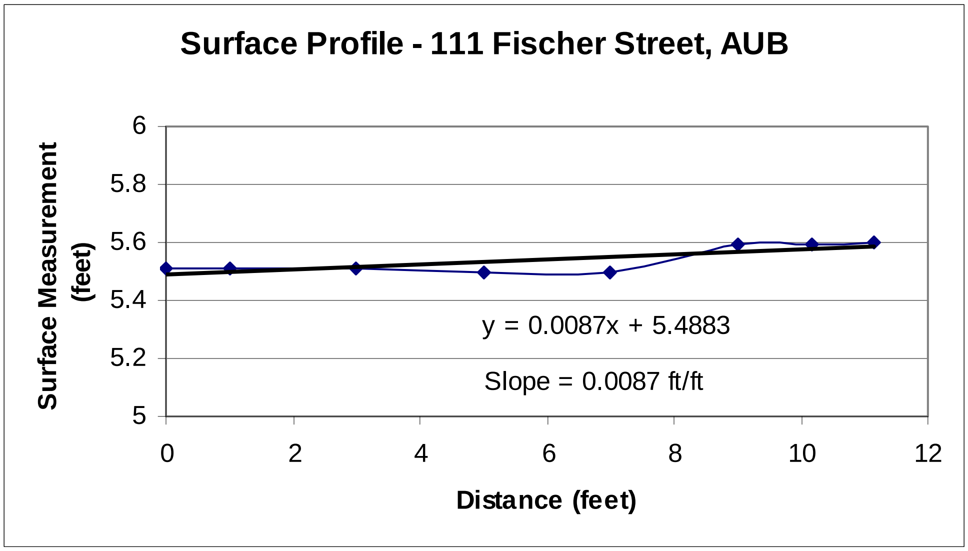

Figure 22. - Surface Profile – 111 Fischer Street, AUB

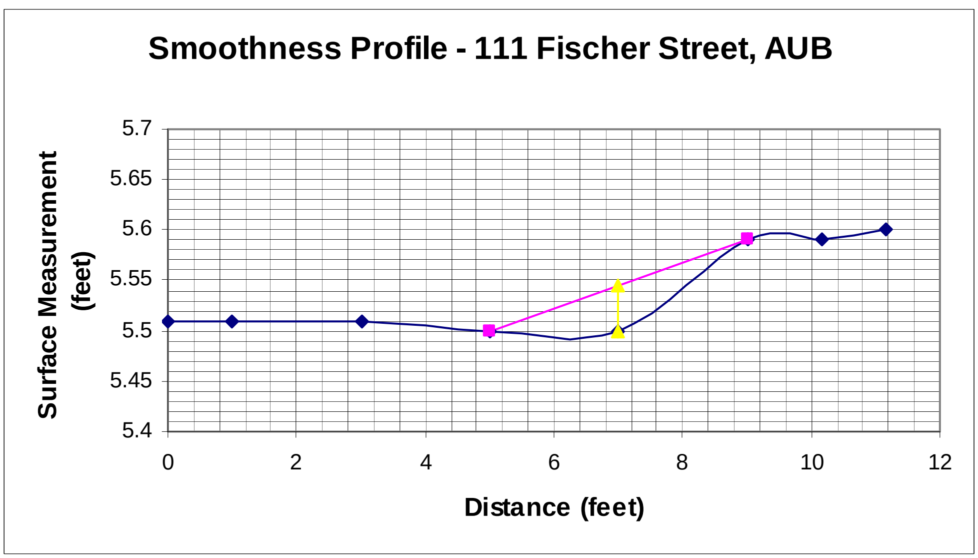

Figure 23. - Smoothness Profile – 111 Fischer Street, AUB

Figure 24. - Photographs – 111 Fischer Street, AUB

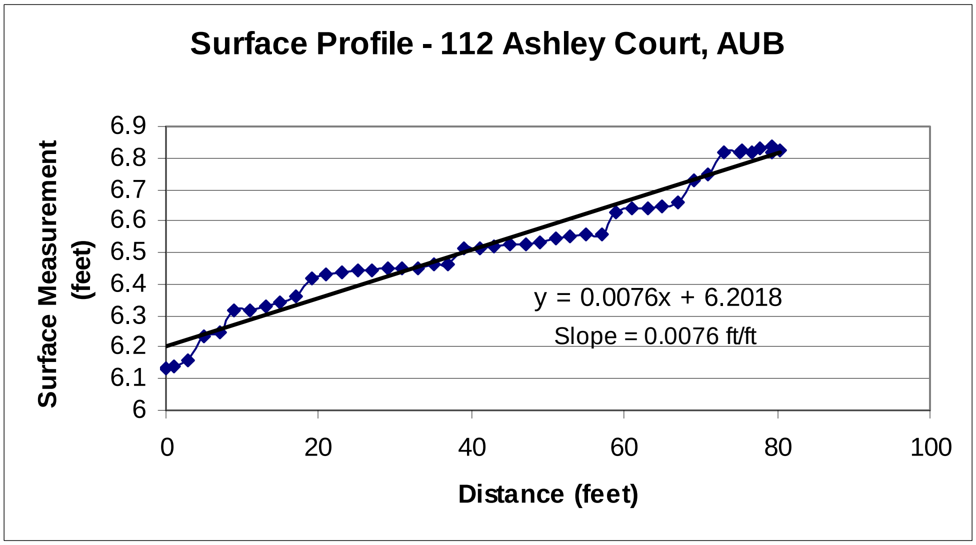

Figure 25. – Surface Profile – 112 Ashley Court, AUB

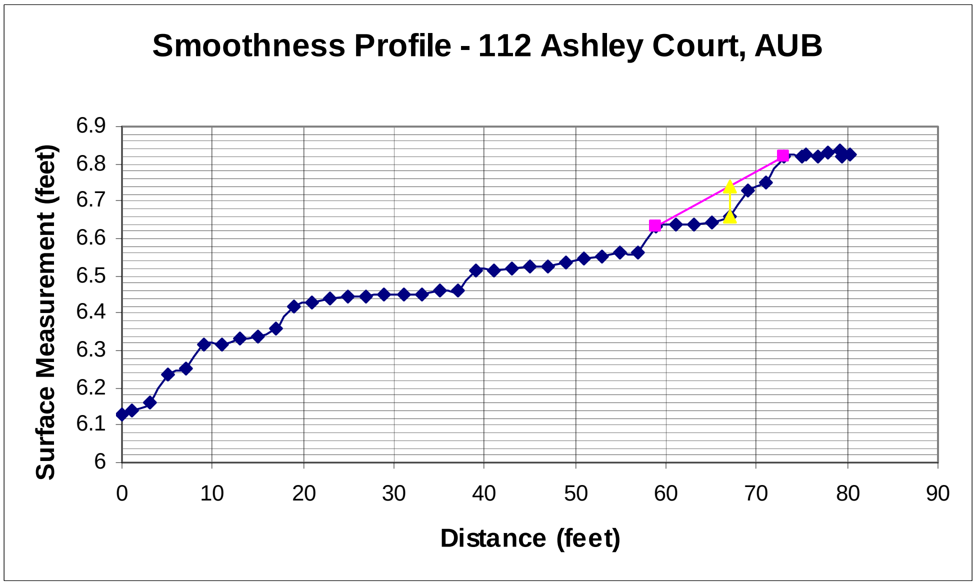

Figure 26. – Smoothness Profile – 112 Ashley Court, AUB

Figure 27. – Photographs – 112 Ashley Court, AUB

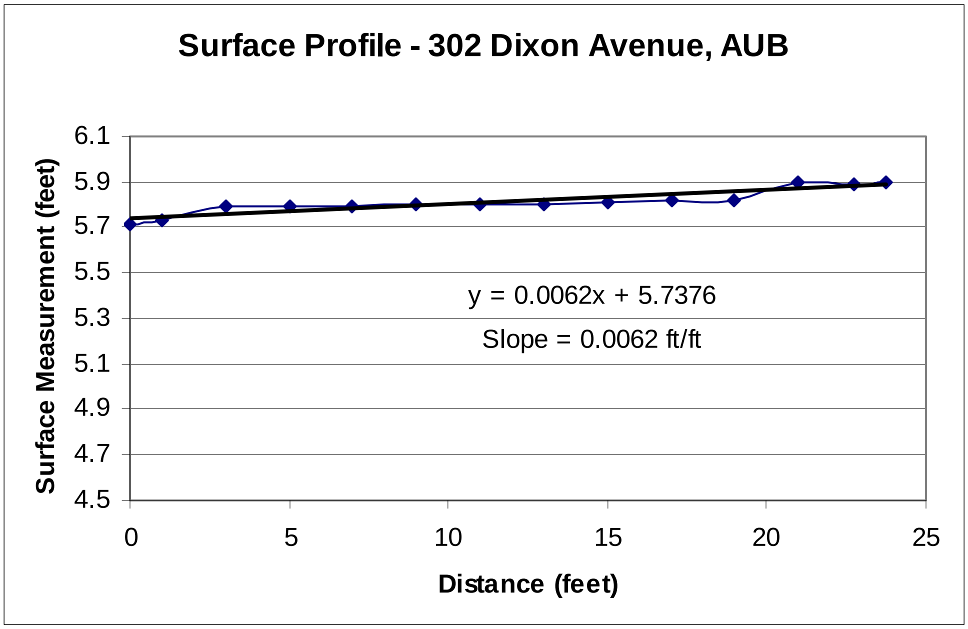

Figure 28 – Surface Profile – 302 Dixon Avenue, AUB

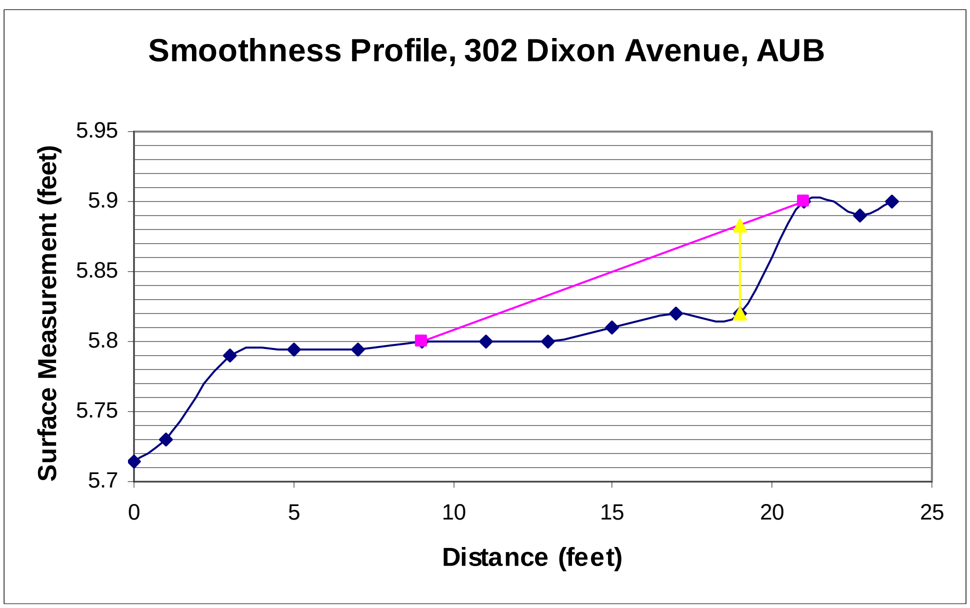

Figure 29 – Smoothness Profile – 302 Dixon Avenue, AUB

Figure 30 – Photographs – 302 Dixon Avenue, AUB

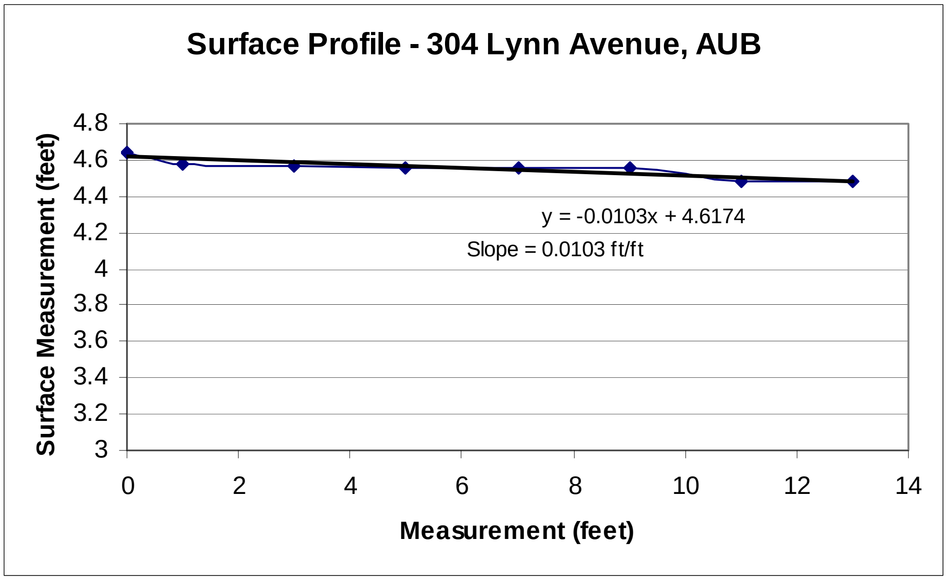

Figure 31 – Surface Profile – 304 Lynn Avenue, AUB

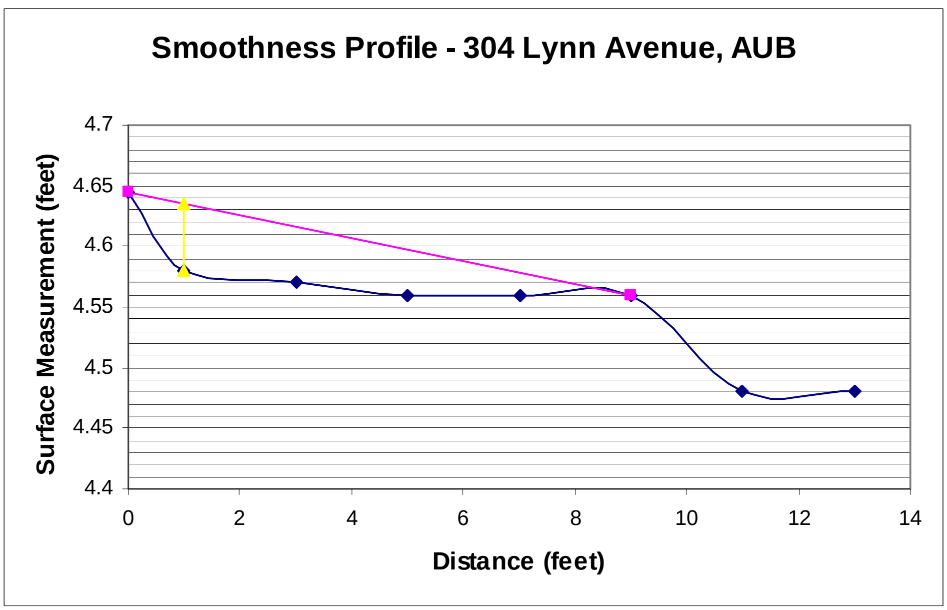

Figure 32 – Smoothness Profile – 304 Lynn Avenue, AUB

Figure 33 – Photographs – 304 Lynn Avenue, AUB

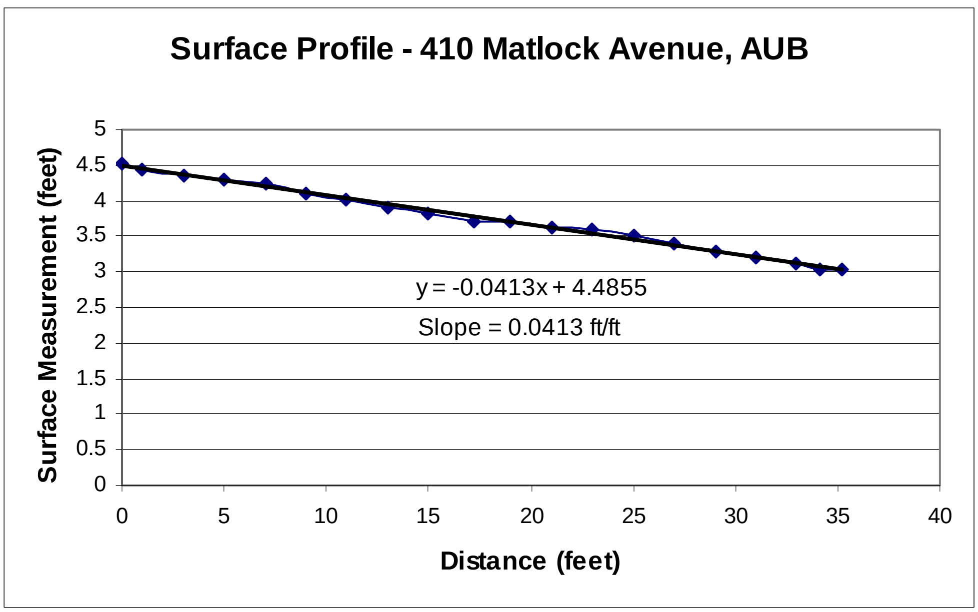

Figure 34 – Surface Profile – 401 Matlock Avenue, AUB

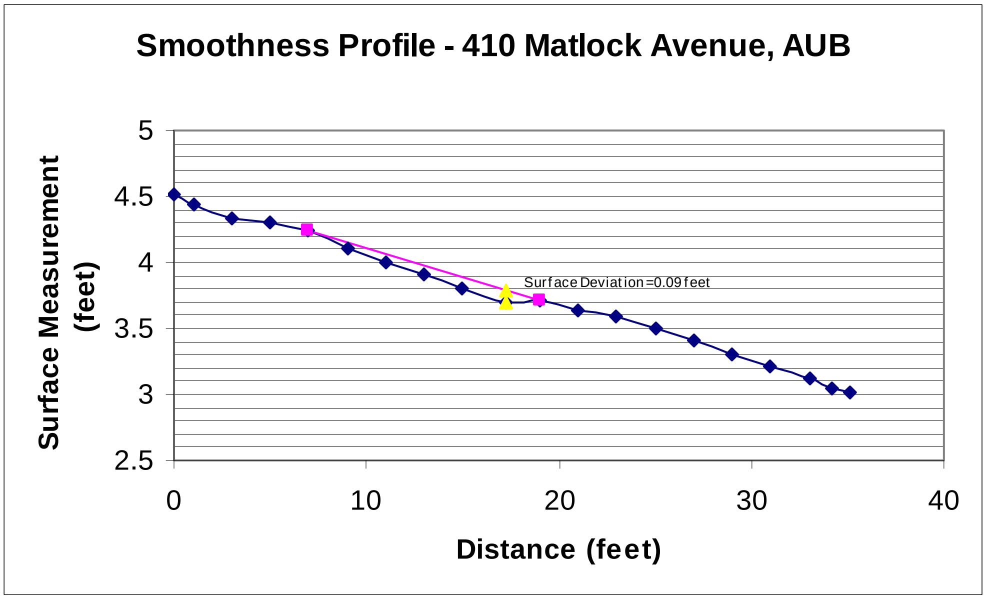

Figure 35 – Smoothness Profile – 401 Matlock Avenue, AUB

Figure 36 – Photographs – 401 Matlock Avenue, AUB

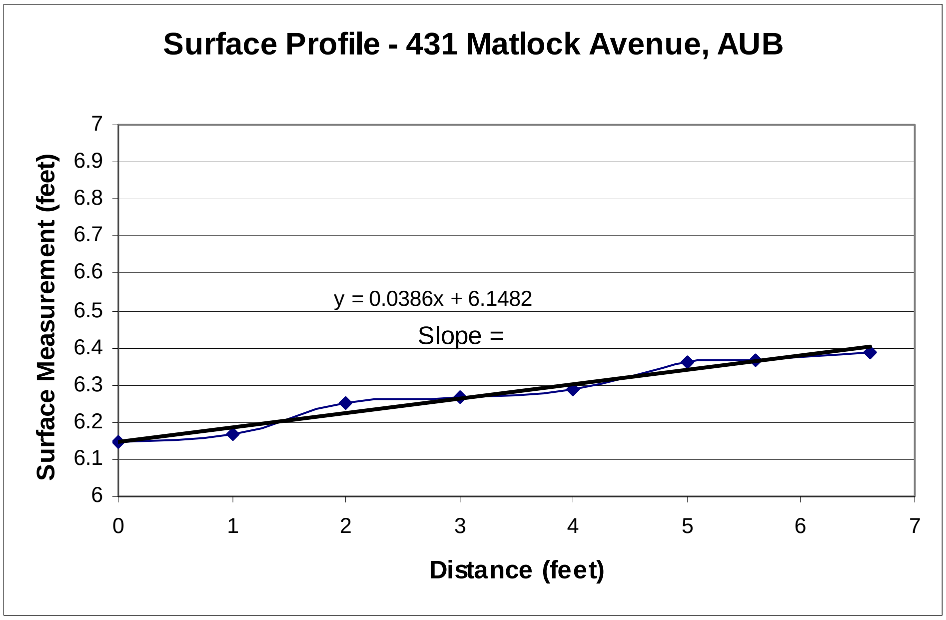

Figure 37 – Surface Profile – 431 Matlock Avenue, AUB

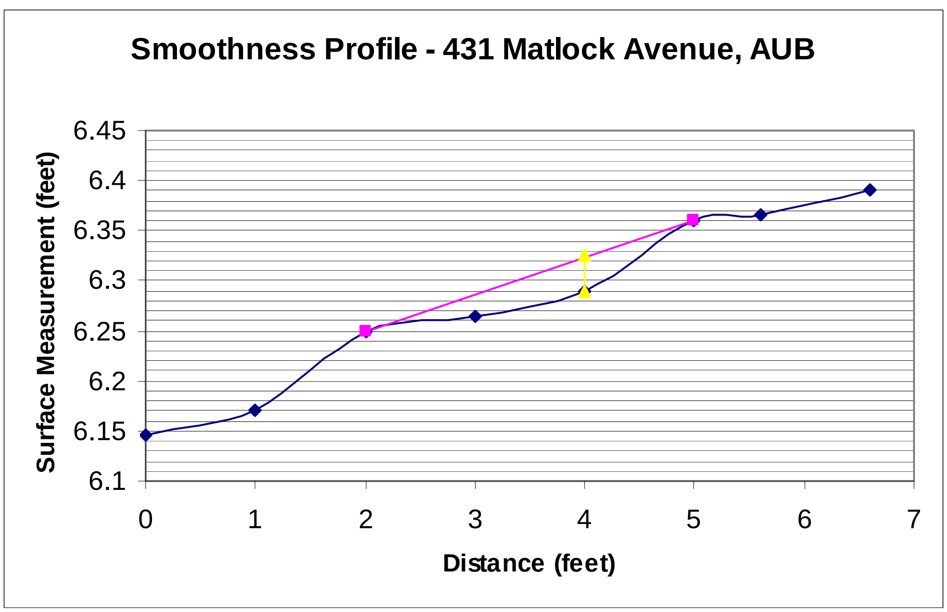

Figure 38 – Smoothness Profile – 431 Matlock Avenue, AUB


Figure 39 – Photographs – 431 Matlock Avenue, AUB

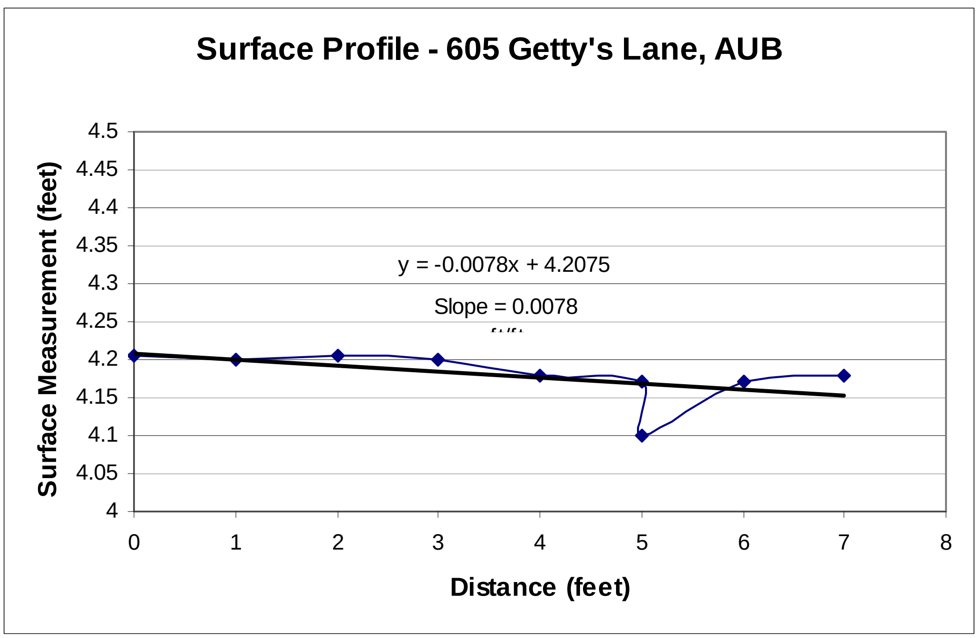

Figure 40 – Surface Profile – 605 Getty's Lane, AUB

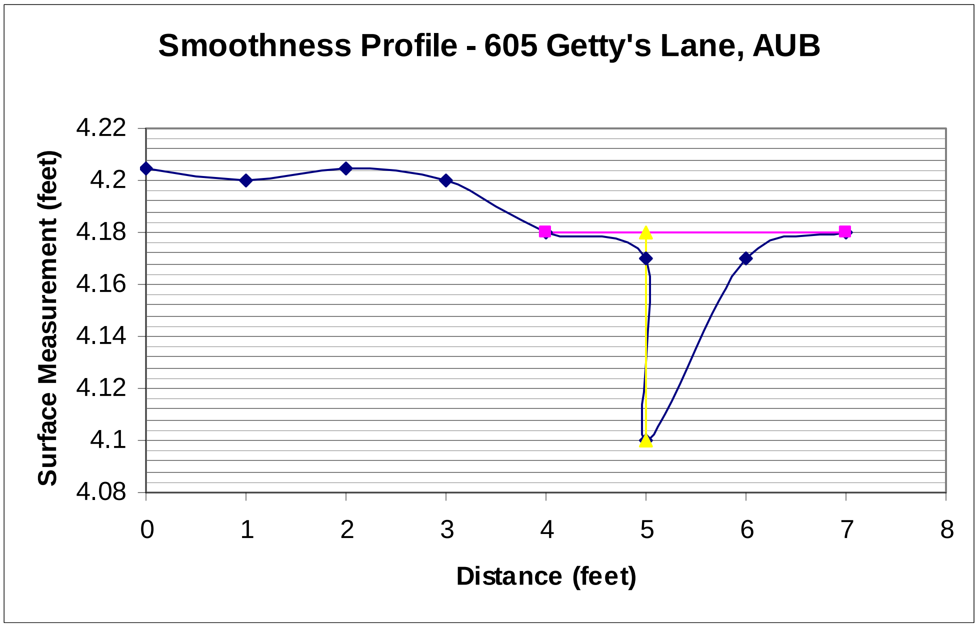

Figure 41 – Smoothness Profile – 605 Getty’s Lane, AUB

Figure 42 – Photographs – 605 Getty's Lane, AUB

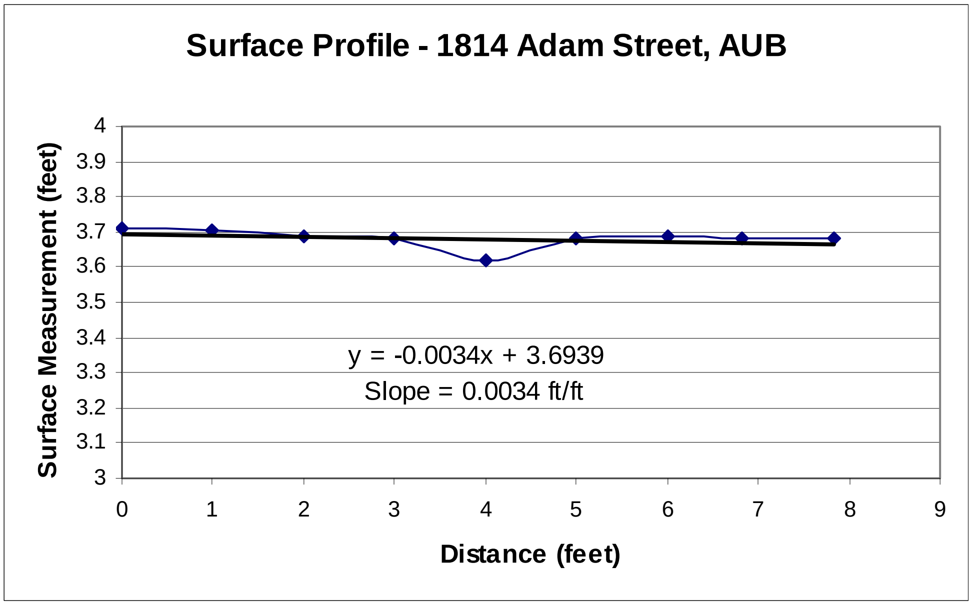

Figure 43 – Surface Profile – 1814 Adam Street, AUB

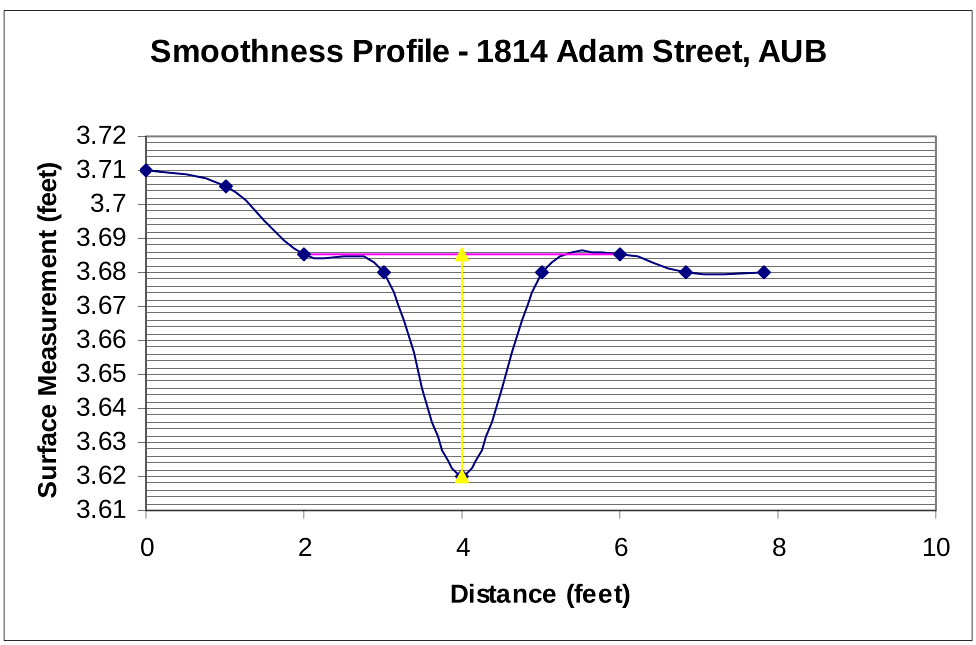

Figure 44 – Smoothness Profile – 1814 Adam Street, AUB

Figure 45 – Photographs – 1814 Adam Street, AUB

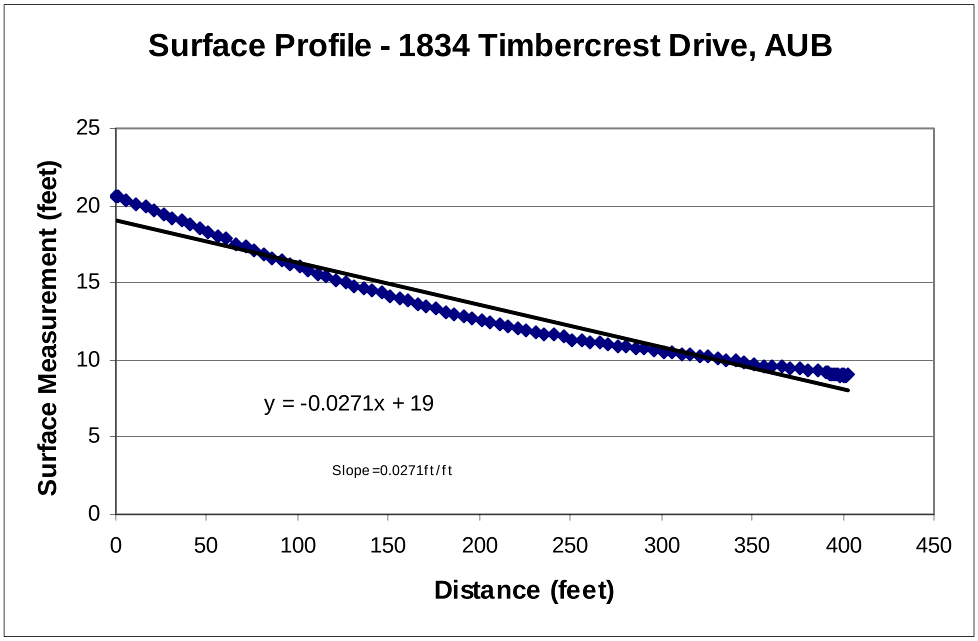

Figure 46 – Surface Profile – 1834 Timbercrest Drive, AUB

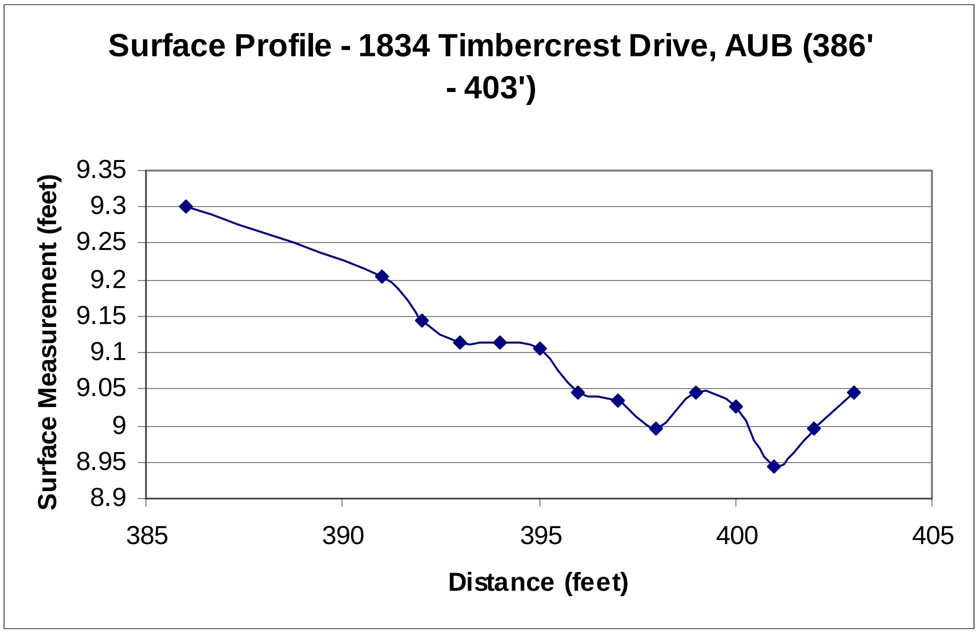

Figure 47 – Smoothness Profile – 1834 Timbercrest Drive, AUB

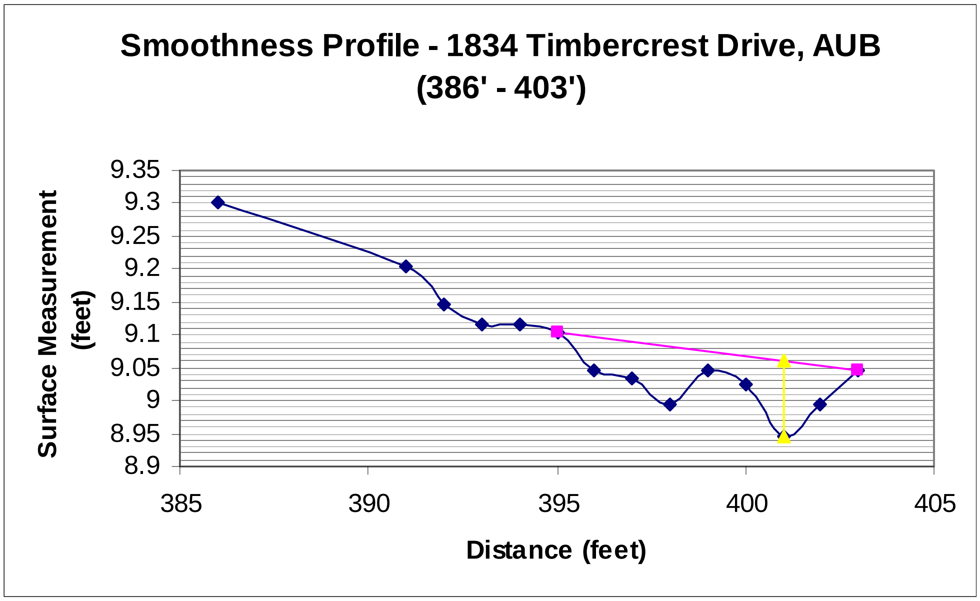

Figure 48 – Smoothness Profile – 1834 Timbercrest Drive, AUB 2

Figure 49 – Photographs – 1834 Timbercrest Drive, AUB

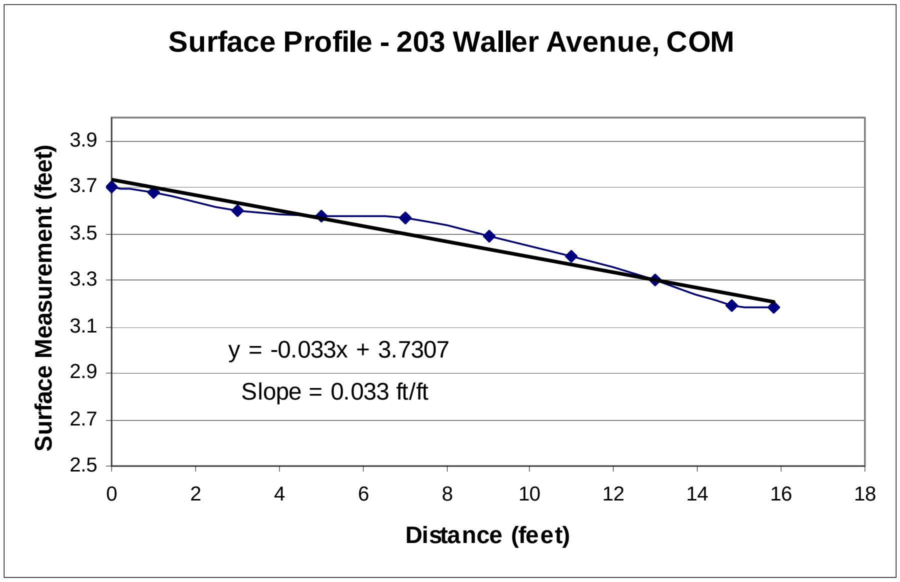

Figure 50 – Surface Profile – 203 Waller Avenue, COM

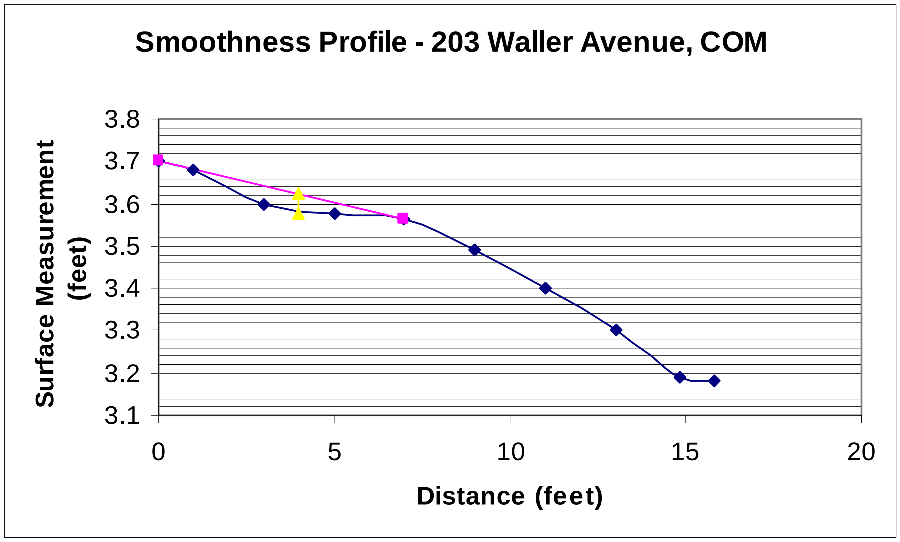

Figure 51 – Smoothness Profile – 203 Waller Avenue, COM

Figure 52 – Photographs – 203 Waller Avenue, COM

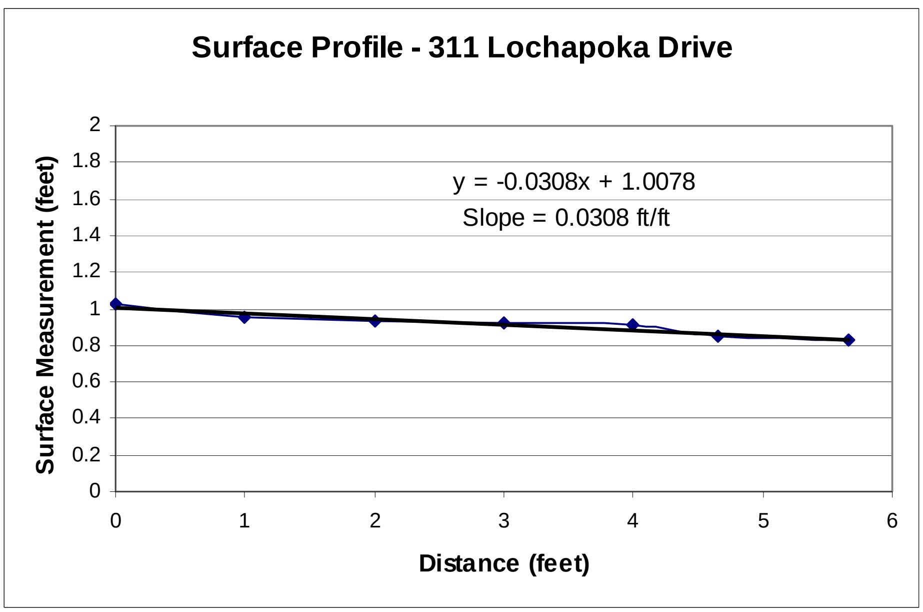

Figure 53 – Surface Profile – 311 Lochapoka Drive, COM

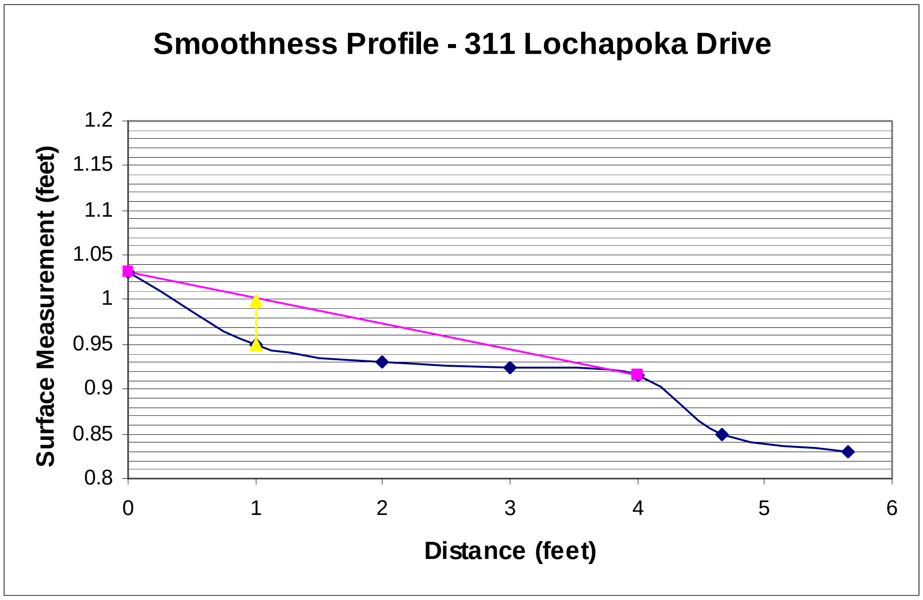

Figure 54 – Smoothness Profile – 311 Lochapoka Drive, COM


Figure 55 – Photographs – 311 Lochapoka Drive, COM

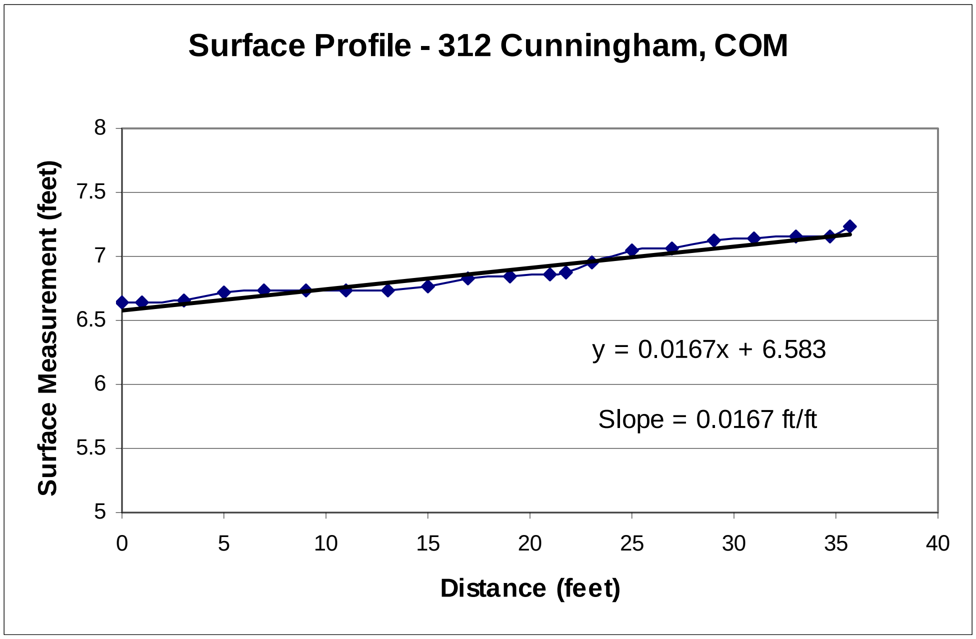

Figure 56 – Surface Profile – 312 Cunningham Drive, COM

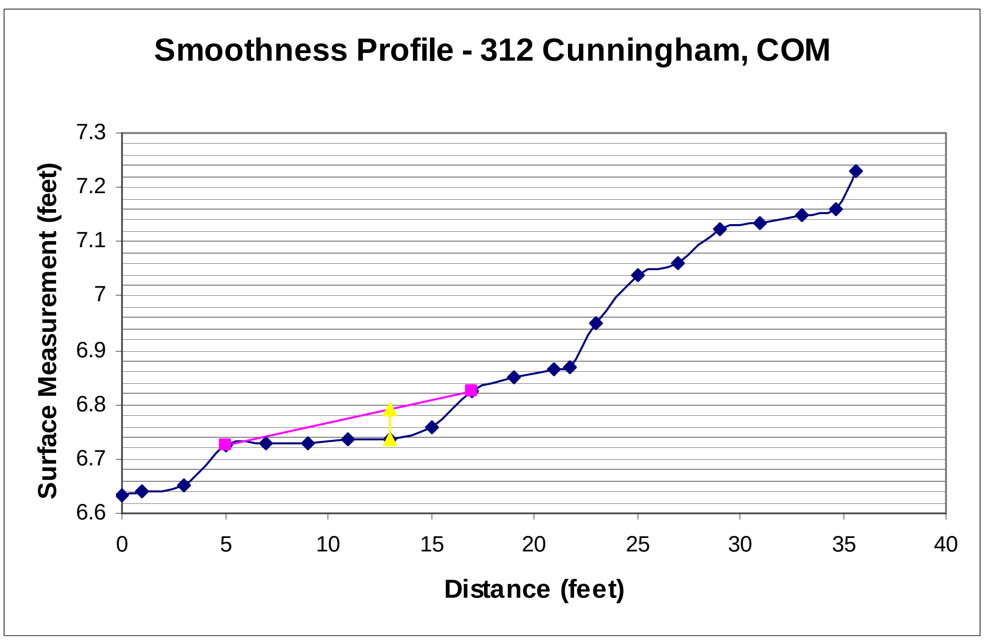

Figure 57 – Smoothness Profile – 312 Cunningham Drive, COM

Figure 58 – Photographs – 312 Cunningham Drive, COM

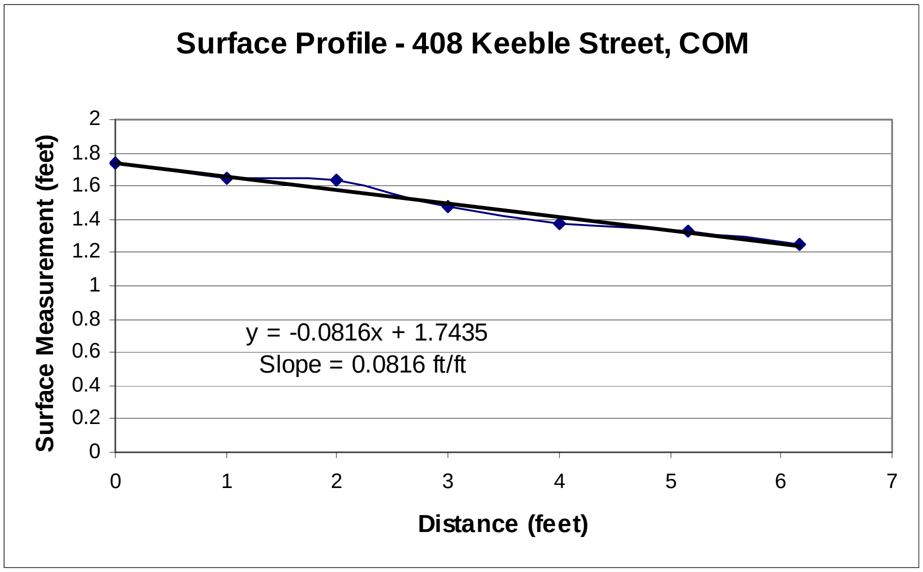

Figure 59 – Surface Profile – 408 Keeble Street, COM

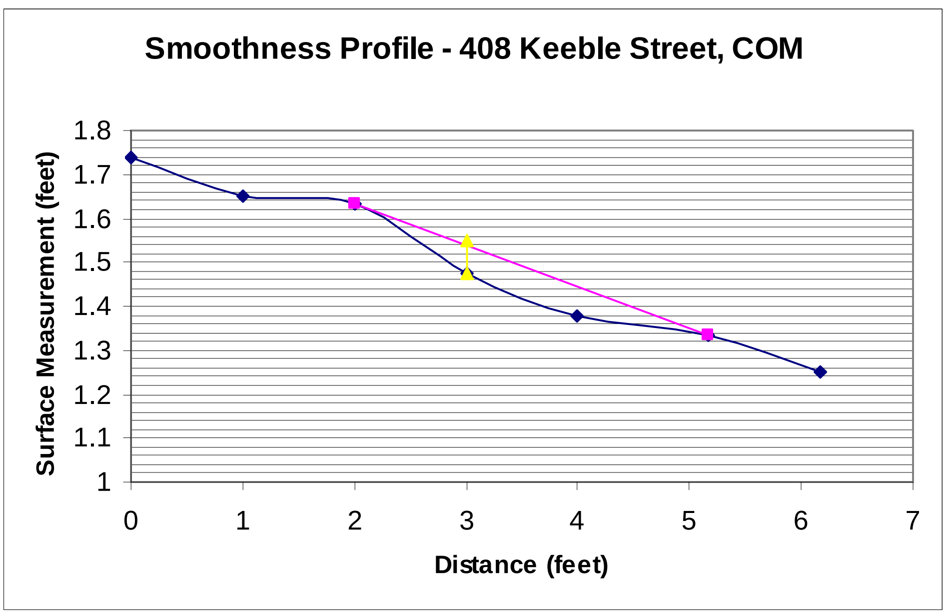

Figure 60 – Smoothness Profile – 408 Keeble Street, COM

Figure 61 – Photographs – 408 Keeble Street, COM

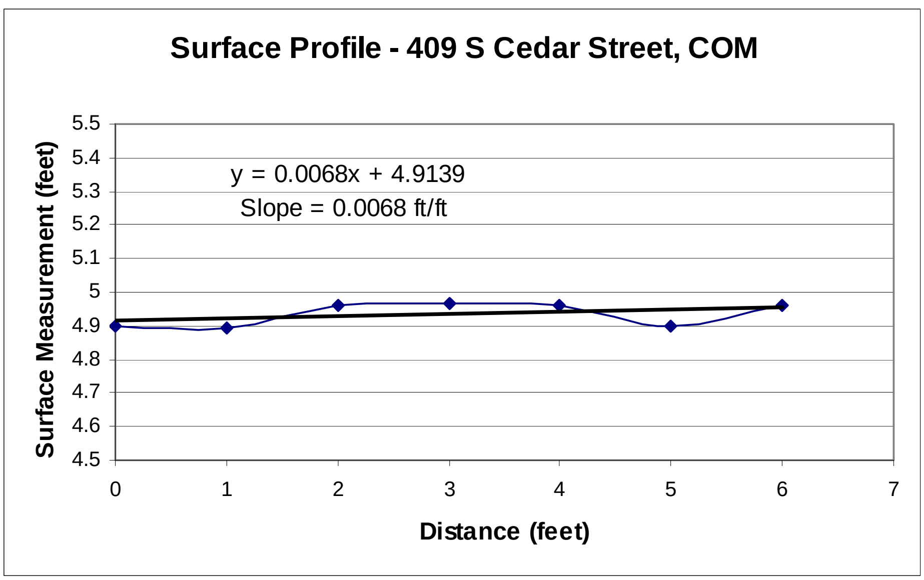

Figure 62 – Surface Profile – 409 S Cedar Street, COM

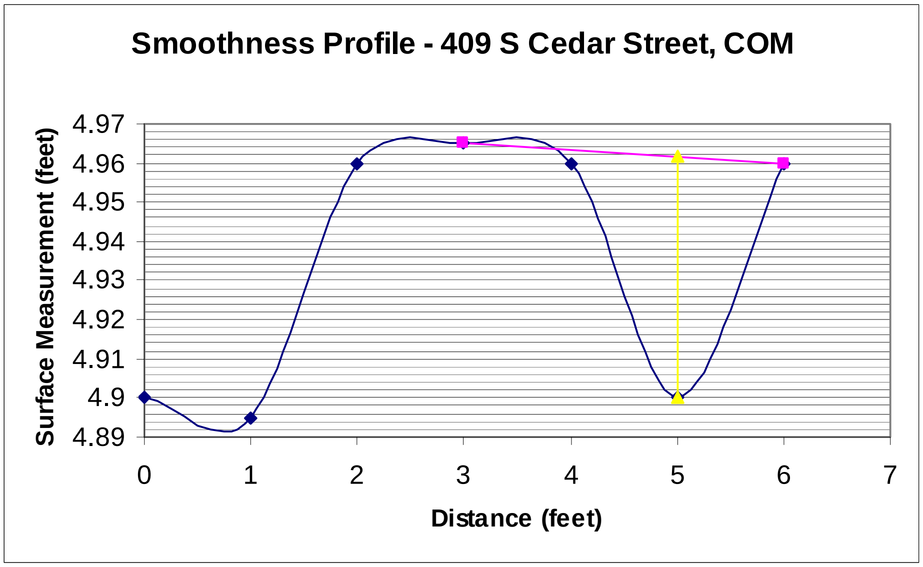

Figure 63 – Smoothness Profile – 409 S Cedar Street, COM

Figure 64 – Photographs – 409 S Cedar Street, COM

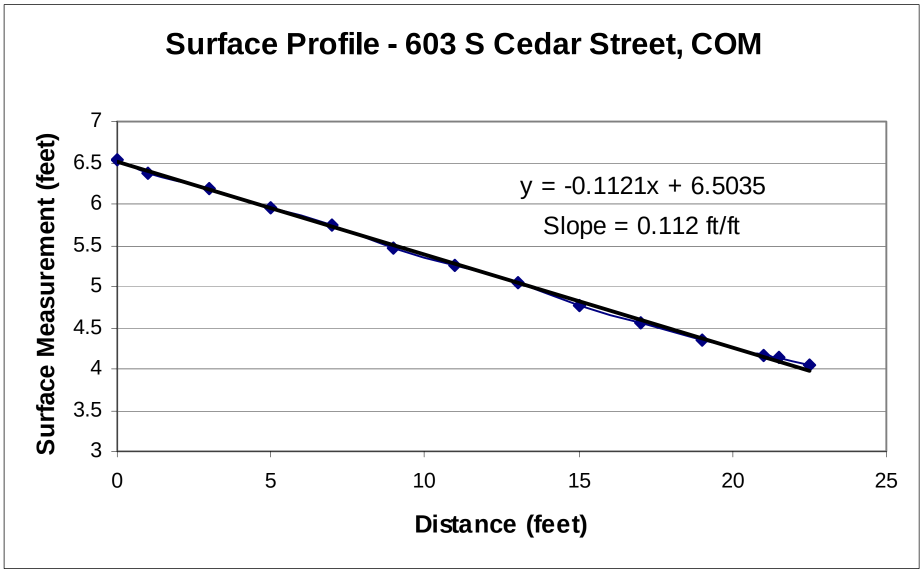

Figure 65 – Surface Profile – 603 S Cedar Street, COM

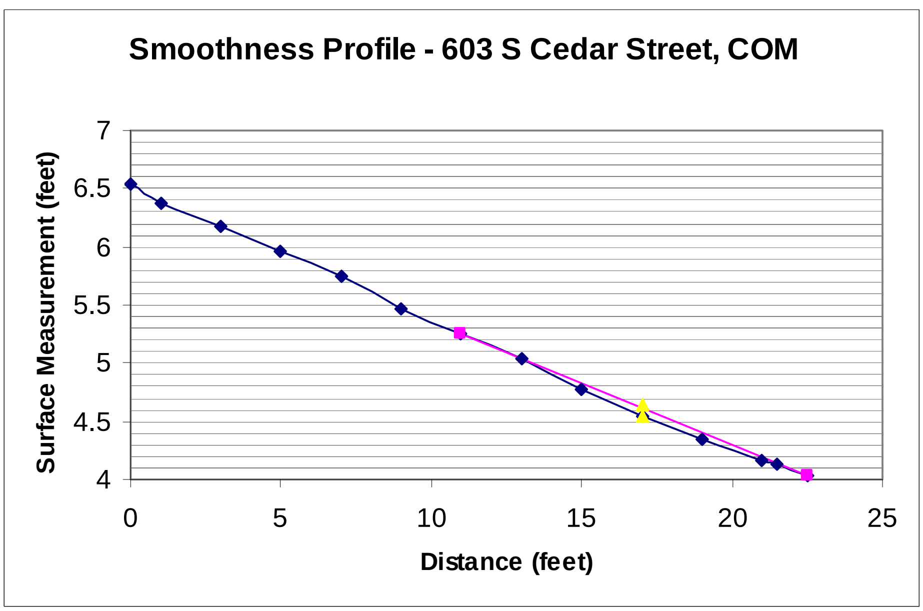

Figure 66 – Smoothness Profile – 603 S Cedar Street, COM

Figure 67 – Photographs – 603 S Cedar Street, COM

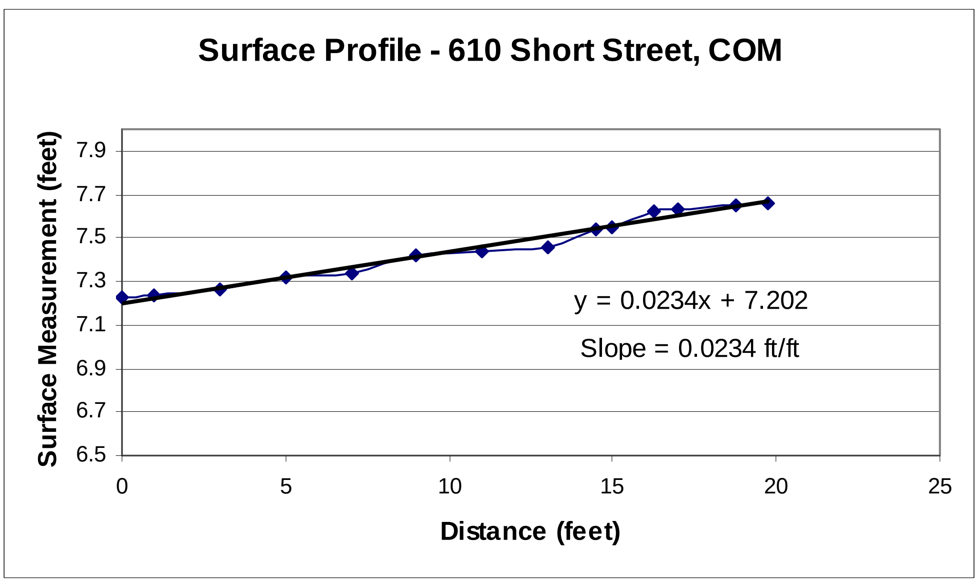

Figure 68 – Surface Profile – 610 Short Street, COM

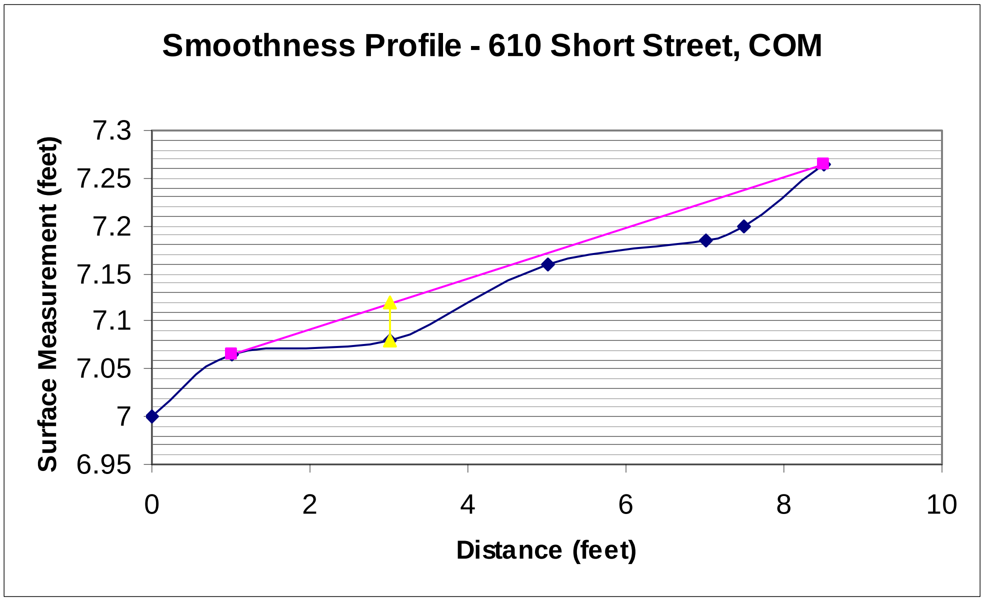

Figure 69 – Smoothness Profile – 610 Short Street, COM

Figure 70 – Photographs – 610 Short Street, COM

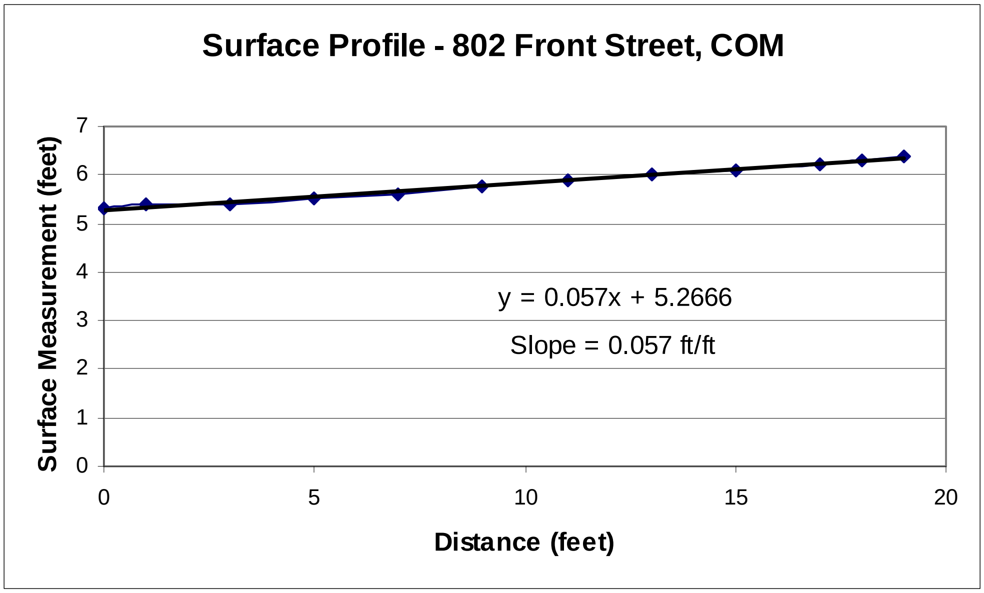

Figure 71 – Surface Profile – 802 Front Street, COM

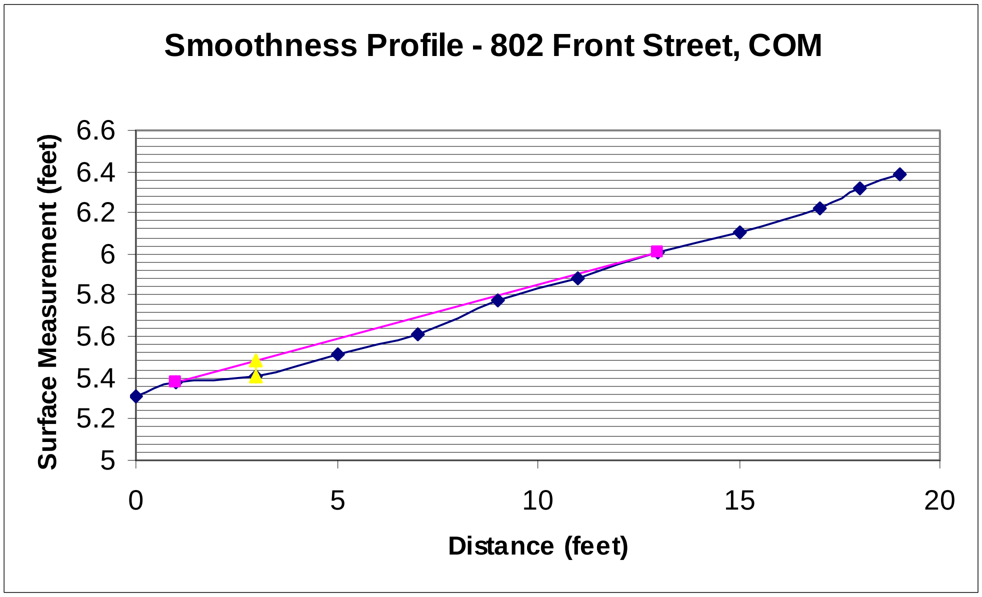

Figure 72 – Smoothness Profile – 802 Front Street, COM

Figure 73 – Photographs – 802 Front Street, COM

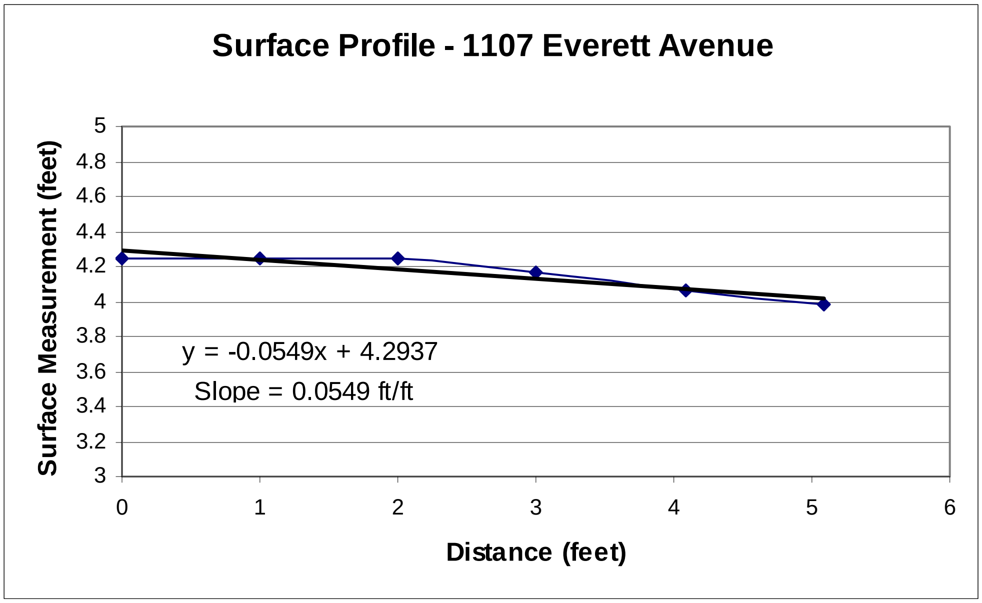

Figure 74 – Surface Profile – 1107 Everett Avenue, COM

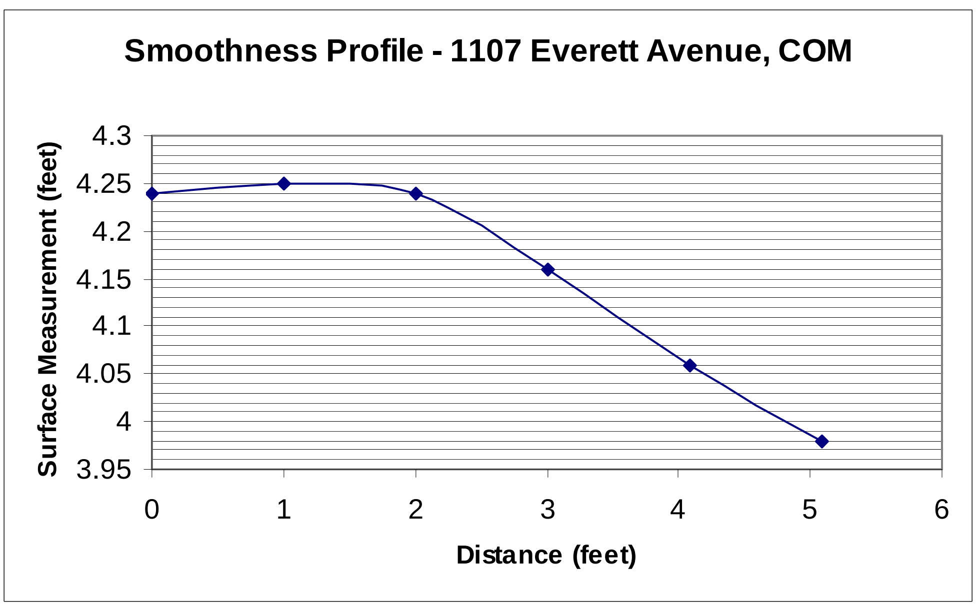

Figure 75 – Smoothness Profile – 1107 Everett Avenue, COM

Figure 76 – Photographs – 1107 Everett Avenue, COM

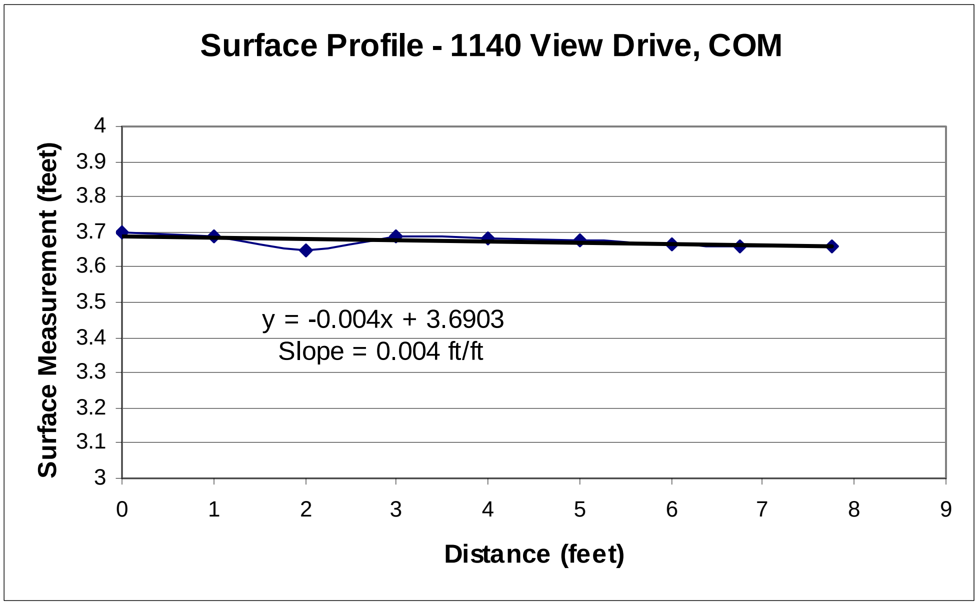

Figure 77 – Surface Profile – 1140 View Drive, COM

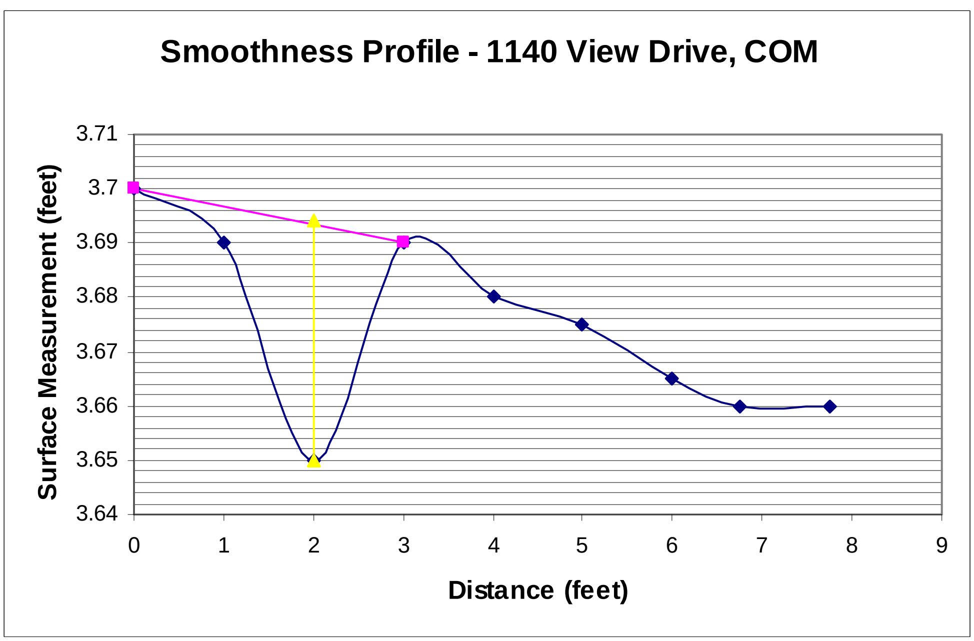

Figure 78 – Smoothness Profile – 1140 View Drive, COM

Figure 79 – Photographs – 1140 View Drive, COM

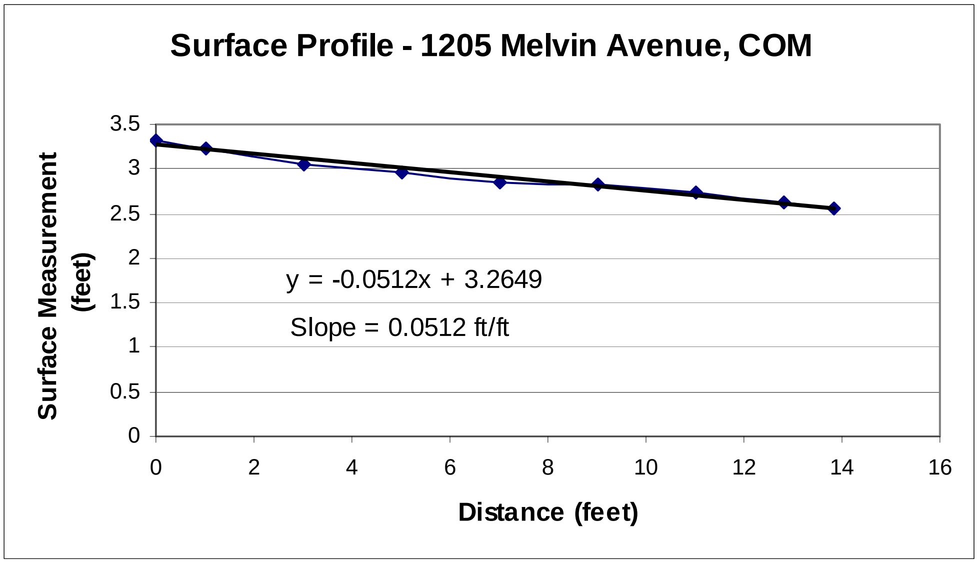

Figure 80 – Surface Profile – 1205 Melvin Avenue, COM

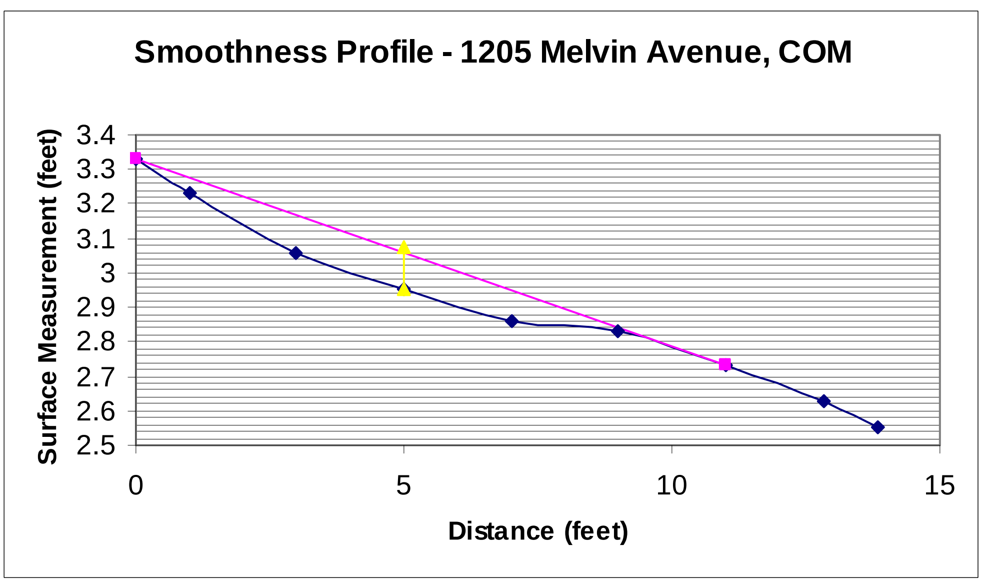

Figure 81 – Smoothness Profile – 1205 Melvin Avenue, COM

Figure 82 – Photographs – 1205 Melvin Avenue, COM

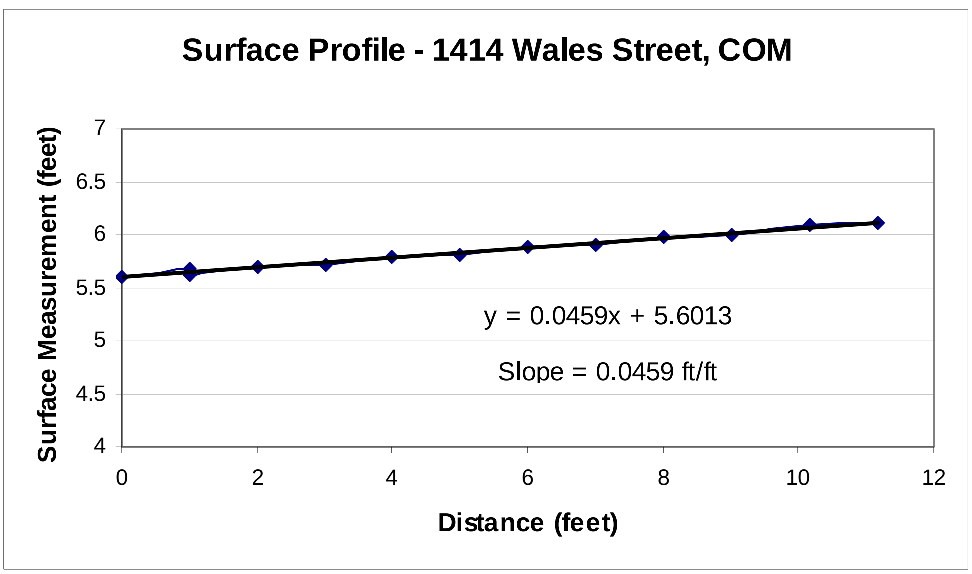

Figure 83 – Surface Profile – 1414 Wales Street, COM

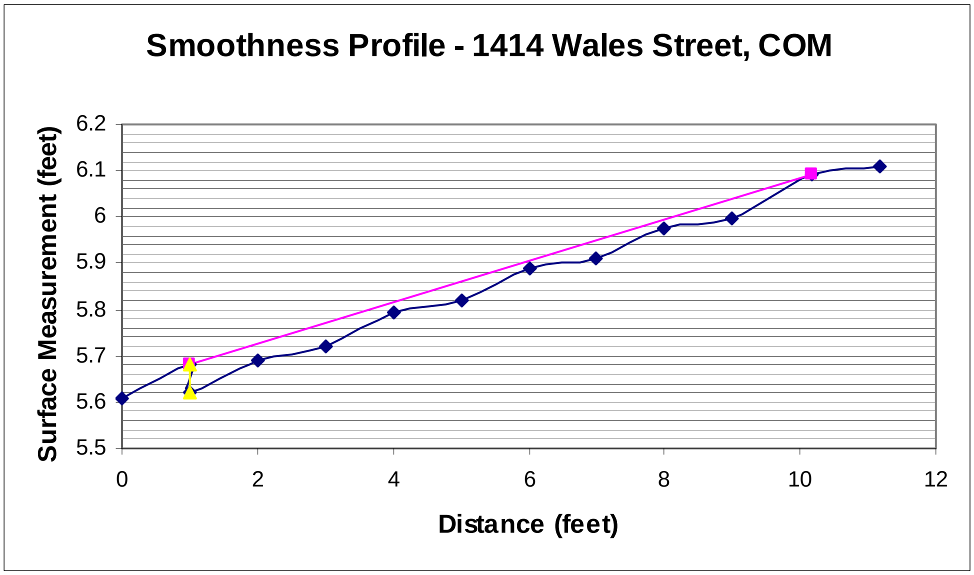

Figure 84 – Smoothness Profile – 1414 Wales Street, COM

Figure 85 – Photographs – 1414 Wales Street, COM

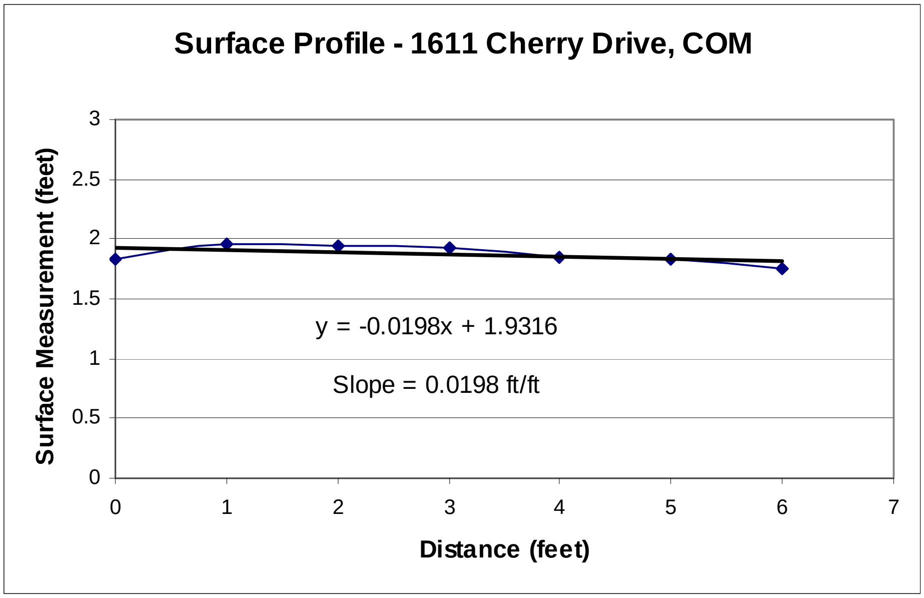

Figure 86 – Surface Profile – 1611 Cherry Drive, COM

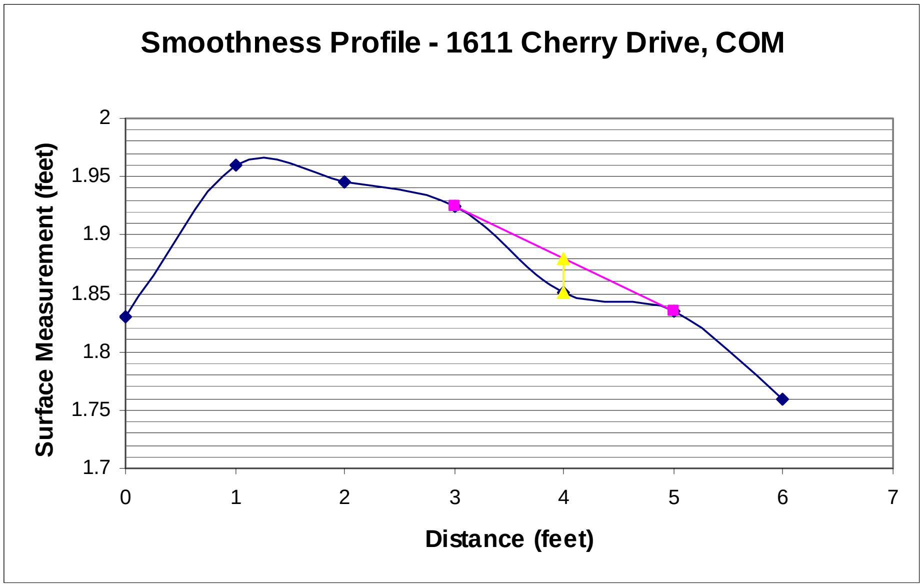

Figure 87 – Smoothness Profile – 1611 Cherry Drive, COM

Figure 88 – Photographs – 1611 Cherry Drive, COM

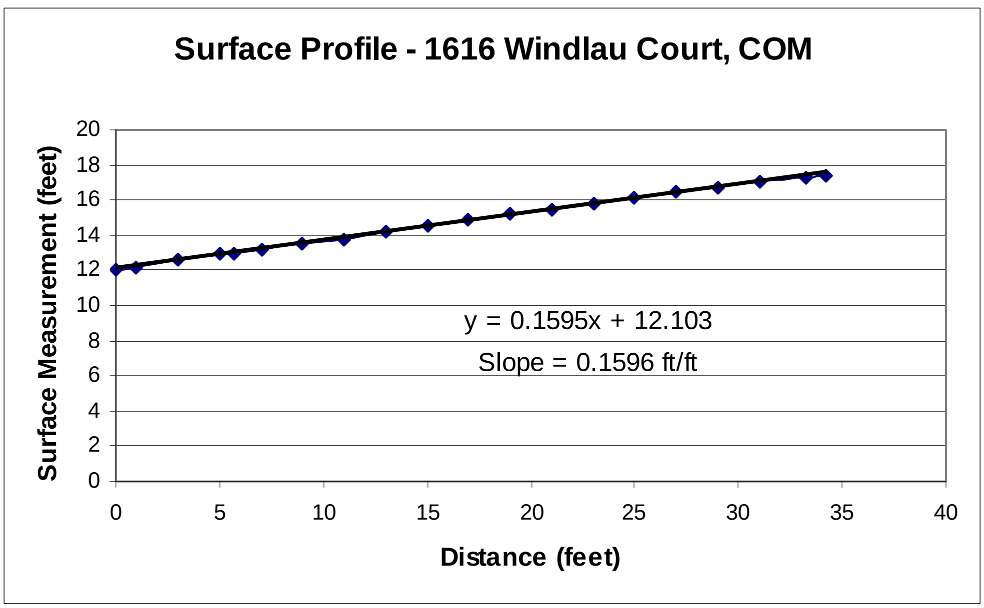

Figure 89 – Surface Profile – 1616 Windlau Court, COM

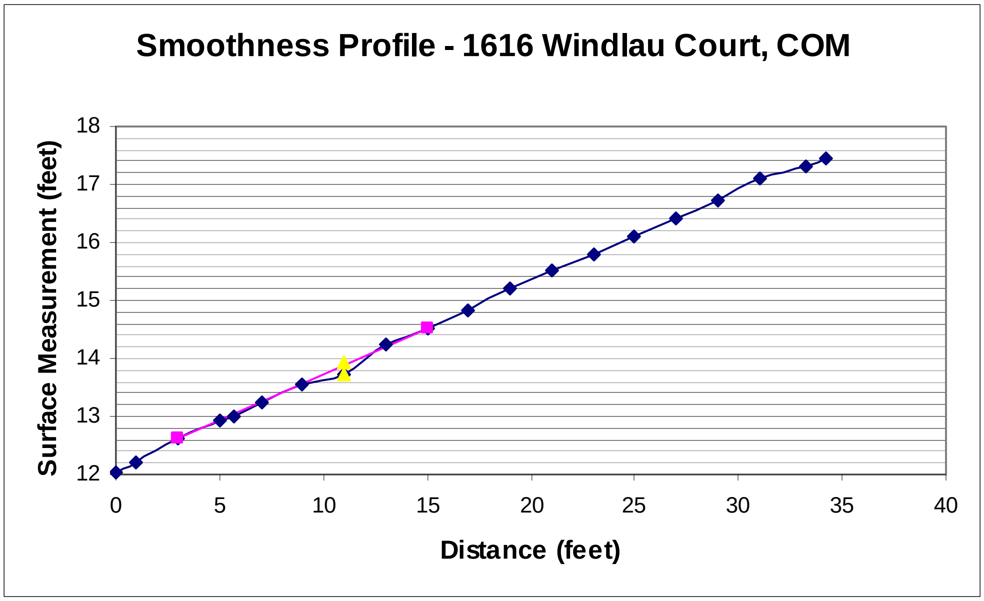

Figure 90 – Smoothness Profile – 1616 Windlau Court, COM

Figure 91 – Photographs – 1616 Windlau Court, COM

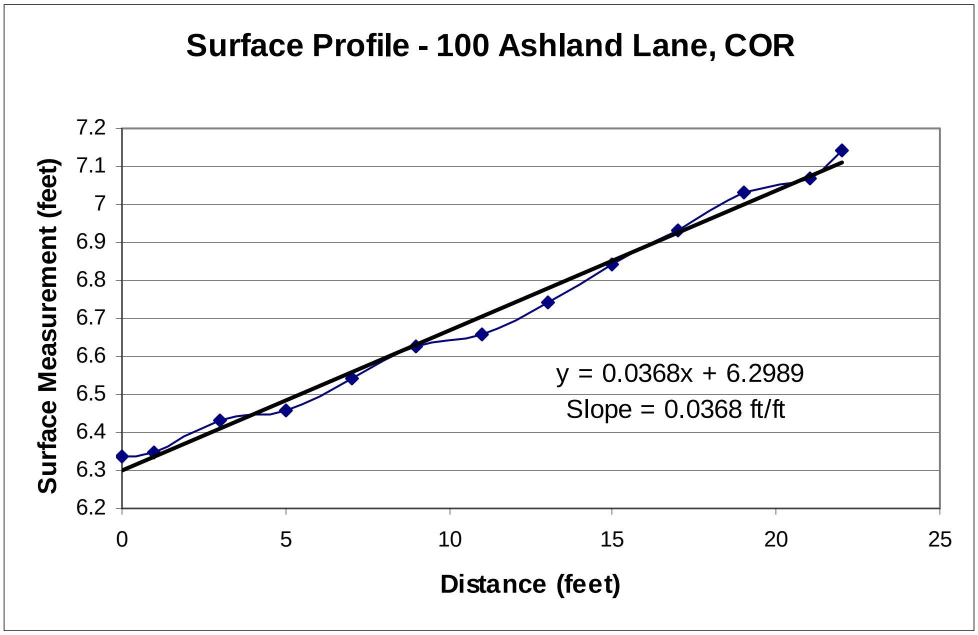

Figure 92 – Surface Profile – 100 Ashland Lane, COR

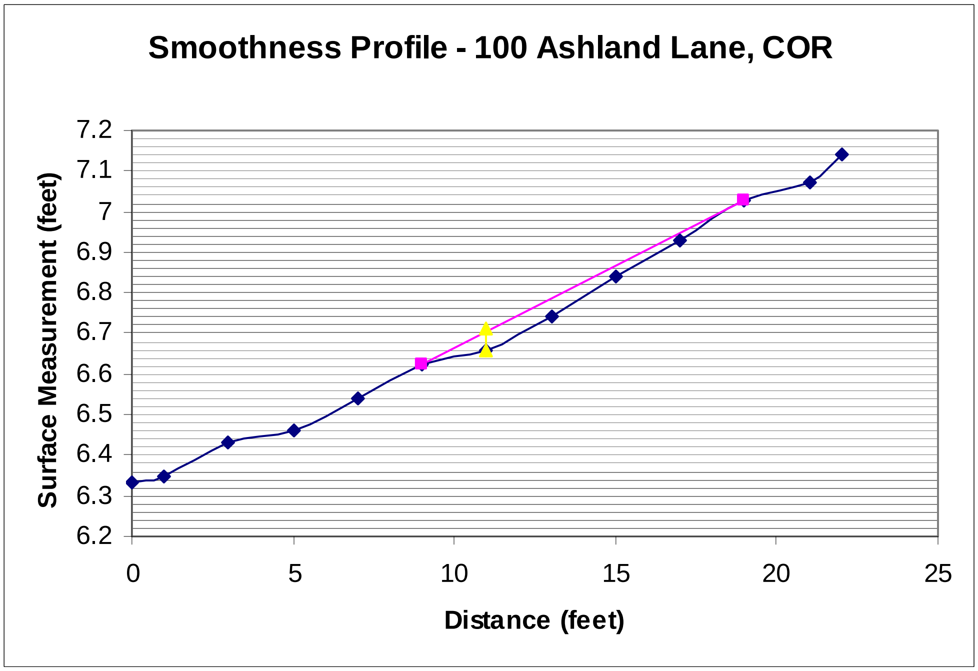

Figure 93 – Smoothness Profile – 100 Ashland Lane, COR

Figure 94 – Photographs – 100 Ashland Lane, COR

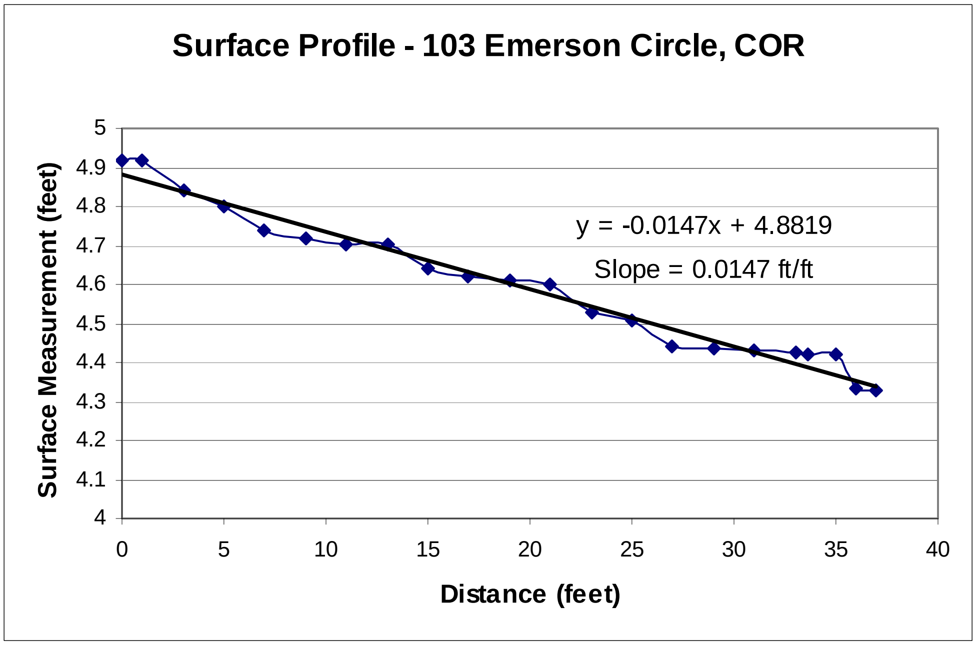

Figure 95 – Surface Profile – 103 Emerson Circle, COR

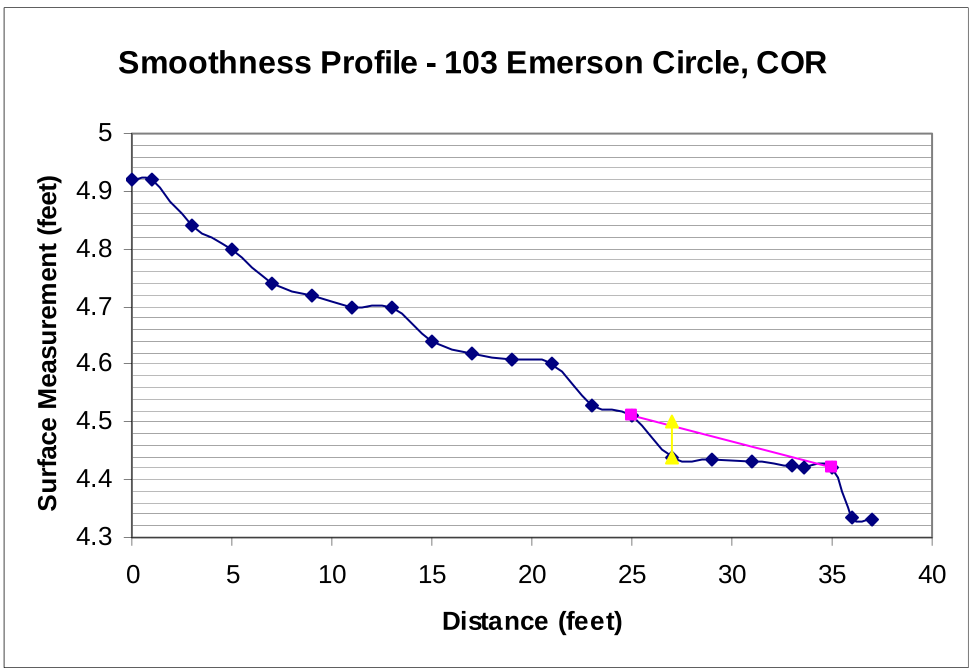

Figure 96 – Smoothness Profile – 103 Emerson Circle, COR

Figure 97 – Photographs – 103 Emerson Circle, COR

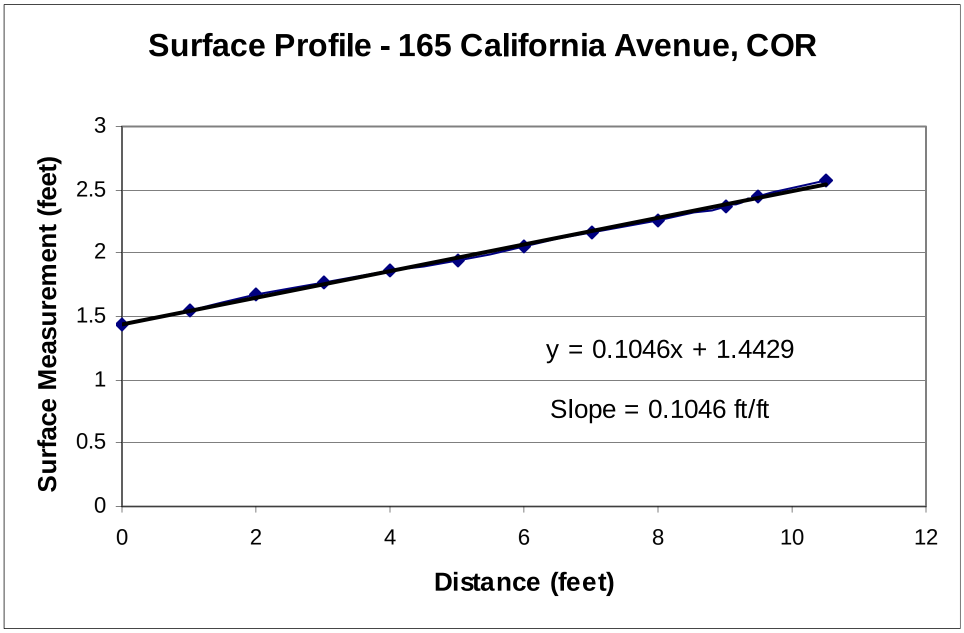

Figure 98 – Surface Profile – 165 California Avenue, COR

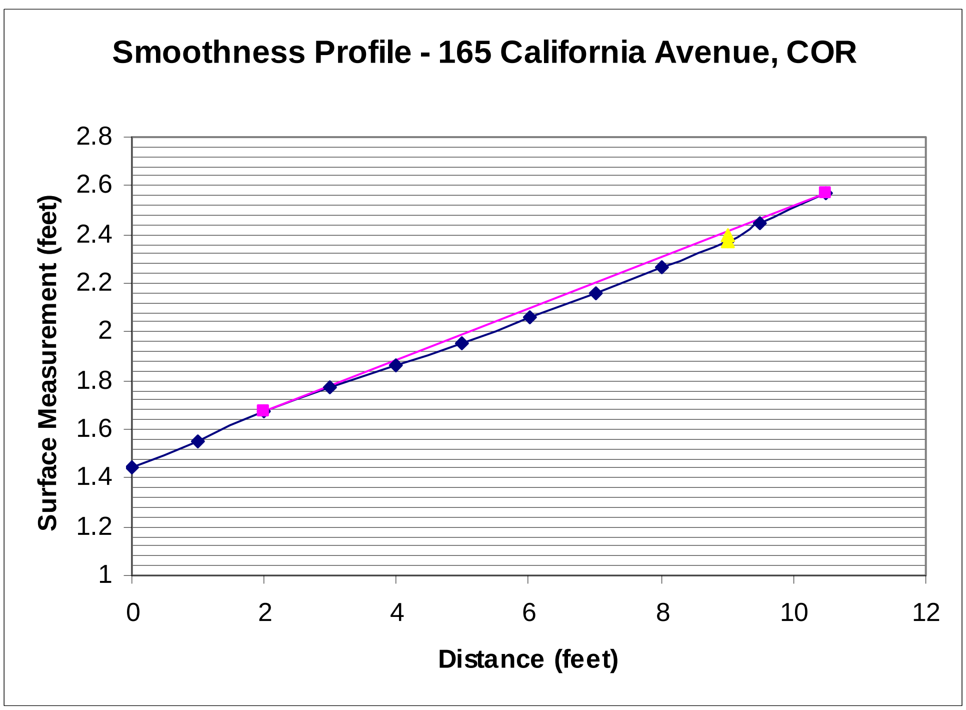

Figure 99 – Smoothness Profile – 165 California Avenue, COR

Figure 100 – Photographs – 165 California Avenue, COR

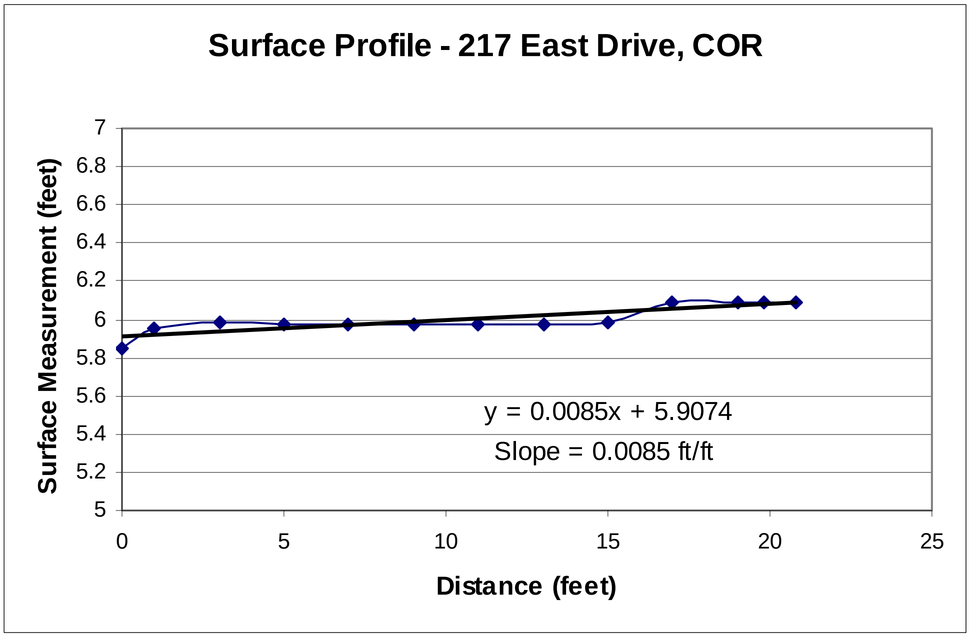

Figure 101 – Surface Profile – 217 East Drive, COR

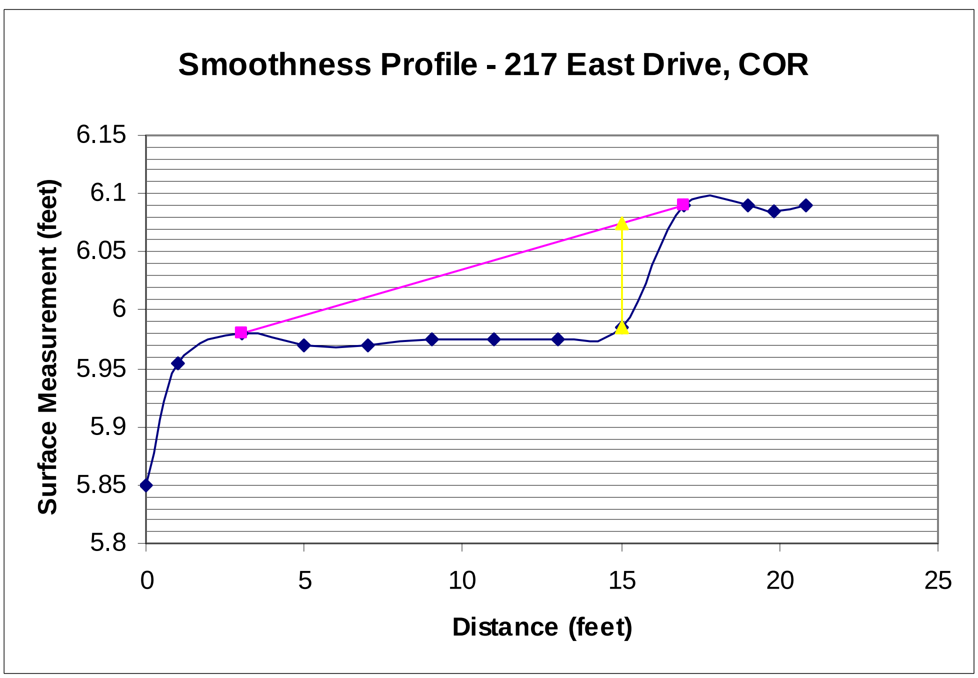

Figure 102 – Smoothness Profile – 217 East Drive, COR

Figure 103 – Photographs – 217 East Drive, COR

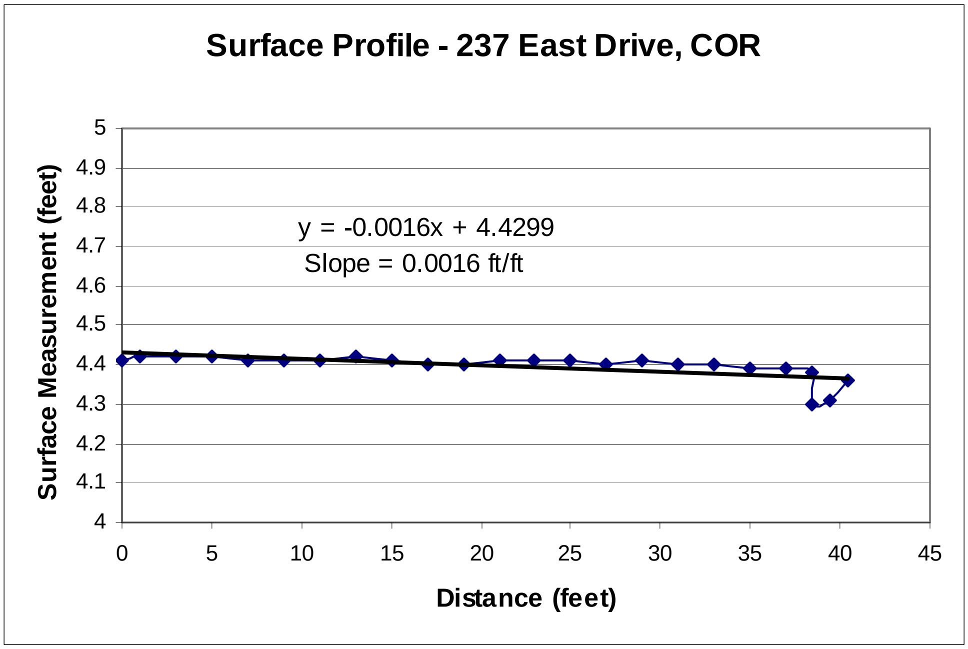

Figure 104 – Surface Profile – 237 East Drive, COR

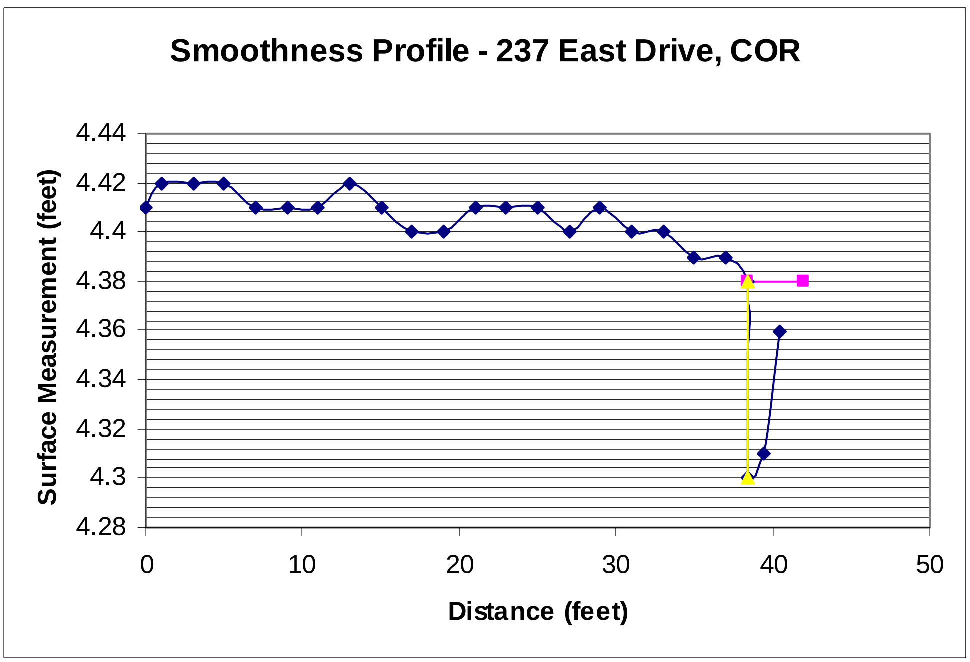

Figure 105 – Smoothness Profile – 237 East Drive, COR

Figure 106 – Photographs – 237 East Drive, COR

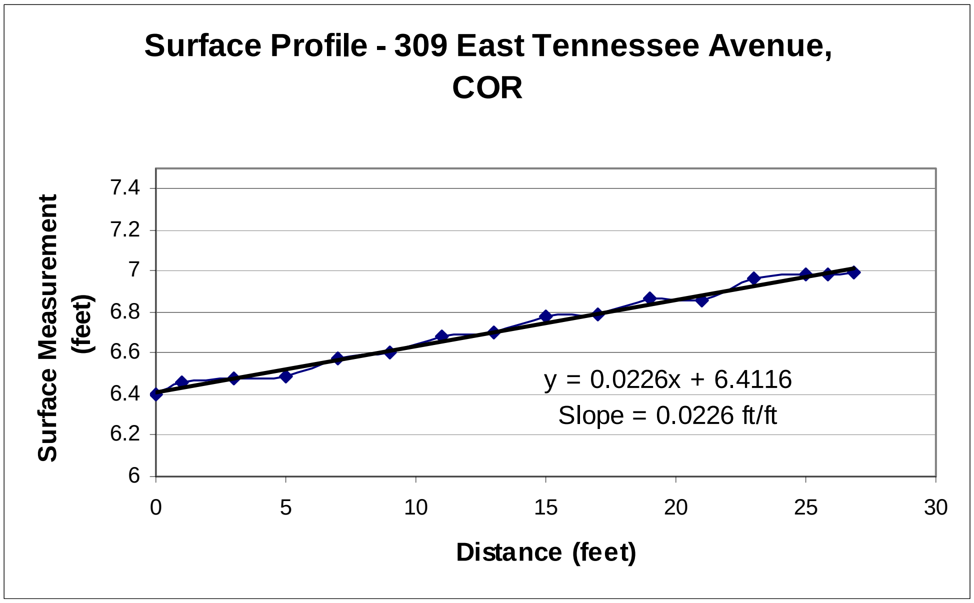

Figure 107 – Surface Profile – 309 East Tennessee Avenue, COR

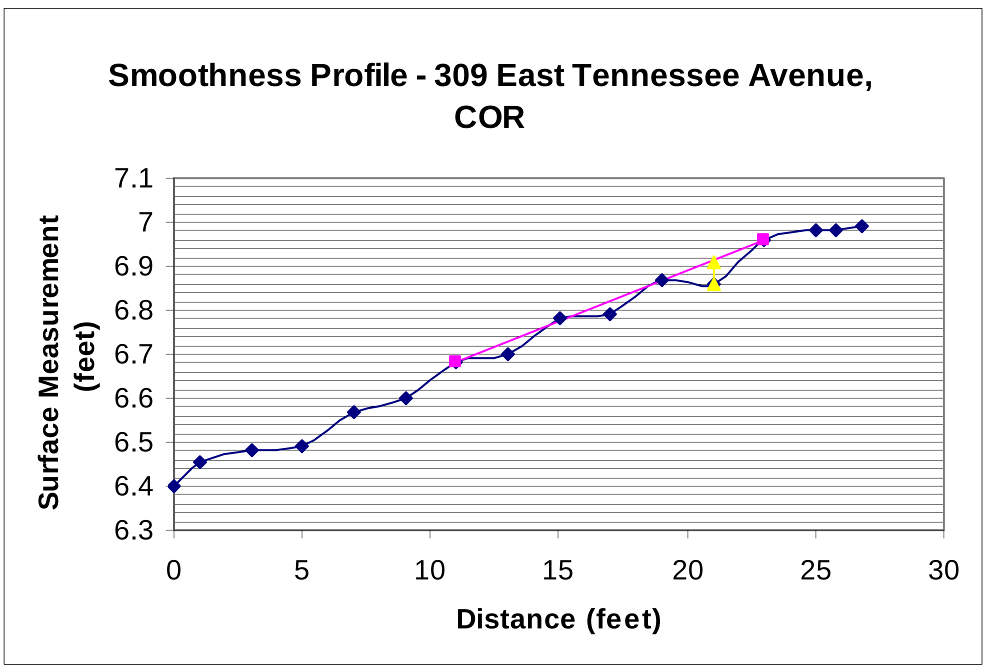

Figure 108 – Smoothness Profile – 309 East Tennessee Avenue, COR


Figure 109 – Photographs – 309 East Tennessee Avenue, COR

Figure 110 – Photographs – 440 East Drive, COR

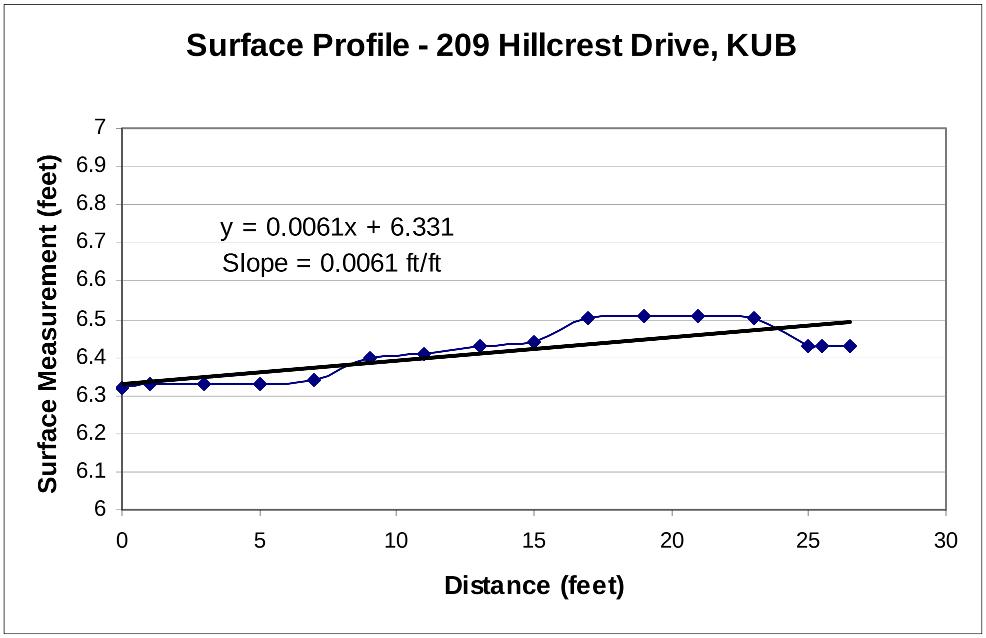

Figure 111 – Surface Profile – 209 Hillcrest Drive, KUB

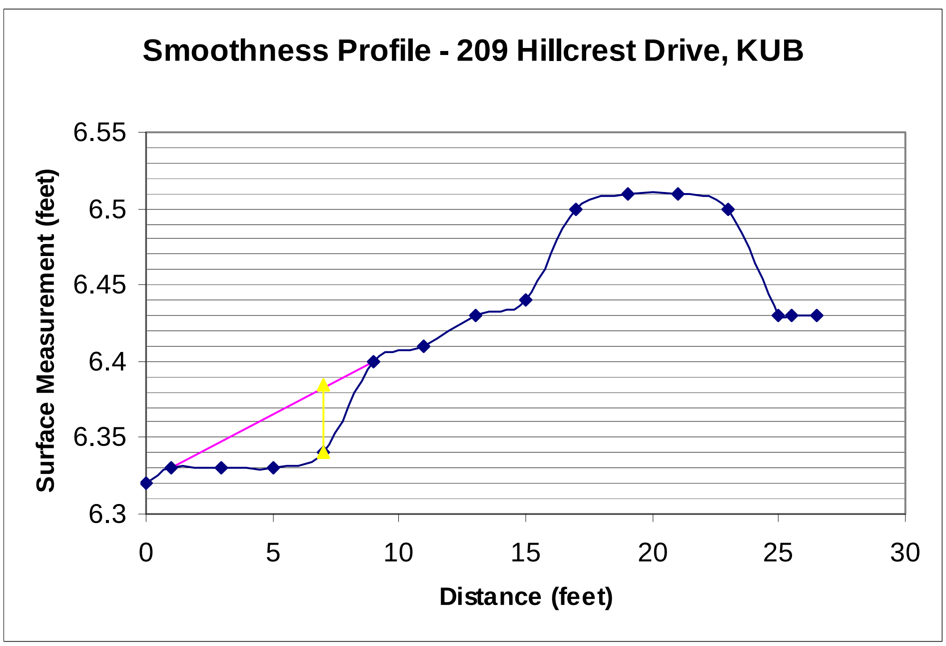

Figure 112 – Smoothness Profile – 209 Hillcrest Drive, KUB

Figure 113 – Photographs – 209 Hillcrest Drive, KUB

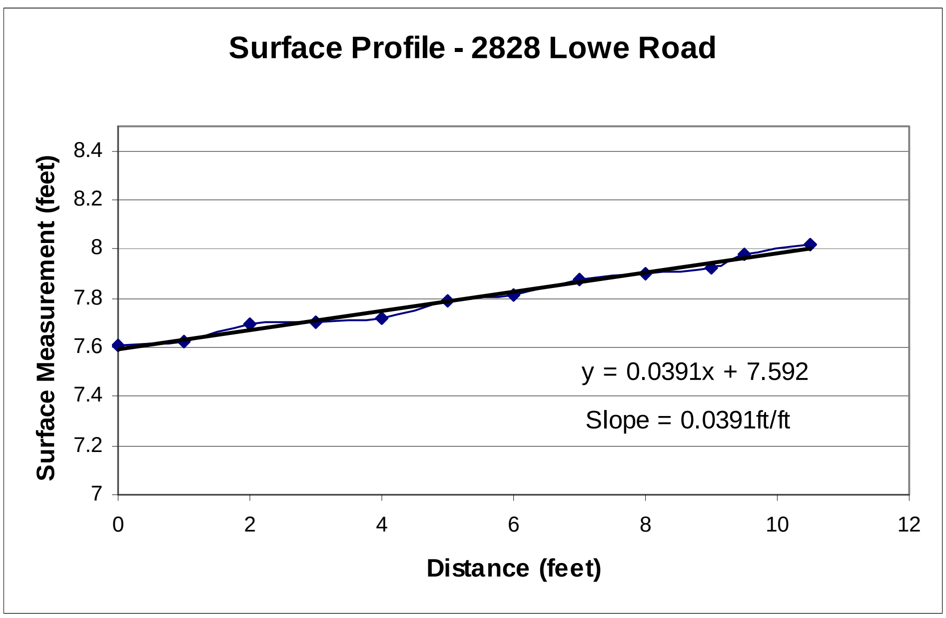

Figure 114 – Surface Profile – 2828 Lowe Road, KUB

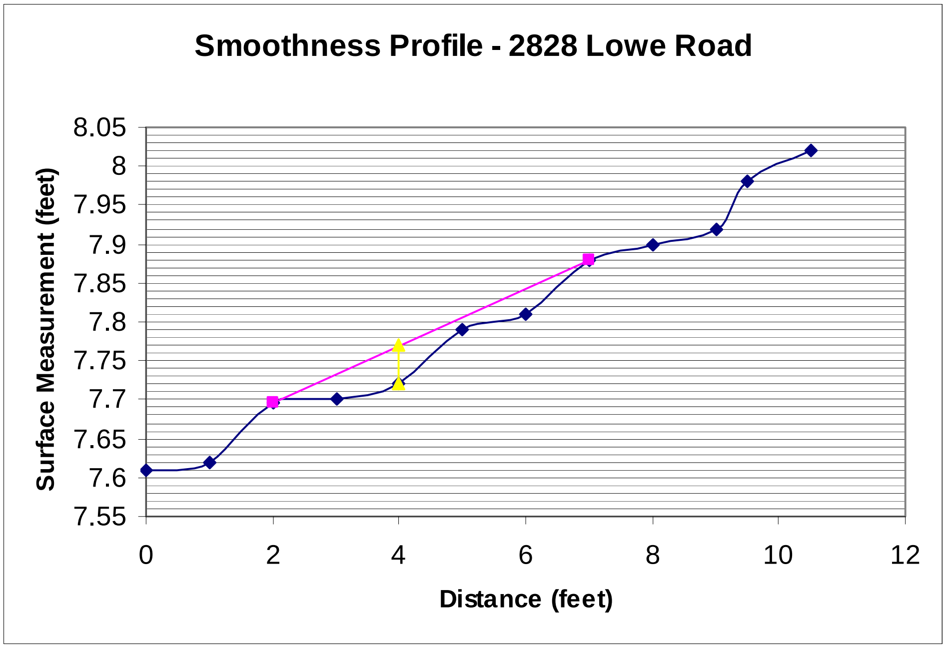

Figure 115 – Smoothness Profile – 2828 Lowe Road, KUB

Figure 116 – Photographs – 2828 Lowe Road, KUB

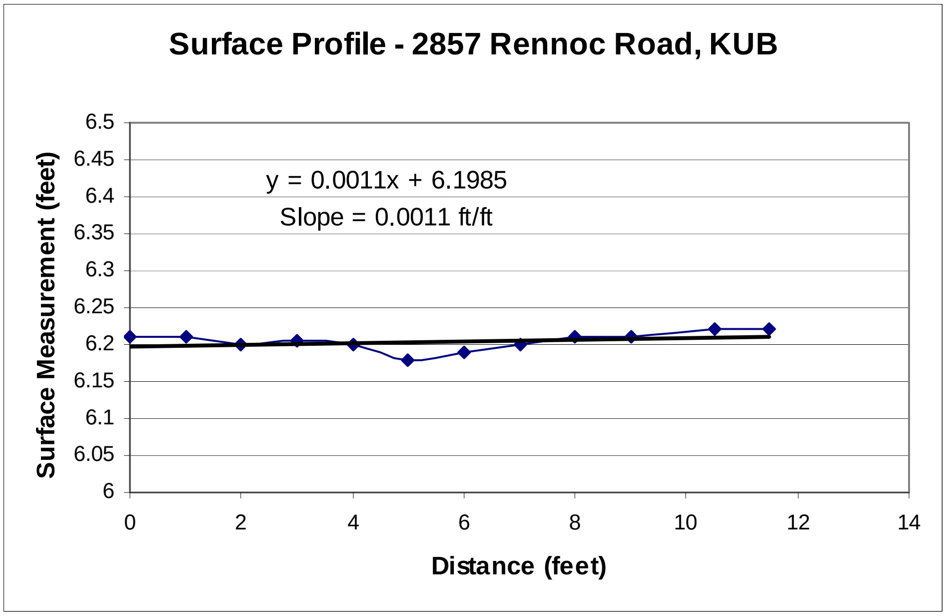

Figure 117 – Surface Profile – 2857 Rennoc Road, KUB

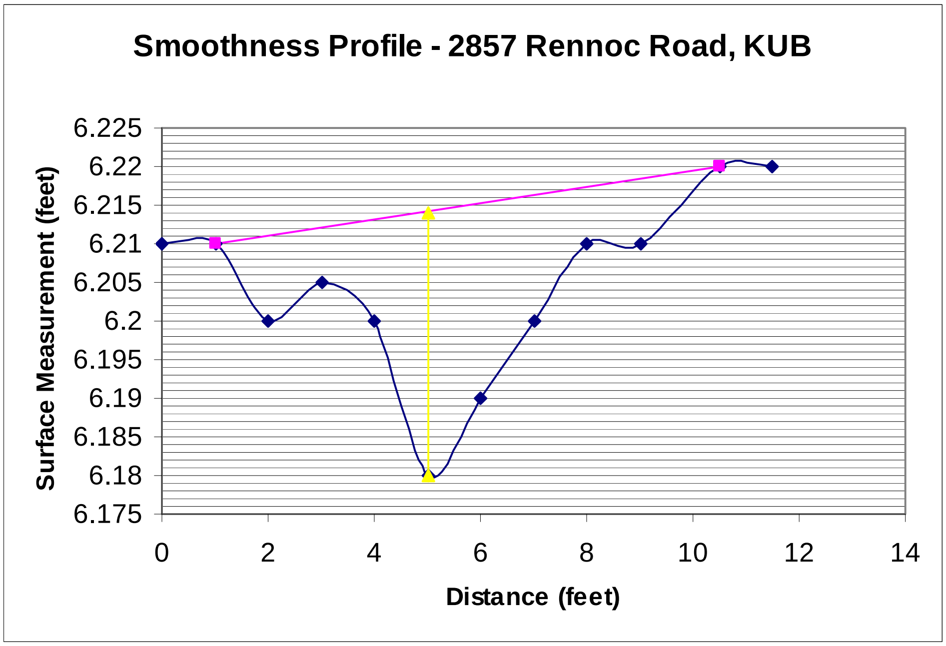

Figure 118 – Smoothness Profile – 2857 Rennoc Road, KUB

Figure 119 – Photographs – 2857 Rennoc Road, KUB

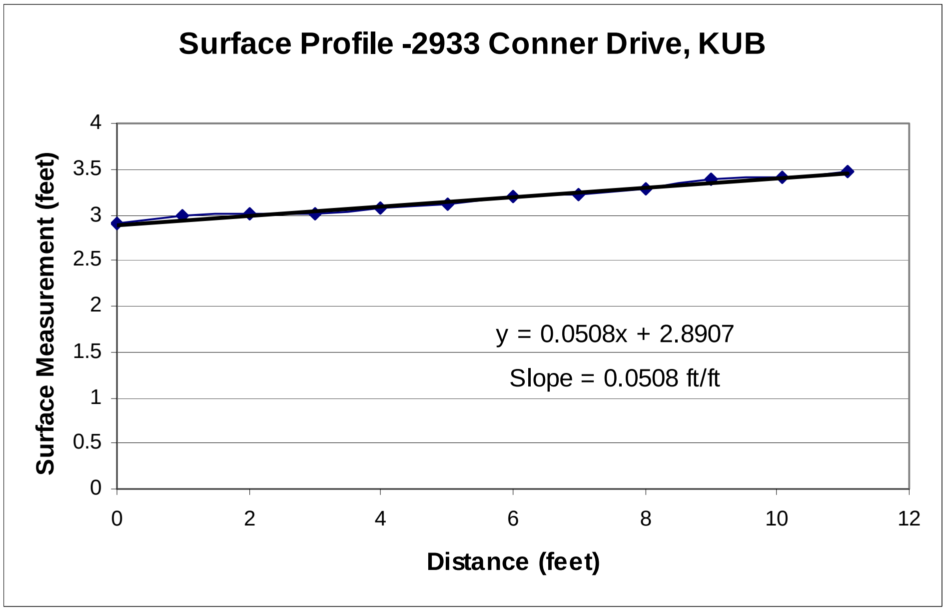

Figure 120 – Surface Profile – 2933 Conner Drive, KUB

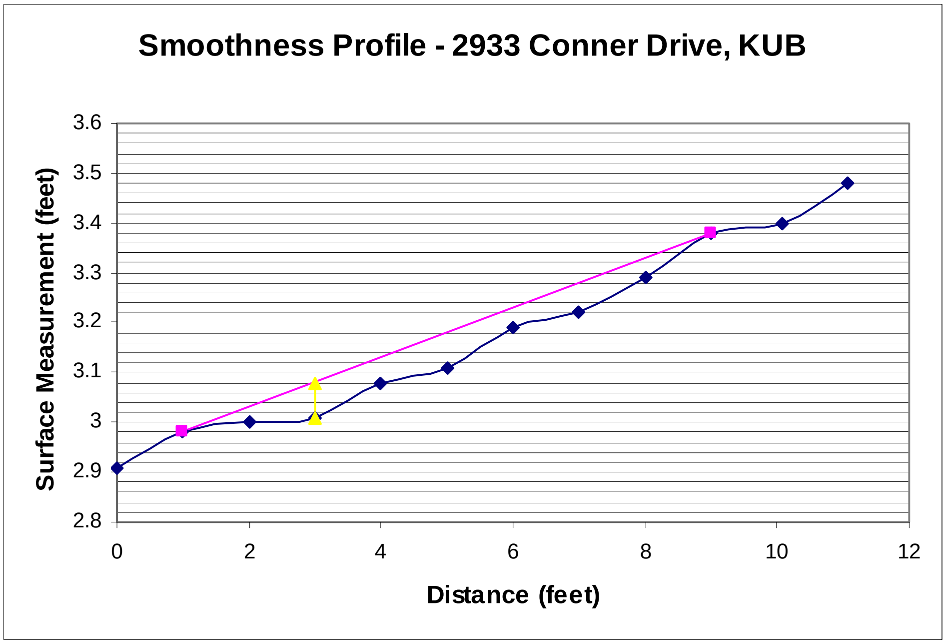

Figure 121 – Smoothness Profile – 2933 Conner Drive, KUB


Figure 122 – Photographs – 2933 Conner Drive, KUB

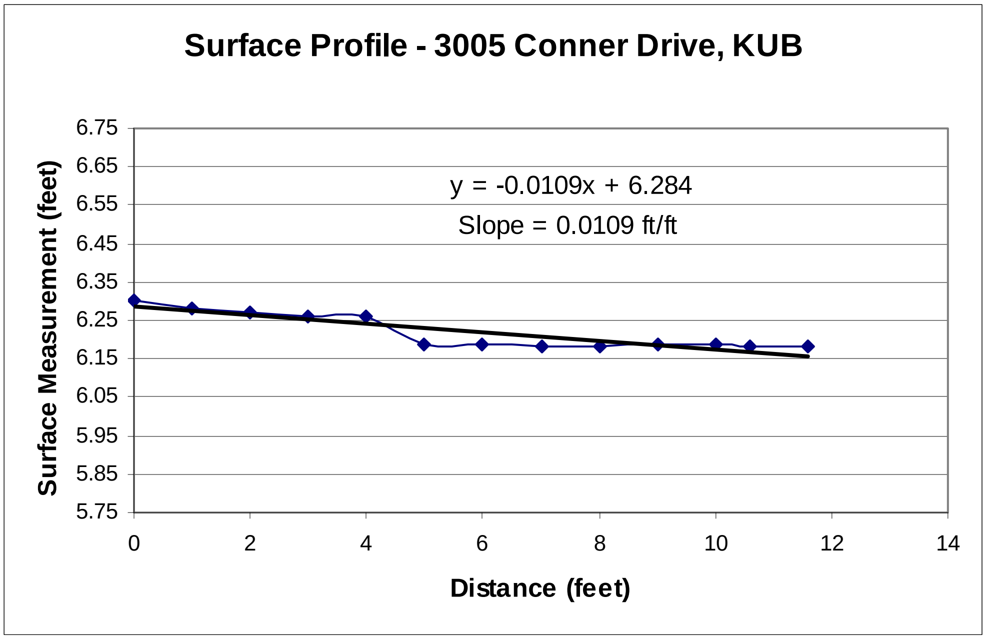

Figure 123 – Surface Profile – 3005 Conner Drive, KUB

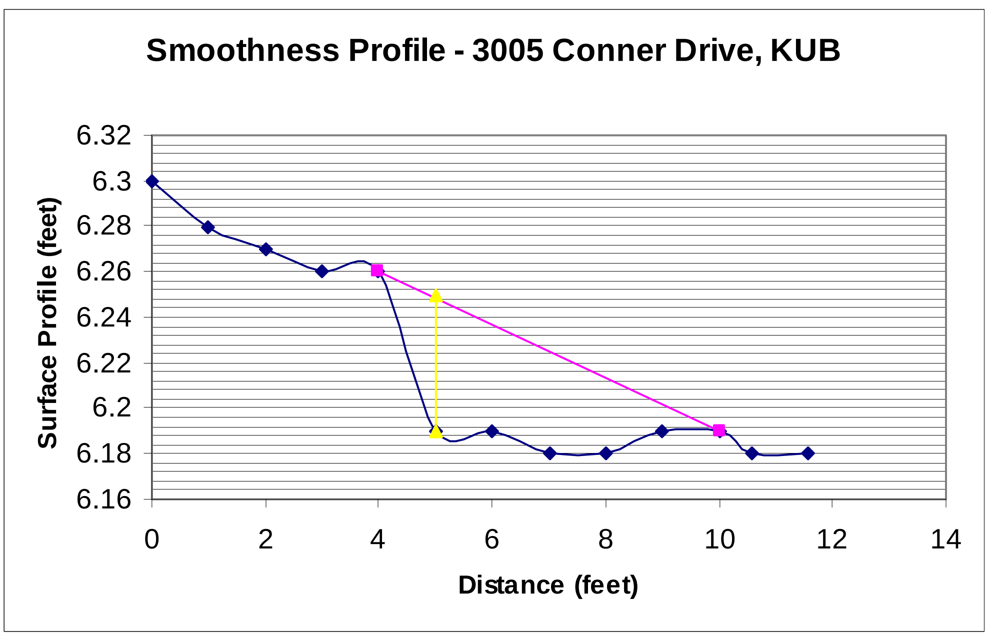

Figure 124 – Smoothness Profile – 3005 Conner Drive, KUB

Figure 125 – Photographs – 3005 Conner Drive, KUB

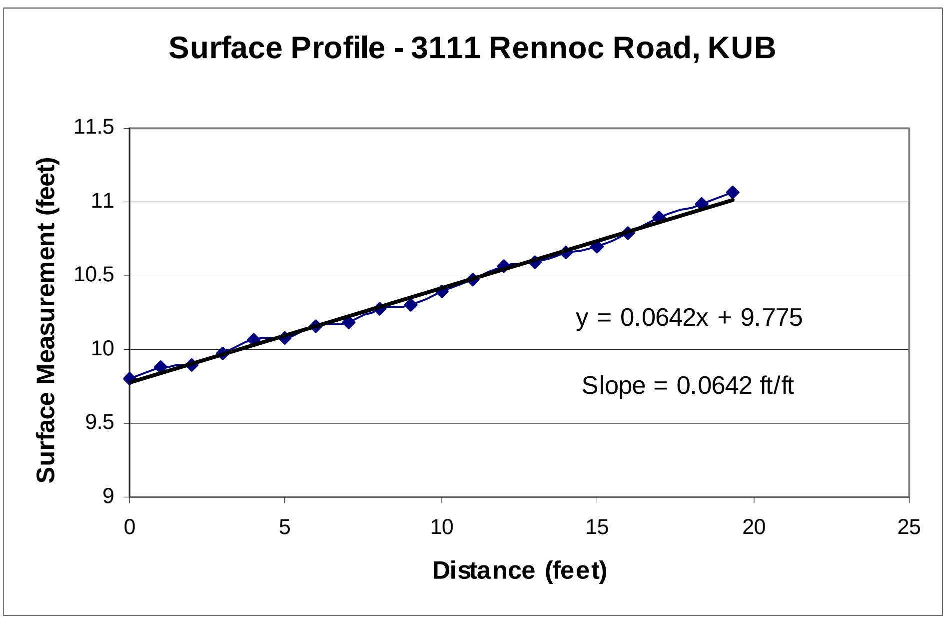

Figure 126 – Surface Profile – 3111 Rennoc Road, KUB

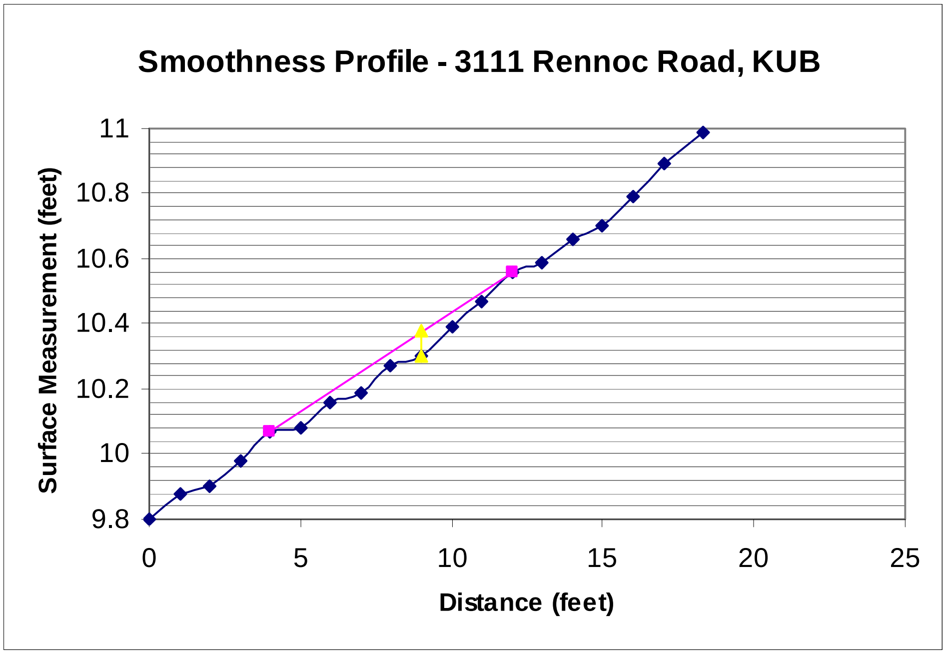

Figure 127 – Smoothness Profile – 3111 Rennoc Road, KUB


Figure 128 – Photographs – 3111 Rennoc Road, KUB

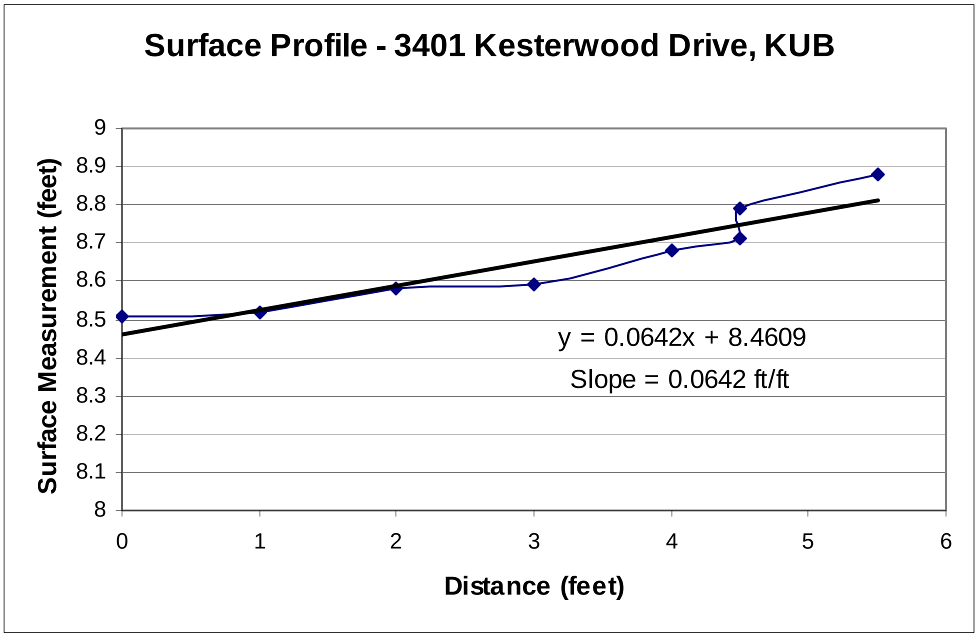

Figure 129 – Surface Profile – 3401 Kesterwood Drive, KUB

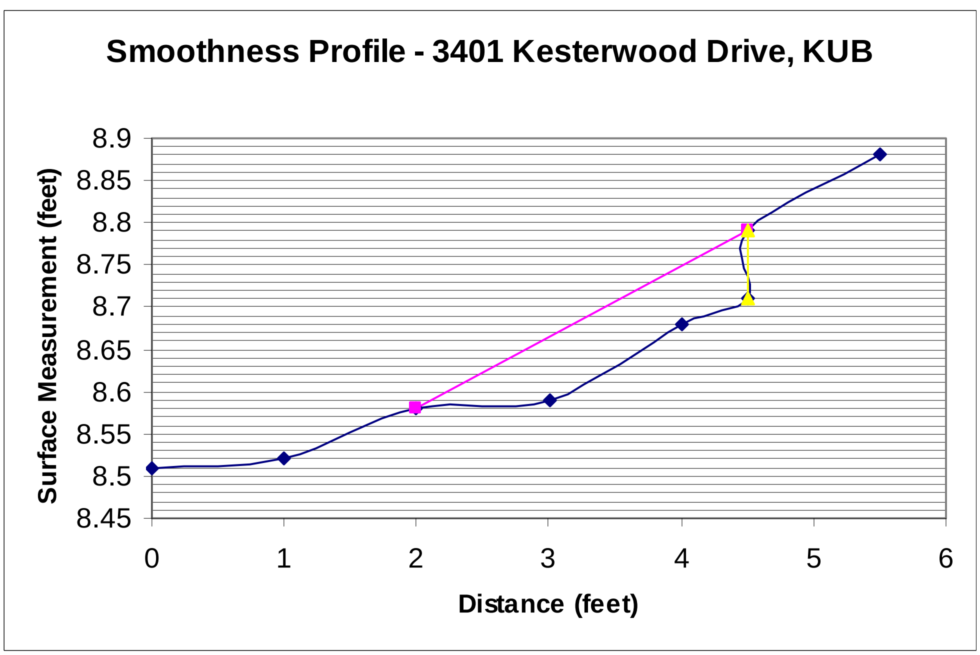

Figure 130 – Smoothness Profile – 3401 Kesterwood Drive, KUB

Figure 131 – Photographs – 3401 Kesterwood Drive, KUB

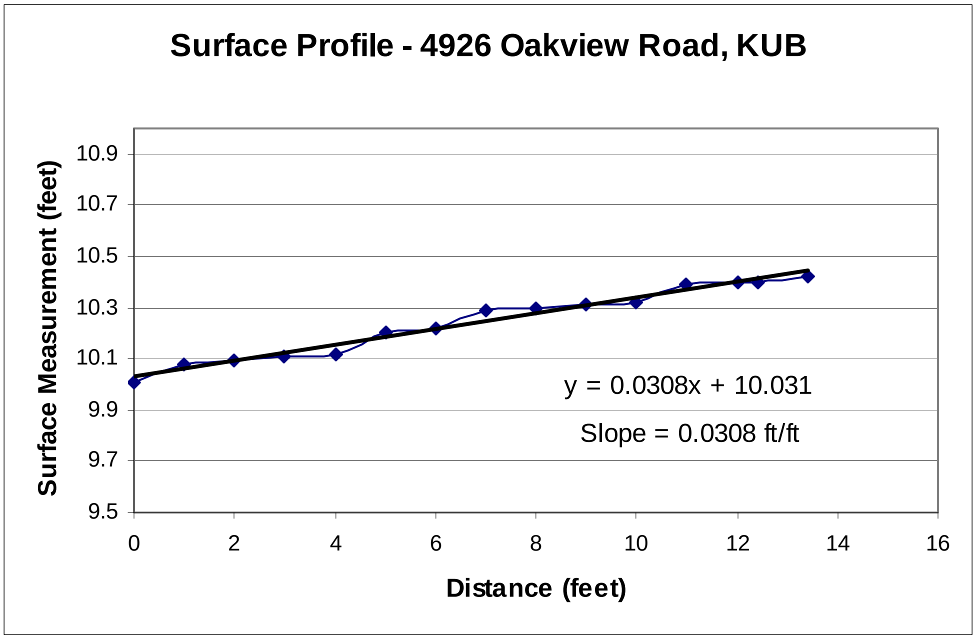

Figure 132 – Surface Profile – 4926 Oakview Road, KUB

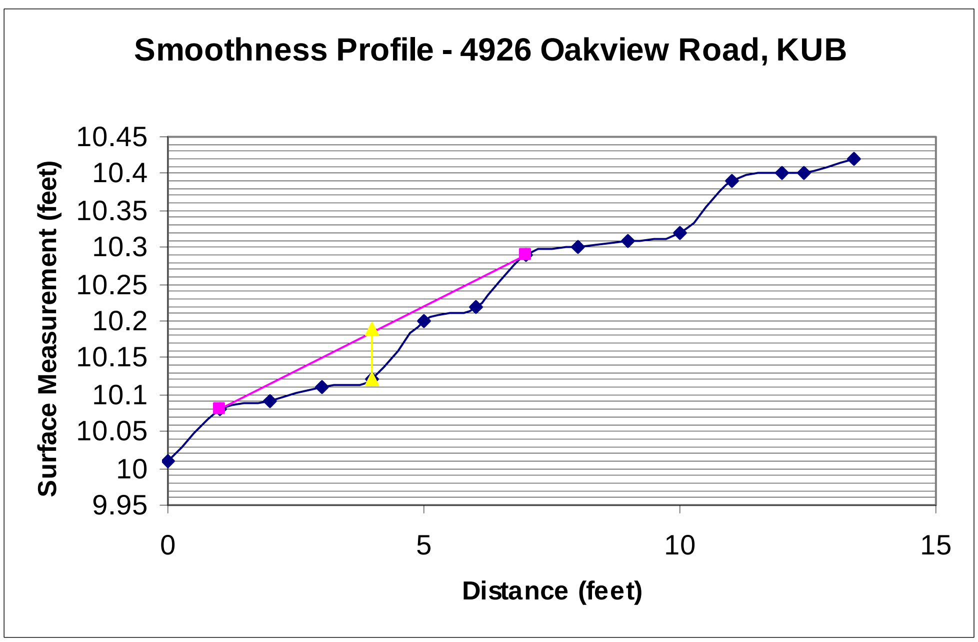

Figure 133 – Smoothness Profile – 4926 Oakview Road, KUB

Figure 134 – Photographs – 4926 Oakview Road, KUB

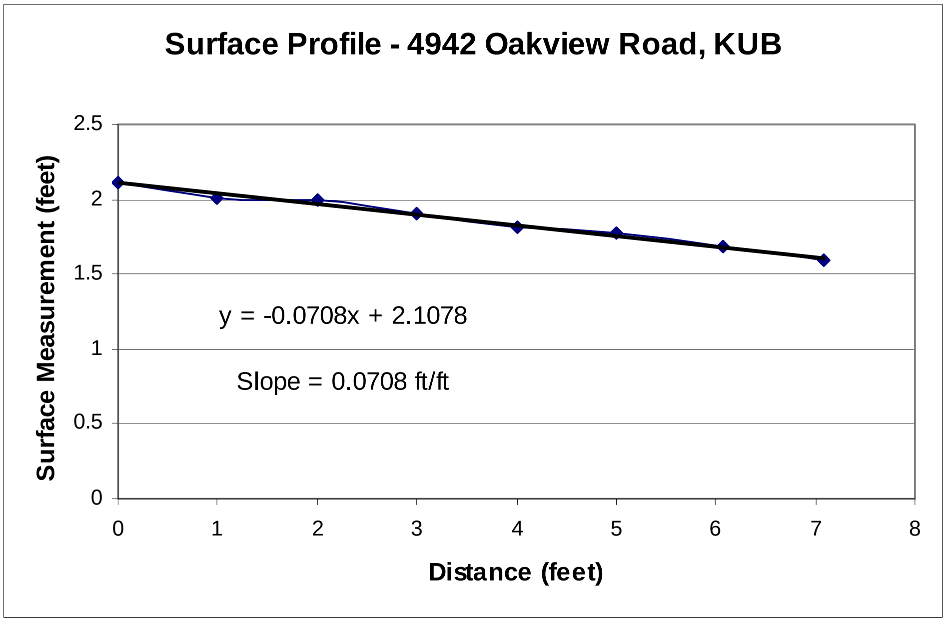

Figure 135 – Surface Profile – 4942 Oakview Road, KUB

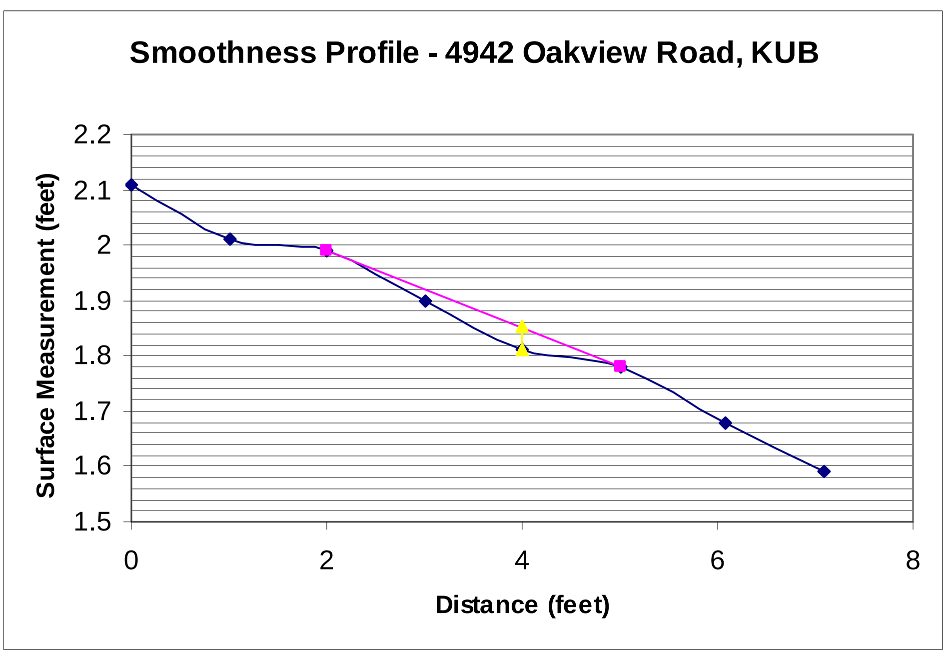

Figure 136 – Smoothness Profile – 4942 Oakview Road, KUB

Figure 137 – Photographs – 4942 Oakview Road, KUB

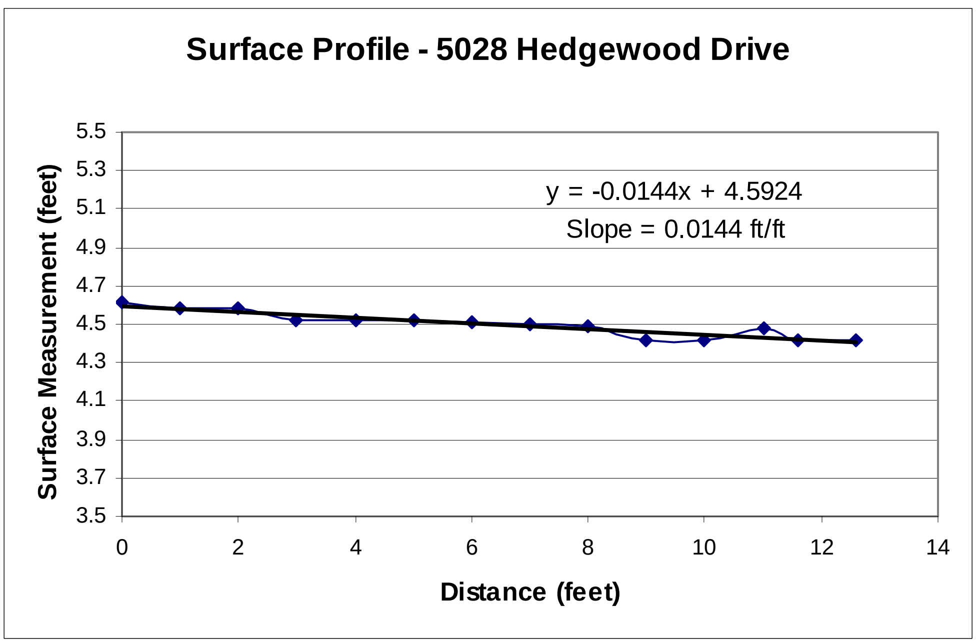

Figure 138 – Surface Profile – 5028 Hedgewood Drive, KUB

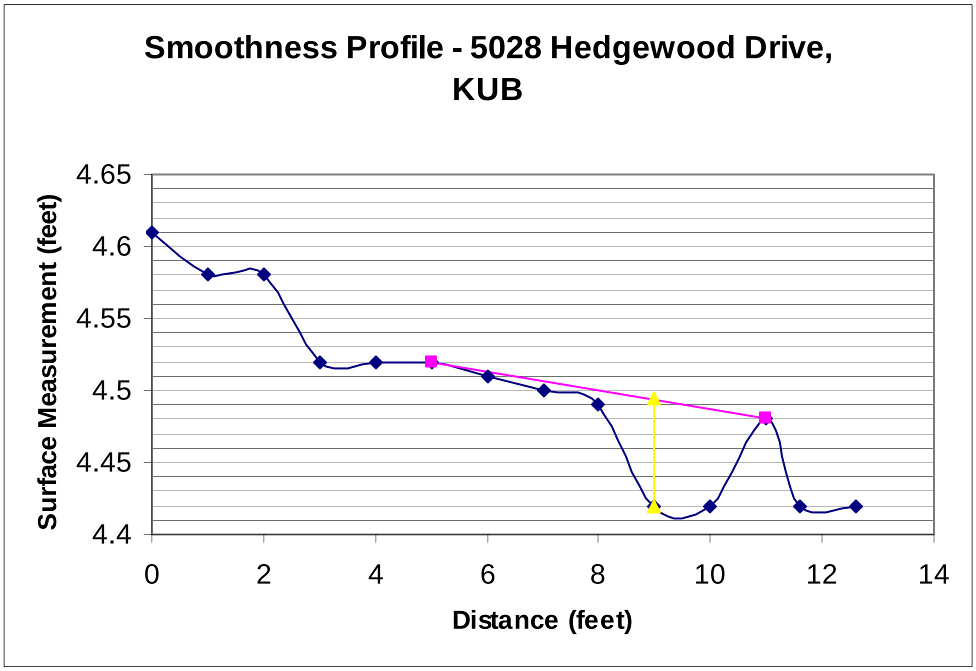

Figure 139 – Smoothness Profile – 5028 Hedgewood Drive, KUB

Figure 140 – Photographs – 5028 Hedgewood Drive, KUB

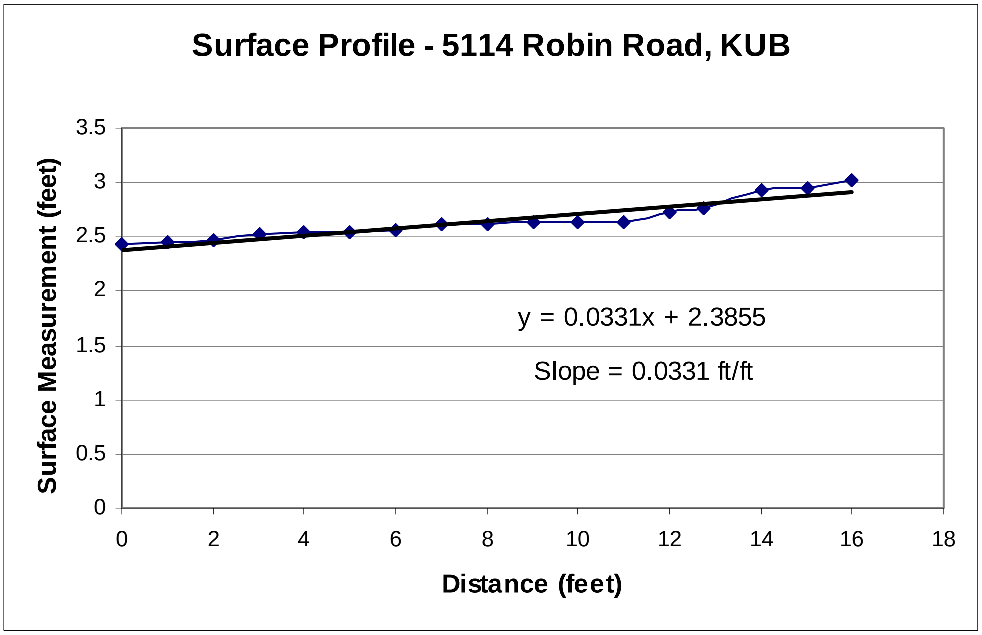

Figure 141 – Surface Profile – 5114 Robin Road, KUB

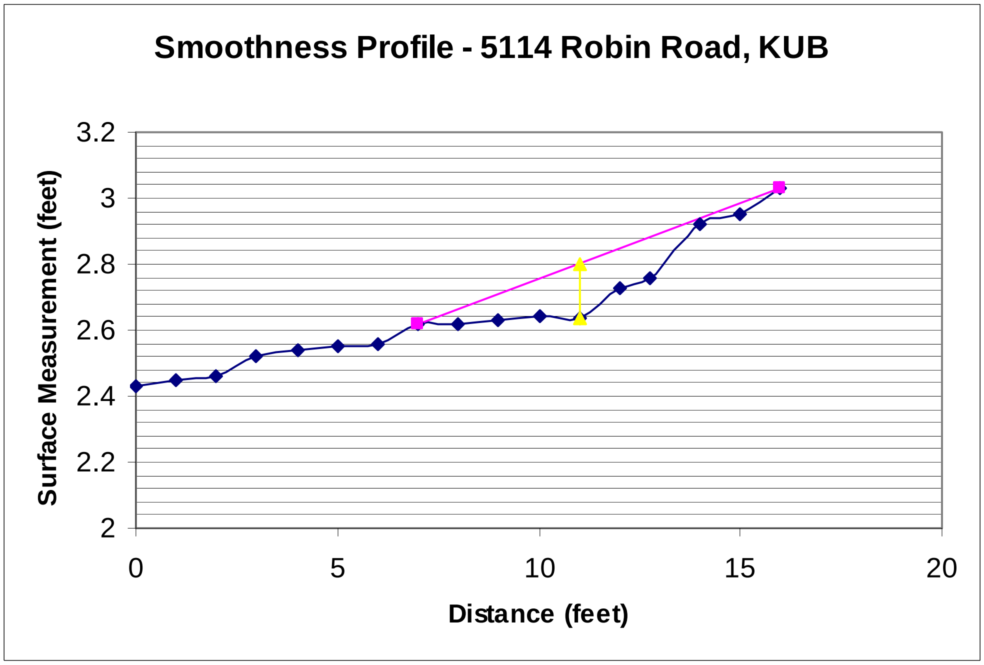

Figure 142 – Smoothness Profile – 5114 Robin Road, KUB

Figure 143 – Photographs – 5114 Robin Road, KUB

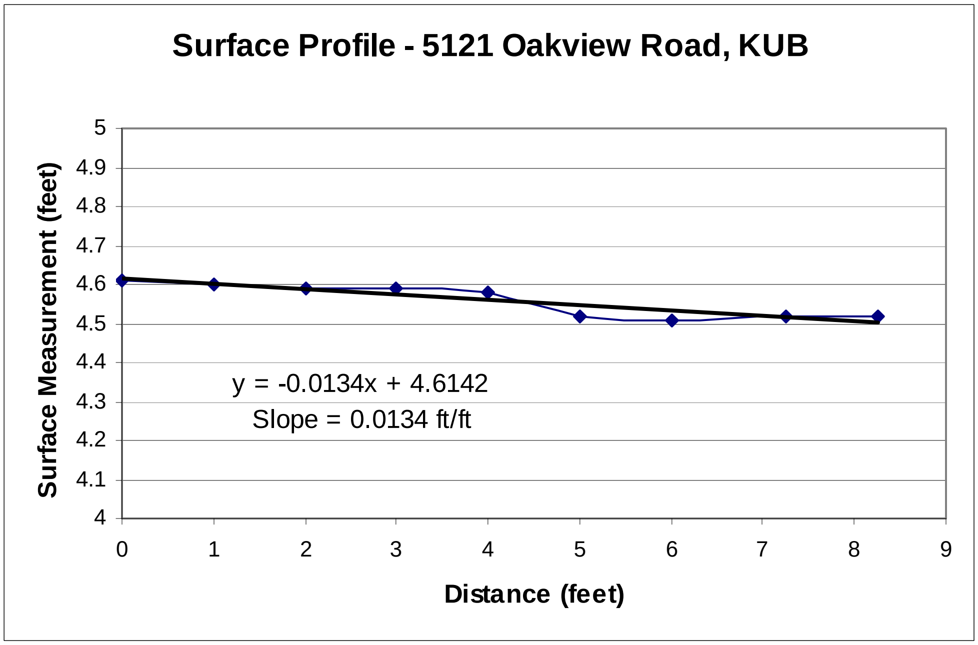

Figure 144 – Surface Profile – 5121 Oakview Road, KUB

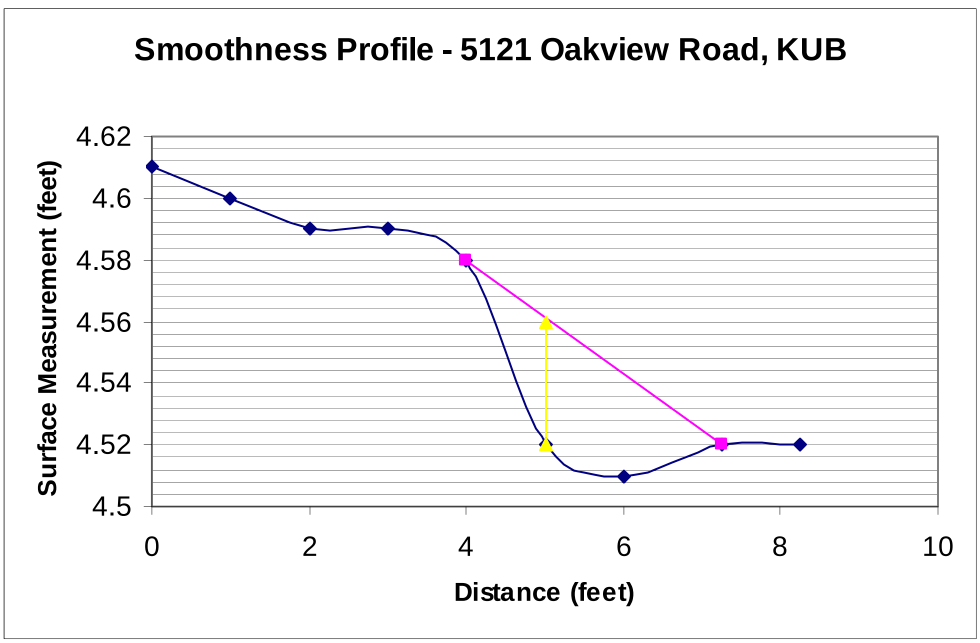

Figure 145 – Smoothness Profile – 5121 Oakview Road, KUB

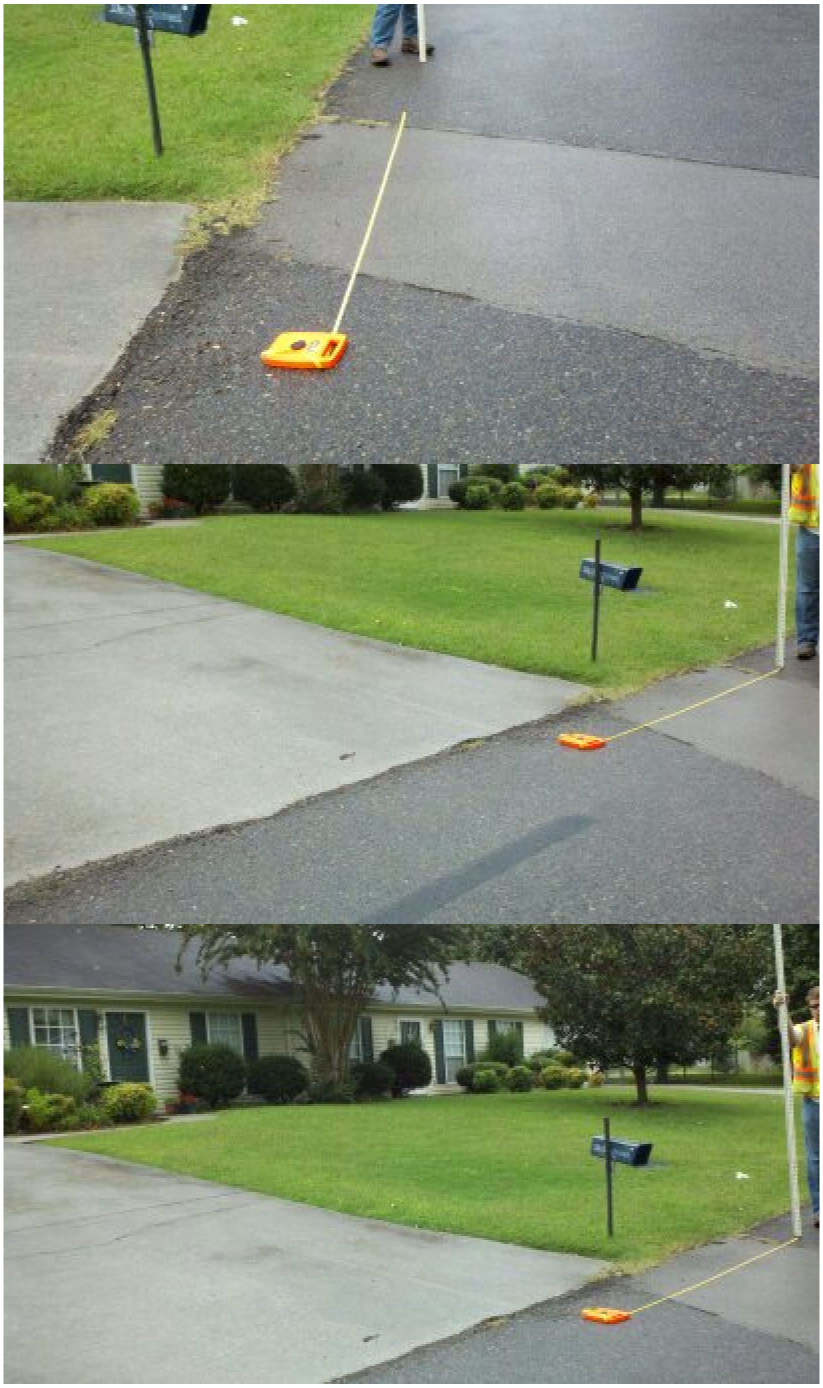

Figure 146 –Photographs – 5121 Oakview Road, KUB

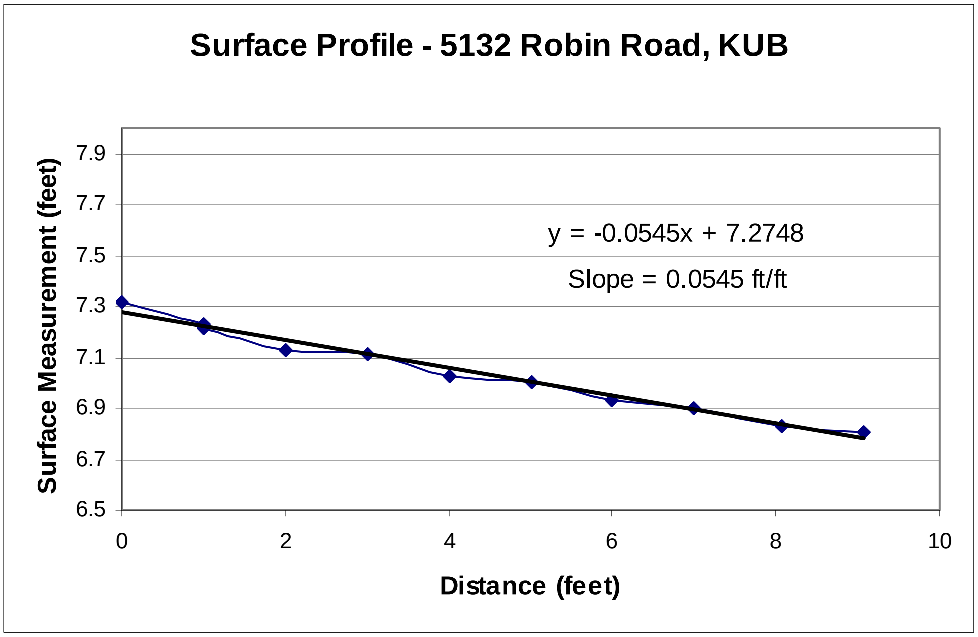

Figure 147 – Surface Profile – 5132 Robin Road, KUB

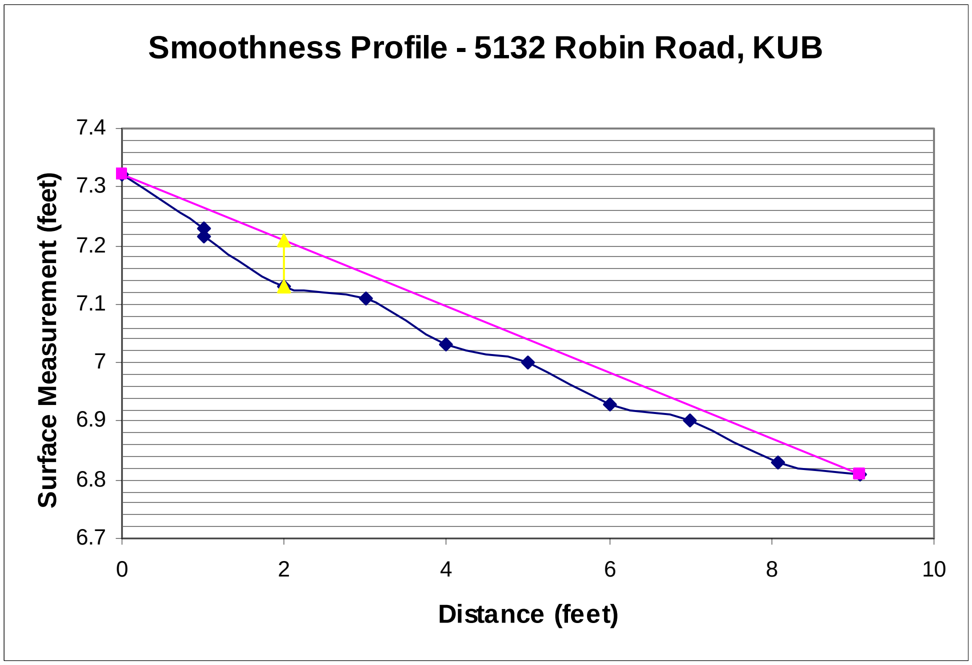

Figure 148 – Smoothness Profile – 5132 Robin Road, KUB

Figure 149 – Photographs – 5132 Robin Road, KUB

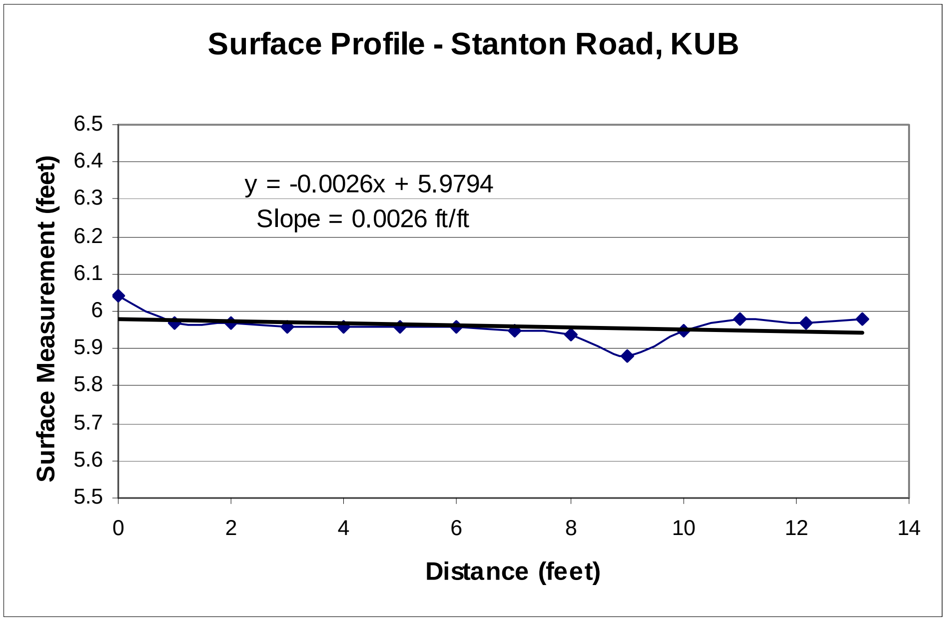

Figure 150 – Surface Profile – Stanton Road, KUB

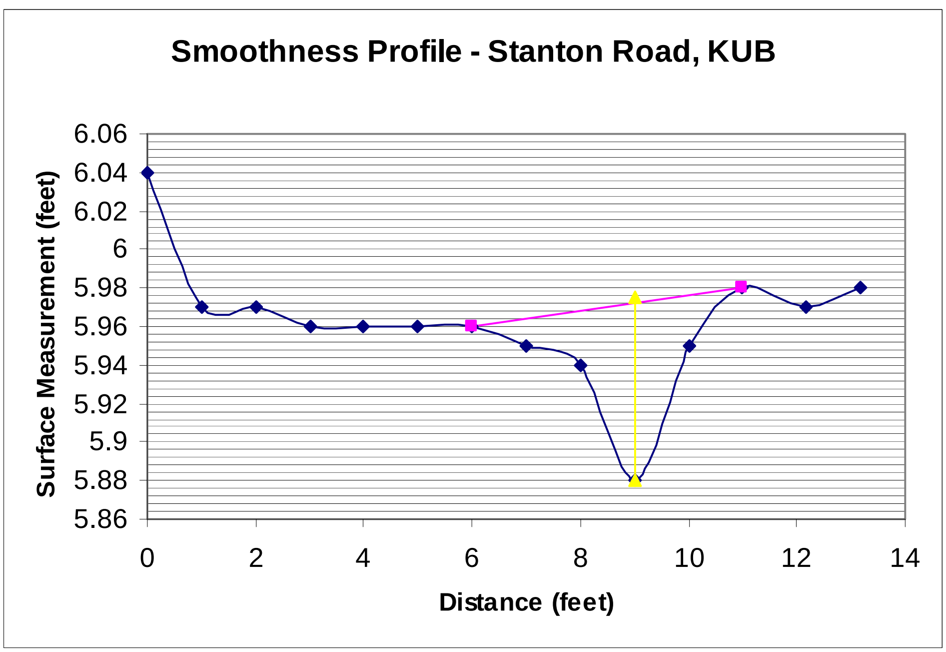

Figure 151 – Smoothness Profile – Stanton Road, KUB

Figure 152 – Photographs – Stanton Road, KUB

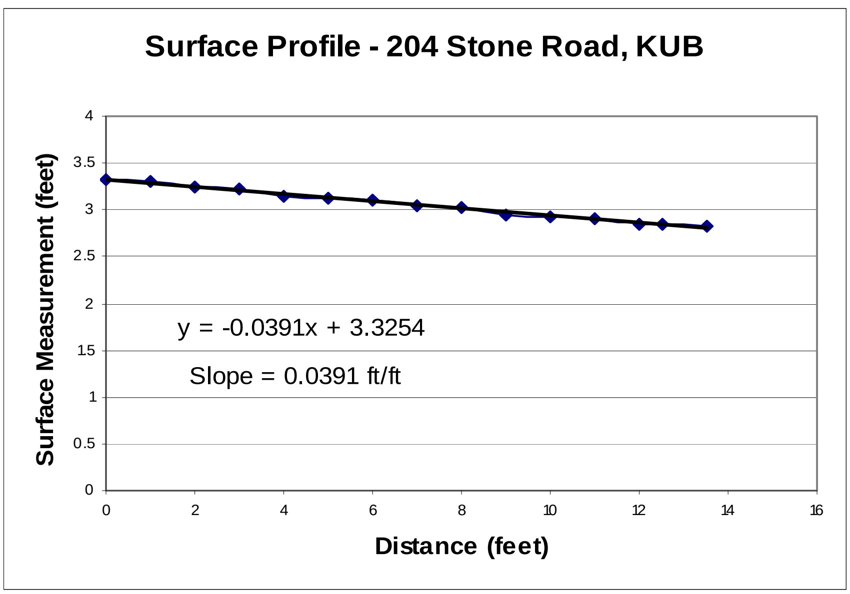

Figure 153 – Surface Profile – 204 Stone Road, KUB

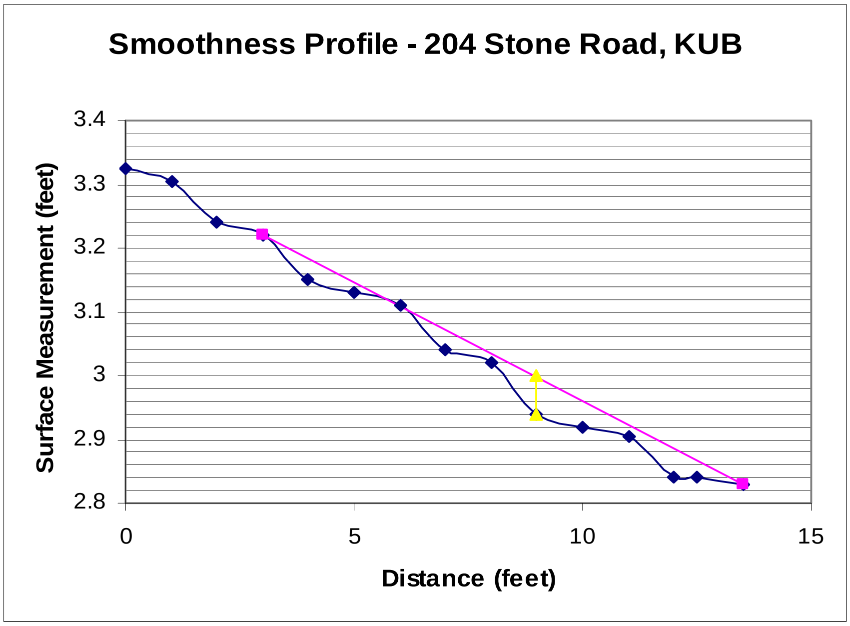

Figure 154 – Smoothness Profile – 204 Stone Road, KUB


Figure 155 – Photographs – 204 Stone Road, KUB

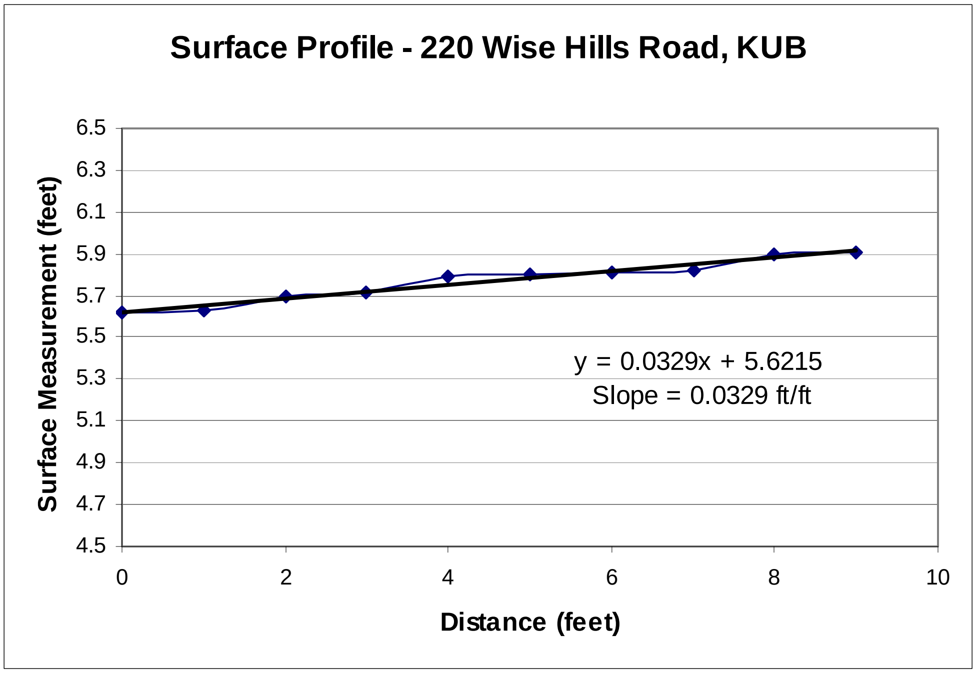

Figure 156 – Surface Profile – 220 Wise Hills Road, KUB

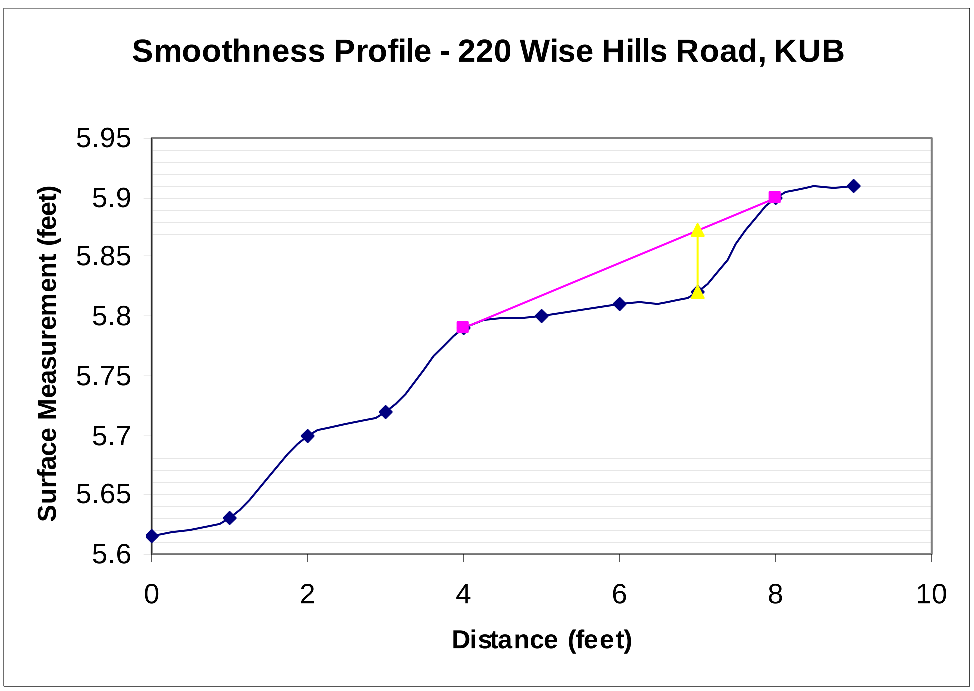

Figure 157 – Smoothness Profile – 220 Wise Hills Road, KUB

Figure 158 – Photographs – 220 Wise Hills Road, KUB

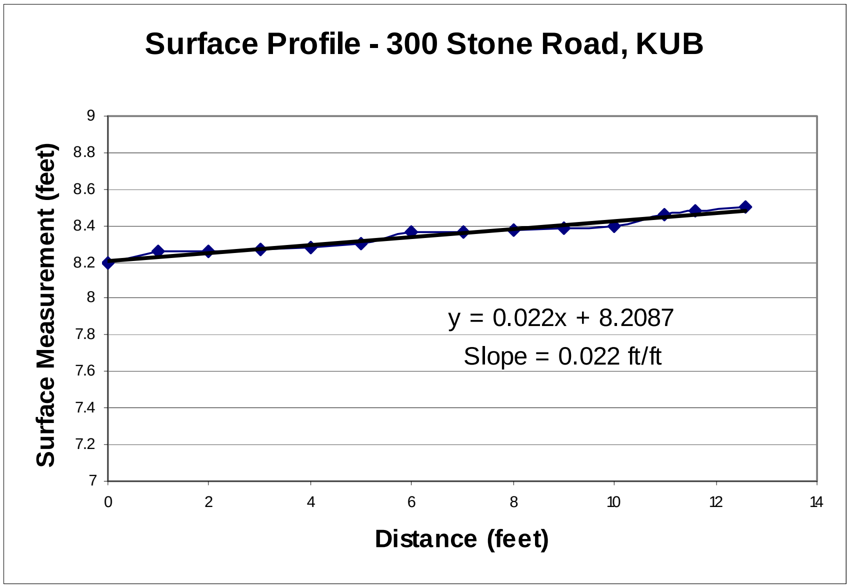

Figure 159 – Surface Profile – 300 Stone Road, KUB

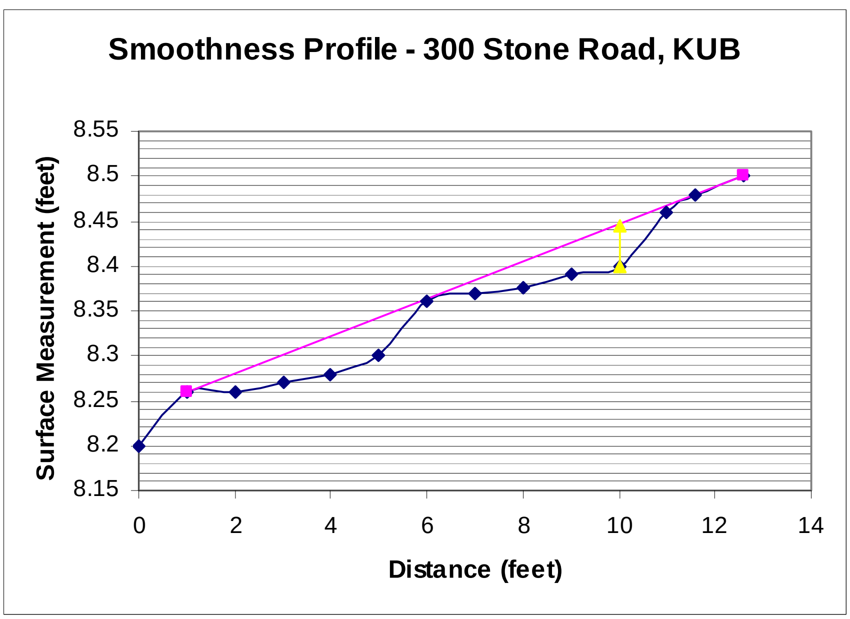

Figure 160 – Smoothness Profile – 300 Stone Road, KUB

Figure 161 – Photographs – 300 Stone Road, KUB

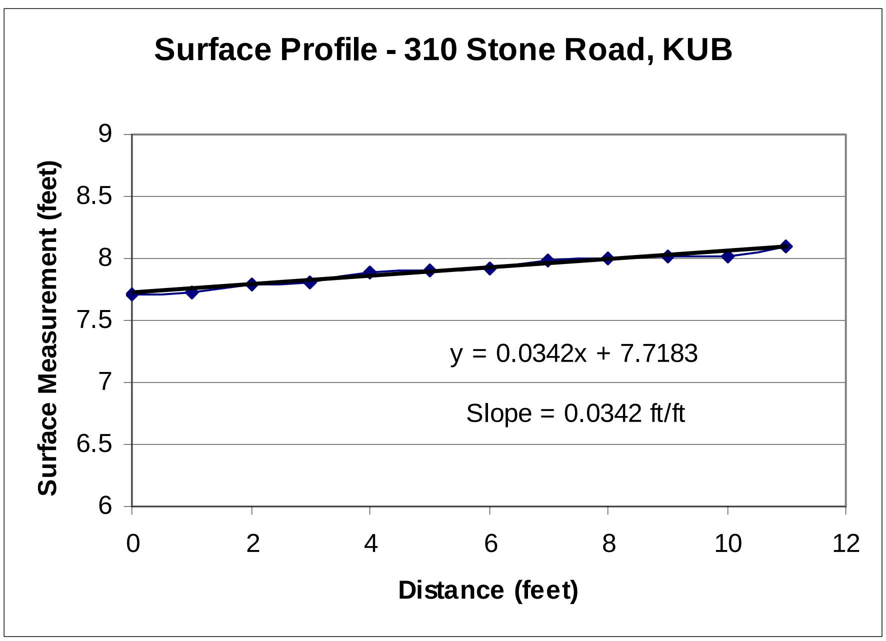

Figure 162 – Surface Profile – 310 Stone Road, KUB

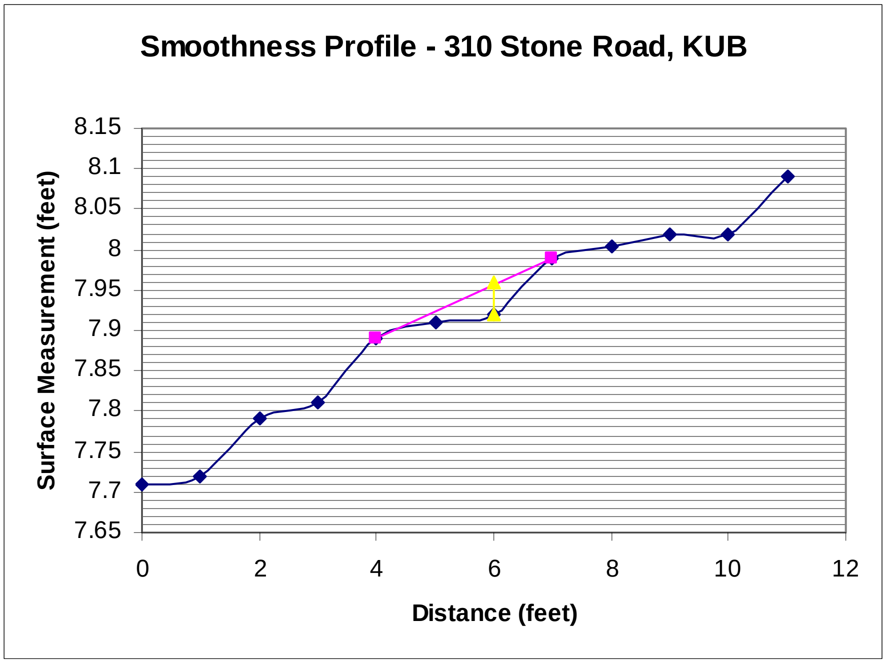

Figure 163 – Smoothness Profile – 310 Stone Road, KUB

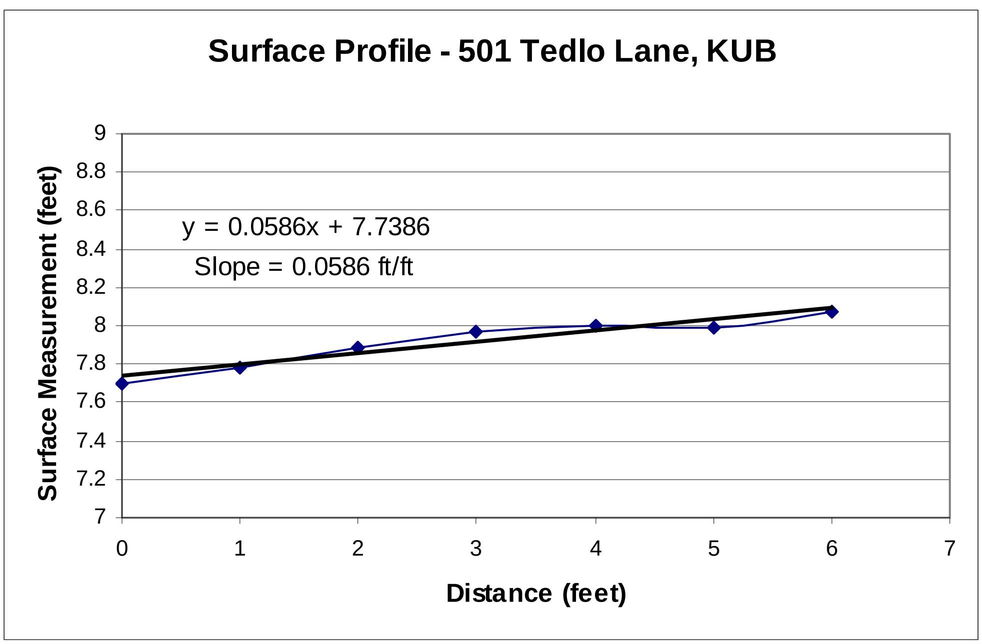

Figure 164 – Surface Profile – 501 Tedlo Lane, KUB

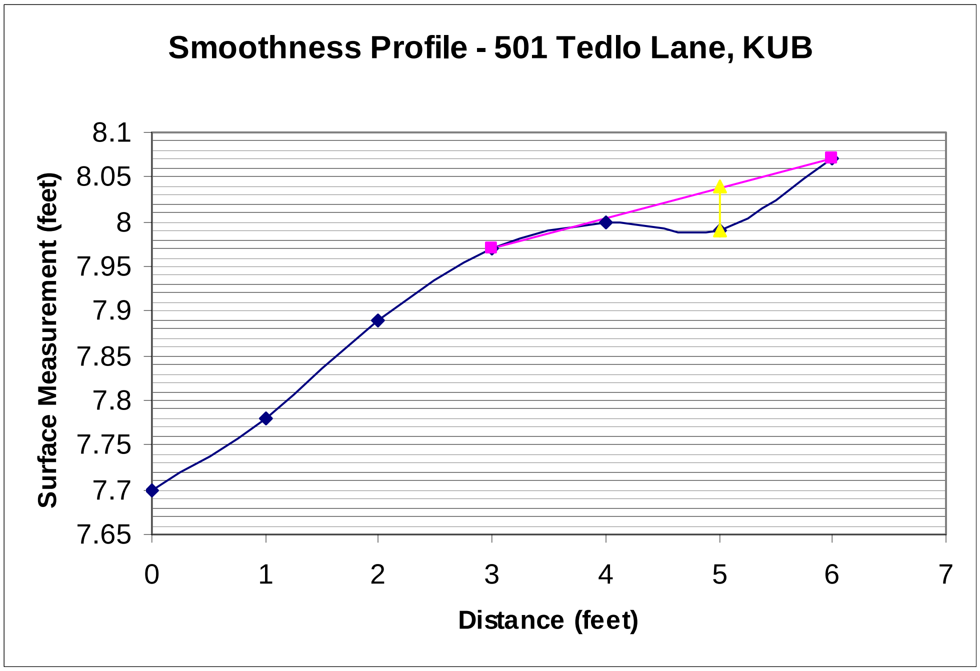

Figure 165 – Smoothness Profile – 501 Tedlo Lane, KUB

Figure 166 – Photographs – 501 Tedlo Lane, KUB

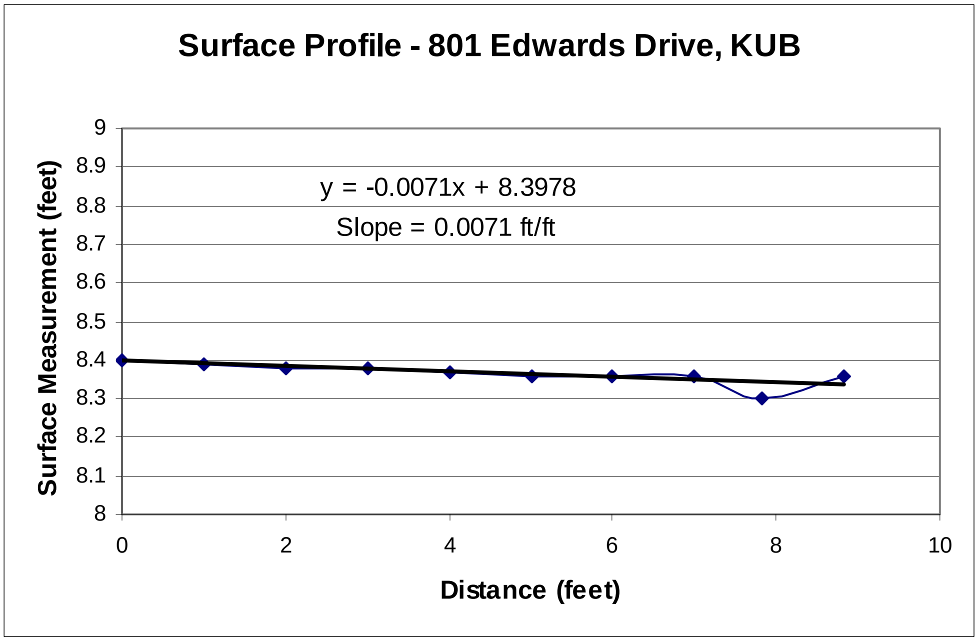

Figure 167 – Surface Profile – 801 Edwards Drive, KUB

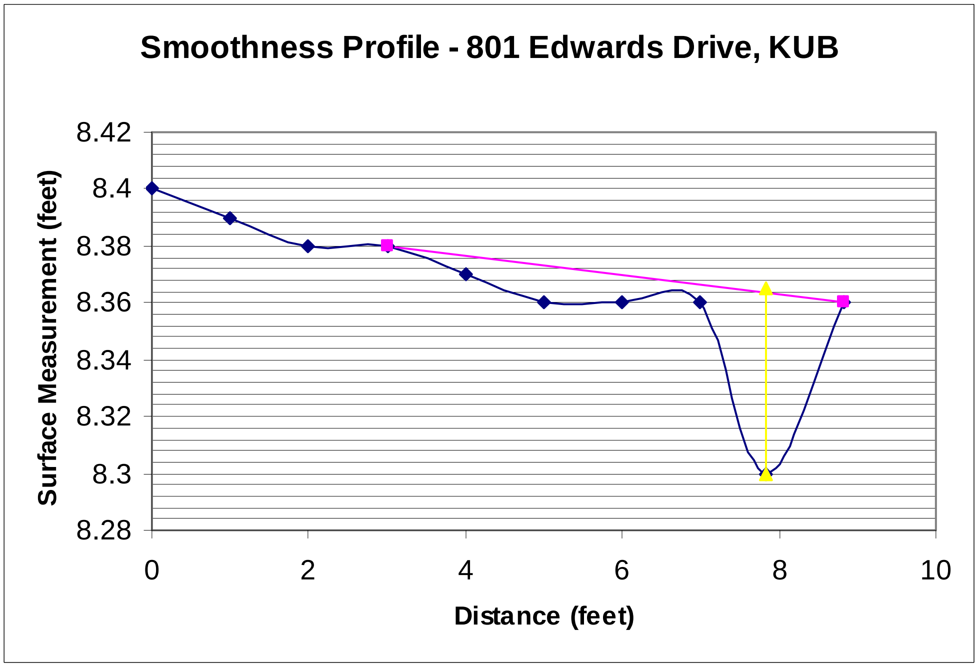

Figure 168 – Smoothness Profile – 801 Edwards Drive, KUB

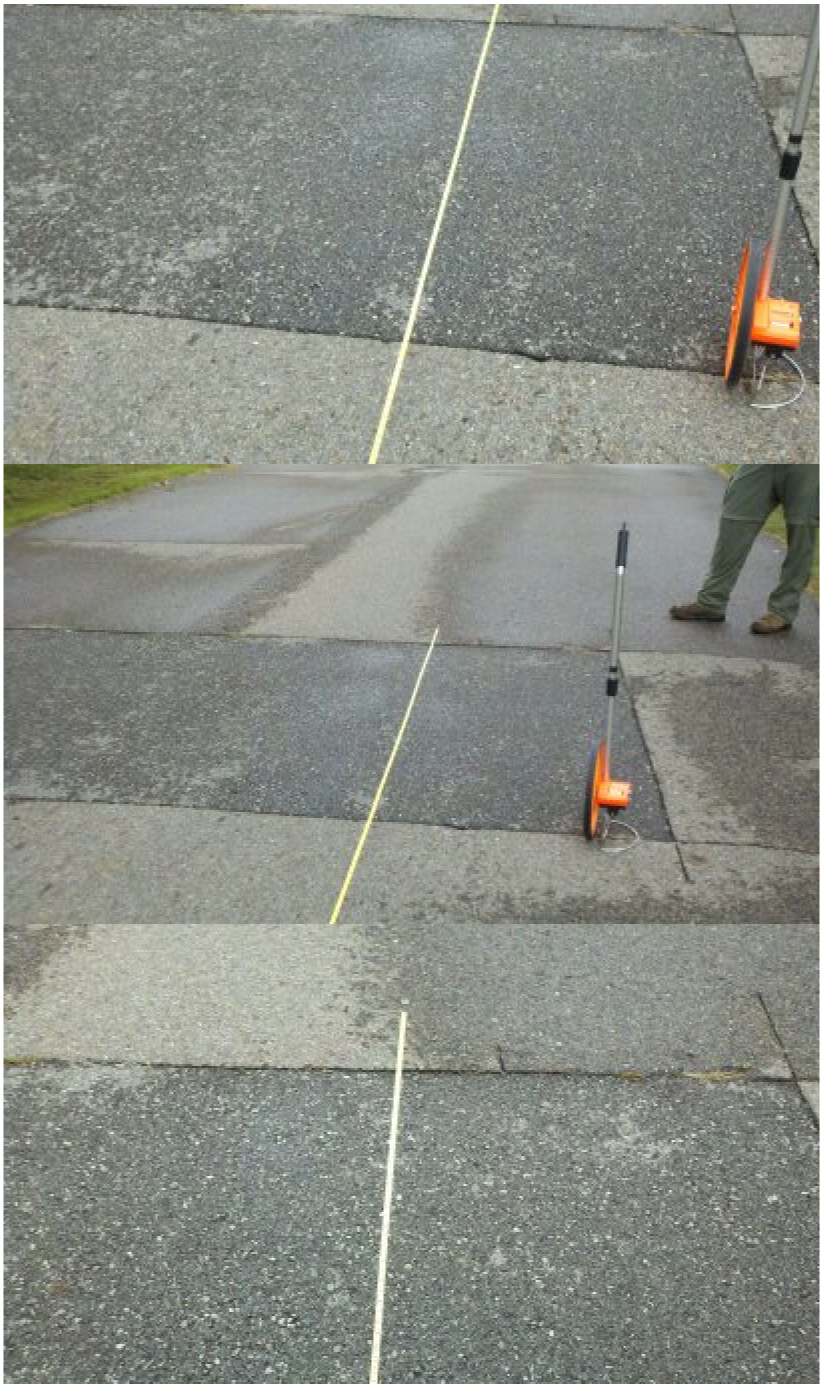

Figure 169 – Photographs – 801 Edwards Drive, KUB

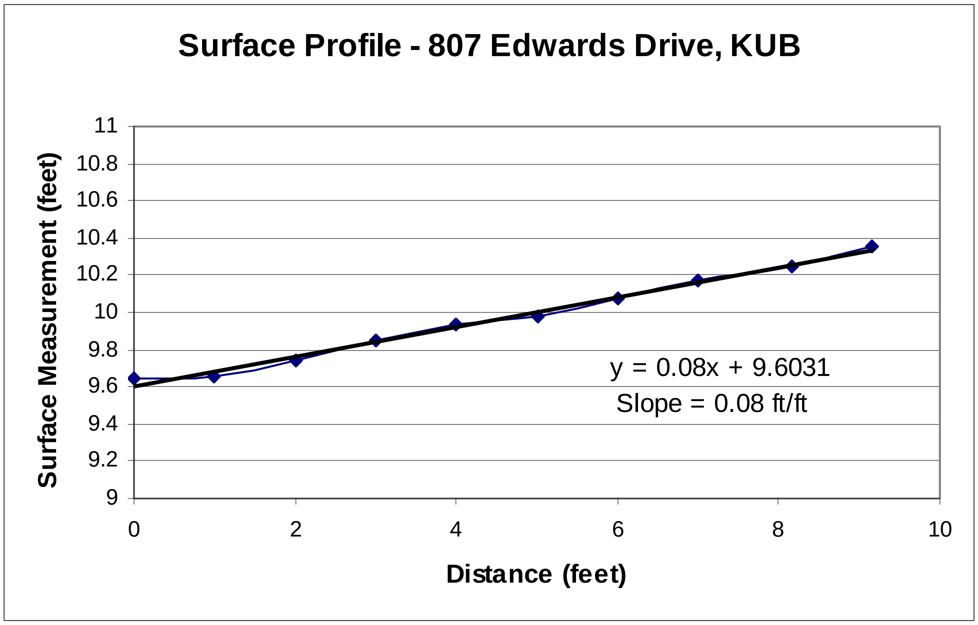

Figure 170 – Surface Profile – 807 Edwards Drive, KUB

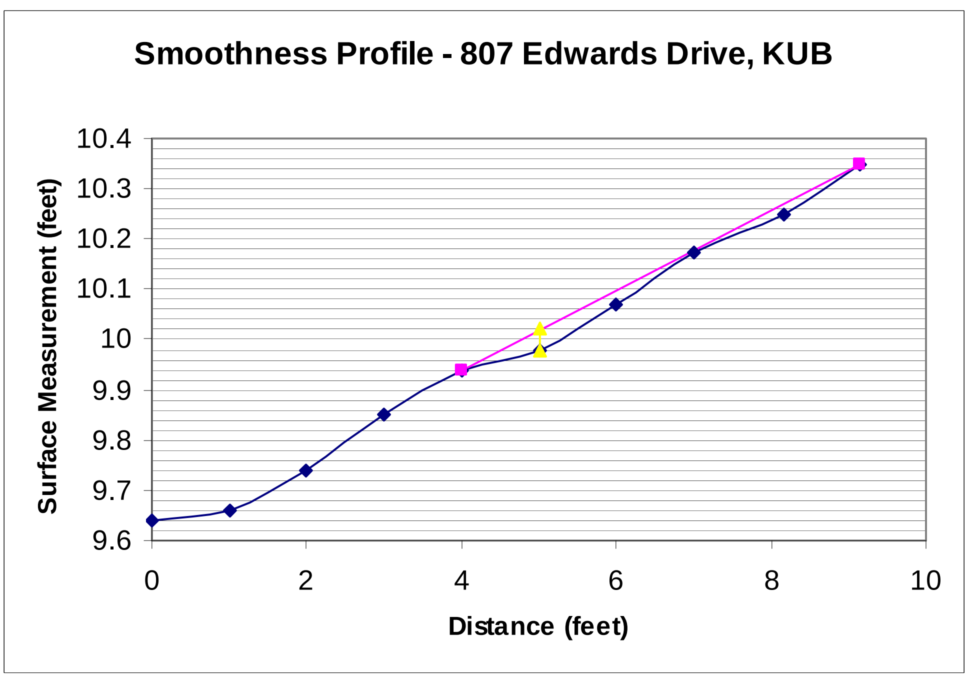

Figure 171 – Smoothness Profile – 807 Edwards Drive, KUB

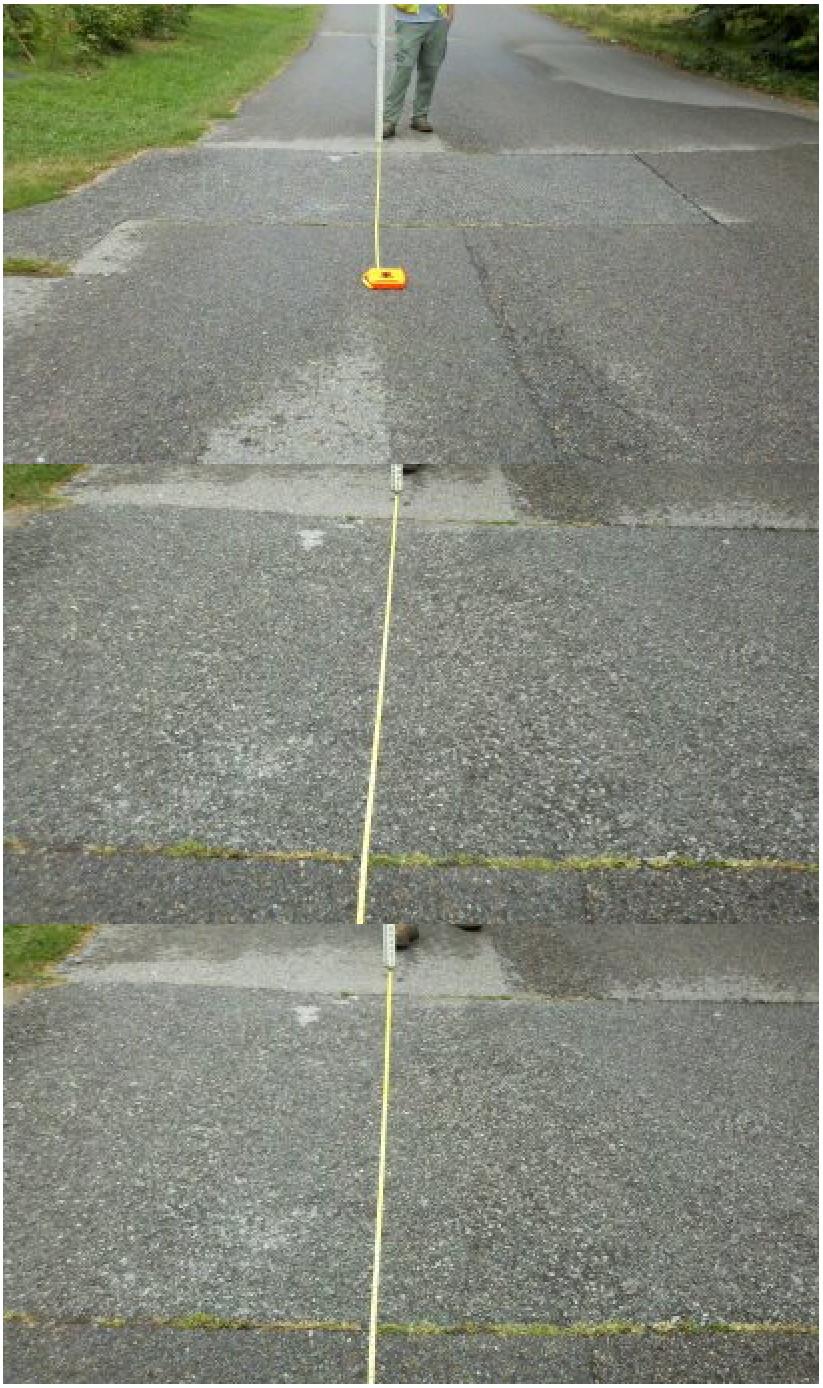
Figure 172 – Photographs – 807 Edwards Drive, KUB

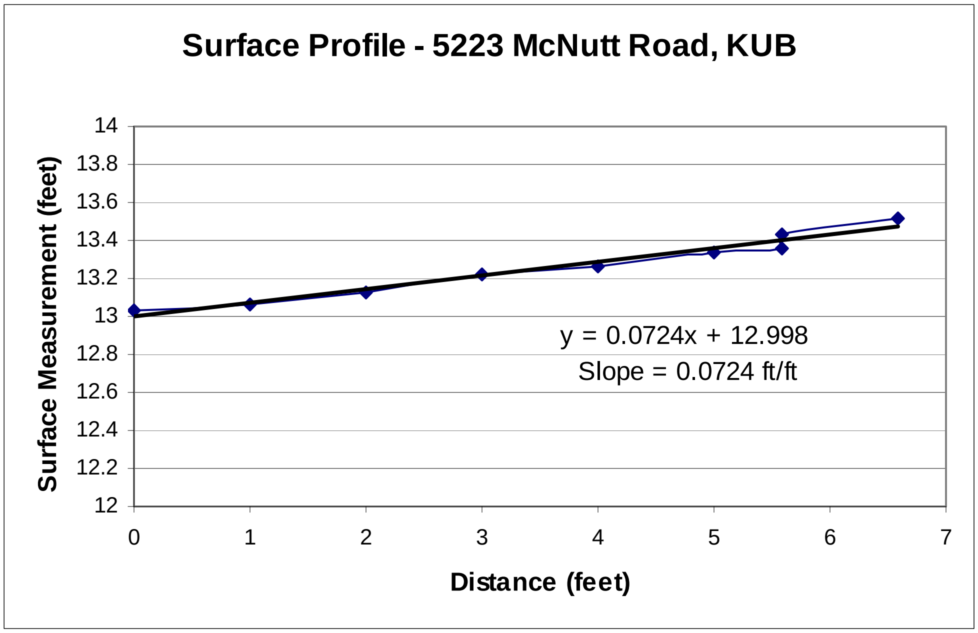

Figure 173 – Surface Profile – 5223 McNutt Road, KUB

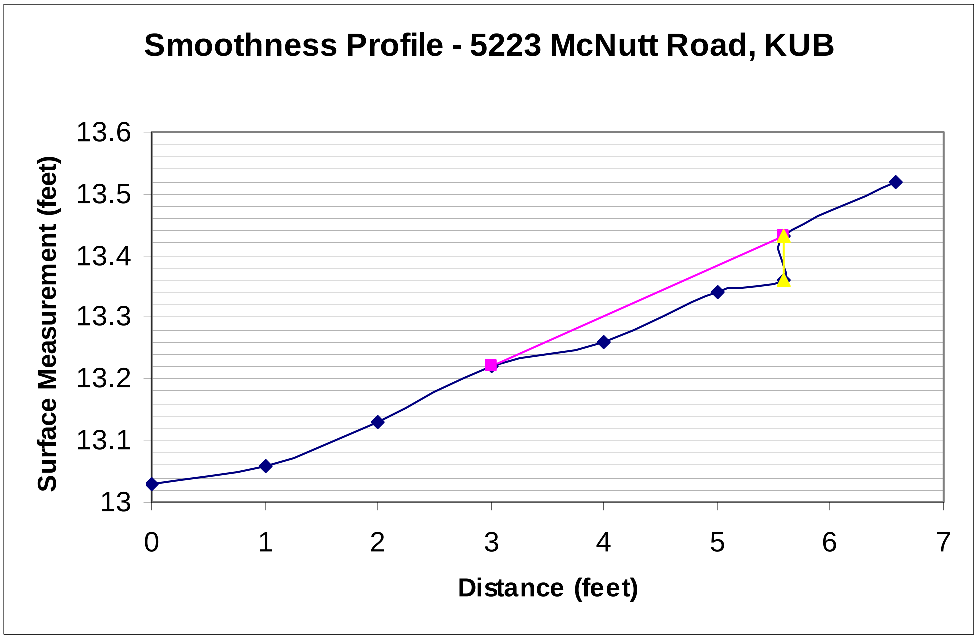

Figure 174 – Smoothness Profile – 5223 McNutt Road, KUB

Figure 175 – Photographs – 5223 McNutt Road, KUB

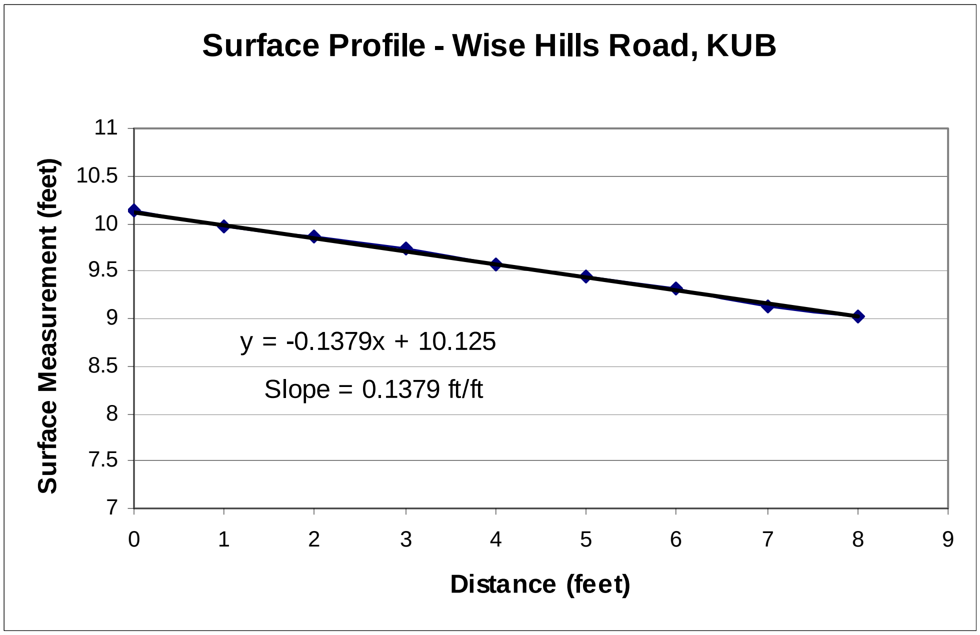

Figure 176 – Surface Profile – Wise Hills Road, KUB

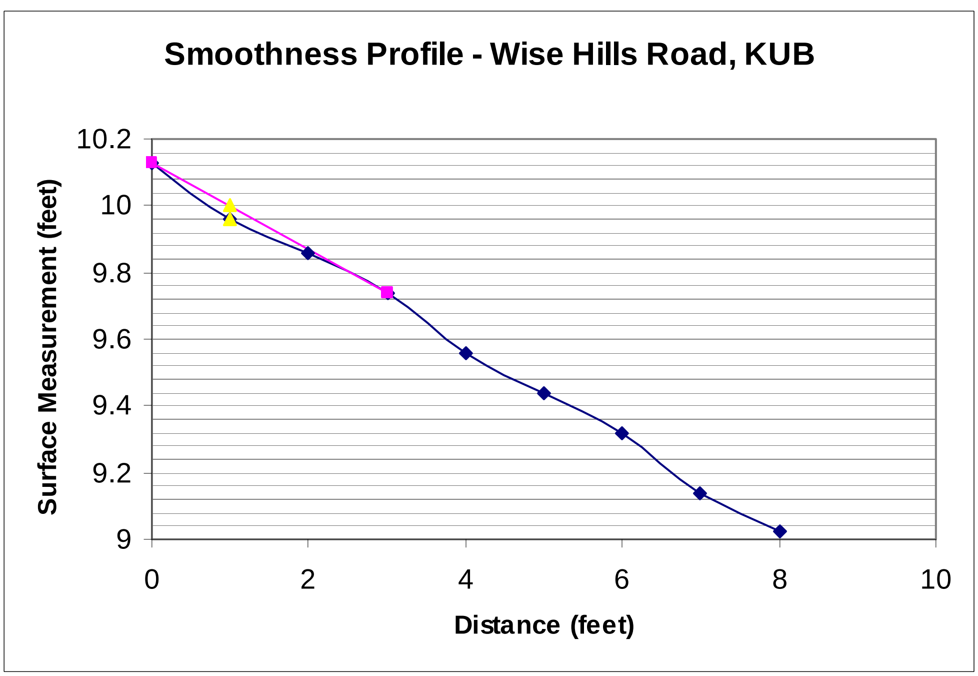

Figure 177 – Smoothness Profile – Wise Hills Road, KUB

Figure 178 – Photographs – Wise Hills Road, KUB

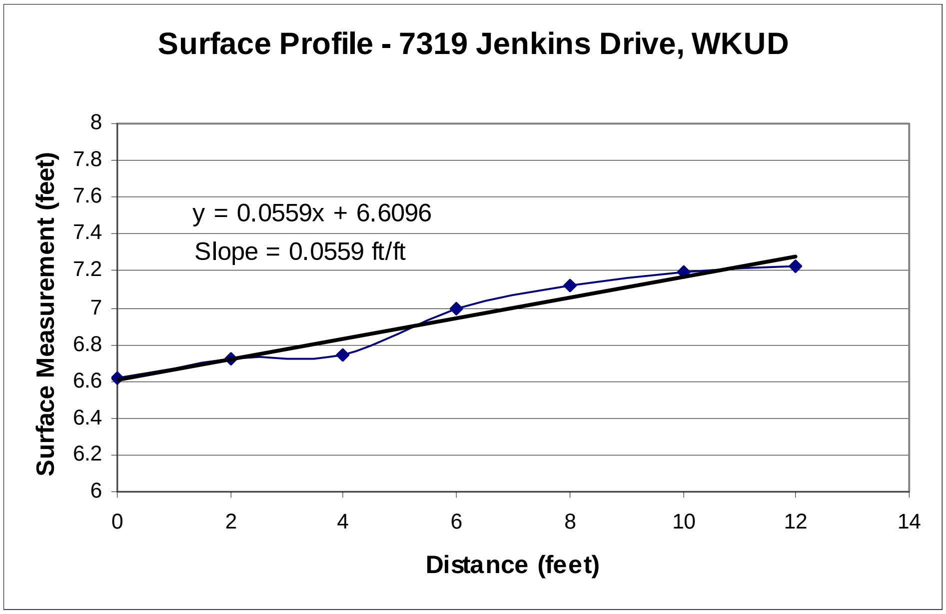

Figure 179 – Surface Profile – 7319 Jenkins Drive, WKUD

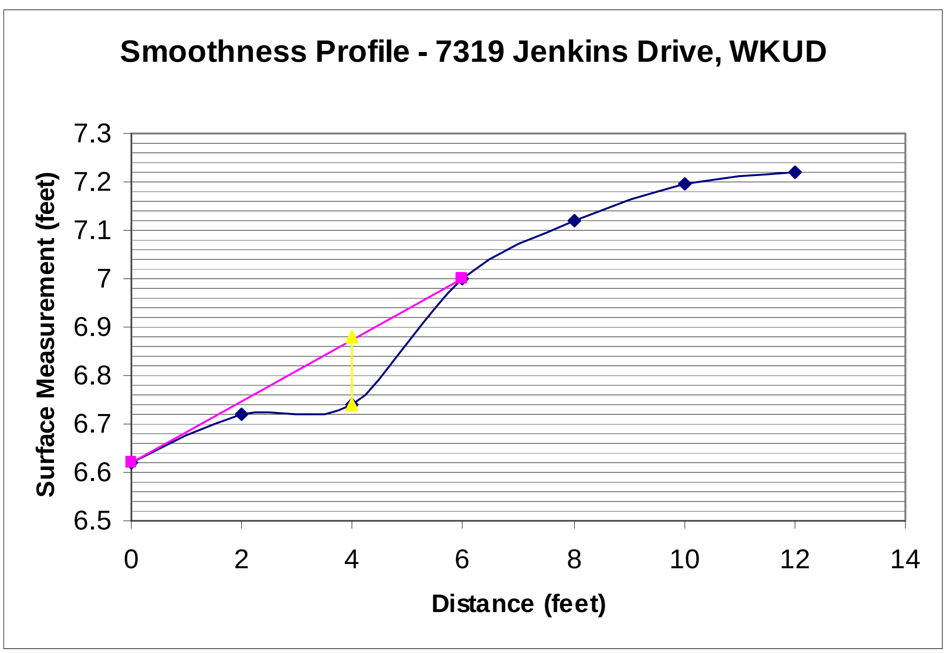

Figure 180 – Smoothness Profile – 7319 Jenkins Drive, WKUD

Figure 181 – Photographs – 7319 Jenkins Drive, WKUD

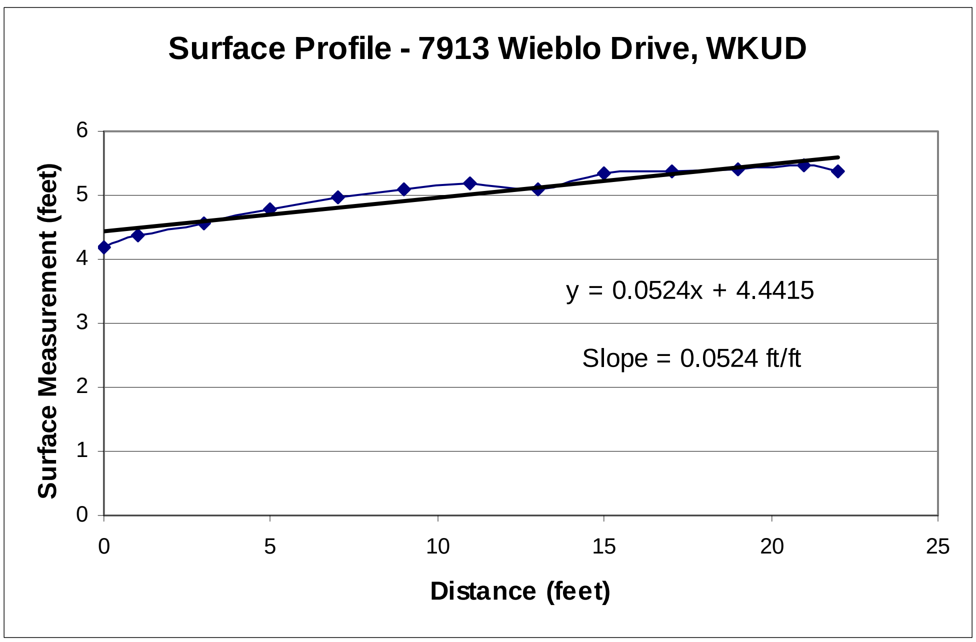

Figure 182 – Surface Profile – 7913 Wieblo Drive, WKUD

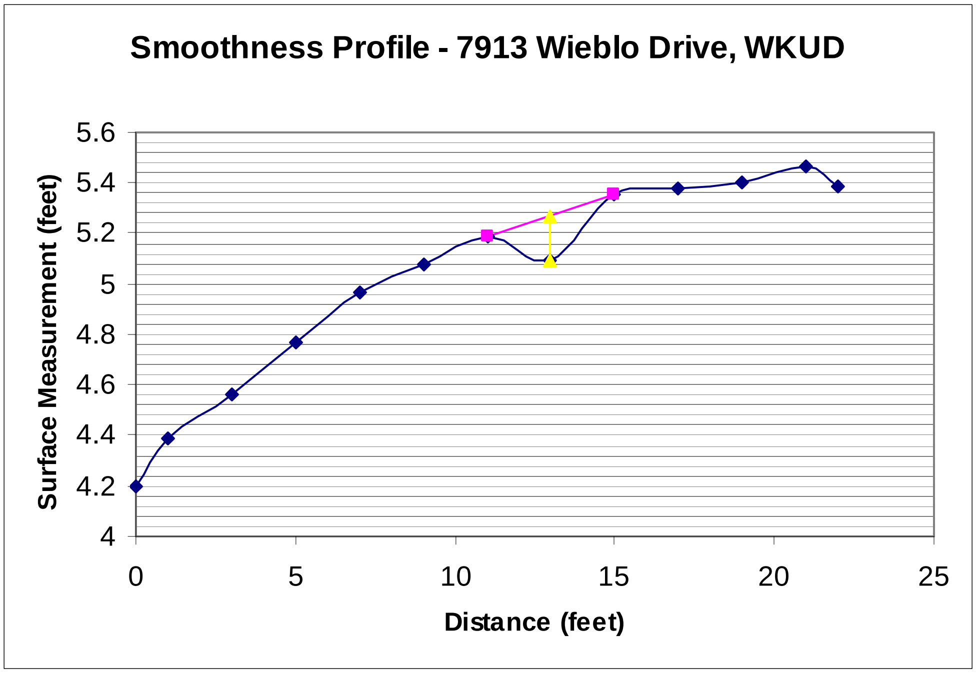

Figure 183 – Smoothness Profile – 7913 Wieblo Drive, WKUD

Figure 184 – Photographs – 7913 Wieblo Drive, WKUD

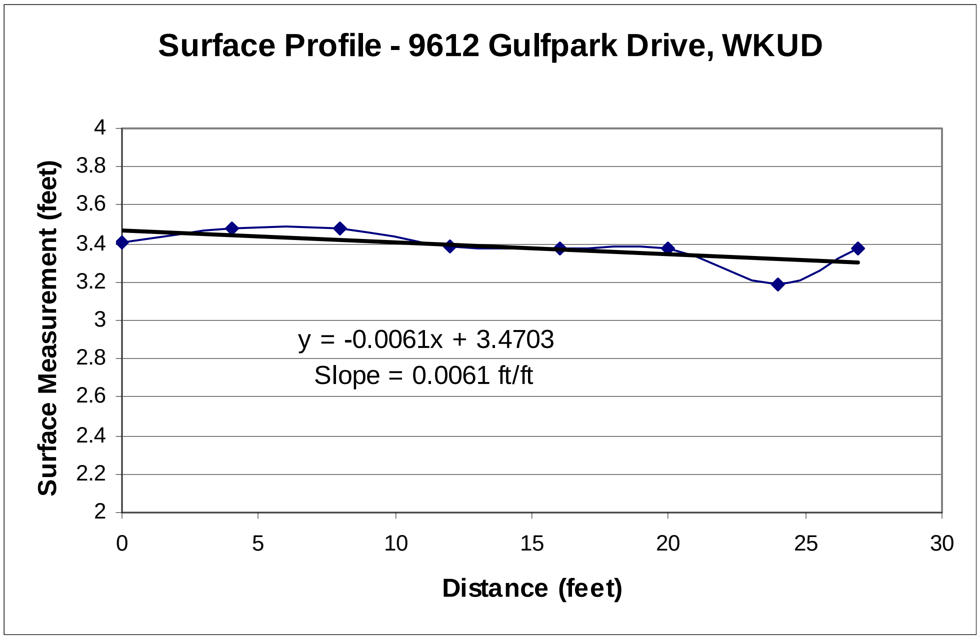

Figure 185 – Surface Profile – 9612 Gulfpark Drive, WKUD

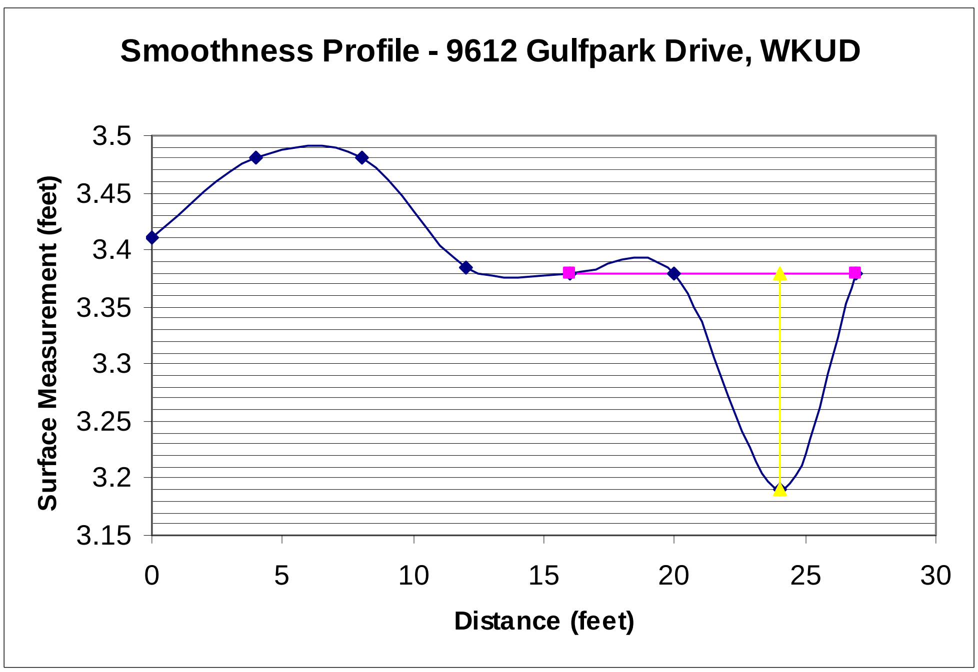

Figure 186 – Smoothness Profile – 9612 Gulfpark Drive, WKUD


Figure 187 – Photographs – 9612 Gulfpark Drive, WKUD

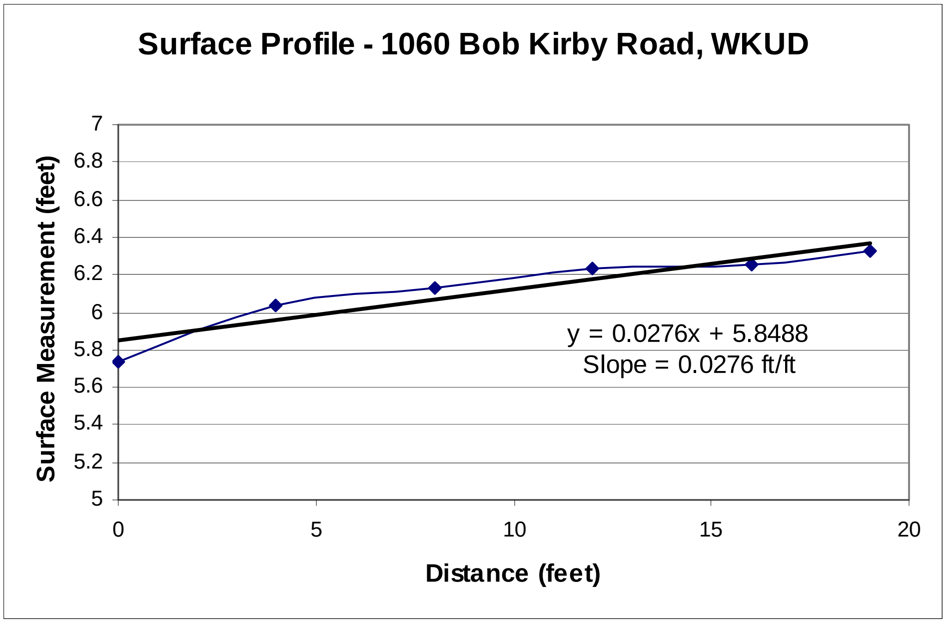

Figure 188 – Surface Profile – 1060 Bob Kirby Road, WKUD

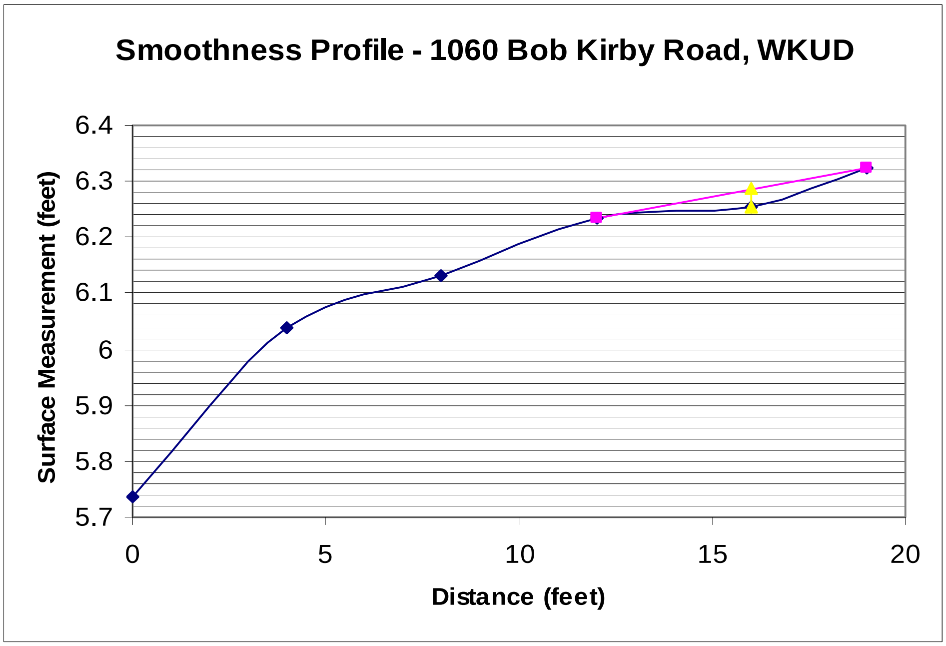

Figure 189 – Smoothness Profile – 1060 Bob Kirby Road, WKUD

Figure 190 – Photographs – 1060 Bob Kirby Road, WKUD

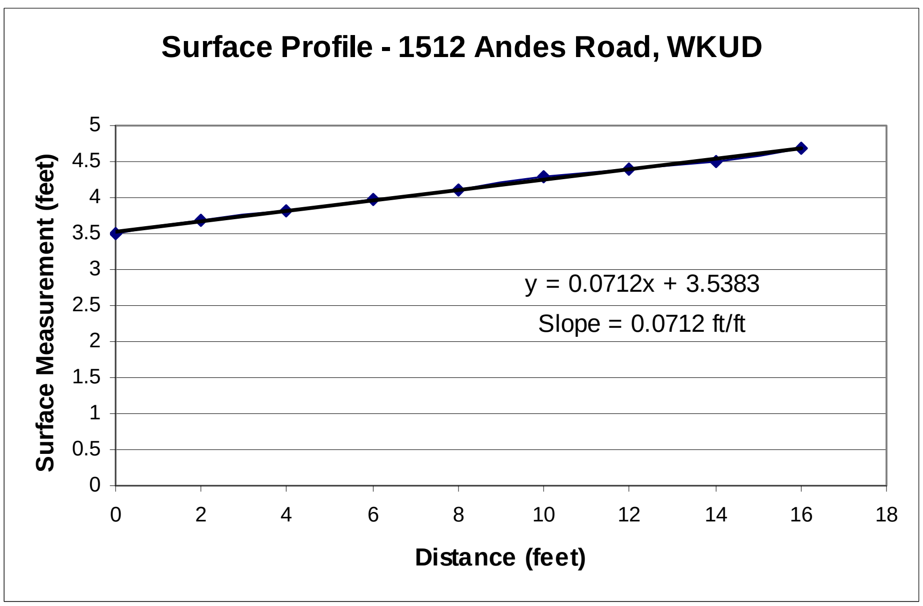

Figure 191 – Surface Profile – 1512 Andes Road, WKUD

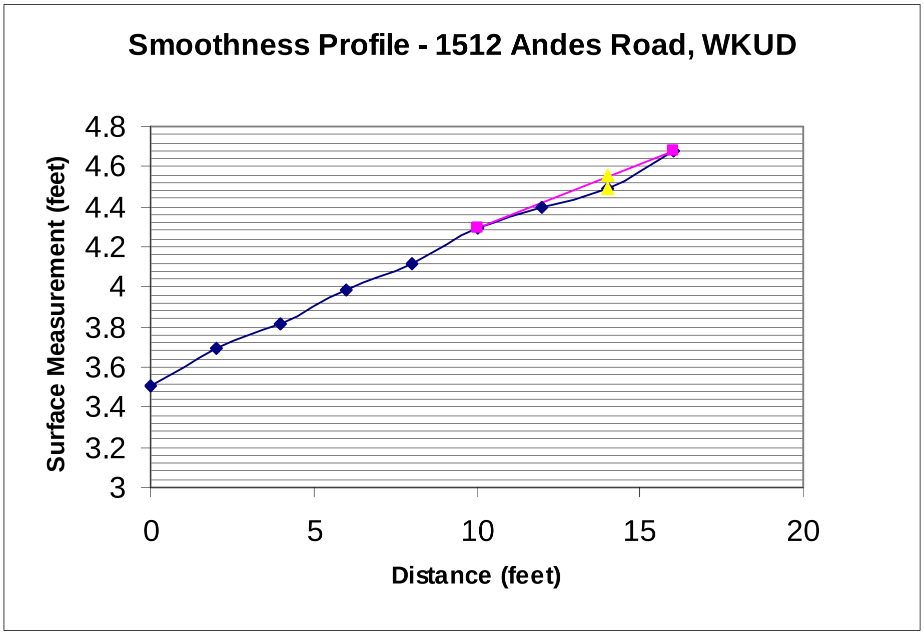

Figure 192 – Smoothness Profile – 1512 Andes Road, WKUD

Figure 193 – Photographs – 1512 Andes Road, WKUD

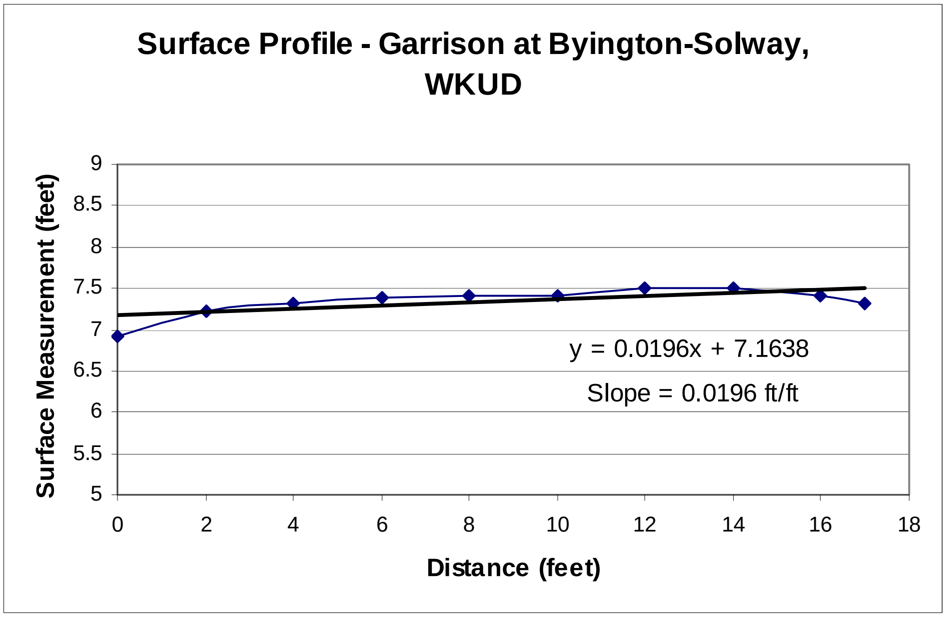

Figure 194 – Surface Profile – Garrison at Byington-Solway, WKUD

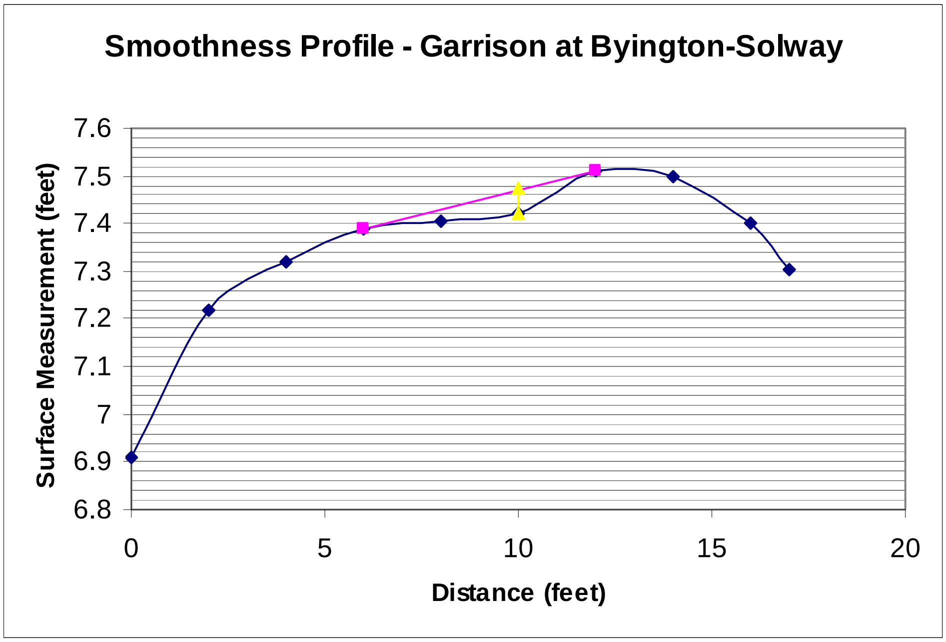

Figure 195 – Smoothness Profile – Garrison at Byington-Solway, WKUD

Figure 196– Photographs – Garrison at Byington-Solway, WKUD

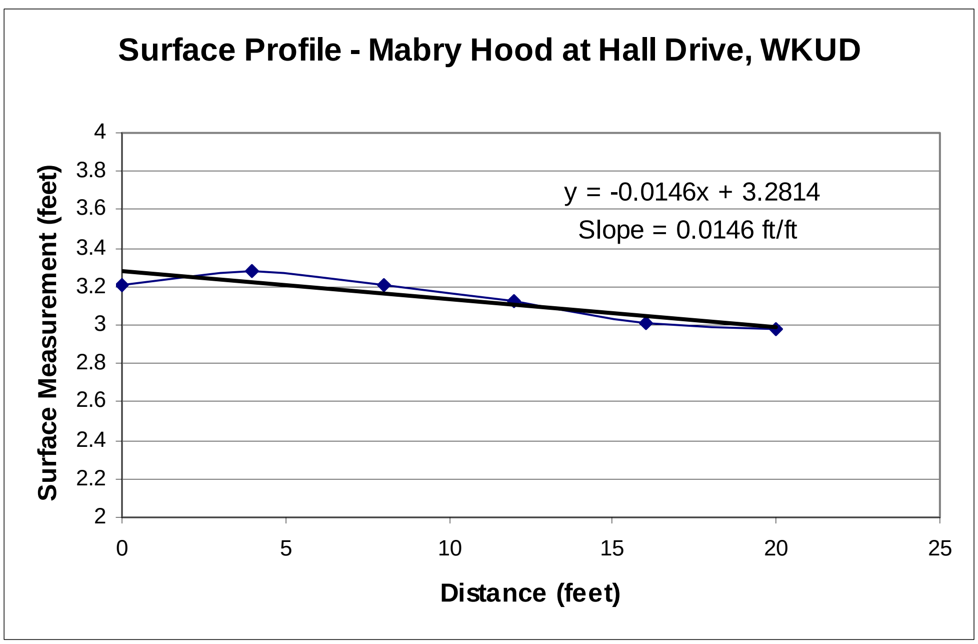

Figure 197– Surface Profile – Mabry Hood at Hall Drive, WKUD

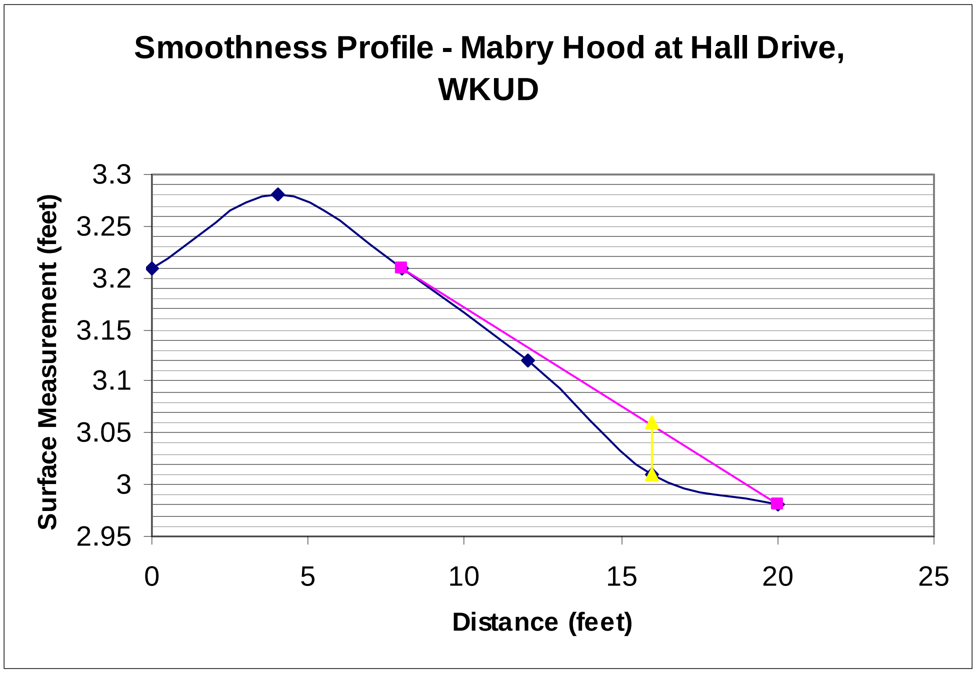

Figure 198– Smoothness Profile – Mabry Hood at Hall Drive, WKUD

Vita

Susan Gail Lowe was born in Athens Tennessee March 20, 1984. She graduated from Loudon High School in 2002. Upon graduation, she began her higher education at Roane State Community College and later transferred to the University of Tennessee to complete her Bachelor of Science degree in Civil Engineering that she earned in spring of 2007. While earning her degree she married Michael DeLand and became Susan Gail DeLand. She entered graduate school in spring of 2008 and completed the requirements for the degree of Master of Science in Civil Engineering (Public Works) in December of 2010. She is currently employed by Knoxville Utilities Board and resides in Lenoir City, TN.