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SMOOTHNESS EVALUATION OF EXPEDIENT REPAIRS AT AVON PARK

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FOREWORD

APR Consultants, Inc. (APR) is pleased to provide this report of profile measurements and assessments of pavement smoothness for Runway 05-23 at the Avon Park Florida test range.

A handwritten signature in black ink, appearing to read "Tony Gerardi". The signature is written in a cursive, flowing style with a horizontal line above the first few letters.

Tony Gerardi
President
APR Consultants, Inc.

SUMMARY

On 31 August 2009, APR Consultants, Inc. (APR) traveled to the Avon Park test range to measure and assess 13 lines of survey in two sections of Runway 05-23. Using APR's Auto Rod and Level™ profiling device (AR&L), nine lines of survey were measured in the area designated as Test Section 1, and an additional four lines of survey were measured in the area designated as Test Section 2. All of these profile measurements were compared to the baseline measurements conducted in July 2009 (prior to the crater exercise). The before and after measured profile data used in the analyses have been emailed to the Air Force POC for this project. The July baseline data was emailed in July. The September data was emailed on 9 September 2009.

This report compares the July 2009 (baseline) profiles to the September 2009 profiles (after expedient crater repairs). APR's analyses include comparisons of profile plots, aircraft simulations and 16 and 100-foot straightedge simulations.



Figure 1: APR's Auto Rod and Level™ Profiling Device

At the onset of the repair exercise a maximum allowable deviation was set at 1.25 inches. All repairs made were within that criterion. Before aircraft testing began, it was decided to mill any repair that was greater than .75 inch. The result was that all repairs were .75 inches or less. The analysis and results in this report however are for the repairs before they were milled to .75 inches.

Test Section 1 starts 120 feet from the painted threshold of the 05 end. Each line was approximately 850 feet in length.

Specifically, listing from the left side of the runway to the right, the following lines were measured in Test Section 1:

42.5 feet left of centerline (CL)	12.5 feet right of centerline
30.0 feet left of centerline	21.5 feet right of centerline
12.5 feet left of centerline	30.0 feet right of centerline
5 feet left of centerline	42.5 feet right of centerline
5 feet right of centerline	

Test Section 2 was measured beginning 3,807 feet from the painted threshold of Runway 05. Each line was approximately 488 feet in length. Test Section 2, again from the left side of the runway to the right, consisted of the following lines:

12.5 feet left of centerline	5 feet right of centerline
5 feet left of centerline	12.5 feet right of centerline

Figure 2 depicts the approximate layout of these lines as they relate to the runway.

Comparisons of the profile plots clearly identify the locations of the expedient repairs. The identifiers are at the approximate center of each repair. The identifiers are also annotated in the data profile sets.

Comparisons of the before and after straightedge plots quantifies the maximum deviation from a 16-foot and 100-foot straightedge. These plots also show the location and spacing between each repair.

Takeoff and landing simulations of the F-16 and C-130 aircraft show that the response can be moderate if the repairs are encountered at a resonant speed. This occurred on the C-130 aircraft taking off from the 05 end of the runway. The reason for the moderate response is that multiple bumps in succession set up a rhythm that the aircraft responded to. Figures 68 & 69 show the C-130 before and after aircraft response. This is a significant finding. Just as the aircraft was rebounding from one bump, another is encountered. Had this series of bumps been encountered at a different speed (e.g. using a displaced threshold) the response would have been no greater than that on a typical undamaged runway.

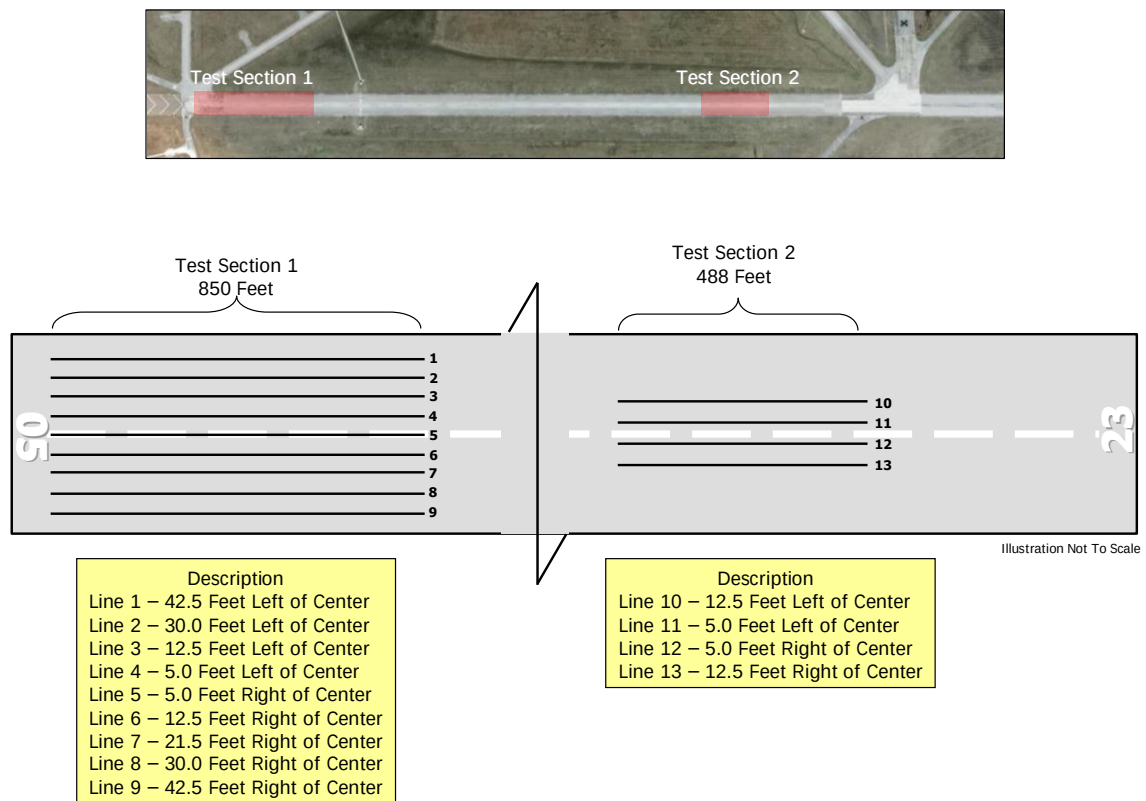


Figure 2. General layout of Test Sections 1 and 2 at Avon Park.

Figure 2: The General Layout of Test Sections 1 and 2 at Avon Park

INTRODUCTION

In a time of conflict, runways and taxiways can become prime targets. In order to respond to an attack, it is essential to make expedient repairs to the damaged pavements. These expedient repairs must be acceptable from a structural integrity and serviceability standpoint. Serviceability includes surface smoothness. The surface irregularities must not cause unacceptable aircraft response.

The importance of pavement smoothness on runways involves more than ride quality. It also includes:

Aborted Takeoff: This is probably the most important reason to have smooth runways. The high aircraft speed, coupled with the required short stopping distance, mandates a maximum braking effort. The aircraft will pitch forward on the nose landing gear (NLG), compressing the tires and the NLG strut. The compressed tires will heat up and possibly blow the fuse plugs. The high loads also risks fracturing the NLG drag brace, which would cause the NLG to collapse. **Aircraft and Pavement Useful Life:** Even though the aircraft is on the ground during takeoff and landing for only 30 seconds or so, it is half of the Ground-Air-Ground (GAG) fatigue cycle. Many commercial aircraft are designed for 20,000 GAG cycles. Military aircraft service life may vary, but they still have a design useful life. The useful life of the aircraft is reduced when operations occur on rough surfaces. The margin for overloads is small. It also costs more to operate and maintain aircraft on rough runways. In addition, it reduces the useful life of the pavement itself.

Stopping Distance: It takes more distance to stop an aircraft on a rough runway than on a smooth runway. When an aircraft has vertical motion caused by bumps, the normal load on the main landing gear (MLG) varies, and therefore, the braking force varies. In addition, the antiskid system is given false information about the speed because of the changing tire diameter. Finally, roughness can affect a pilot's ability to maintain steady brake pressure.

To conduct a pavement smoothness assessment, it is necessary to collect frequent elevation data and include all of the grade changes and wavelengths that can affect the aircraft's dynamic response. For this effort, APR Consultants' Auto Rod and Level™ (AR&L) was used to measure the profile data. A data point was measured every foot.

Aircraft response to airport pavement roughness can be broken into three categories: shock, short wavelength and long wavelength response.

Shock is the result of encountering a sharp change in elevation such as a step bump, a raised slab or spall. Shock loading is typically too fast for the suspension system to fully absorb the energy. It is felt by pilots and passengers as a jolt.

Short wavelength response is caused by roughness the suspension system can more readily react to, such as the FAA's AC 150/5370 – 10B new pavement smoothness criteria (a .25-inch bump in 16 feet).

Long wavelength response is caused by bumps and dips like intersections with crowns, vertical curves or other rapid changes in grade that the aircraft responds to as a whole. It excites the rigid body modes of vibration.

Most of the expedient repairs made during this demonstration were short wavelength.

PAVEMENT SMOOTHNESS ASSESSMENT TOOLS

APR has developed several methods to quantify roughness on a runway. There are four main tools that APR typically uses in a smoothness assessment.

First, a visual analysis of the pavement profile, usually 500 feet at a time, is made to visually identify obvious rough areas and to insure that the measured data is good.

Second, a straightedge analysis is used to locate suspected areas of roughness. This analysis usually includes two different straightedges. Normally, a 16-foot straightedge is used to compare the profile to the Federal Aviation Agency (FAA) criteria for new pavement acceptance (FAA Advisory Circular AC# 150/5370-10B dated 4/25/05). A 100-foot straightedge is also used to search for longer wavelength roughness that affects aircraft whole body response.

Third, takeoff and landing simulations help to determine the probability of possible rough areas being encountered at sensitive speeds. Aircraft simulation, especially takeoff and landing, is the primary tool in runway analysis. To quantify roughness APR uses the prediction of aircraft vertical acceleration in g-forces. According to a study published in Volume III of the Shock and Vibration Handbook, Chapter 44 “Effects of Shock and Vibration on Man” by D. E. Goldman and H. E. Von Gierke, a .4 g level of acceleration is the starting level of human discomfort. This .4 g level is the threshold APR uses when analyzing aircraft response to pavement roughness.

The final factor in the analysis is engineering judgment. Experience enables APR to take into account things such as aircraft type, airport specifics, threshold locations, etc, in quantifying smoothness levels.

PROFILE EVALUATION

Visual analysis: A visual analysis of each line of survey was conducted to compare profiles of the before and after expedient repairs. The expedient repairs are obvious. Most repairs have identifiers on the profile plots. Those not identified were not marked on-site presumably because the repair process caused them to be removed.

All analysis figures are contained in the appendix. Figure A-1 is a plot of the centerline of the entire runway from threshold to threshold. It shows the full length profile measured in July and in September. Each of the 13 test section lines of survey are plotted with the before and after expedient repairs. The profile plots are followed by 16-foot and 100-foot straightedge plots of the before and after expedient repairs. Figures A-2 through A-45 are the results for test section one. Figures A-46 through A-65 are the results for test section two. The crater repair identifications that were visible during the survey, which are shown on the plots, are also contained in the data files emailed to the AF point of contact (POC).

A summary of the straightedge results are shown in Table 1. The table contains the percent of time that the threshold criterion was exceeded; .25 inch for the 16-foot straightedge and 1 inch for the 100-foot straightedge. Even though the expedient repairs were all shorter wavelength, the 100-foot straightedge results show changes as well. The table shows the percent of time that the criteria were exceeded before and after the expedient repairs. The point increase is also shown.

The 5-foot left of center (LOC) profile is the roughest line measured. It has a maximum deviation from a 16-foot straightedge of 1-inch. This line is also of particular interest since it is on the runway keel section and will be encountered by the aircraft that use the runway.

Table 1: Summary of 16 and 100-Foot Straightedge Analyses Results

Test Section 1

16-Foot Straightedge Analysis Results: Overall Percent of the Time 0.25-Inch Threshold Exceeded									
Runway 05-23 at Avon Park, Test Section 1									
Line of Survey	Centerline *	5FT Left	5FT Right	12.5 FT Left	12.5FT Right	30FT Left	30FT Right	42.5FT Left	42.5FT Right
Before Craters	6.35%	14.61%	8.14%	11.59%	10.70%	11.98%	11.55%	26.52%	18.68%
After Crater Repairs	7.31%	25.84%	20.22%	21.36%	23.80%	15.43%	16.35%	28.93%	17.60%
Point Increase	0.97	11.23	12.08	9.77	13.10	3.45	4.80	2.41	-1.08

* Full length of runway 05 on the CL only

100-Foot Straightedge Analysis Results: Overall Percent of the Time 1.00-Inch Threshold Exceeded									
Runway 05-23 at Avon Park, Test Section 1									
Line of Survey	Centerline *	5FT Left	5FT Right	12.5 FT Left	12.5FT Right	30FT Left	30FT Right	42.5FT Left	42.5FT Right
Before Craters	1.02%	0.13%	0.00%	0.00%	0.00%	0.00%	0.00%	1.59%	13.18%
After Crater Repairs	1.23%	25.93%	6.38%	1.46%	7.89%	1.59%	15.78%	8.99%	17.31%
Point Increase	0.21	25.80	6.38	1.46	7.89	1.59	15.78	7.40	4.13

Test Section 2

16-Foot Straightedge Analysis Results: Overall Percent of the Time 0.25-Inch Threshold Exceeded									
Runway 05-23 at Avon Park, Test Section 2									
Line of Survey	Centerline *	5FT Left	5FT Right	12.5 FT Left	12.5FT Right				
Before Craters	6.35%	5.51%	6.57%	2.54%	23.73%				
After Crater Repairs	7.31%	10.36%	17.55%	13.32%	30.66%				
Point Increase	0.97	4.85	10.98	10.78	6.93				

100-Foot Straightedge Analysis Results: Overall Percent of the Time 1.00-Inch Threshold Exceeded									
Runway 05-23 at Avon Park, Test Section 2									
Line of Survey	Centerline *	5FT Left	5FT Right	12.5 FT Left	12.5FT Right				
Before Craters	1.02%	0.00%	0.00%	0.00%	0.00%				
After Crater Repairs	1.23%	8.23%	4.63%	11.05%	0.00%				
Point Increase	0.21	8.23	4.63	11.05	0.00				

AIRCRAFT SIMULATION

To quantify the ride quality of the pavement, takeoff, landing and 60-knot constant-speed taxi operations were conducted using an F-16, and a C-130 aircraft. The plotted output of the more significant simulations can be found in Figures A-66 through A-75.

Figure 68 is a C-130 takeoff on the undamaged Runway 05 profiles. The plotted result is typical for C-130 operations on an aging commercial runway. Full length profiles were simulated for the centerline (CL) and 5 feet left and right of the CL before the crater exercise. Figure 69 is a C-130 takeoff on the same runway after the expedient repairs were made. The takeoff simulation produced moderate aircraft response which was a surprising result. The term moderate is based on the g-level experienced at the cockpit pilot station (PS) and/or the aircraft center of gravity (CG). Moderate, as defined by APR's experience, is multiple events where the acceleration is above .6 g. The C-130 is very capable of rough field operations; consequently, little response was expected on the repaired Avon Park runway. However, the moderate accelerations produced at the cockpit indicate that a resonant loading condition was occurring. This was caused by the fact that multiple repairs were involved. Just as the aircraft was rebounding from one bump, another was encountered. It should be noted that the moderate response predicted for C-130 is not enough to prevent operations, but could reduce aircraft fatigue life and increase operational maintenance.

The repairs were encountered at a speed that was tuned to the natural frequency of the C-130. The speed that section 1 was encountered began at 30 knots and ended at 43 knots. Had the section 1 repairs been located on another section of the runway, they would not have caused a moderate response. Figure A-68 shows that the response is acceptable if the threshold is displaced just 500 feet.

Several landing simulations were also conducted. Figures A-72 through A-75 show that the repairs had very little impact on the F-16 or C-130 response.

A summary of the constants speed runs (60 knots) over each test section is shown in table 2 below. The peak vertical acceleration and the Ride Quality Factor (RQF) are shown for each run. The RQF is a normalized summation of the cg and pilot's station acceleration for the entire run. The 60 knot taxi runs did not reveal much about the significance of each repair. The plotted takeoff simulations are more revealing.

Table 2: Summary of 60 Knot Constant Speed Simulations
Test Section 1

	Peak G and (Ride Quality Factor): F-16 Response Taxi at 60 Knots								
Line of Survey	Centerline *	5FT Left	5FT Right	12.5 FT Left	12.5FT Right	30FT Left	30FT Right	42.5FT Left	42.5FT Right
Before Craters	.52 (2.94)	.41 (2.82)	.39 (2.69)	.35 (1.59)	.31 (2.03)	.40 (2.18)	.35 (1.86)	.41 (3.02)	.61 (2.74)
After Crater Repairs	.50 (2.92)	.58 (2.45)	.41 (2.51)	.54 (2.37)	.62 (2.48)	.39 (2.15)	.37 (2.39)	.47 (3.18)	.52 (2.99)

* Full length takeoff Simulation on runway 05 CL

	Peak G and (Ride Quality Factor): C-130 Response Taxi at 60 Knots								
Line of Survey	Centerline *	5FT Left	5FT Right	12.5 FT Left	12.5FT Right	30FT Left	30FT Right	42.5FT Left	42.5FT Right
Before Craters	.4 (1.66)	.22 (1.55)	.40 (1.72)	.24 (1.50)	.26 (1.67)	.34 (2.05)	.30 (1.72)	.37 (1.96)	.42 (2.42)
After Crater Repairs	.75 (2.23)	.38 (2.02)	.31 (1.64)	.40 (2.13)	.35 (1.80)	.32 (2.06)	.35 (1.68)	.45 (2.25)	.42 (2.43)

Test Section 2

	Peak G and (Ride Quality Factor): F-16 Response Taxi at 60 Knots								
Line of Survey	Centerline *	5FT Left	5FT Right	12.5 FT Left	12.5FT Right				
Before Craters	.52 (2.94)	.28 (1.77)	.25 (1.81)	.30 (1.60)	.24 (1.88)				
After Crater Repairs	.50 (2.92)	.26 (1.59)	.58 (3.32)	.33 (1.74)	.52 (2.52)				

	Peak G and (Ride Quality Factor): C-130 Response Taxi at 60 Knots								
Line of Survey	Centerline *	5FT Left	5FT Right	12.5 Ft Left	12.5FT Right				
Before Craters	.4 (1.66)	.28 (1.65)	.22 (1.28)	.29 (1.20)	.24 (1.41)				
After Crater Repairs	.75 (2.23)	.32 (1.77)	.32 (1.89)	.43 (1.53)	.27 (1.54)				

CONCLUSIONS

APR Consultants, Inc. has conducted an analysis of Runway 05-23 at the Avon Park test range before and after expedient repairs were made in a cratered runway demonstration.

At the onset of the repair exercise a maximum allowable deviation was set at 1.25 inches. All repairs made were within that criterion. Before aircraft testing began, it was decided to mill any repair that was greater than .75 inch. The result was that all repairs were less than .75 inches. The results in this report are for the repairs before they were milled.

The 16-foot straightedge analysis shows that almost all repairs produced a mild bump, as opposed to a dip. All repairs exceeded the .25 inch FAA new pavement smoothness acceptance criteria. Most exceeded .5 inch and several exceeded 1 inch. The most significant repair had a maximum deviation of more than 1-inch from a 16-foot straightedge (Crater Repair R1C03).

It should be noted that the allowable criteria for crater repair is .75 inches (not .25). The FAA criterion was used in this report because it is an official criterion and it allows for comparison to hundreds of other profiles that APR has analyzed. The .75 inch (crater repair criteria) can be viewed on these plots as well.

It should also be noted that the FAA criterion is for new pavement acceptance and allows deviations greater than .25-inch up to 15% of the time per lot. If greater than 15%, the lot is supposed to be removed; any deviation greater than .4-inches must be corrected. Finally, the “Boeing Curve” (Fig. A-76) provides some guidance for single event bumps and dips. It should be noted that the Boeing curve does not mention multiple event bump encounters or the speed at which they were encountered by the aircraft.

The 100-foot straightedge analysis shows degradation as well; however, the 16-foot straightedge analysis is more indicative of the degradation caused by the repairs since all of the repairs were short wavelength. The 1-inch criterion was exceeded on all test section profiles. The 100-foot straightedge and the 1-inch threshold is not an official criterion. It is a tool that APR has used successfully on hundreds of runway profiles to identify long wavelength bumps and dips that affect aircraft rigid body response.

F-16 and C-130 takeoff, landing and 60-knot taxi simulations were made on the repaired runway. The takeoff simulations showed surprisingly significant aircraft response particularly for the C-130 aircraft which is very capable when operating on rough runways. It became evident that multiple repairs spaced relatively close to each other cause a resonant response with the C-130. This is a significant finding. Landing simulations showed little change between before and after expedient repairs.

APR Consultants does not have the necessary data to simulate the F-15 or C-17 which are to be flight tested on the repaired runway. Consequently, we cannot predict how they will respond. It is unlikely that the C-17 will have much response because of its rough

field design. However, it is likely that mild to moderate response could be experienced by the F-15 if test section 1 is encountered at a resonant speed.

RECOMMENDATIONS

It is recommended that multiple event repairs in close proximity be held to a smaller allowable amplitude than bumps or dips that stand alone.

Repairs that are not in the runway keel section are less likely to be encountered by the aircraft, especially during takeoff, which produces the most aircraft response. It may be possible to relax the smoothness criteria if the craters are outside the keel section.

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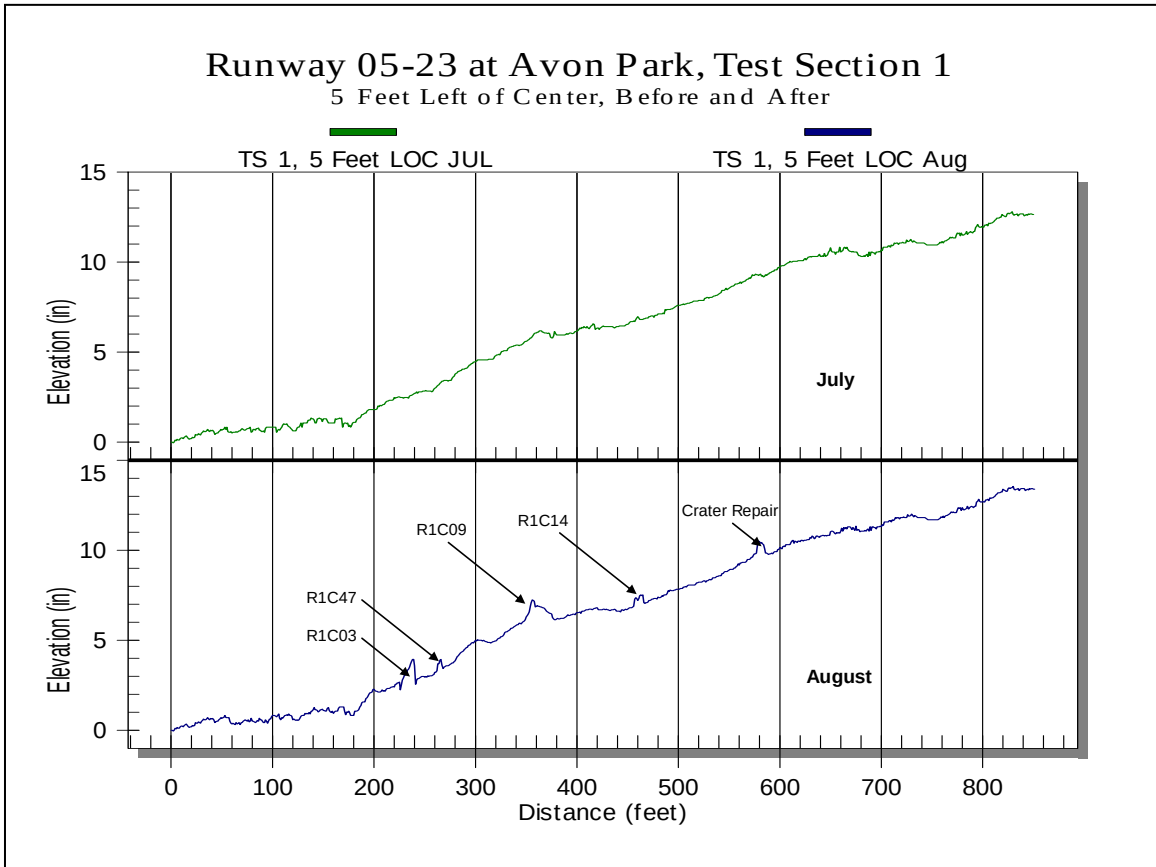


Figure A-1: Profile Plots of Test Section 1 on Runway 5-23, 5 Feet Left of Center Before and After

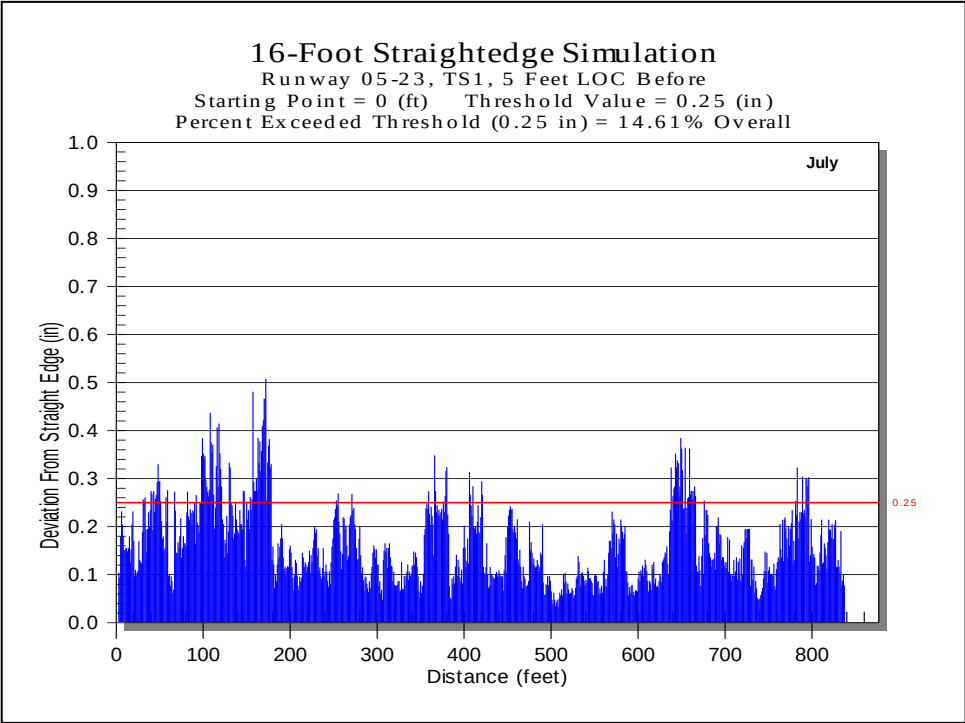


Figure A-2: 16-Foot Straightedge Simulation on Test Section 1, 5 Feet Left of Center Before Craters

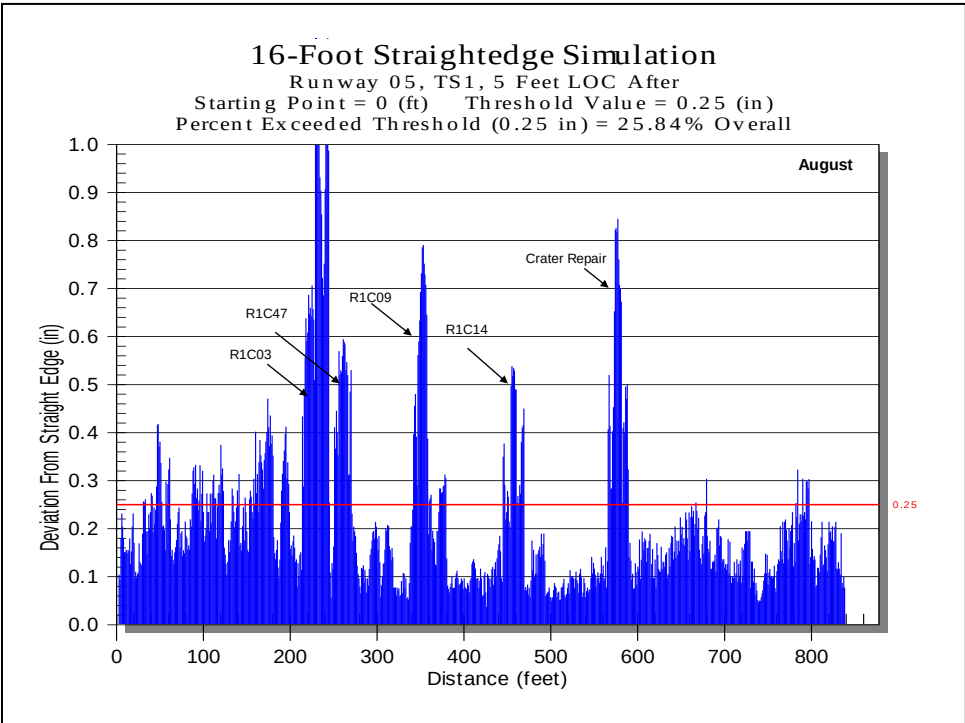


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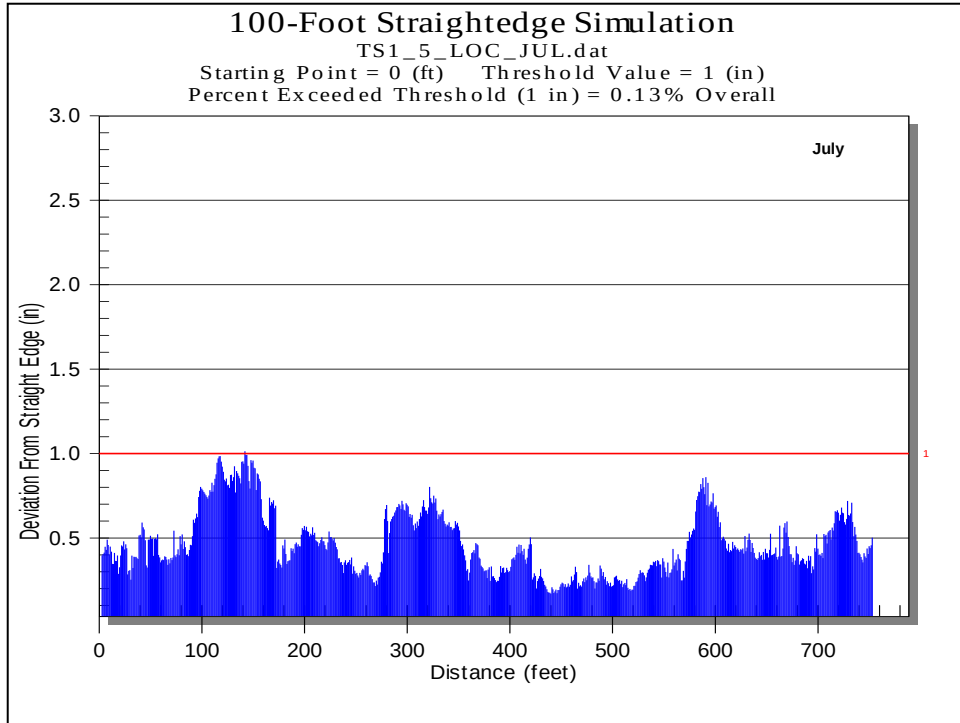


Figure A-4: 100-Ffoot Straightedge Simulation on Test Section 1, 5 Feet Left of Center Before Craters

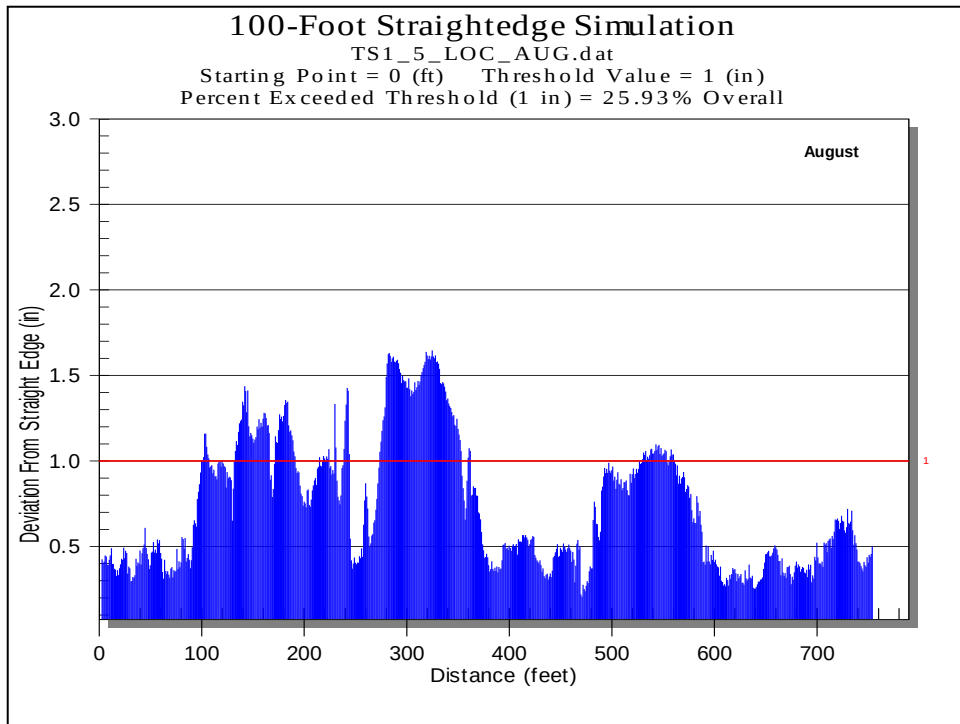


Figure A-5: 100-Foot Straightedge Simulation on Test Section 1, 5 Feet Left of Center After Repairs

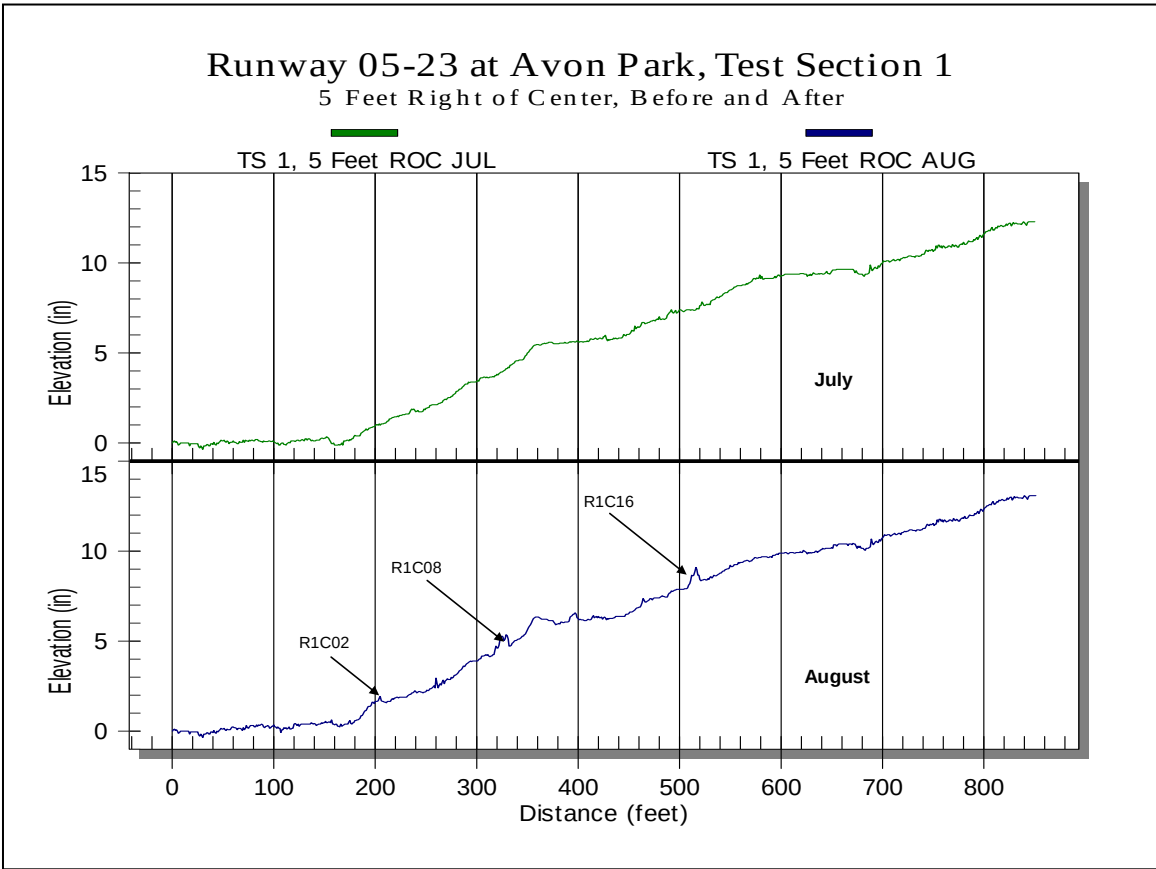


Figure A-6: Profile Plots of Test Section 1 on Runway 5-23, 5 Feet Right of Center Before and After

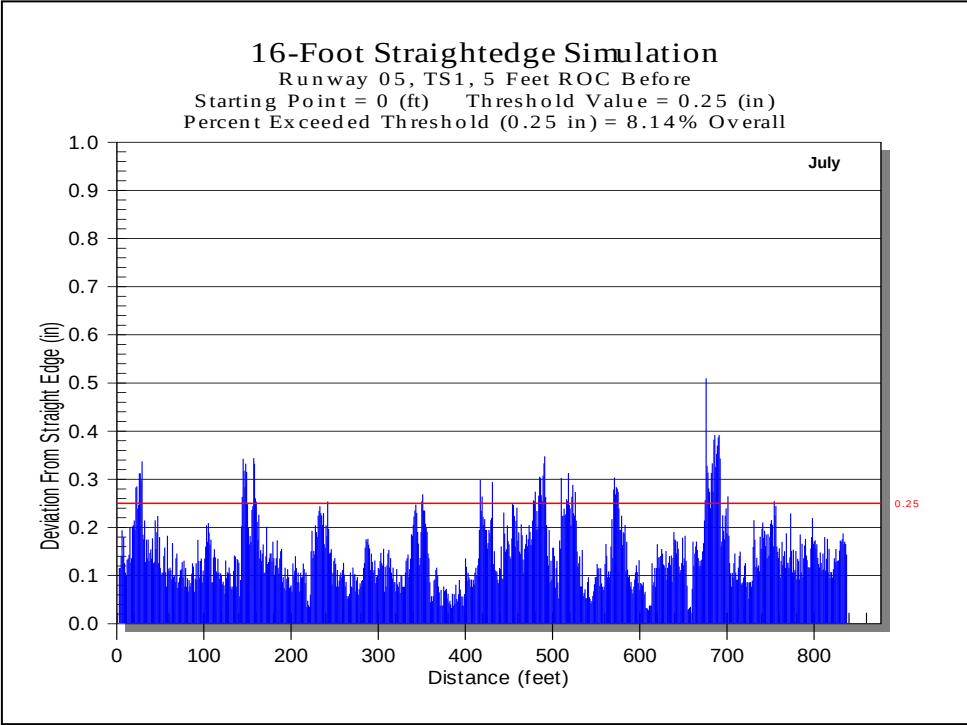


Figure A-7: 16-Foot Straightedge Simulation on Test Section 1, 5 Feet Right of Center Before Craters

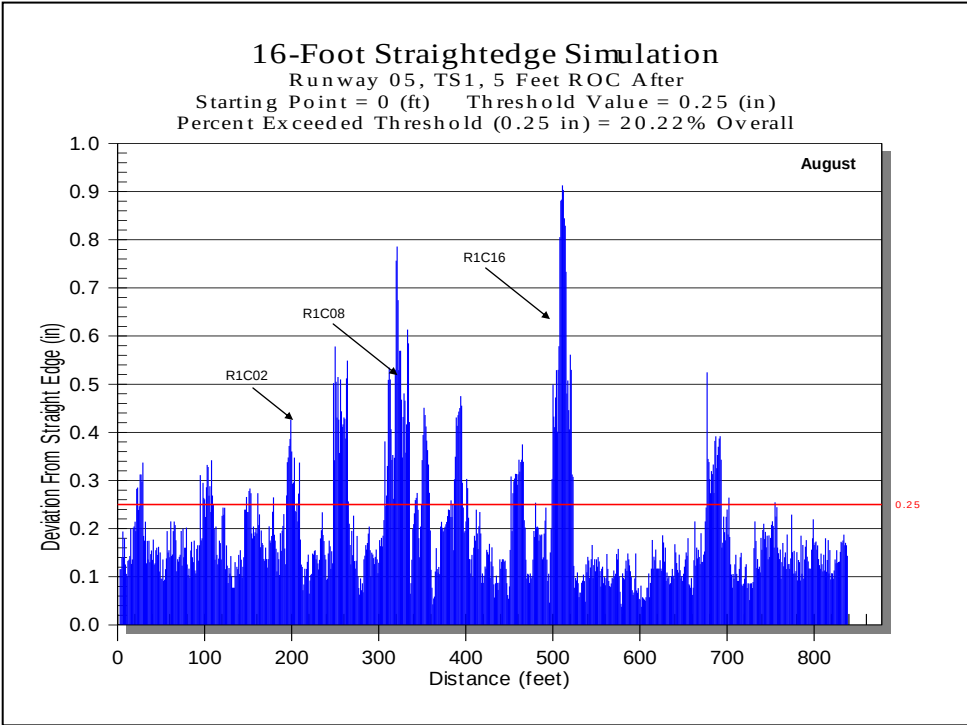


Figure A-8: 16-Foot Straightedge Simulation on Test Section 1, 5 Feet Right of Center After Repairs

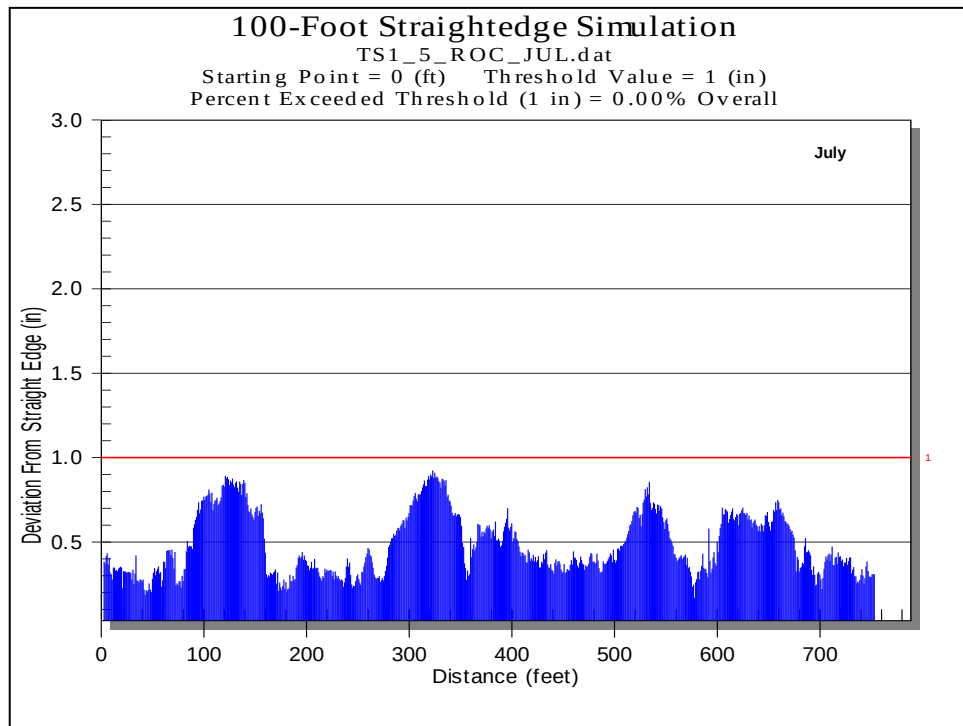


Figure A-9: 100-Foot Straightedge Simulation on Test Section 1, 5 Feet Right of Center Before Craters

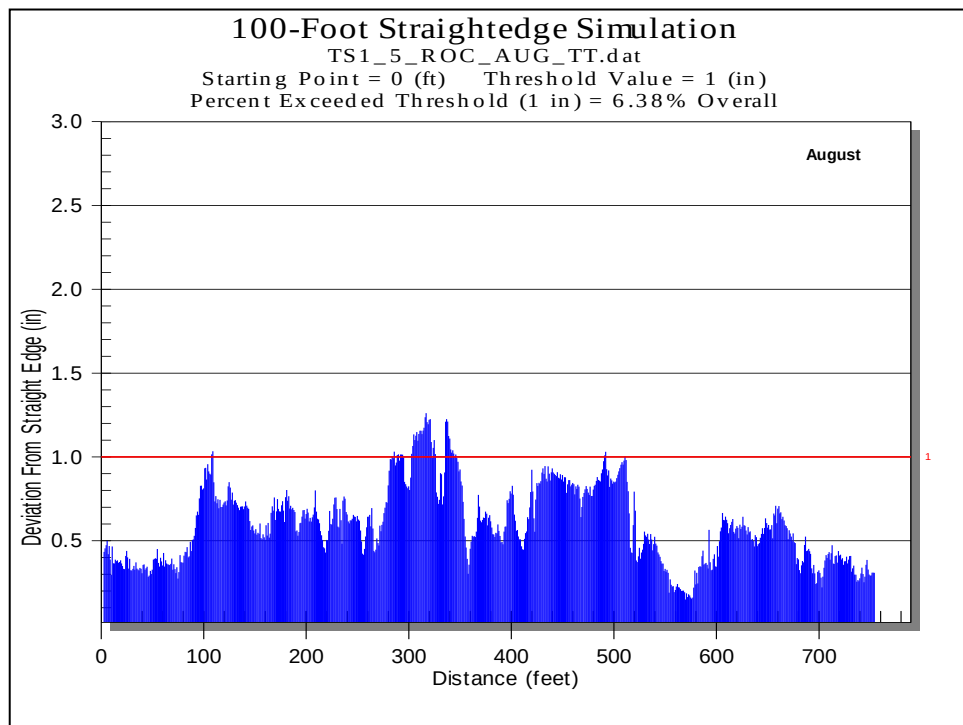


Figure A-10: 100-Foot Straightedge Simulation on Test Section 1, 5 Feet Right of Center After Repairs

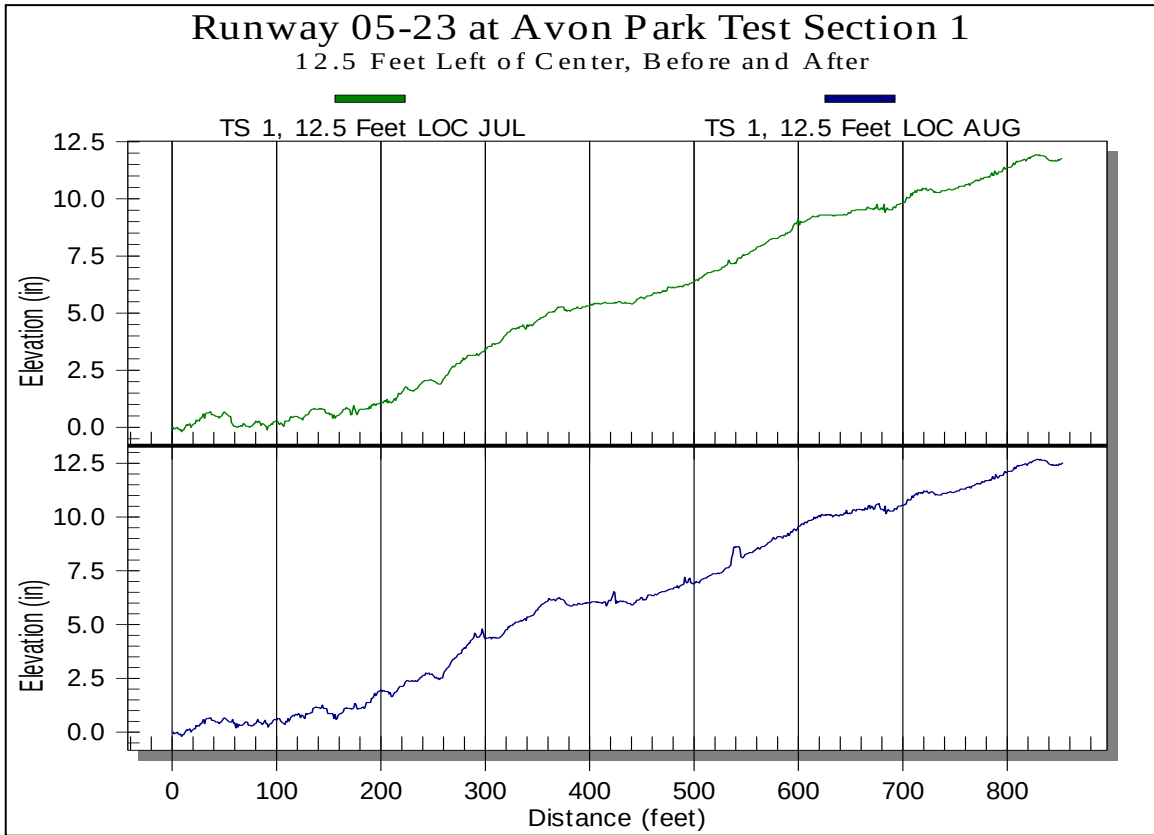


Figure A-11: Profile Plots of Test Section 1 on Runway 5-23, 12.5 Feet Left of Center Before and After

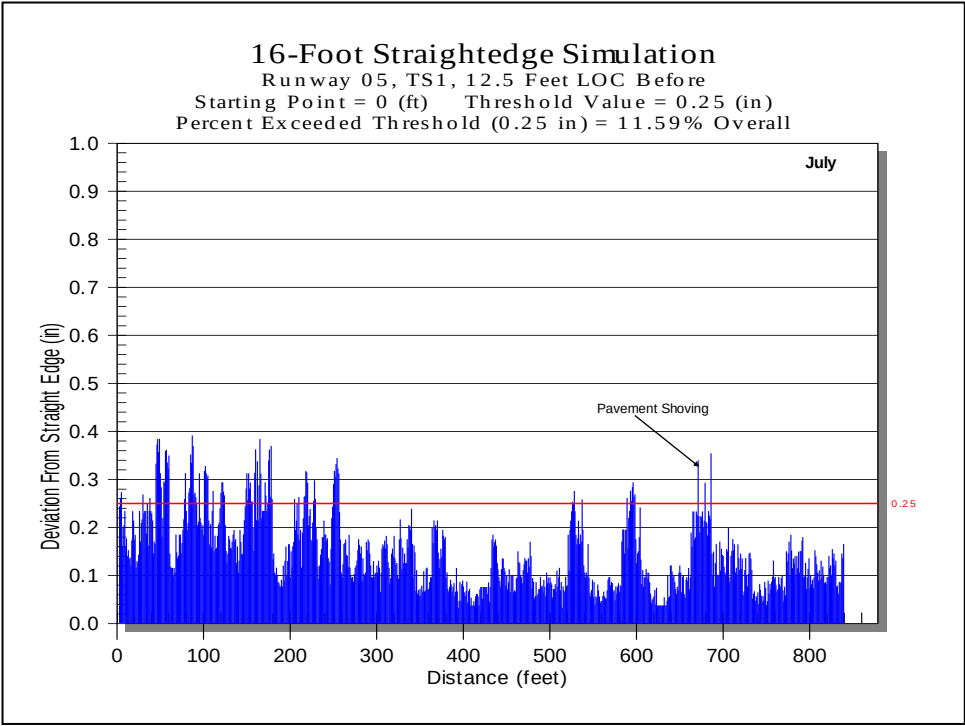


Figure A-12: 16-Foot Straightedge Simulation on Test Section 1, 12.5 Feet Left of Center Before Craters

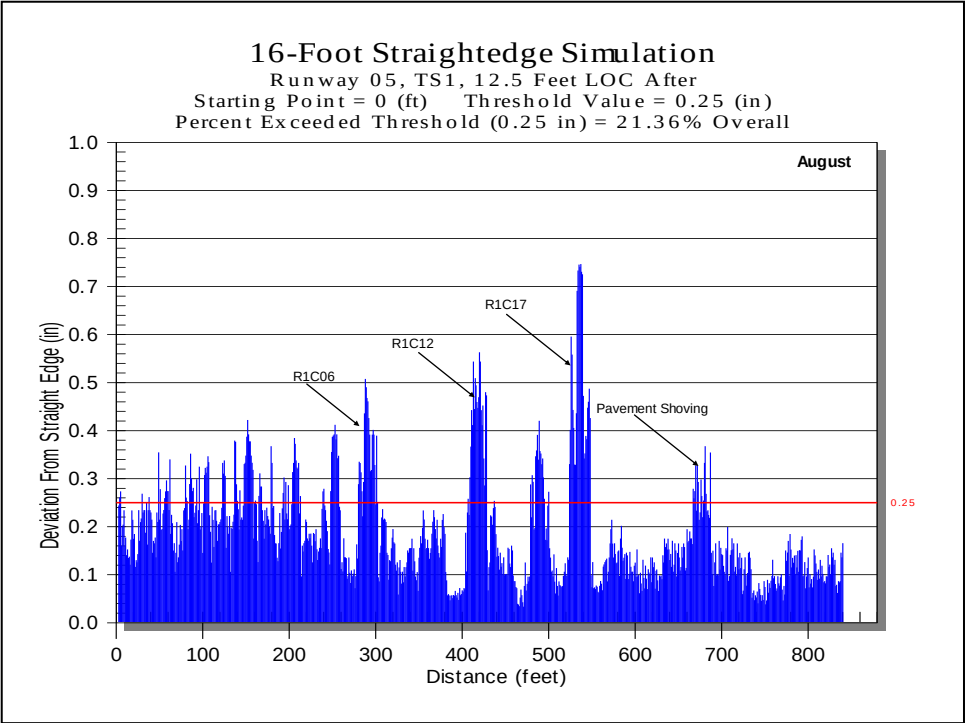


Figure A-13: 16-Foot Straightedge Simulation on Test Section 1, 12.5 Feet Left of Center After Repairs

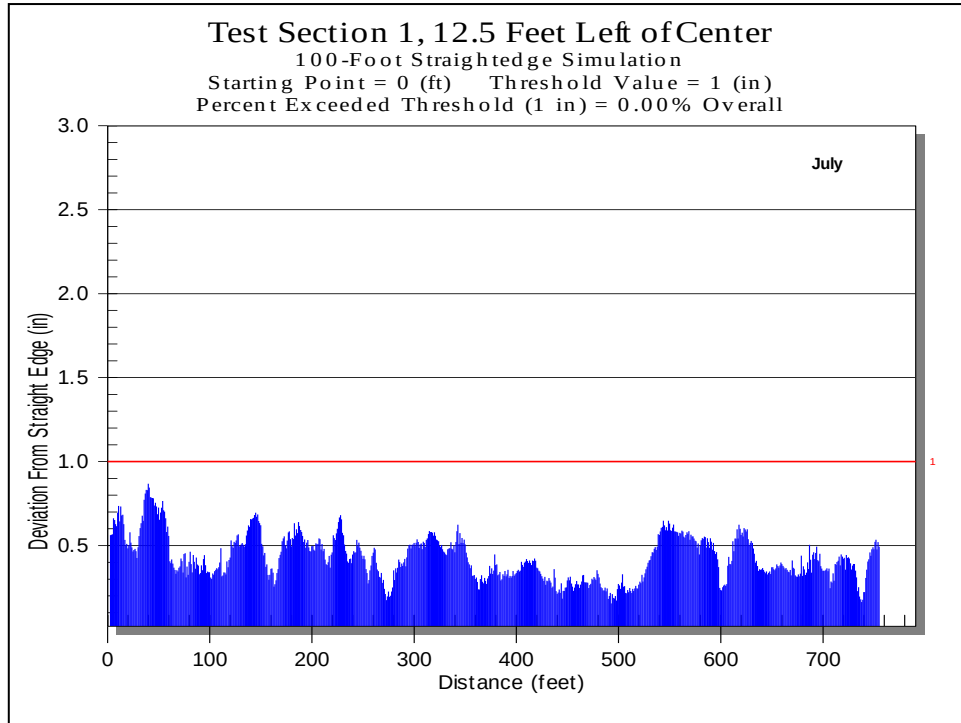


Figure A-14: 100-Foot Straightedge Simulation on Test Section 1, 12.5 Feet Left of Center Before Craters

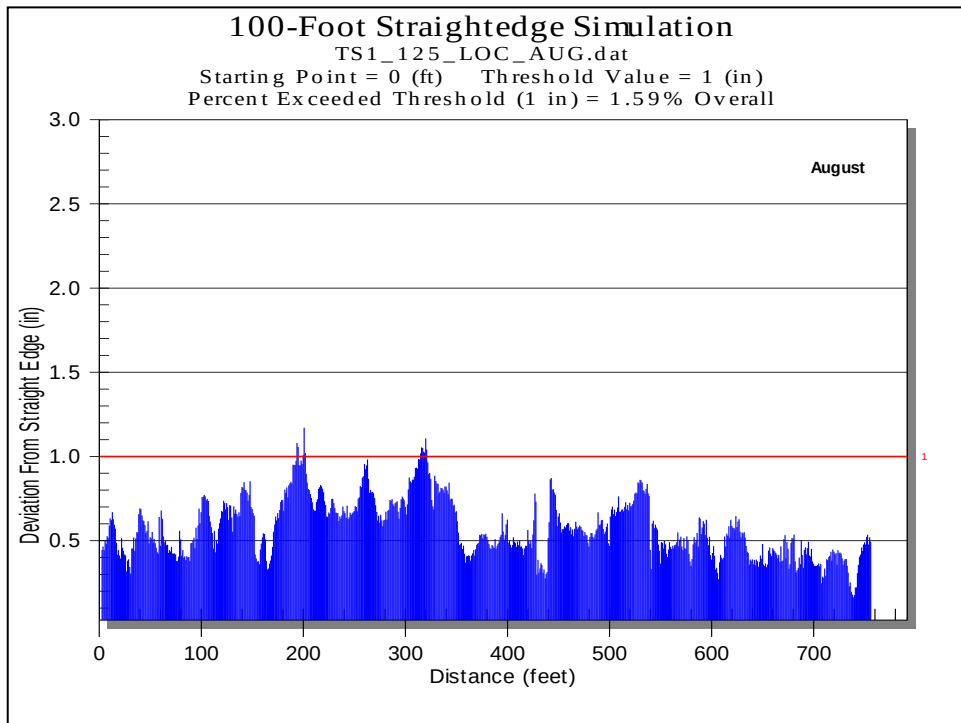


Figure A-15: 100-Foot Straightedge Simulation on Test Section 1, 12.5 Feet Left of Center After Repairs

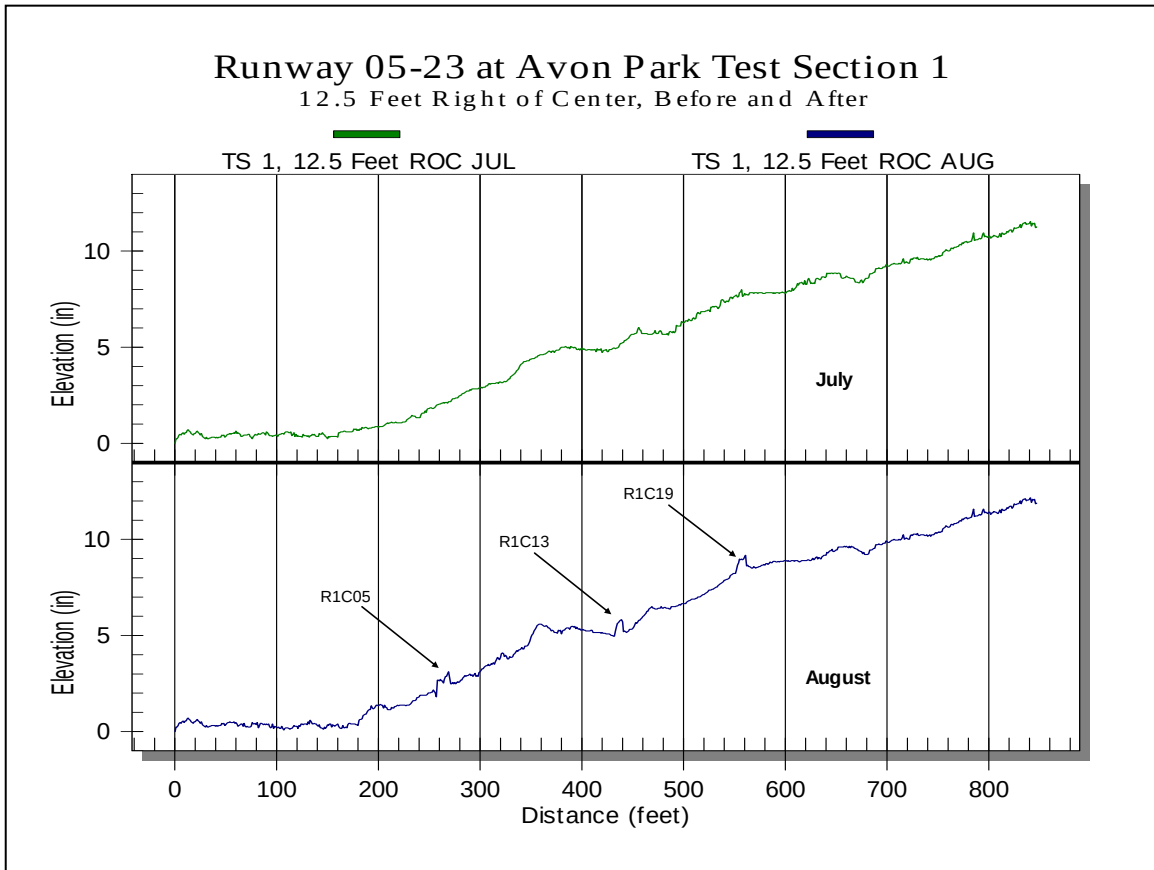


Figure A-16: Profile Plots of Test Section 1 on Runway 5-23, 12.5 Feet Right of Center Before and After

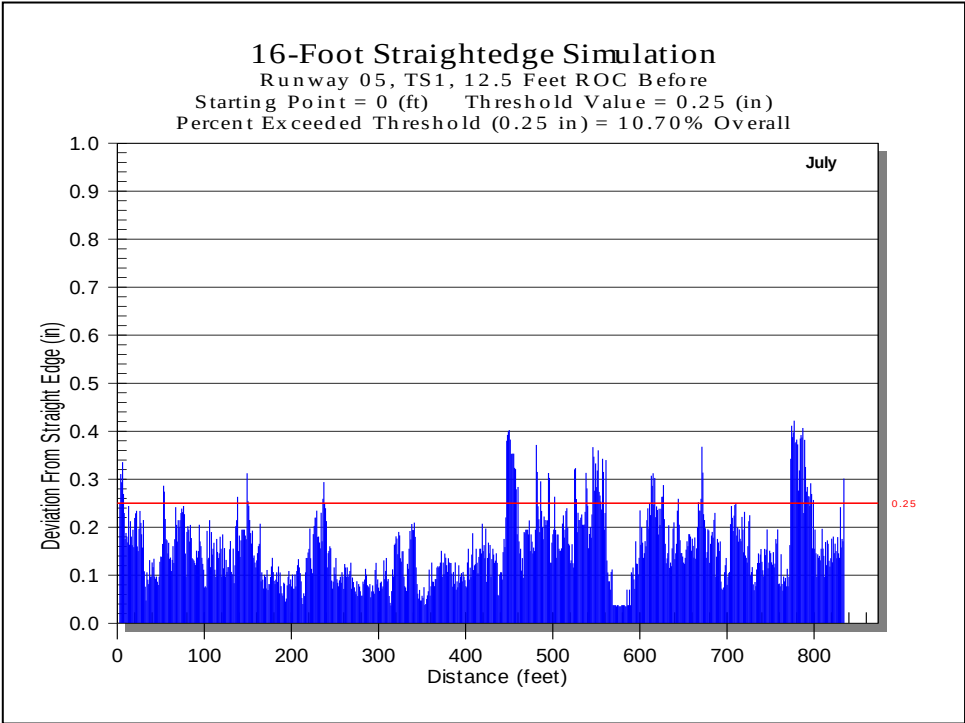


Figure A-17: 16-Foot Straightedge Simulation on Test Section 1, 12.5 Feet Right of Center Before Craters

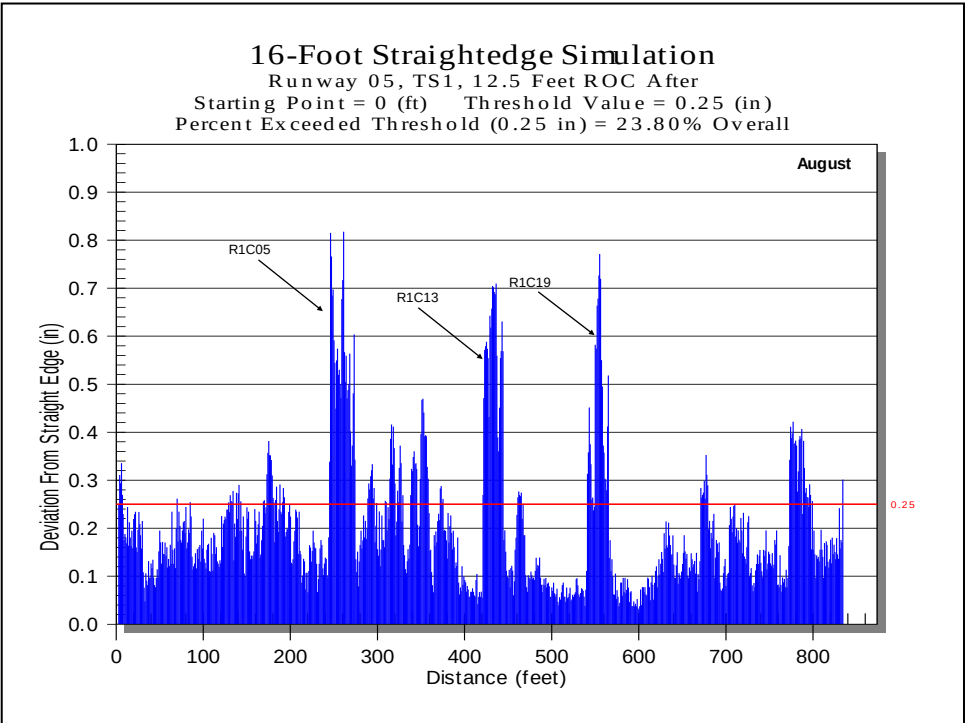


Figure A-18: 16-Foot Straightedge Simulation on Test Section 1, 12.5 Feet Right of Center After Repairs

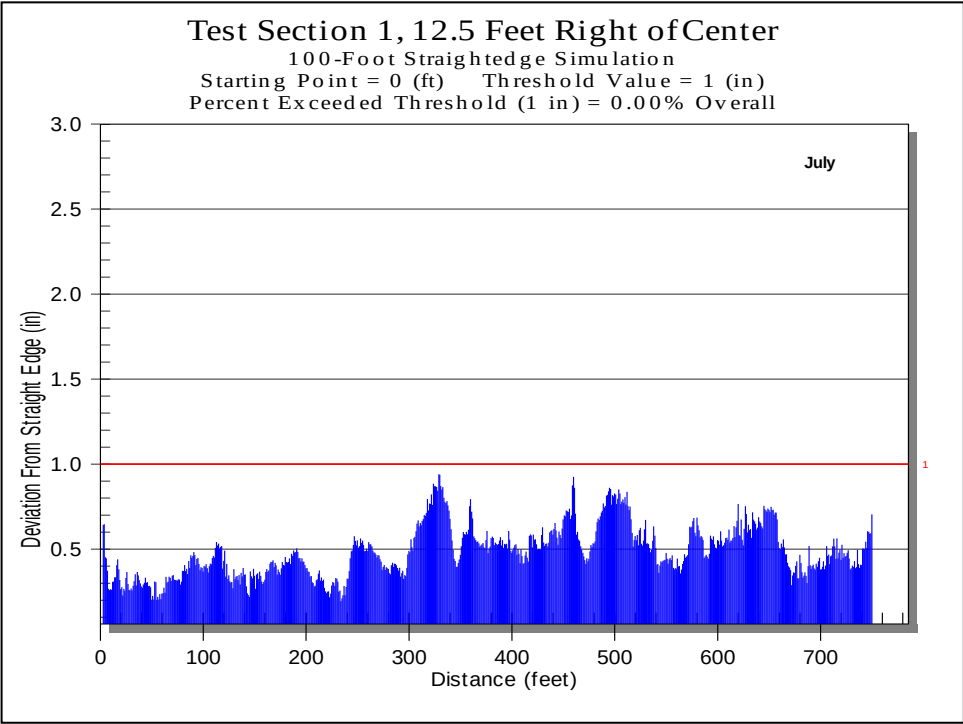


Figure A-19: 100-Foot Straightedge Simulation on Test Section 1, 12.5 Feet Right of Center Before Craters

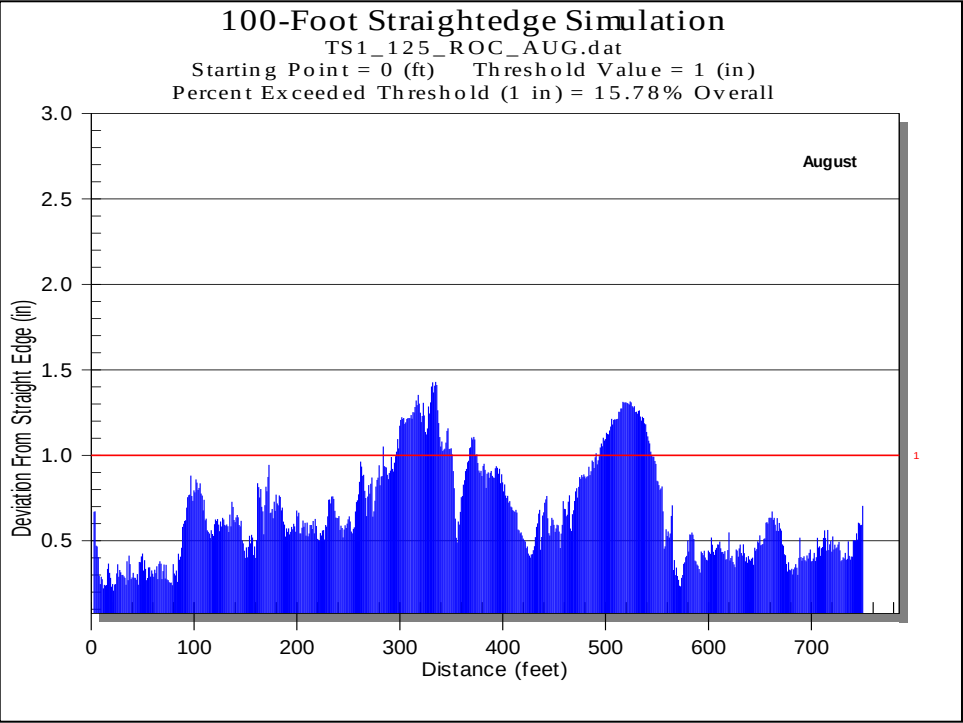


Figure A-20: 100-Foot Straightedge Simulation on Test Section 1, 12.5 Feet Right of Center After Repairs

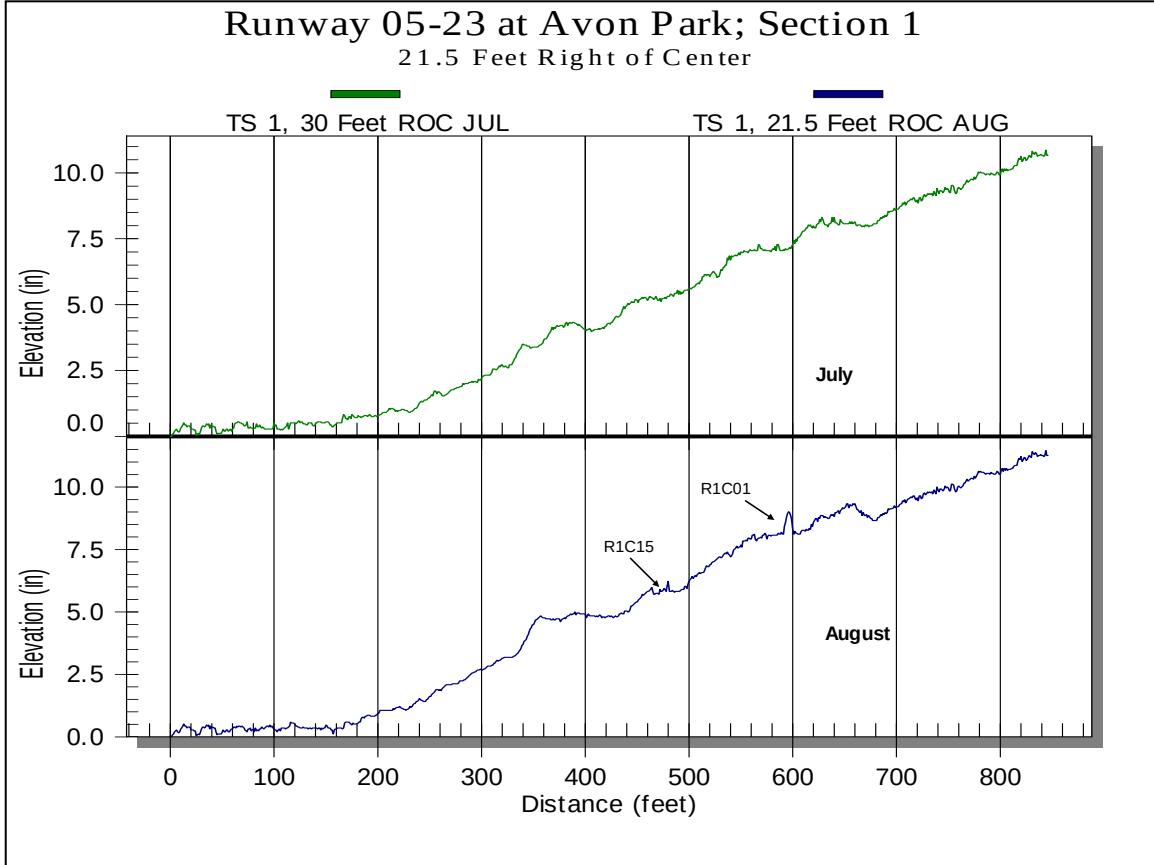


Figure A-21: Profile Plots of Test Section 1 on Runway 5-23, 21.5 Feet Left of Center Before and After

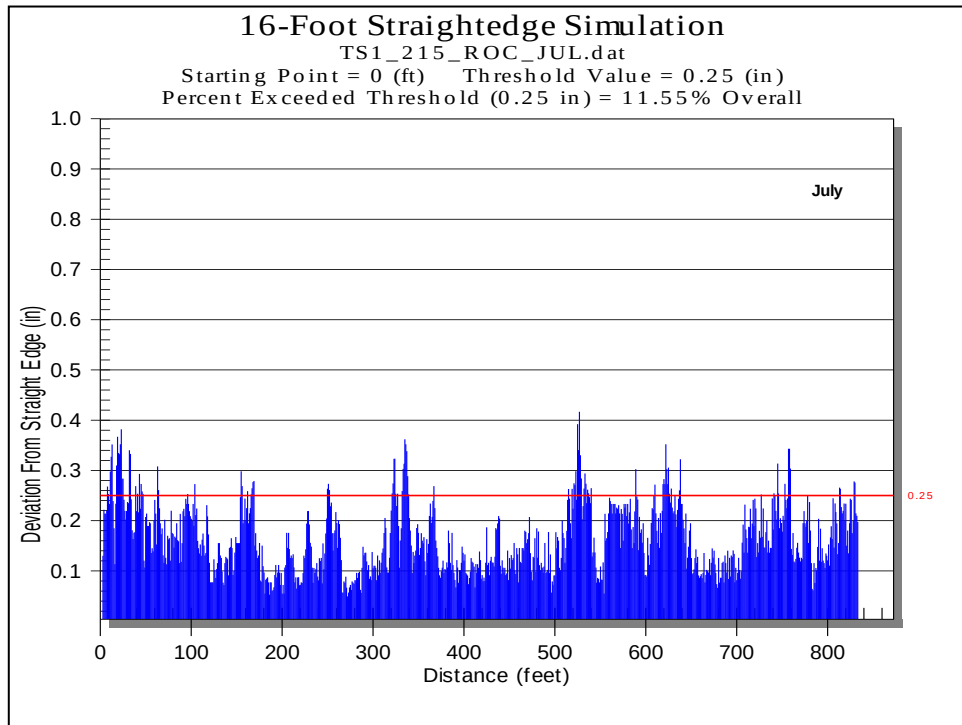


Figure A-22: 16-Foot Straightedge Simulation on Test Section 1, 21.5 Feet Right of Center Before Craters

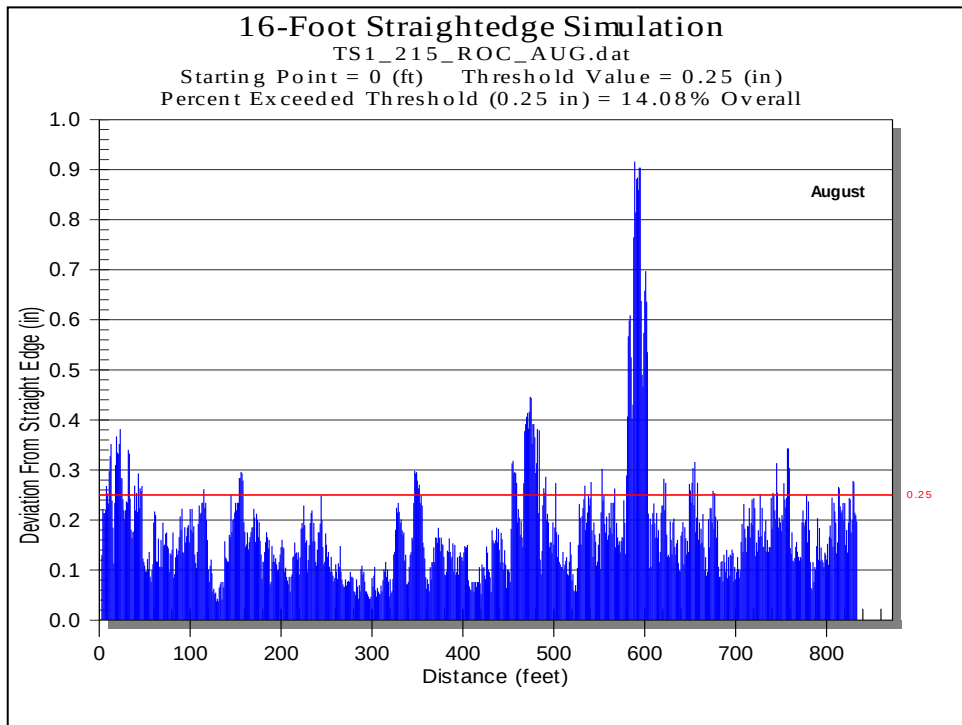


Figure A-23: 16-Foot Straightedge Simulation on Test Section 1, 21.5 Feet Right of Center After Repairs

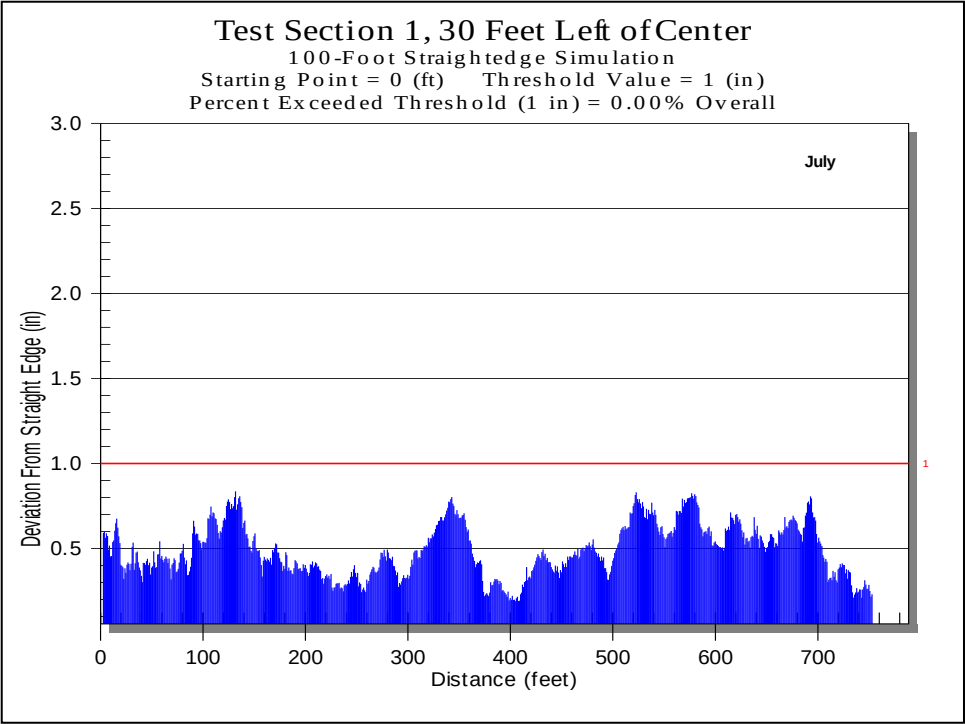


Figure A-24: 100-Foot Straightedge Simulation on Test Section 1, 21.5 Feet Right of Center Before Craters

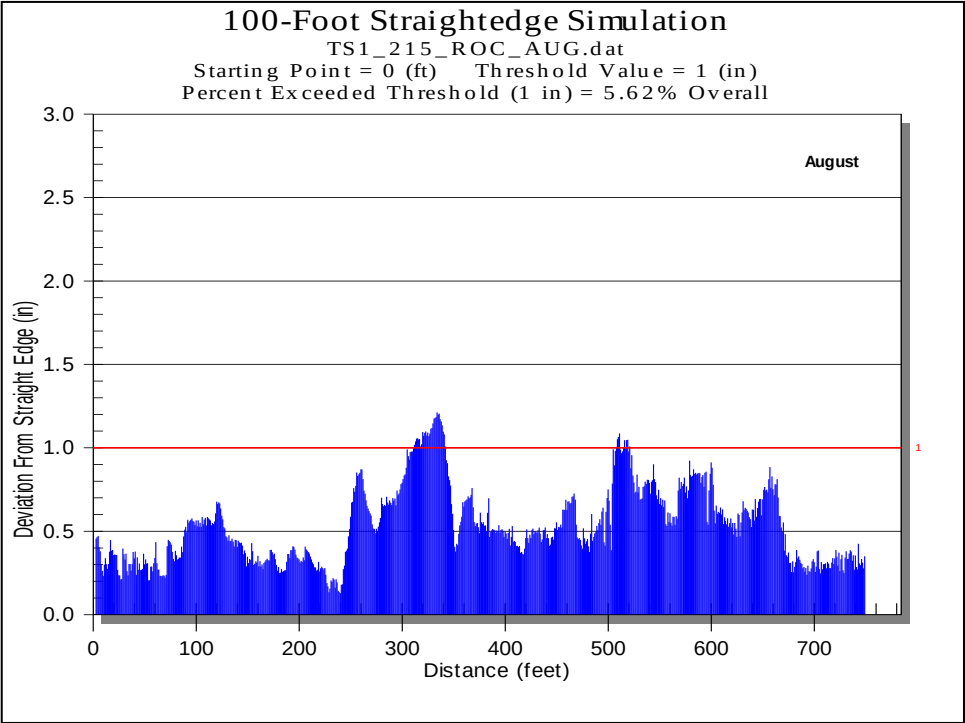


Figure A-25: 100-Foot Straightedge Simulation on Test Section 1, 21.5 Feet Right of Center After Repairs

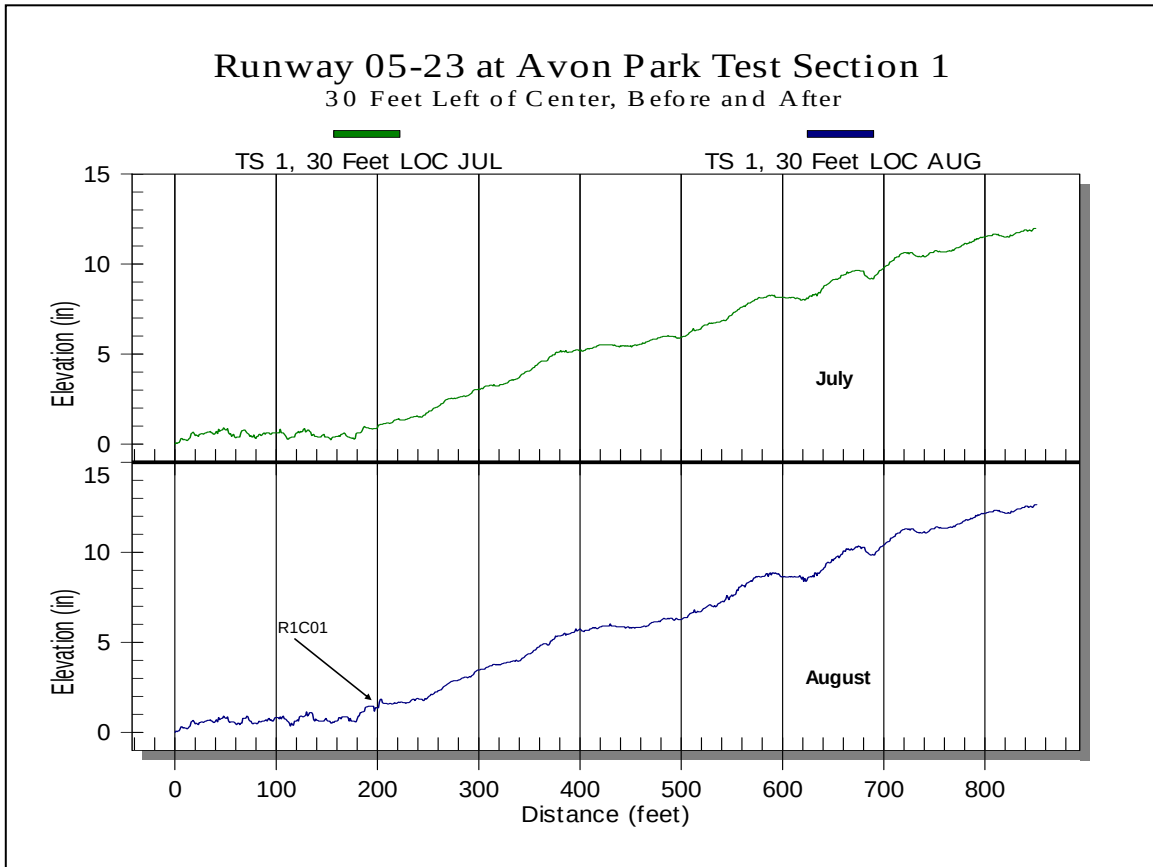


Figure A-26: Profile Plots of Test Section 1 on Runway 5-23, 30 Feet Left of Center Before and After

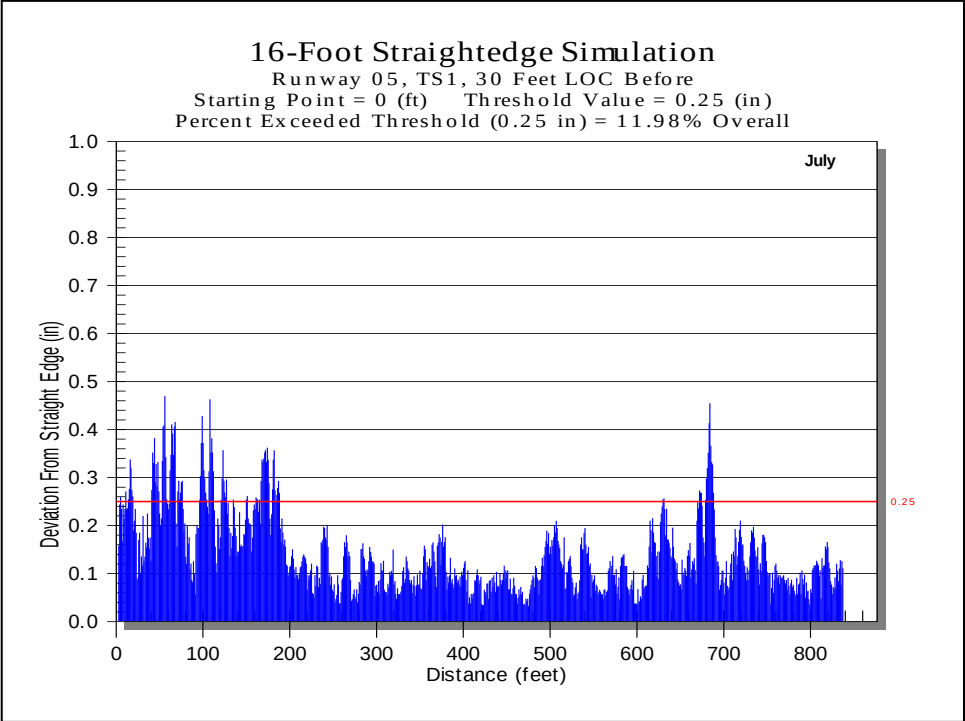


Figure A-27: 16-Foot Straightedge Simulation on Test Section 1, 30 Feet Left of Center Before Craters

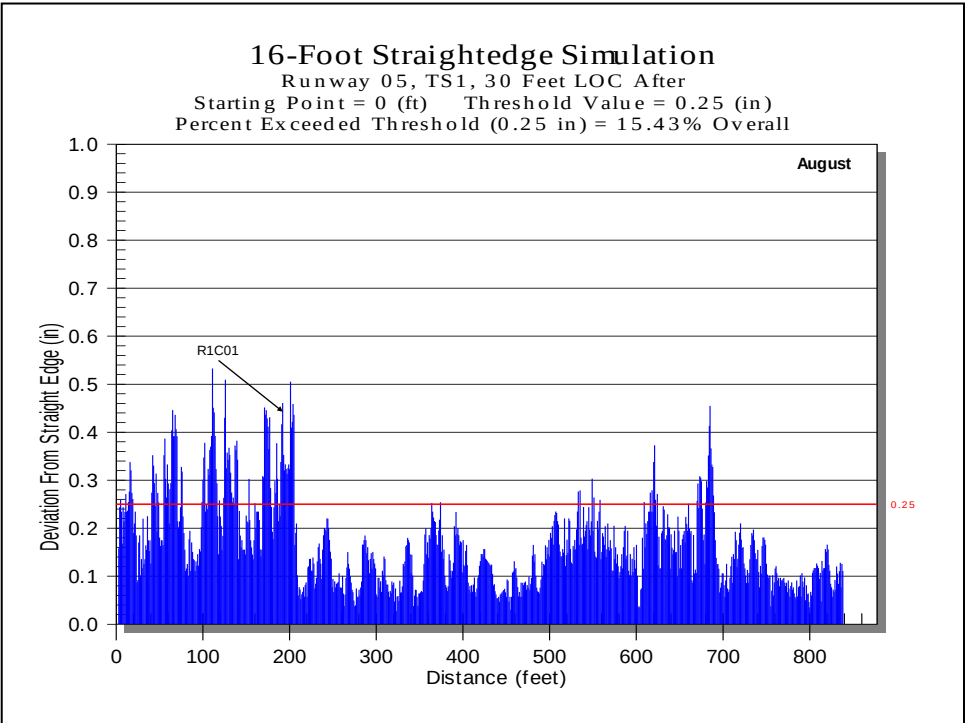


Figure A-28: 16-Foot Straightedge Simulation on Test Section 1, 30 Feet Left of Center After Repairs

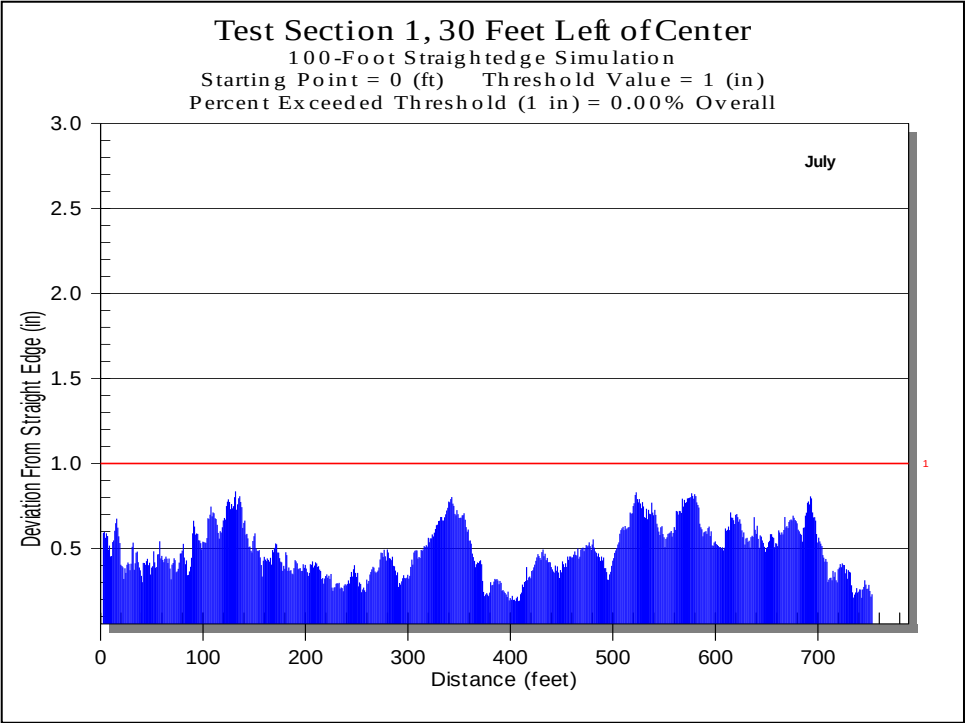


Figure A-29: 100-Foot Straightedge Simulation on Test Section 1, 30 Feet Left of Center Before Craters

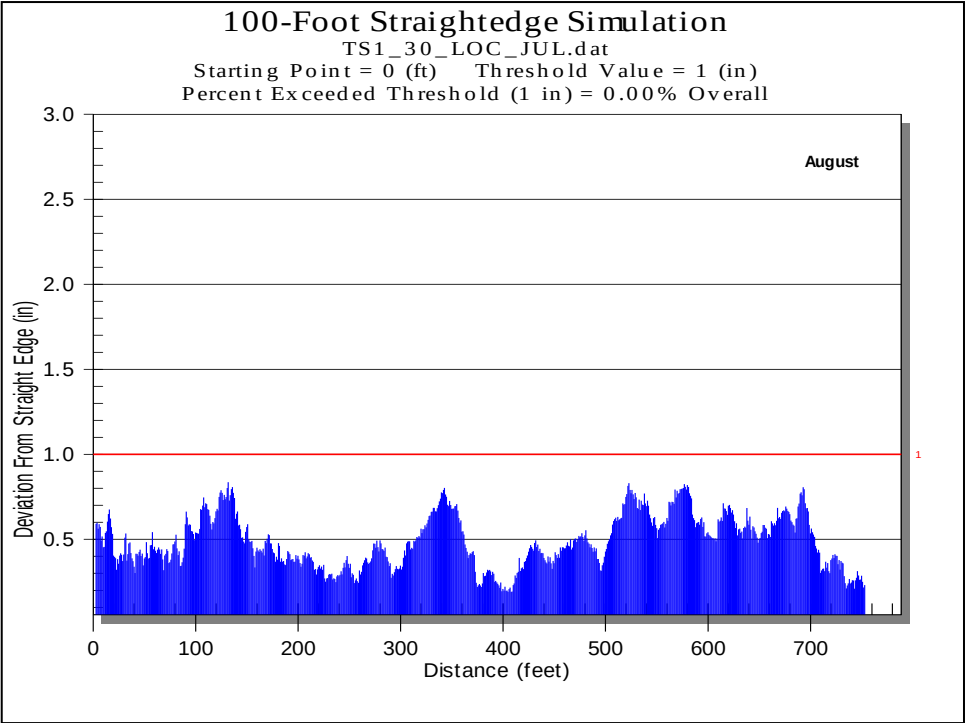


Figure A-30: 100-Foot Straightedge Simulation on Test Section 1, 30 Feet Left of Center After Repairs

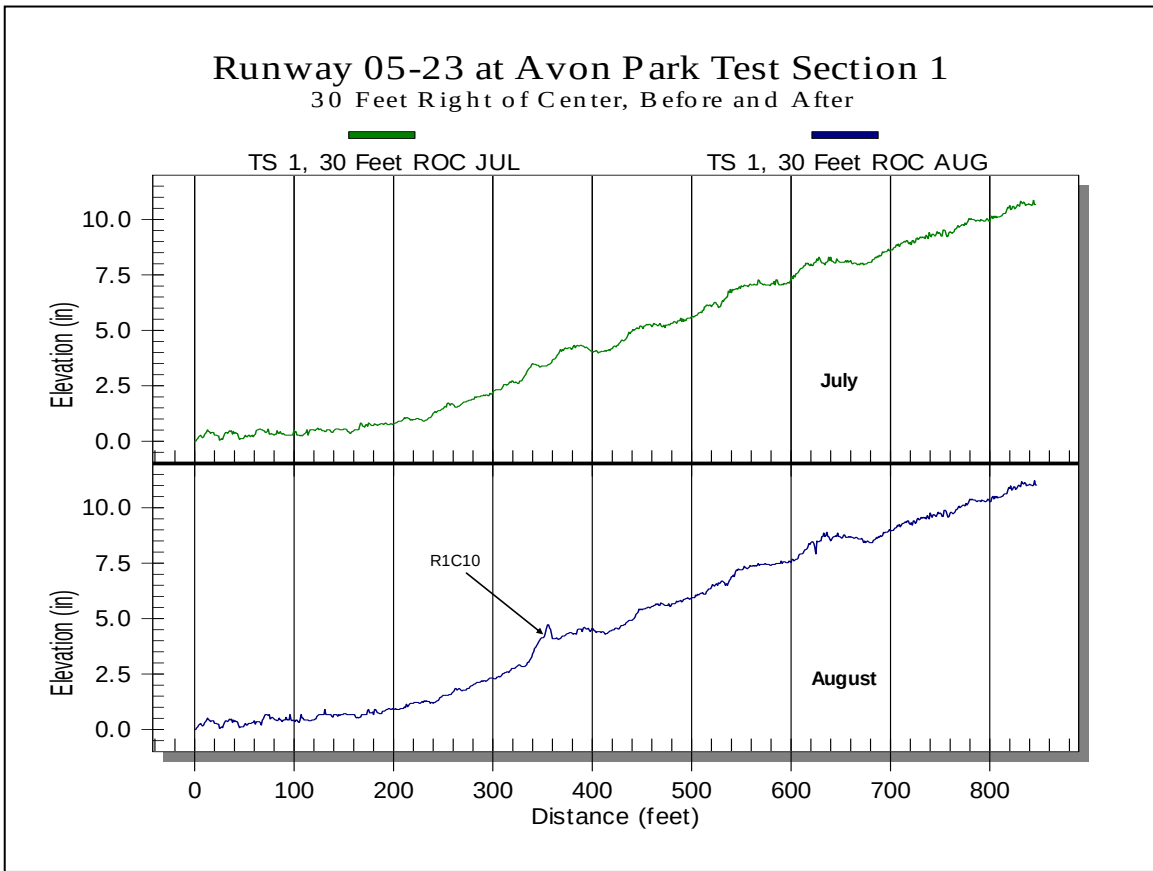


Figure A-31: Profile Plots of Test Section 1 on Runway 5-23, 30 Feet Right of Center Before and After

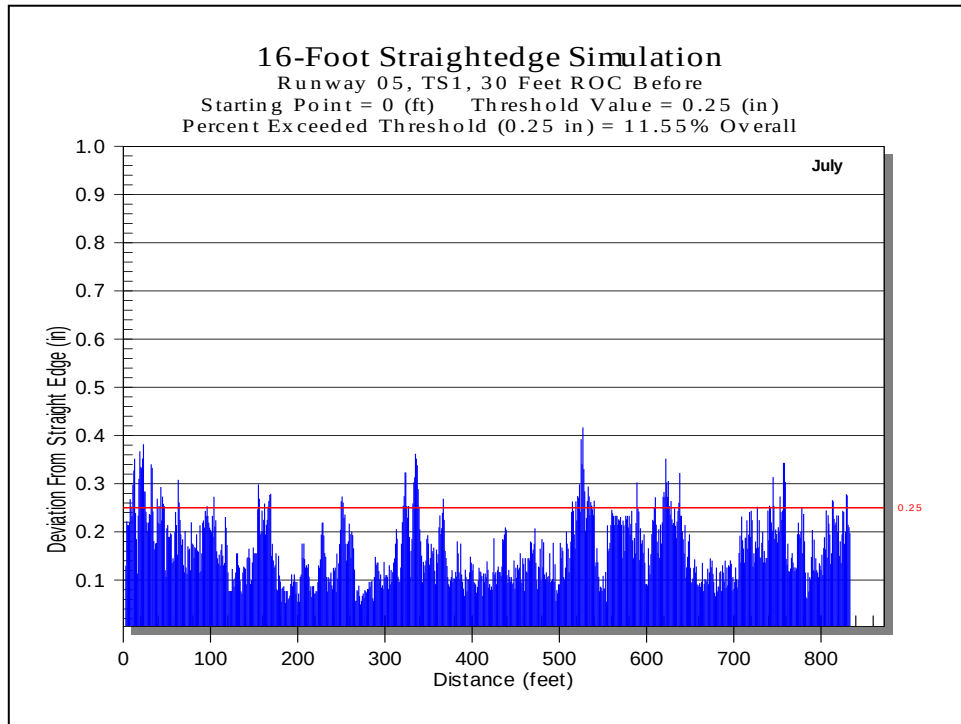


Figure A-32: 16-Foot Straightedge Simulation on Test Section 1, 30 Feet Right of Center Before Craters

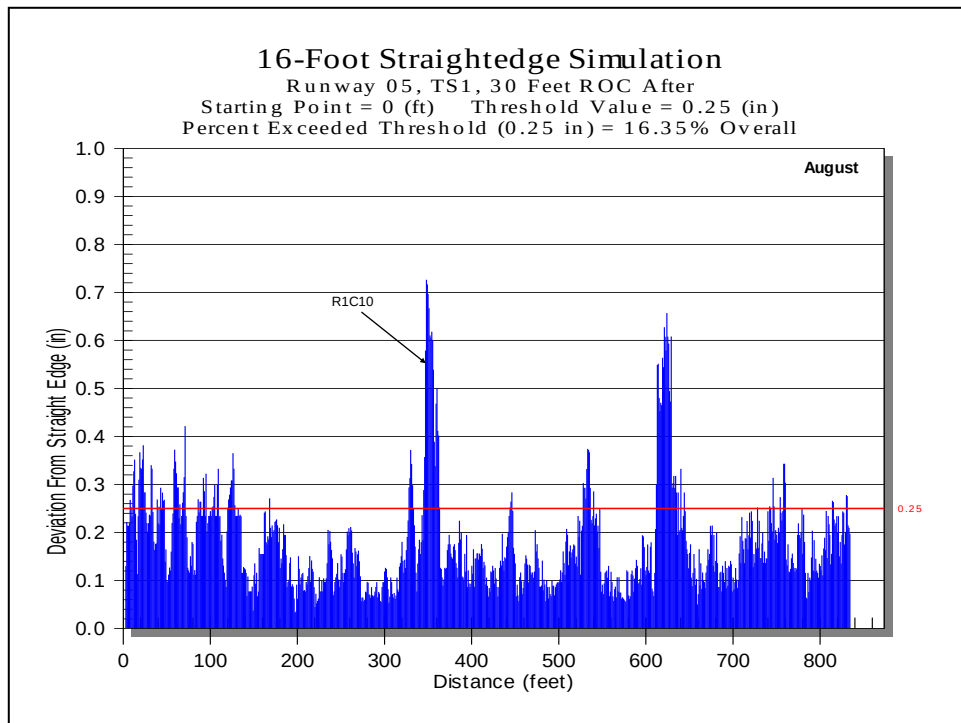


Figure A-33: 16-Foot Straightedge Simulation on Test Section 1, 30 Feet Right of Center After Repairs.

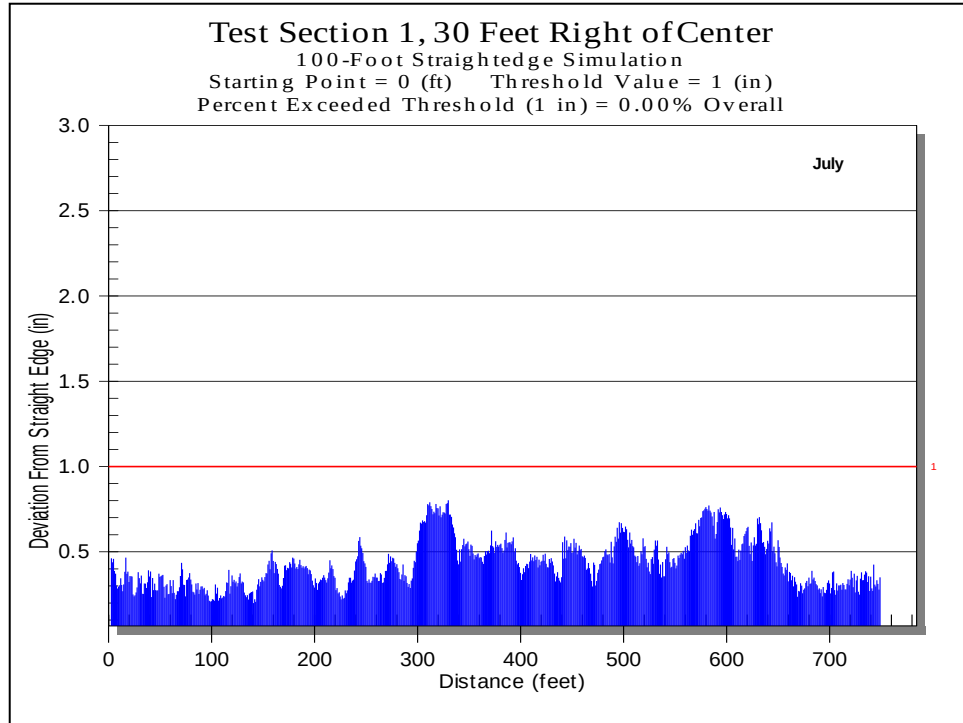


Figure A-34: 100-Foot Straightedge Simulation on Test Section 1, 30 Feet Right of Center Before Craters

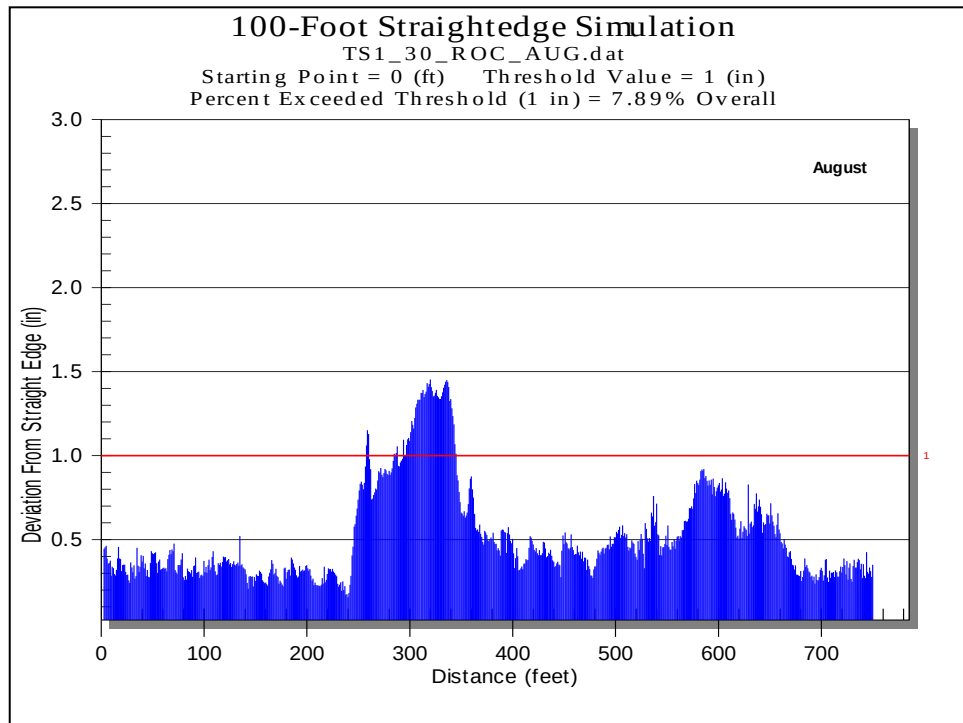


Figure A-35: 100-Foot Straightedge Simulation on Test Section 1, 30 Feet Right of Center After Repairs

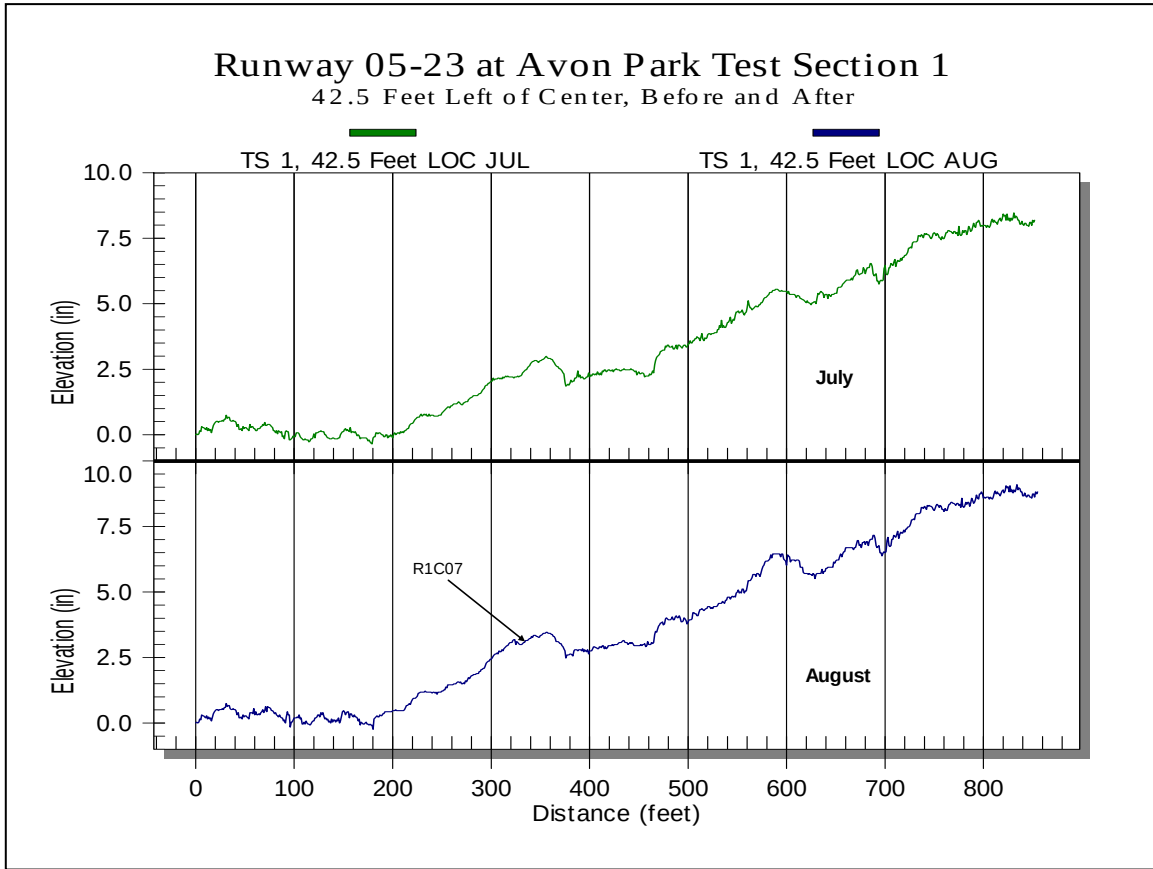


Figure A-36: Profile Plots of Test Section 1 on Runway 5-23, 42.5 Feet Left of Center Before and After

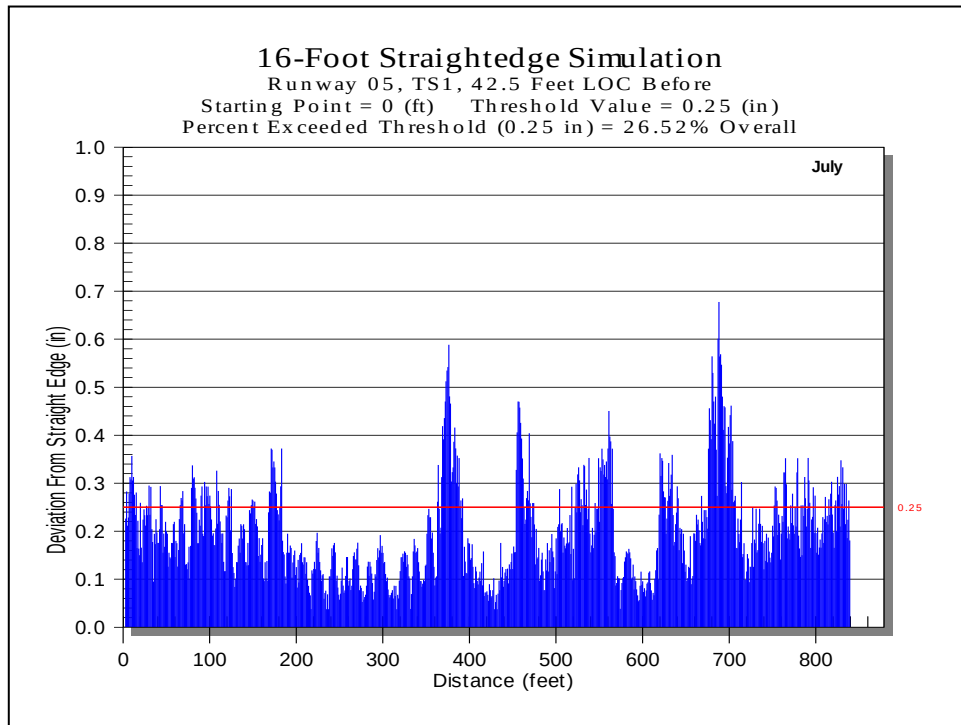


Figure A-37: 16-Foot Straightedge Simulation on Test Section 1, 42.5 Feet Left of Center Before Craters

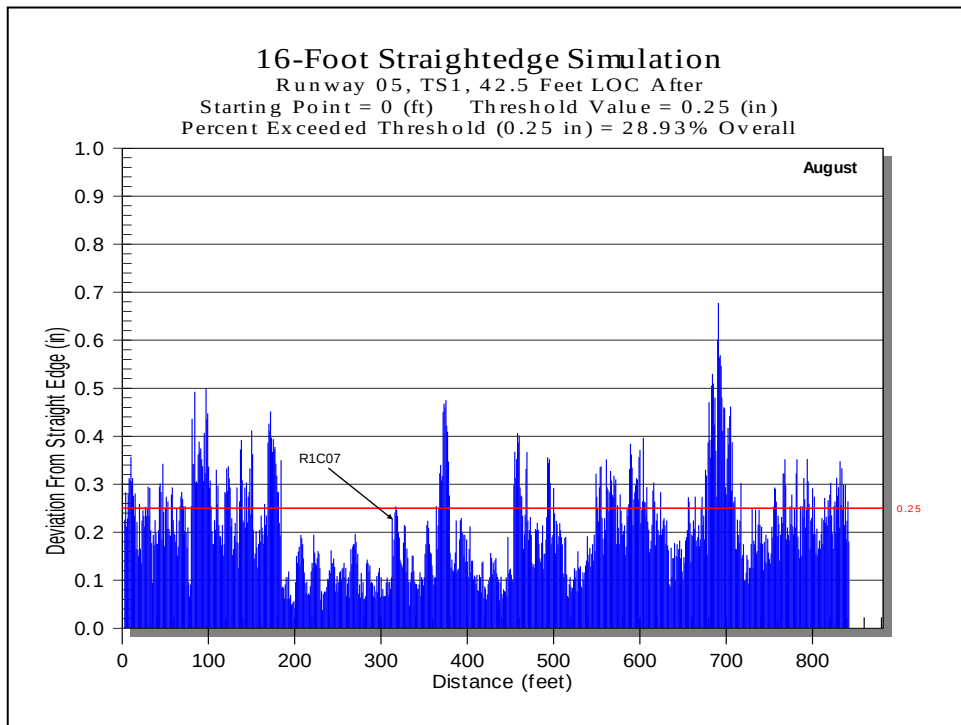


Figure A-38: 16-Foot Straightedge Simulation on Test Section 1, 42.5 Feet Left of Center After Repairs

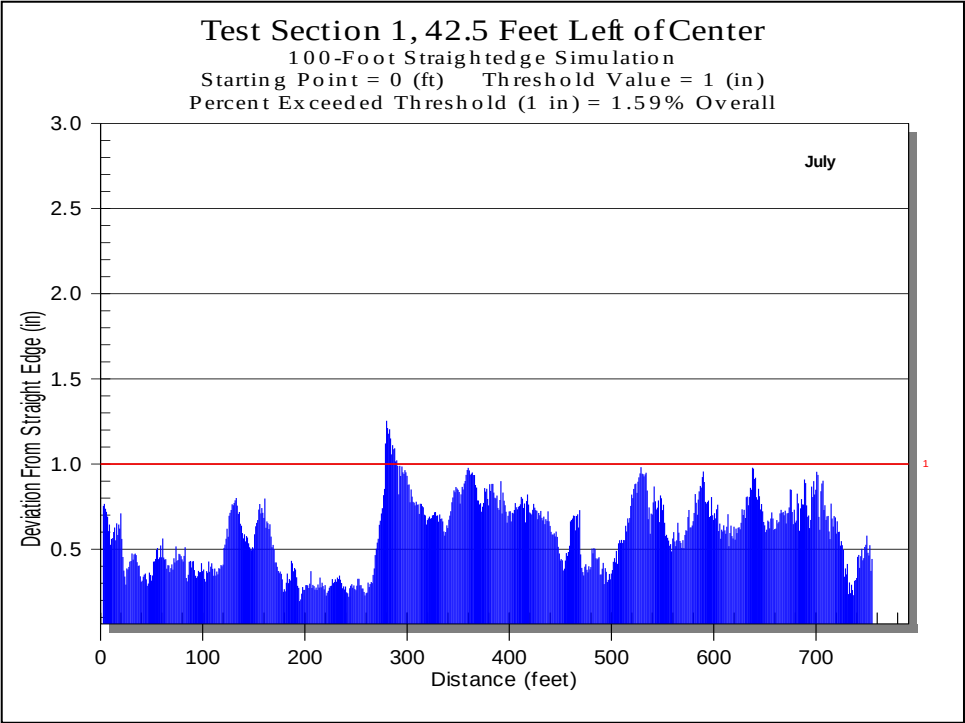


Figure A-39: 100-Foot Straightedge Simulation on Test Section 1, 42.5 Feet Left of Center Before Craters

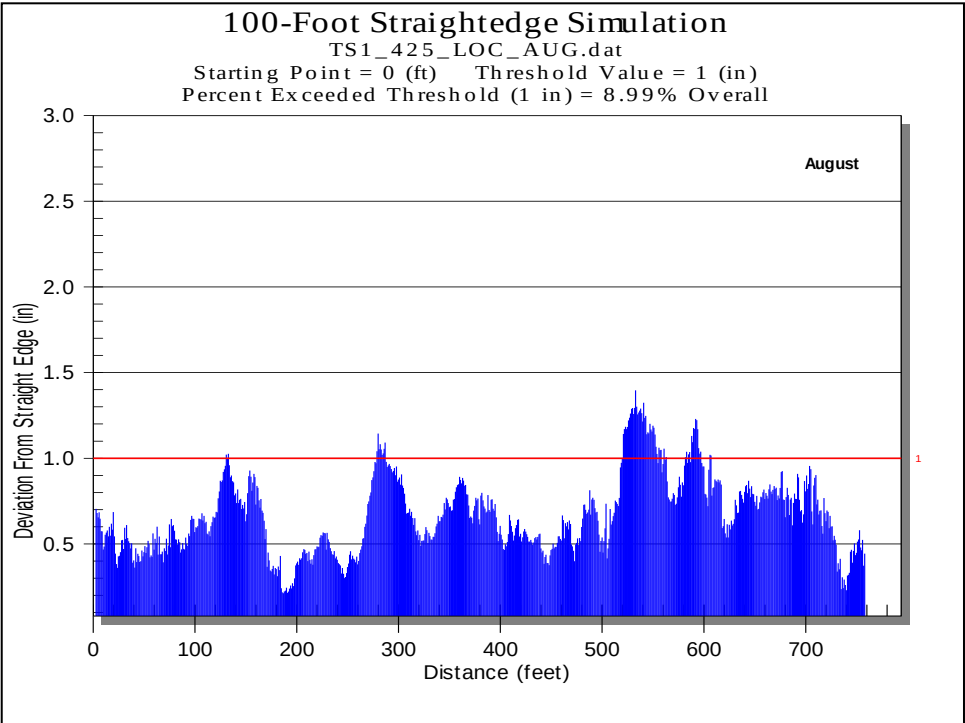


Figure A-40: 100-Foot Straightedge Simulation on Test Section 1, 42.5 Feet Left of Center After Repairs

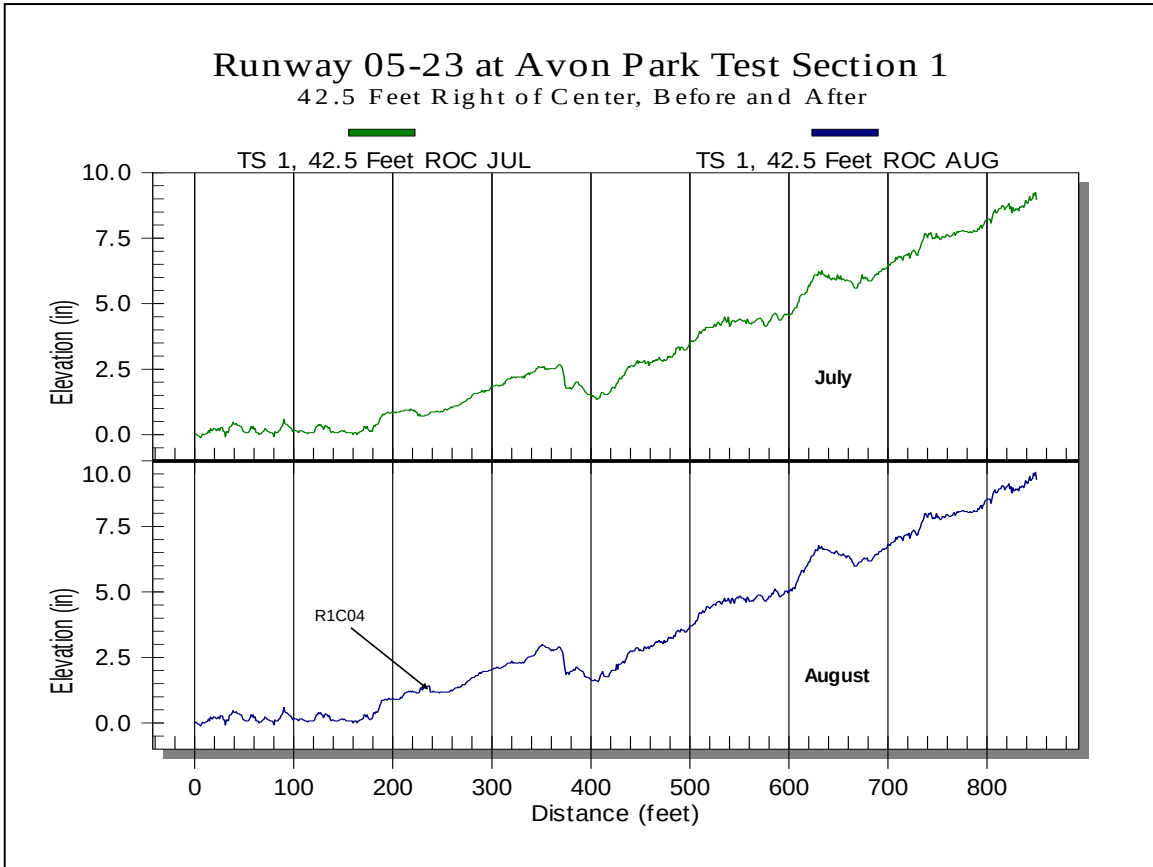


Figure A-41: Profile Plots of Test Section 1 on Runway 5-23, 42.5 Feet Right of Center Before and After

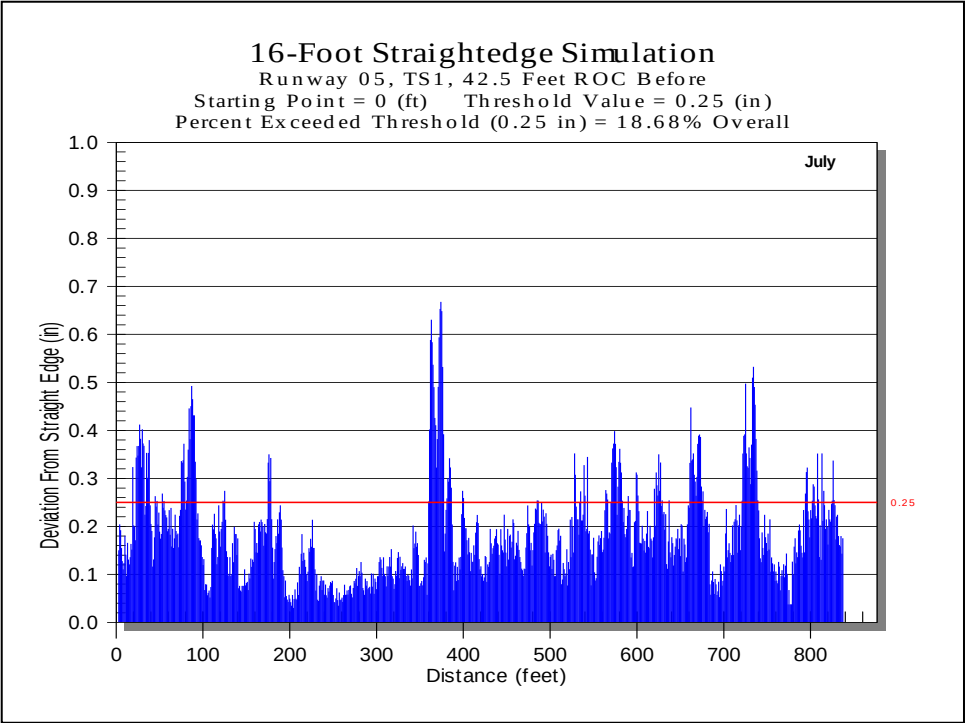


Figure A-42: 16-Foot Straightedge Simulation on Test Section 1, 42.5 Feet Right of Center Before Craters

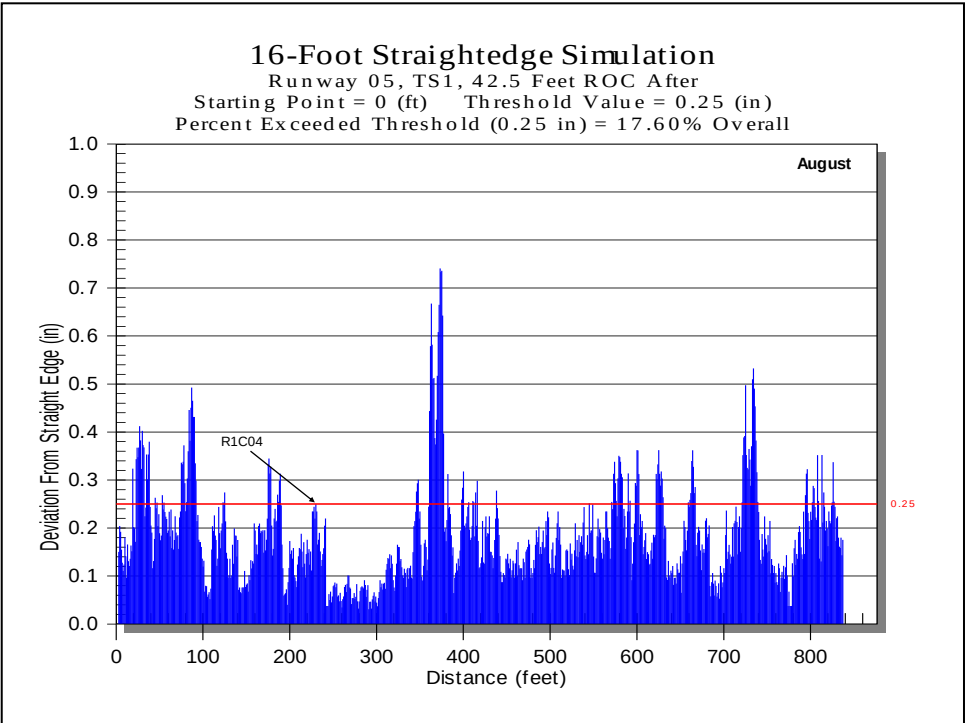


Figure A-43: 16-Foot Straightedge Simulation on Test Section 1, 42.5 Feet Right of Center After Repairs

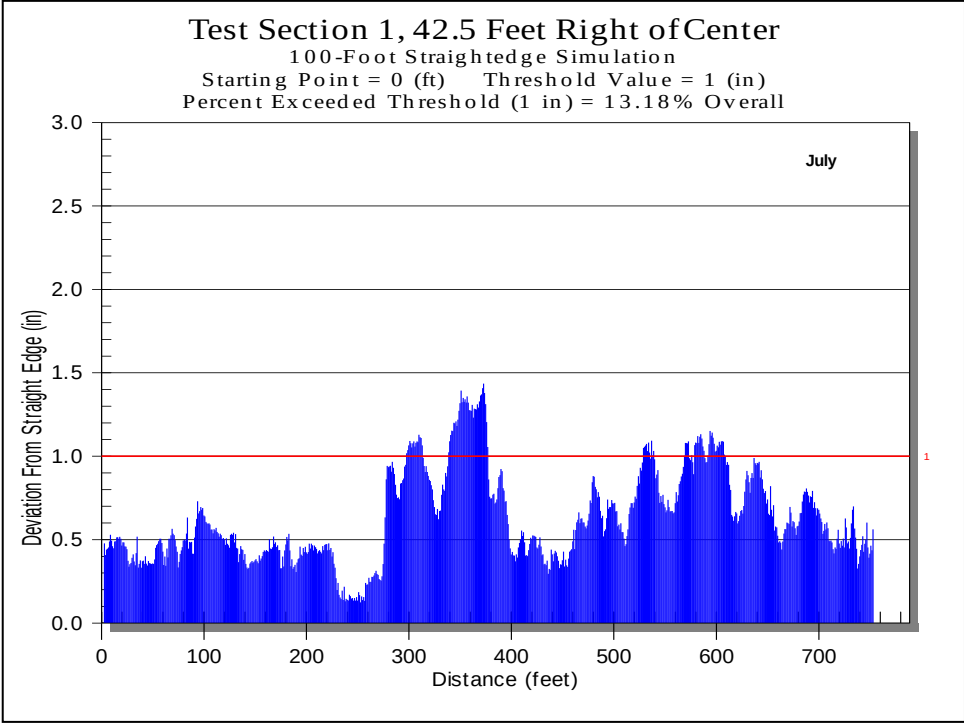


Figure A-44: 100-Foot Straightedge Simulation on Test Section 1, 42.5 Feet Right of Center Before Craters

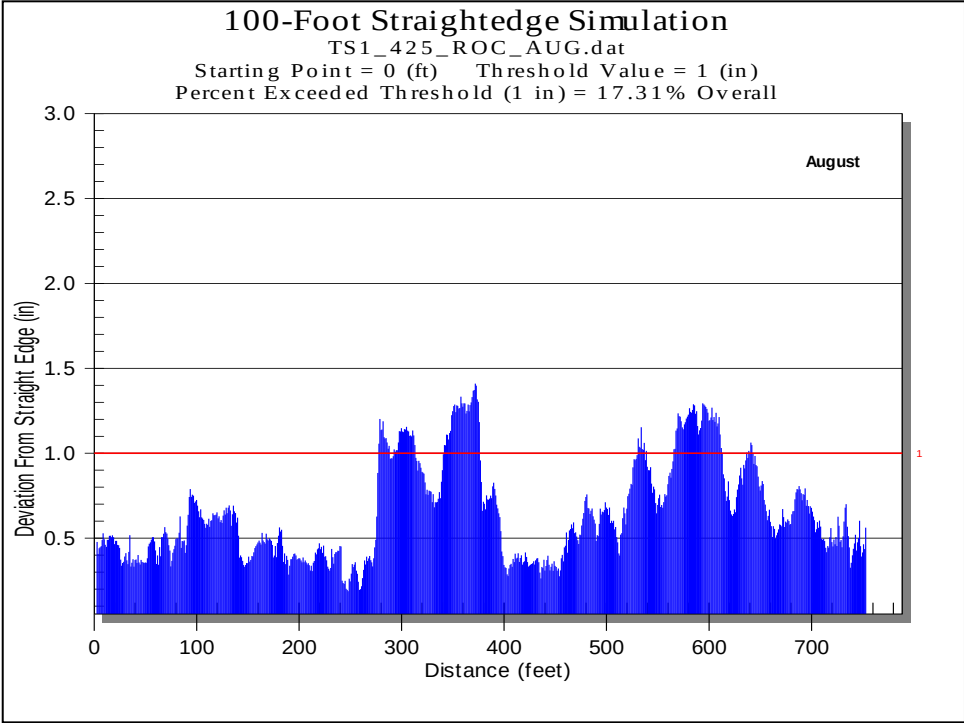


Figure A-45: 100-Foot Straightedge Simulation on Test Section 1, 42.5 Feet Right of Center After Repairs

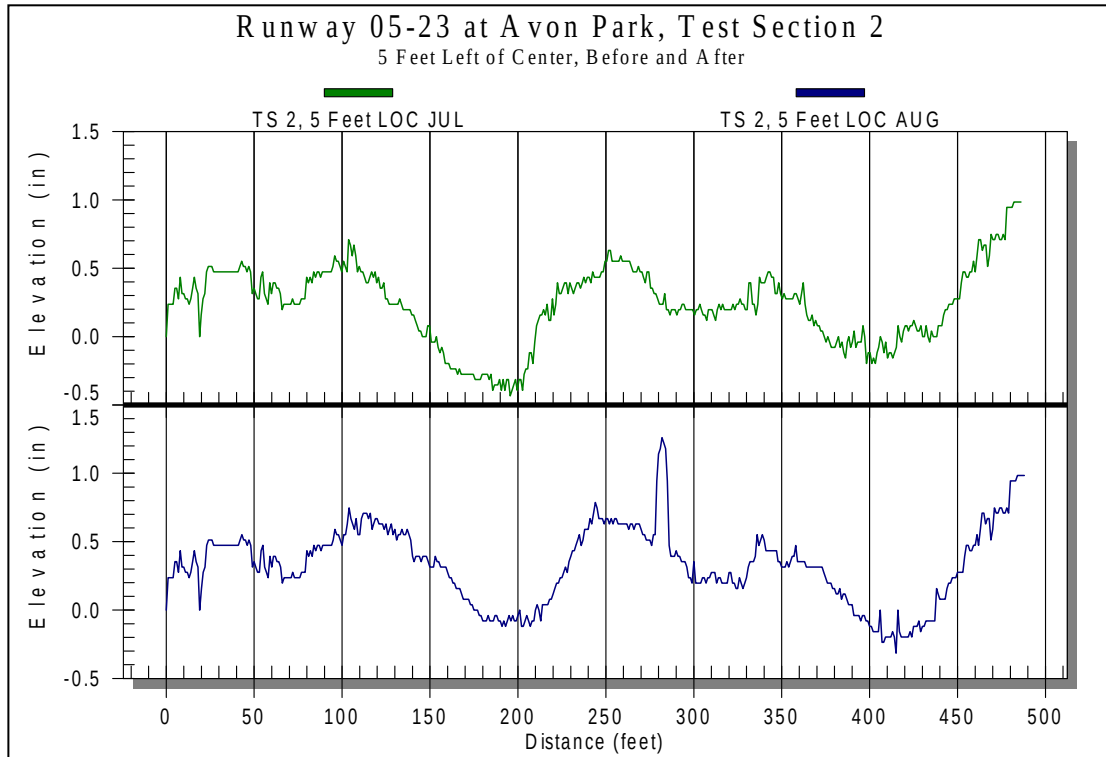


Figure A-46: Profile Plots of Test Section 2 on Runway 5-23, 5 Feet Left of Center Before and After

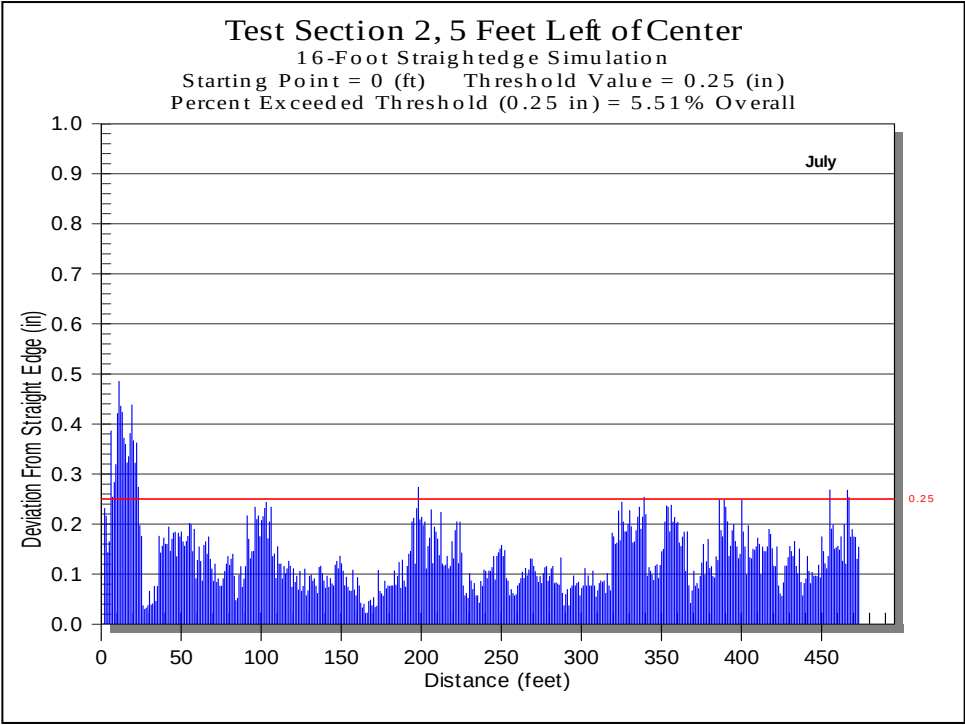


Figure A-47: 16-Foot Straightedge Simulation on Test Section 2, 5 Feet Left of Center Before Crater

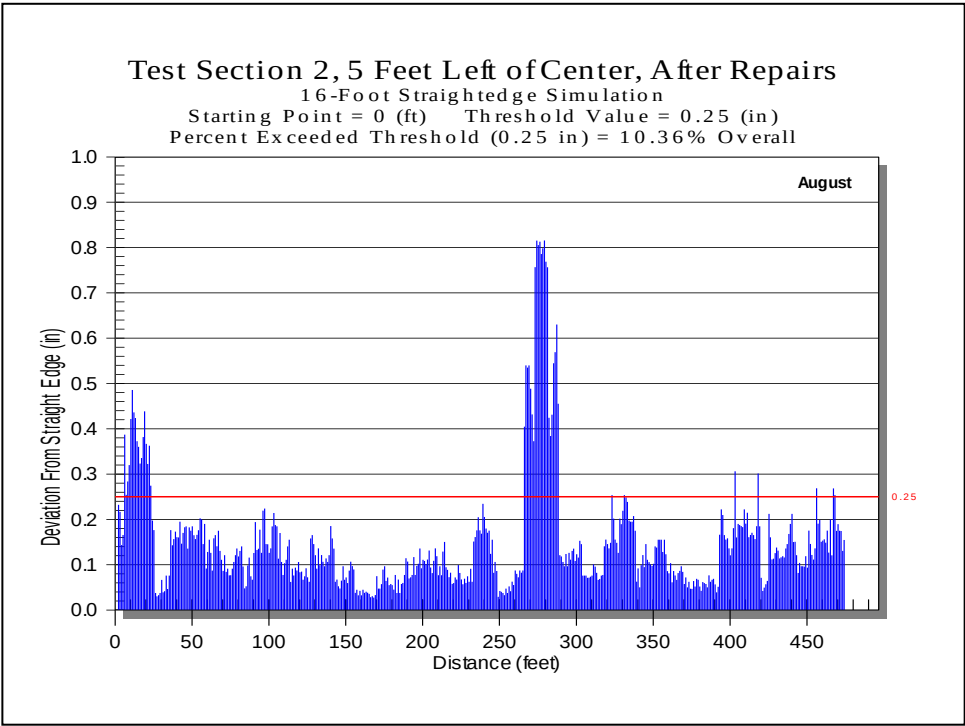


Figure A-48: 16-Foot Straightedge Simulation on Test Section 2, 5 Feet Left of Center After Repairs

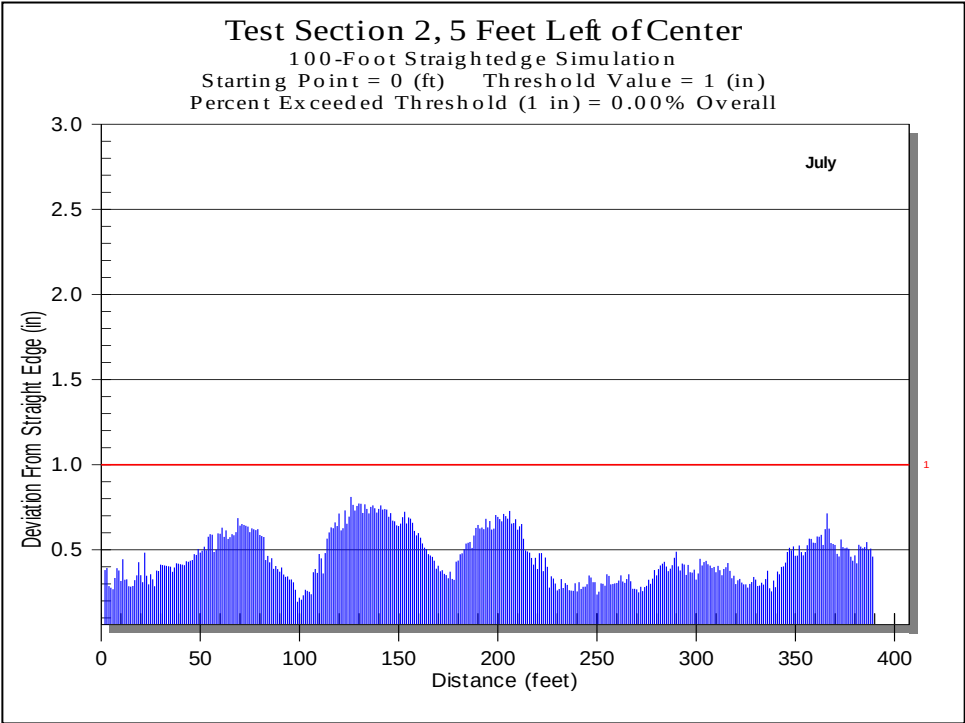


Figure A-49: 100-Foot Straightedge Simulation on Test Section 2, 5 Feet Left of Center Before Craters

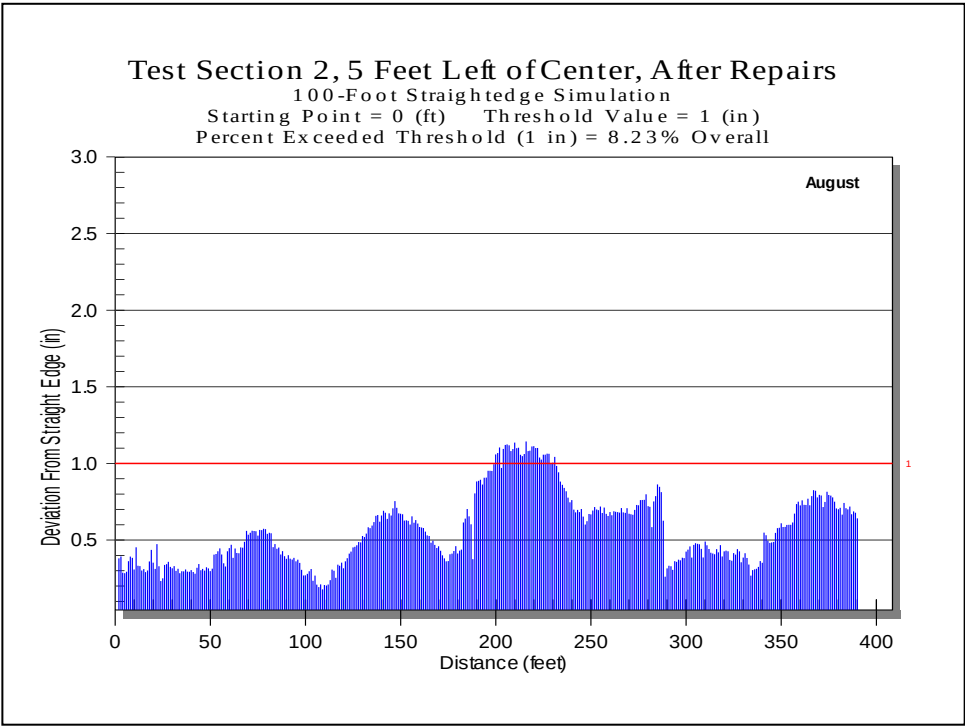


Figure A-50: 100-Foot Straightedge Simulation on Test Section 2, 5 Feet Left of Center After Repairs

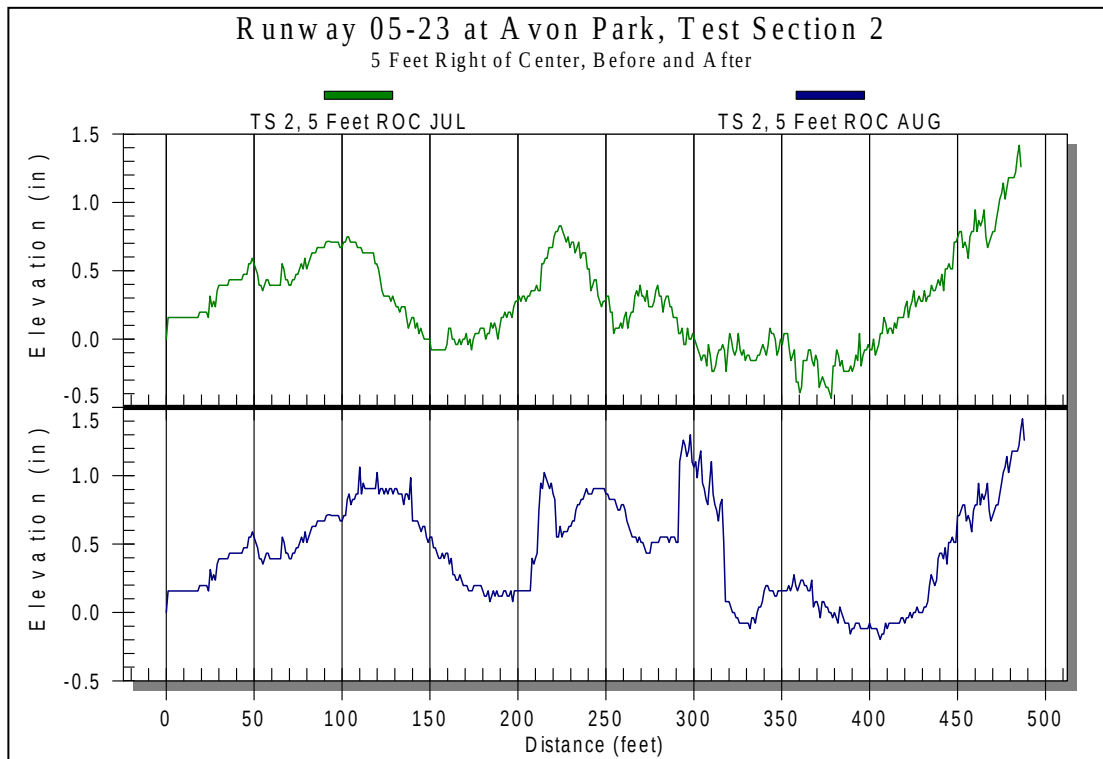


Figure A-51: Plots of Test Section 2 on Runway 5-23, 5 Feet Right of Center Before and After

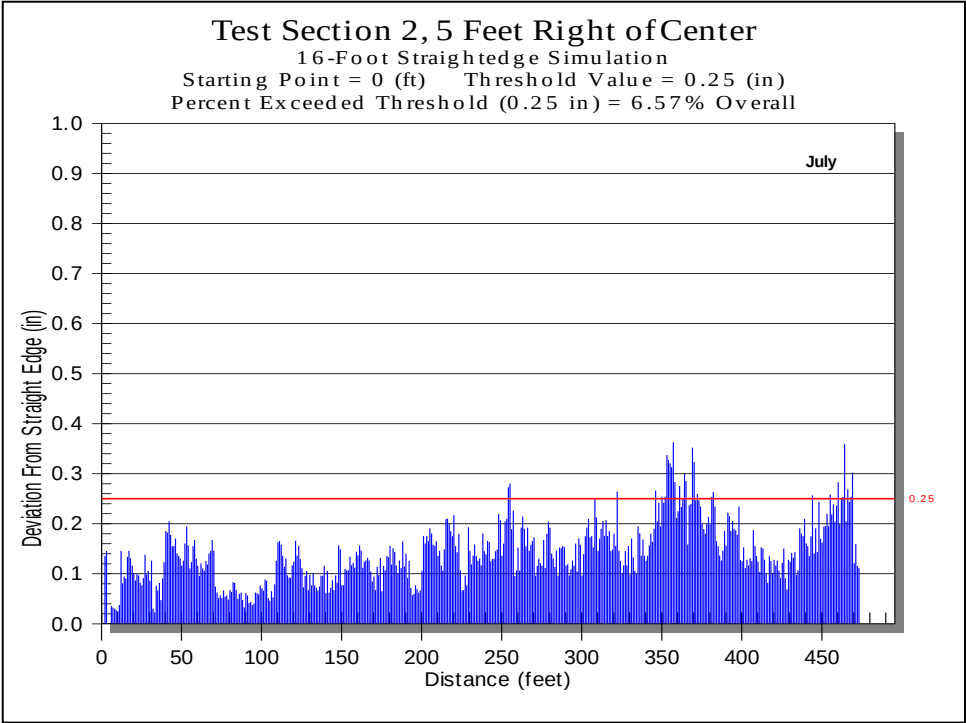


Figure A-52: 16-Foot Straightedge Simulation on Test Section 2, 5 Feet Right of Center Before Craters

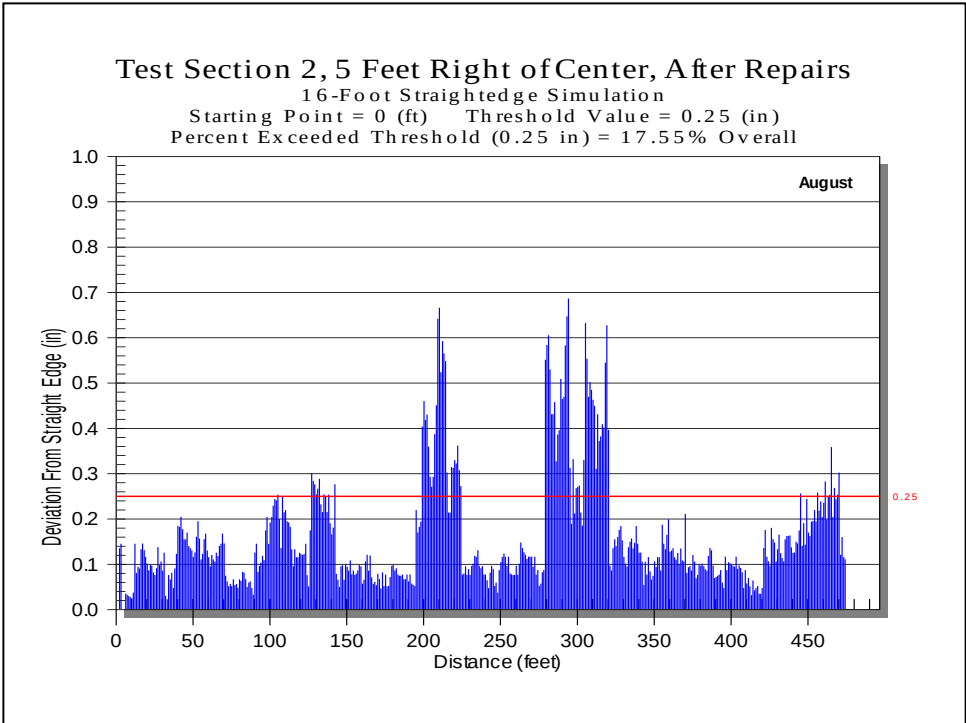


Figure A-53: 16-Foot Straightedge Simulation on Test Section 2, 5 Feet Right of Center After Repairs

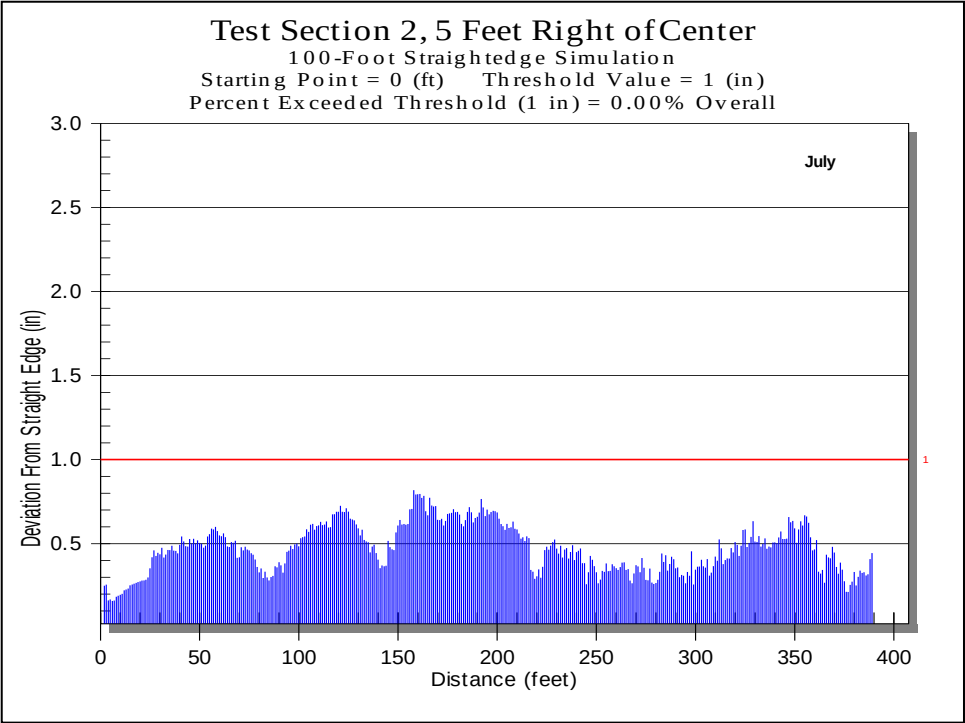


Figure A-54: 100-Foot Straightedge Simulation on Test Section 2, 5 Feet Right of Center Before Craters

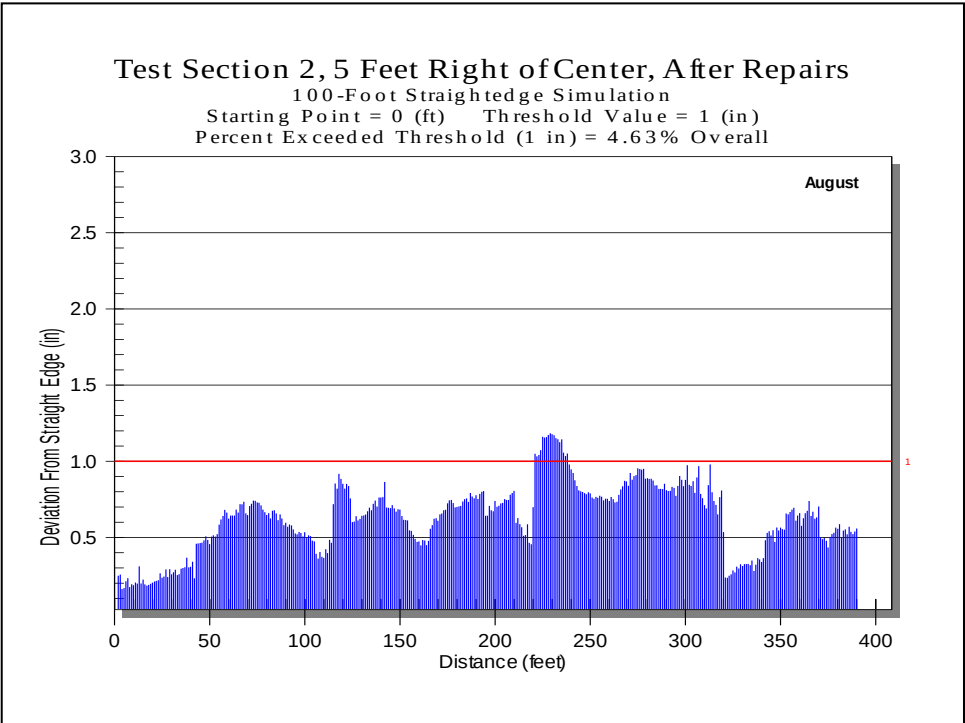


Figure A-55: 100-Foot Straightedge Simulation on Test Section 2, 5 Feet Right of Center After Repairs

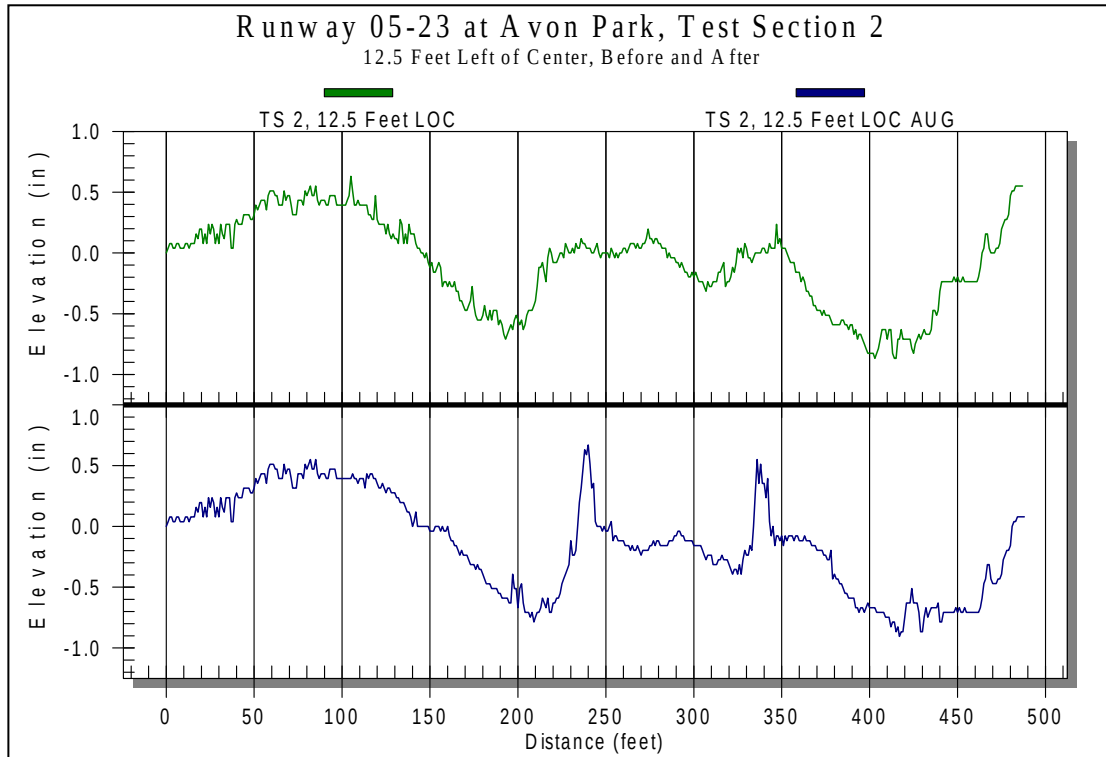


Figure A-56: Plots of Test Section 2 on Runway 5-23, 12.5 Feet Left of Center Before and After

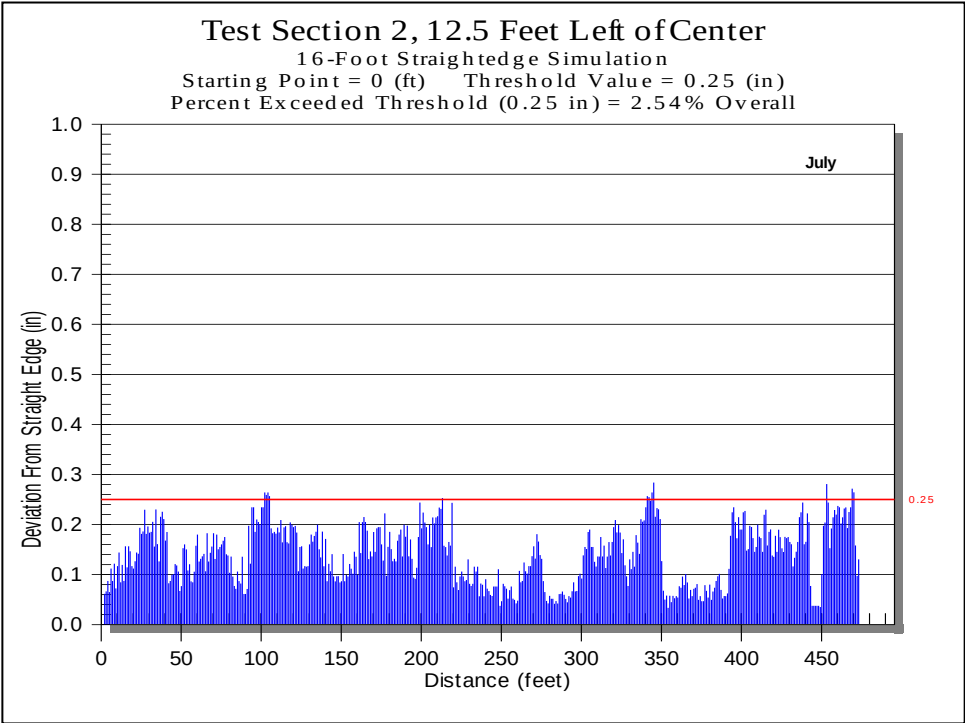


Figure A-57: 16-Foot Straightedge Simulation on Test Section 2, 12.5 Feet Left of Center Before Craters

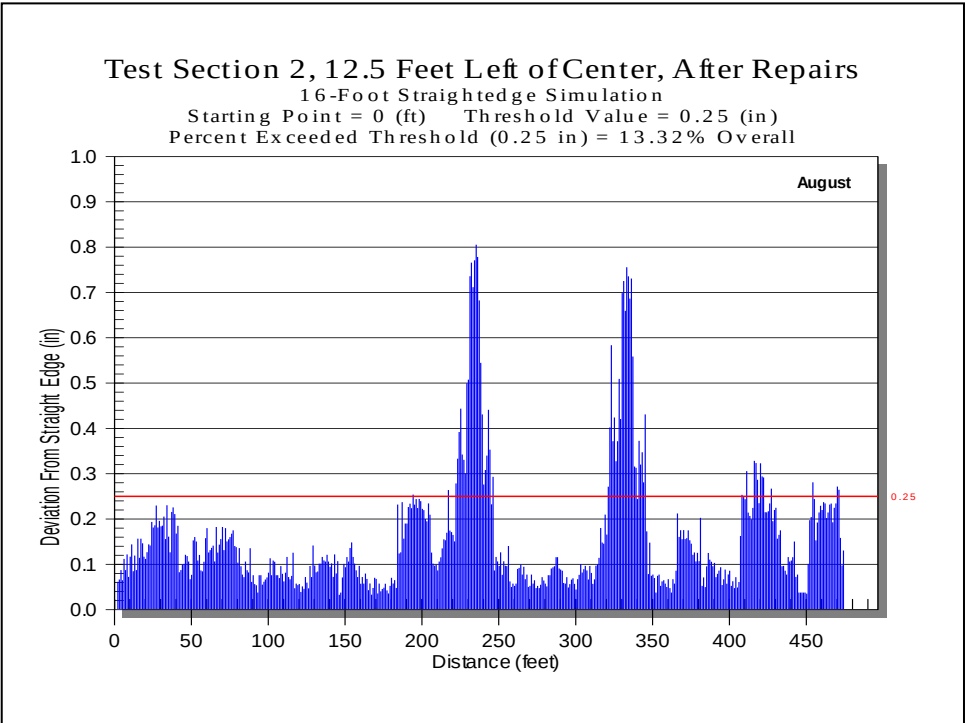


Figure A-58: 16-Foot Straightedge Simulation on Test Section 2, 12.5 Feet Left of Center After Repairs

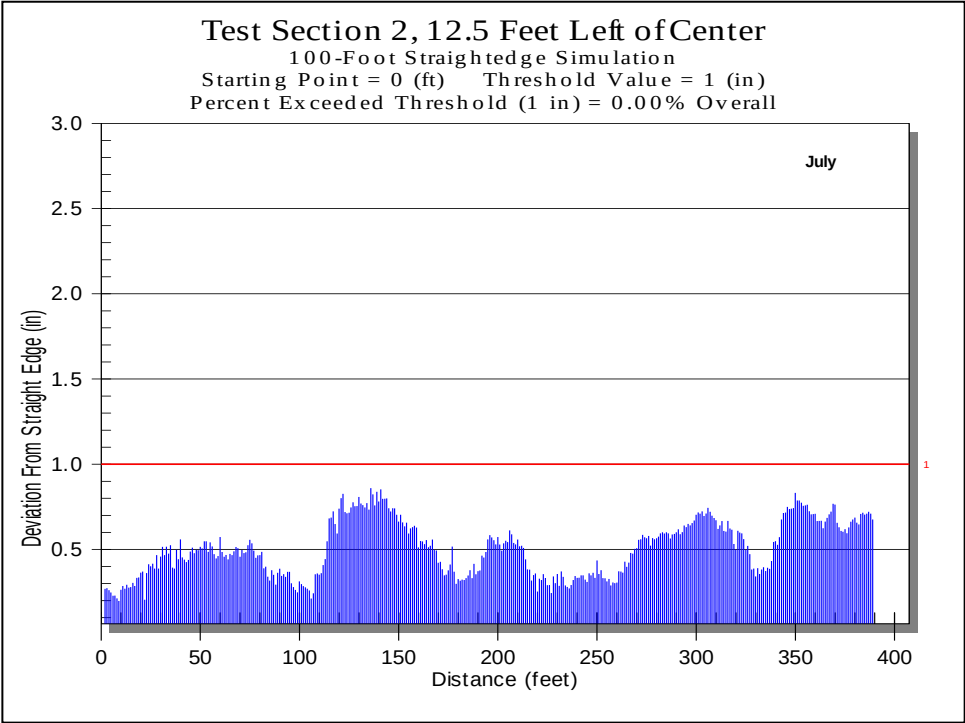


Figure A-59: 100-Foot Straightedge Simulation on Test Section 2, 12.5 Feet Left of Center Before Craters

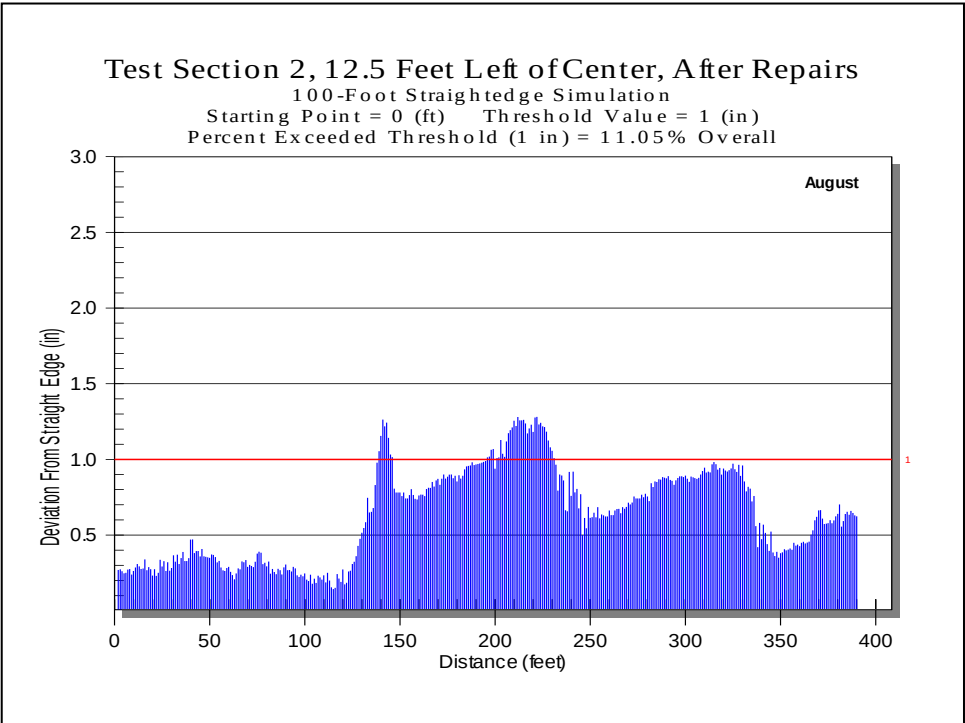


Figure A-60: 100-Foot Straightedge Simulation on Test Section 2, 12.5 Feet Left of Center After Repairs

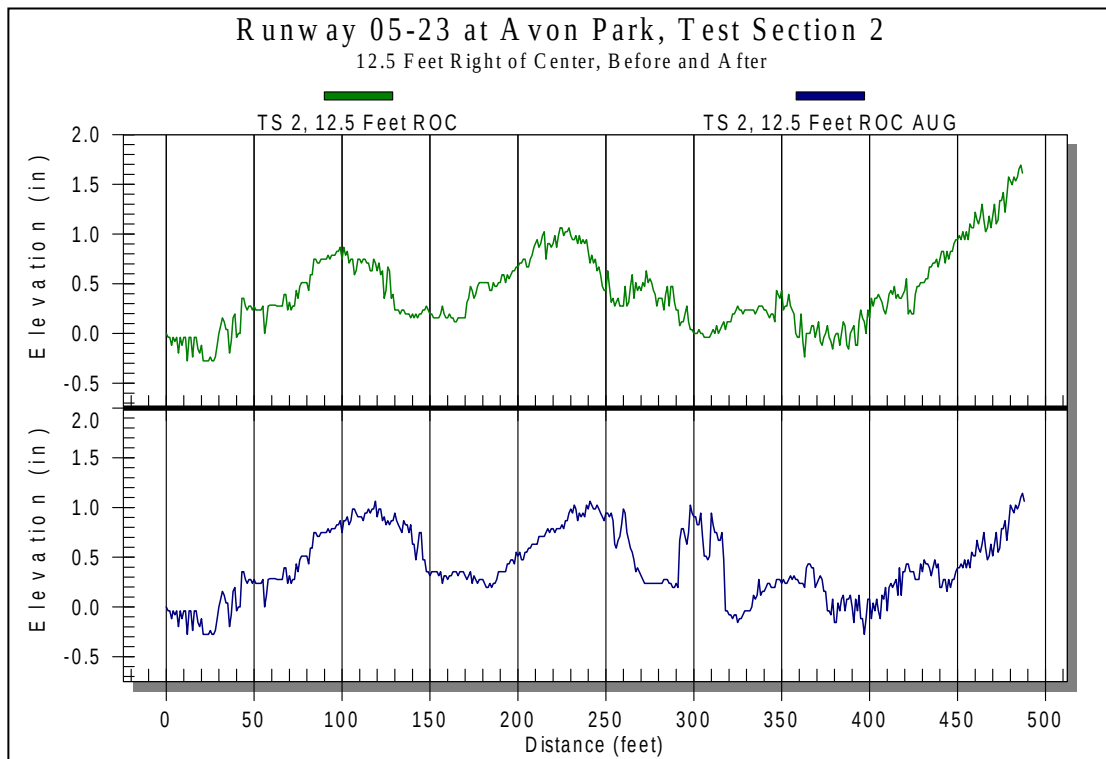


Figure A-61: Plots of Test Section 2 on Runway 5-23, 12.5 Feet Right of Center Before and After

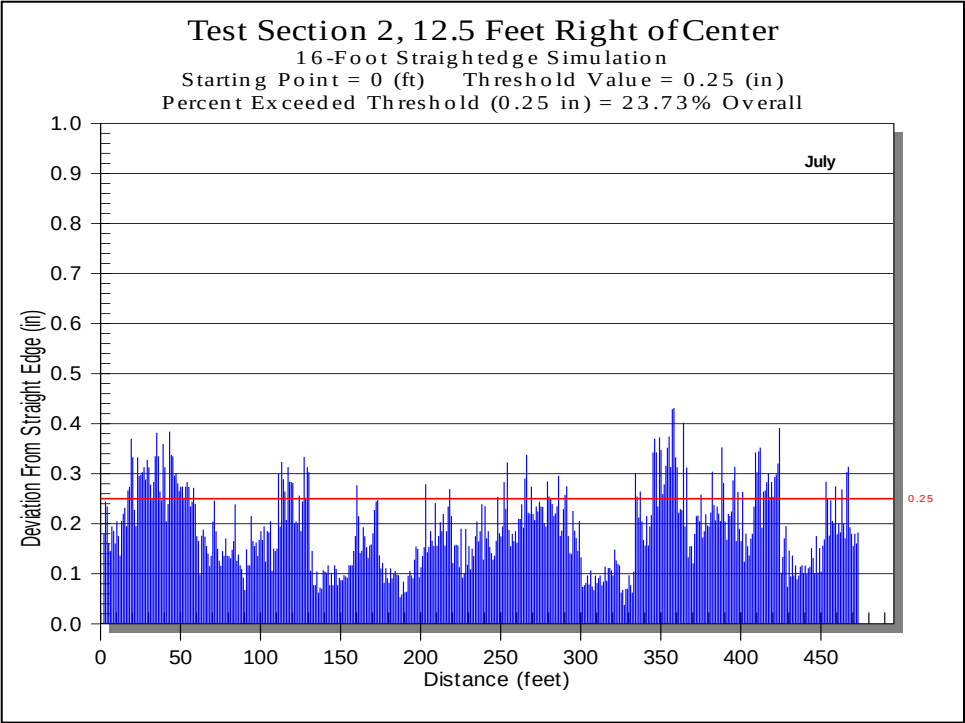


Figure A-62: 16-Foot Straightedge Simulation on Test Section 2, 12.5 Feet Right of Center Before Craters

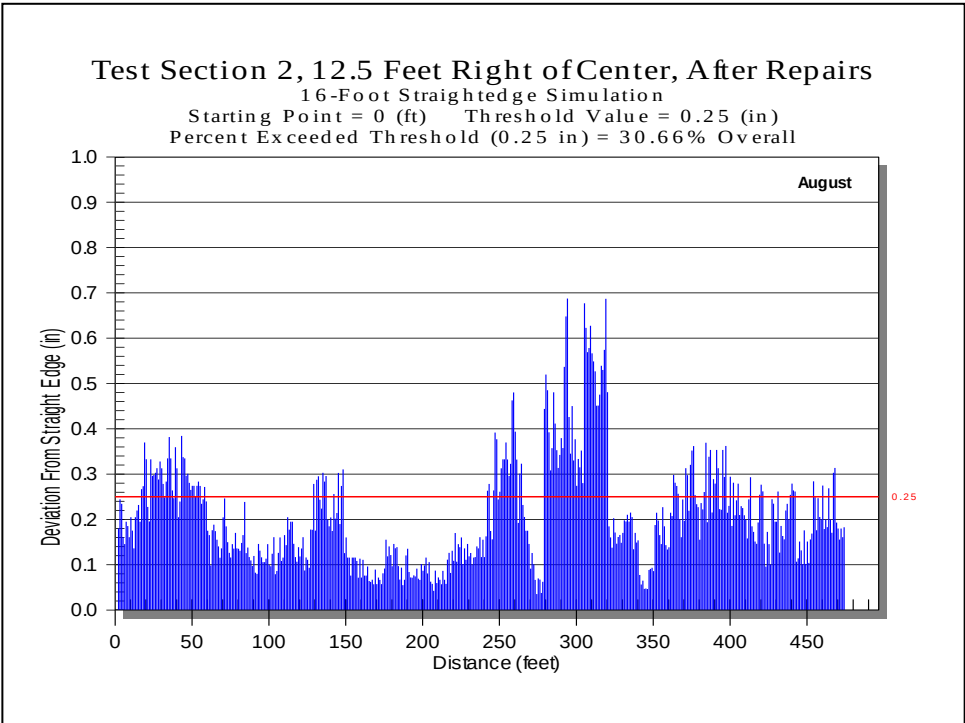


Figure A-63: 16-Foot Straightedge Simulation on Test Section 2, 12.5 Feet Right of Center Before Craters

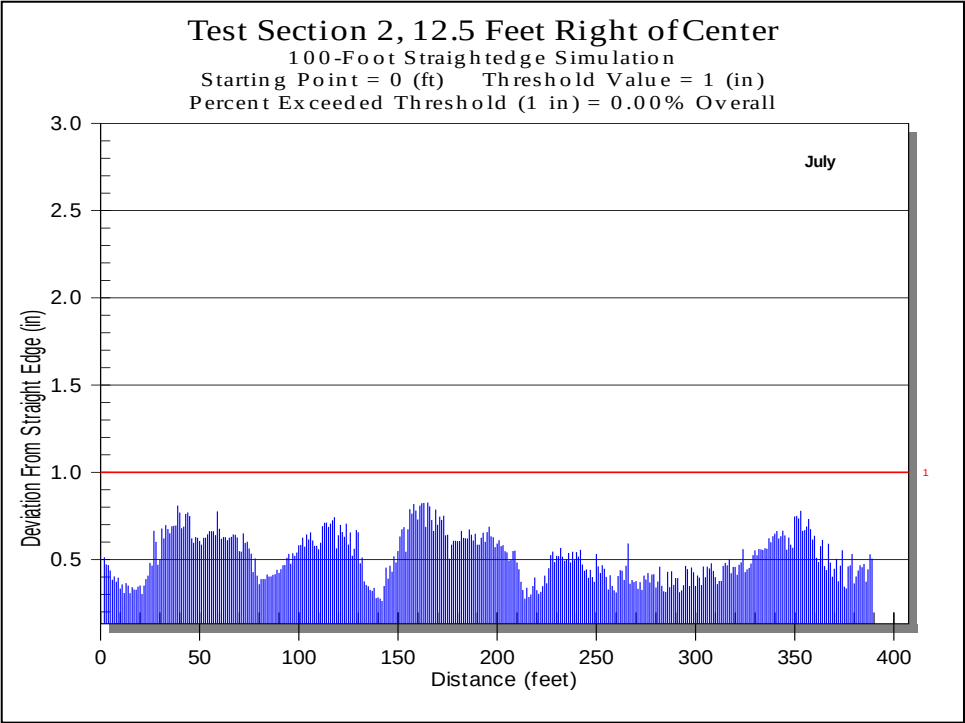


Figure A-64: 100-Foot Straightedge Simulation on Test Section 2, 12.5 Feet Right of Center Before Craters

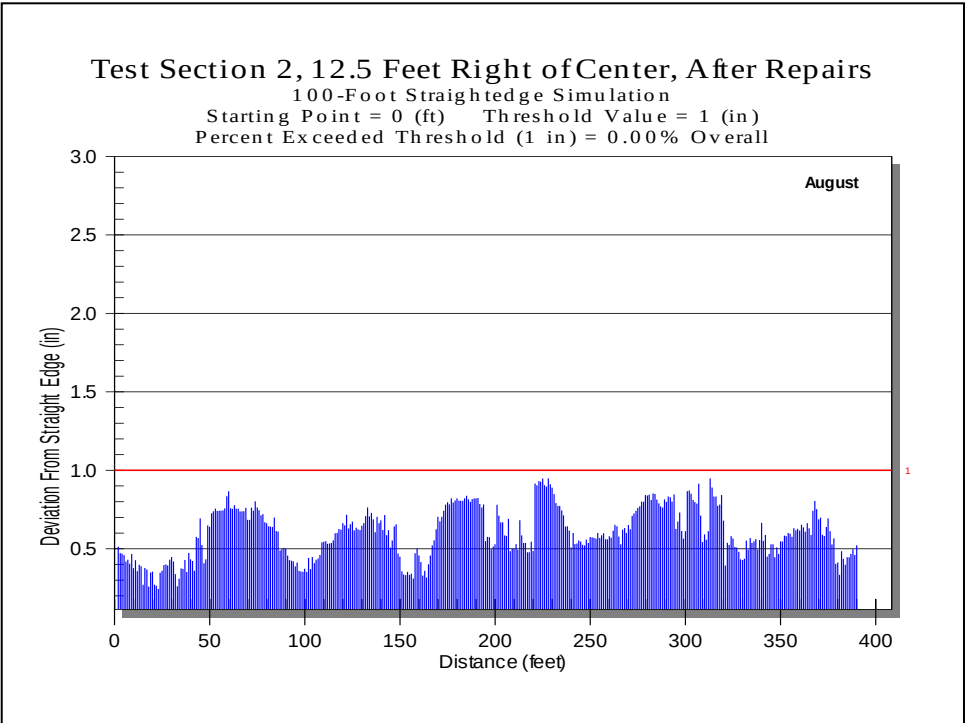


Figure A-65: 100-Foot Straightedge Simulation on Test Section 2, 12.5 Feet Right of Center After Repairs

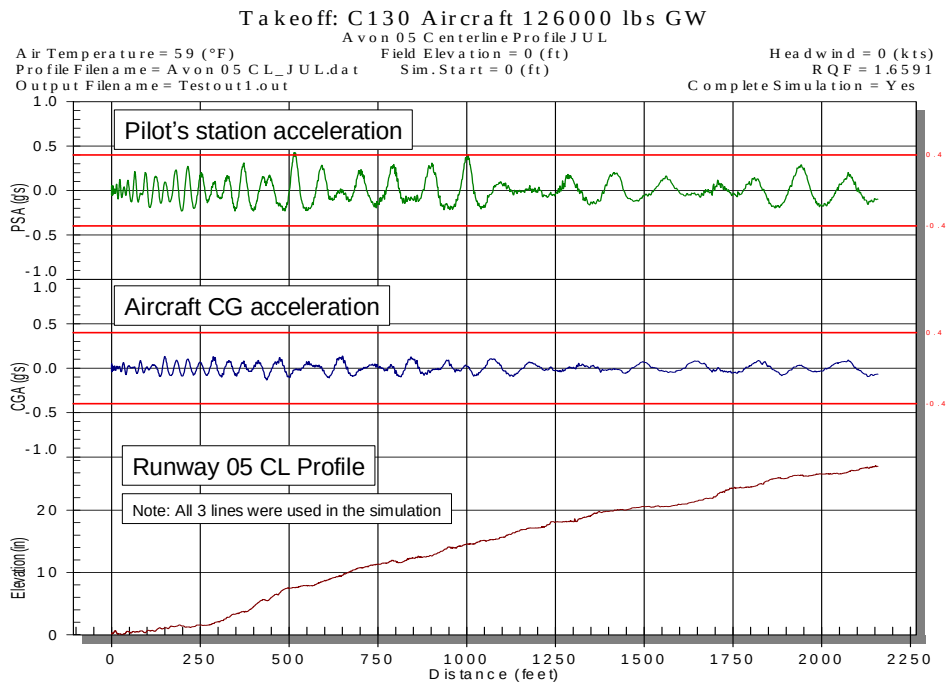


Figure A-66: C-130 Takeoff on Avon Runway 05 Before Damage

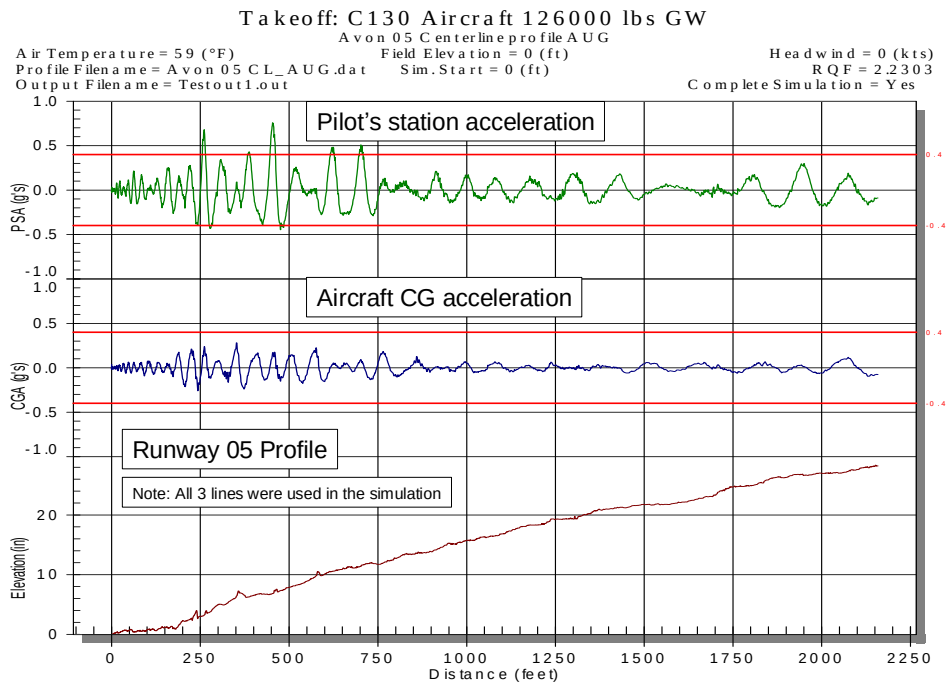


Figure A-67: C-130 Takeoff on Avon Runway 05 After Expedient Repairs

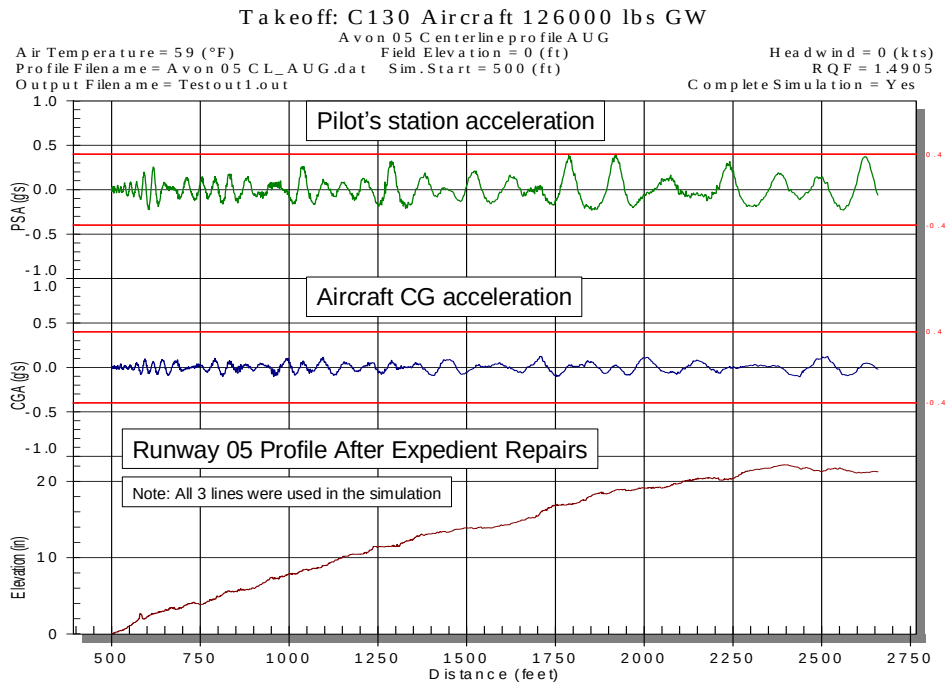


Figure A-68: C-130 Takeoff on Avon Runway 05 After Expedient Repairs With 500 Foot Displaced Threshold

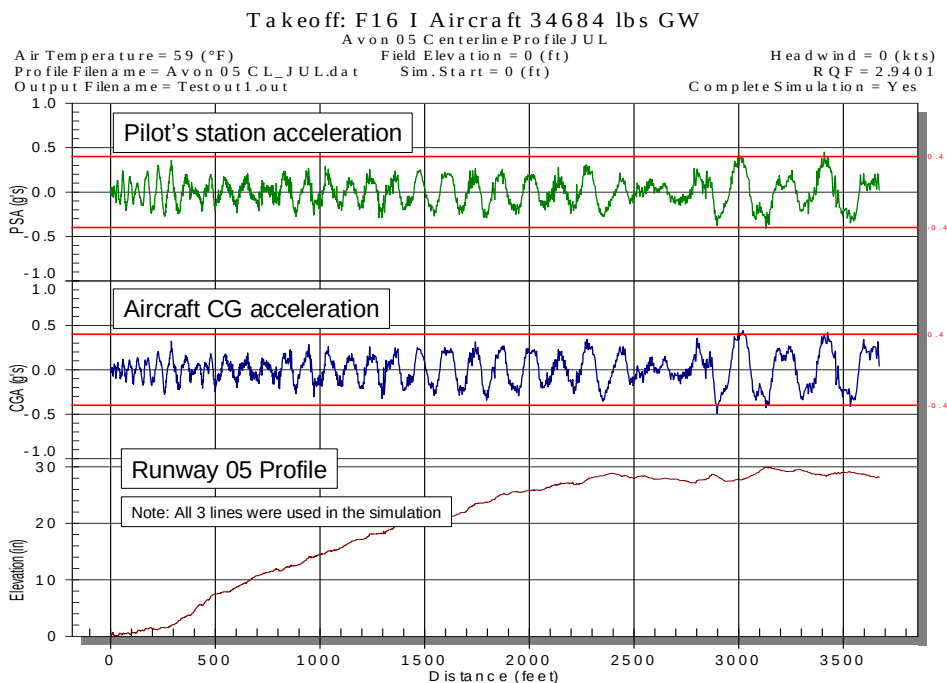


Figure A-69: F-16 Takeoff on Avon Runway 05 Before Damage

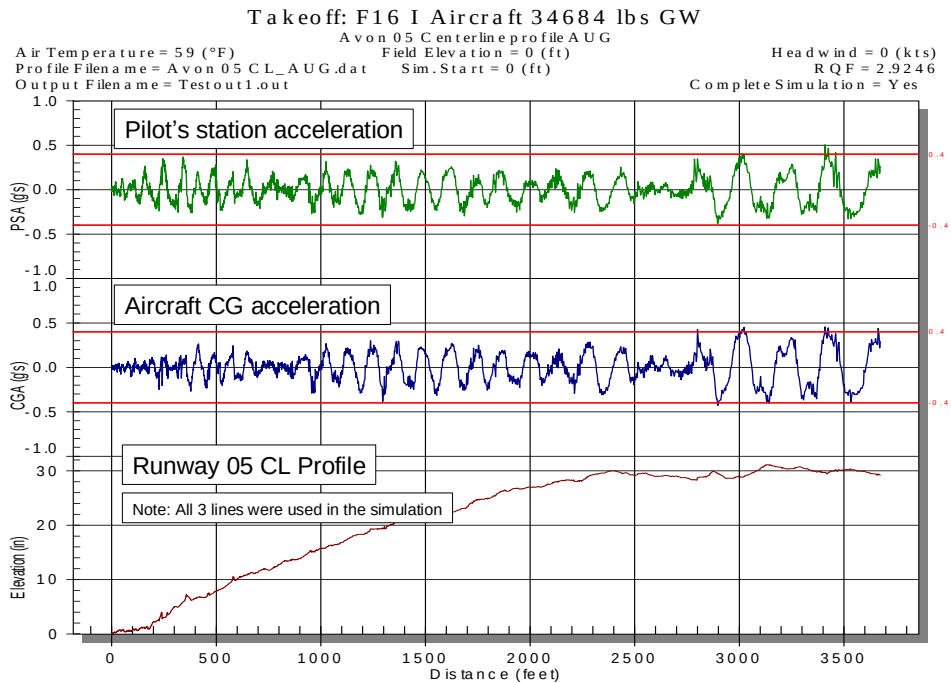


Figure A-70: F-16 Takeoff on Avon Runway 05 After Expedient Repairs

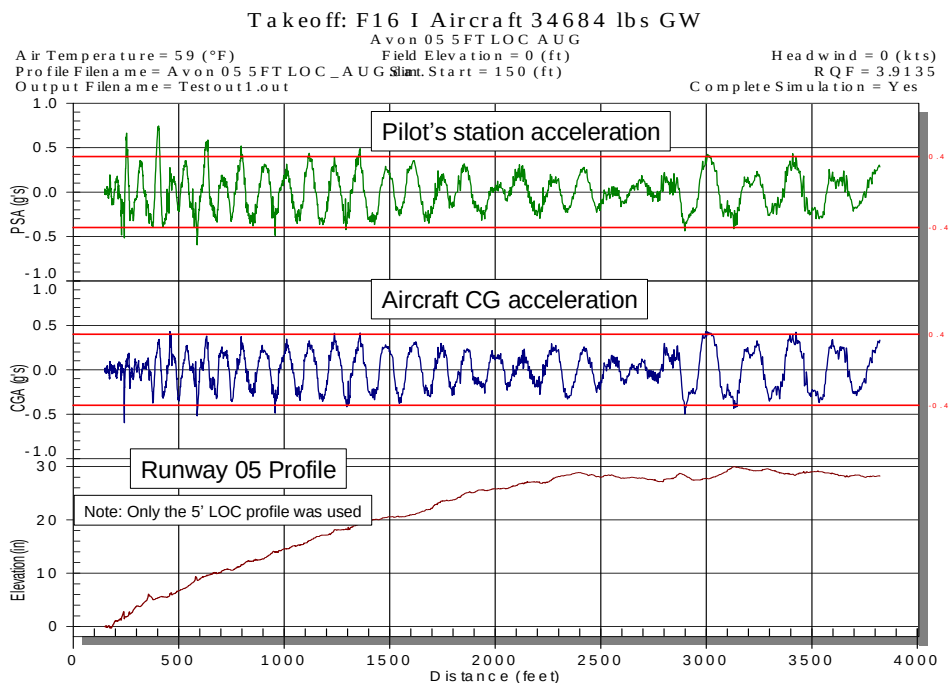


Figure A-71: F-16 Takeoff on Avon Runway 05 After Expedient Repairs

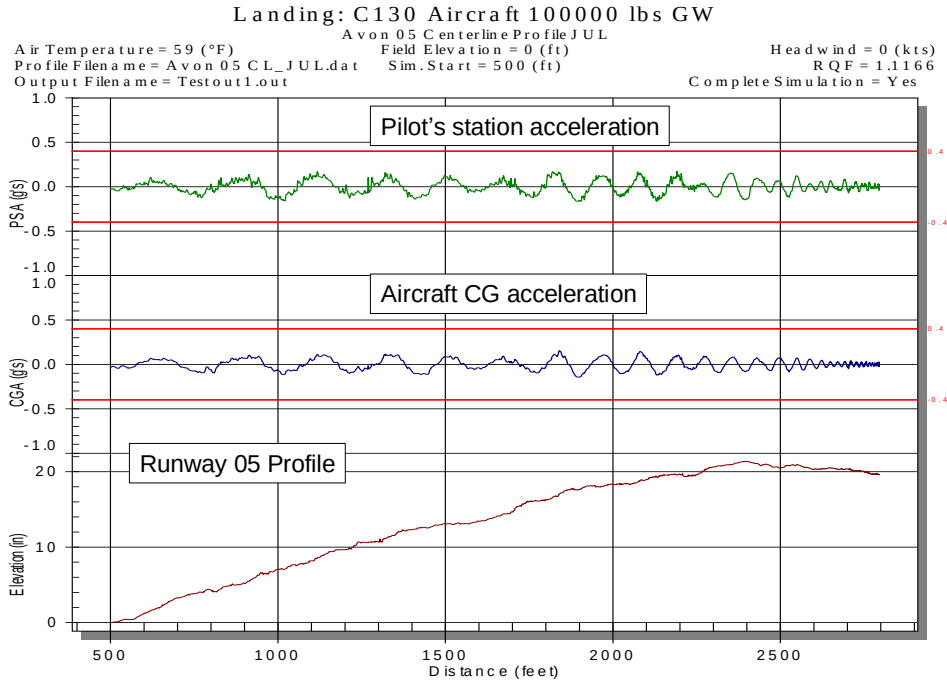


Figure A-72: C-130 Landing on Avon Runway 05 Before Damage

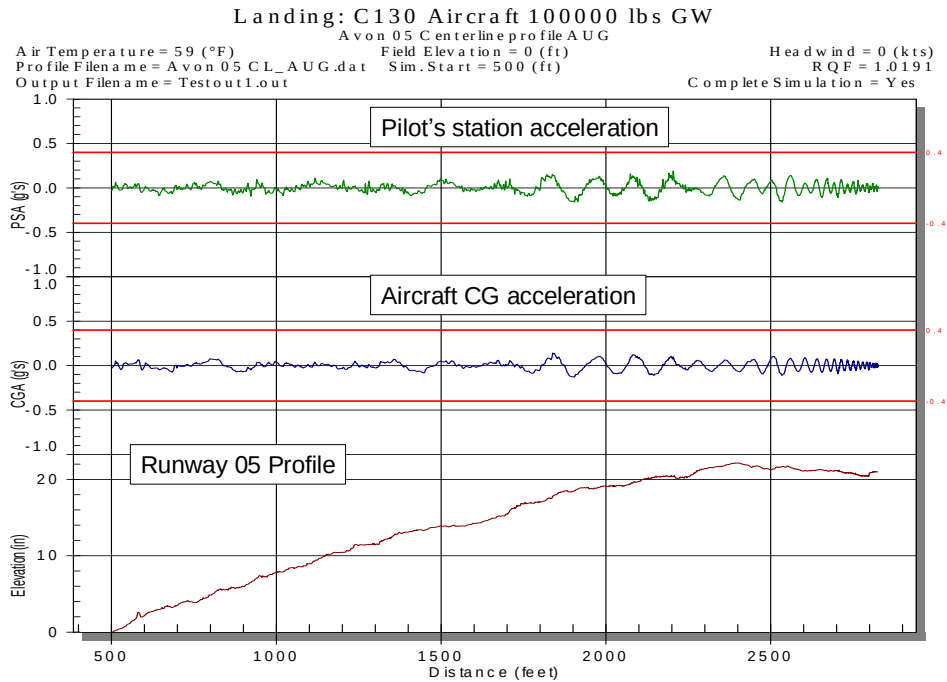


Figure A-73: C-130 Landing on Avon Runway 05 After Expedient Repair

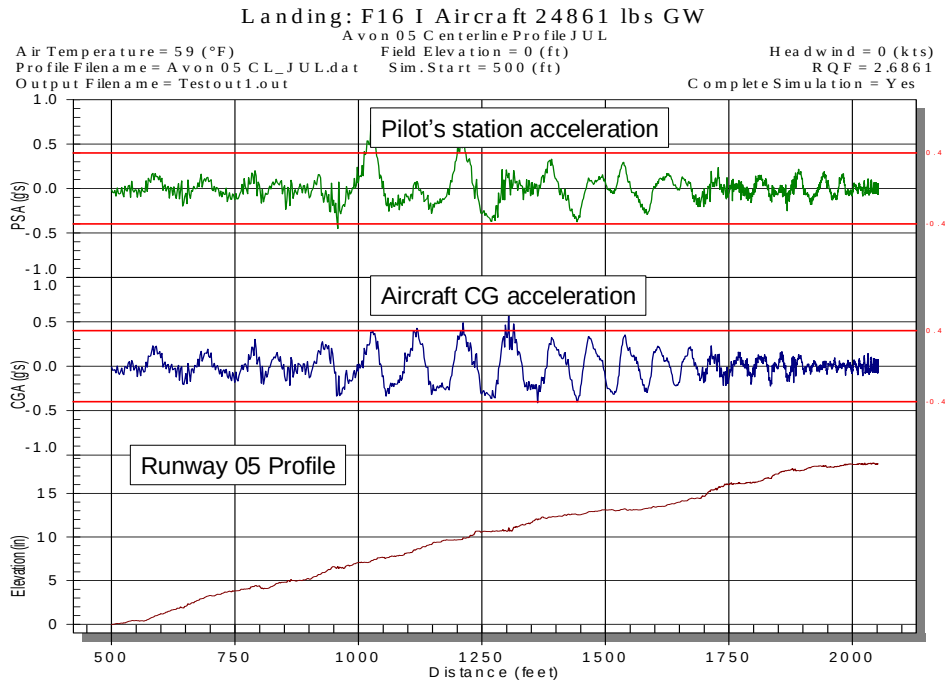


Figure A-74: F-16 Landing on Avon Runway 05 Before Damage

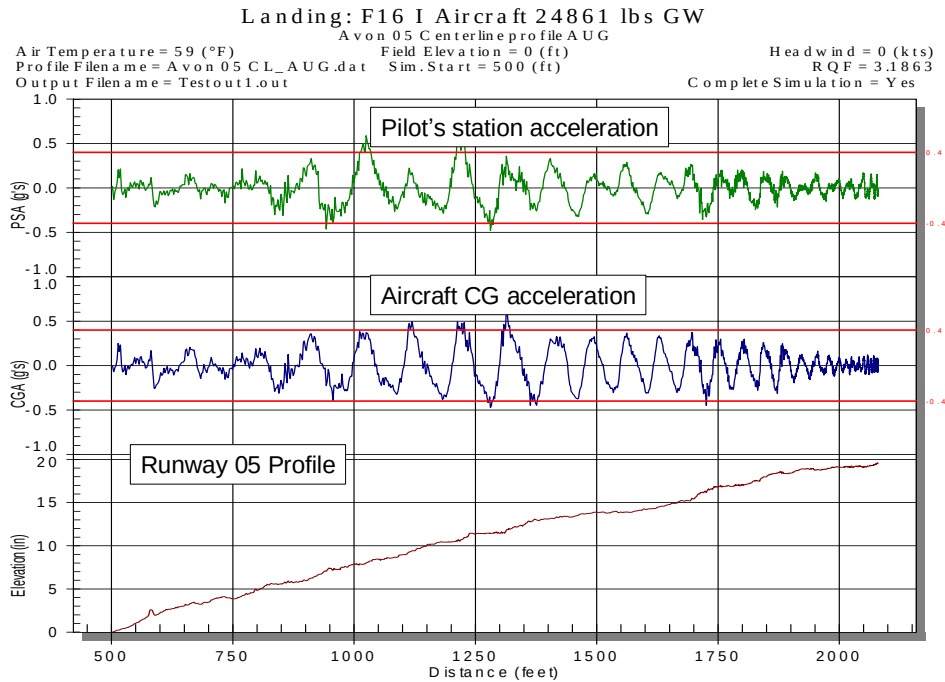


Figure A-75: F-16 Landing on Avon Runway 05 After Expedient Repair

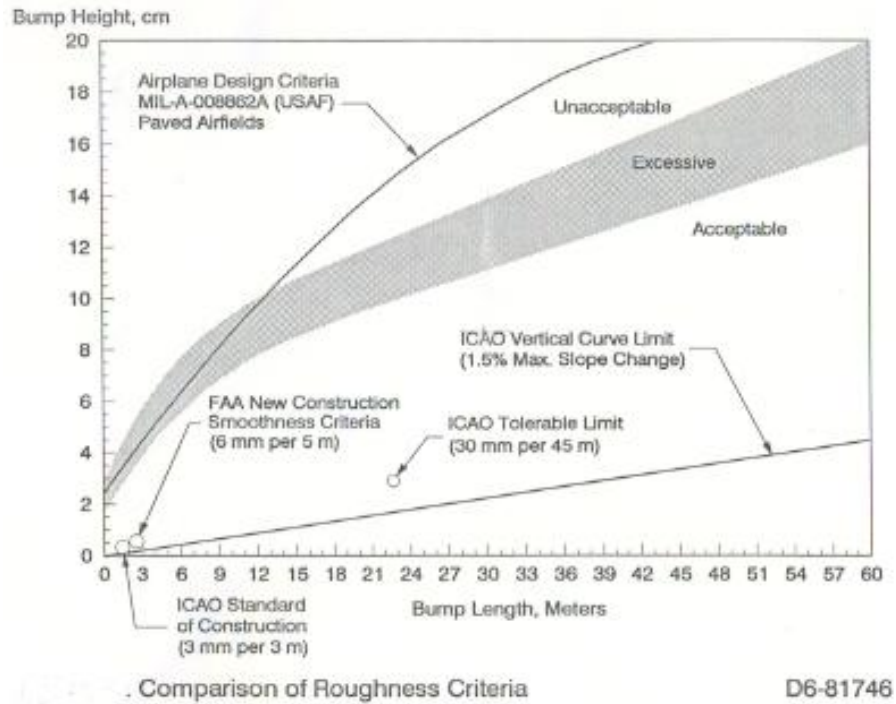


Figure A-76: The Boeing Curve

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

AR&L	Auto Rod and Level TM
CG	Center of Gravity
CL	Centerline
FAA	Federal Aviation Agency
GAG	Ground-Air-Ground
LOC	Left of Center
MLG	Main Landing Gear
NLG	Nose landing Gear
POC	Point of Contact
PS	Pilot Station
RQF	Ride Quality Factor