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INFRASTRUCTURE MANAGEMENT AND ENGINEERING

INVESTIGATE FEASIBILITY OF USING GROUND PENETRATING RADAR IN QC/QA OF RUBBLIZATION PROJECTS

FINAL REPORT

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State Job No. 134431
July 2011

Prepared in cooperation with
The Ohio Department of Transportation and
The U.S. Department of Transportation Federal Highway Administration

1. Report No. **FHWA/OH-2010/15**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and subtitle **Investigate Feasibility Of Using Ground Penetrating Radar In QC/QA of Rubblization Projects**		5. Report Date **July 2011** 6. Performing Organization Code
7. Author(s) **Dr. Arudi Rajagopal**		8. Performing Organization Report No. 10. Work Unit No. (TRAIS)
9. Performing Organization Name and Address **Infrastructure Management & Engineering, Inc.** **2300 East Kemper Road, Suite A-17** **Cincinnati OH 45241-6501**		11. Contract or Grant No. **134431** 13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address **Ohio Department of Transportation, 1980, West Broad Street** **Columbus, OH 43223**		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract:

This study investigated if Ground Penetrating Radar can offer a suitable technology for mapping the physical condition of fractured slab rapidly, particularly under the steel reinforcement, without disturbing the fractured layer. A 4000' long composite pavement section was selected on BUT/WAR 75 in Ohio. The asphalt concrete layer was milled and the jointed reinforce concrete pavement was exposed. A thorough GPR assessment of the pavement prior to rubblization was performed, allowing a "baseline" condition assessment. Three passes were made to collect data along two wheel paths and the center of the lane. Following this, the exposed concrete pavement was rubblized in accordance with ODOT's rubblization specification using a resonant type pavement breaker and three multi head type pavement breakers. GPR tests were conducted on the rubblized layer at the same locations. Soon after completing GPR studies, several test pits were made using a backhoe. Physical measurements of the particle sizes were made through the depth of concrete pavement. This information, *ground truth*, was used to verify the information obtained from GPR signals. The data was analyzed to investigate any evidence leading to determination of fragments exceeding the size specification.

Analysis of the data collected on the exposed concrete pavement, prior to rubblization, showed no significant peak in reflection of signals between the top and bottom of the slab. Analysis of the data on rubblized layer showed some peaks. However, the strength of the signals (reflections) was not strong enough to detect significant peaks. This analysis revealed the sensitivity of the data was not adequate enough to distinguish two layers within the concrete slab. In other words, the data did not indicate significant peak at the interface of rubblized and partially rubblized layers within the concrete slab. It became apparent that by increasing the signal-to-noise ratio, it may become possible to differentiate and distinguish the two internal layers.

In summary, the study provided insight into additional data needed to establish GPR as a potential device in the future for evaluating the size fragments in R/R project. Lessons learned lead to a conclusion that, further work is needed to establish GPR as a rational, non-destructive and quick procedure to estimate the particle sizes in a rubblization project.

17. Key Words Ground Penetrating Radar, Reflection Cracking, Break and Seat, Rubblization, Pavement Breaker, Fractured Slab Technique, Pavement Performance		18. Distribution Statement **No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161**	
19. Security Classif. (of this report) **Unclassified**	20. Security Classif. (of this page) **Unclassified**	21. No. of Pages **59**	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed pages authorized**

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ACKNOWLEDGMENTS

The investigators wish to convey their appreciation to Mr. Roger Green, Mr. Aric Morse, Mr. Adam Au, Mr. David Humphrey and Ms. Julia Miller of the Ohio Department of Transportation for their help throughout the life of this project. Thanks are also due to Mr. Dwayne McKinney of ODOT for his assistance in collecting deflection data. The cooperation extended by the Office of research and development is duly acknowledged. The following agencies participated in this study:

- Flexible pavements of Ohio, Columbus, Ohio
- Resonant Machines Inc, Kansas City, Missouri
- Antigo Construction Inc., Antigo, Wisconsin
- Specialties Company LLC, Indianapolis, Indiana
- Wagway Tool Company, Indiana
- The Jurgensen Companies, Cincinnati, Ohio

Special thanks are due to the District Eight personnel for their cooperation during demonstration project. Dr. C. Keshav’s assistance in data processing is highly appreciated.

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1.1 Rubblization of Concrete Pavements

Rubblization and Rolling (R/R) of concrete pavements before placing an asphalt concrete overlay (AC) is a pre-overlay treatment applied by Ohio and many other state departments of transportation in their pursuit to control reflection cracking of composite pavements. The procedure is deemed to assist not only in mitigation of reflection cracking but also in increasing the overall performance and service life of AC overlays. A few state agencies have reported that AC overlay on rubblized and rolled (R/R) concrete pavement outperformed other traditional rehabilitation techniques [1, 2, 3]. As a result, the practice of rubblizing and rolling concrete pavements prior to construction of AC overlays is becoming a widely accepted major rehabilitation technique in many states.

Figures 1 through 3 illustrate the general steps followed in a rubblization project. To begin with, the concrete pavement is exposed by milling the AC layer, if any. The concrete pavement is then rubblized using a pavement breaker. Figure2 shows two types of breakers used for this purpose. The rubblized layer is then rolled using a Z-roller and the surface is covered by an AC overlay within 24 hours.

Figure 1. Asphalt Concrete Layer Milled to Expose Concrete Pavement Prior to Rubblization

Figure 2.Rubblization using Resonant Machine and Multi Head Breaker

Figure 3. Rolling with a Vibratory Steel Roller

1.2 ODOT's Use of Rubblization

The Ohio Department of Transportation (ODOT) constructed its first rubblization project in 1988 on LIC/MUS-70. Since then, as evident from Figure 4, ODOT has consistently used this treatment on many of its rehabilitation projects. Between 1988 and 2002, nearly 2.0 million square yards of concrete pavements have been rubblized. It is expected that during the next five years, approximately 200 additional miles of concrete/composite pavements become candidate for rehabilitation in Ohio [4]. Needless to say, continued application of rubblization treatment will mandate a careful scrutiny of associated factors.

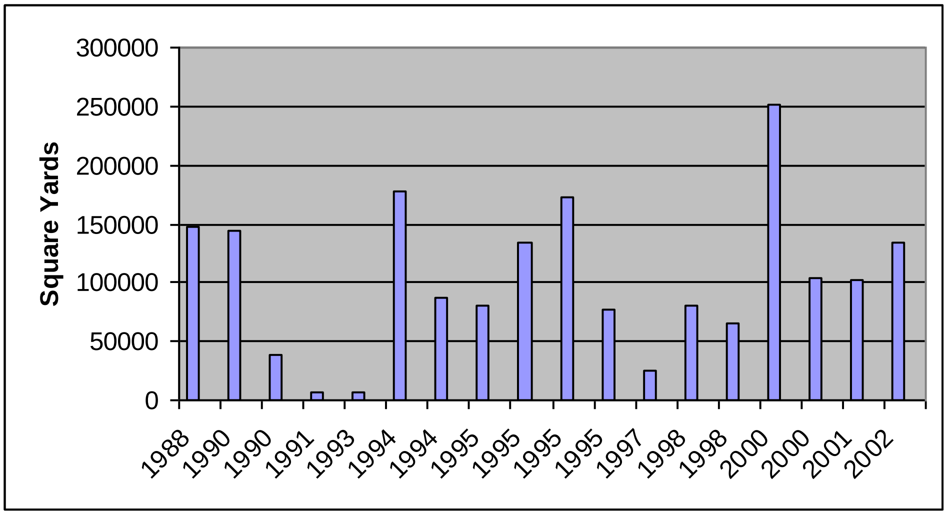

Figure 4. Time History of ODOT's Rubblization Projects

1.3 Rubblization Practices in Other States

Currently, more than half of the states have implemented specifications for rubblization. Key states that have constructed a significant number of rubblization projects include Arkansas, Alabama, Illinois, Iowa, Kansas, Louisiana, Nevada, New Jersey, New York, Ohio, Oregon, Pennsylvania, South Carolina, West Virginia, and Wisconsin. The performance of many of the ongoing or completed projects in these states has been documented in research reports. For example, the reports based on studies in Illinois by Heckel [2], Nevada by Bemanian [5], and Indiana by Galal [6] adequately describe the number of projects investigated, project-to-project variations, type(s) of pavement breakers used, type and thickness of asphalt overlays, performance monitoring procedures, and the state's overall experience in designing, constructing and monitoring rubblization projects.

1.4 ODOT's Rubblization Specification

On ODOT projects, rubblization is accomplished using a self-contained and self-propelled unit of either the resonant frequency type or multiple head breaker type of pavement breakers, as outlined in the Construction Manual Specifications Item 320 [7]. With either type of breaker, ODOT specification requires the existing pavement is reduced into particles ranging from sand sized pieces to pieces not exceeding 6 inches in their largest dimension, the majority being a nominal 1 to 2 inches in size. Rolling is to be accomplished using a vibratory steel roller with a total weight of not less than 10 tons (9 metric tons).

1.5 Perceived Consequences of not Meeting the Size Specification

Transverse joints are constructed in concrete pavements to regulate the location of the cracking due to thermal movements. When the slabs experience temperature changes, they undergo expansion and contraction, resulting in horizontal movements at the joints. Depending on the direction of horizontal movement, the joints will either converge or diverge. In either case, such movements exert stresses on the AC overlay initiating a crack right above the joint. Experience suggests that cracking is more pronounced due to the opening of joints during cold temperatures, when the asphalt is more stiff and brittle.

Using the basic principles of physics it can be proved the extent of thermal movements is directly proportional to the original length of the concrete slabs. The primary intent of rubblization is to reduce the effective length of concrete slabs and debond the steel from the concrete to either eliminate the horizontal movements or minimize the movements to an extent they no longer exert undue tensile stresses in the AC layer.

But the question is, '*what is the optimum size of the concrete slabs to minimize horizontal movements?*' Based on the experience gathered from field experiments of fractured slab techniques such as *crack and seat* and *break and seat* in Ohio [8], coupled with a review of R/R specifications in other states, Michigan in particular, ODOT has established the specification for R/R wherein the maximum particle size is limited to 6 inches [7]. A concurrent study [9] is investigating the potential of increasing the maximum size to 12 inches.

The rubblization specifications are developed to ensure the procedure will obliterate slab action. In the event of not meeting the size specification, it is inferred that concrete slabs would still retain a part of slab action and thereby contribute to horizontal movements at some point of time during the performance. Such movements adversely affect the overall performance of constructed pavements causing premature deterioration. Compliance with the size specifications required by the DOTs is an important requirement to build well-performing, economical and long-lasting pavements.

1.6 Quality Control and Quality Assurance Issues

Quality control relates to any activity that examines products to determine if they meet their specifications. Quality assurance includes any activity that focuses on ensuring the needed levels of quality are achieved. In essence, if QC is about *detecting* defects, the QA is about *avoiding* them.

A thorough QC/QA process is critical to the successful completion of R/R program. To ensure the extent of breaking meets desired size specification, ODOT requires a test pit at the beginning of the project to check for proper particle size throughout the thickness of the concrete. The test pits are approximately 3ft x 3ft. If the engineer has verified and confirmed the specification requirements, the digging of test pits is not usually continued throughout the project. Instead, the field personnel rely on visual observation of fracturing pattern obtained on the top surface and assume a similar pattern through the depth of concrete.

Currently, the only available test procedure is to visually verify the extent of fracturing through the test pits. Any QC/QA program requires the tests are conducted at regular intervals to ensure desired quality is being met. For instance, a QC/QA program for the construction of an asphalt concrete overlay requires a series of tests for each day's production. In comparison, for rubblization, only one test is performed for the entire project spanning several days. Additional pits are rarely made.

The primary objective of making test pits is to determine the energy required for pavement fracturing. The energy depends on many site-specific conditions namely, soil type and condition, age and condition of concrete slabs and joints. Once these conditions change, the required energy will also change. It has been generally observed that particles on the surface conform to the specifications, while the particles particularly below the reinforcing steel may fall out of specifications. This fact can be illustrated from a demonstration project in Ohio. As shown in Figure 5, the surface appearance suggested the desired particles were indeed obtained. However, once the test pits were opened, it was immediately obvious that a significant amount of large, uncracked pieces were being produced (Figure 6). This illustration emphasizes the need to examine the distribution of particle sizes through the depth of concrete slab at regular intervals.

Figure 5. Particle Size Observed on the Surface of Rubblized Layer

Figure 6. Large Uncracked Pieces at the Bottom of Concrete Pavement

The test pits, although serve the purpose, are destructive tests, time consuming, and costly. If an alternative procedure can be developed to monitor the fracturing results with reduced effort, perhaps on real-time, appropriate actions can be initiated which will resolve the aforesaid concerns. This study investigated a new idea that utilizes Ground Penetrating Radar (GPR) device to monitor the fracturing process. The intent of the study was to determine if GPR will provide a rational, rapid, non-destructive technology to map the physical condition of broken fragments through the depth of concrete slabs.

2. GPR – PRINCIPLES AND APPLICATIONS

Ground-penetrating radar (GPR) is a geophysical method that uses radar pulses to image the subsurface. This non-destructive method uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum, and detects the reflected signals from subsurface structures [10]. Figure 7 illustrates the fundamental principles of GPR technology.

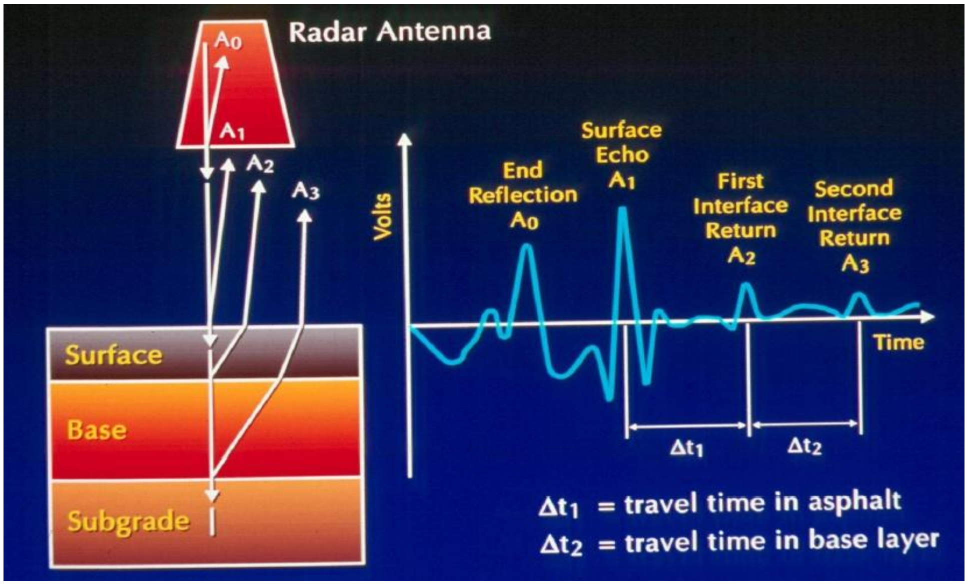

Figure 7. Fundamental Principles of GPR Technology [11]

GPR is a high resolution electromagnetic technique. Electromagnetic waves travel at a specific velocity that is determined primarily by the permittivity of the material. The relationship between the velocity of the wave and material properties is the fundamental basis for using GPR to investigate the subsurface [12].

The GPR system primarily consists of three main components namely [13]:

1. Control unit
2. Antenna
3. Power supply

The control unit consists of electronic components to generate and transmit the pulse of radar energy. The antenna receives the radar pulses produced by the control unit, amplifies it and transmits it into the ground. Basically there are two classes of antenna: a) *ground-coupled* and b) *air-coupled*(also called *horn* antenna). The ground-coupled antennas operate in a wide range of central frequencies from 16MHz to 1500MHz with a depth penetration up to 90ft. Air-launched antenna on the other hand operates at a higher frequency ranging from 500MHz to 2500MHz. However, the depthpenetration of air-launched antenna is limited to about 3ft [13, 14]. Figure 8 and 9 show the two types of antenna. With air-launched antenna, data can be collected at 50mph which makes it suitable for scanning large areas without the need for traffic control.

Figure 8. Ground-Coupled Antenna

Figure 9. Air-Launched Antenna

GPR uses high-frequency (usually polarized) radio waves and transmits into the ground. When the wave hits a buried object or a boundary with different dielectric constants, the receiving antenna records variations in the reflected return signal. Dielectric constant is a number relating the ability of a material to carry alternating current to the ability of vacuum to carry alternating current. The waves reflected at significant layer interfaces are captured and displayed as a plot of return voltage versus time. Computer programs are used to process the signals to map subsurface information.

General applications of GPR include locating buried voids/cavities, underground storage tanks, sewers, foundations, ancient landfills, pipelines and cables. It can also be used to characterize bedrock, ice, the internal structure of floors/walls, pavement (concrete and asphalt) thickness evaluation, air void detection surveys, concrete deterioration surveys, internal steelwork in concrete and rebar corrosion surveys [10]. Thickness values determined by GPR have been used in conjunction with Falling Weight Deflectometer (FWD) surveys to refine the in-situ modulus values.

3. PRESENT STUDY - OBJECTIVES

The specific objectives of this study are as below:

- Document GPR technology
- Review QC/QA of rubblization in other states
- Conduct field experiment with GPR to investigate its feasibility for QC/QA
- Compare GPR data with visual observation from test pits
- Conduct deflection studies using Falling Weight Deflectometer to determine if the load distribution characteristics can be related to particle size distribution

- Construct physical models in the laboratory to validate field data
- Generate information to determine the potential of GPR for quality assessment of rubblization projects

It should be recognized that this is a feasibility study with intent to investigate if the proposed technology has the potential to develop into a formidable system.

4. BACKGROUND AND SIGNIFICANCE

In the last ten years, several studies have been carried out to investigate the feasibility and benefits of the GPR device for evaluation of pavements. A report published by Infrasense [15] in 2006 for the South Dakota Department of Transportation comprehensively describes the intended uses, extent of use, range of applications and perceived benefits. As noted in the report, the reported advantages of GPR are a) the ability to scan large areas quickly, b) the ability to minimize coring and traffic control, c) the detection of conditions not detectable by other means, and d) the discovery of unknown subsurface conditions prior to construction. The most common applications of interest to pavement engineers include the determination of pavement thickness, variations in subgrade moisture, and deterioration in concrete pavements. Accurate determination of pavement thickness and subgrade moisture can also aid in enhancing pavement layer backcalculation procedures. The report cites most of the publications to-date. Based on extensive study on 22 projects, the Minnesota DOT [16] reaffirms the potential of GPR in the above applications. A workshop organized by GPRI [17], a user group, in 2008 in Florida was represented by industry, academic and research organizations. The presentations and the group discussions highlighted the advancement, latest applications, and potential of the GPR technology in the future. Interestingly, a study by the Texas Transportation Institute [18] found it useful to determine the pavement thickness, non-uniformity of existing construction and areas with excessively wet subgrade of rubblization projects in Texas. However, no reference was made by any of the aforementioned reports regarding the use of GPR in quality control of rubblization projects.

From the review of the past and ongoing studies it became apparent that either the previous investigators have not attempted to use GPR to determine the quality of rubblization or they found this technology not applicable. The latter fact was corroborated by extensive discussions with equipment manufacturers and consultants who use GPR on a routine basis.

5. OVERVIEW OF THE EXPERIMENT

An experiment was set up to systematically investigate the applicability of GPR to evaluate the quality of rubblization, in line with the objectives of the study. The tasks performed are as below:

1. Organize a project evaluation team
2. Select a test site for rubblization
3. Rubblize the concrete pavement
4. Conduct field evaluation before and after rubblization
5. Construct physical models in the laboratory
6. Compile and analyze data

The project evaluation team comprised of engineers representing ODOT’s Office of Pavement Engineering, Office of Construction Administration and District Pavement Engineers. The Flexible Pavements Association of Ohio represented the construction industry. The ensuing sections describe the details of the field and laboratory evaluations and discussion of the results.

6. TEST SECTION

A major rehabilitation project was underway on I-75 in Butler/Warren County. A considerable length of composite pavement on the project was scheduled for reconstruction. The prime contractor, Jergensen Company, had commissioned a multi head breaker for removal and replacement. This site was selected for a concurrent study to develop a 1-day demonstration of various pavement breakers to rubblize the concrete pavement in conformity with ODOT specification [7]. Among other tasks, it was decided to evaluate the quality of rubblization using a GPR.

The general location of the project is shown is Figure 10. From the available project, a 4000ft long stretch in the south bound driving lane between station 95 and 135 which was scheduled for removal and replacement was selected for a demonstration of rubblization equipment. The existing pavement consisted of 6inches thick AC on the top of 9inches JRCP with joints spaced at 60ft intervals. The test section was uniform throughout the length with respect to pavement condition, composition, and geometry. Subgrade soil was A-6b type and remained uniform throughout. The condition of in-service and exposed concrete pavement selected is shown in Figures 11 and 12.

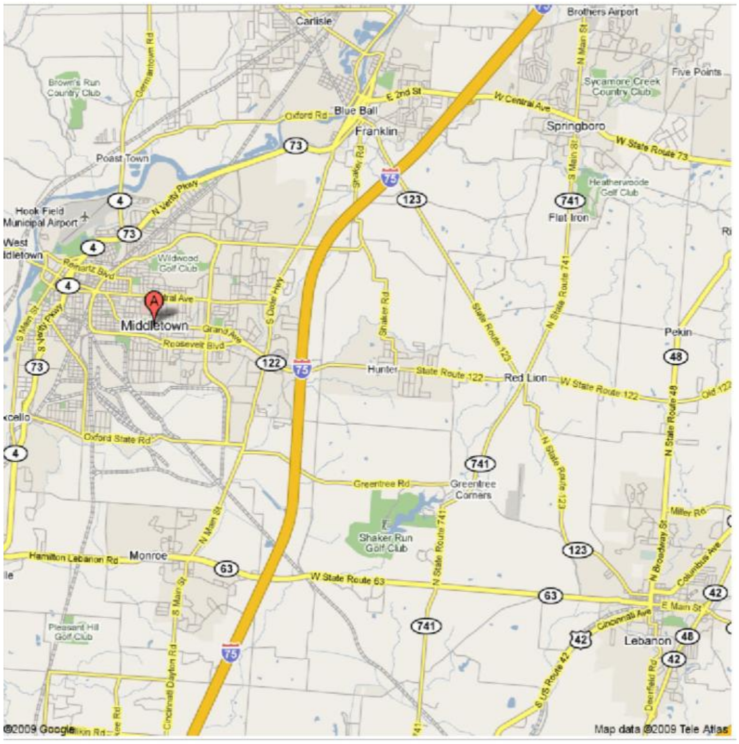

Figure 10.Rubblization Project on I-75 South Bound, between SR 63 and SR 122

Figure 11. General Condition of Project – In-service Composite Pavement, Prior to Milling

Figure 12. Exposed Concrete Pavement After Milling the AC Layer

7. FIELD STUDIES

On the exposed concrete layer, a visual condition survey was conducted to record the general condition of the test pavement, location and condition of joints, the extent of cracking and patching. A complete photographic record of test pavement was made. Following this, ODOT collected deflection data using a Falling Weight Deflectometer. The visual survey, deflection data and the construction drawings demonstrated that pavement is uniform and its condition is homogeneous throughout the test section. The raw FWD data collected at this section is included in Appendix A.

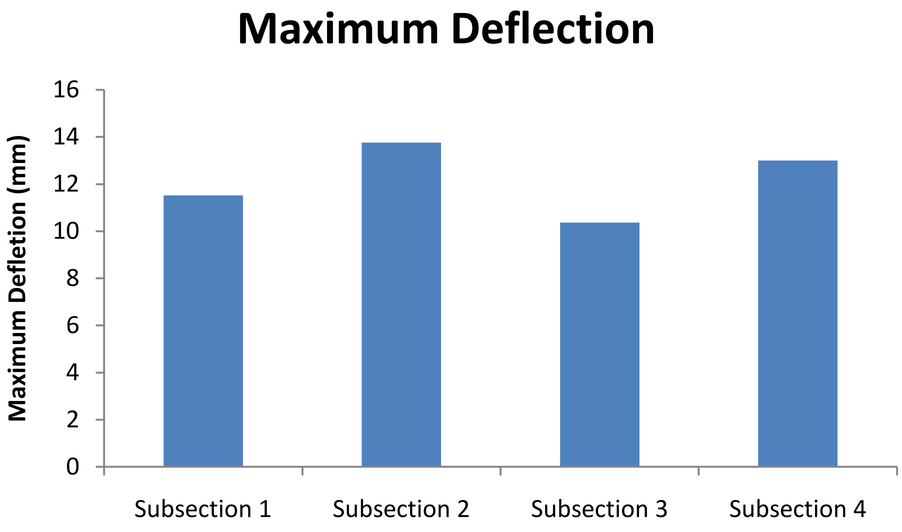

Figure 13. Variation in Maximum Deflection

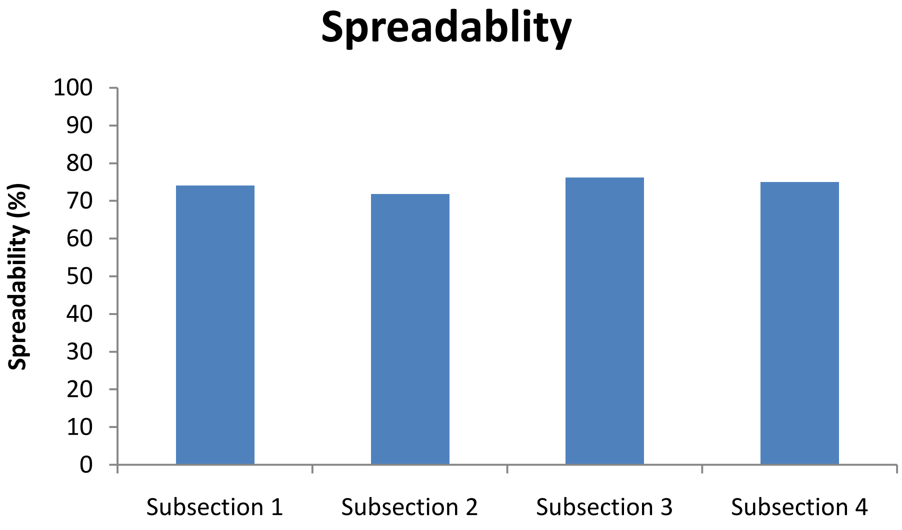

Figure 14. Variation in Spreadability

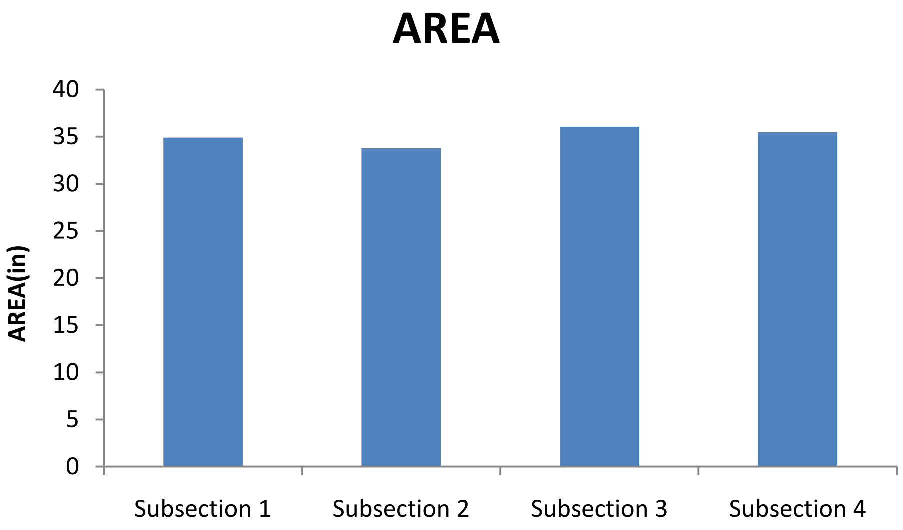

Figure 15. Variation in AREA

GPR was used to determine whether it can offer a suitable technology for mapping the physical condition of fractured slab rapidly, without disturbing the fractured layer. A GSSI Roadscan 2F system horn antenna with central frequency of 2GHz along with the SIR-20 data acquisition and control system was used for data collection. Figure 16 and 17 show the GPR system in operation.

Figure 16. GPR Device in Operation on R/R Project

Figure 17. Control Unit, Data Acquisition System and GPS Receiver

A thorough GPR assessment of the pavement prior to rubblization was performed, allowing a “baseline” condition assessment. Three passes were made to collect data along two wheel paths and the center of the lane. Data was collected using program default settings such as one scan per feet and 512 samples per scan. Figure 18 and 19 illustrate sample data collection screen and data processing screen.

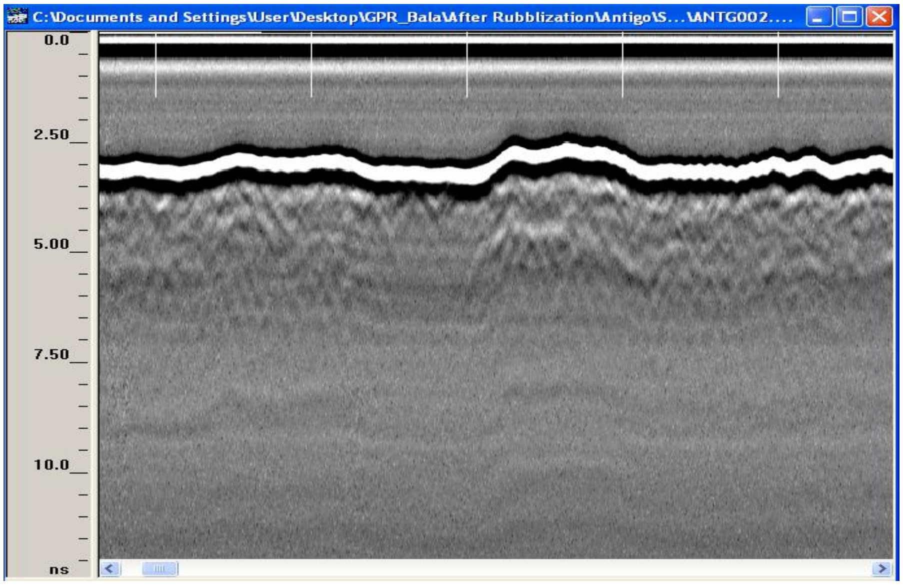

Figure 18. GPR Data Acquisition Interface

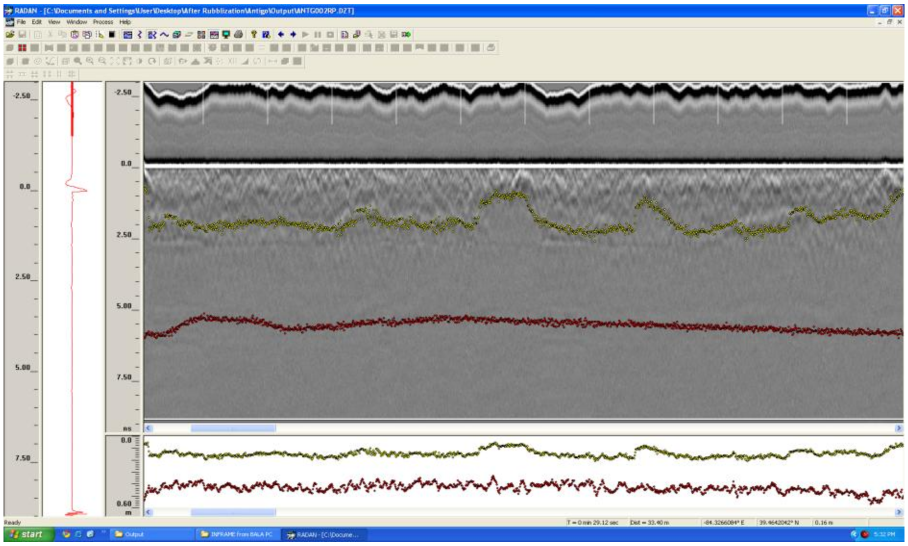

Figure 19. GPR Data Processing to Derive Number of Significant Layers and Their Thickness

Data acquisition and processing was made using RADAN software [13]. This analysis provided information about the thickness of concrete and base layers through the project, and the location of steel reinforcements and dowel rods. This is the routine type of information which the users of GPR deduce from the field data. Following this, the exposed concrete pavement was rubblized and rolled in accordance with ODOT's R/R specification. Figure 20 and 21 show typical distributions of particle size on the surface at two locations.

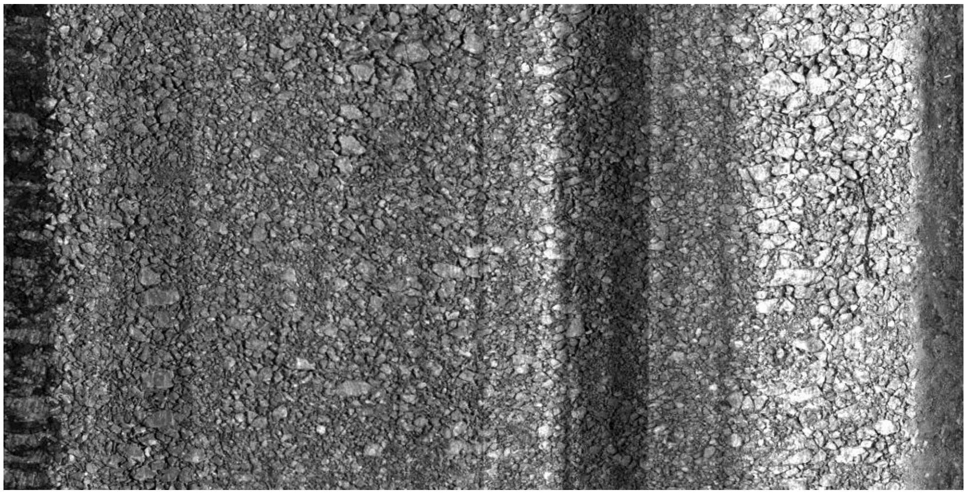

Figure 20. Particle Size Distribution Observed on the Surface after Rubblizing

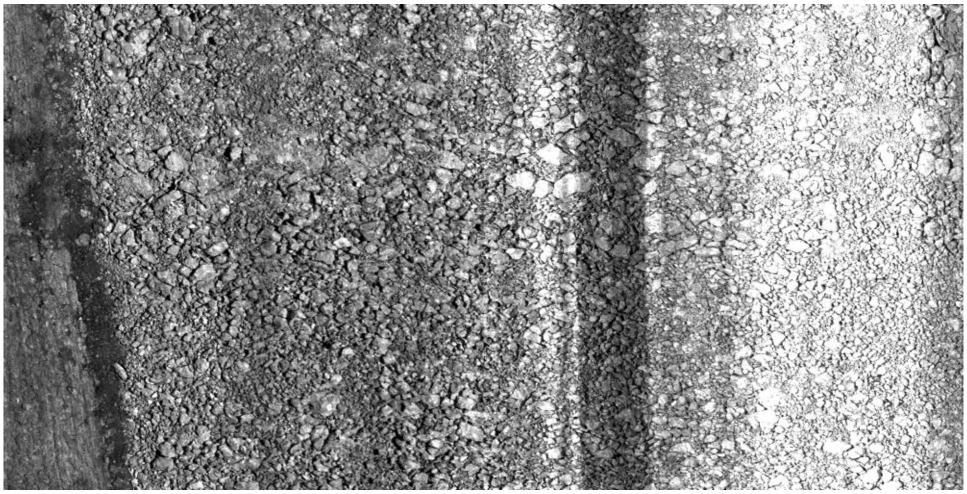

Figure 21. Particle Size Distribution Observed on the Surface after Rubblizing

GPR tests were conducted on the R/R layer at the same locations corresponding to the intact concrete pavement prior to rubblization. A lot of thought process went into the data collection efforts on the rubblized layer. To understand this, consider an intact slab as illustrated in Figure 22.

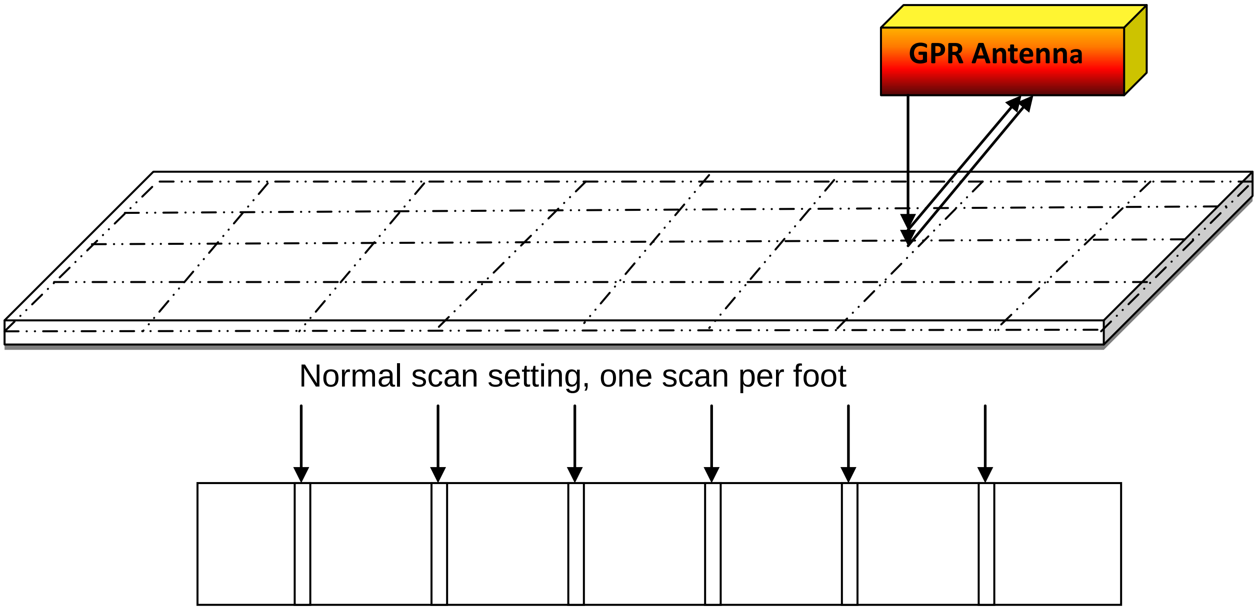

Figure 22. Scan Settings for an Intact Slab

This slab can be considered nearly identical in its thickness and material properties. The intent of GPR data in such case is to acquire data related to thickness of pavement and location of reinforcement. Data collection at 1ft intervals should provide the necessary amount of data to glean such information.

The rubblization process will create a material with significant cracks, voids and discontinuities. These changes can disperse and/or scatter GPR energy and make it more difficult to image coherent subsurface reflections from material boundaries within, or immediately beneath. However, there is a possibility that enough GPR energy may return to the receiving antenna and allow an assessment of the "quality" of the rubblization process to be made by observing and comparing GPR data obtained before and after the rubblization process and characterizing "internal" GPR reflections, within the known time domain of the signal response from undamaged pavement, as well as reflections from the bottom of the pavement. Here the quality of rubblization is defined by the size of particles in relation to the maximum allowable particle size in the specification. By identifying the changes – and isolating them from the multiple reflections expected to be generated as a result of the fracturing of the pavement – it may be possible that a correct identification of the critical signal elements which can be correlated to physical data within the rubblized pavement be made. The GPR signal may include enough "key indicators" within the signal profile that allow partially-rubblized pavement to be distinguished from fully-rubblized pavement, and also offer some ability to assess (even qualitatively) the degree of rubblization that has been achieved.

Degree of rubblization can be quantified by expressing the percentage of particles larger than specified. To do this, it becomes necessary to at least approximately assess the size of the particles and compare with the maximum permissible size. Initially, the data was collected at 1ft intervals as was done on the intact pavement. But scanning the pavement at 1ft intervals may not allow mapping of particles less than 1ft as conceptualized in Figure 23. Hence it was decided to increase the density of data acquisition by changing the scan settings to 12 scans per feet (one scan every inch). Owing to increased number of scans, the speed of data acquisition was reduced to around 5mph. Figure 24 shows the revised scan settings to acquire additional data.

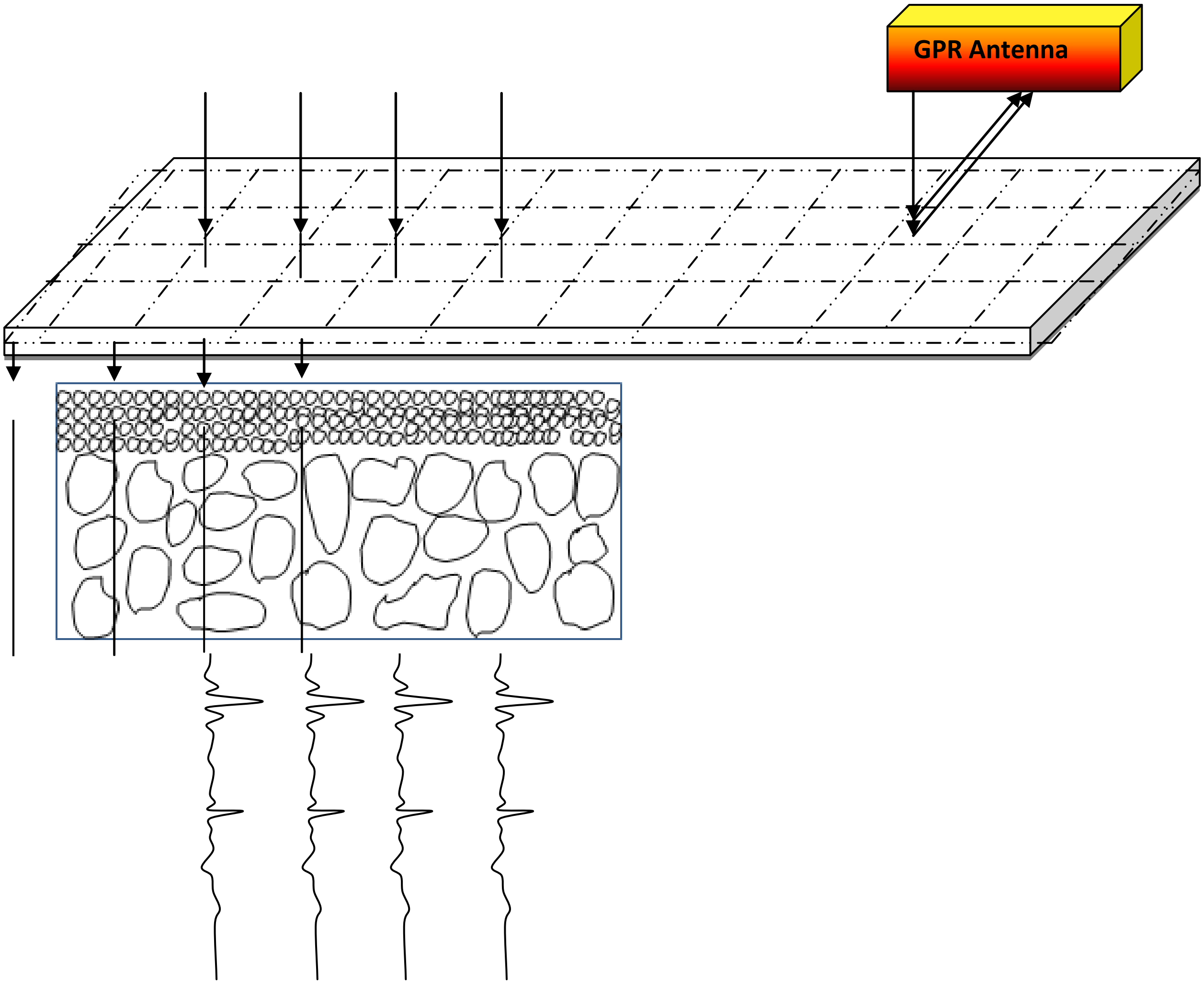

Figure 23. Illustration Showing the Need to Increase Scan Density

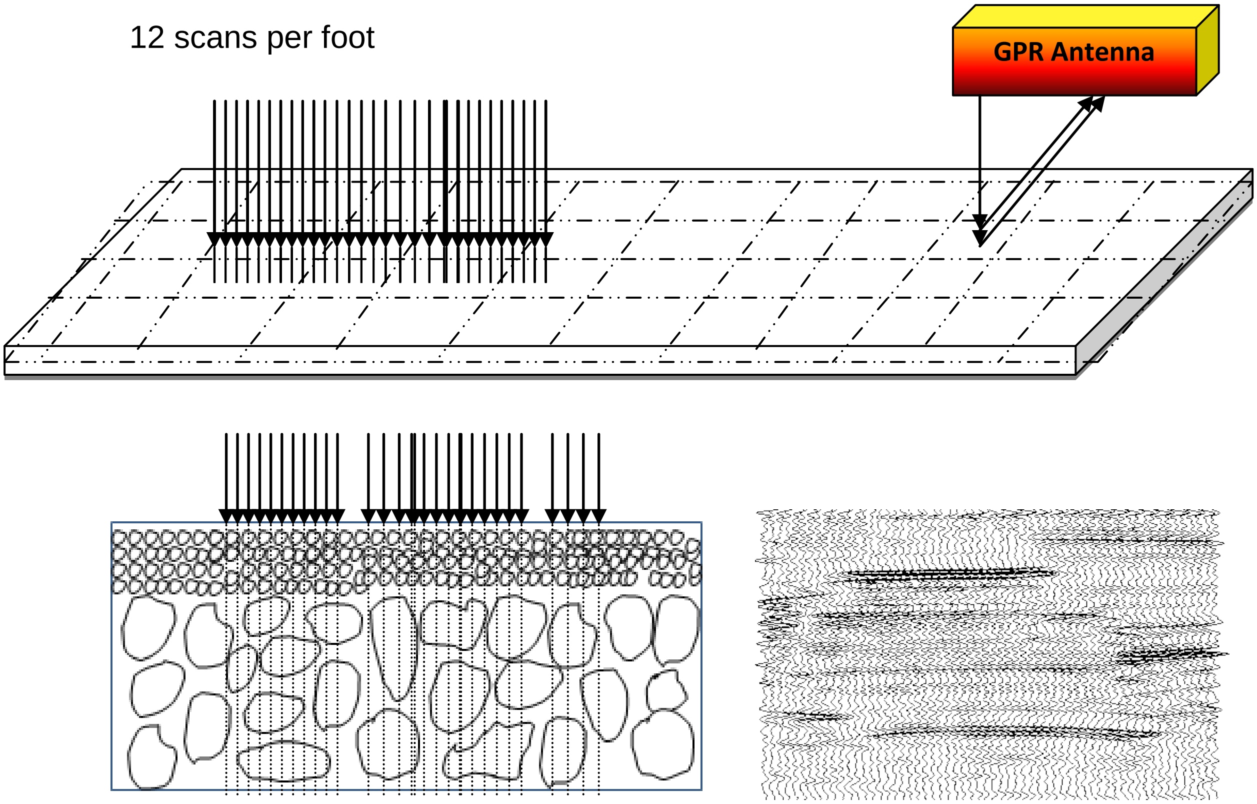

Figure 24. Data Acquisition with increased Scan Settings

Soon after completing GPR studies, several test pits were made using a backhoe. Physical measurements of the particle sizes were made throughout the depth of concrete using a measuring tape. This information, *ground truth*, was used to verify and validate the information obtained from GPR signals. Figure 25 and 26 show typical test pit along the test section.

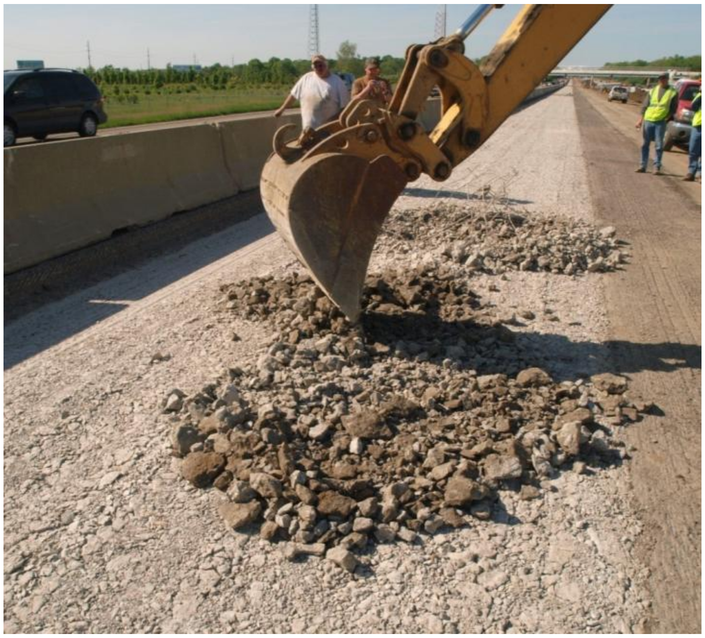

Figure 25. Making a Test Pit to Expose the Material through the Depth

Figure 26. Observed Particle Sizes at the Bottom on Concrete Slab in a Test Pit

8. ANALYSIS

The purpose of GPR is to transmit electromagnetic waves of known frequency into the pavement and record their time of return. The transmitted waves travel through the depth of pavement through each layer. Every time, there is a significant change in the layer (material) types, part of the waves bounce back (reflect) and part travel through or get scattered (lost energy). The reflected waves are captured by the receiver. The strength of the reflected waves and their time of travel through a medium is analyzed using signal processing algorithms which lead to an assessment of the nature and thickness of each material. The GPR device generates data in the form of time vs. signal amplitude. At the transition between the successive layers, the amplitude of the reflected signal results in a peak. The time difference between the successive peaks is translated into thickness of each layer.

Rubblization essentially transforms the homogeneous concrete layer into two distinct layers – one above the steel with particles sizes smaller than 3inches, and the lower layer with particle sizes significantly larger than 3inches. The rubblized layers above and below the reinforcing steel aretermed as *fully rubblized* and *partially rubblized* layers respectively in this report. Even though the two layers are made up of the same material, the effective dielectric constant may be different because of the variation in the air gap. As a result, it can be hypothesized that signal path through the partial layers may not remain the same and should result in a peak at the interface of two layers.

The data obtained in the present study was analyzed to verify the above hypothesis. First the data collected on the intact slab was analyzed. The intact slab being nearly homogeneous, no significant peak in reflection of signals was found between the top and bottom of the slab. Analysis of the data on rubblized layer showed some peaks.

However, the strength of the signals (reflections) was not strong enough to detect significant peaks. This analysis revealed the sensitivity of the data was not adequate enough to distinguish two layers within the concrete slab. In other words, the data did not indicate significant peak at the interface of rubblized and partially rubblized layers within the concrete slab. The peaks at the interface may still exist but may be so small that it is not being detected. This observation is illustrated in Figures 27 and 28.

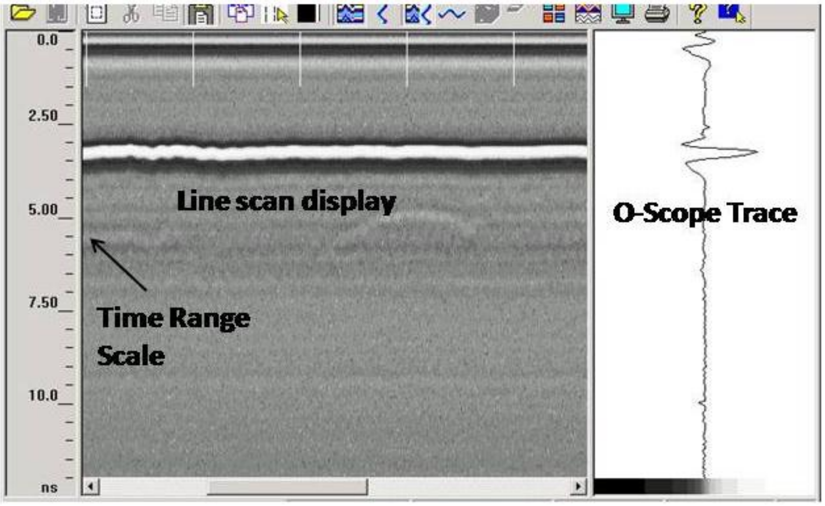

Figure 27. An Example of Line Scan Display on the Exposed Concrete Pavement Before Rubblization

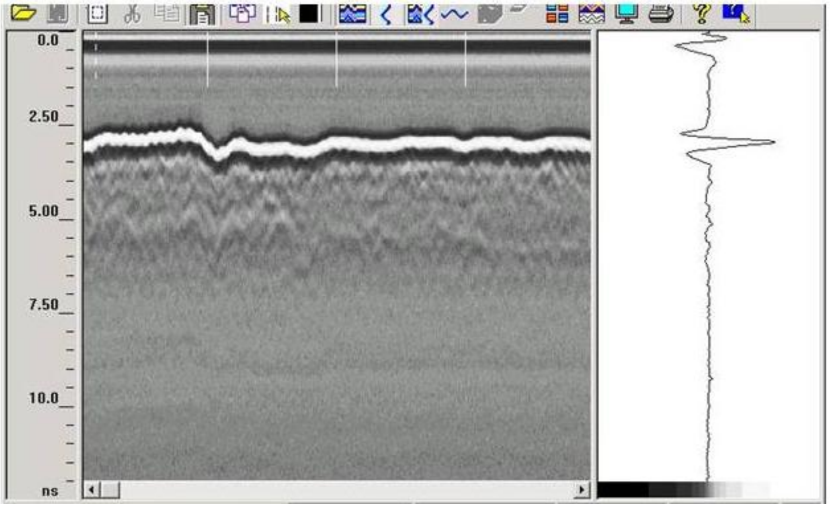

Figure 28. An Example of Line Scan Display After Rubblization

Perhaps, detection of small peaks can be done by: (i) increasing the sensitivity of measurements, and (ii) improving the Signal-to-Noise Ratio (SNR). Increasing the sensitivity and preprocessing the small peaks can be accomplished by using noise reduction techniques. For typical GPR measurements made in the present study, SNR is in the range of 5 – 18dB. The edge detection algorithms used today, such as gradient filtering, Soble/Prewitt operators, Gaussian smoothing and Matched filters, require a high SNR, in 20-30dB range. The GPR signals from R/R projects require higher SNR to be useful in detecting and grading presence of targets.

When SNR of raw measurement data is 20dB or greater, edge detection can be significantly enhanced by pre-processing of measurement signals and removing the noise component. One of many techniques that can be applied is ‘Spectral Subtraction’. An estimate of noise power N is made from known segments of measurement area, where targets are not present and this estimate is subtracted from the composite (S+N) power, as shown in Figure 29. The output signal $S^{\sim}(n)$ is then used as input to an edge detector.

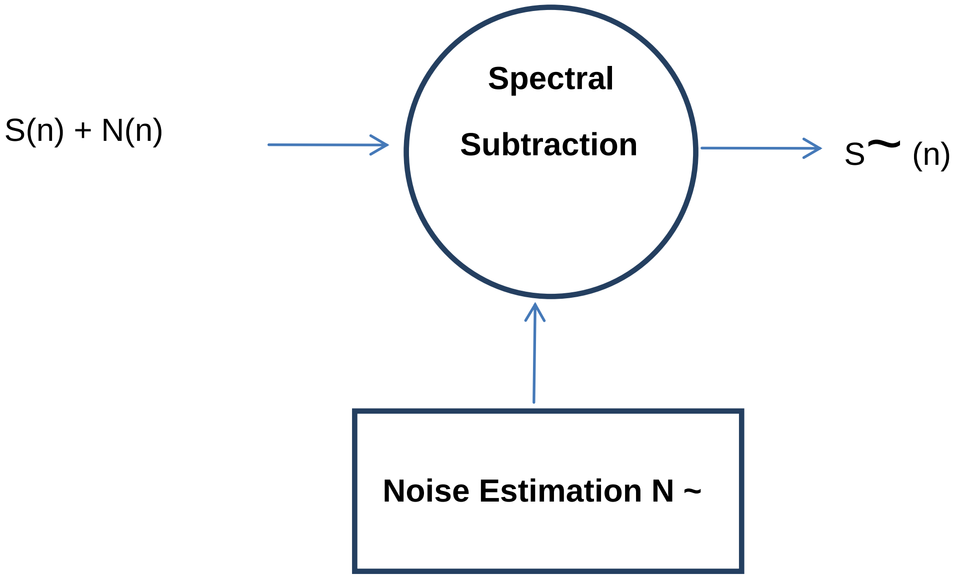

Figure 29. Spectral Subtraction

A number of algorithms are available for detecting edges of interest and then determining the shapes of target objects such as, Matched filters, Linear discriminators, and Gradient methods. Recently, algorithms based on Multi-Layer Perceptrons (MLP), sometimes known as Artificial Neural Nets have been applied to edge detection with great promise. MLP detectors can be effectively applied to GPR processing.

The input layer of MLP consists of $n \times n$ inputs each representing one cell in the $n \times n$ image mask. Typically, $n = 4$. The mask scans the image and detects presence or absence of target object. MLP is trained using a traditional backpropagation algorithm. Output layer consists of two outputs – edge/no edge for each of the $n \times n$ cell. The training and testing of MLP is show in Figure 30.

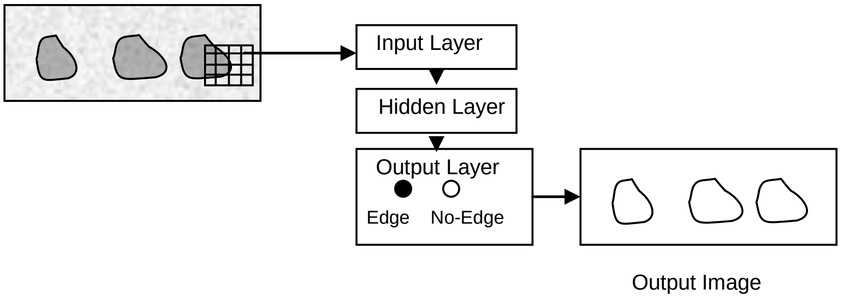

Figure 30. MLP for Processing GPR Signals

The performance of an MLP classifier as above is largely dependent on the size and quality of training data that are used to train the Neural network parameters (weights). In the GPR case, we can construct a training set by developing images of known target objects (rocks/gravel) embedded in a known pattern in the background of interest (laid out in a known grid, for example). The MLP detector can then be trained on known edges and then tested on unknown measurements. Typically, 500-1000 known edge/non-edge measurements are required to train an MLP. Noise suppression techniques as outlined above can be used to pre-process the input image, which will result in signal features/parameters than can better discriminate between edge and non-edge areas. After edge detection, continuity constraints can be applied to determine the exact shape and attributes of the target object.

One of the ways to develop training set is by conducting tests on materials with known size and shape configuration. To capture this idea, a physical model was constructed in the laboratory using concrete blocks. The goal was to determine if the GPR unit can be used to map the known configuration of objects and to some extent replicate the configuration. Figure 31 through 34 show the GPR unit setup in the laboratory, and the concrete blocks used in two layers.

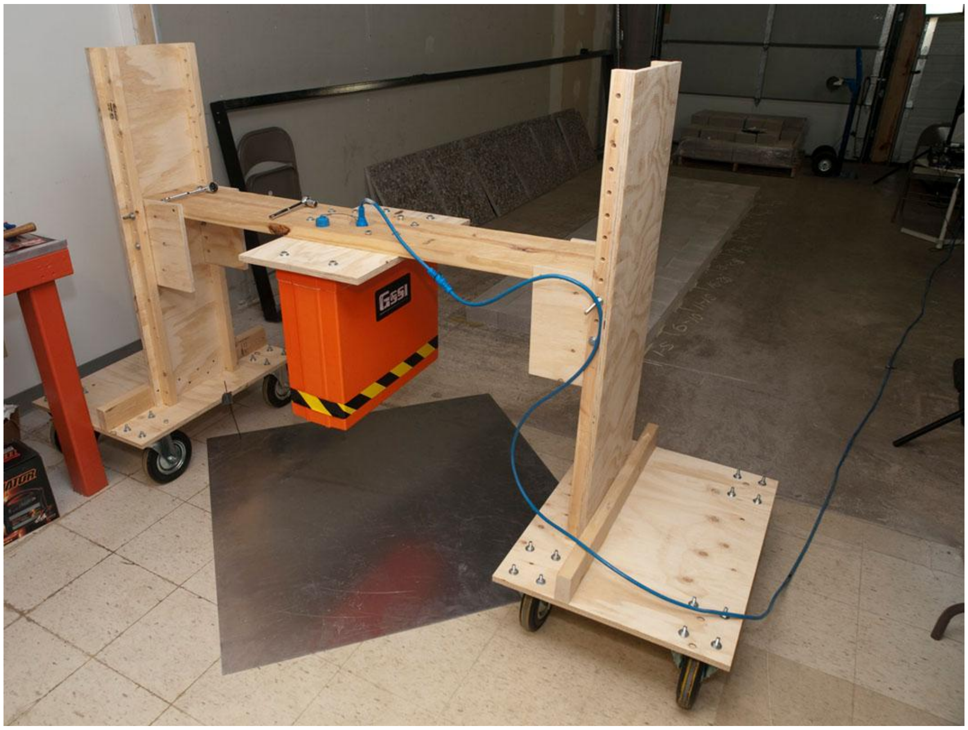

Figure 31. Setting up of GPR Antenna for Laboratory Studies

Figure 32. Concrete Blocks Representing Partially Rubblized Fragments

Figure 33. Gravel Paver Block Representing Fully Rubblized Layer

Figure 34. Side View Showing Experimental Setup

A number of iterations were made to change the configuration in terms of the gap between the blocks, the way the blocks were positions and so on and the data was collected each time. A typical line scan display obtained is illustrated from Figures 35 through 37.

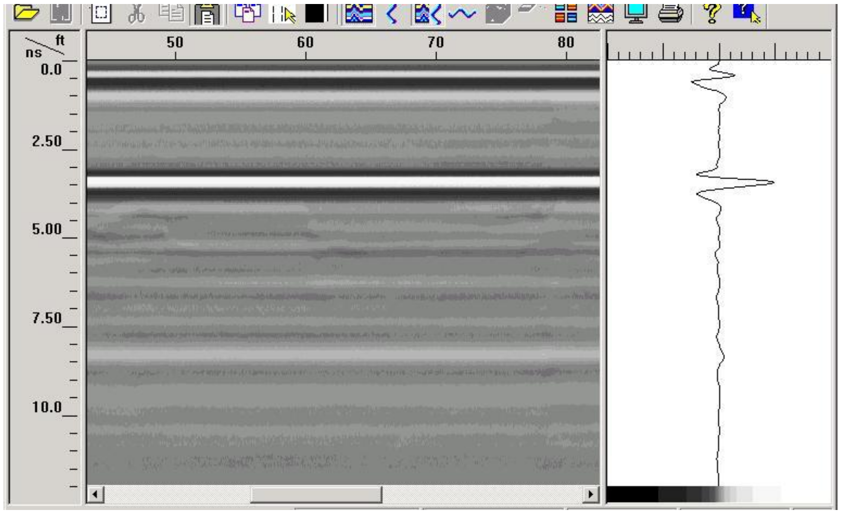

Figure 35. Line Scan Display on Concrete surface representing exposed concrete pavement

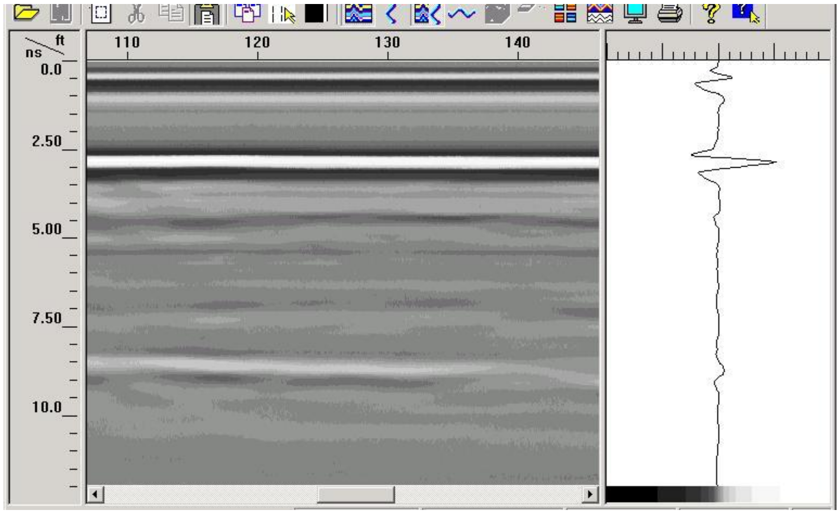

Figure 36. Line Scan Display on Concrete blocks representing partially rubblized fragments

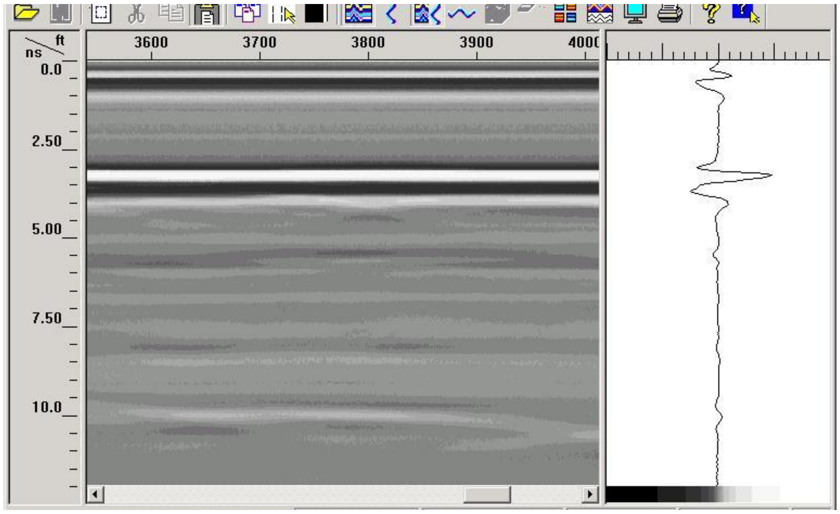

Figure 37. Line Scan Display on Paver Block representing fully rubblized layer on the top of partially rubblized layer

The GPR data again was not strong enough to detect the peaks between partially and fully rubblized layers. However, it became obvious that, the lab tests on materials with known configuration along with procedures to increase the sensitivity of measurement may help in to advance this technology. Additional efforts in the future may assist in accomplishing the objectives stated in the present study.

9. SUMMARY AND CONCLUSIONS

Since 1988, the Ohio Department of Transportation has been using rubblization and roll technique as an option for the major rehabilitation of in-service composite pavements. Twenty seven projects covering over 2 million SY of pavement have been rubblized under this program. ODOT developed R/R specification in 1987 based on a review of the specifications in other states, primarily Michigan DOT.

According to the R/R specification, ODOT requires the concrete pavement to be rubblized such that the resulting fragments are less than 6inches in their largest dimension. Verification of compliance with specification is a 2-step process. First, the particle size distribution on the surface is visually observed. Next, to determine the particle sizes through the depth, under the steel reinforcement in particular, a test pit is made. The test pit, normally 3ft x 3ft in size, is made using a backhoe to expose the material underneath and allow visual observation of particle size derived.

Observing surface particles is easy and can be accomplished in real time with minimal efforts. However, test pits require more time, effort and expenses. Additionally, they cause smoothness issues after restoring them.

This study investigated the applicability of GPR to non-destructively monitor the particle size through the depth in R/R projects. GPR has been used successfully to map subsurface information. However, a review of the literature revealed that no attempt has been made to verify the quality of rubblization using GPR. An effort was made in this study to investigate if the GPR can potentially be used to map the size of particles through the depth of concrete slab after rubblization. A field study was set up on I-75 in Butler/Warren County. The AC layer on the existing composite pavement was milled and the concrete layer was exposed. GPR survey was made on the intact concrete slab to obtain 'base-line' data. The concrete pavement was then rubblized and rolled in accordance with ODOT's R/R specification. GPS survey was repeated along the same locations as the survey on the intact concrete slab. As the work progressed, appropriate changes were made to the settings for data acquisition so as to acquire a large amount of highly dense data.

The goal of the analysis was set to determine if the fragments due to rubblization were larger than prescribed. GPR signals from before and after rubblization was processed and compared to detect differences in peak signals. A difference could provide substantial information regarding the changes that may have occurred due to rubblization. However, the data did not reveal such differences. This was because the reflections were not strong enough to detect changes. It became apparent that by increasing the signal-to-noise ratio and following the same field experiment procedure, it may become possible to differentiate and distinguish the two internal layers.

The present study provided insight into additional data needed to establish GPR as a potential device in the future for evaluating the size fragments in a R/R project. Lessons learned lead to a conclusion that, by continuing the work initiated in this study it is possible to establish a rational, non-destructive and quick procedure to estimate the particle sizes derived through the pavement as a result of rubblization. It is recommended that ODOT and other state DOTs further explore this idea by utilizing the concepts underlined and carrying out additional research.

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Appendix A

(FWD deflection data on exposed concrete pavement prior to demonstration of rubblization)

```
R80        20090429WAR75A  36F20
70     08002-036 60000  00  60 .
 150   0-305 305 457 610 9141524  5.90  0.00-12.00 12.00 18.00 24.00 36.00 60.00
c:\Program Files\Dynatest\Fw.FWD
WAR 75  (Rubblize)
S
S
86234-XX86231-XX   10185   15930
 7.915.0 3.510.0 3.020.0 5.010.0
Ld   447 1.010  92.1           .
D1  3192 1.002 1.017           .
D2  3462 1.001 1.012           .
D3  3313 1.005 1.029           .
D4   474 1.004 1.032           .
D5   475 1.002 1.040           .
D6   478 0.990 1.072           .
D7   479 1.002 1.012           .
D* N0    1.000 1.000           .
D* N0    1.000 1.000           .
D* N0    1.000 1.000           .
RDM
11   5   1110 1 1              .
   5 2.0   2 2.0
```

```
*After Mill Before Rubblize
DtCty PxNnnnS 000+0.0 000+0.0 St
  Cty P Nnnn
000+0.0 000+0.0 St ...
 300   0   0   0   0   0   0   0 11.81  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      58     174    5193   17950
234............................................................
234............................................................
                                .
***............................................................
                                .
                                .
Load Tra
*After Mill Before Rubblize
  13470Left-17.8   18 14 51113   0  64  58
 627 103  95  95  84  81  67  37  9969  4.06  3.75  3.73  3.31  3.20  2.63  1.47
 805 137 120 121 111 104  87  51 12795  5.38  4.74  4.77  4.36  4.08  3.43  2.00
 989 168 152 153 141 131 111  66 15709  6.62  5.98  6.04  5.54  5.17  4.36  2.60
S   13293Left-17.8   18 14 51115   0  64  58
 594  94  84  84  76  72  61  37  9432  3.70  3.29  3.29  3.01  2.82  2.39  1.46
 758 122 110 110 101  95  80  50 12039  4.80  4.35  4.33  3.97  3.74  3.16  1.95
 977 155 142 141 130 121 104  64 15522  6.10  5.58  5.55  5.11  4.78  4.09  2.52
S   13136Left-17.8   18 14 51116   0  64  58
 663 401 197 165  97  87  72  39 10538 15.78  7.74  6.48  3.83  3.43  2.83  1.53
 858 499 260 214 128 117  96  54 13627 19.63 10.24  8.44  5.03  4.61  3.76  2.12
1053 623 338 272 166 152 124  71 16727 24.54 13.31 10.71  6.52  5.98  4.87  2.78
S   12135Left-17.8   18 14 51117   0  64  58
```

```
 612 271 183 192 165 148 118  62  9717 10.66  7.21  7.56  6.49  5.81  4.64  2.43
 820 356 255 259 222 199 158  82 13025 14.03 10.02 10.20  8.75  7.85  6.23  3.22
 999 496 330 337 289 260 206 106 15873 19.52 13.00 13.27 11.39 10.23  8.12  4.17
S   13118Left-17.8   18 14 51118   0  64  58
 638 116 106 106  97  92  79  50 10133  4.56  4.17  4.16  3.83  3.62  3.11  1.98
 825 158 141 140 131 122 105  68 13112  6.24  5.54  5.52  5.15  4.80  4.13  2.66
1012 197 182 181 169 157 137  89 16070  7.75  7.16  7.13  6.67  6.19  5.38  3.49
S   12994Left-17.8   18 14 51119   0  64  58
 591 130 122 123 116 110  97  65  9388  5.10  4.81  4.85  4.56  4.32  3.83  2.57
 771 173 162 163 153 146 129  87 12247  6.80  6.36  6.42  6.03  5.73  5.09  3.43
 969 225 208 210 197 187 166 113 15391  8.84  8.17  8.26  7.76  7.36  6.55  4.44
S   12836Left-17.8   18 14 51122   0  64  58
 632 282 208 272 127  69  52  34 10045 11.10  8.19 10.69  5.00  2.71  2.06  1.34
 810 398 273 364 167  94  73  47 12871 15.65 10.74 14.35  6.56  3.70  2.87  1.85
 980 470 346 467 200 116  92  56 15566 18.52 13.64 18.37  7.88  4.56  3.63  2.22
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 586 868 189 114  98  90  77  40  9311 34.17  7.43  4.49  3.84  3.54  3.02  1.57
 7991092 253 165 126 111  90  49 12696 42.98  9.95  6.49  4.97  4.36  3.54  1.93
 9781444 332 216 165 144 117  64 15544 56.87 13.09  8.50  6.50  5.67  4.62  2.52
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 822 127 115 114 105  98  83  50 13058  5.00  4.54  4.50  4.13  3.85  3.26  1.97
1016 159 146 146 134 126 107  67 16147  6.27  5.73  5.75  5.29  4.96  4.23  2.63
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S   12477Left-17.8   17 14 51126   0  63  57
 645 198 153 106  92  69  55  35 10242  7.78  6.01  4.19  3.64  2.70  2.17  1.37
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 609 369  77 182 151 133 102  47  9673 14.52  3.02  7.15  5.95  5.24  4.01  1.87
 809 474 112 252 211 186 143  68 12850 18.67  4.41  9.94  8.31  7.33  5.63  2.68
 992 589 148 326 274 241 186  89 15752 23.19  5.81 12.84 10.80  9.50  7.31  3.50
S   12452Left-17.8   17 14 51128   0  63  57
 629 106  94  96  87  88  70  42  9990  4.17  3.69  3.76  3.43  3.45  2.77  1.65
 820 139 122 127 118 112  94  56 13025  5.46  4.80  5.00  4.65  4.41  3.69  2.20
1001 172 152 161 151 139 119  73 15906  6.78  6.00  6.32  5.93  5.48  4.69  2.87
S   12284Left-17.8   17 14 51129   0  63  57
 641 118 107 105  93  88  75  44 10188  4.63  4.20  4.14  3.67  3.47  2.94  1.73
 830 154 143 137 123 116  97  55 13189  6.08  5.62  5.38  4.84  4.57  3.81  2.15
1005 198 187 179 161 152 128  72 15972  7.78  7.36  7.04  6.33  6.00  5.03  2.82
S   12050Left-17.8   17 14 51130   0  63  57
 616 109 101 100  92  87  75  46  9782  4.28  3.96  3.95  3.64  3.44  2.96  1.83
 775 150 136 136 126 119 103  65 12313  5.90  5.37  5.36  4.95  4.67  4.04  2.56
 987 188 174 176 163 153 133  84 15687  7.41  6.87  6.91  6.42  6.04  5.24  3.30
S   11879Left-17.8   17 14 51132   0  63  57
 644 164 130 166 114  76  54  34 10231  6.47  5.12  6.54  4.47  3.01  2.13  1.34
 818 220 171 218 148 102  71  43 13003  8.65  6.73  8.58  5.81  4.02  2.78  1.69
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 801 146 135 125 112 105  87  51 12718  5.74  5.31  4.92  4.41  4.15  3.42  2.02
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 812 155 140 141 128 118  97  50 12893  6.10  5.50  5.55  5.02  4.65  3.83  1.98
 984 200 185 185 168 156 129  69 15632  7.86  7.29  7.30  6.63  6.13  5.09  2.71
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 767 173 138 141 126 118  97  52 12181  6.80  5.42  5.57  4.98  4.63  3.80  2.05
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 810 190 165 168 152 147 116  64 12871  7.47  6.51  6.63  5.98  5.79  4.56  2.52
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S   11159Left-17.8   17 14 51141   0  63  57
 641 474 217 180  85  66  51  30 10177 18.67  8.56  7.09  3.33  2.59  2.00  1.20
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 996 812 390 312 157 113  92  51 15818 31.96 15.35 12.27  6.19  4.44  3.64  2.01
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 6233272 148 193 132 113  83  39  9892128.83  5.84  7.61  5.19  4.43  3.26  1.53
```

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 8211083 209 260 182 155 115  53 13047 42.63  8.24 10.24  7.15  6.10  4.54  2.09
10161358 280 337 242 207 156  72 16147 53.47 11.01 13.25  9.54  8.15  6.13  2.82
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 640 129  99 108  90  81  62  33 10166  5.08  3.88  4.25  3.56  3.17  2.45  1.28
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 817 246 143 135  93  86  66  36 12981  9.69  5.62  5.31  3.67  3.37  2.58  1.40
1005 321 185 172 124 111  86  47 15961 12.63  7.28  6.79  4.90  4.36  3.39  1.86
S   10858Left-17.8   17 14 51147   0  63  57
 636 154 112 108  91  80  61  32 10111  6.07  4.42  4.24  3.60  3.15  2.39  1.26
 821 206 154 145 123 108  83  45 13047  8.12  6.05  5.69  4.86  4.24  3.27  1.77
 992 272 199 187 160 139 107  57 15763 10.69  7.85  7.36  6.28  5.46  4.22  2.26
S   10834Left-17.8   17 14 51148   0  63  57
 631  84  74  76  71  66  57  39 10023  3.31  2.93  3.01  2.79  2.60  2.23  1.52
 821 107  95  97  89  82  70  44 13047  4.22  3.74  3.81  3.50  3.24  2.75  1.72
1003 141 124 126 117 108  92  57 15939  5.55  4.90  4.97  4.60  4.26  3.62  2.23
S   10719Left-17.8   17 14 51149   0  63  57
 643 103  84  89  83  76  64  44 10220  4.07  3.32  3.52  3.27  3.00  2.53  1.72
 821 135 110 115 105  94  77  43 13036  5.31  4.35  4.52  4.12  3.69  3.03  1.70
1000 173 145 150 136 123 100  56 15884  6.83  5.71  5.89  5.37  4.83  3.95  2.19
S   10562Left-17.8   17 14 51151   0  63  57
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 643 126 100 123 110  91  45  26 10220  4.98  3.94  4.84  4.32  3.59  1.77  1.01
 847 174 139 170 151 123  64  37 13452  6.84  5.47  6.70  5.93  4.84  2.51  1.45
1025 223 179 253 198 157  81  48 16289  8.79  7.04  9.97  7.80  6.20  3.18  1.89
S   10560Left-17.8   19 16 51152   0  66  60
 643 207 127 123  65  57  45  25 10210  8.15  5.01  4.84  2.57  2.24  1.77  0.98
 847 283 177 171  93  80  65  37 13452 11.14  6.96  6.73  3.67  3.15  2.57  1.47
1029 374 234 227 120 104  85  49 16344 14.72  9.20  8.94  4.73  4.11  3.34  1.93
S   10537Left-17.8   19 16 51153   0  66  60
 659  78  69  71  65  61  51  30 10472  3.06  2.73  2.81  2.57  2.41  2.01  1.19
 847 107  93  94  87  83  68  40 13452  4.20  3.67  3.72  3.42  3.25  2.68  1.59
1033 139 121 122 112 108  89  53 16410  5.48  4.76  4.82  4.41  4.24  3.49  2.10
S   10364Left-17.8   19 16 51155   0  66  60
 624  86  77  81  72  70  60  36  9914  3.40  3.02  3.19  2.82  2.75  2.37  1.41
 798 117 103 110  99  94  81  48 12674  4.62  4.05  4.32  3.90  3.71  3.18  1.89
 993 150 132 141 127 121 104  62 15774  5.90  5.19  5.54  5.00  4.77  4.09  2.43
S   10203Left-17.8   19 16 51157   0  66  60
 613 175 135 163 138 108  59  34  9738  6.88  5.33  6.41  5.43  4.25  2.34  1.33
 821 241 185 219 187 155  82  47 13047  9.49  7.30  8.64  7.37  6.11  3.22  1.85
 992 354 237 278 240 203 106  60 15752 13.93  9.35 10.96  9.45  7.98  4.16  2.35
S   10202Left-17.8   19 16 51158   0  66  60
 663 529 163 134  92  82  65  34 10538 20.82  6.43  5.29  3.64  3.23  2.56  1.35
 846 649 222 180 126 111  88  46 13441 25.56  8.74  7.09  4.95  4.36  3.46  1.80
1026 800 291 237 168 147 119  61 16300 31.50 11.44  9.33  6.63  5.80  4.68  2.39
S   10185Left-17.8   19 16 51159   0  66  60
 667 100  88  92  82  77  63  37 10593  3.93  3.45  3.63  3.24  3.03  2.47  1.44
 847 135 119 125 111 106  86  51 13452  5.31  4.70  4.93  4.38  4.16  3.40  2.00
1023 176 154 160 145 134 112  66 16245  6.93  6.05  6.28  5.70  5.26  4.39  2.60
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