CENTER FOR
PORTLAND CEMENT CONCRETE
PAVEMENT TECHNOLOGY

Stringless Portland Cement Concrete Paving

Final Report
February 2004

Iowa Department of Transportation

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IOWA STATE UNIVERSITY

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The mission of the PCC Center is to advance the state of the art of portland cement concrete pavement technology. The center focuses on improving design, materials science, construction, and maintenance in order to produce a durable, cost-effective, sustainable pavement.

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16. Abstract

This report describes results from a study evaluating the use of stringless paving using a combination of global positioning and laser technologies. CMI and Geologic Computer Systems developed this technology and successfully implemented it on construction earthmoving and grading projects. Concrete paving is a new area for considering this technology. Fred Carlson Co. agreed to test the stringless paving technology on two challenging concrete paving projects located in Washington County, Iowa.

The evaluation was conducted on two paving projects in Washington County, Iowa, during the summer of 2003. The research team from Iowa State University monitored the guidance and elevation conformance to the original design. They employed a combination of physical depth checks, surface location and elevation surveys, concrete yield checks, and physical survey of the control stakes and string line elevations. A final check on profile of the pavement surface was accomplished by the use of the Iowa Department of Transportation Light Weight Surface Analyzer (LISA). Due to the speed of paving and the rapid changes in terrain, the laser technology was abandoned for this project. Total control of the guidance and elevation controls on the slip-form paver were moved from string line to global positioning systems (GPS).

The evaluation was a success, and the results indicate that GPS control is feasible and approaching the desired goals of guidance and profile control with the use of three dimensional design models. Further enhancements are needed in the physical features of the slip-form paver oil system controls and in the computer program for controlling elevation.

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STRINGLESS PORTLAND CEMENT CONCRETE PAVING

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Final Report • February 2004

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

Slip-form concrete paving machine guidance and elevation have always been controlled by one or two string lines. This report describes the results of a study which evaluated the use of stringless paving controlled by global positioning and laser technologies. CMI Corporation and Geologic Computer Systems developed this technology for construction equipment control on earthmoving equipment. This project represented the first attempt to move the technology to concrete paving equipment.

The evaluation was conducted on two paving projects in Washington County, Iowa, during the summer of 2003. The contractor for both projects was Fred Carlson Company Inc. The research team from Iowa State University monitored the guidance and elevation conformance to the original design. They employed a combination of physical depth checks, surface location and elevation surveys, concrete yield checks, and physical survey of the control stakes and string line elevations. A final check on profile of the pavement surface was accomplished by the use of the Iowa Department of Transportation Light Weight Surface Analyzer (LISA).

Due to the speed of paving and the rapid changes in terrain, the laser technology was abandoned for this project. Total control of the guidance and elevation controls on the slip-form paver were moved from string line to global positioning systems (GPS).

Several tests were made over a two-week period during the field trial development of the system. The final evaluation was made during the last two days of paving and provided the research team with significant information. GPS control proved to provide excellent guidance of the slip-form paver. Pavement depth checks through physical probing of the fresh concrete and coring of the hardened concrete displayed no signs of unacceptable deviation from the design values. Concrete yield checks of the produced materials indicated the same results. Conventional surveys of the elevations of the top edge of pavement resulted in stringless values in closer conformance to design values than those obtained with the string line control. Pavement profile values were acceptable for the average vehicle operator, but not smooth enough to provide the contractor with profile incentive payment under Iowa DOT Specifications.

The evaluation was a success, and the results indicate that GPS control is feasible and approaching the desired goals of guidance and profile control with the use of three dimensional design models. Further enhancements are needed in the physical features of the slip-form paver oil system controls and in the computer program for controlling elevation.

INTRODUCTION

Background

Current pavement construction technology employs the use of physical guidance systems in the form of a string or a wire line on one or both sides of the slip-form paving train of equipment. This approach provides both the horizontal and vertical control for the machine to place the required pavement thickness in the required location. It also creates a need for space on each side of the paving machine to set the survey control line near the paver. Spacing of the control line stakes can also have a positive or negative impact on the smoothness of the final pavement surface (Rasmussen et al. 2004). The actual placement and verification of the physical guidance systems on each side of the paving machine costs time, requires manpower, and limits access to the area in front of the slip-form paver.

Washington County, Iowa, has long been a leader in concrete paving technology and is ready to look at advancement in the area of concrete placement. It has expended funds to provide global positioning systems (GPS) control to a section of highway in an effort to reduce the amount of staking required to both grade and pave the project. Washington County has the capability to develop the multidimensional design model that feeds the automated paving machine control system for control of the top of subgrade elevation and the top of paving elevations.

Automated control of the construction machines such as trimmers, slip-form pavers, and texture/cure machines should provide both vertical and horizontal control to the machines and eliminate the need for the control staking line on each side of the pavement construction area. In this case the same control used for the development of the graded cross section will be used for the slip-form paver control. Can the automated equipment control system be used to control the horizontal and vertical alignment of the slip-form paver and provide a smooth riding surface for the final product? This is the question that the research set out to answer.

Two companies expressed interest in demonstrating this equipment. The first automated control system, developed by Leica Geosystems, could only be fitted to GOMACO Paving equipment of a relatively new vintage at this time. Due to construction equipment specification and research project site limitations, this automated control system was not evaluated in this project. The research team gave consideration to the second vendor. CMI Terex Corporation and Geologic Computer Systems developed a system called GeoSite Manager System, which has been successfully used on earthmoving and grading projects. Washington and Keokuk Counties staff were aware of this limitation and agreed to proceed with the project.

Advantages and Disadvantages for Using Stringless Paving

There are several advantages to county and state department of transportation (DOT) agencies for using stringless paving techniques. The elimination of paving pins needed to set string lines is the main reason why this new technology is being investigated. This is a very time consuming process that must be completed or contracted out by the different public organizations. Most projects require three separate survey circuits and an original survey to calculate a design. After calculating the design, the paving pins must be set to their exact location, and a follow up check involving level survey shots is needed on each pin. These shots must then be compared to the design, and a fill or cut to the final pavement must be calculated and written on each stake, allowing the contractor to set the string height. It has been estimated that total cost of establishing survey control for the string line can cost from $10,000 to $16,000 per mile in a rural setting. This includes the following activities: setting pins, leveling pins, calculating cut/fill quantities, writing on wood stakes, installing the string line (threading string line through horizontally-aligned rods which are clamped to vertical stakes that are driven into the ground), and removing the string line.

The time frame when these stakes can be placed is also an issue that might cause a project to be delayed. Washington County had one of its roads recycled as a sub base for the new pavement. The old pavement had to be hauled to the crusher and then replaced before the paving pins could be set. The sooner the paving pins could get set, the sooner the paving crew could get the string lines set and start paving.

Access along these roads will be another advantage to replacing the string lines, especially on most county roads where the shoulders are limited. Additional access roads have to be built to allow for access to all residences during construction. The string lines not only affect travel during the paving, but also before the paving starts because of the difficulty of driving from the road surface to adjacent roads and driveways.

The main advantage of stringless paving to contractors will be the elimination of string lines. Both the labor cost of placing and removing the string lines, and the difficulty of working around the paving pins and string lines throughout the project will be eliminated. Placing and removing the string lines is a continuous job that occupies a small crew throughout the project. The related costs include not only the labor cost, but also the cost of the equipment, such as tractors or trucks, that is needed to haul and distribute the string lines, as well as the actual hardware that is needed for the string lines. The overall challenges of working around the stakes and string lines can be eliminated leaving fewer obstructions when moving equipment around and preparing the sub-base for paving. An increase in efficiency and productivity is also possible with more direct routes delivering concrete and materials to the site. The need to build wider shoulders on certain projects can be eliminated without the extra width needed for the string lines.

Paving machines also require some very precise sensors to follow the string lines and control the movement of the slip-form paving machine (Figures 1 and 2). These sensors would be eliminated with stringless paving and would decrease the overall width of paving machines, making it easier to cross bridges and other tight spots. Crossing the bridges can delay a project for an entire day when the paving machines widths are altered (Figure 3). However, with stringless paving these sensors and additional bars are not needed, which can cut the crossing time down to a few hours.

Figure 1. Stakes and String Line for Concrete Road Paving

Figure 2. Sensors Used to Read String Lines

Figure 3. Slip-form Paving Machine Being Reconfigured to Cross Narrow Bridge

Timing of a project can also be an issue if the contractor wants to start as soon as they are awarded the contract. The contractor has to wait for the paving pins to be set and also wait for their own crews to set the string lines before they can begin paving. With these systems, the move in and move out times on projects will be reduced. This will be especially advantageous on projects with live traffic, reducing the need to set string lines in hazardous areas and having shorter construction periods that disrupt traffic.

There are also some drawbacks to using stringless paving technique. Counties and DOTs will be required to create three-dimensional (3-D) digital designs of their projects to be entered into the paving machine control systems. A significant number of counties and DOTs have already started doing this, and in the near future, most design work will be done on these digital programs. There will also be a need for land surveying knowledge to convert some data to 3-D GPS coordinates.

When using GPS survey systems, calibrated monuments for the base station must be set along the project to obtain the highest accuracy possible. These base stations supply the GPS receiver with additional data to help refine the exact location of the receiver and increase the accurateness. Once again, some counties already have these monuments tied into the state plane coordinates, and in the near future, it is anticipated that these monuments will be created in most counties. However, those counties without the monument systems can still set temporary monuments along the project that will serve the same purpose.

Contractor personnel can no longer see errors in stringline control and correct during construction. GPS signals can be temporarily lost in high foliage density areas or under structures.

The greatest disadvantage to contractors would be the need of more technically educated employees. The computer systems that would be needed to guide the paving machines would require an individual to have some knowledge about computers and GPS surveying. Once these systems are further developed, they can hopefully be very user - friendly and be as easy to run as a current paving machine. There are always possibilities of problems when using computers, and someone with the knowledge of how to fix these problems would probably be needed on site to eliminate any extended breakdowns due to a stringless control system malfunction.

The initial investment that must be placed into these systems will also be a major deterrent. A main computer will be needed to run this system along with the GPS equipment and laser system. Regardless of the age of the slip-form paving train equipment, machine monitoring and control will require adjustment mechanisms, including proportional hydraulic valves (computer controlled) and tilt sensors across and along the slip-form paver. However, if the stringless systems are added to new paving machines and replace the existing control systems, the difference in cost would be minor. Like all new technologies, the systems will initially be more expensive because of the need to pay for the research that created them, but in a few years, the prices will fall once there is greater competition.

Study Objective

The objective of this research is to evaluate the use of GPS and laser control to guide the concrete slip-form paver in the alignment and depth control of the final Portland cement pavement. The research compared the results to the design depths, quantities, alignment, profile, and smoothness obtained by other means in similar projects in Washington Co.

STRINGLESS PAVING APPROACHES

Automation of operations due to adverse environments or intensive labor requirements has been a key incentive for research in this area. Many such automated operations are being used in agriculture, mining, and construction. One of the barriers to achieving a higher level of automation, and also a topic that has been actively researched in recent years, is the positioning and guidance of this equipment.

Various types of equipment are used in heavy highway construction. Peyret (2000) classified the construction machines used for road construction into three main groups based on different positioning accuracy requirements:

- Earth-moving and mining equipment, e.g., shovels, drills, scrapers, bulldozers, excavators, etc.
- “Surfacing equipment”, which refers to machines that move on the surface of the ground without noticeable changes in height. These include compactors, cement spreaders, mixers, and trimmers.
- “Profiling equipment”, which refers to machines that modify the profile of the worksite by addition or removal of material. These include pavers, autograders, and milling machines.

Different levels of accuracy are required of the positioning and control systems on these construction machines. The accuracy requirements in terms of level for the various layers of pavement are typically ± 1.2 in (± 3 cm) for sub-base, ± 0.8 in (± 2 cm) for the base, ± 0.6 in (± 1.5 cm) for the binder course, and ± 0.2 in (± 0.5 cm) for the wearing course (Peyret 2000). While some of these requirements are easy to meet, the accuracy level of positioning of slip-form pavers remains a difficult challenge to be solved.

Construction equipment positioning and control requires control of all six degrees of freedom of the equipment (x, y, z, roll, pitch, and yaw). Technologies that are popularly used or considered promising to solve the problem include Real Time Kinematic (RTK) GPS, laser levels, and robotic total stations.

Guidance with Robotic Total Stations

Successful applications of robotic total stations on heavy highway construction equipment, including concrete pavers, have been reported by GOMACO Corporation and Leica Geosystems in several cases around the world. The 3-D machine control system developed by Leica Geosystems has the following components (Leica Geosystems 2001):

- The Leica "Commander Box" with an industrial PC, a touch screen, an integrated floppy drive, a keyboard, and a radio modems
- The "LMGS-S for Slip-Form Pavers" software package
- Automatic total station(s) TCA 1800/2003
- Dual axis tilt sensor(s)
- Required accessories, like the 360° precision prisms, TCPS26 radio modem, data transmission cables, batteries, and masts.

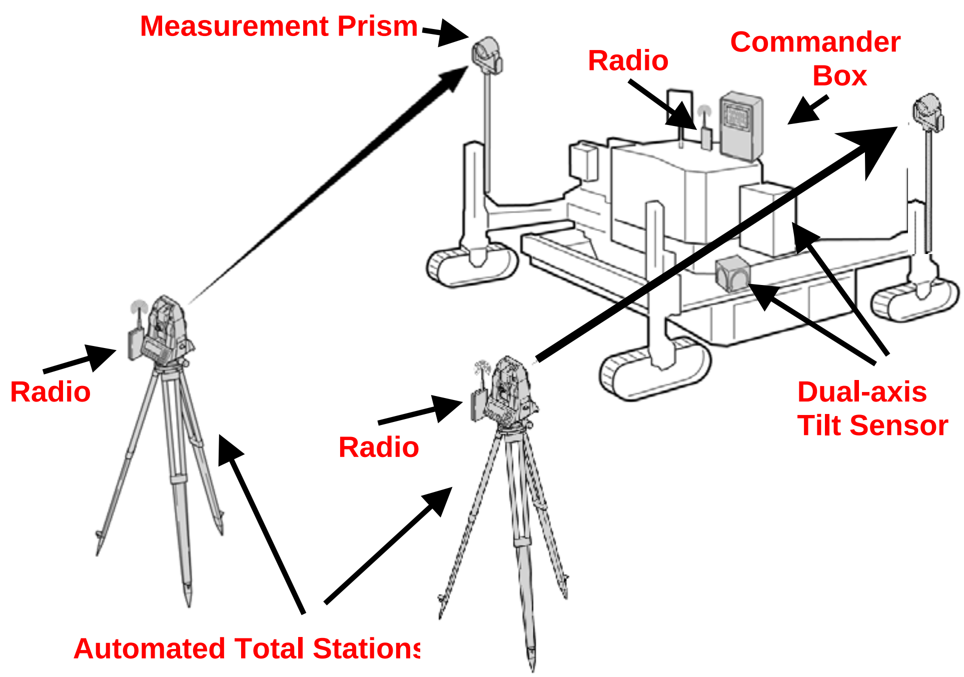

Figure 4. Typical Setup of GOMACO Stringless Control System

Table 1. Technical Specifications for Leica LMGS-S System and Components

Total Station	TCA 1800	TCA 2003
Angular measurement referring to 200 m distance	0.3 mgon (1 in) 0.04 in (1 mm)	0.15 mgon (0.5 in) 0.02 in (0.5 mm)
Distance measurement		
Static	0.04 in (1 mm) + 2 ppm	0.04 in (1 mm) + 1 ppm
Dynamic	0.2 in (5 mm)	0.2 in (5 mm)
Target recognition	0.08 in (2 mm) bis 330 ft (100 m)	0.04 in (1 mm) bis 330ft (100 m)
Target speed	60m/min bei 100 m	60m/min bei 100 m
Range		
Normal prism	3300 ft (1000 m) (static) 1650 ft (500 m) (dynamic)	3300 ft (1000 m) (static) 1650 ft (500 m) (dynamic)
360° prism	1650 ft (500 m) (static) 1155 ft (350 m) (dynamic)	1650 ft (500 m) (static) 1155 ft (350 m) (dynamic)
Target search	Automatic	Automatic
Area	Selectable	Selectable
Slope sensors (standard deviation)		
Method of measurement	Liquid sensor	
Area of measurement	±60°	
Accuracy	2‰	
Frequency of measurements	0 – 100 Hz	
Interface	CAN	
Class of protection	IP 67	
Total system		
Height accuracy of machine position	0.08-0.16 in / 660 ft (2 – 4 mm / 200 m)	
Accuracy of machine location	0.2-0.4 in /660 ft (5 – 10 mm / 200 m)	
Range (recommended)	±660 ft (± 200 m)	
Frequency of measurements	5 – 10 Hz	
Temperature range	- 20 °C – 50 °C	
Temperature range IPC	- 0 °C – 50 °C	
Voltage	24 V	

During the paving process, two prisms are mounted on the paver. Leica's Automatic Target Recognition System that comes with the automatic total stations scans the position of the prisms at a frequency of 6 Hz (approximately every 0.1 – 0.2 in (2.5 – 5 mm) movement of the paver). By using the positions of the two prisms and historical data (positions of target points from previous scans), the computer system is able to identify the position (x, y, z coordinates) and attitude (yaw, pitch, and roll) of the paver. Data are transferred between the total station and the computer system using the radio modem. After comparing this information with the design data stored in the computer, the system is able to send out adjustment commands to the pavers control system. Figure 4 reveals a typical setup of the GOMACO stringless control system. Technical specifications of LMGS-S system and its components are listed in Table1.

GOMACO's system has been tested on a number of different projects including an airport taxiway and 1100 ft (335 m) of a residential street in Ida Groove, IA. The system has been developed to be applicable to grading and paving equipment. The total stations are standard surveying total stations that can be used for survey work, staking, and checking. The typical accuracies that GOMACO has found using this system are 0.04-0.12 in (1 – 3 mm) with a 300 to 650 ft (100 – 200 m) shooting distance. Like the GPS system, this will require digital plans and a few adjustments to a normal paving machine including mounting the prisms (Figure 4) and control computer (Figure 5) and the addition of some tilt sensors. It will require that accurate monuments be set along the project for the total stations to be set on and localized. These total stations will then be used with a third total station while paving to keep two total stations within range of the paving machine at all times.

Figure 5. GOMACO Control System

GOMACO's system, like the GPS, requires more technical workers with surveying and computer knowledge to set up, run, and fix any problems that might occur. GOMACO's system does not have the possibility of not receiving data like the GPS system might experience, but has to have a clear line of sight to the prisms on the paving machine. Each total station has to be set up and localized before its data can be used by the paving machine control system, which introduces more possibilities of error and is time consuming.

Guidance with GPS and Lasers

GPS is a system developed by the Department of Defense for navigation and positioning use by both the military and civilians. While the accuracy of positioning available to civil engineers is approximately 328 ft (100 meters), this number has been significantly reduced in recent years. Commercially available GPS receivers using Real Time Kinematic GPS (RTK GPS) technology provide positioning accuracy at the level of 0.4 in (10 mm).

Table 2 shows the technical specifications of the Ashtech Z-Xtreme Survey System, which was used in the testing projects. The displayed accuracy makes the RTK GPS a satisfactory solution in the positioning of construction equipment that requires lower levels of accuracy. Whether it is accurate enough to be used in a paving operation remains to be determined.

Table 2. Technical Specifications for Ashtech Z-Xtreme Survey System

Static, Rapid Static	
Horizontal	± 0.2 in (5 mm) + 0.5 ppm
Vertical	± 0.4 in (10 mm) + 1 ppm
Post Processed Kinematic	
Horizontal	± 0.4 in (10 mm) + 0.5 ppm
Vertical	± 0.8 in (20 mm) + 1 ppm
Real Time Code Differential Position	
Horizontal	< 3.28 ft (1 m)
Real Time Kinematic (RTK)	
Horizontal	± 0.4 in (10 mm) + 0.5 ppm RMS
Vertical	± 0.8 in (20 mm) + 1 ppm RMS
Initialization Reliability	Typically > 99.9%

The main shortcoming for using GPS for construction equipment positioning is its accuracy in measuring elevations, which is normally twice as large as the horizontal accuracy of the same GPS. According to a study conducted by Peyret (2000), the overall accuracy of RTK GPS can be represented by

- a bias between + 0.8 in (20 mm) to – 0.8 in (- 20 mm)
- a standard deviation under 0.4 in (10 mm)

Thus, for the slip-form paving application, raw measurements from RTK GPS cannot be used directly because of lack of accuracy. The study further proved that the bias, or drift, which is related with the constellation plot, and some local phenomena such as multi-path effects, is repeatable within given limits of time and space. Based on this repeatability, the accuracy of the RTK GPS results can be improved using modifications external to the GPS signal processing.

Another method to compensate the inadequate elevation accuracy of the GPS results is using laser levels in combination with GPS for construction machine positioning. Typically, rotating-beam lasers are used in this kind of system with rotation speeds in the range of 300 to 600 rpm. The laser levels typically have a working radius of up to 1000 ft (300 m) and an accuracy of better than 0.4 in (10mm) per 330 ft (100 m).

While laser levels can improve the elevation accuracy of the control system, a few obvious disadvantages exist with this method (Geologic Computer Systems 2003):

- Optical equipment is vulnerable to environmental inference (e.g., rain, dust, snow, and temperature) and requires line of sight.
- Lasers only work within the height of the receiver mast.
- Lasers and laser masts are mechanical devices and suffer from wear and tear.
- Rotating lasers consume a lot of power – operation requires a deep cell battery charged daily to run.
- Lasers are potentially unstable – windy conditions easily make a laser tripod sway in the wind, affecting accuracy. In high winds, the wind may even cause the laser to shutdown and reset itself. Bad soil conditions may also make a laser unstable, such as placement on frozen ground when the air temperature is above 32 degrees Fahrenheit.

STUDY METHODOLOGY

The research methodology included the following activities:

1. Identification of three paving projects in Washington Co. scheduled for paving in 2003 to test the stringless control system.
2. Contractor placement of RTK GPS and laser beam receiver equipment on the slip-form paver to sense and control the elevation and location of the pavement edges.
3. Use of Quality Management Concrete (QMC) specifications for monitoring and appraising the project.
    a. Measurement of the concrete payment by the cubic yard and square yard to reduce the risk to the contractor for placement depths.
    b. Survey of the final paved surface to verify the vertical and horizontal alignment of the final pavement surface at the edges and centerline.
    c. Use of the Iowa DOT profile device to establish the final road surface profile in the outer wheel path of the roadway in each direction.
    d. Depth checks and yield checks by the research team and county personnel to verify the pavement section being built.
    e. Selected coring of the final pavement surface to determine the depth of concrete relative to the final surface elevations.
4. Analysis of results and recommendations.

FIELD TESTS

Two paving projects in Washington County were selected for evaluating the stringless paving technology. The first project (called "Coppock Quarry Road" project) was completed on 320th Street in Washington County. The street is approximately three miles (4.6 km) in length, contains minor horizontal curves, and has considerable vertical slopes. The pavement was built on an existing granular surface road that had been reconstructed in two segments over the last six years.

The second project (called "Ashby" project) was completed on 170th Street in Washington County. The street is six miles (9.6 km) in length, contains minor horizontal curves, and has considerable vertical grades as well. The contractor for both projects was Fred Carlson Company Inc.

Washington County surveyed the existing graded surface and created a 3-D design model. This was done to establish the horizontal and vertical alignment for finish grading and paving purposes. The survey information is placed in a design model for input into the machine control system.

Stringless Paving Equipment Used

CMI Terex Corporation and GeoLogic Computer Systems, a Michigan-based company, are the leading firms behind this new method of GPS stringless paving. Their method uses a global positioning survey system accompanied by lasers to control and guide a paving machine. GeoLogic is working with the Fred Carlson Company Inc. (Carlson) of Decorah, IA, which is a large paving contractor. There are a number of other smaller contributors helping with this system including Marsh Electronics of California. This was the first time that this system had ever been used on a slip-form paving machine and is still in its experimental and developmental phases.

Carlson and GeoLogic fitted a CMI 1992 slip-form paving machine with the new system. It included a GPS receiver mounted over the front right track and two laser sensors mounted on separate 5.5 ft (1.68 m) laser masts located on opposite sides of the paving machine (Figure 6).

Final trimming of the subgrade was accomplished by a modified CMI autograder (Iowa Special). This machine both trims the subgrade and conveys the Portland cement concrete from the haul units to the trimmed subgrade. The Iowa Special (30 years old) and texture/cure machine were not equipped with the GPS stringless system, so two string lines were still constructed and used by these machines. The slip-form paving machine was also controlled by the string lines for the first day so that the new system could be monitored without controlling the paving machine. The stringless system was then tried and proved to have some problems in the programming of the computer system, which controlled the paving machine. For the next few days, the new control system was turned on and off from the string lines allowing for settings and programs to be adjusted and tested throughout the week. The GPS system proved that it was possible to control and steer the paving machine but certain problems still existed. These problems will be discussed further in this section.

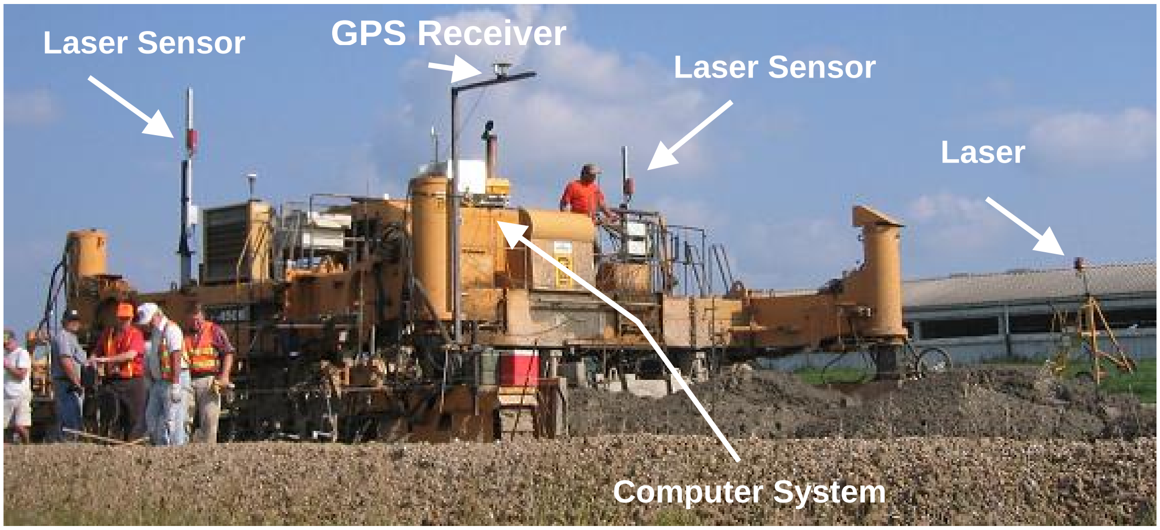

Figure 6. CMI Slip-form Paving Machine with GPS Guidance Equipment Attached

The CMI slip-form paving machine required a number of changes and additions including the following: valves to be replaced; a GPS controller, computer screen, keyboard, and laser gages to be mounted next to the existing controls; and two five and a half foot laser masts to be mounted on opposite sides of the paving machine.

Figure 7. GPS Controller, Screen, and Keyboard with Laser Height Gages

Figure 8. Current Control Panel on CMI Paving Machine

In Figure 7 and 8, the new controls and the existing control panel from the CMI paving machine can be observed. This same GPS control system can easily be unplugged and removed from the paving machine and placed on the all-terrain vehicle (ATV) to do staking or other survey work (Figure 9). The GPS equipment being used is the same equipment that can be used for surveying, attached to a grader or bulldozer for guidance, and for any other GPS use. The lasers are ordinary high-resolution lasers that most contractors already have and use to do grading and other construction (Figure 10). With the wide range of applications of all these pieces of the stringless paving system, it will be a very useful investment not just for paving.

Figure 9. GPS System Installed on ATV

Figure 10. High-Resolution Laser

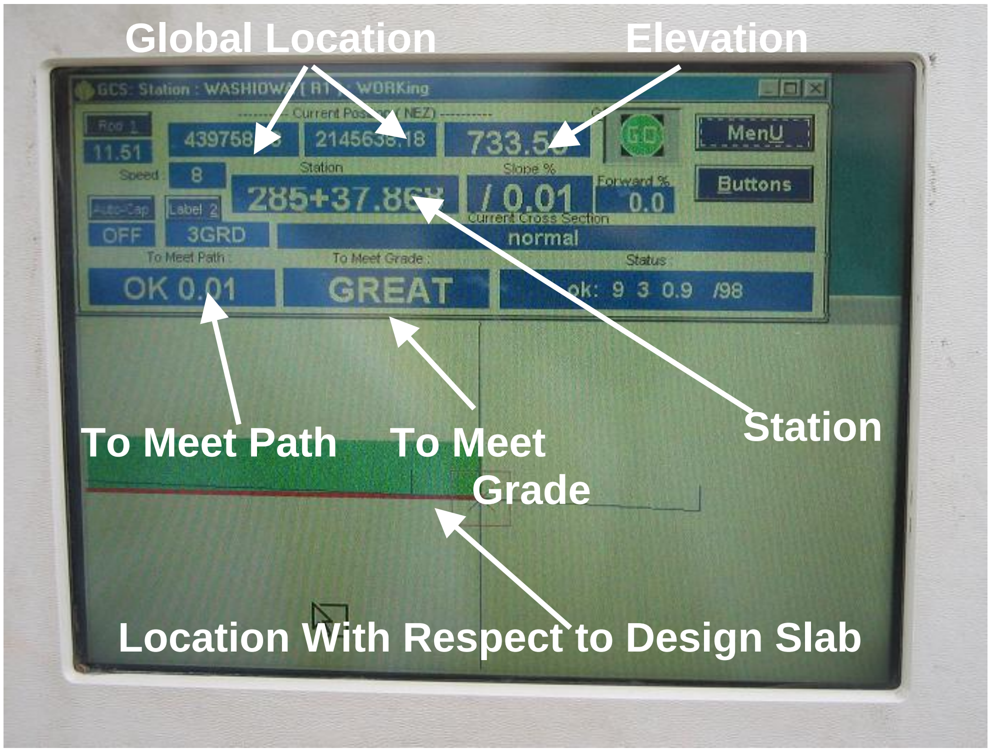

Figure 11. Sample Screen of Data from Stringless Paving Control Computer

The stringless paving computer system, which will combine the GPS data with the laser data and control the paving machine, runs on a standard Windows operating system. It is designed to use common construction terms for all the adjustments and window options in the program. It contains approximately 140 different screens of data that read like a set of plans so it can be easily understood and adjusted. In Figure 11, one can see a sample screen for the Washington County project while the paving machine was running. It has the current GPS coordinates and elevation, the station that is nearest to these coordinates, and the distance that the paving machine needs to go to meet the design at this station. In this figure, the paving machine is off the path by one hundredth of a foot, and the elevation is near perfect. Below these data in Figure 11, is a cross sectional view of the pavement slab and where the paving machine is located with respect to this slab.

Coppock Quarry Road (320th Street)

Paving of the Coppock Project started on August 12, 2003 and ended on August 14th. A CMI Slip-form Paver and a CMI "Iowa Special" trimmer were used for the project. The GPS/Laser machine control system was installed on the slip-form paver. To ensure that the project could be finished as planned in case of failure of the stringless system, traditional string lines and control system based on string lines were also installed on the paver. The road is approximately 15,000 ft (4,572 m) in length. Paving started from station 299+90 and ended at station 154+40.

The paving process started with traditional string line control. The GPS steering (horizontal x, y coordinates) control was initiated near station 292+00 and ended at station 259+75. During this process, laser elevation control was turned on and off several times. The GPS horizontal control proved very successful during the 3300 ft (1000 m) section (Figure 12). A few problems were identified with the laser elevation control. Some of these problems were related to the disadvantages of using laser control listed previously. Some were related to the computer program developed by Geologic. After a meeting with all the parties involved in the research, it was decided that GPS elevation control will be used in place of the laser control. With the current technology, the elevations obtained by GPS devices should be accurate enough for the purpose of this paving project. During the remainder of the project, the Geologic engineers continued to adjust their system to use GPS for the elevation control.

Ashby Road (170th Street)

Paving of the Ashby Project started on August 25, 2003 and ended on September 3rd. The first few days of the project turned out to be a testing and correction process for the Geologic computer system. After a few days of switching on and off the stringless control system, a relatively long section was finally paved continuously under GPS elevation control. This section is about 1300 ft (400 m) in length. Paving started from station 17+10 and ended at station 3+80 (Figure 13). Data collected from this section were used to compare with data from sections where string line control was used.

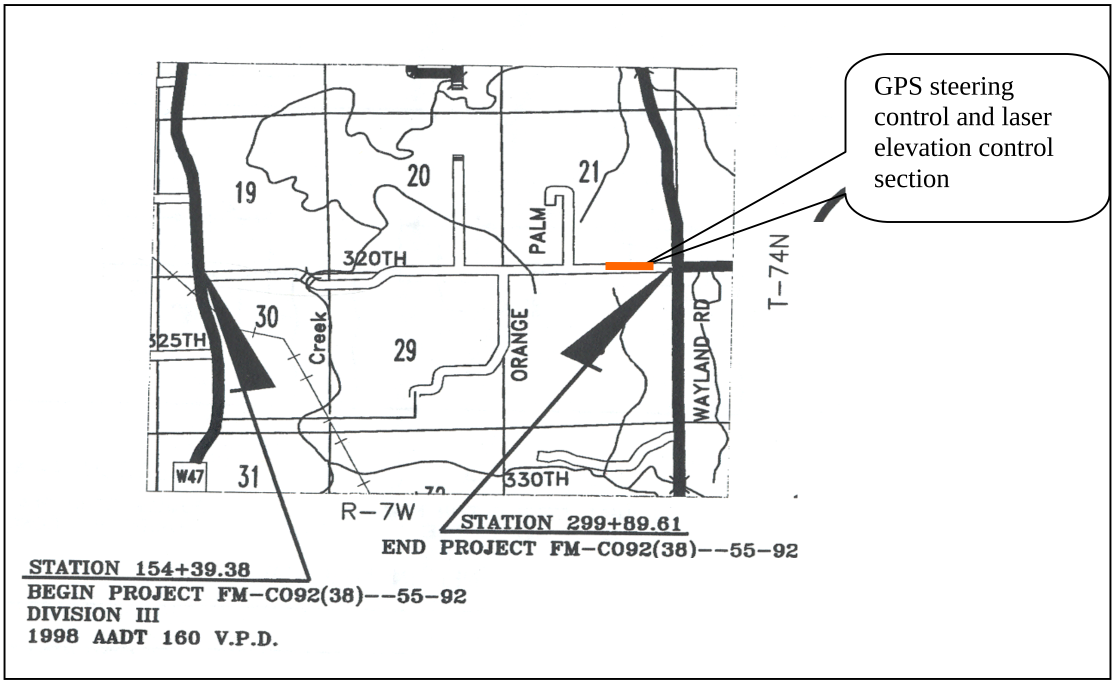

Figure 12. Location of GPS Steering Section on Coppock Project

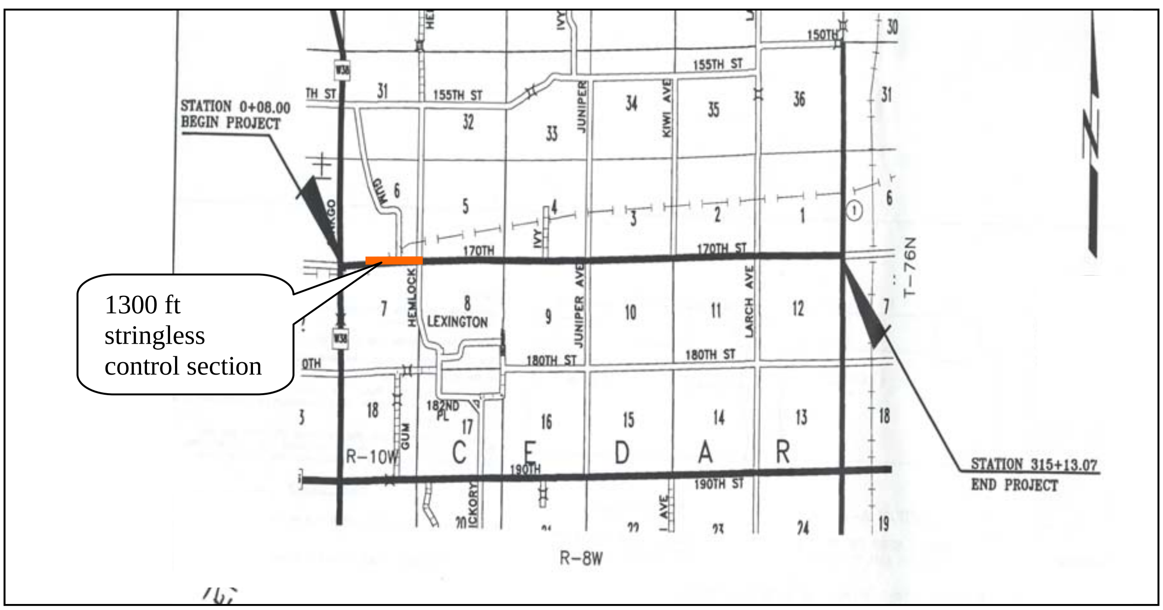

Figure 13. Location of Stringless Control Paving Test Section on Ashby Project

Issues Encountered During Construction

It appears that the greatest challenge encountered during the research dealt with the programming of the computer system that controlled the paving machine. Watching the computer screen, which showed the deviation from the design location and elevation, it appeared that the GPS and lasers were accurate enough to steer the paving machine. However, the GPS elevation data experienced excess variability between readings. Field observations during paving attribute the variability to a combination of soft subgrade in the paver track line and computer overcorrection. The variability in profile near the west end is attributed to the required transition to meet the existing pavement at the end of project. The computer program tried to adjust the paving machine to these changes when in reality it was unnecessary. The research team sees this project as developmental research to allow the computer programmers to find out what their programs need to do. This research allowed them to make changes to their programs to see how these changes would affect and control the paving machine on a real project.

It was also observed that the stringless control system required frequent adjustment to the location of the paving machine, causing some of the hydraulics and valves to be constantly moving up and down. This type of movement is also observed under string line control, but in that case it is not as violent as experienced with the GPS controlled equipment. This constant adjustment was hard on these pieces of machinery, and Carlson did not let this continue as they observed what the stringless system was doing to these hydraulic valves, as shown in Figure 14.

Moreover, the actual location of the GPS receiver on the paving machine proved to be an important detail. The GPS receiver needed to be mounted above the front track of the paving machine. This track controls the turning of the slip-form paving machine, and if the receiver is not mounted over this location, the system will not recognize a turn instantaneously. If a turn is not immediately detected, the control system will try to further correct for the deviation from the design when the correction has already been made.

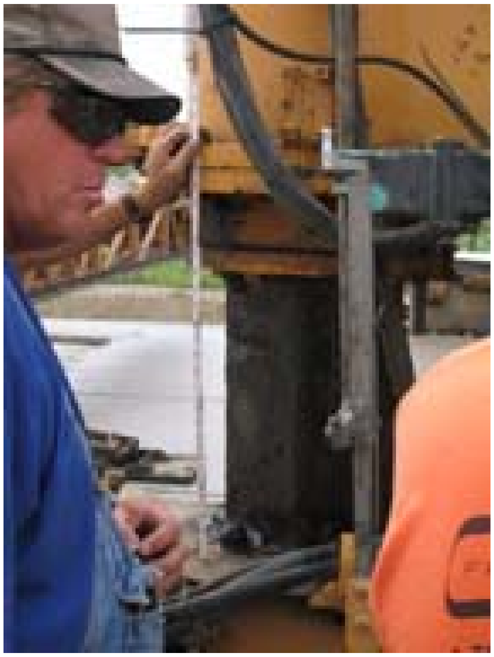

Figure 14. Measuring Movement of Hydraulic Cylinder

DATA COLLECTION

Four aspects of pavement quality are considered relevant to the choice of method to use for the paving machine positioning control: pavement smoothness, pavement thickness, yield quantities, and conformance to the design elevation. Data related to these aspects were collected and analyzed to evaluate the proposed stringless paving method.

Pavement Smoothness

Pavement smoothness is the primary concern for Washington County. To achieve better pavement smoothness in road construction, many states, including Iowa, use pavement smoothness as an incentive to contractors (Iowa DOT 2001). Typically, the unit price of the construction contract is adjusted according to the achieved pavement smoothness. For the Ashby project, the Light Weight Profiler was used to verify profile of the finished surface in the outside wheel-path in each direction and establish the level of smoothness obtained (Appendix A). This work was done by the research team in cooperation with the Iowa DOT Office of Special Investigations.

Pavement Thickness

Pavement thickness is considered an important aspect because it influences the strength and durability of the pavement, as well as the construction cost. To check the pavement thickness, two types of data were collected: pavement thickness checks during placement (Appendix B) and coring depths (Appendix C).

Yield Quantities

Measuring yield quantities is also important because it is directly related to the construction cost. Contract price for the two test projects are determined by the yield quantities. Daily yield quantities for the main line pavement were collected for both Ashby and Coppock roads (Appendix D).

Conformance to Design Elevations

While no express specifications were found about how closely the finished pavement elevation should be to the design elevation, this quality has a close relationship with the thickness and yield amounts. It is difficult to imagine that significant deviation from the design elevation occurred, and the above two qualities are still well under control. The research team conducted surveys to verify the elevations of the pavement edges and centerline of the finished paved surface. The pavement surface elevations from sections where stringless control was used and those where string line control was used were compared to test if a significant difference existed between the two control methods (Appendix E).

ANALYSIS

Pavement Smoothness

The pavement surface profile for the section between station 54+00 and station 3+00 for the Ashby project was obtained using a Light Weight Profiler from the Iowa DOT. The profile was divided into several intervals, from which two intervals were selected. One of them represented stringless control, and the other represented string-line control. Ride statistics, such as International Roughness Index (IRI), Profile Index (PI), Ride Number (RN), and California Profilograph Index (CPI) were calculated for these two intervals using Profile Viewer and Analyzer (ProVAL) software (Appendix A).

The CPI (Table 3) analysis simulates the output of a California Profilograph device. This result can be used to compare with the contract price adjustment schedule provided in Iowa DOT specifications (Table 4). IRI, which is proposed by the World Bank, is a specific profile index derived through a few rigorously defined mathematical transforms from a single profile.

The PI is determined from the profilogram by measuring and summing "scallops" that appear outside of a "blanking band" and is reported in millimeters/ kilometers (inches/miles). The blanking band, which is a plastic scale 1.70 in (43.2 mm) wide and 21.12 in (536.4 mm) long, represents a pavement length of 528 ft (160.9 m) at a scale of 1 in = 25 ft (1 mm = 0.3 m). Near the center of the scale is an opaque band 0.2 in (5.1 mm) wide extending the entire length of 21.12 in (536.4 mm). On either side of this band there are scribed lines 0.1 in (2.5 mm) apart, parallel to the opaque band.

The RN is the result of NCHRP research in the 1980s. It uses a 0-5 scale. Determining RN also requires a series of rigorous mathematical steps. Details of determining the IRI, PI, and RN can be found in I.M. 341 (Iowa DOT) and in The Little Book of Profiling by Sayers and Karamihas (1998).

Table 3. California Profile Index for Intervals for Ashby Project

Segment (ft)	Eastbound		Westbound	
	Raw CPI in/mile (mm/km)	Rounded CPI in/mile (mm/km)	Raw CPI in/mile (mm/km)	Rounded CPI in/mile (mm/km)
Interval I (stringless control)	20.55 (319.23)	20.81 (323.27)	26.80 (416.32)	27.16 (421.91)
Interval II	7.86 (122.10)	8.10 (125.83)	6.47 (100.51)	6.86 (106.56)
Interval III	2.26 (35.51)	2.48 (38.52)	1.44 (22.37)	1.52 (23.61)
Interval IV	10.45 (162.33)	9.89 (153.63)	35.96 (558.61)	36.49 (556.84)
Interval V	1.58 (24.54)	1.61 (25.01)	3.26 (50.64)	3.31 (51.42)

The eastbound filtered profile is shown in Figure 15 and is divided into five intervals. The first 1300 ft (396 m) interval used stringless control solely. The next interval has a number of small sections where the paver was controlled by the stringless system. The remaining three sections essentially used string line control. They were divided into three sections because one part of the pavement is unusually rougher than other parts. The reason for this unusual roughness should be investigated further, and this part is isolated as an individual interval.

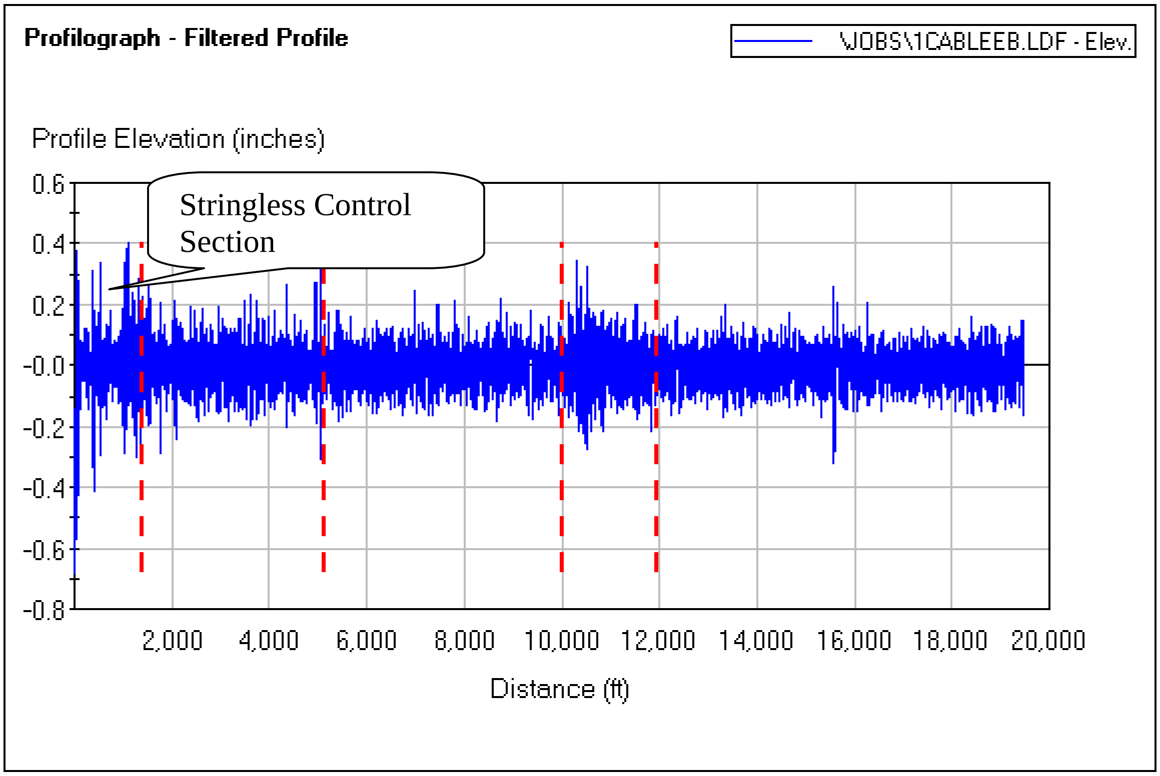

Figure 15. Eastbound Filtered Profile with Intervals - Ashby Project

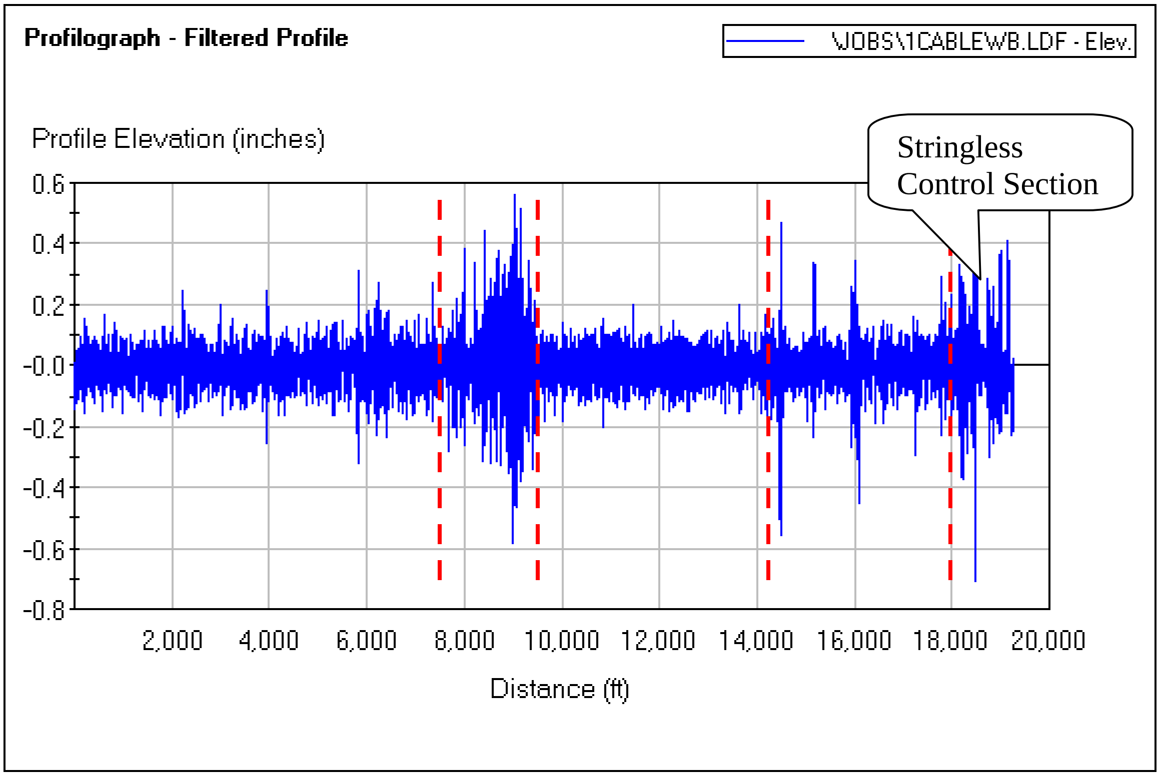

Figure 16. Westbound Filtered Profile with Intervals - Ashby Project

The westbound filtered profile is shown in Figure 16. This profile is also divided into five intervals by the same dividing points (as close as possible) as in the eastbound profile. The California Profile Index for each interval in the two profiles (Table 3) shows that the interval using stringless control in both profiles has higher CPI's than other intervals. This means that the pavement smoothness using stringless control is not as good as that of sections paved under string line control.

Table 4. Incentives for Pavement Smoothness (Schedule B, Iowa DOT)

Initial Profile Index	New Pavements	Resurfaced Pavements
in/mile(mm/km)	Dollars Per Segment	Dollars Per Segment
0 - 4.0 (0 - 60)	600	300
4.1 - 8.0 (65.1 - 130)	500	250
8.1 - 12.0 (130.1 - 190)	400	200
12.1 - 22.0 (190.1 - 350)	Unit Price	Unit Price
22.1 - 30.0 (1) (350.1-470)	Grind or -500	Grind or -250
30.1 & over (2) (470.1 & over)	Grind Only	Grind Only

As a confirmation, ride statistics at intervals were also calculated using the program ProVAL (Tables 5 and 6). The results also indicate that, in this case, the stringless control section is less smooth than other sections.

Table 5. Ride Statistics at Intervals for Eastbound Profile

Interval mile (m)	Eastbound		
	IRI in/mile (mm/km)	PI in/mile (mm/km)	RN
0.000 to 0.200 (0-322)	138.6 (2188)	199.9 (3155)	3.02
0.200 to 0.400 (322-644)	121.6 (1919)	162.7 (2568)	3.32
0.400 to 0.600 (644-966)	116.7 (1842)	162.4 (2563)	3.32
0.600 to 0.800 (966-1287)	94.1 (1485)	160.5 (2533)	3.33
0.800 to 1.000 (1287-1609)	90.2 (1424)	169.1 (2669)	3.26
1.000 to 1.200 (1609-1931)	84.8 (1338)	147.2 (2323)	3.45
1.200 to 1.400 (1931-2253)	89.2 (1408)	147.8 (2333)	3.44
1.400 to 1.600 (2253-2575)	86.9 (1372)	159.6 (2519)	3.34
1.600 to 1.800 (2575-2897)	88.4 (1395)	157.1 (2479)	3.36
1.800 to 2.000 (2897-3219)	98.0 (1547)	168.6 (2661)	3.27
2.000 to 2.200 (3219-3541)	96.3 (1520)	154.2 (2434)	3.39
2.200 to 2.400 (3541-3862)	82.6 (1304)	143.0 (2257)	3.48
2.400 to 2.600 (3862-4184)	82.3 (1299)	155.1 (2448)	3.38
2.600 to 2.800 (4184-4506)	85.4 (1348)	152.9 (2413)	3.40
2.800 to 3.000 (4506-4828)	80.2 (1266)	150.6 (2377)	3.42
3.000 to 3.200 (4828-5150)	78.4 (1237)	146.6 (2314)	3.45
3.200 to 3.400 (5150-5472)	86.2 (1360)	150.1 (2369)	3.42
3.400 to 3.600 (5472-5794)	81.1 (1280)	150.3 (2372)	3.42
3.600 to 3.693 (5794-5943)	81.4 (1285)	160.5 (2533)	3.33

Note: Shaded cells indicate stringless control paving section.

Table 6. Ride Statistics at Intervals for Westbound Profile

Interval mile (m)	Westbound		
	IRI in/mile (mm/km)	PI in/mile (mm/km)	RN
0.000 to 0.200 (0-322)	90.6 (1430)	142.9 (2255)	3.49
0.200 to 0.400 (322-644)	81.2 (1282)	130.9 (2066)	3.59
0.400 to 0.600 (644-966)	84.0 (1326)	147.1 (2322)	3.45
0.600 to 0.800 (966-1287)	86.7 (1368)	153.7 (2426)	3.39
0.800 to 1.000 (1287-1609)	77.7 (1226)	137.6 (2172)	3.53
1.000 to 1.200 (1609-1931)	93.4 (1474)	151.5 (2391)	3.41
1.200 to 1.400 (1931-2253)	98.5 (1555)	158.7 (2505)	3.35
1.400 to 1.600 (2253-2575)	115.0 (1815)	169.3 (2672)	3.26
1.600 to 1.800 (2575-2897)	173.7 (2741)	208.5 (3291)	2.95
1.800 to 2.000 (2897-3219)	88.8 (1402)	154.3 (2435)	3.39
2.000 to 2.200 (3219-3541)	86.4 (1364)	146.4 (2311)	3.46
2.200 to 2.400 (3541-3862)	81.0 (1278)	146.0 (2304)	3.46
2.400 to 2.600 (3862-4184)	81.4 (1285)	136.7 (2158)	3.54
2.600 to 2.800 (4184-4506)	90.9 (1435)	150.0 (2367)	3.42
2.800 to 3.000 (4506-4828)	75.8 (1196)	139.2 (2197)	3.52
3.000 to 3.200 (4828-5150)	101.2 (1597)	157.2 (2481)	3.36
3.200 to 3.400 (5150-5472)	99.4 (1569)	153.7 (2426)	3.39
3.400 to 3.600 (5472-5794)	138.0 (2178)	234.1 (3695)	2.77
3.600 to 3.693 (5794-5943)	89.8 (1417)	116.1 (1832)	3.73

Note: Shaded cells indicate stringless control paving section.

Pavement Thickness

Pavement thickness was checked for the Ashby project from Station 137+50 to Station 5+00 at an interval of 250 feet (76.2m). One-way ANOVA (Appendix B) was conducted to test if the mean pavement thicknesses obtained by the two control methods at both edges and at the centerline are different. With the data available, the results indicate that the pavement depths in the stringless controlled paving section are not significantly less accurate than those in the string line controlled section.

Eleven cores were randomly taken at the edges of the pavement. The coring depths are shown in Appendix C. No problems were identified related to pavement thickness using the coring depth method.

Table 7.Summary Statistics for Pavement Depth Checks at the Edges & Center Line

	Groups	Count	Mean in (mm)	Variance
North Edge	Stringless Control	48	8.79 (223)	0.59
	String Line Control	5	9.15 (232)	0.06
Center Line	Stringless Control	48	7.39 (188)	0.49
	String Line Control	5	7.23 (184)	0.22
South Edge	Stringless Control	48	8.95 (227)	0.36
	String Line Control	5	8.74 (222)	0.11

Yield Quantities

Daily yield quantities for the pavement were collected for the Ashby and Coppock road projects (Appendix D). Actual cumulative yield quantities and the quantities calculated from the design drawings were compared.

According to design, the area for the cross-section is 1.78 yd^2 per foot of length (1.49 m^2) for both Ashby and Coppock project. The total length for Ashby Road is 31,505.07 ft (9,602.7 m), which equals 10,501.69 yards. The total length for Coppock Quarry Road is 14,550.23 ft (4,434.9 m), which equals 4,850.08 yards. Thus, the total quantity of concrete is 18,669.67 yd^3 (14,274.0 m^3) for the Ashby project and 8,622.36 yd^3 (6592.3 m^3) for the Coppock project.

The total yield quantity is 19,198 yd^3 (14,667.9 m^3) for Ashby project and 8,744 yd^3 (6685.3 m^3) for the Coppock project. The Ashby project yield quantity exceeds the design quantity by 2.8%. The Coppock project exceeds design quantity by 1.4%.

Conformance to Design Elevations

To compare the elevation conformance, a comparison was made between top of concrete elevations for sections that involved string line and stringless control on the Ashby project. For string line control, random elevations were sampled between Station 135+00 and Station 115+00. The difference between actual pavement surface elevation and design elevation at both north and south edges were calculated at 25 ft intervals for this section and for the 1300 ft section using stringless control. One-way ANOVA analysis was conducted to test if these differences for the two sections were significant.

Table 8. Summary Statistics for Pavement Surface Elevation Deviation from Design

Location	Groups	Count	Mean ft (mm)	Variance
North Edge	String Line	81	-0.05 (-15.2)	0.000216
	Stringless	57	-0.04 (-12.2)	0.000746
South Edge	String Line	81	-0.03 (-9.1)	0.000232
	Stringless	57	-0.01 (-3.5)	0.00088

The summary statistics for the data are shown in Table 8. The ANOVA test results are shown in Appendix E. The results show that the differences in elevation (actual compared to design) for both edges are significantly different. The stringless control results actually had better elevation conformance compared to the string line control method.

RESULTS

- The research was successful in demonstrating the use of GPS to guide the slip-form paver and determining the top of pavement elevation.
- GPS receiver locations on the slip-form paver (front, middle, or rear) are critical to coordination with the 3-D design program and proper machine control.
- Concrete yield, depth, and profile elevations (pavement centerline and edges) can adequately be controlled with GPS to meet pavement design requirements.
- GPS computer control was not able to produce pavement surface profiles smooth enough to allow for ride incentive to be paid.
- Paving equipment hydraulic controls (valves) and computer software must be modified to allow for uniform changes in elevation as the equipment moves forward to meet profile specification requirements.

RECOMMENDATIONS

Based on the findings of this research, several recommendations are suggested in order to enhance the functionality of this system:

- Urge continuation of GPS slip-form paver control system development. The GPS system, in its current state, is capable of guiding the paver and controlling elevation to achieve acceptable concrete yield and reasonable profile for low volume roads. Additional software development is required to control elevation that will result in surface profiles that provide for Iowa DOT specification incentive payments.

- The current system is applicable to all CMI slip-form paving train equipment and appears to be applicable to other equipment brands. Each equipment brand may require minor modifications such as the addition of proportional hydraulic control valves.
- Identify additional demonstration projects to allow for fine-tuning of the software for profile control. These sites would be used to evaluate continued development in the elevation profile control with GPS or GPS/laser systems. They can also be used to evaluate other potential limitations in the operation of GPS control such as loss of line-of-sight with satellites.
- Consider Iowa DOT specification changes that use 3-D models to control the paving and profile operations for quality, quantity, and depth evaluation. State and local government officials already have the software to provide 3-D models of the pavement to the control system. This effort returns responsibility for the pavement depth and surface profile to the design engineer. Pavement smoothness and profile will be the responsibility of the designer and not of the contractor. The designer and contractor must assure a solid track line to work from in paving. The contractor must develop computer quality control programs. Ride incentive must now be tied to the profile deviations from the design profile. Concrete yield limits must be checked daily. Concrete depth checks can be greatly reduced or eliminated. Comparisons between design profiles at edges or in wheel paths to values obtained in the same locations by high-speed profilers can identify any serious depth problems.

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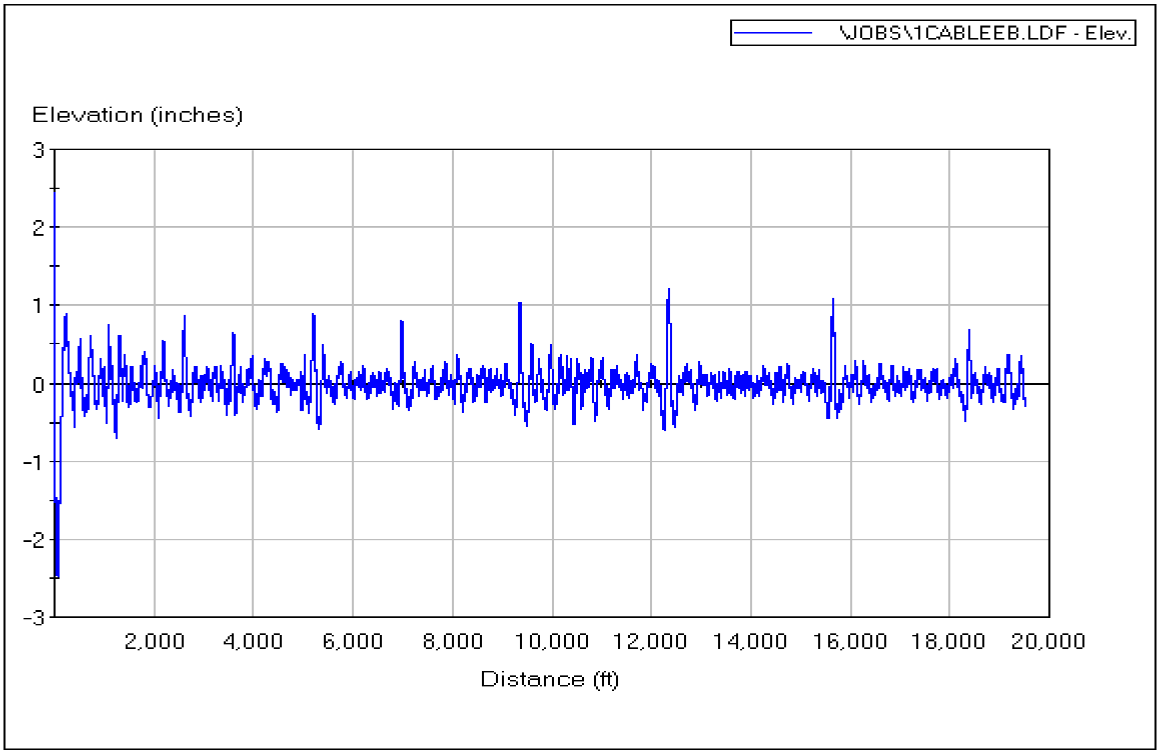
APPENDIX A. Profiler Result Analysis Report

A. East Bound Profile – Ashby Project

1. Elevation Profile



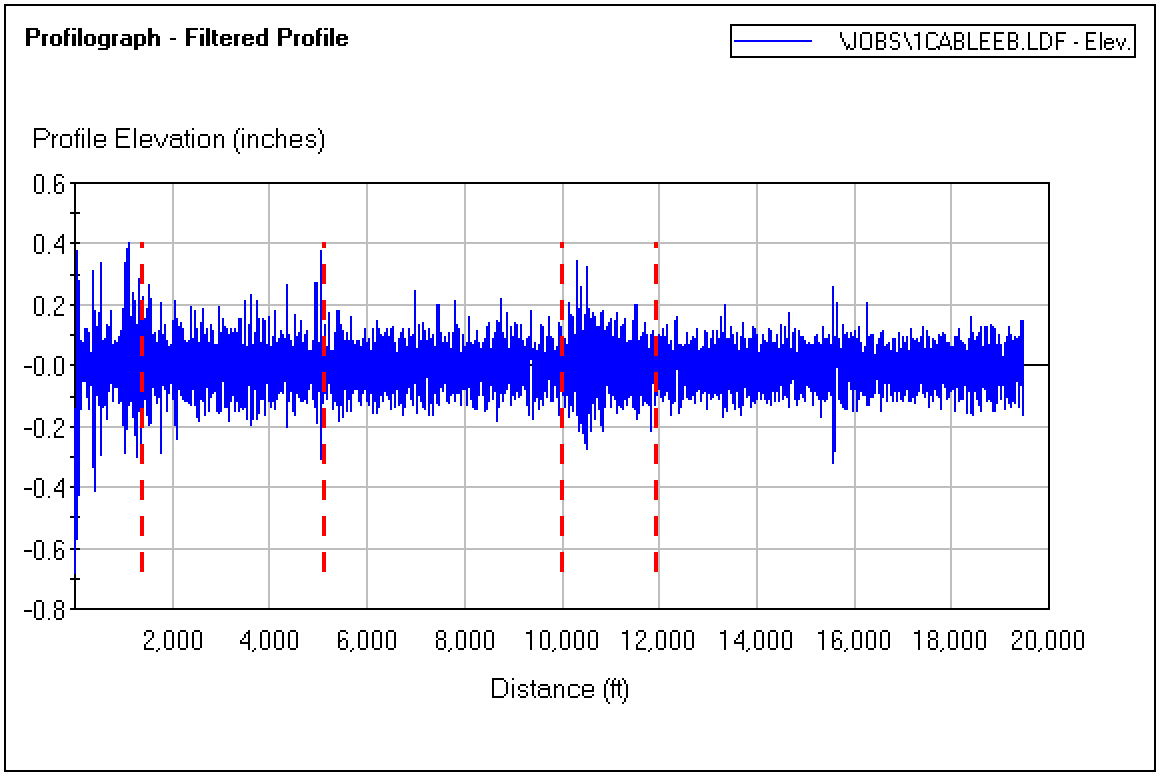
2. Analysis – Profilograph

Inputs

Input	Value	Unit
Blanking Band	0.2	in
Minimum Scallop Width	2	ft
Minimum Scallop Height	0.03	in
Scallop Rounding Increment	0.05	in
Number of Wheel Offsets	6	
Wheel Offset 1	8.75	ft
Wheel Offset 2	11.25	ft
Wheel Offset 3	13.75	ft
Wheel Offset 4	16.25	ft
Wheel Offset 5	11.25	ft
Wheel Offset 6	13.75	ft

Outputs (inches / mile)

Segment (ft)	Elev.	
	Raw CPI	Rounded CPI
16.3000 to 1411.9000	20.55	20.81
1412.0000 to 5125.7000	7.86	8.10
5125.8000 to 10031.9000	2.26	2.48
10032.0000 to 11953.5000	10.45	9.89
11953.6000 to 19483.8000	1.58	1.61



3. Analysis - Ride Statistics at Intervals

Input

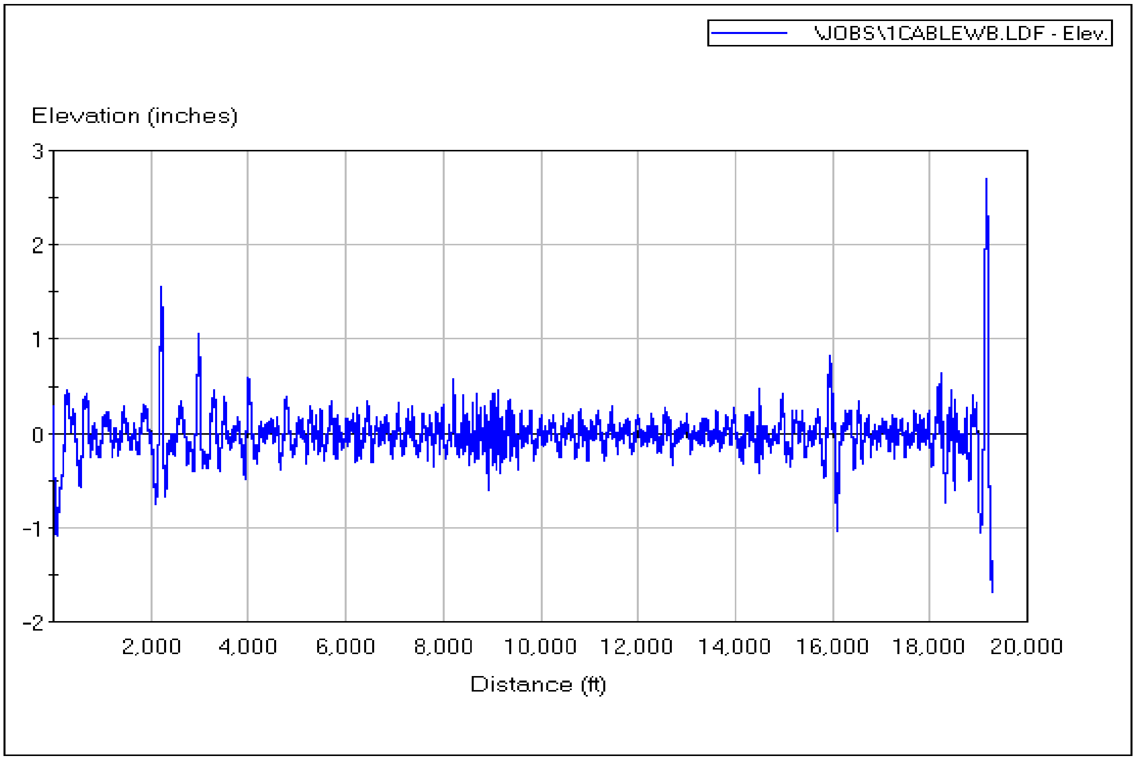
Input	Value	Unit
Vehicle Velocity	49.7	mph
Apply 250mm Filter	Yes	
Segment Length	0.2	mile

Output

	Elev.		
Interval (mile)	IRI	PI	RN
0.000 to 0.200 (Stringless Control)	138.6	199.9	3.02
0.200 to 0.400	121.6	162.7	3.32
0.400 to 0.600	116.7	162.4	3.32
0.600 to 0.800	94.1	160.5	3.33
0.800 to 1.000	90.2	169.1	3.26
1.000 to 1.200	84.8	147.2	3.45
1.200 to 1.400	89.2	147.8	3.44
1.400 to 1.600	86.9	159.6	3.34
1.600 to 1.800	88.4	157.1	3.36
1.800 to 2.000	98.0	168.6	3.27
2.000 to 2.200	96.3	154.2	3.39
2.200 to 2.400	82.6	143.0	3.48
2.400 to 2.600	82.3	155.1	3.38
2.600 to 2.800	85.4	152.9	3.40
2.800 to 3.000	80.2	150.6	3.42
3.000 to 3.200	78.4	146.6	3.45
3.200 to 3.400	86.2	150.1	3.42
3.400 to 3.600	81.1	150.3	3.42
3.600 to 3.693	81.4	160.5	3.33

B. West Bound – Ashby Project

1. Elevation Profile



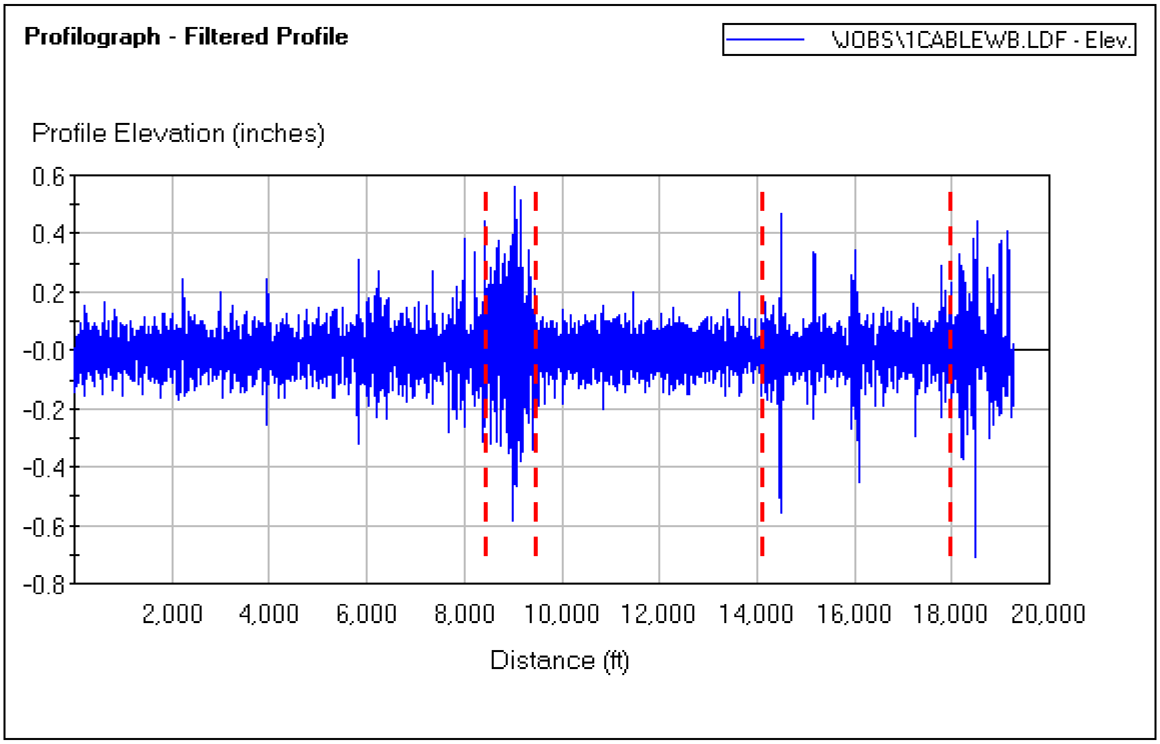
2. Analysis - Profilograph

Inputs

Input	Value	Unit
Blanking Band	0.2	in
Minimum Scallop Width	2	ft
Minimum Scallop Height	0.03	in
Scallop Rounding Increment	0.05	in
Number of Wheel Offsets	6	
Wheel Offset 1	8.75	ft
Wheel Offset 2	11.25	ft
Wheel Offset 3	13.75	ft
Wheel Offset 4	16.25	ft
Wheel Offset 5	11.25	ft
Wheel Offset 6	13.75	ft

Outputs (inches/mile)

Segment (ft)	Elev.	
	Raw CPI	Rounded CPI
16.3000 to 7524.1000	3.26	3.31
7524.2000 to 9535.7000	35.96	36.49
9535.8000 to 14235.9000	1.44	1.52
14236.0000 to 18007.7000	6.47	6.86
18007.8000 to 19271.5000	26.80	27.16



3. Analysis - Ride Statistics at Intervals

Input

Input	Value	Unit
Vehicle Velocity	49.7	mph
Apply 250mm Filter	Yes	
Segment Length	0.2	mile

Output

	Elev.		
Interval (mile)	IRI	PI	RN
0.000 to 0.200	90.6	142.9	3.49
0.200 to 0.400	81.2	130.9	3.59
0.400 to 0.600	84.0	147.1	3.45
0.600 to 0.800	86.7	153.7	3.39
0.800 to 1.000	77.7	137.6	3.53
1.000 to 1.200	93.4	151.5	3.41
1.200 to 1.400	98.5	158.7	3.35
1.400 to 1.600	115.0	169.3	3.26
1.600 to 1.800	173.7	208.5	2.95
1.800 to 2.000	88.8	154.3	3.39
2.000 to 2.200	86.4	146.4	3.46
2.200 to 2.400	81.0	146.0	3.46
2.400 to 2.600	81.4	136.7	3.54
2.600 to 2.800	90.9	150.0	3.42
2.800 to 3.000	75.8	139.2	3.52
3.000 to 3.200	101.2	157.2	3.36
3.200 to 3.400	99.4	153.7	3.39
3.400 to 3.600 (Stringless Control)	138.0	234.1	2.77
3.600 to 3.653 (Stringless Control)	89.8	116.1	3.73

APPENDIX B. Pavement Depths Check Results

Ashby Project

1. Depth Check Summary Statistics – Ashby Project

	South Edge	Center Line	North Edge
Mean	8.76	7.37	8.94
Standard Error	0.12	0.09	0.08
Median	8.875	7.125	9
Mode	8.875	7	9
Standard Deviation	0.85	0.68	0.58
Sample Variance	0.73	0.46	0.34
Range	6.5	3.5	4.375
Minimum	5.625	6.75	5.625
Maximum	12.125	10.25	10
Count	54	54	54
Confidence Level (95.0%)	0.23	0.19	0.16

2. One-Way ANOVA Test Results

   a. One-Way ANOVA Results (Thickness at North Edge)

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.589929	1	0.589929	1.07265	0.305234	4.030397
Within Groups	28.04863	51	0.549973			
Total	28.63856	52				

   b. One-Way ANOVA Results (Thickness at Center Line)

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.128156	1	0.128156	0.270783	0.605059	4.030397
Within Groups	24.13717	51	0.473278			
Total	24.26533	52				

   c. One-Way ANOVA Results (Thickness at South Edge)

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.214041	1	0.214041	0.622778	0.43367	4.030397
Within Groups	17.52808	51	0.343688			
Total	17.74212	52				

3. Data

Station	South Edge (in)	Center Line (in)	North Edge (in)	Station	South Edge (in)	Center Line (in)	North Edge (in)
137+50	8	6 3/4	9	70+00	8 3/4	7 1/4	8 7/8
135+00	8 3/4	7	9	67+50	9 1/4	8	9 1/8
132+50	8 5/8	6 7/8	8 7/8	65+00	5 5/8	7	9
130+00	8 5/8	7 1/4	9	62+50	8 7/8	6 7/8	9
127+50	9	10 1/4	8 3/4	60+00	9 1/2	8	8 3/4
125+00	9	9 3/8	9 3/8	57+50	9 1/8	8	9
122+50	8 7/8	6 7/8	5 5/8	55+00	9	7 1/2	9 1/4
120+00	8 3/8	7	9	52+50	8 5/8	8	9 1/8
117+50	8 5/8	7 1/8	8 7/8	50+00	8 1/2	8	9 1/2
115+00	12 1/8	8 1/2	8 7/8	47+50	9 1/2	7	9
112+50	8 7/8	7 1/8	8 1/2	45+00	9 5/8	6 7/8	9
110+00	8 7/8	7 5/8	9 1/4	42+50	9 1/4	7	9 1/8
107+50	8 7/8	7 5/8	9 1/4	40+00	8 7/8	7	9
105+00	8 3/4	7 1/8	9	37+50	8 7/8	7	9 3/8
102+50	8 7/8	8 3/8	10	35+00	8 7/8	7 1/8	8 5/8
100+00	8 3/4	7	9	32+50	8 5/8	8	9 1/2
97+50	8 5/8	7 3/8	9 1/8	30+00	--	--	--
95+00	8 5/8	7 7/8	9 1/4	27+50	8 1/2	7 1/2	9 1/4
92+50	9 1/2	6 7/8	9 1/4	25+00	8 3/4	7	9 1/4
90+00	9	7 1/8	9 1/8	22+50	8 7/8	6 7/8	9 1/8
87+50	8 7/8	8 1/4	9 1/2	20+00	8 1/2	7	8 3/4
85+00	8	6 7/8	8	17+50	9	7	8 7/8
82+50	7 3/4	6 3/4	7 3/4	15+00	8 7/8	7	8 3/7
80+00	8	6 3/4	9	12+50	9 1/2	6 3/4	8 3/8
77+50	8 3/4	7	9	10+00	9 1/4	7 1/8	9
75+00	8 5/8	6 7/8	8 7/8	7+50	9	7 1/4	9 1/8
72+50	8 5/8	7 1/4	9	5+00	9 1/8	8	8 3/4
				2+50	5 5/8	7	9 1/8

Note:
1. South Edge and North Edge Elevations are 1.5 feet from the pavement edges.
1. Shaded cells indicate stringless paving section

Coppock Project

1. Depth Check Summary Statistics

	South Edge	Center Line	North Edge
Mean	8.78	7.27	8.87
Standard Error	0.04	0.05	0.03
Median	8.75	7.25	8.88
Mode	8.75	7.25	8.88
Standard Deviation	0.34	0.40	0.28
Sample Variance	0.12	0.16	0.08
Range	1.50	2.00	1.38
Minimum	8.25	6.38	8.38
Maximum	9.75	8.38	9.75
Count	71.00	71.00	71.00
Confidence Level (95.0%)	0.08	0.09	0.07

2. Data

Station	South Edge (in)	Center Line (in)	North Edge (in)	Station	South Edge (in)	Center Line (in)	North Edge (in)
BOP 154+39	9 ¾	8 1/4	9 1/4	222+50	9	8	9 1/8
155+00	9 ½	8 3/8	9 3/4	225+00	8 1/4	7 1/4	8 5/8
157+50	8 ¾	7 3/8	8 3/4	227+50	8 1/2	7 5/8	8 3/8
160+00	8 7/8	7 1/4	8 7/8	230+00	8 5/8	7 3/8	8 5/8
162+50	9 1/8	7 1/2	8 7/8	232+50	8 3/8	7 3/8	8 7/8
165+00	8 ¾	7	8 5/8	235+00	8 3/4	7 1/2	8 7/8
167+50	8 5/8	7 1/8	8 1/2	237+50	8 7/8	7 5/8	8 7/8
170+00	8 3/8	6 7/8	8 1/2	240+00	8 7/8	7 1/4	8 7/8
172+50	----	7 1/4	----	242+50	9 1/4	7 3/8	8 5/8
175+00	8 ¾	7 1/2	8 1/2	PC 244+75	8 3/8	7 1/4	8 5/8
177+50	----	----	----	245+00	8 5/8	7 1/4	8 5/8
PC 178+00	8 ¾	7 1/4	8 1/2	PI 247+50	8 3/4	7 1/4	8 5/8
180+00	9 1/8	7 3/8	8 3/4	250+00	8 3/4	7 3/8	9 1/8
PI 180+75	8 ½	7 3/4	8 3/4	PC 250+50	----	----	----
182+50	9 ¾	8 1/4	9 1/8	252+50	9	7 1/8	8 7/8
PT 183+75	9	7 1/2	9 3/8	PC 252+75	----	----	----
185+00	9	8	8 7/8	255+00	8 7/8	7 1/4	9
187+50	----	----	----	PI 255+75	8 1/4	7 1/4	8 7/8
PC 189+50	----	----	----	257+50	8 5/8	7 1/4	9
190+00	8 7/8	6 7/8	9 1/2	PT 258+50	8 1/2	7 1/4	8 7/8
PI 191+75	----	----	----	260+00	8 7/8	6 7/8	8 7/8
192+50	8 ¼	6 7/8	8 1/2	262+50	8 5/8	7 1/8	9
PT 193+75	----	----	----	265+00	8 1/2	6 7/8	8 7/8
195+00	8 7/8	7 1/8	9	267+50	8 1/2	6 7/8	8 1/2
197+50	8 ¾	7	8 1/2	270+00	8 1/4	7	8 3/4
200+00	8 ¾	7	8 1/2	PC 271+00	8 3/8	6 7/8	8 7/8
202+50	8 7/8	6 3/4	8 3/4	272+50	8 3/8	7	8 7/8
PC 204+50	9	7 1/2	8 7/9	PI 273+75	8 3/4	7 1/8	9
205+00	9	7	8 3/4	275+00	8 5/8	7 1/4	9
207+50	8 ½	7 3/8	9 1/4	PT 276+75	8 3/8	7	8 7/8
PI 207+75	8 7/8	7 3/8	8 1/2	277+50	8 3/8	7	9 1/8
210+00	8 7/8	7 1/2	9	280+80	8 1/4	8	9
PC 210+75	8 ¾	7 1/2	9	282+50	8 7/8	7 1/8	9 1/4
212+50	9	7 1/2	9	285+00	8 1/4	6 3/8	8 3/8
PC 214+50	9 ¼	7 1/2	9 1/4	287+50	8 5/8	7 1/4	9
215+00	9 1/8	7 1/2	9 1/2	290+00	9 1/2	7 7/8	9
217+50	9 1/8	6 5/8	8 3/4	292+50	8 1/2	6 5/8	9
PI 218+00	9	6 5/8	8 5/8	295+00	8 1/2	6 1/2	8 1/2
220+00	9	7 1/2	9 3/8	297+50	9	7 1/4	9
PC 221+25	9 ¼	----	9 1/8	EOP 299+90	----	----	----

APPENDIX C. Coring Results (Ashby Project)

Photo #	Core #	Core Length (in)	Location	Station
1	6N	9	2.75 ft (0.84 m) from edge	15+00
2	6N	9	2.75 ft (0.84 m) from edge	15+00
3	4N	9	3.35 ft (1.02 m) from edge	105+00
4	2N	9	2.75 ft (0.84 m) from edge	135+00
5	2S	8.75	3.5 ft (1.07 m) from edge	135+00
6	5S	8.75	2.75 ft (0.84 m) from edge	35+00
7	3N	9	3.5 ft (1.07 m) from edge	110+00
8	5N	9	3.25 ft (0.99 m) from edge	35+00
9	4S	8.75	2.75 ft (0.84 m) from edge	105+00
10	6S	8.75	2.5 ft (0.76 m) from edge	15+00
11	3S	9	3.5 ft (1.07 m) from edge	110+00

APPENDIX D. Yield Quantities for Main Line Pavement

Ashby Project

Date	Daily Qty.- yd^3 (m^3)	Cumulative Qty.- yd^3 (m^3)
08/20/03	2,000 (1,529.1)	2,000 (1,529.1)
08/21/03	2,954 (2,258.5)	4,954 (3,787.6)
08/22/03	2,280 (1,743.2)	7,234 (5,530.8)
08/25/03	3,402 (2,601.0)	10,636 (8,131.8)
08/26/03	3,216 (2,458.8)	13,852 (10,590.6)
08/27/03	3,482 (2,662.2)	17,334 (13,252.8)
08/28/03	1,864 (1,425.1)	19,198 (14,667.9)

Coppock Project

Date	Daily Qty.- yd^3 (m^3)	Cumulative Qty.- yd^3 (m^3)
08/12/03	2,776 (2,122.4)	2,776 (2,122.4)
08/13/03	3,632 (2,776.9)	6,408 (4,899.3)
08/14/03	2,336 (1,786.0)	8,744 (6,685.3)

APPENDIX E. Pavement Elevations Survey Result

Ashby Project

1. One-Way ANOVA Test Results

   a. One-way ANOVA Results for Pavement Elevation Deviation at North Edge

ANOVA	North Edge					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00278	1	0.00278	6.401685	0.012541	3.910742
Within Groups	0.05907	136	0.000434			
Total	0.06185	137				

   b. One-way ANOVA Results for Pavement Elevation Deviation at South Edge

ANOVA	South Edge					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.012193	1	0.012193	24.43325	2.23E-06	3.910742
Within Groups	0.067868	136	0.000499			
Total	0.080061	137				

2. Data

   a. Pavement Surface Elevations (Stringless control)

Station		North Edge (ft)			North Edge (ft)		
		Adj. Elv.	Dsgn Pvmt	Diff.	Adj. Elv.	Dsgn Pvmt	Diff.
4	00	801.92	801.99	-0.07	801.95	801.99	-0.04
	25	801.94	801.97	-0.03	801.98	801.97	0.01
	50	801.90	801.95	-0.05	801.95	801.95	0.00
	75	801.90	801.93	-0.03	801.94	801.93	0.01
5	00	801.88	801.91	-0.03	801.93	801.91	0.02
	25	801.86	801.89	-0.03	801.87	801.89	-0.02
	50	801.81	801.87	-0.06	801.84	801.87	-0.03
	75	801.75	801.85	-0.10	801.80	801.85	-0.05
6	00	801.73	801.83	-0.10	801.79	801.83	-0.04
	25	801.75	801.81	-0.06	801.77	801.81	-0.04
	50	801.73	801.79	-0.06	801.75	801.79	-0.04
	75	801.66	801.77	-0.11	801.71	801.77	-0.06
7	00	801.68	801.75	-0.07	801.72	801.75	-0.03
	25	801.68	801.73	-0.05	801.71	801.73	-0.02
	50	801.65	801.71	-0.06	801.68	801.71	-0.03
	75	801.65	801.69	-0.04	801.65	801.69	-0.04
8	00	801.64	801.67	-0.03	801.63	801.67	-0.04
	25	801.61	801.66	-0.05	801.61	801.66	-0.05
	50	801.59	801.64	-0.05	801.60	801.64	-0.04
	75	801.59	801.62	-0.03	801.60	801.62	-0.02

Station		North Edge			North Edge		
		Adj. Elv.	Dsgn Pvmt	Diff.	Adj. Elv.	Dsgn Pvmt	Diff.
9	00	801.59	801.60	-0.01	801.62	801.60	0.02
	25	801.57	801.58	-0.01	801.62	801.58	0.04
	50	801.54	801.56	-0.02	801.57	801.56	0.01
	75	801.50	801.54	-0.04	801.55	801.54	0.01
10	00	801.47	801.52	-0.05	801.53	801.52	0.01
	25	801.44	801.50	-0.06	801.49	801.50	-0.01
	50	801.46	801.48	-0.02	801.47	801.48	-0.01
	75	801.45	801.46	-0.01	801.51	801.46	0.05
11	00	801.42	801.44	-0.02	801.50	801.44	0.06
	25	801.39	801.42	-0.03	801.46	801.42	0.04
	50	801.39	801.40	-0.01	801.42	801.40	0.02
	75	801.36	801.38	-0.02	801.38	801.38	0.00
12	00	801.29	801.36	-0.07	801.33	801.36	-0.03
	25	801.23	801.34	-0.11	801.30	801.34	-0.04
	50	801.25	801.32	-0.07	801.29	801.32	-0.03
	75	801.23	801.28	-0.05	801.28	801.28	0.00
13	00	801.24	801.24	0.00	801.29	801.24	0.05
	25	801.19	801.19	0.00	801.23	801.19	0.04
	50	801.13	801.12	0.01	801.14	801.12	0.02
	75	801.04	801.05	-0.01	801.04	801.05	-0.01
14	00	800.97	800.97	0.00	801.00	800.97	0.03
	25	800.87	800.88	-0.01	800.89	800.88	0.01
	50	800.76	800.78	-0.02	800.77	800.78	-0.01
	75	800.64	800.67	-0.03	800.63	800.67	-0.04
15	00	800.52	800.55	-0.03	800.53	800.55	-0.02
	25	800.39	800.42	-0.03	800.41	800.42	-0.01
	50	800.24	800.29	-0.05	800.27	800.29	-0.02
	75	800.13	800.14	-0.01	800.13	800.14	-0.01
16	00	799.96	799.98	-0.02	799.97	799.98	-0.01
	25	799.77	799.82	-0.05	799.79	799.82	-0.03
	50	799.58	799.64	-0.06	799.62	799.64	-0.02
	75	799.41	799.46	-0.05	799.44	799.46	-0.02
17	00	799.23	799.26	-0.03	799.25	799.26	-0.01

b. Pavement Surface Elevations (String line control with stringless control intervals)

Station		North Edge			North Edge		
		Adj. Elv.	Dsgn Pvmt	Diff.	Adj. Elv.	Dsgn Pvmt	Diff.
18	00	798.33	798.39	-0.06	798.36	798.39	-0.03
	25	798.09	798.15	-0.06	798.12	798.15	-0.03
	50	797.84	797.90	-0.06	797.88	797.90	-0.02
	75	797.57	797.64	-0.07	797.60	797.64	-0.04
19	00	797.31	797.37	-0.06	797.32	797.37	-0.05
	25	797.02	797.09	-0.07	797.00	797.09	-0.09
	50	796.73	796.80	-0.07	796.72	796.80	-0.08
	75	796.42	796.50	-0.08	796.43	796.50	-0.07
20	00	796.17	796.20	-0.03	796.19	796.20	-0.01
	25	795.82	795.88	-0.06	795.86	795.88	-0.02
	50	795.49	795.55	-0.06	795.51	795.55	-0.04
	75	795.15	795.22	-0.07	795.19	795.22	-0.03
21	00	794.85	794.87	-0.02	794.85	794.87	-0.02
	25	794.50	794.52	-0.02	794.54	794.52	0.02
	50	794.14	794.15	-0.01	794.18	794.15	0.03
	75	793.76	793.78	-0.02	793.80	793.78	0.02
22	00	793.39	793.40	-0.01	793.40	793.40	0.00
	25	793.00	793.00	0.00	793.01	793.00	0.01
	50	792.60	792.60	0.00	792.61	792.60	0.01
	75	792.22	792.19	0.03	792.20	792.19	0.01
23	00	791.74	791.77	-0.03	791.76	791.77	-0.01
	25	791.32	791.34	-0.02	791.34	791.34	0.00
	50	790.88	790.90	-0.02	790.90	790.90	0.00
	75	790.44	790.45	-0.01	790.44	790.45	-0.01
24	00	789.96	789.99	-0.03	789.97	789.99	-0.02
	25	789.50	789.52	-0.02	789.50	789.52	-0.02
	50	789.02	789.05	-0.03	789.04	789.05	-0.01
	75	788.55	788.58	-0.03	788.58	788.58	0.00
25	00	788.06	788.11	-0.05	788.10	788.11	-0.01
	25	787.67	787.63	0.04	787.71	787.63	0.08
	50	787.18	787.16	0.02	787.22	787.16	0.06
	75	786.71	786.69	0.02	786.74	786.69	0.05
26	00	786.22	786.22	0.00	786.25	786.22	0.03
	25	785.77	785.77	0.00	785.80	785.77	0.03
	50	785.36	785.34	0.02	785.36	785.34	0.02
	75	784.91	784.93	-0.02	784.96	784.93	0.03
27	00	784.51	784.53	-0.02	784.54	784.53	0.01
	25	784.13	784.15	-0.02	784.15	784.15	0.00
	50	783.75	783.79	-0.04	783.79	783.79	0.00
	75	783.40	783.45	-0.05	783.45	783.45	0.00

Station		North Edge Adj. Elv.	North Edge Dsgn Pvmt	North Edge Diff.	North Edge Adj. Elv.	North Edge Dsgn Pvmt	North Edge Diff.
28	00	783.06	783.13	-0.07	783.12	783.13	-0.01
	25	782.78	782.82	-0.04	782.82	782.82	0.00
	50	782.50	782.54	-0.04	782.52	782.54	-0.02
	75	782.23	782.27	-0.04	782.26	782.27	-0.01
29	00	781.97	782.02	-0.05	781.98	782.02	-0.04
	25	781.75	781.78	-0.03	781.76	781.78	-0.02
	50	781.56	781.57	-0.01	781.56	781.57	-0.01
	75	781.35	781.37	-0.02	781.38	781.37	0.01
30	00	781.16	781.19	-0.03	781.19	781.19	0.00
	25	781.01	781.03	-0.02	781.06	781.03	0.03
	50	780.85	780.89	-0.04	780.91	780.89	0.02
	75	780.71	780.76	-0.05	780.77	780.76	0.01
31	00	780.59	780.65	-0.06	780.66	780.65	0.01
	25	780.50	780.56	-0.06	780.58	780.56	0.02
	50	780.44	780.49	-0.05	780.50	780.49	0.01
	75	780.39	780.44	-0.05	780.46	780.44	0.02
32	00	780.37	780.40	-0.03	780.42	780.40	0.02
	25	780.34	780.38	-0.04	780.39	780.38	0.01
	50	780.34	780.39	-0.05	780.38	780.39	-0.01
	75	780.35	780.40	-0.05	780.39	780.40	-0.01
33	00	780.39	780.44	-0.05	780.42	780.44	-0.02
	25	780.44	780.49	-0.05	780.47	780.49	-0.02
	50	780.51	780.57	-0.06	780.54	780.57	-0.03
	75	780.60	780.66	-0.06	780.64	780.66	-0.02
34	00	780.69	780.77	-0.08	780.76	780.77	-0.01
	25	780.82	780.89	-0.07	780.88	780.89	-0.01
	50	780.91	781.04	-0.13	781.01	781.04	-0.03
	75	781.15	781.20	-0.05	781.18	781.20	-0.02
35	00	781.38	781.38	0.00	781.37	781.38	-0.01
	25	781.47	781.58	-0.11	781.48	781.58	-0.10
	50	781.66	781.79	-0.13	781.69	781.79	-0.10
	75	781.90	782.03	-0.13	781.92	782.03	-0.11
36	00	782.11	782.27	-0.16	782.17	782.27	-0.10
	25	782.38	782.52	-0.14	782.41	782.52	-0.11
	50	782.64	782.77	-0.13	782.66	782.77	-0.11
	75	782.89	783.01	-0.12	782.92	783.01	-0.09
37	00	783.17	783.26	-0.09	783.17	783.26	-0.09
	25	783.42	783.51	-0.09	783.41	783.51	-0.10
	50	783.65	783.75	-0.10	783.66	783.75	-0.09
	75	783.91	784.00	-0.09	783.91	784.00	-0.09

Station		North Edge			North Edge		
		Adj. Elv.	Dsgn Pvmt	Diff.	Adj. Elv.	Dsgn Pvmt	Diff.
38	00	784.15	784.25	-0.10	784.17	784.25	-0.08
	25	784.38	784.49	-0.11	784.41	784.49	-0.08
	50	784.62	784.74	-0.12	784.66	784.74	-0.08
	75	784.87	784.99	-0.12	784.90	784.99	-0.09
39	00	785.13	785.23	-0.10	785.15	785.23	-0.08
	25	785.36	785.48	-0.12	785.39	785.48	-0.09
	50	785.61	785.73	-0.12	785.64	785.73	-0.09
	75	785.88	785.98	-0.10	785.90	785.98	-0.08
40	00	786.14	786.23	-0.09	786.16	786.23	-0.07
	25	786.41	786.50	-0.09	786.43	786.50	-0.07
	50	786.68	786.78	-0.10	786.70	786.78	-0.08
	75	786.95	787.07	-0.12	787.00	787.07	-0.07
41	00	787.27	787.38	-0.11	787.31	787.38	-0.07
	25	787.61	787.71	-0.10	787.63	787.71	-0.08
	50	787.96	788.05	-0.09	787.98	788.05	-0.07
	75	788.32	788.40	-0.08	788.33	788.40	-0.07
42	00	788.69	788.76	-0.07	788.71	788.76	-0.05
	25	789.06	789.14	-0.08	789.08	789.14	-0.06
	50	789.44	789.54	-0.10	789.47	789.54	-0.07
	75	789.86	789.95	-0.09	789.88	789.95	-0.07
43	00	790.29	790.37	-0.08	790.31	790.37	-0.06
	25	790.72	790.81	-0.09	790.74	790.81	-0.07
43	50	791.18	791.26	-0.08	791.19	791.26	-0.07
	75	791.62	791.72	-0.10	791.64	791.72	-0.08
44	00	792.12	792.20	-0.08	792.14	792.20	-0.06
	25	792.62	792.69	-0.07	792.64	792.69	-0.05
	50	793.13	793.20	-0.07	793.14	793.20	-0.06
	75	793.66	793.72	-0.06	793.67	793.72	-0.05
45	00	794.16	794.25	-0.09	794.23	794.25	-0.02
	25	794.64	794.80	-0.16	794.68	794.80	-0.12
	50	795.16	795.35	-0.19	795.23	795.35	-0.12
	75	795.73	795.88	-0.15	795.75	795.88	-0.13
46	00	796.27	796.39	-0.12	796.27	796.39	-0.12
	25	796.76	796.88	-0.12	796.77	796.88	-0.11
	50	797.22	797.35	-0.13	797.26	797.35	-0.09
	75	797.69	797.81	-0.12	797.71	797.81	-0.10
47	00	798.15	798.24	-0.09	798.17	798.24	-0.07
	25	798.57	798.66	-0.09	798.60	798.66	-0.06
	50	798.99	799.06	-0.07	799.00	799.06	-0.06
	75	799.35	799.45	-0.10	799.38	799.45	-0.07

Station		North Edge Adj. Elv.	Dsgn Pvmt	Diff.	North Edge Adj. Elv.	Dsgn Pvmt	Diff.
48	00	799.75	799.81	-0.06	799.76	799.81	-0.05
	25	800.09	800.16	-0.07	800.11	800.16	-0.05
	50	800.40	800.48	-0.08	800.44	800.48	-0.04
	75	800.70	800.79	-0.09	800.75	800.79	-0.04
49	00	801.02	801.09	-0.07	801.05	801.09	-0.04
	25	801.29	801.36	-0.07	801.31	801.36	-0.05
	50	801.51	801.61	-0.10	801.55	801.61	-0.06
	75	801.76	801.85	-0.09	801.79	801.85	-0.06
50	00	802.01	802.07	-0.06	802.03	802.07	-0.04
	25	802.22	802.27	-0.05	802.25	802.27	-0.02
	50	802.34	802.45	-0.11	802.40	802.45	-0.05
	75	802.54	802.62	-0.08	802.58	802.62	-0.04
51	00	802.65	802.76	-0.11	802.72	802.76	-0.04
	25	802.80	802.89	-0.09	802.85	802.89	-0.04
	50	802.92	803.00	-0.08	802.96	803.00	-0.04
	75	803.03	803.09	-0.06	803.04	803.09	-0.05
52	00	803.09	803.16	-0.07	803.11	803.16	-0.05
	25	803.13	803.22	-0.09	803.15	803.22	-0.07
	50	803.18	803.26	-0.08	803.18	803.26	-0.08
	75	803.19	803.27	-0.08	803.18	803.27	-0.09
53	00	803.20	803.27	-0.07	803.19	803.27	-0.08
	25	803.17	803.26	-0.09	803.19	803.26	-0.07
	50	803.15	803.23	-0.08	803.17	803.23	-0.06
	75	803.12	803.20	-0.08	803.15	803.20	-0.05
54	00	803.10	803.17	-0.07	803.14	803.17	-0.03

b. Pavement Surface Elevations (Stringline control)

Station		North			Center Line			South		
		Adj.Elv.	Dsgn Pvmt	Diff.	Adj.Elv.	Dsgn Pvmt	Diff.	Adj.Elv.	Dsgn Pvmt	Diff.
135	+00	797.86	797.91	-0.05	798.13	798.15	-0.02	797.89	797.91	-0.02
134	+75	797.91	797.94	-0.03	798.18	798.18	0.00	797.93	797.94	-0.01
	+50	797.95	797.98	-0.03	798.22	798.22	0.00	797.96	797.98	-0.02
	+25	797.98	798.02	-0.04	798.25	798.26	-0.01	798.00	798.02	-0.02
	+00	798.01	798.06	-0.05	798.29	798.30	-0.01	798.04	798.06	-0.02
133	+75	798.04	798.10	-0.06	798.32	798.34	-0.02	798.06	798.10	-0.04
	+50	798.09	798.14	-0.05	798.37	798.38	-0.01	798.11	798.14	-0.03
	+25	798.11	798.18	-0.07	798.39	798.42	-0.03	798.15	798.18	-0.03
	+00	798.14	798.22	-0.08	798.43	798.46	-0.03	798.18	798.22	-0.04
132	+75	798.23	798.26	-0.03	798.50	798.50	0.00	798.24	798.26	-0.02
	+50	798.25	798.30	-0.05	798.53	798.54	-0.01	798.28	798.30	-0.02
	+25	798.29	798.34	-0.05	798.56	798.58	-0.02	798.32	798.34	-0.02
	+00	798.32	798.39	-0.07	798.61	798.63	-0.02	798.35	798.39	-0.04
131	+75	798.36	798.43	-0.07	798.65	798.67	-0.02	798.39	798.43	-0.04
	+50	798.41	798.47	-0.06	798.69	798.71	-0.02	798.43	798.47	-0.04
	+25	798.45	798.51	-0.06	798.79	798.75	0.04	798.48	798.51	-0.03
	+00	798.49	798.55	-0.06	798.78	798.79	-0.01	798.53	798.55	-0.02
130	+75	798.55	798.59	-0.04	798.83	798.83	0.00	798.57	798.59	-0.02
	+50	798.60	798.63	-0.03	798.87	798.87	0.00	798.61	798.63	-0.02
	+25	798.63	798.67	-0.04	798.90	798.91	-0.01	798.65	798.67	-0.02
	+00	798.67	798.71	-0.04	798.93	798.95	-0.02	798.68	798.71	-0.03
129	+75	798.68	798.75	-0.07	798.95	798.99	-0.04	798.71	798.75	-0.04
	+50	798.72	798.79	-0.07	799.00	799.03	-0.04	798.76	798.79	-0.03
	+25	798.77	798.84	-0.07	799.05	799.08	-0.04	798.80	798.84	-0.04
	+00	798.81	798.88	-0.07	799.09	799.12	-0.03	798.84	798.88	-0.04
128	+75	798.86	798.92	-0.06	799.13	799.16	-0.03	798.89	798.92	-0.03
	+50	798.90	798.96	-0.06	799.17	799.20	-0.03	798.92	798.96	-0.04
	+25	798.93	799.00	-0.07	799.21	799.24	-0.04	798.97	799.00	-0.03
	+00	798.99	799.04	-0.05	799.25	799.28	-0.03	799.01	799.04	-0.03
127	+75	799.03	799.08	-0.05	799.29	799.32	-0.02	799.05	799.08	-0.03
	+50	799.08	799.12	-0.04	799.32	799.36	-0.01	798.99	799.12	-0.13
	+25	799.11	799.16	-0.05	799.36	799.40	-0.02	799.12	799.16	-0.04
	+00	799.15	799.20	-0.05	799.42	799.44	-0.02	799.16	799.20	-0.04
126	+75	799.20	799.24	-0.04	799.45	799.48	-0.01	799.20	799.24	-0.04
	+50	799.23	799.29	-0.06	799.49	799.53	-0.03	799.22	799.29	-0.07
	+25	799.27	799.33	-0.06	799.52	799.57	-0.03	799.27	799.33	-0.06
	+00	799.31	799.37	-0.06	799.57	799.61	-0.04	799.33	799.37	-0.04
125	+75	799.35	799.41	-0.06	799.62	799.65	-0.03	799.37	799.41	-0.04
	+50	799.40	799.45	-0.05	799.67	799.69	-0.02	799.42	799.45	-0.03
	+25	799.44	799.49	-0.05	799.72	799.73	-0.02	799.46	799.49	-0.03
	+00	799.49	799.53	-0.04	799.75	799.77	-0.02	799.50	799.53	-0.03

Station		North			Center Line			South		
		Adj.Elv.	Dsgn Pvmt	Diff.	Adj.Elv.	Dsgn Pvmt	Diff.	Adj.Elv.	Dsgn Pvmt	Diff.
124	+75	799.52	799.57	-0.05	799.79	799.81	-0.02	799.54	799.57	-0.03
	+50	799.57	799.61	-0.04	799.84	799.85	-0.01	799.59	799.61	-0.02
	+25	799.60	799.65	-0.05	799.89	799.89	-0.02	799.63	799.65	-0.02
	+00	799.62	799.69	-0.07	799.92	799.93	-0.01	799.67	799.69	-0.02
123	+75	799.68	799.74	-0.06	799.95	799.98	-0.03	799.71	799.74	-0.03
	+50	799.71	799.78	-0.07	800.00	800.02	-0.04	799.75	799.78	-0.03
	+25	799.76	799.82	-0.06	800.04	800.06	-0.03	799.79	799.82	-0.03
	+00	799.79	799.86	-0.07	800.08	800.10	-0.02	799.83	799.86	-0.03
122	+75	799.85	799.90	-0.05	800.13	800.14	-0.02	799.87	799.90	-0.03
	+50	799.88	799.94	-0.06	800.16	800.18	-0.03	799.91	799.94	-0.03
	+25	799.94	799.98	-0.04	800.21	800.22	-0.01	799.95	799.98	-0.03
	+00	799.97	800.02	-0.05	800.24	800.26	-0.02	799.99	800.02	-0.03
121	+75	800.01	800.06	-0.05	800.29	800.30	-0.02	800.03	800.06	-0.03
	+50	800.04	800.09	-0.05	800.32	800.33	-0.02	800.07	800.09	-0.02
	+25	800.12	800.13	-0.01	800.37	800.37	0.02	800.10	800.13	-0.03
	+00	800.12	800.17	-0.05	800.39	800.41	-0.02	800.14	800.17	-0.03
120	+75	800.16	800.20	-0.04	800.43	800.44	-0.01	800.17	800.20	-0.03
	+50	800.20	800.24	-0.04	800.46	800.48	-0.01	800.21	800.24	-0.03
	+25	800.22	800.27	-0.05	800.50	800.51	-0.02	800.25	800.27	-0.02
	+00	800.26	800.31	-0.05	800.53	800.55	-0.02	800.27	800.31	-0.04
119	+75	800.30	800.34	-0.04	800.57	800.58	-0.01	800.34	800.34	0.00
	+50	800.34	800.38	-0.04	800.60	800.62	-0.01	800.35	800.38	-0.03
	+25	800.36	800.41	-0.05	800.63	800.65	-0.02	800.38	800.41	-0.03
	+00	800.39	800.44	-0.05	800.66	800.68	-0.02	800.41	800.44	-0.03
118	+75	800.42	800.47	-0.05	800.69	800.71	-0.02	800.44	800.47	-0.03
	+50	800.45	800.50	-0.05	800.72	800.74	-0.02	800.47	800.50	-0.03
	+25	800.49	800.53	-0.04	800.75	800.77	-0.01	800.50	800.53	-0.03
	+00	800.52	800.56	-0.04	800.77	800.80	-0.03	800.52	800.56	-0.04
117	+75	800.55	800.59	-0.04	800.81	800.83	-0.01	800.57	800.59	-0.02
	+50	800.59	800.62	-0.03	800.84	800.86	0.00	800.58	800.62	-0.04
	+25	800.60	800.65	-0.05	800.86	800.89	-0.02	800.61	800.65	-0.04
	+00	800.65	800.68	-0.03	800.91	800.92	-0.01	800.65	800.68	-0.03
116	+75	800.70	800.71	-0.01	800.96	800.95	0.02	800.69	800.71	-0.02
	+50	800.71	800.73	-0.02	800.97	800.97	0.01	800.71	800.73	-0.02
	+25	800.72	800.76	-0.04	801.00	801.00	-0.01	800.75	800.76	-0.01
	+00	800.74	800.78	-0.04	801.02	801.02	0.00	800.76	800.78	-0.02
115	+75	800.78	800.81	-0.03	801.04	801.05	0.00	800.79	800.81	-0.02
	+50	800.82	800.83	-0.01	801.08	801.07	0.02	800.82	800.83	-0.01
	+25	800.80	800.86	-0.06	801.08	801.10	-0.03	800.83	800.86	-0.03
115	+00	800.85	800.88	-0.03	801.12	801.12	0.00	800.86	800.88	-0.02

Coppock Project

Pavement Surface Elevations

	North Edge			Center Line			South Edge		
Station	Act. Ele.	Dsgn. Ele.	Diff.	Act. Ele.	Dsgn. Ele.	Diff.	Act. Ele.	Dsgn. Ele.	Diff.
295+00	727.17	727.20	-0.03	727.39	727.44	-0.05	727.09	727.20	-0.11
290+00	733.39	733.49	-0.10	733.61	733.73	-0.12	733.38	733.49	-0.11
285+00	733.07	733.65	-0.58	733.44	733.89	-0.45	733.37	733.65	-0.28
276+75	733.15	733.22	-0.07	733.37	733.46	-0.09	733.13	733.22	-0.09
275+00	733.22	733.07	0.15	733.42	733.31	0.11	733.17	733.07	0.10
273+75	733.11	732.97	0.14	733.31	733.21	0.10	733.09	732.97	0.12
271+00	732.87	732.75	0.12	733.08	732.99	0.09	732.86	732.75	0.11
270+00	732.78	732.66	0.12	732.99	732.90	0.09	732.75	732.66	0.09
265+00	732.22	732.24	-0.02	732.44	732.48	-0.04	732.21	732.24	-0.03
260+00	730.00	730.00	0.00	730.22	730.24	-0.02	729.98	730.00	-0.02
258+50	728.74	728.95	-0.21	729.00	729.19	-0.19	728.77	728.95	-0.18
255+75	727.18	727.22	-0.04	727.43	727.46	-0.03	727.20	727.22	-0.02
255+00	726.87	726.93	-0.06	727.12	727.17	-0.05	726.90	726.93	-0.03
252+75	726.55	726.58	-0.03	726.79	726.82	-0.03	726.57	726.58	-0.01
PC 250+55	726.43	726.47	-0.04	726.68	726.71	-0.03	726.45	726.47	-0.02
250+00	726.41	726.42	-0.01	726.64	726.66	-0.02	726.41	726.42	-0.01
PI 247+55	725.95	725.98	-0.03	726.17	726.22	-0.05	725.95	725.98	-0.03
245+00	725.25	725.22	0.03	725.46	725.46	0.00	725.23	725.22	0.01
240+00	722.72	722.71	0.01	722.95	722.95	0.00	722.75	722.71	0.04
235+00	718.91	718.91	0.00	719.10	719.15	-0.05	718.92	718.91	0.01
230+00	714.51	714.51	0.00	714.74	714.75	-0.01	714.53	714.51	0.02
225+00	710.12	710.12	0.00	710.36	710.36	0.00	710.14	710.12	0.02
PC 221+25	708.88	708.66	0.22	709.41	709.38	0.03	709.92	710.10	-0.18
220+00	709.10	709.01	0.09	709.72	709.73	-0.01	710.28	710.45	-0.17
218+00	709.69	709.58	0.11	710.30	710.30	0.00	710.92	711.02	-0.10
215+00	709.51	709.42	0.09	710.15	710.14	0.01	710.73	710.86	-0.13
214+50	709.23	709.07	0.16	709.91	709.79	0.12	710.30	710.51	-0.21
210+00	702.79	702.90	-0.11	702.22	702.18	0.04	701.56	701.46	0.10
210+75	704.34	704.72	-0.38	703.79	704.00	-0.21	703.18	703.28	-0.10
PI 207+75	695.95	696.10	-0.15	695.42	695.38	0.04	694.77	694.66	0.11
205+00	684.88	685.07	-0.19	684.32	684.35	-0.03	683.69	683.63	0.06
PC 204+50	682.47	682.74	-0.27	682.04	682.02	0.02	681.41	681.30	0.11
200+00	658.78	658.77	0.01	658.99	659.01	-0.02	658.77	658.77	0.00
195+00	634.37	634.39	-0.02	634.36	634.40	-0.04	634.12	634.16	-0.04

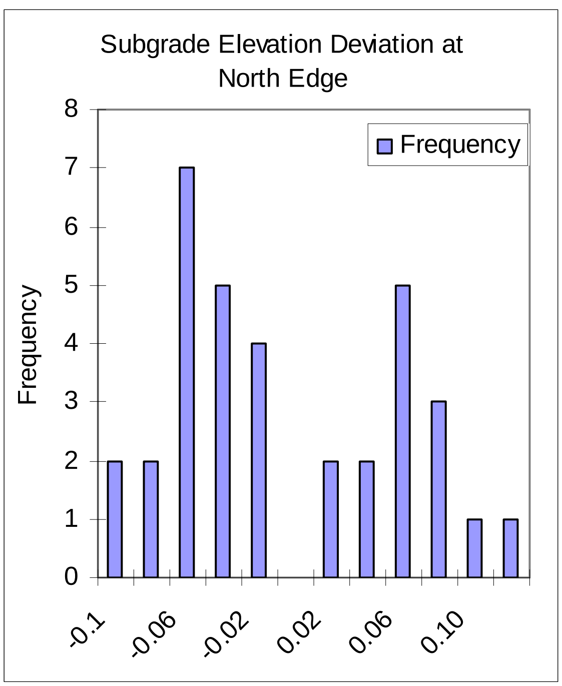
APPENDIX F. Subgrade Elevation Difference from Design Elevation

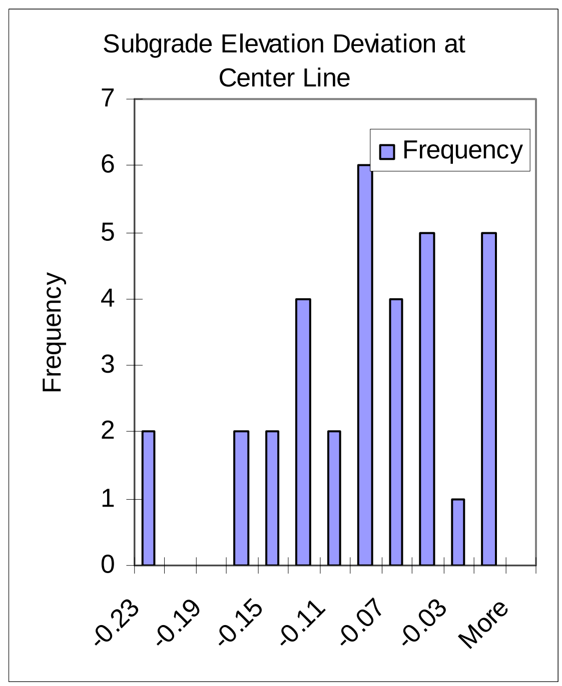
Ashby Project

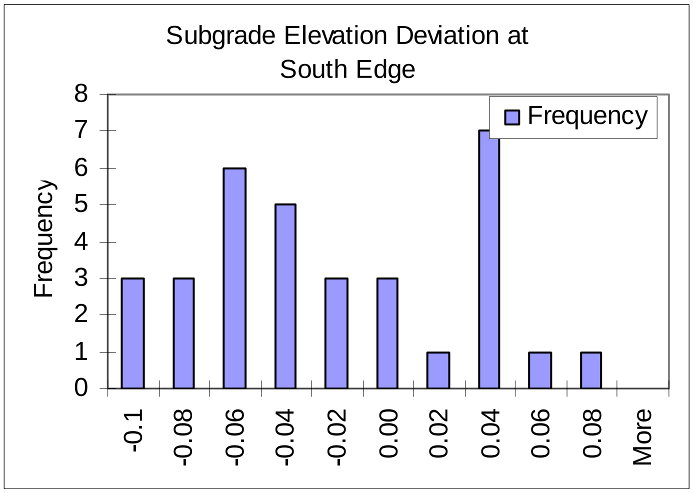
a) Summary Statistics for Subgrade Elevations

	North Edge	Center Line	South Edge
Mean	0.002	-0.078	-0.013
Standard Error	0.011	0.011	0.009
Median	-0.02	-0.07	-0.03
Mode	-0.02	-0.03	0.05
Standard Deviation	0.063	0.060	0.053
Sample Variance	0.0040	0.0036	0.0028
Range	0.21	0.24	0.19
Minimum	-0.09	-0.23	-0.09
Maximum	0.12	0.01	0.1
Count	34	33	33
Confidence Level (95.0%)	0.022	0.021	0.019

b) Histograms for Subgrade Elevation Difference







c) Data

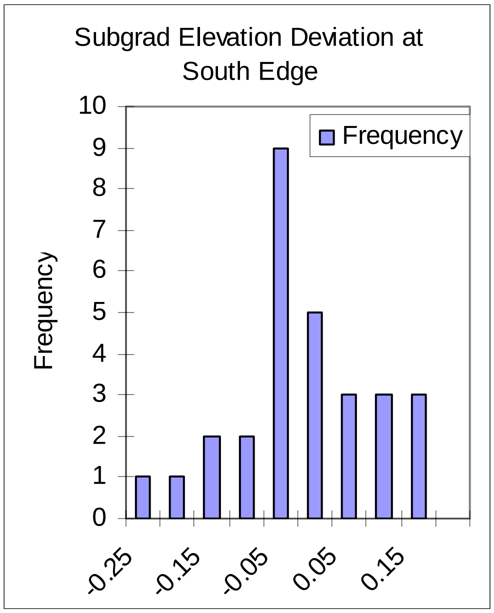
Instr. Pos.	North Edge			Center Line			South Edge		
	Adj. Elev.	Dsgn Grade	Diff.	Adj. Elev.	Dsgn Grade	Diff.	Adj. Elev.	Dsgn Grade	Diff.
184+00	795.61	795.58	0.03	795.99	795.99	0.00	795.68	795.58	0.10
183+00	795.63	795.58	0.05	796.00	795.99	0.01	795.63	795.58	0.05
182+00	795.61	795.57	0.04	795.90	795.98	-0.08	795.62	795.57	0.05
181+00	795.57	795.56	0.01	795.88	795.97	-0.09	795.48	795.56	-0.08
180+00	795.58	795.53	0.05	795.91	795.94	-0.03	795.56	795.53	0.03
179+00	795.55	795.49	0.06	795.89	795.90	-0.01	795.51	795.49	0.02
178+00	795.49	795.45	0.04	795.81	795.86	-0.05	795.52	795.45	0.07
177+00	795.49	795.41	0.08	795.75	795.83	-0.08	795.45	795.41	0.04
176+00	795.42	795.38	0.04	795.78	795.79	-0.01	795.43	795.38	0.05
175+00	795.43	795.34	0.09	795.75	795.75	0.00	795.40	795.34	0.06
174+00	795.30	795.30	0.00	--	--	--	795.34	795.30	0.04
173+00	795.31	795.26	0.05	795.64	795.67	-0.03	795.31	795.26	0.05
172+00	795.26	795.22	0.04	795.53	795.63	-0.10	795.24	795.22	0.02
171+00	795.21	795.21	0.00	795.55	795.62	-0.07	795.22	795.21	0.01
135+00	797.14	797.16	-0.02	797.54	797.57	-0.03	797.14	797.16	-0.02
134+00	797.25	797.31	-0.06	797.67	797.72	-0.05	797.25	797.31	-0.06
133+00	797.41	797.47	-0.06	797.81	797.88	-0.07	797.43	797.47	-0.04
132+00	797.58	797.64	-0.06	798.01	798.05	-0.04	797.60	797.64	-0.04
131+00	797.75	797.80	-0.05	798.18	798.21	-0.03	797.76	797.80	-0.04
130+00	797.92	797.96	-0.04	798.20	798.37	-0.17	797.88	797.96	-0.08
129+00		798.13	*		798.54	*		798.13	*
128+00	798.27	798.29	-0.02	798.56	798.70	-0.14	798.25	798.29	-0.04
127+00	798.42	798.45	-0.03	798.75	798.86	-0.11	798.39	798.45	-0.06
126+00	798.55	798.62	-0.07	798.80	799.03	-0.23	798.53	798.62	-0.09
125+00	798.74	798.78	-0.04	798.97	799.19	-0.22	798.72	798.78	-0.06
124+00	798.85	798.94	-0.09	799.23	799.35	-0.12	798.89	798.94	-0.05
123+00	799.07	799.11	-0.04	799.44	799.52	-0.08	799.09	799.11	-0.02

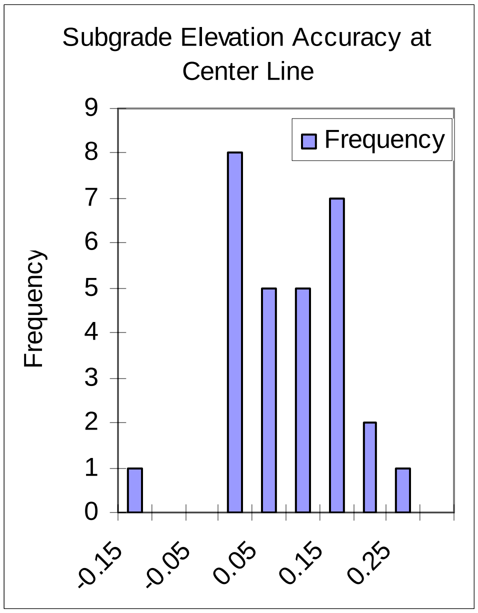
Instr. Pos.	North Edge			Center Line			South Edge		
	Adj. Elev.	Dsgn Grade	Diff.	Adj. Elev.	Dsgn Grade	Diff.	Adj. Elev.	Dsgn Grade	Diff.
122+00	799.23	799.27	-0.04	799.64	799.68	-0.04	799.22	799.27	-0.05
121+00	799.37	799.42	-0.05	799.71	799.83	-0.12	799.36	799.42	-0.06
120+00	799.51	799.56	-0.05	799.91	799.97	-0.06	799.47	799.56	-0.09
119+00	799.65	799.69	-0.04	800.03	800.10	-0.07	799.62	799.69	-0.07
118+00	799.79	799.81	-0.02	800.11	800.22	-0.11	799.77	799.81	-0.04
117+00	799.91	799.93	-0.02	800.28	800.34	-0.06	799.90	799.93	-0.03
116+00	799.99	800.03	-0.04	800.31	800.44	-0.13	800.03	800.03	0.00
115+00	800.04	800.13	-0.09	800.37	800.54	-0.17	799.64	800.13	-0.49

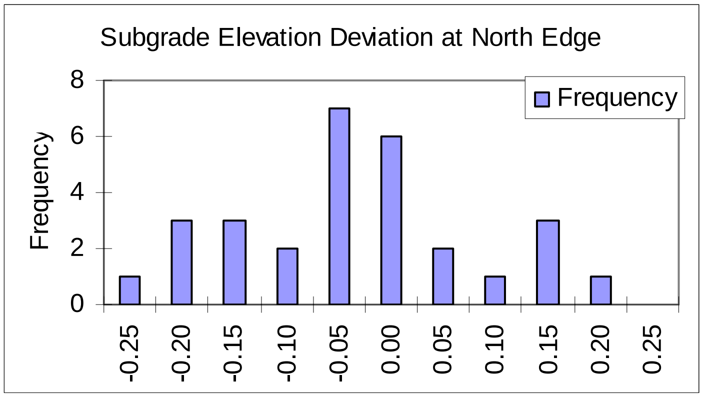
Coppock Project

a) Summary Statistics

	South Edge	Center Line	North Edge
Mean	0.006207	0.052759	-0.0031
Standard Error	0.019095	0.01528	0.020863
Median	0	0.05	0
Mode	0.01	0.01	0.04
Standard Deviation	0.102832	0.082284	0.112348
Sample Variance	0.010574	0.006771	0.012622
Range	0.44	0.38	0.42
Minimum	-0.25	-0.17	-0.21
Maximum	0.19	0.21	0.21
Count	29	29	29
Confidence Level(95.0%)	0.039115	0.031299	0.042735







b) Data

Instr. Pos.	South Edge Adj. Elev.	South Edge Dsgn Grade	South Edge Diff.	Center Line Adj. Elev.	Center Line Dsgn Grade	Center Line Diff.	North Edge Adj. Elev.	North Edge Dsgn Grade	North Edge Diff.
295+00	726.45	----	----	726.86	726.85	0.01	726.45	----	----
290+00	732.74	732.75	-0.01	733.15	732.99	0.16	732.74	732.7	0.04
285+00	732.9	732.91	-0.01	733.31	733.3	0.01	732.9	732.93	-0.03
280+00	732.73	732.66	0.07	733.14	732.93	0.21	732.73	732.65	0.08
276+75	732.47	732.37	0.1	732.88	732.73	0.15	732.47	732.44	0.03
275+00	732.32	732.27	0.05	732.73	732.61	0.12	732.32	732.28	0.04
273+75	732.22	732.16	0.06	732.63	732.52	0.11	732.22	732.15	0.07
271+00	731.98	731.97	0.01	732.39	732.29	0.1	731.98	731.95	0.03
270+00	731.91	731.88	0.03	732.32	732.24	0.08	731.91	731.86	0.05
265+00	731.49	731.48	0.01	731.9	731.86	0.04	731.49	731.67	-0.18
260+00	729.25	730.21	-0.96	729.66	729.54	0.12	729.25	729.26	-0.01
258+50	728.2	728.2	0	728.61	728.51	0.1	728.2	728.2	0
255+75	726.47	726.44	0	726.88		----	726.47	726.49	-0.05
245+00	724.47	724.51	-0.04	724.88	724.83	0.05	724.47	724.47	0
240+00	721.96	721.95	0.01	722.37	722.32	0.05	721.96	721.99	-0.03
235+00	718.16	718.16	0	718.57	718.51	0.06	718.16	718.18	-0.02
230+00	713.76	713.78	-0.02	714.17	714.05	0.12	713.76	713.77	-0.01
225+00	709.37	709.4	-0.03	709.78	709.78	0	709.37	709.42	-0.05
PC 221+25	707.91	708.16	-0.25	708.8	708.66	0.14	709.35	709.14	0.21
220+00	708.26	708.41	-0.15	709.15	709.32	-0.17	709.7	709.6	0.1
218+00	708.83	708.92	-0.09	709.72	709.76	-0.04	710.27	710.08	0.19
215+00	708.67	708.79	-0.12	709.56	709.55	0.01	710.11	709.94	0.17
214+50	708.32	708.49	-0.17	709.21	709.21	0	709.76	709.58	0.18
210+00	702.15	702.01	0.14	701.6	701.63	-0.03	700.71	700.84	-0.13
210+75	703.97	703.78	0.19	703.42	703.44	-0.02	702.53	702.66	-0.13
PI 207+75	695.35	695.2	0.12	694.8	694.81	-0.01	693.91	694.04	-0.16
205+00	684.32	684.13	0.16	683.77	683.75	0.02	682.88	683.01	-0.16
PC 204+50	681.99	681.78	0.18	681.44	681.48	-0.04	680.55	680.73	-0.21
200+00	658.02	658.06	-0.07	658.43	658.43	0	658.02	658.11	-0.12
195+00	633.64	633.64	-0.03	633.82	633.64	0.18	633.41	633.37	0.01

APPENDIX G. String Line Elevation Survey Results

Station		N/S	Elevation	W.Co Data	Diff.	String to pin	Cut/Fill	Diff.
135	+00	S		797.79		2.13	0.12	2.01
134	+75	S		797.95		2.00	-0.01	2.01
	+50	S	797.88	797.90	-0.02	2.12	0.08	2.04
	+25	S	797.97	798.01	-0.04	2.04	0.01	2.03
	+00	S	798.00	798.03	-0.03	2.04	0.03	2.01
133	+75	S	797.92	797.96	-0.04	2.15	0.14	2.01
	+50	S	797.96	798.00	-0.04	2.15	0.14	2.01
	+25	S	797.99	797.97	0.02	2.25	0.21	2.04
	+00	S	797.93	797.98	-0.05	2.27	0.24	2.03
132	+75	S	798.07	798.09	-0.02	2.18	0.17	2.01
	+50	S	798.03	798.06	-0.03	2.27	0.24	2.03
	+25	S	798.08	798.09	-0.01	2.26	0.25	2.01
	+00	S	798.12	798.13	-0.01	2.27	0.26	2.01
131	+75	S	798.34	798.36	-0.02	2.08	0.07	2.01
	+50	S	798.31	798.34	-0.03	2.14	0.13	2.01
	+25	S	798.24	798.28	-0.04	2.22	0.23	1.99
	+00	S	798.27	798.29	-0.02	2.28	0.27	2.01
130	+75	S	798.41	798.44	-0.03	2.17	0.15	2.02
	+50	S	798.41	798.46	-0.05	2.18	0.17	2.01
	+25	S	798.41	798.45	-0.04	2.23	0.22	2.01
	+00	S	798.41	798.46	-0.05	2.26	0.25	2.01
129	+75	S	*	798.16	*	*	0.59	*
	+50	S	*	798.20	*	*	0.59	*
	+25	S	*	798.27	*	*	0.57	*
	+00	S	*	798.44	*	*	0.44	*
128	+75	S	798.89	798.94	-0.05	2.02	-0.02	2.04
	+50	S	798.91	798.96	-0.05	2.03	0.00	2.03
	+25	S	798.89	798.93	-0.04	2.08	0.07	2.01
	+00	S	798.91	798.97	-0.06	2.11	0.07	2.04
127	+75	S	*	798.70	*	*	0.38	*
	+50	S	*	799.10	*	*	*	*
	+25	S	*	799.02	*	*	0.14	*
	+00	S	*	799.04	*	*	*	*
126	+75	S	*	799.09	*	*	0.15	*
	+50	S	799.22	799.32	-0.10	1.98	-0.03	2.01
	+25	S	799.05	799.15	-0.10	2.19	0.18	2.01
	+00	S	799.20	799.28	-0.08	2.09	0.09	2.00
125	+75	S	798.98	799.26	-0.28	2.35	0.15	2.20
	+50	S	799.28	799.38	-0.10	2.08	0.07	2.01
	+25	S	799.25	799.32	-0.07	2.18	0.17	2.01
	+00	S	799.31	799.39	-0.08	2.14	0.14	2.00
124	+75	S	799.42	799.50	-0.08	2.08	0.07	2.01
	+50	S	799.42	799.51	-0.09	2.11	0.10	2.01
	+25	S	799.48	799.55	-0.07	2.10	0.10	2.00
	+00	S	799.49	799.69	-0.20	2.14	0.00	2.14

Station		N/S	Elevation	W.Co Data	Diff.	String to pin	Cut/Fill	Diff.
123	+75	S	799.53	799.61	-0.08	2.14	0.13	2.01
	+50	S	799.57	799.66	-0.09	2.13	0.12	2.01
	+25	S	799.57	799.66	-0.09	2.16	0.16	2.00
	+00	S	799.65	799.73	-0.08	2.14	0.13	2.01
122	+75	S	799.49	799.57	-0.08	2.34	0.33	2.01
	+50	S	799.49	799.58	-0.09	2.37	0.36	2.01
	+25	S	799.60	799.69	-0.09	2.29	0.29	2.00
	+00	S	799.60	799.69	-0.09	2.35	0.33	2.02
121	+75	S	799.70	799.81	-0.11	2.27	0.25	2.02
	+50	S	799.73	799.84	-0.11	2.26	0.25	2.01
	+25	S	799.93	800.03	-0.10	2.11	0.10	2.01
	+00	S	799.94	800.07	-0.13	2.13	0.10	2.03
120	+75	S	800.02	800.15	-0.13	2.06	0.05	2.01
	+50	S	800.06	800.19	-0.13	2.05	0.05	2.00
	+25	S	800.23	800.35	-0.12	1.93	0.08	1.85
	+00	S	800.19	800.32	-0.13	2.00	-0.01	2.01
119	+75	S	800.09	800.21	-0.12	2.13	0.13	2.00
	+50	S	800.06	800.23	-0.17	2.18	0.15	2.03
	+25	S	800.18	800.32	-0.14	2.09	0.09	2.00
	+00	S	800.22	800.36	-0.14	2.08	0.08	2.00
118	+75	S	800.11	800.23	-0.12	2.24	0.24	2.00
	+50	S	800.07	800.22	-0.15	2.28	0.28	2.00
	+25	S	800.25	800.39	-0.14	2.13	0.14	1.99
	+00	S	800.34	800.50	-0.16	2.05	0.06	1.99
117	+75	S	800.30	800.49	-0.19	2.11	0.10	2.01
	+50	S	800.45	800.57	-0.12	2.03	0.05	1.98
	+25	S	800.48	800.61	-0.13	2.04	0.04	2.00
	+00	S	800.36	800.46	-0.10	2.22	0.22	2.00
116	+75	S	800.22	800.36	-0.14	2.36	0.35	2.01
	+50	S	800.07	800.25	-0.18	2.51	0.48	2.03
	+25	S	*	800.04	*	*	0.72	*
	+00	S	*	800.08	*	*	0.70	*
115	+75	S	*	800.12	*	*	0.69	*
	+50	S	800.33	800.50	-0.17	2.33	0.32	2.01
	+25	S	800.38	800.56	-0.18	2.29	0.30	1.99
	+00	S	800.47	800.65	-0.18	2.23	0.23	2.00
115	+00	N	*	800.98	*	1.91	0.10	1.81
	+25	N	*	800.72	*	2.10	0.14	1.96
	+50	N	800.43	800.58	-0.15	2.27	0.25	2.02
	+75	N	*	800.38	*	*	0.43	*
116	+00	N	*	800.41	*	*	0.37	*
	+25	N	*	800.42	*	*	0.34	*
	+50	N	*	800.19	*	*	*	*
	+75	N	799.95	800.35	-0.40	2.58	0.36	2.22

Station		N/S	Elevation	W.Co Data	Diff.	String to pin	Cut/Fill	Diff.
117	+00	N	800.15	800.28	-0.13	2.36	0.40	1.96
	+25	N	800.08	800.24	-0.16	2.42	0.41	2.01
	+50	N	800.04	800.20	-0.16	2.42	0.42	2.00
	+75	N	800.20	800.35	-0.15	2.25	0.24	2.01
118	+00	N	800.36	800.52	-0.16	2.04	0.04	2.00
	+25	N	800.37	800.54	-0.17	1.99	0.01	1.98
	+50	N	800.30	800.45	-0.15	2.04	0.05	1.99
	+75	N	800.08	800.23	-0.15	2.24	0.24	2.00
119	+00	N	800.18	800.31	-0.13	2.13	0.13	2.00
	+25	N	800.15	800.26	-0.11	2.16	0.15	2.01
	+50	N	800.01	800.14	-0.13	2.25	0.24	2.01
	+75	N	799.98	800.10	-0.12	2.27	0.24	2.03
120	+00	N	800.01	800.12	-0.11	2.20	0.19	2.01
	+25	N	800.00	800.13	-0.13	2.17	0.14	2.03
	+50	N	799.96	800.10	-0.14	2.14	0.14	2.00
	+75	N	800.00	800.14	-0.14	2.07	0.06	2.01
121	+00	N	800.16	800.29	-0.13	1.90	-0.12	2.02
	+25	N	800.19	800.32	-0.13	1.82	-0.19	2.01
	+50	N	800.14	800.25	-0.11	1.85	-0.16	2.01
	+75	N	799.71	799.82	-0.11	2.23	0.24	1.99
122	+00	N	799.87	799.97	-0.10	2.05	0.05	2.00
	+25	N	799.79	799.88	-0.09	2.11	0.10	2.01
	+50	N	799.91	800.00	-0.09	1.91	0.06	1.85
	+75	N	799.79	799.87	-0.08	2.01	*	*
123	+00	N	799.79	799.87	-0.08	1.99	-0.01	2.00
	+25	N	799.74	799.83	-0.09	2.00	-0.01	2.01
	+50	N	799.64	799.72	-0.08	2.07	0.06	2.01
	+75	N	799.63	799.72	-0.09	2.01	0.02	1.99
124	+00	N	799.57	799.68	-0.11	2.01	0.01	2.00
	+25	N	799.52	799.60	-0.08	2.05	0.05	2.00
	+50	N	799.46	799.55	-0.09	2.07	0.06	2.01
	+75	N	799.44	799.51	-0.07	2.07	0.06	2.01
125	+00	N	799.46	799.55	-0.09	1.99	-0.02	2.01
	+25	N	799.50	799.56	-0.06	1.91	-0.07	1.98
	+50	N	799.43	799.51	-0.08	1.94	-0.06	2.00
	+75	N	799.26	799.36	-0.10	2.06	0.05	2.01
126	+00	N	799.02	799.23	-0.21	2.25	0.14	2.11
	+25	N	799.21	799.28	-0.07	2.05	0.05	2.00
	+50	N	799.08	799.14	-0.06	2.15	0.15	2.00
	+75	N	799.08	799.15	-0.07	2.11	0.09	2.02
127	+00	N	798.83	798.90	-0.07	2.31	0.30	2.01
	+25	N	798.73	798.82	-0.09	2.38	0.34	2.04
	+50	N	798.64	798.80	-0.16	2.46	0.32	2.14
	+75	N	798.82	798.87	-0.05	2.22	0.21	2.01

Station		N/S	Elevation	W.Co Data	Diff.	String to pin	Cut/Fill	Diff.
128	+00	N	798.76	798.81	-0.05	2.24	0.23	2.01
	+25	N	798.71	798.77	-0.06	2.20	0.23	1.97
	+50	N	798.61	798.66	-0.05	2.28	0.30	1.98
	+75	N	798.55	798.58	-0.03	2.34	*	*
129	+00	N	*	798.30	*	*	*	*
	+25	N	*	798.24	*	*	*	*
	+50	N	*	798.19	*	*	0.06	*
	+75	N	*	798.27	*	*	0.45	*
130	+00	N	798.34	798.40	-0.06	2.31	0.31	2.00
	+25	N	798.37	798.40	-0.03	2.27	0.27	2.00
	+50	N	798.27	798.31	-0.04	2.34	0.32	2.02
	+75	N	798.16	798.19	-0.03	2.41	0.40	2.01
131	+00	N	798.20	798.23	-0.03	2.33	0.32	2.01
	+25	N	798.29	798.32	-0.03	2.20	0.19	2.01
	+50	N	798.21	798.24	-0.03	2.23	0.23	2.00
	+75	N	798.19	798.23	-0.04	2.19	0.20	1.99
132	+00	N	798.25	798.28	-0.03	2.10	0.11	1.99
	+25	N	798.17	798.20	-0.03	2.13	0.14	1.99
	+50	N	798.03	798.06	-0.03	2.24	0.24	2.00
	+75	N	798.08	798.11	-0.03	2.14	0.15	1.99
133	+00	N	797.96	797.99	-0.03	2.23	0.23	2.00
	+25	N	797.98	797.97	0.01	2.22	0.21	2.01
	+50	N	797.87	797.91	-0.04	2.23	0.23	2.00
	+75	N	797.80	797.85	-0.05	2.25	0.25	2.00
134	+00	N	797.85	797.89	-0.04	2.18	0.17	2.01
	+25	N	797.81	797.85	-0.04	2.17	0.17	2.00
	+50	N	*	797.91	*	2.07	0.07	2.00
	+75	N	*	797.78	*	2.17	0.16	2.01
135	+00	N	*	797.79	*	2.13	0.12	2.01