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FINAL REPORT

A FIELD VERIFICATION INSTRUMENT TO ASSESS THE PLACEMENT ACCURACY OF DOWEL BARS AND TIE BARS IN PCCP

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16 Abstract

This report describes the design and construction of a prototype instrument for location of steel dowel bars and tie bars in highway concrete. The instrument consists of a non-metallic (wooden) wheeled platform which carries a commercially available metal detector known as a covermeter, specially modified for this project. The covermeter is designed to be held in the hand and swept over a concrete wall or road, displaying the distance to steel within the concrete. The modified covermeter, mounted on the platform together with a notebook computer, outputs a serial data stream which is converted by the included software into information about the location and orientation of an array of dowel bars. Operation of the instrument consists of pushing it slowly across the road surface along a saw cut. The output display consists of three-dimensional color depictions of the dowel array, showing the calculated positions and displacements.

The instrument is able to detect dowel bars to a depth of about 30 cm. It is able to resolve a 10-mm horizontal and a 5-mm vertical displacement at a depth of 15 cm. Bar orientation is described in pitch (rotation about a horizontal axis normal to the bar) and yaw (rotation about a vertical axis). The instrument can readily resolve a 7-degree misalignment in both pitch and yaw. This represents a one-diameter rotation about the center of a bar. Although these resolutions can be improved, the cart would have to be moved at an impractically slow rate over the road.

In 2001, a German firm introduced a device called MITScan (marketed in the US in late 2002), which it claims would scan roadbed automatically and output three-dimensional position information about the dowels in pavement. Initial tests of this device have been conducted by CalTran and Gomaco; results to this date, while promising, are not conclusive. With our experience, the KSU team could design a device equivalent to MITScan. This would require the use of multiple sensors, a stronger excitation signal, and custom-designed electronics and control circuitry. Of course, this would defeat the purpose of using an off-the-shelf sensor unit. If the manufacturer's performance claims can be substantiated, and if this resolution is necessary to the application, we would recommend the purchase of the MITScan for high-resolution measurements.

The present apparatus may be useful for lower resolution measurements. Applications might include surveys of known good pavement for the purpose of determining acceptable limits for displacements and misalignments of dowel bars and tie bars. The data collected could be used to support or to revise the established dowel bar placement standards. Additionally, the unit provides a low-cost approach to timely monitoring of contractor performance, and may be used to troubleshoot suspect pavement sections. If these applications are of interest, we would recommend that the instrument we have developed based on an off-the-shelf covermeter be hardened for field use and refined with software enhancements as described in the Future Work section of this report.

17 Key Words
Dowel Bars, Concrete Pavement, Metal Detector Tie Bars, Steel Location Scan, Sensor, and Magnetic Pulse Induction

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Final Report

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A Report on Research Sponsored By

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

KANSAS STATE UNIVERSITY
MANHATTAN, KANSAS

October 2005

PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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DISCLAIMER

Executive Summary and Recommendation

This report describes the design and construction of a prototype instrument for location of steel dowel bars and tie bars in highway concrete. The instrument consists of a non-metallic (wooden) wheeled platform which carries a commercially available metal detector known as a covermeter, specially modified for this project. The covermeter is designed to be held in the hand and swept over a concrete wall or road, displaying the distance to steel within the concrete. The modified covermeter, mounted on the platform together with a notebook computer, outputs a serial data stream which is converted by the included software into information about the location and orientation of an array of dowel bars. Operation of the instrument consists of pushing it slowly across the road surface along a saw cut. The output display consists of three-dimensional color depictions of the dowel array, showing the calculated positions and displacements.

The instrument is able to detect dowel bars to a depth of about 30 cm. It is able to resolve a 10-mm horizontal and a 5-mm vertical displacement at a depth of 15 cm. Bar orientation is described in pitch (rotation about a horizontal axis normal to the bar) and yaw (rotation about a vertical axis). The instrument can readily resolve a 7-degree misalignment in both pitch and yaw. This represents a one-diameter rotation about the center of a bar. Although these resolutions can be improved, the cart would have to be moved at an impractically slow rate over the road.

In 2001, a German firm introduced a device called MITScan (marketed in the US in late 2002), which it claims would scan roadbed automatically and output three-dimensional position information about the dowels in pavement. Initial tests of this device have been conducted by CalTran and Gomaco; results to this date, while promising, are not conclusive. With our experience, the KSU team could design a device equivalent to MITScan. This would require the use of multiple sensors, a stronger excitation signal, and custom-designed electronics and control circuitry. Of course, this would defeat the purpose of using an off-the-shelf sensor unit. If the manufacturer’s performance claims can be substantiated, and if this resolution is necessary to the application, we would recommend the purchase of the MITScan for high-resolution measurements.

The present apparatus may be useful for lower resolution measurements. Applications might include surveys of known good pavement for the purpose of determining acceptable limits for displacements and misalignments of dowel bars and tie bars. The data collected could be used to support or to revise the established dowel bar placement standards. Additionally, the unit provides a low-cost approach to timely monitoring of contractor performance, and may be used to troubleshoot suspect pavement sections. If these applications are of interest, we would recommend that the instrument we have developed based on an off-the-shelf covermeter be hardened for field use and refined with software enhancements as described in the Future Work section of this report.

Introduction

In Portland-cement concrete paving for high-traffic highways, concrete is poured and cut into 16-foot sections measured in the direction of travel. These slabs are connected with steel dowels placed parallel to the roadbed and spaced twelve inches apart across it; the dowels serve to transfer load between slabs, while preventing vertical displacement. In Kansas, the specifications for dowel placement require less than 2mm deviation from parallel alignment. However, prior to 2002 no instrument existed to quickly and precisely determine the placement of the dowels in hardened concrete. KDOT and concrete contractors wished to have such a device to check already-poured roadbed, and potentially to monitor dowel placement as concrete is poured.

In 2001, a German firm introduced a device called MITScan (marketed in the US in late 2002), which it claims would scan roadbed automatically and output three-dimensional position information about the dowels in a roadbed [1]. This KSU project was initiated to develop a simple instrument that would provide a useful degree of this functionality at lower cost and using off-the-shelf components.

The primary objectives of the proposed project were to develop a mechanism that is easily portable, time and manpower efficient, and durable. The detection range of the instrument should be sufficient to locate dowel bars and tie bars on the majority of KDOT paving project (approximately 12 inches, more or less depending on the size of the steel.) Since pulse induction techniques will detect any highly conductive medium, the device must isolate any magnetic or conductive material at least 18 inches from the sensor head requiring that the structure of the instrument be constructed out of plastic, resin or wood.

The project consisted of two primary tasks. The first was to assemble a working instrument capable of collecting the magnetic-pulse-induction sensor readings in a man-power and time efficient manner.

The second primary task was to convert the scanned sensor readings into easily discernable graphics as well as to estimate the position of the steel from the sensor readings.

Background

KDOT had in its possession a "covermeter" manufactured by Koelectric. This device uses an induction coil to create a magnetic field which magnetizes steel in its vicinity (Figure 1). "Send" and "receive" coils are housed in a sensor puck. The "send" coil has a iron core and is composed of large-gauge wire to conduct current better. The "receive" coil has an air core and is composed of a finer gauge wire with a great number of windings. The current pulse in "*send*" coil #1 creates a magnetic field that when applied to the dowel bar induces a current in it. The induced current creates a (second) magnetic field. This new magnetic field induces a current in "*receive*" coil #2. The received current pulse is converted into a digital signal suitable for computer processing.

The measurement is complicated by several factors. The send coil induces current in the receive coil as well as the target steel, so the received signal must not be read until this more proximate signal decays. The return signal from the target steel is magnitudes smaller than the send signal, and decays with a time constant dependent on both the conductivity and magnetic permeability of the target steel. It is the measurement and analysis of this decay signature that provides the desired information about the location and orientation of the steel dowel. Finally, while this arrangement will detect any metal within range, the coils are arranged to optimally detect long steel bars oriented parallel to the coils' long axis.

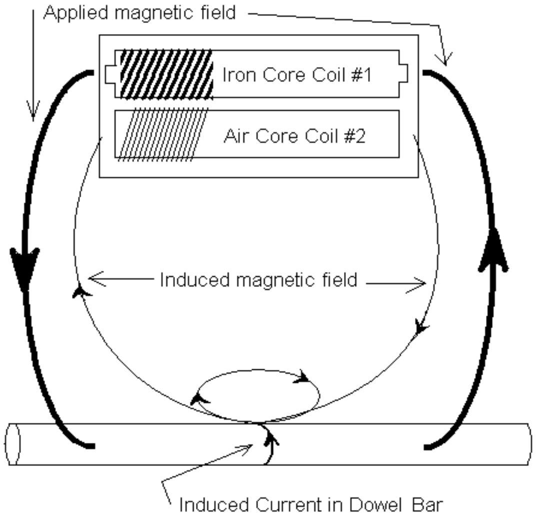


Figure 1. Operation of covermeter sensor head.

Stan Young at KDOT developed a test bed consisting of a wooden x-y table over a plastic tub in which dowel bars could be placed, in or out of baskets. This bed was fitted with shaft-position encoders on the sliding sensor support, and he was able to scan the covermeter puck over the dowel bars and create a two-dimensional array of signal strength with position. KDOT's Koelectric meter had no data output port, only on-screen readings and audible tones characteristic of metal detectors and Geiger counters, which output a higher-pitched tone to indicate stronger signal. The meter was modified to tap off the signal to the audio speaker. Received signal strength was determined by measuring the frequency of the audible output of the covermeter. These measurements justified the further pursuit of this technique at Kansas State University.

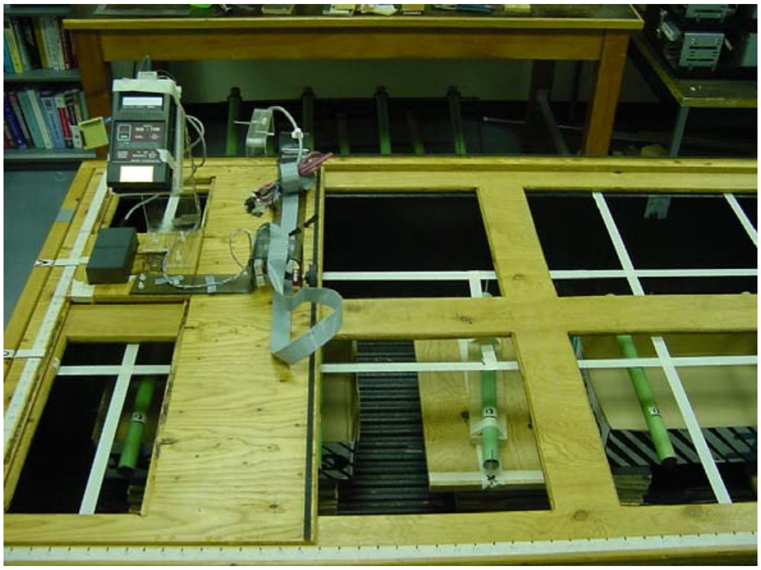


Figure 2. KDOT testbed and covermeter.

Covermeter Evaluation

Work began at KSU by determining the sensitivity and resolution capabilities of the covermeter. By recording signal strength at depth increments of 1/16" over the range from 3 to 12 inches, we created the graph in Figure 3. Each data point is the result of time-averaging the audio-frequency signal (signal strength) from the meter over a few seconds. Averaging was necessary because of variations (noise) in the audio signal internally generated by the instrument. The curve shown in Figure 3, drawn from the initial data collected, is very nearly that of a simple decaying exponential. From the smooth nature of this initial curve we were hopeful that we could resolve 1/8" differences at six inches' depth, if the noise problem could be reduced.

At this point we ordered a specially designed covermeter directly from Koelectric. This meter has a built-in serial data output which can be streamed to a dumb-terminal application or otherwise input to a computer program. The output is an 8-character, two's-complement hexadecimal string. We hoped to minimize the noise difficulties we encountered with the audio output from the first meter, and reduce the need for averaging, by accepting signal strength data directly. The modified meter outputs data at a 20-Hz rate.

The first task with the modified meter was to replicate the above described work. To determine the signal strength variation with position along the long axis of the bar, we collected data for the plot shown in Figure 4. From this we chose two positions (A2 and B2) maximally distant from the center line but at which signal strength is the same as at the center. We chose 4 inches off the center line as ideal. A second, outer position pair (A1 and B1) was chosen 8" off center to aid in determining pitch, yaw and horizontal displacement.

Signal strength vs. depth curves at the A, B and center positions are shown in Fig. 5. By symmetry, the signals measured at positions A1 and B1 are essentially the same, as are the data measured at A2 and B2. The same curves are shown in Fig. 6 with a log scale on the y axis and an exponential curve fit. Since the curves are not simple exponentials, we decided that we could obtain better accuracy by using a look-up table of the data plotted in Fig. 5. Again, these points are the results of averaging several seconds' worth of data from the modified covermeter. Data obtained from the meter without processing remains noisy, but this noise is random in nature and can be filtered by averaging, though that would insert a time delay. Averaging over one second per position is probably adequate.

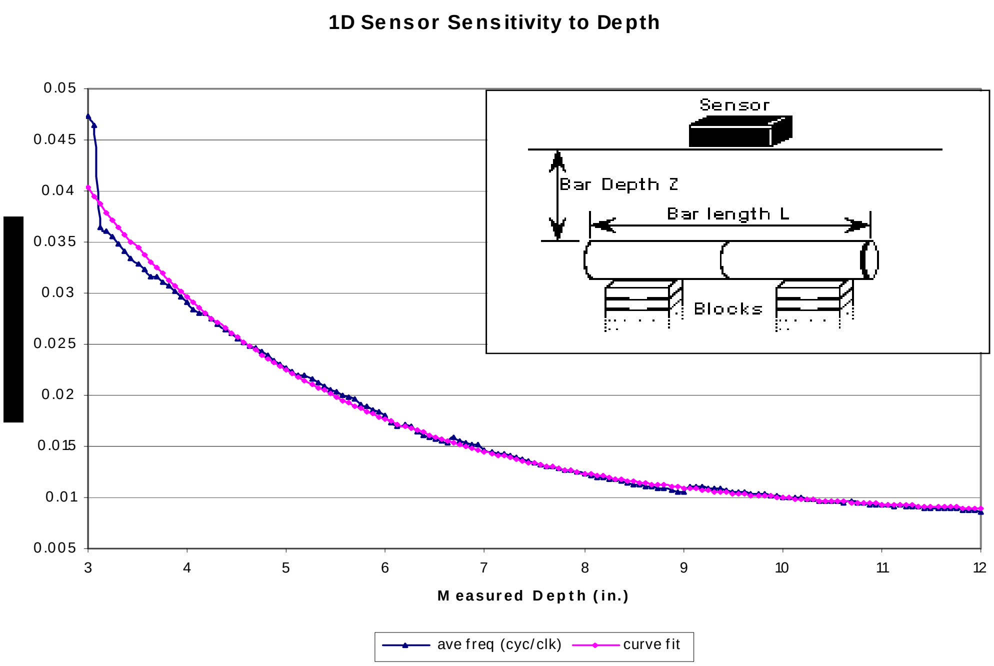


Figure 3. Covermeter signal output vs. depth plot. Dowel bar and meter puck orientation shown in inset. Smooth curve is an exponential fit.

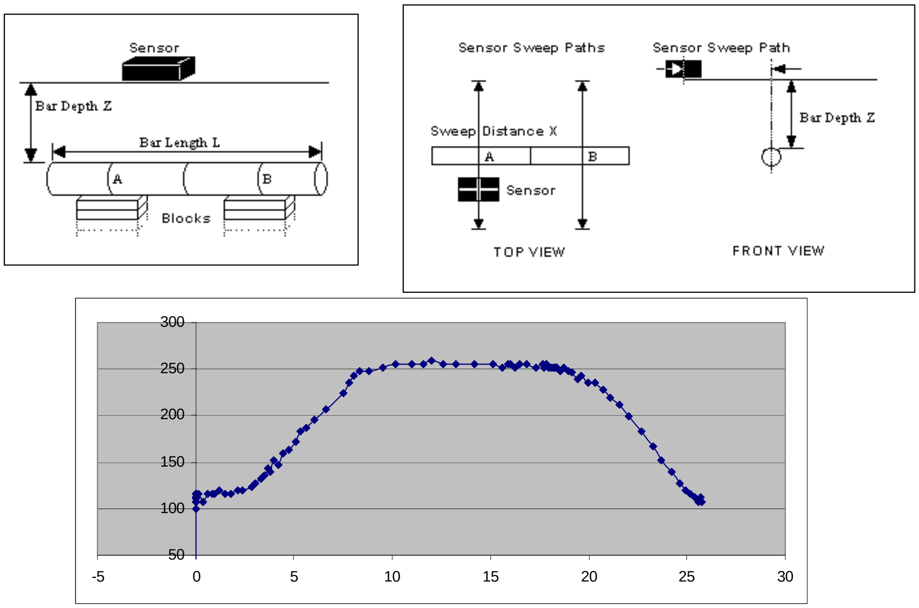


Figure 4. Above: orientation of sensor puck relative to bar for measurement. Below: plot of signal strength vs. position along long axis of the 18"-long dowel bar, showing measurement positions. Dowel center is at about 14 inches.

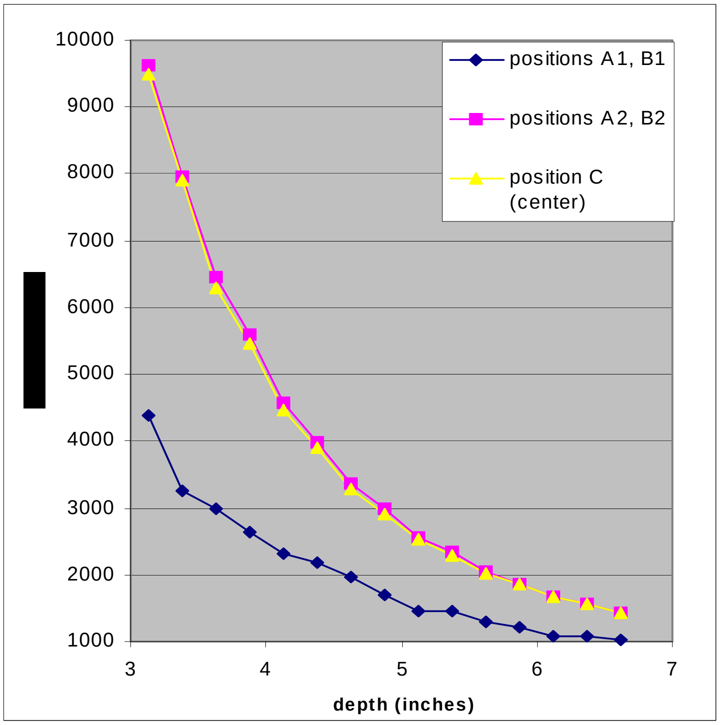


Figure 5. Signal strength vs. depth at three positions across bar.

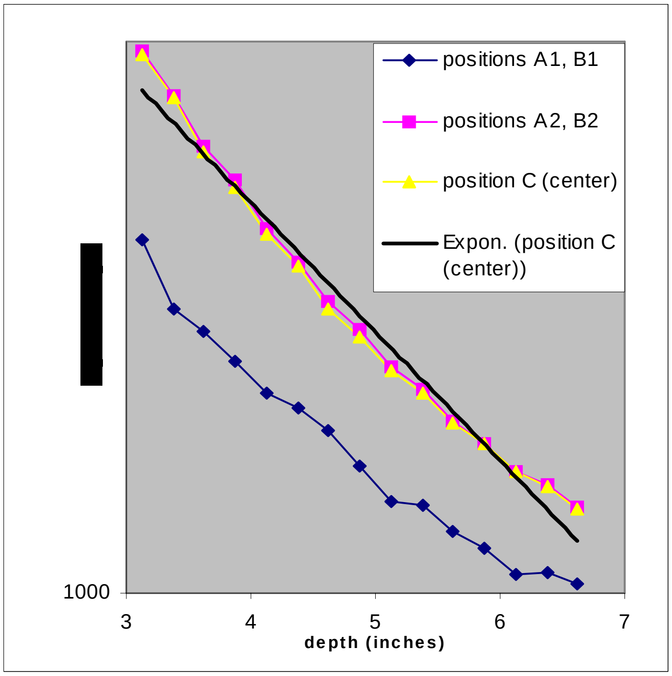


Figure 6. Same as Fig. 5 on semilog scale.

Data Collection

We set up an array of 5 bars and scanned them to determine what data we need to collect and what displacement can be detected. The minimum repeatable resolution in depth (z axis, see Figure 7) was found to be approximately 0.25 inch at a nominal depth of 6 inches (Figure 8). At the same depth, the minimum resolution in horizontal offset along the x axis was .5 inch (Figure 9). Multiple strips of data corresponding to positions A1, A2, center, B2 and B1 allow us to determine dowel bar pitch, yaw and displacement along x and y (Fig. 10). For example, if the signal strength at position A2 is less than that at the center and B2, either a rotation around the x axis (pitch) or a displacement along y is indicated. These can be distinguished by comparing signal strengths of center, B2 and B1: if the dowel is displaced, center, B2 and possibly B1 will be of equal strength and A1 will be of very low value, while if pitch is the problem, a gradient will exist across all five peaks. Similarly, if the position of the maximum signal strength along the x axis differs between A2 and B2, a rotation about the z axis (yaw) is indicated. Combinations of these dislocations may be logically determined from the 5 strips of data.

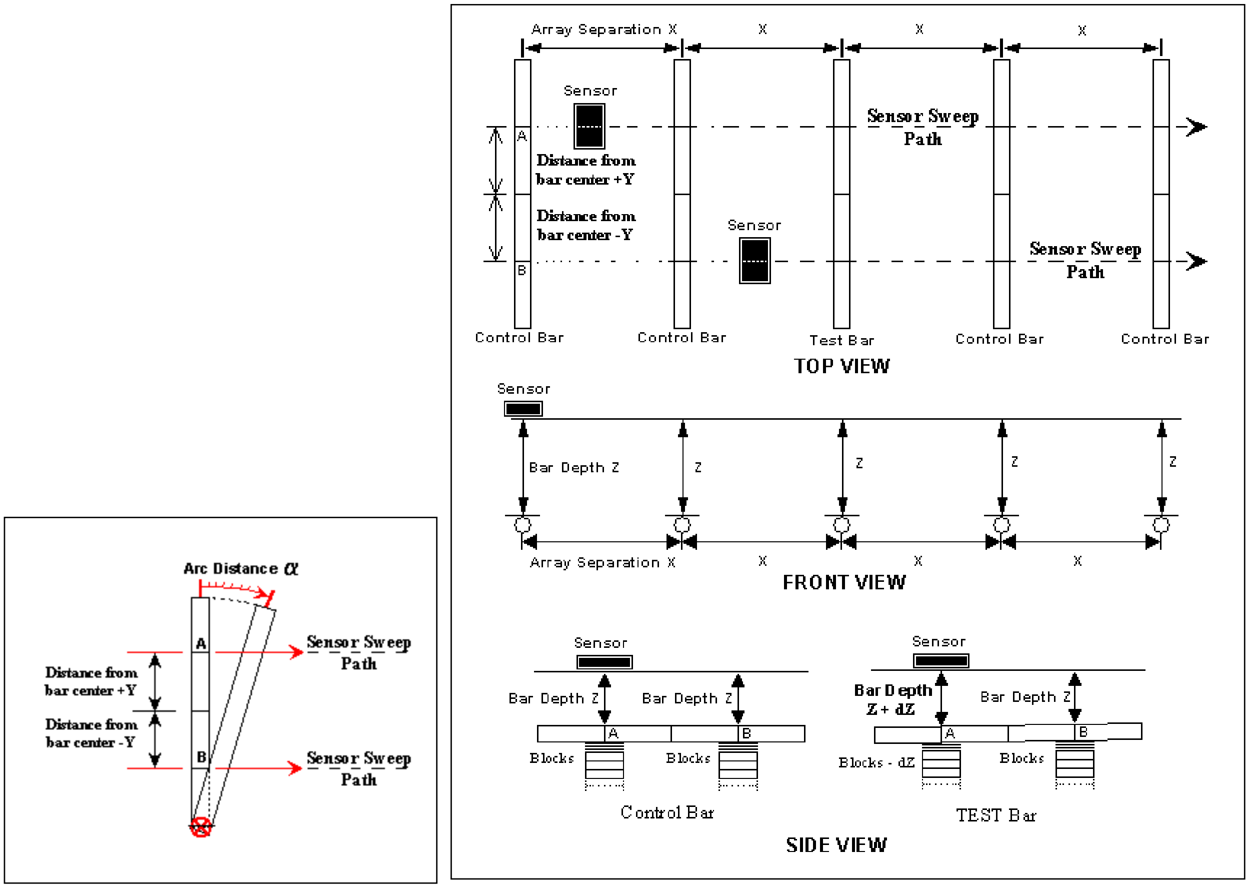


Figure 7. Dowel bar positions, scanning positions and axis labels.

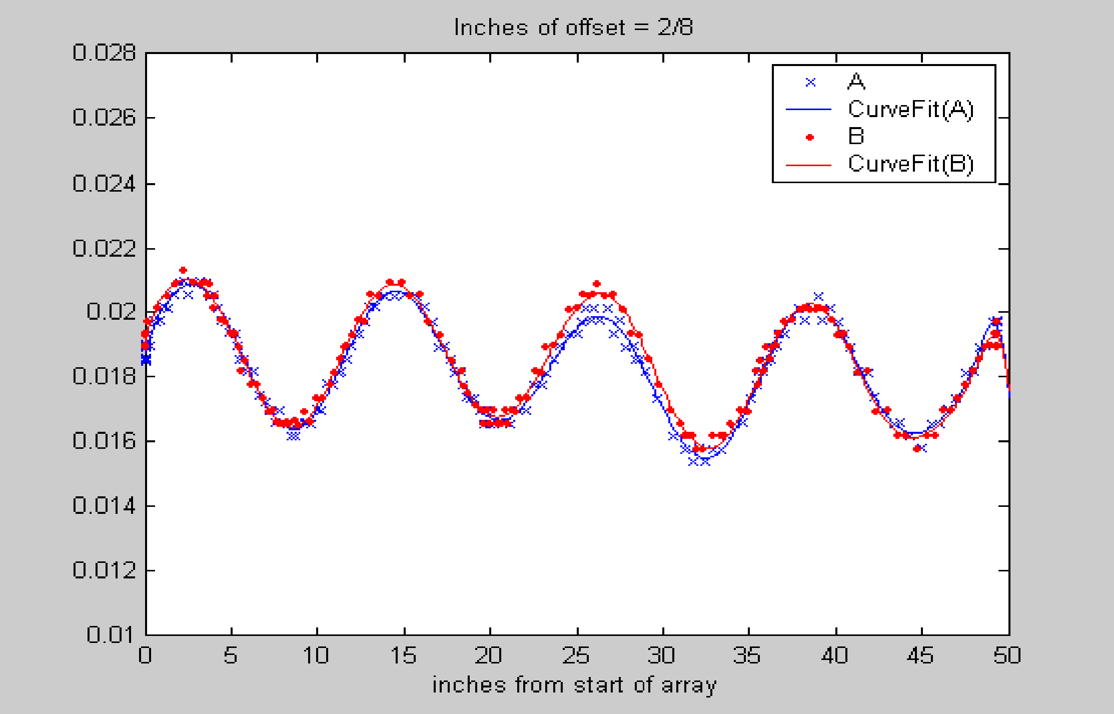


Figure 8. Comparison of centerline data for an array of 5 bars at nominal 6” depth with center bar (B): level with, and (A): depressed 0.25” from the other bars.

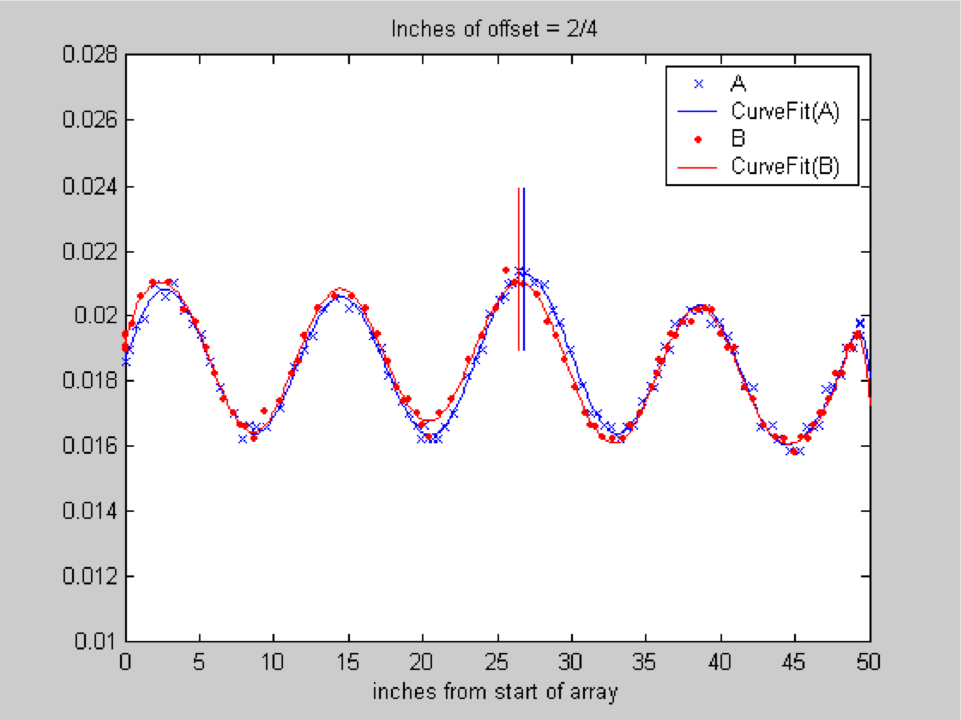


Figure 9. Comparison of centerline data for 5-bar array with center bar displaced 0.5 inches along x (A). Vertical lines indicate position of peak signal after curve fit.

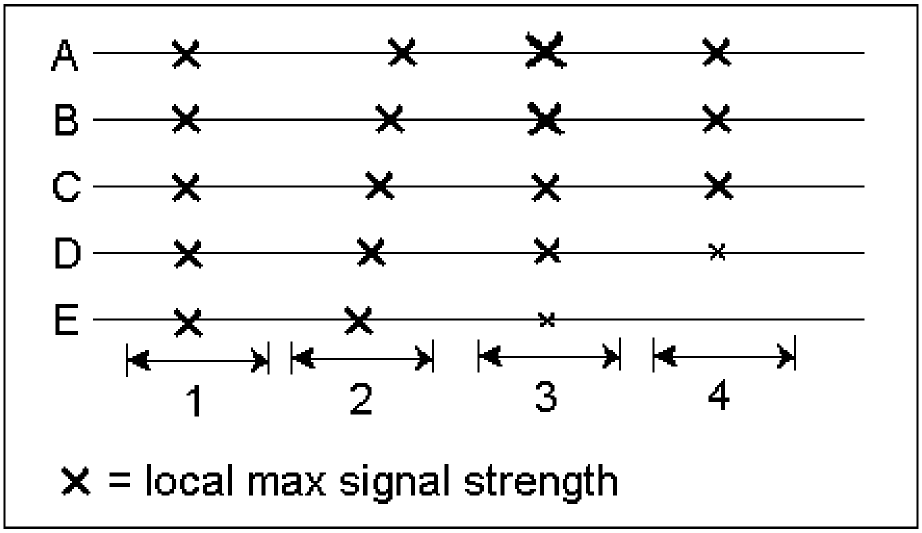


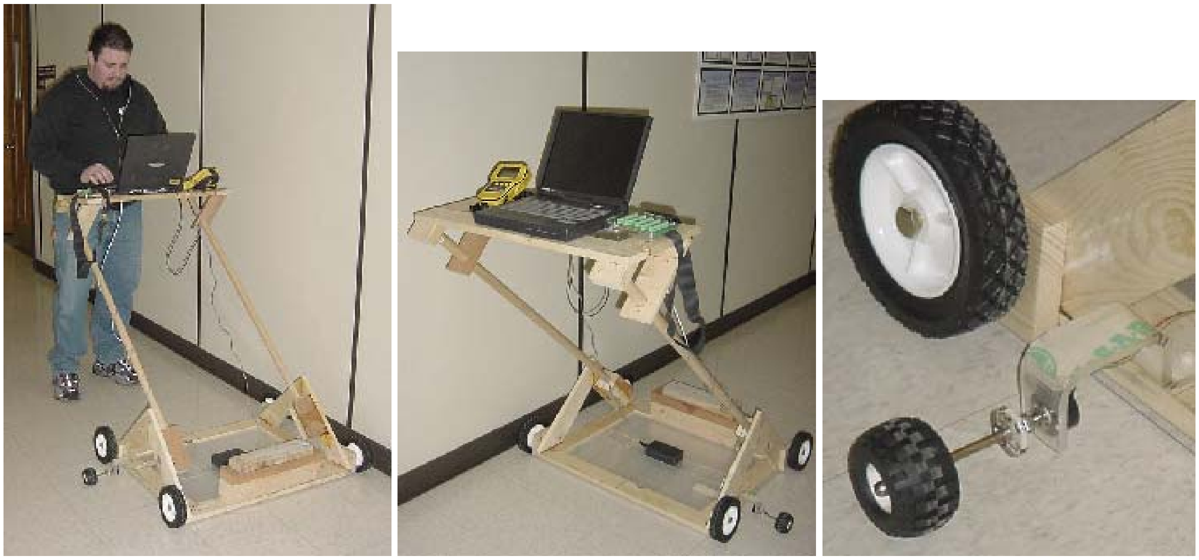
Figure 10. Diagram of expected signal strength and position for various dowel bar dislocations. Relative strength indicated by symbol size. 1: bar in correct location. 2: yaw. 3: pitch. 4: displacement along y.

Development of Measurement Cart

To facilitate taking the necessary measurements, a non-conductive (wood and plastic) cart was designed to hold the sensor puck in the correct positions while supporting the laptop computer used to acquire, process and display data. Two different acrylic sheets with holes cut in them fit in the base to correctly position the puck along the y axis. To determine position along the x axis, a shaft-position encoder was mounted to a small wheel to one side of the cart. The operator uses a centering line on the base to keep the cart aligned with the saw cut on the pavement. The signal from the encoder is input to the computer through a data acquisition card (DAQ). The signal from the covermeter is input through the serial port. The cart and position encoder are shown in Figures 11-13.

A National Instruments' LabVIEW program was written to control data input and save the data for future processing. On stimulus from an encoder wheel click, the program reads the serial data input from the covermeter and stores the position and signal strength data in two separate text files. The signal strength data is displayed on the LabVIEW front panel as a hexadecimal number and on a simulated analog meter permitting the operator to monitor program status. Before storing the data, LabVIEW adds a hexadecimal constant to render all output positive, then converts the hexadecimal output to decimal.

Due to physical (electromagnetic) constraints, signal strength data is transmitted from the covermeter at 20 Hz, so we are limited to a cart speed of 1 to 2 inches per second. At a faster traversal speed, absolute accuracy of the measurement process decreases. The signal strength values are still meaningful: orientation (pitch, yaw) can still be determined independent of absolute depth accuracy.



Figures 11-13: Prototype cart and closeup of encoder.

Data analysis:

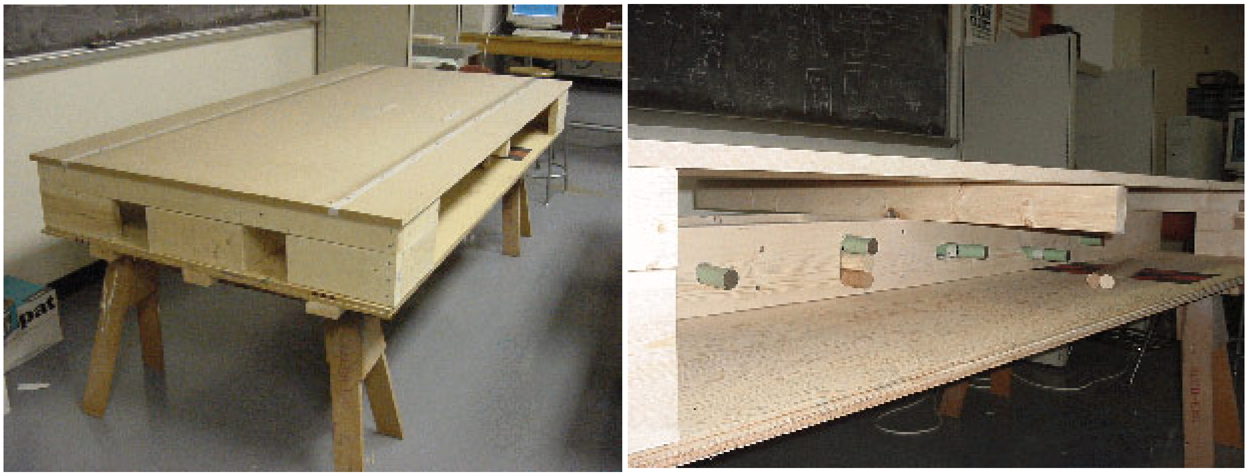
The two data files collected with LabVIEW are processed with a program written in MATLAB to filter noise, locate the signal strength peaks, determine depth and create plots to guide the operator in interpretation.

If the cart is pushed too quickly, the covermeter output will not be proportional to signal strength but will be a fixed level value. This is because data collection is triggered by the encoder count and a new measurement value may not yet be available; the covermeter supplies an arbitrary but constant value instead. The MATLAB program removes these false characters and replaces each with the previous valid number. It then produces a single strip chart of signal strength for all 5 strips vs. distance.

The program locates the local signal strength maximum within successive 12" windows and outputs the depth of the center of each bar it has located using a lookup table compiled from the data shown in Figure 5. At present, the program is written assuming the first bar will be within the first 12" of a strip. The signal maxima are then plotted vs. xy position in three formats: 1) signal strength is color-coded on a 2-D x-y plot; 2) signal strength is the 3rd axis of a 3-D plot, with x and y as the other two axes; 3) using a look-up table, bar depth (z) replaces signal strength as the 3rd axis.

Each of these plots can be manipulated within MATLAB to aid in interpretation. At this point in the project development, interpretation of pitch, yaw and displacement from the graphs is left to the operator.

Specific step-by-step directions for use of both the LabVIEW and MATLAB programs are included in Appendix A: User Manual.



Figures 14 and 15. Artificial road in top and side view. Side view shows dowels in position.

Laboratory Test Results

In order to validate the completed instrument under known conditions, an artificial road was constructed in the lab (Figs. 14, 15). It consists of a wooden framework that allows us to position the dowels with known incremental amounts of pitch, yaw and displacement. It holds 5 dowels and is wide enough to support the cart. It is elevated on sawhorses to keep it clear of the steel flooring.

As can be seen in Figure 15, the three center dowels may be positioned with pitch, yaw, horizontal or vertical displacement, or combinations of these misalignments. Data were collected with the cart for several of these possibilities; these data are shown in Appendix B. One example is shown in Figure 16. Each set of peaks represents a dowel bar. From left to right: 1) correct position; 2) rotated about x (B end high, A end low); 3) rotated about z (yaw, peaks displaced along x); 4) high (all peaks stronger, A1 and B1 magnitudes equal, all peaks aligned in x); 5) correct position.

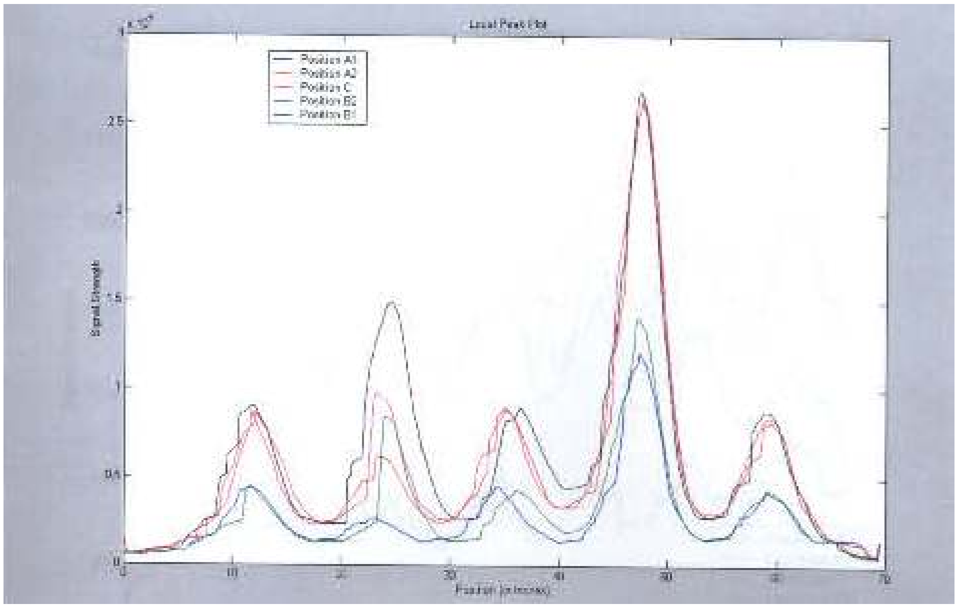


Figure 16. Strip chart graph of signal strength vs. x position for 5 dowel bars in artificial road. Nominal depth 3.5 inches.

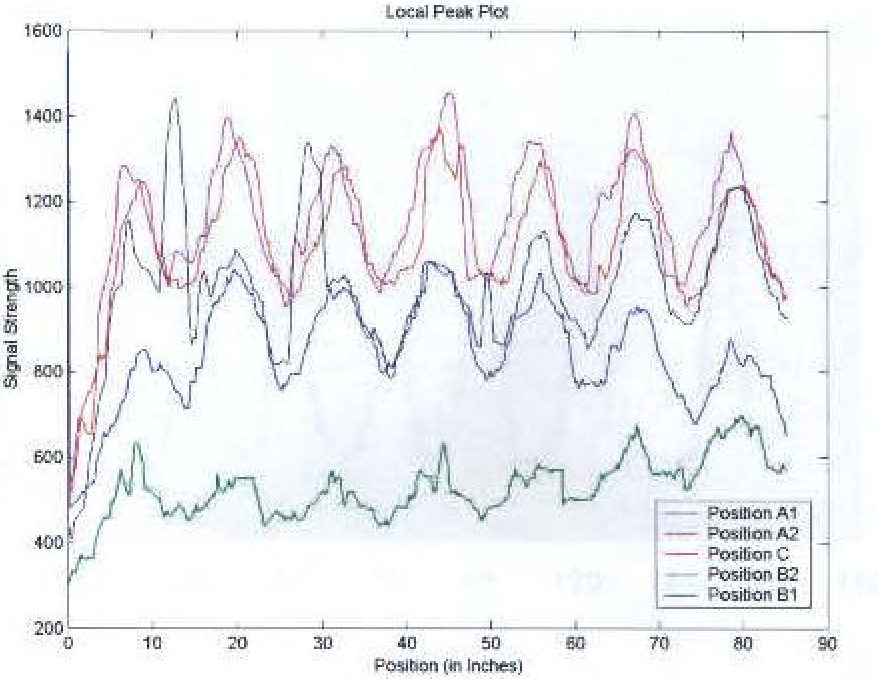


Figure 17. Strip chart of signal strength vs. position for field trial on I-70.

Field Trial Results

One saw cut on I-70 eastbound, just east of the Maple Hill exit, was measured with the instrument to determine its field usefulness. The strip chart result for the first seven dowels from the south shoulder is shown in Figure 17. The results are noisy enough to make conclusions difficult, but some observations may be made. The signal along position B1 (furthest east side of cut) is much weaker than the corresponding signal along A1. Furthermore, the signal at B2 is weaker than at C and A2. These two observations suggest that the bars on this cut are possibly shifted in y and also possibly pitched so the B end is lower than the A end. Since this seems to hold for all bars, the data suggest the B end of the basket has been crushed or deformed. The strength data indicate bar depths in the range of 6.5 to 7 inches. Other MATLAB-generated figures including three-dimensional views of the bars are in Appendix C.

We ran the instrument along the shoulder saw cut to scan for tie bars; the result is shown in Figure 18. The tie bars are easy to see and it appears one is misplaced at the end of this run. This run is with the sensor puck directly over the shoulder saw cut. We could determine absolute depth from peak signal strength with a calibration curve for tie bars.

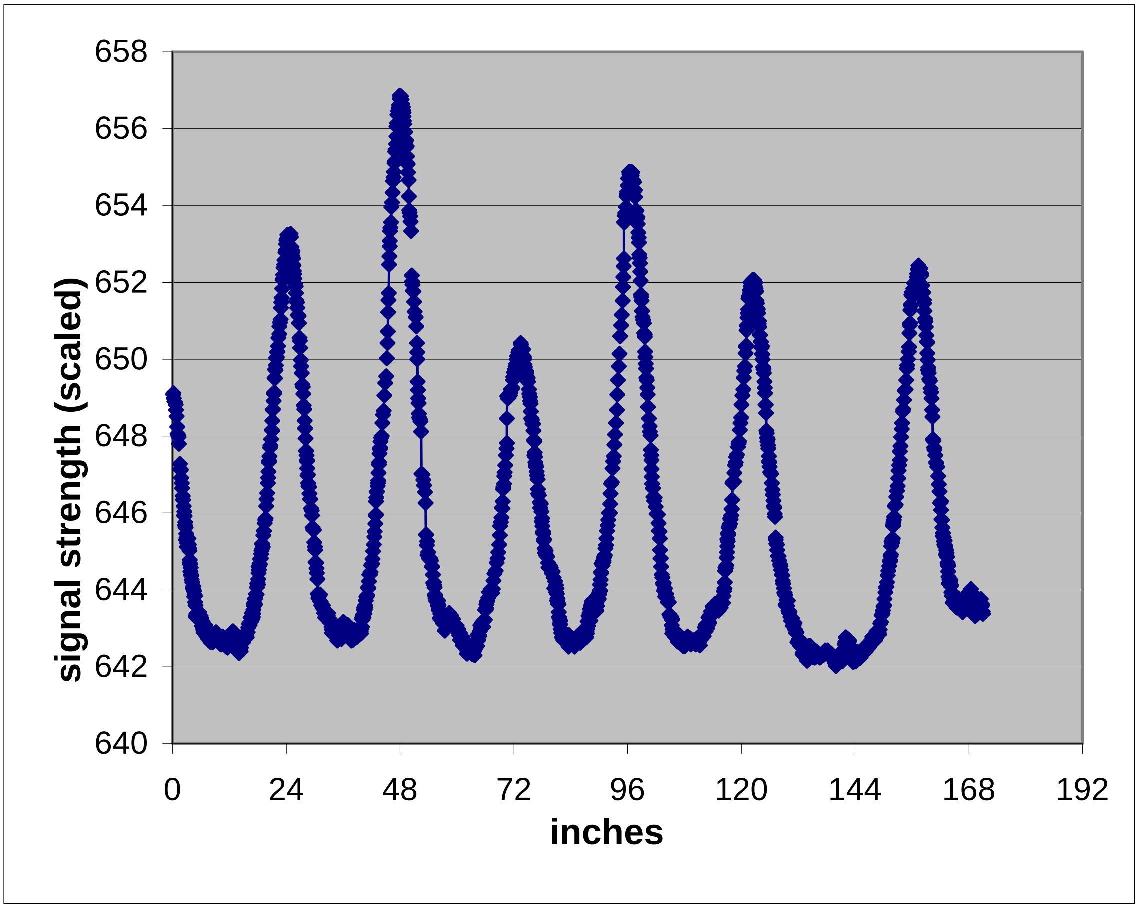


Figure 18. Location of tie bars along one section of pavement (from scanned saw cut running west.)

Discussion

The x-axis position resolution is limited by the maximum update rate of the covermeter. Linear displacement along the x axis translates into encoder counts through the circumference of the encoder wheel and the number of encoder counts per revolution generated by the shaft-position encoder. The minimum possible resolution is one encoder count; with the current wheel this translates into a theoretical resolution of 1/16 inch. The number of encoder counts per second depends on the speed at which the cart is pushed across the concrete. The update rate of the covermeter establishes a maximum usable encoder rate of 20 counts per second which then establishes a maximum speed at which the cart may be pushed of 1.25 inches/second.

The depth resolution of the measurement system is limited by the minimum detectable signal strength increment. Because of the generally exponential shape of the sensor transfer curve, noise becomes a significant part of the total signal at greater depths. To the extent that this noise is random in nature, it may be removed from the signal through filtering (averaging). However, this averaging requires repeated measurements at a given location and requires that the cart not be pushed faster than the repetitively-sampled data rate allows.
Currently the LabVIEW program tries to read the meter with every position encoder click. If instead the signal strength were read on every 5th or 10th click, the mechanical resolution would be decreased from the maximum possible, but would correspond better with the covermeter data rate and would permit some signal averaging. Thus x-axis resolution could be traded for depth (z-axis) resolution, or without averaging, for faster cart speed. Because the covermeter does not provide handshaking signals which would indicate when valid data become available, it is not possible to reverse the data collection process: that is, to use updated signal strength measurements to trigger corresponding position measurements.

Alternatively, a stronger send signal from the sensor puck would improve depth resolution; a larger power source would be needed to drive it. The speed of signal acquisition is ultimately limited by the decay rate of the magnetic field signal. We have determined that the covermeter excitation rate is 400 Hz, while its data output rate is 20 Hz. This difference may reflect internal averaging as well as user-interface overhead. With a complete redesign of the covermeter, it might be possible to increase the data rate by a factor of 5 or more. This would allow either higher cart speed or better depth resolution or a combination of the two.

Future Work

There are a number of software enhancements that could be developed for this instrument. An improved user interface for the LabVIEW program would include a front-panel strip chart graphically showing data as it is collected, a speed monitor to visually guide the operator in maintaining a sufficiently slow speed to prevent overrunning the sensor, and a provision for entering data filenames on the front panel. Within the programs themselves, the MATLAB data processing script can be incorporated into the LabVIEW executable program. Also, the present program assumes the first signal peak (dowel bar) of a run will occur within twelve inches of the instrument’s start position. A peak locator routine could make the program more flexible, to allow for severely mis-placed or missing dowels at the start of any run. Finally, from the collected peak data a routine could be written to calculate and output pitch, yaw and displacement data in tabular form for the set of scanned dowels.

The present, commercially available covermeter is operating near the limit of its range at 6" depth. Greater accuracy could be obtained by designing a new sensor and electronics to create a stronger magnetic field stimulus and thus increase the received signal strength. This would allow determination of steel position at depths greater than six inches with better resolution. Such an improved design could include multiple simultaneous sensors to collect all position data with one sweep of a saw cut. This in turn would require careful coordination of stimulus and detection among the sensors to prevent interference and potentially to take advantage of signal enhancement from multiple excitations.

Lastly, because the instrument must be pushed quite slowly and precisely along a saw cut to collect useful data, it may prove helpful to incorporate the dowel-scanning instrument into a robotic device that would automatically locate and scan along saw cuts.

Conclusion

The instrument developed in this project uses a commercially available product designed to detect steel in concrete (in this case, the Koelectric ProbeA3D Covermeter). We have verified that it can satisfactorily locate steel dowel and tie bars to depths of seven to eight inches, and up to twelve inches if sufficient averaging time is permitted. When mounted in our cart device, it is able to quickly locate dowel and tie bars in roadbed with moderate accuracy. The instrument examines the pavement underlying an entire saw cut at once, processes the data and presents it in a manner permitting the user to quickly ascertain the placement of each bar in three dimensions, as well as patterns of placement of all bars along the scanned cut. With the complete instrument, users need not collect data by hand nor analyze it to discover patterns or locate more than one bar at a time.

At this point in development, positional information can be provided in yaw, pitch and displacement within ½ to 1 inch, when the instrument is operated at a sufficiently slow speed. Software extensions would permit automated display of these quantities in any desired format. A stronger stimulus will be necessary to measure steel positions at depths below seven inches if greater resolution and/or greater scan speed are desired. Even though scan speed is fundamentally limited by the natural decay times of induced magnetic fields in steel, it may be possible to design an enhanced instrument capable of resolving displacements to perhaps 1/8" at more convenient scan rates. A design incorporating multiple probes and software enhancements could result in a more effective locating device of practical utility.

Reference

[1] Magnetic Imaging Tools, http://www.mit_dresden.de/ (in German), June 2001.

Appendix A: User Manual for Dowel Detection Instrument

*****filenames and paths may need revision** - Made for a KDOT***

Operation of the instrument consists of executing the LabVIEW program to collect five strips of data along a saw cut, and then processing the data through the MATLAB program to obtain plots. The steps are as follows, on the KDOT laptop.

Collecting Data:

1) Open LabVIEW 6i, and on the startup screen choose "open file". The LabVIEW file is called ***kdotproj2*** and is found in the ***C:\kdot*** directory.

2) Align the instrument so the centerline is on top of the saw cut. It is probably best to start at the shoulder, with the sensor puck aligned with the saw cut between main road and shoulder. Turn on the covermeter by pressing the red button. The meter will beep and display an initialization screen, and then switch to a screen with depth numbers at the and menus at the bottom. If you like at this point use the yellow arrow button to choose the number of the steel you are expecting to look for; however, the data coming off the serial port will not be affected by the type of steel selected. Hold the puck up an arm's length from any metal (including the laptop, the road surface and any vehicles) and press "calibrate". The meter display should then read 14.2. Place the sensor puck into one of the holes in either template; C, A2 or B2 is preferred for the first run as the signal at A1 and B1 will be weak and it will be harder to tell if all is working properly. The meter will probably read something between 8 and 10 inches unless you are very near some steel.

3) Click on the "run" arrow on the left-hand side of the menu bar at the top of the LabVIEW front panel display. The arrow will look like it is moving, and a hexadecimal number should appear in the output window. Begin slowly pushing the cart forward along the saw cut. The red needle should move about, and numbers should change in the output window as well as in the windows labeled "angle". The bouncing back and forth of the red needle is noise; the slower you go the less bounce you will get and the better your data will be. When you get to the end of the saw cut, or as far as you wish to go, click the "STOP" button and pull the cart back to where you started.

4) LabVIEW saves the position data to a file named ***C:\kdot\ksutests***\position.txt, and the signal data to a file named ***C:\kdot\ksutests***\signal.txt. You must rename these files before starting another run. Open the appropriate directory and rename them position**.txt and signal**.txt, where ** is "C", "A1", "A2", "B1" or "B2", depending on which strip you just scanned. These are the names the MATLAB file will be looking for.

5) Re-align the cart exactly as you did for the first run, move the sensor puck to a different position, click the "run" arrow on the LabVIEW front panel and proceed as for step 3. Repeat until you have scanned all 5 strips.

6) Troubleshooting: the LabVIEW program will occasionally lock up: the red needle will freeze and no numbers will show in the output window, though the "angle" numbers may continue to change. Causes of this may be that Windows has demanded time from LabVIEW, the covermeter has timed out and gone to sleep, or something else. To restore function after checking that the covermeter is awake, first try closing LabVIEW entirely and then restarting it. If this does not work, restart the computer, after checking that the serial cable and DAQ card are firmly connected to the computer. Watch the red needle continually while walking along the saw cut, since the program may freeze in the middle of a run. Be sure to delete the position.txt and signal.txt files before restarting the program. If the covermeter has timed out and you must turn it back on, be sure to re-calibrate it as per step 2 above before starting the LabVIEW program running.

Processing Data:

Once all 5 strips of data have been collected and the files renamed appropriately, open MATLAB and type: ***AmainKDOTv1*** on the command line. The MATLAB program should locate all the data files and process them, opening four graph windows as described in the report. In the command window the program will print a list of all the dowels located and the depth to the center of each bar.

Appendix B: Laboratory Results

The plots that follow are those produced by the Matlab program after collecting five runs of data over five dowel bars in the experimental apparatus shown in Figs. 14 and 15 of the report. Each data set produces four graphs, all of which contain the same data but give differing displays for ease of interpretation. In order, the dowel placements are:

Figs B1-B4: all bars straight and at 6.5" centers below the “road” surface.
Figs B5-B8: three bars at 3.5" depth, second and fourth dropped down one diameter.
Figs B9-B12: nominal depth 3.5"; one bar pitched (one end lower than the other); one yawed (rotated about a vertical axis), and one raised one diameter.
Figs B13-B16: nominal depth 6.5", one bar pitched, one yawed and one raised one diameter.
Figs B17-B20: nominal depth 3.5", one bar raised, one shifted right and one lowered one diameter.
Figs B21-B24: nominal depth 3.5", one raised, one yawed and one lowered one diameter.
Figs B25-B28: nominal depth 6.5", one lowered, one yawed and one raised one diameter.

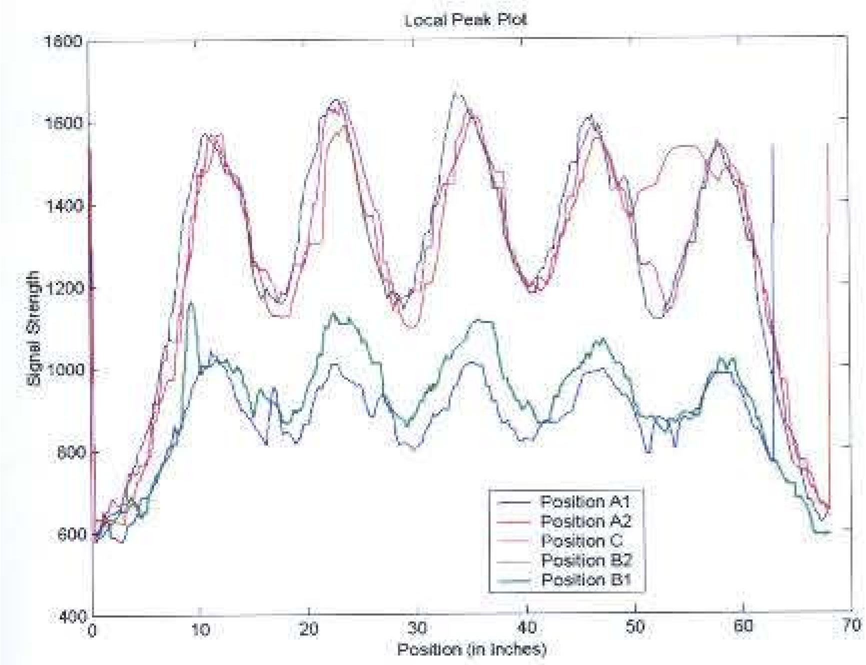


Figure B1. Strip chart of data from 5 bars at 6.5 inches and in correct placement.

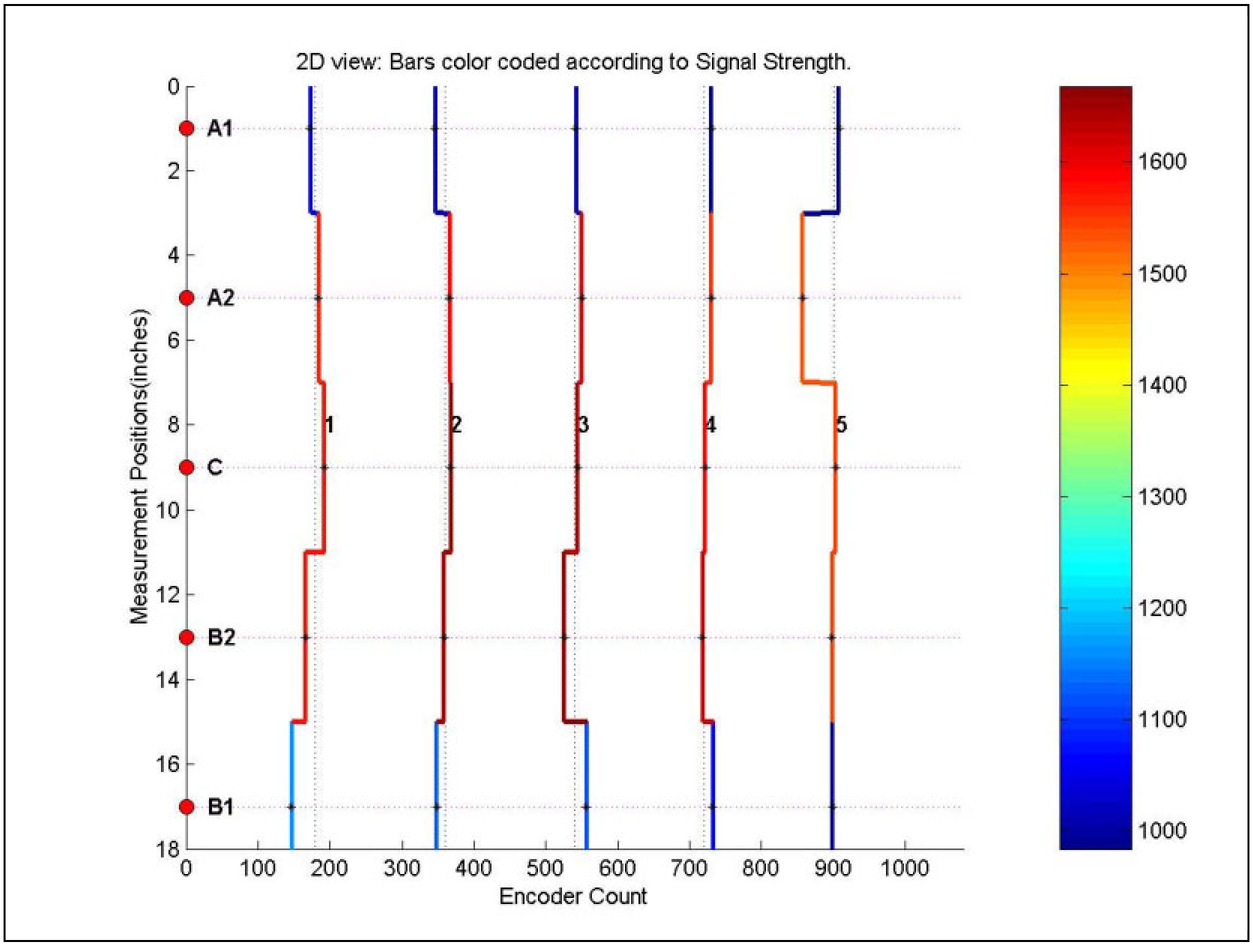


Figure B2. “Top view” of bars as calculated from data in Fig. B1. Color shows signal strength (correlates with depth.) Horizontal axis is perpendicular to traffic flow.

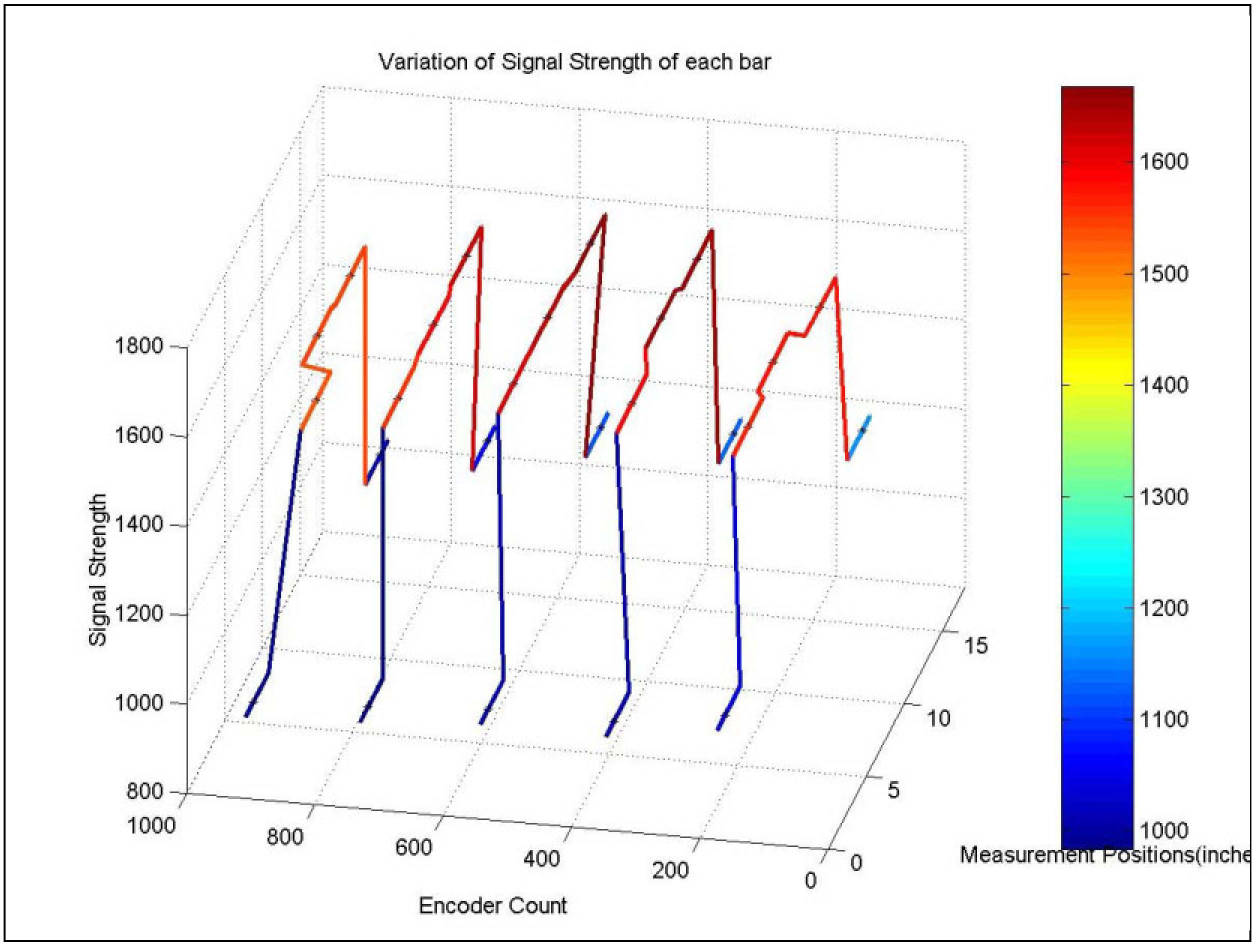


Figure B3. Same data as in Figure B2, with signal strength shown as a third axis.

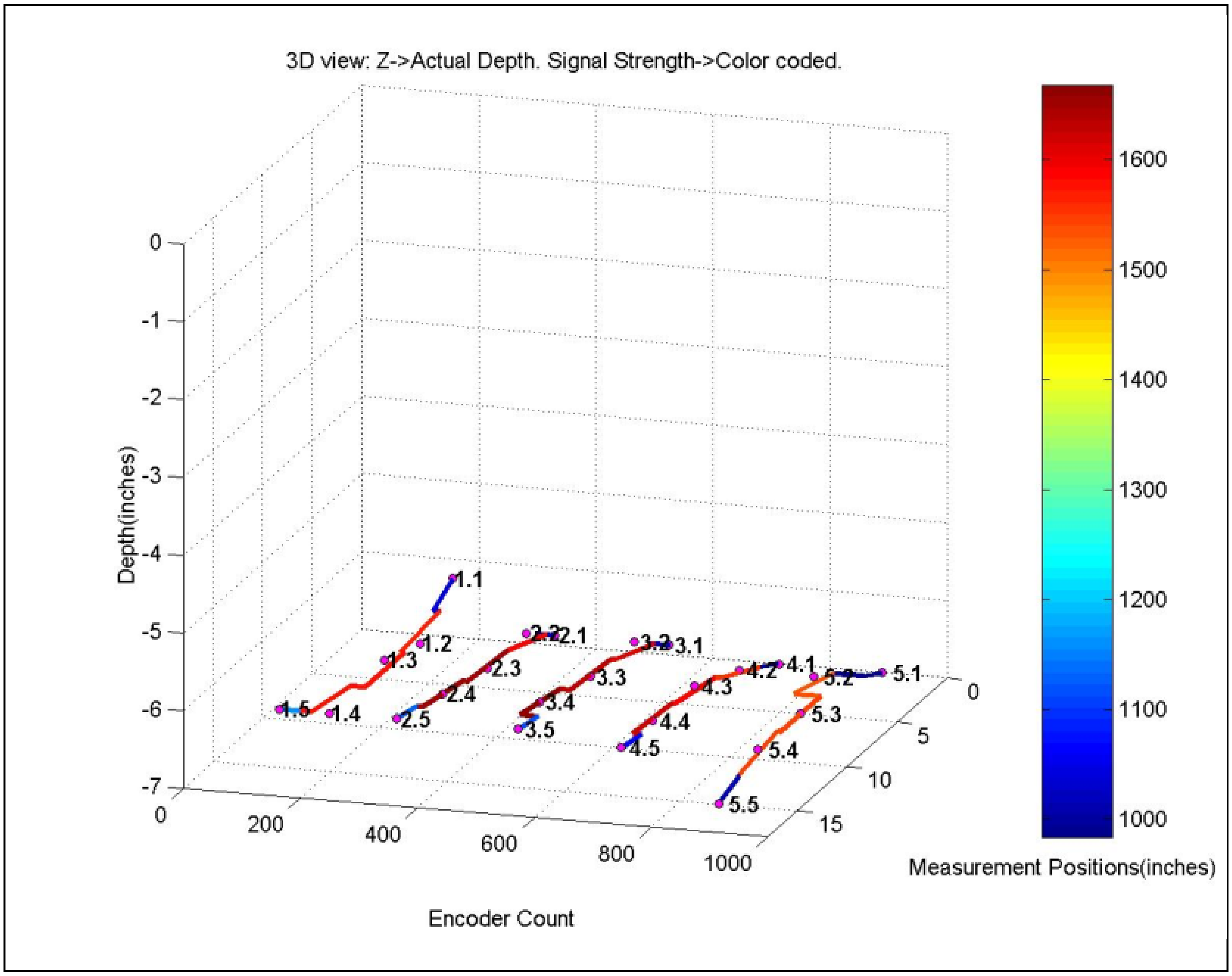


Figure B4. Same as Figure B3 but with signal strength converted to depth. Depth axis assumes zero as surface of concrete. Numbers on lines label dowel number and data stripe, not depth. Calculated depths are 6.25” for bars 1, 2, 3 and 4; 6.5” for bar 5.

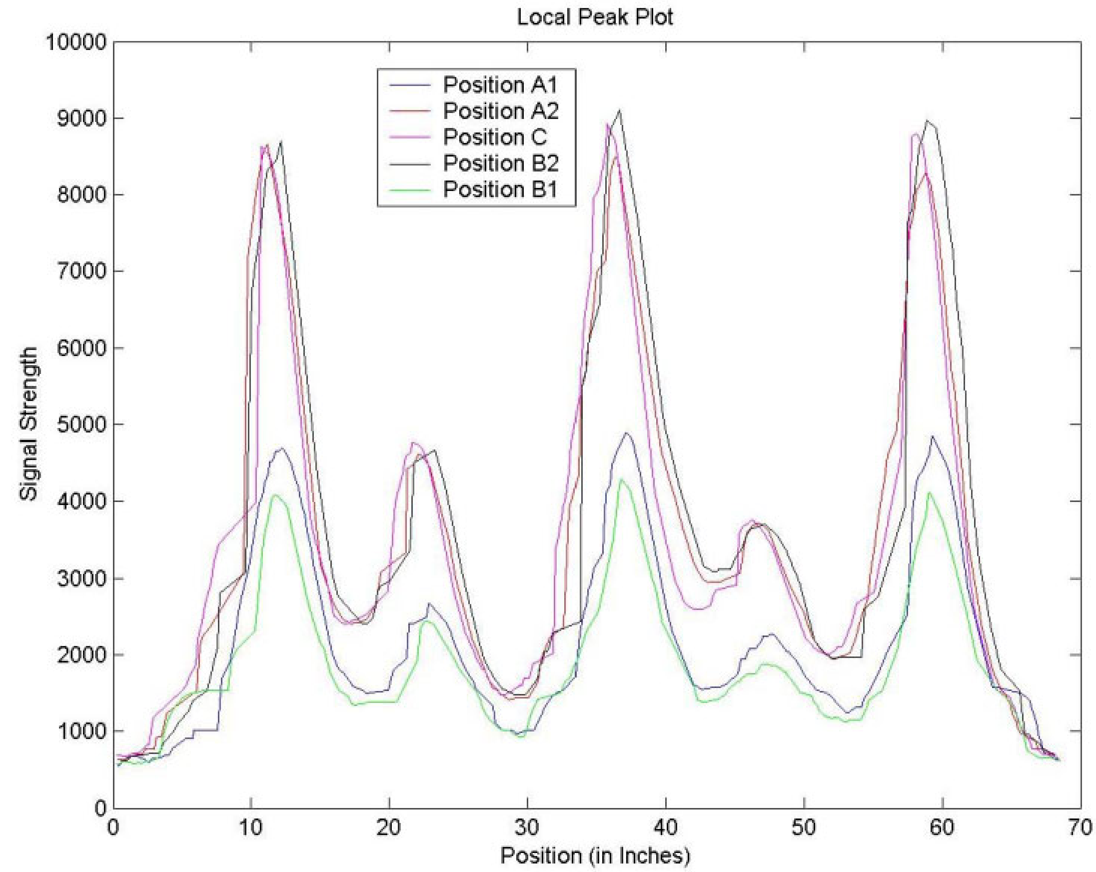


Figure B5. Strip chart data from bars at nominal 3.5” depth; second and fourth bars displaced downwards one diameter; third bar displaced to the right one diameter.

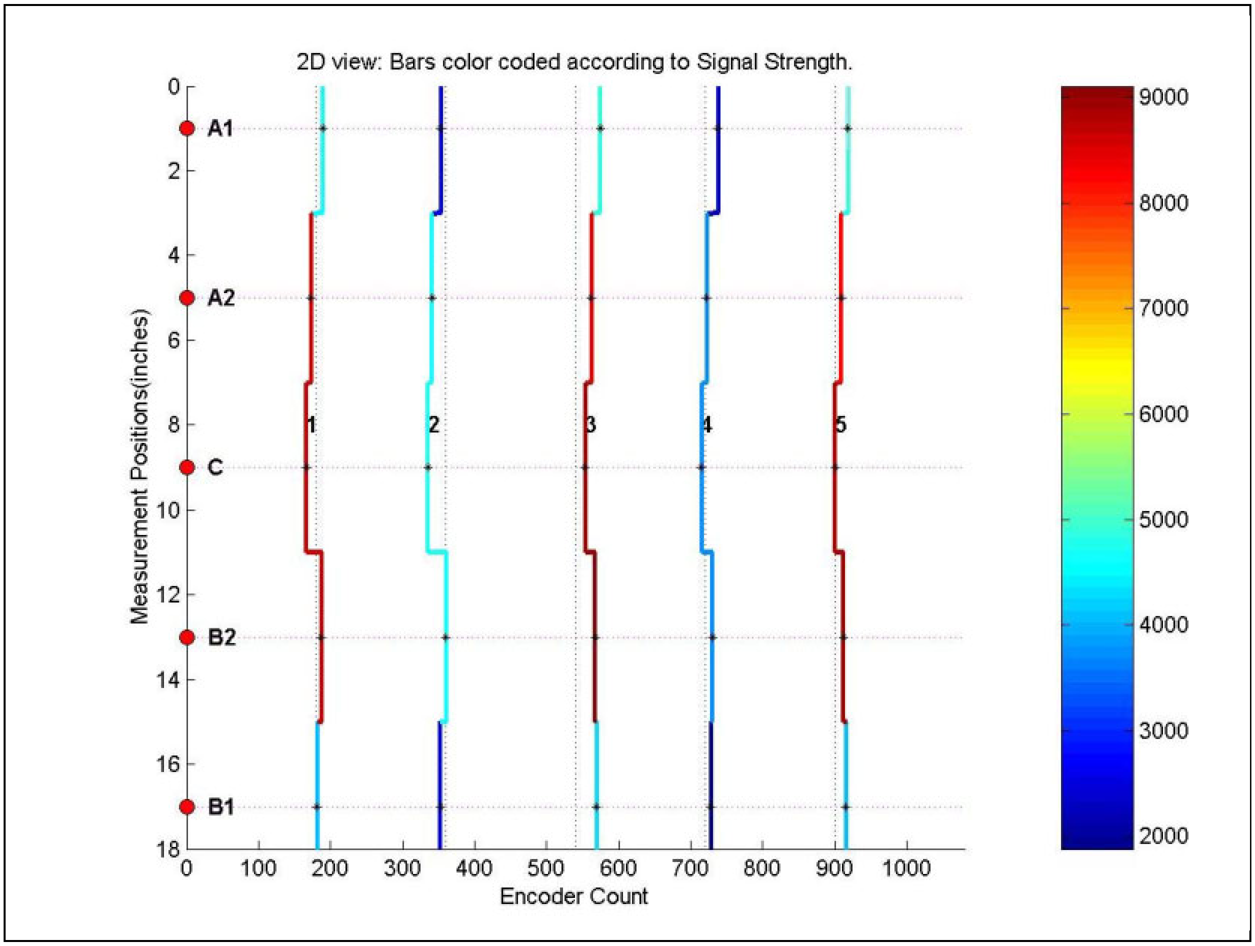


Figure B6. Top view of bars as calculated from data in Fig. B5.

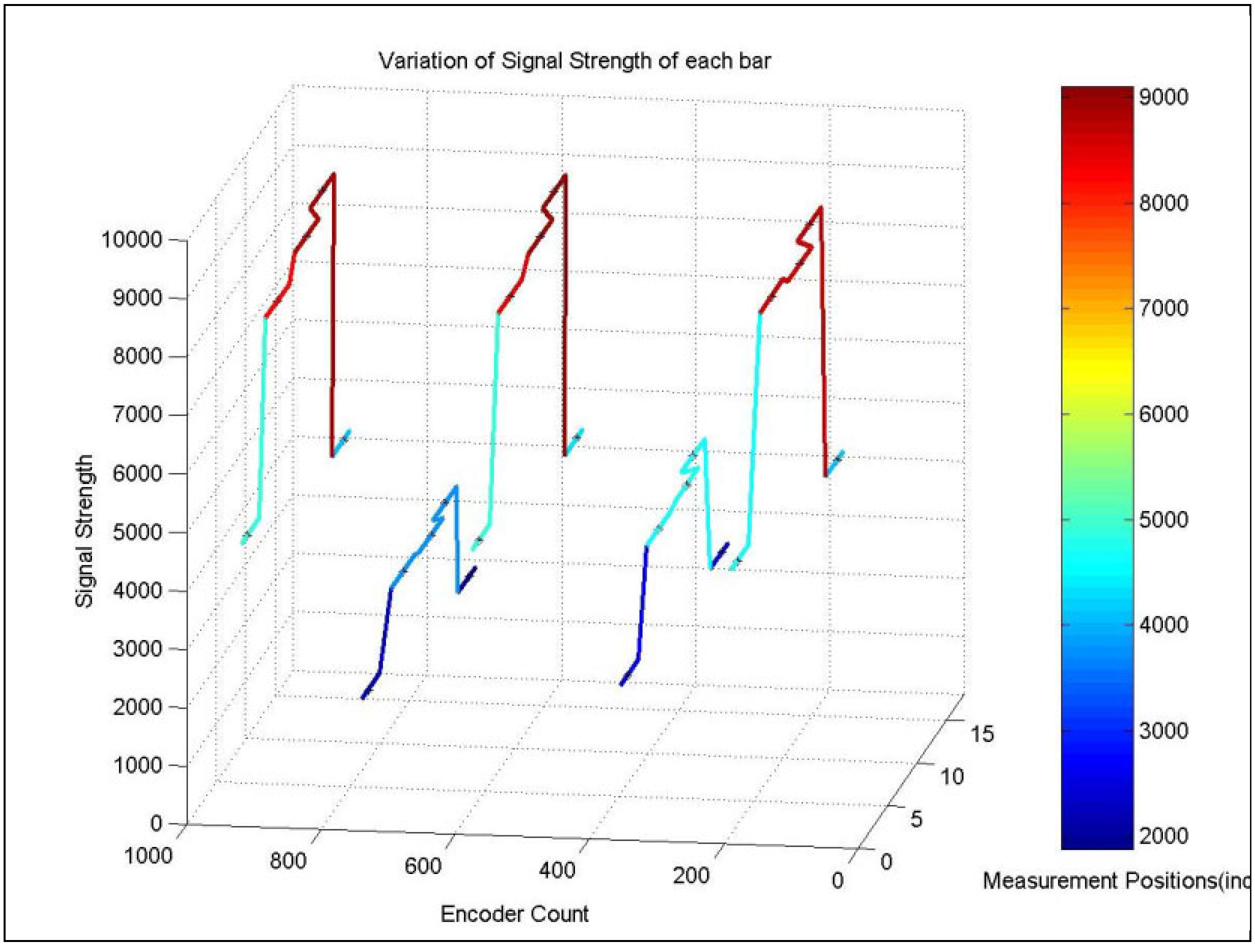


Figure B7. Data from Fig. B6 with depth added as a third axis. Note x axis is reversed left-to-right.

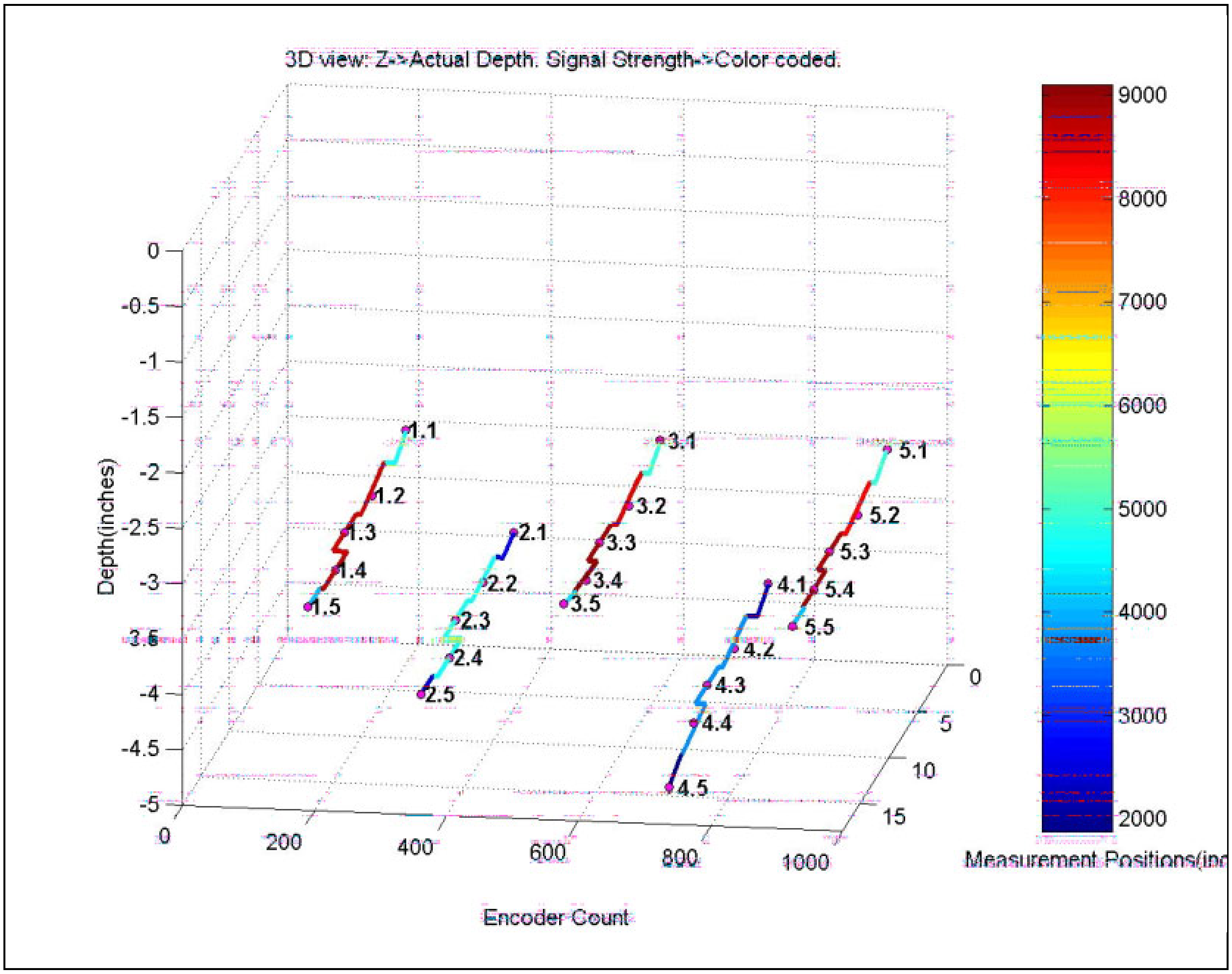


Figure B8. Data from Fig B7 with absolute depth shown. Calculated depths are 3.25” for bars 1, 3, and 5; 4” for bar 2; and 4.5” for bar 4.

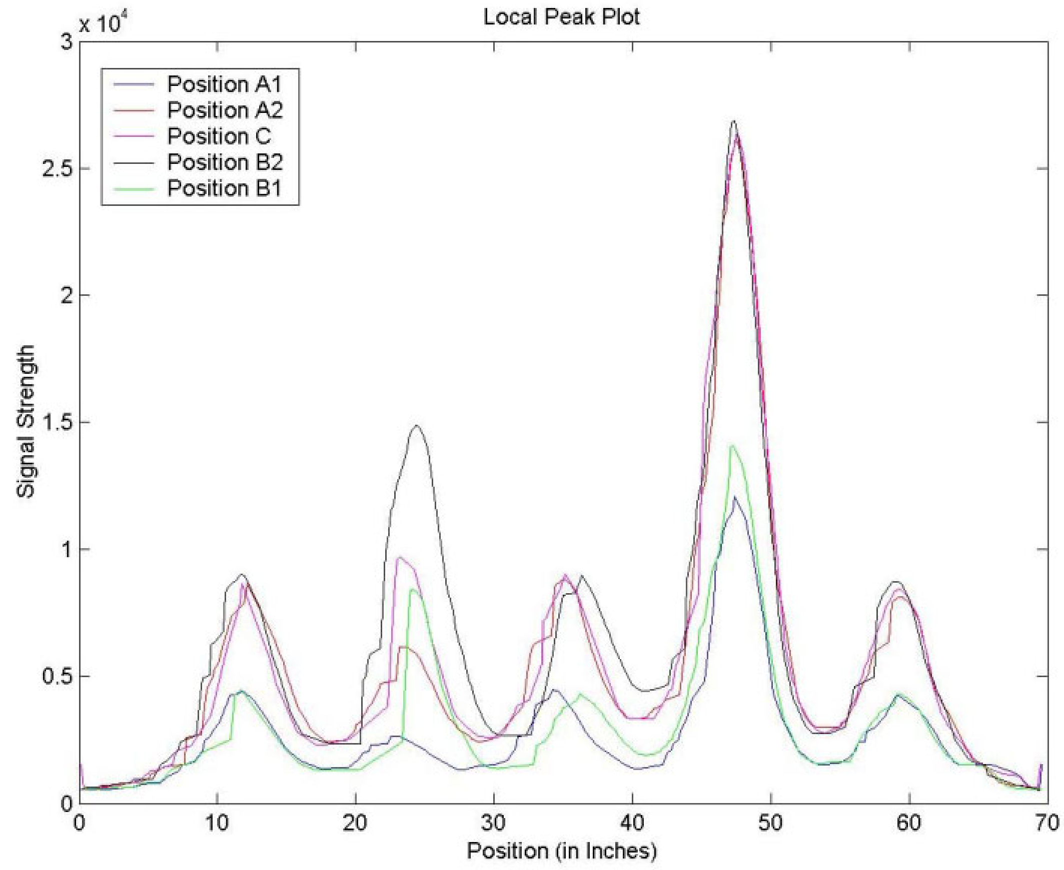


Figure B9. Strip chart of data from array with 3.5-inch nominal depth, second bar pitched (A end down), third bar yawed and fourth bar raised one diameter.

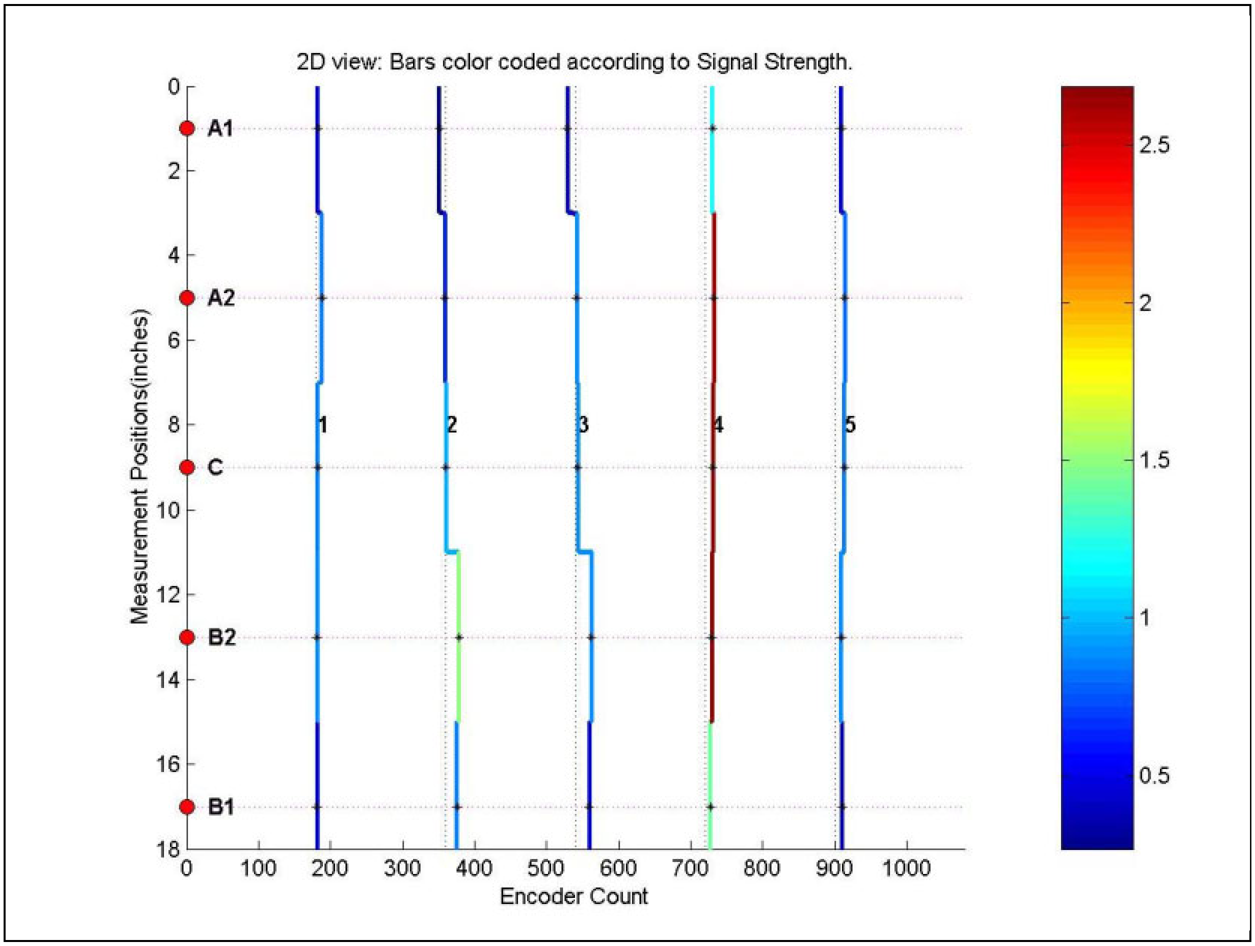


Figure B10. Top view of bars calculated from data in Fig B9.

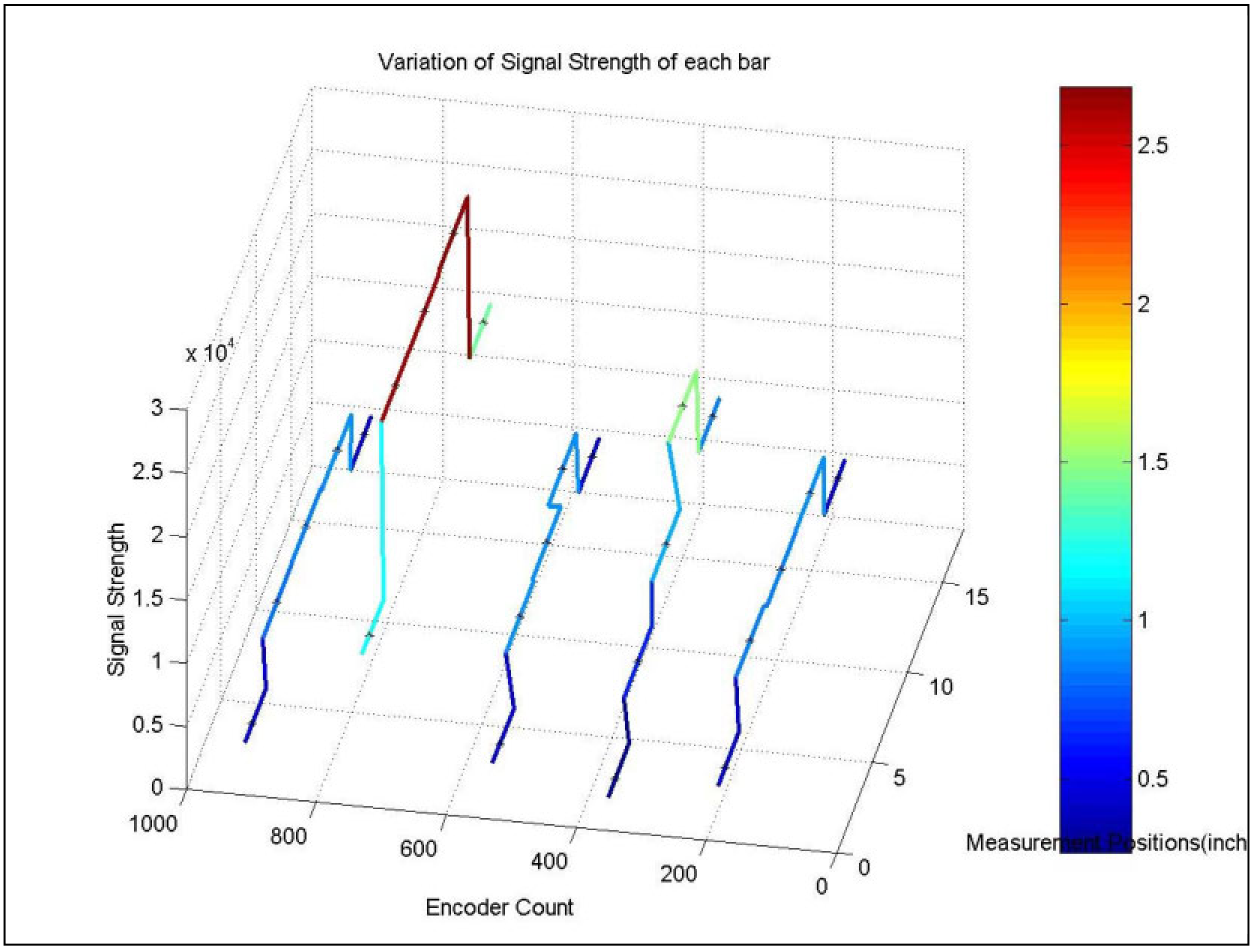


Figure B11. Data from Fig. B10 with signal strength as third (z) axis.

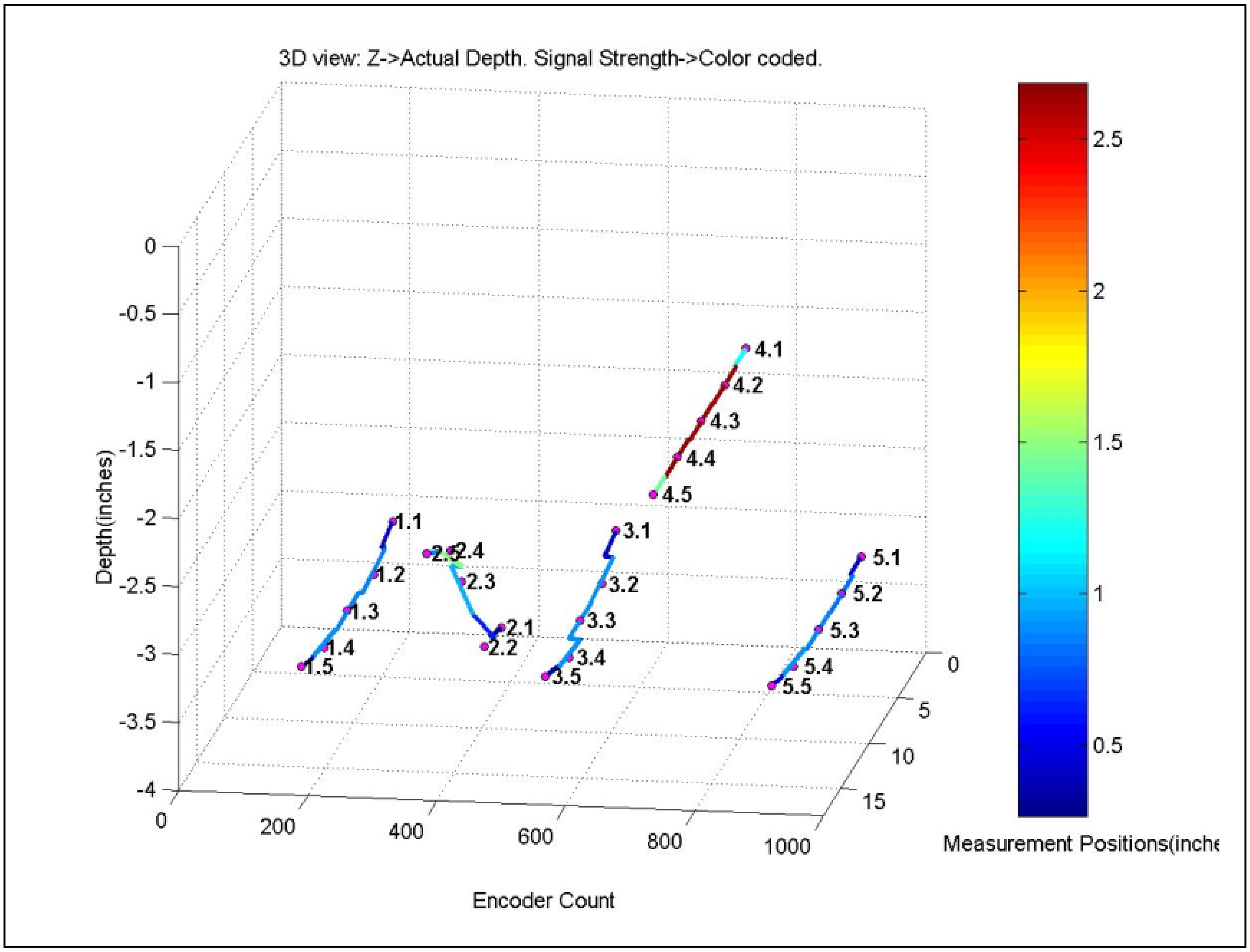


Figure B12. Data from Fig. B11 with depth in inches shown. Calculated nominal depths are: for bars 1, 3 and 5: 3.25"; for bar 2: 3"; for bar 4: 1.75".

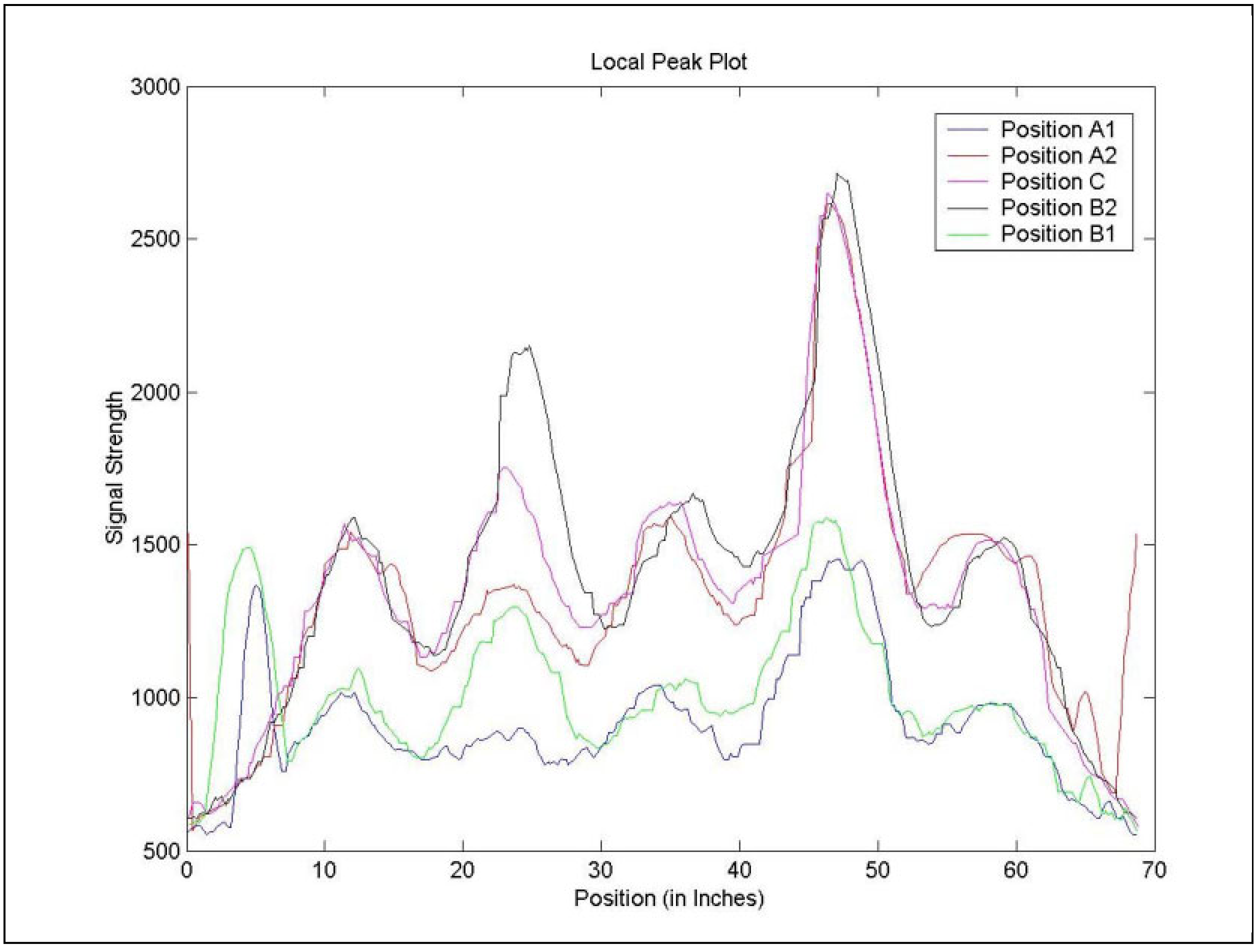


Figure B13. Strip chart of data from array at nominal 6.5-inch depth, with second bar pitched, third bar yawed, fourth bar raised one diameter.

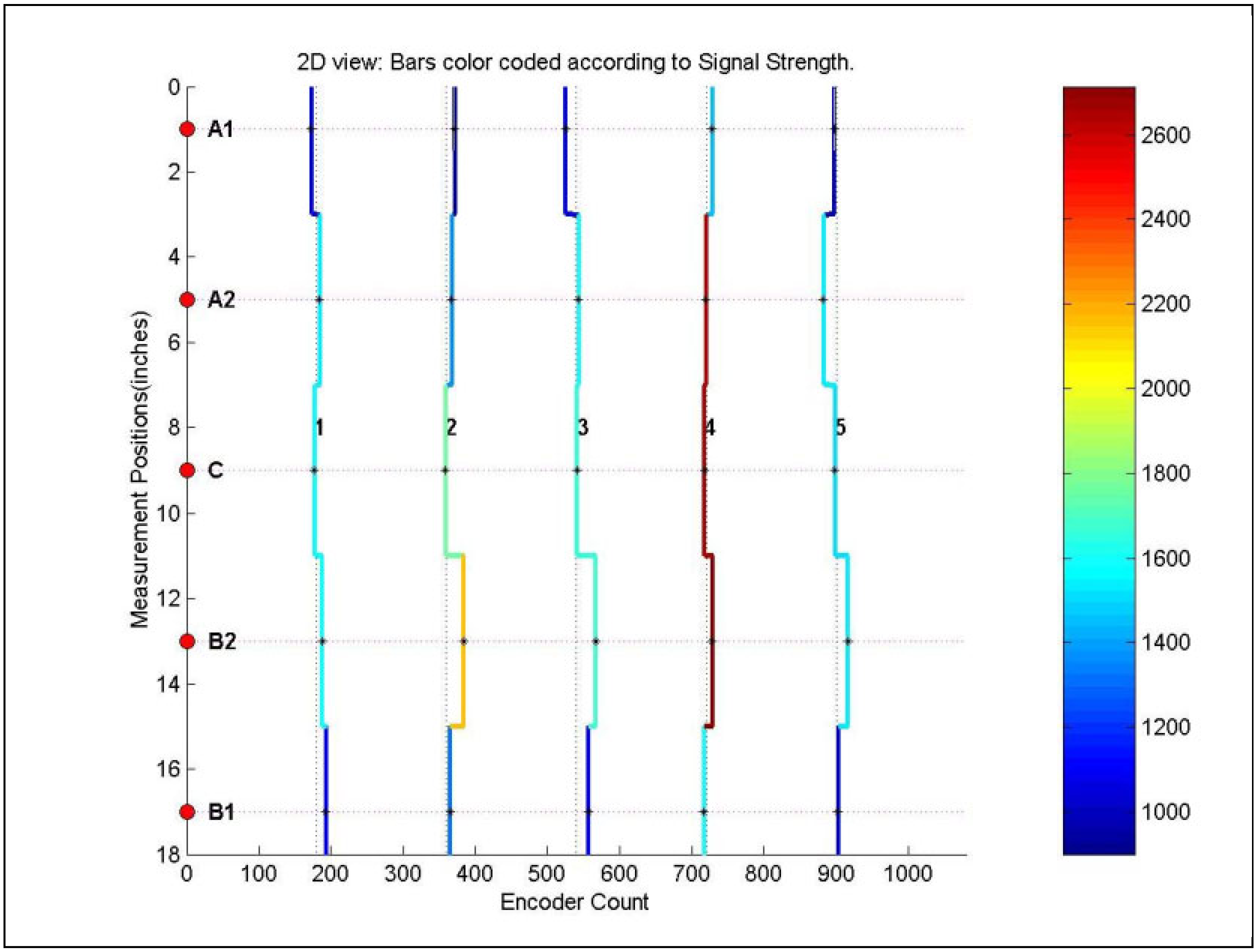


Figure B14. Calculated bar positions, top view, from data in Figure B13.

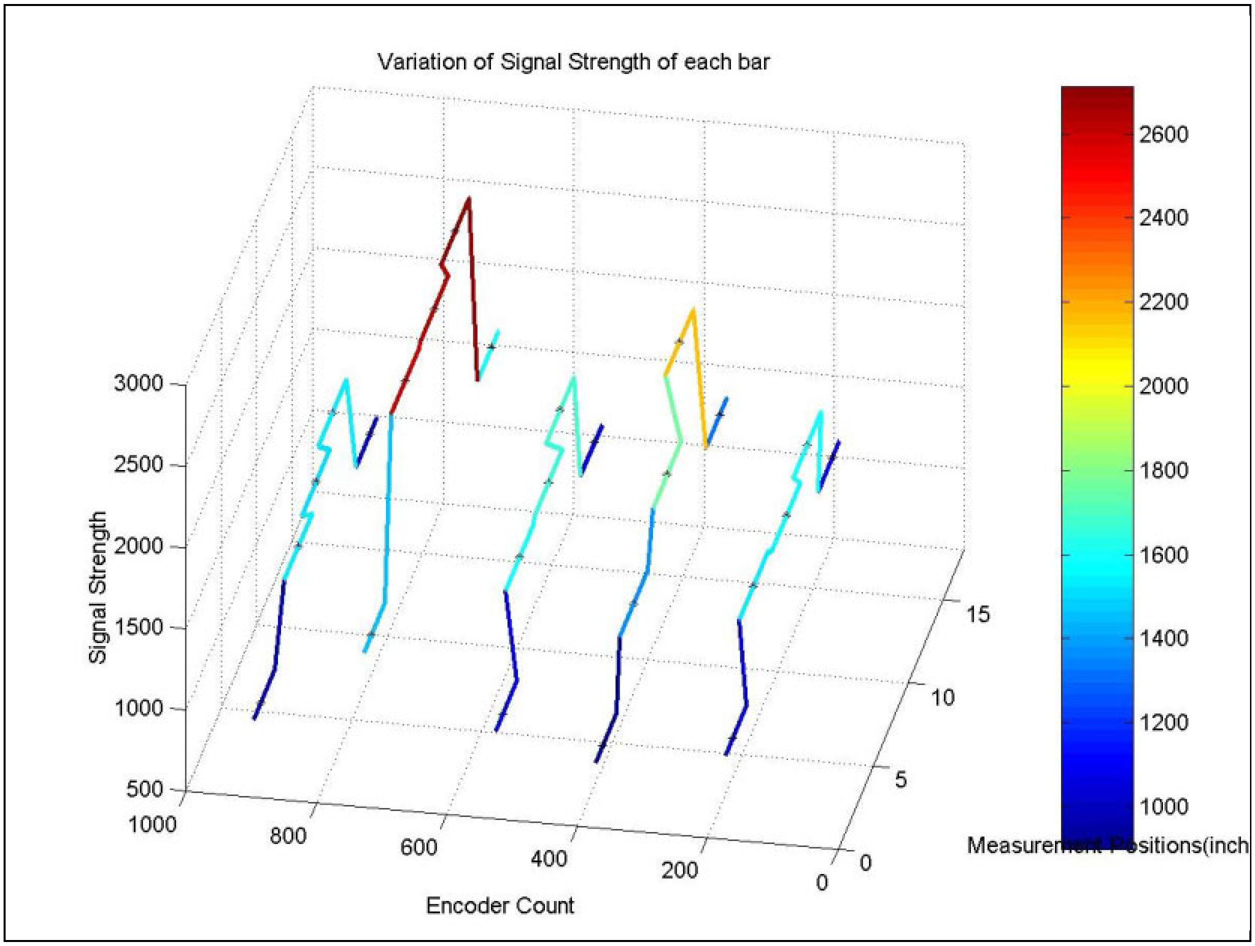


Figure B15. Same as Fig. B16, with signal strength added as third axis.

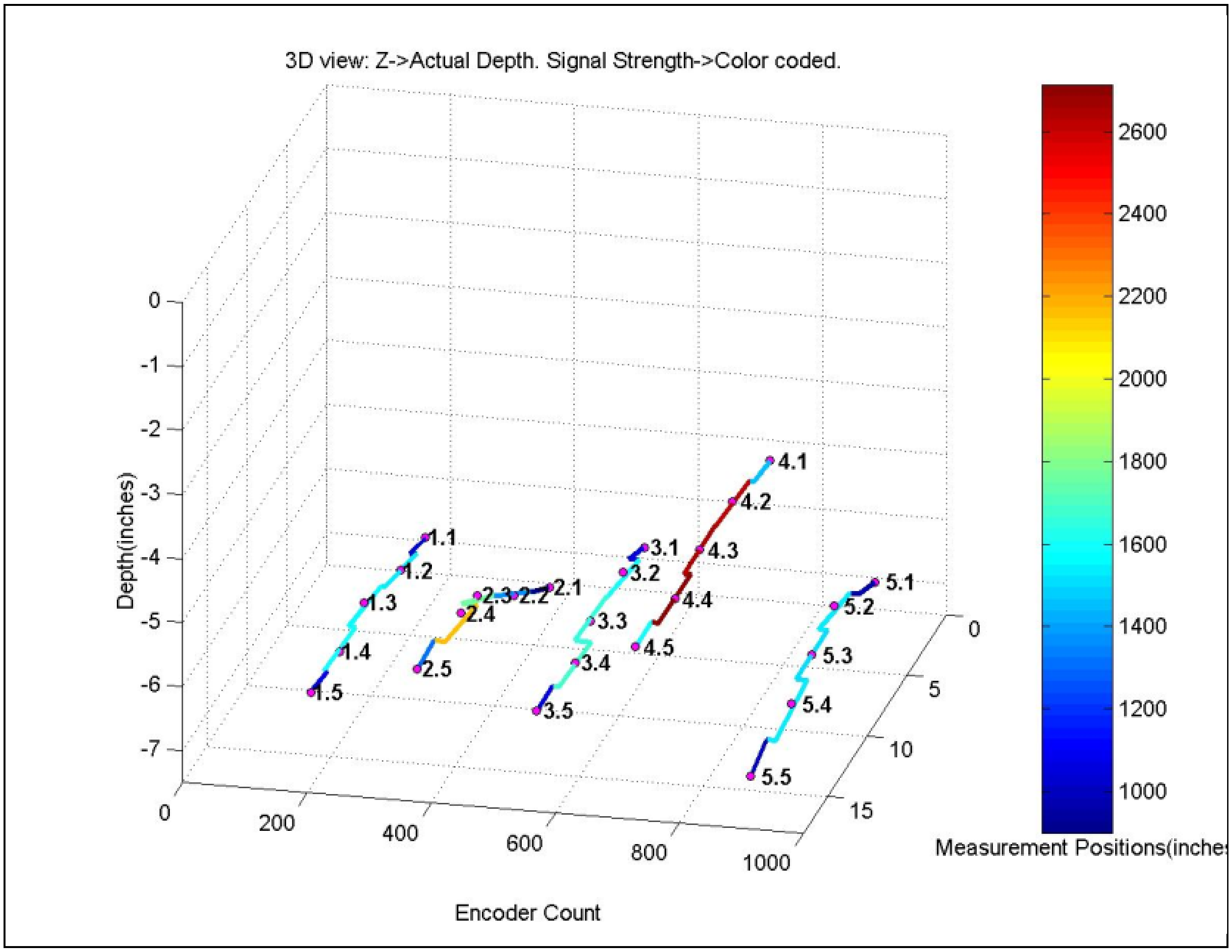


Figure B16. Data from Figure 15 with signal strength converted to depth. Calculated center depths are 6.25” for bars 1, 3 and 5; 6” for bar 2 and 5” for bar 4.

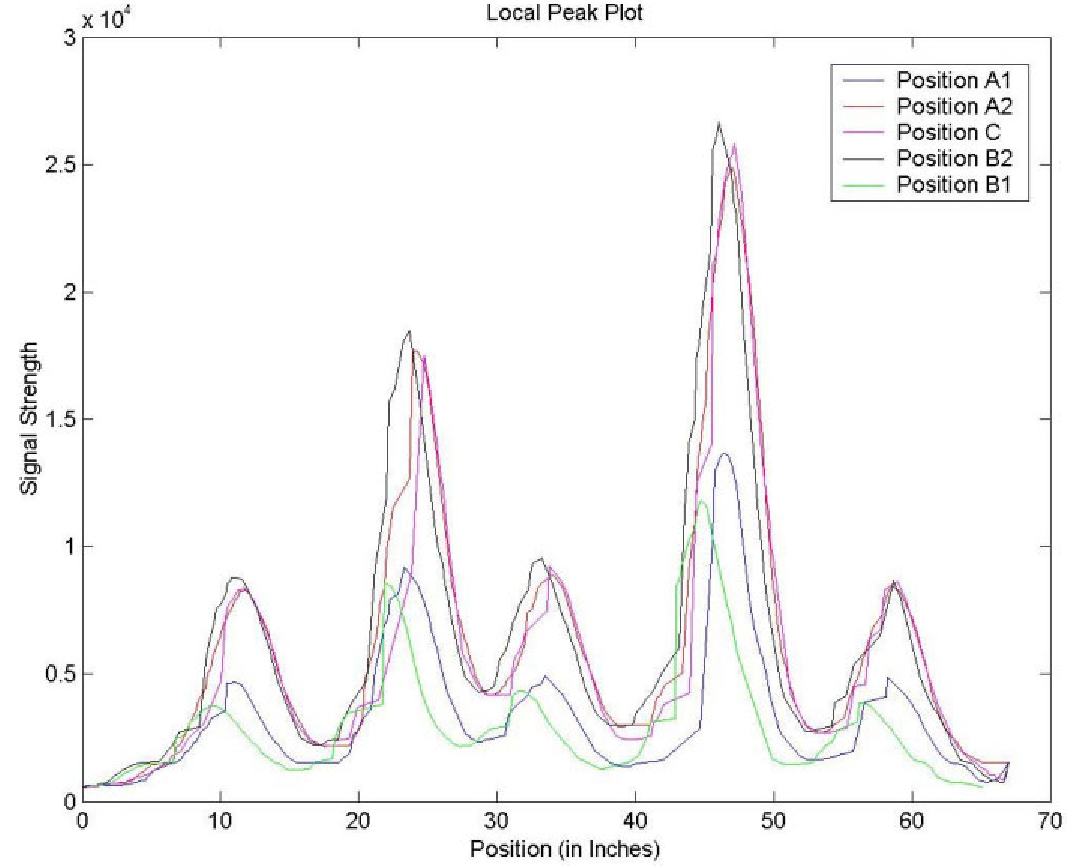


Figure B17. Strip chart from bars at nominal 3.5” depth, with second and fourth bar up one diameter, third bar shifted right one diameter.

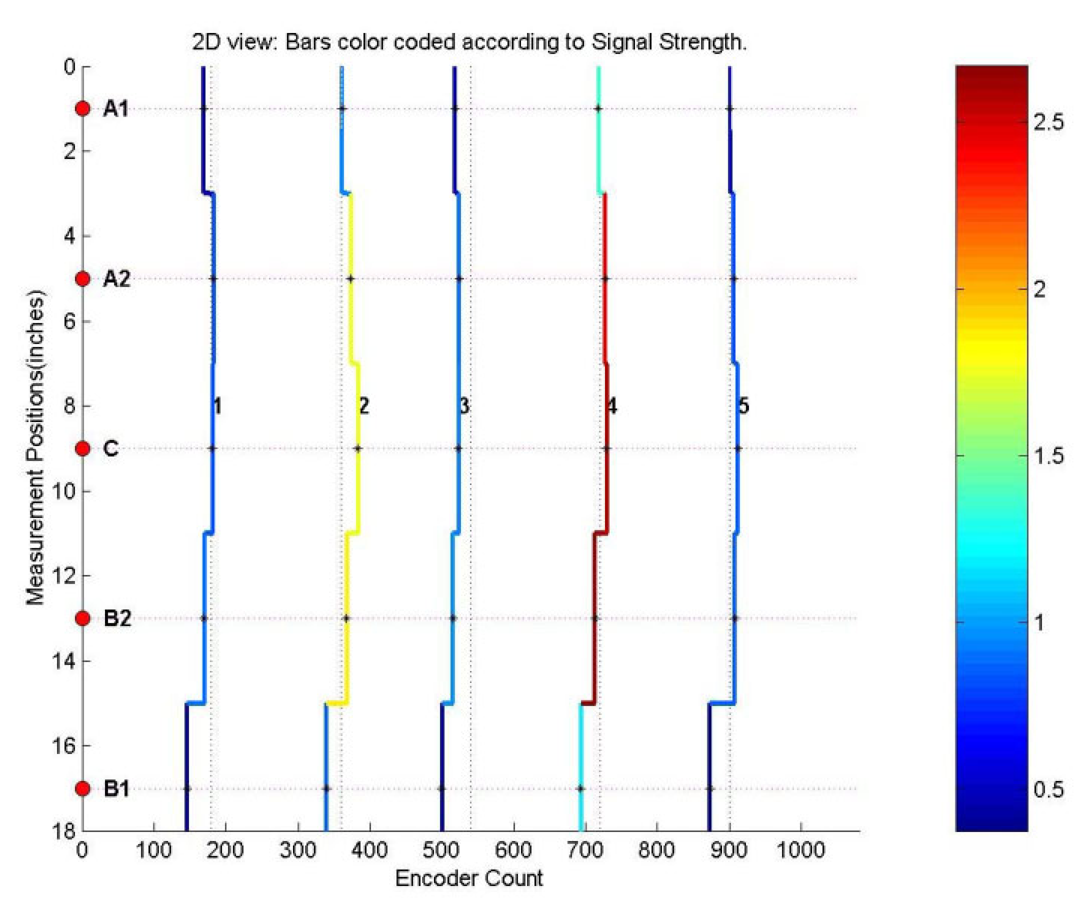


Figure B18. Calculated top view of bars from data in Figure B17.

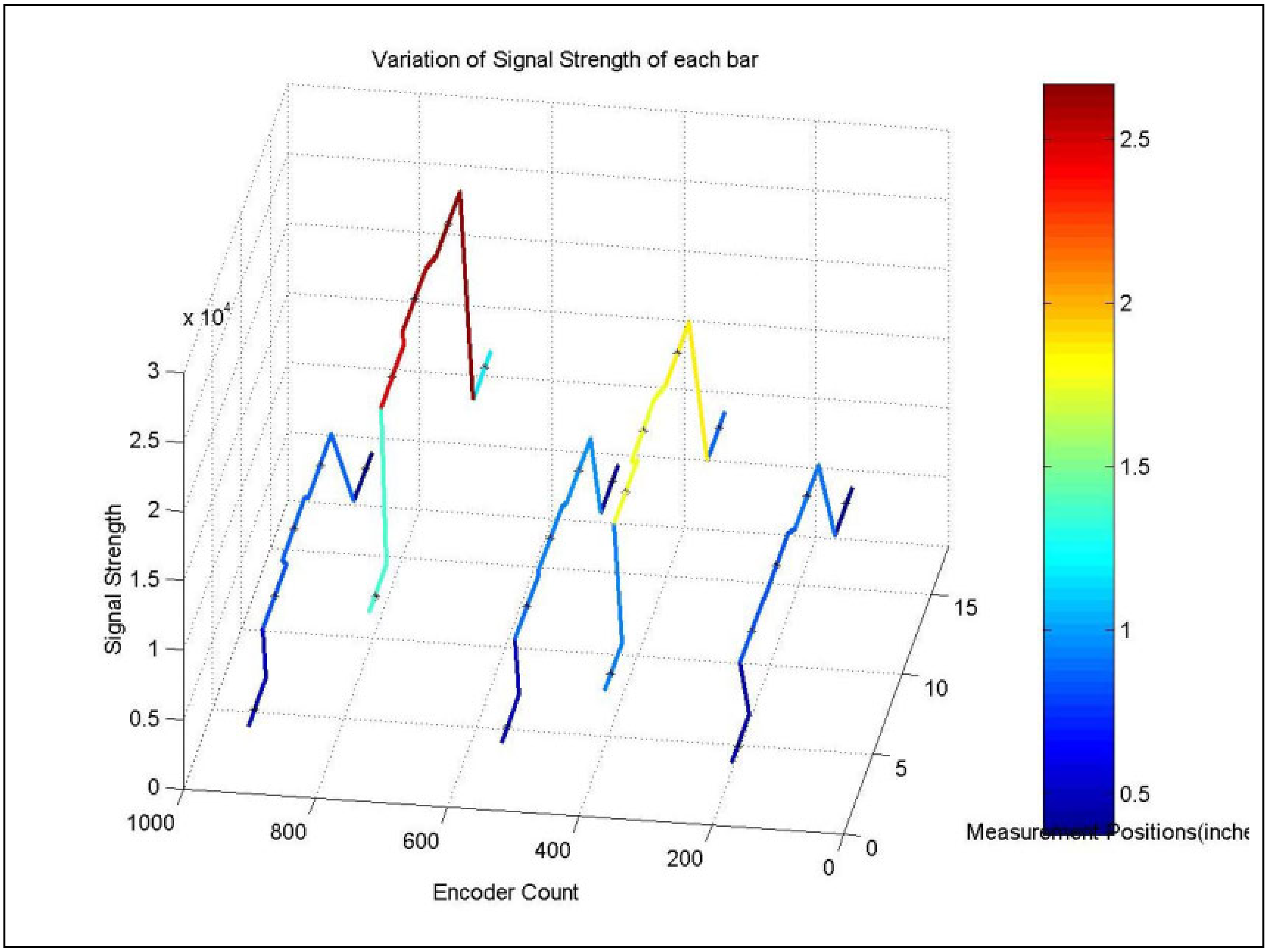


Figure B19. Same as Fig. B18 with signal strength as third axis.

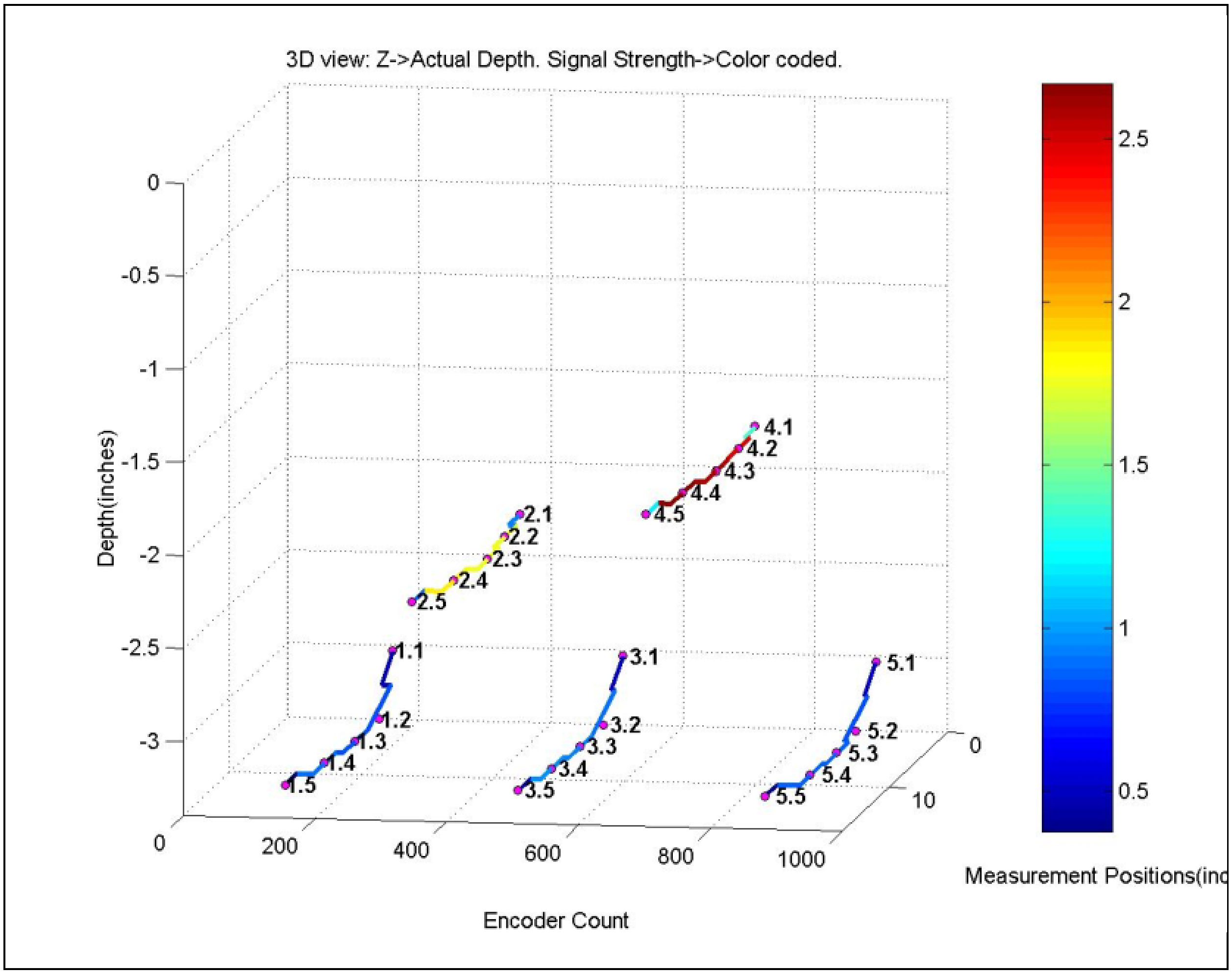


Figure B20. Same as Figure B19 but with signal strength translated to depth. Calculated nominal depths for bars 1, 3 and 5: 3.25”; for bar 2: 2.25”; for bar 4: 1.75”.

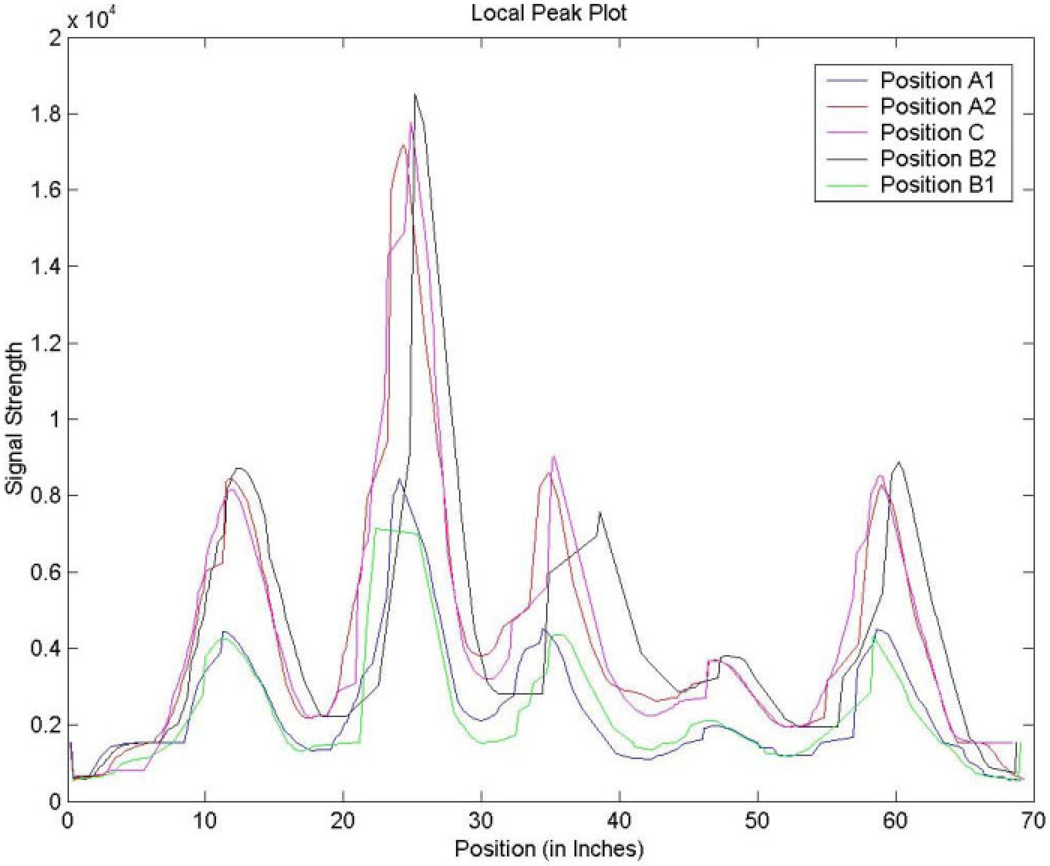


Figure B21. Strip chart of data with array at nominal 3.5” depth; second bar up one diameter, third bar yawed, and fourth bar down one diameter.

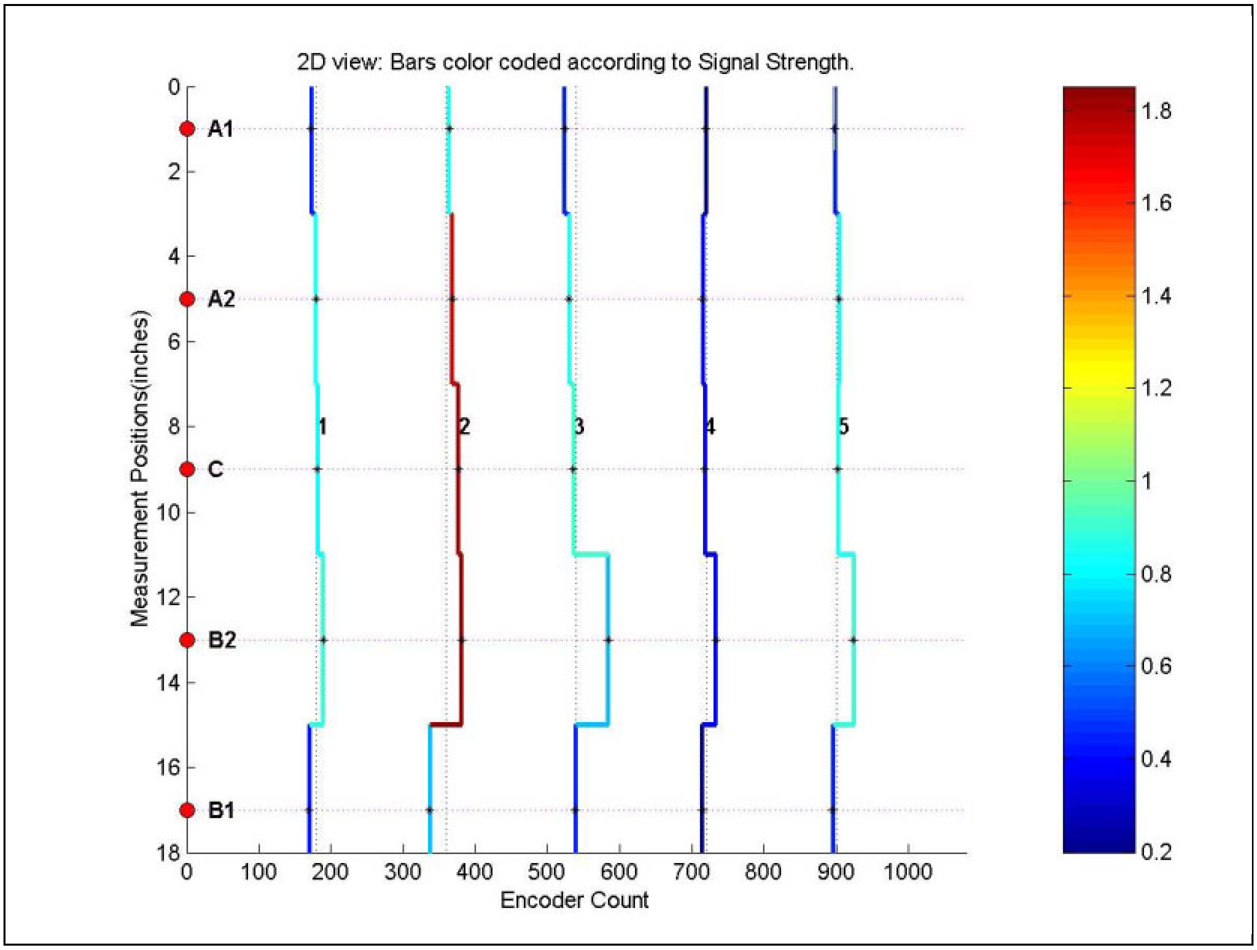


Figure B22. Top view of bars as calculated from data in Figure B21.

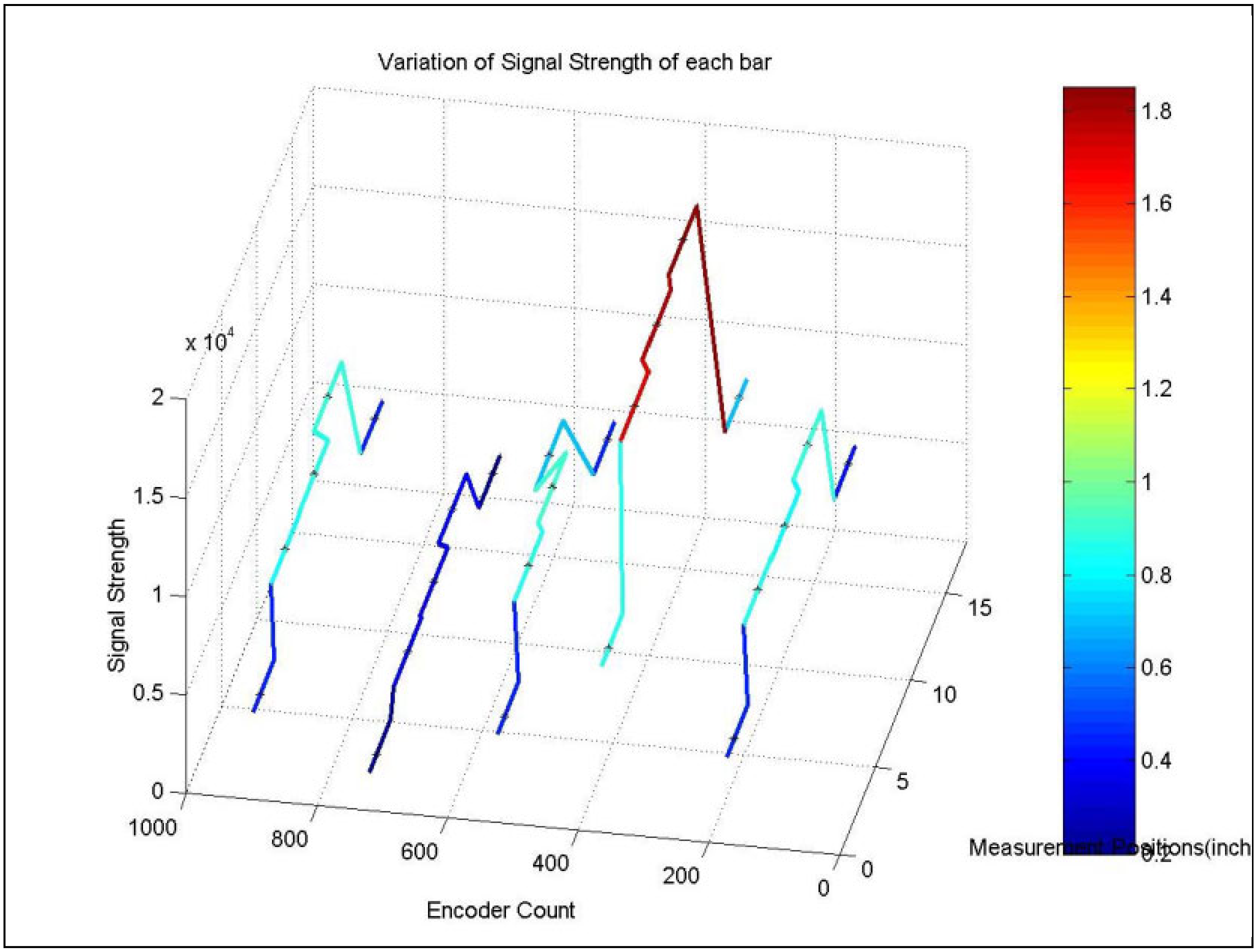


Figure B23. Same as Fig. B22 but with signal strength on third axis.

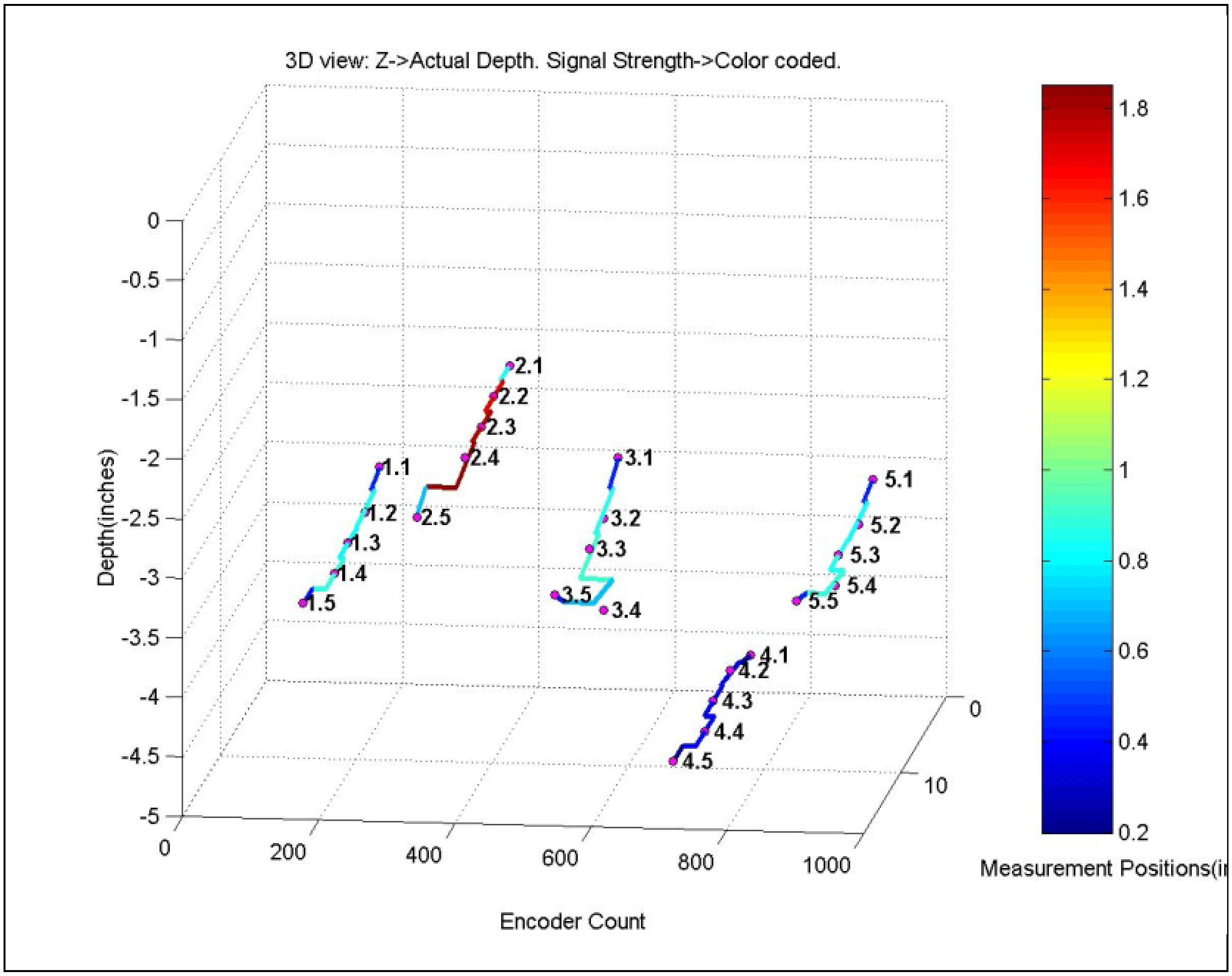


Figure B24. Same as Figure B23 but with signal strength converted to depth. Calculated bar depths are: for bars 1, 3 and 5: 3.25”; for bar 2: 2.25”; for bar 4, 4.5”.

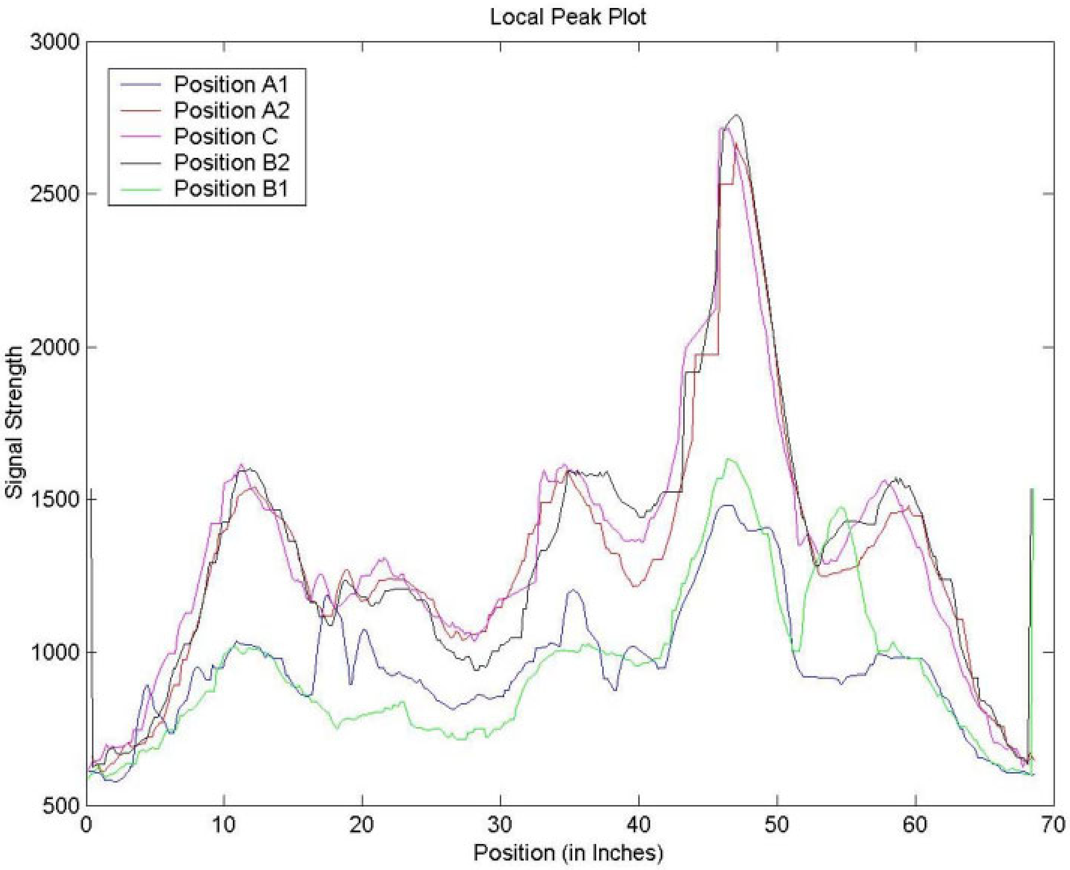


Figure B25. Strip chart of data from array at nominal 6.5” depth, with second bar down one diameter, third bar yawed, fourth bar up one diameter.

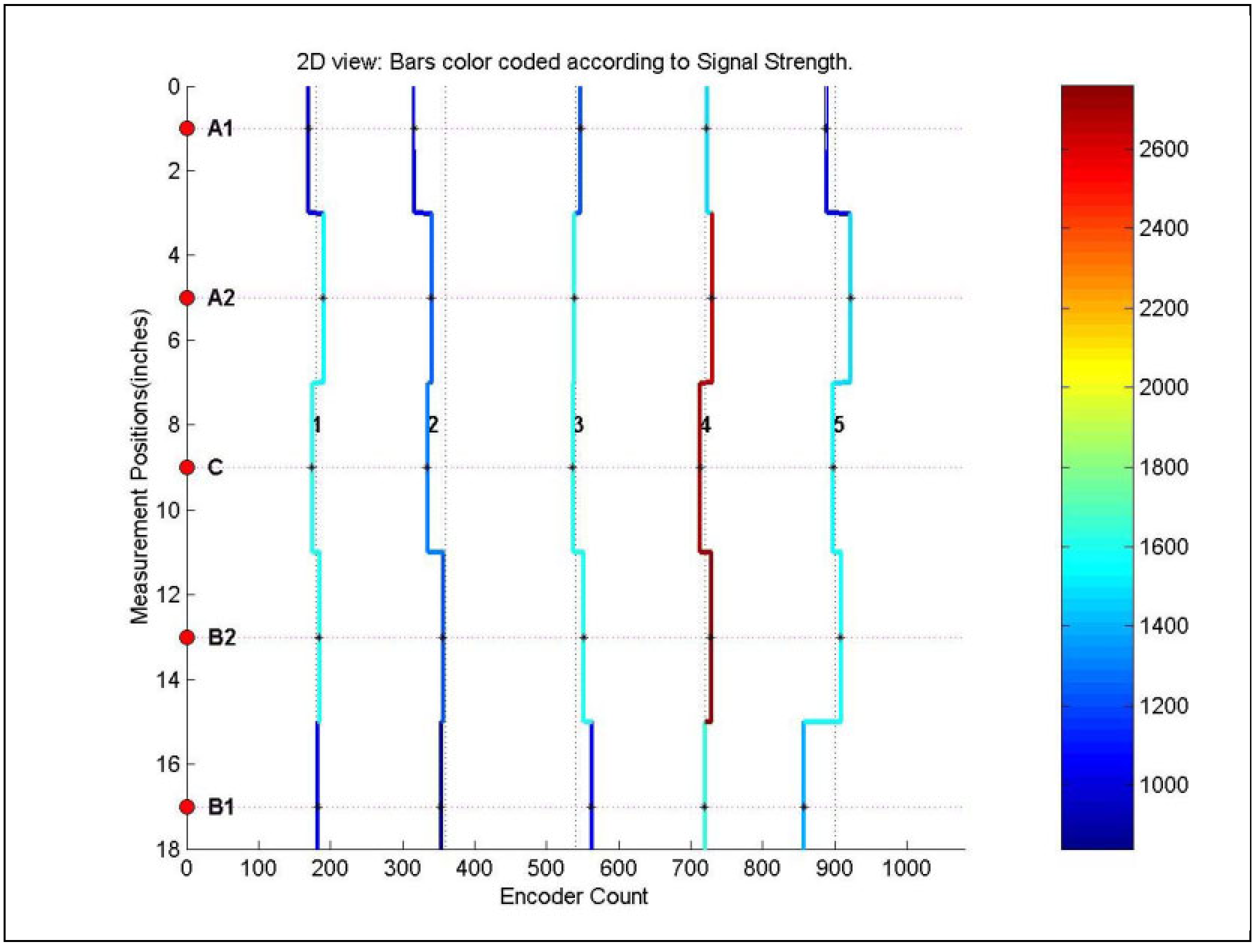


Figure B26. Top view of bars calculated from data in Fig. B25.

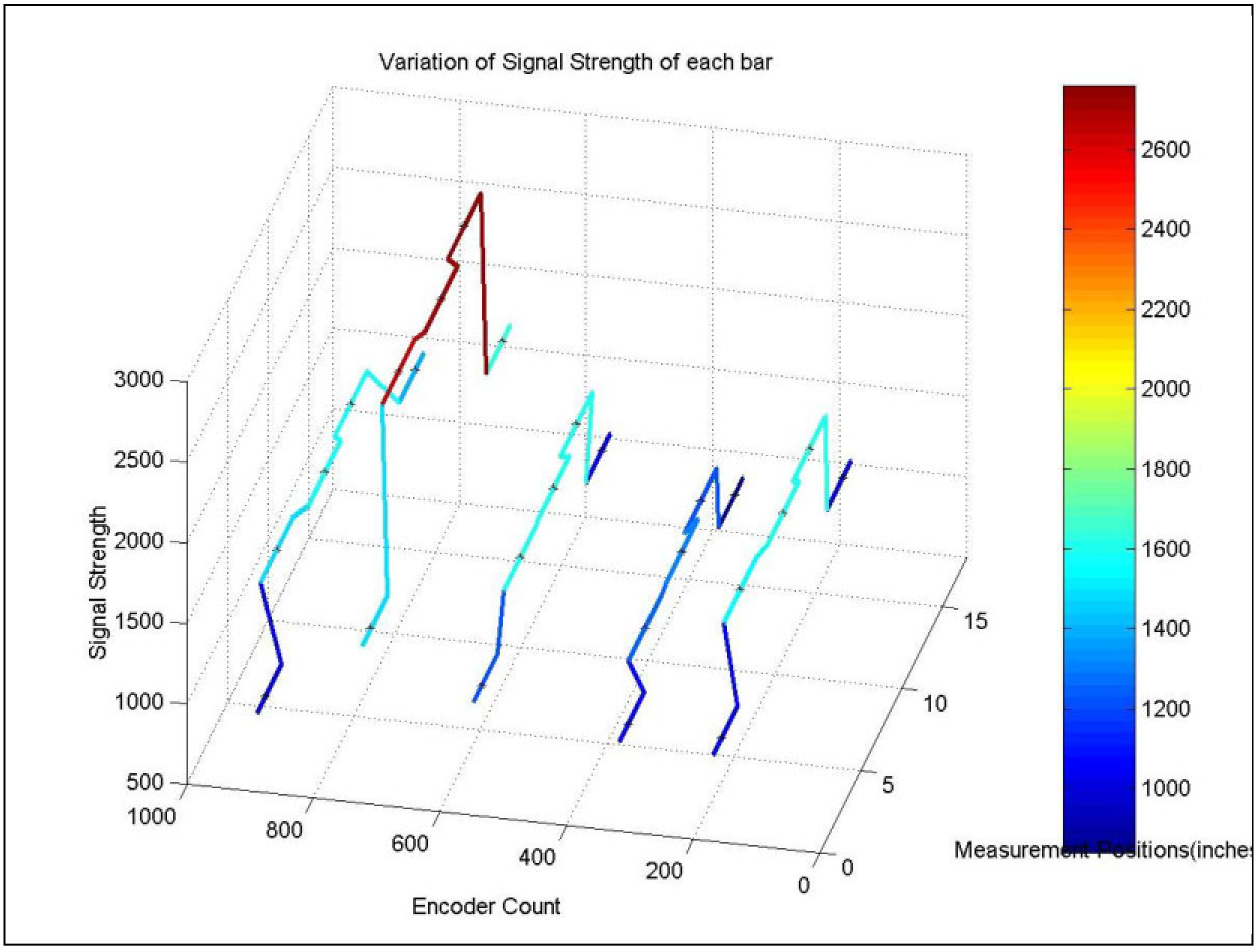


Figure B27. Same as Fig. B26 but with signal strength as third axis. Note horizontal axis sign is reversed.

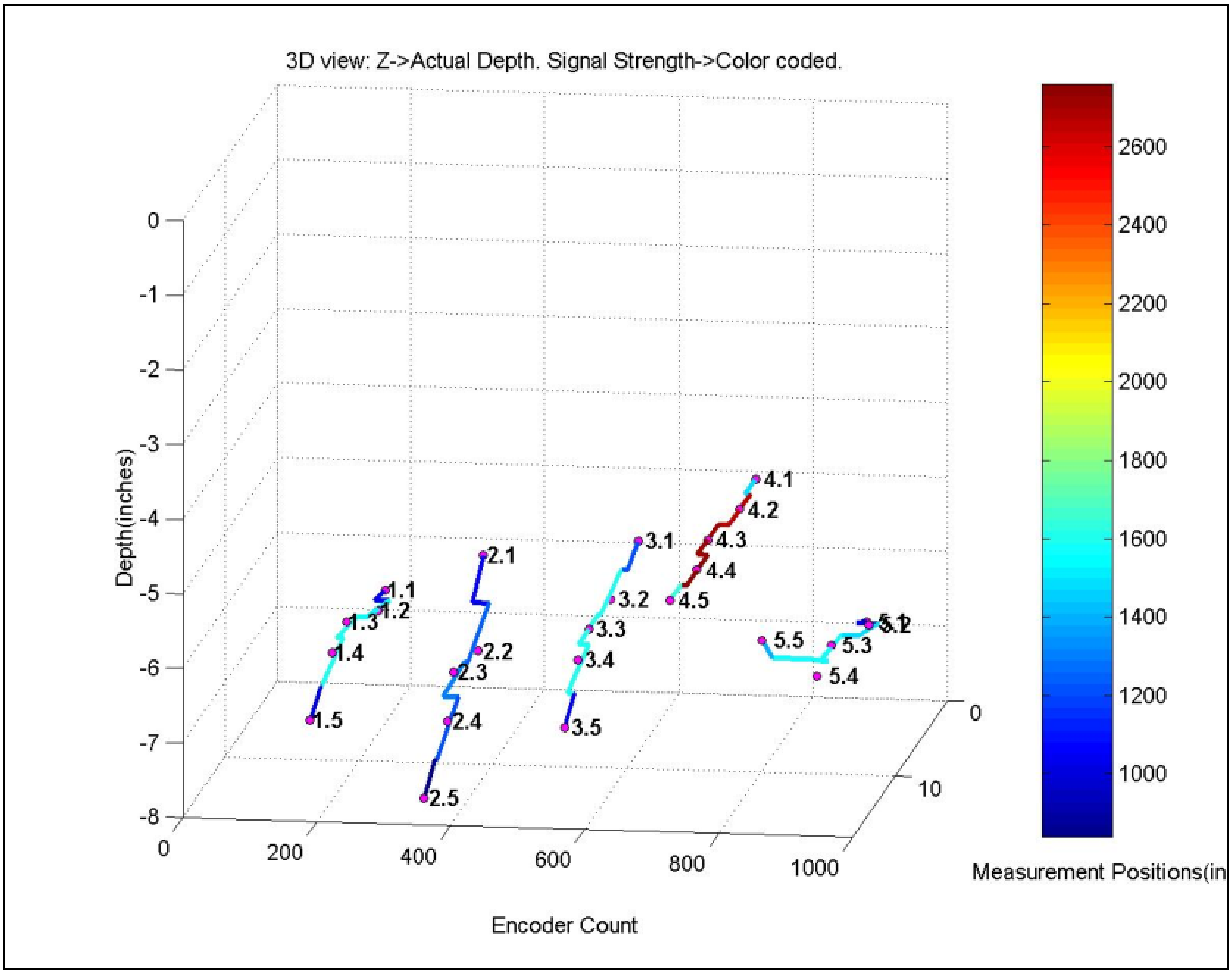


Figure B28. Data from Figure B27 with signal strength converted to depth. Calculated depths as follows: bars 1 and 3: 6.5”; bar 2: 6.875”; bar 4: 5” and bar 5: 6.375”.

Appendix C: Results of Field Trial

The plots that follow are those produced by the Matlab program after collecting five runs of data over a saw cut on I-70 near Maple Hill. Seven bars are included in the run.

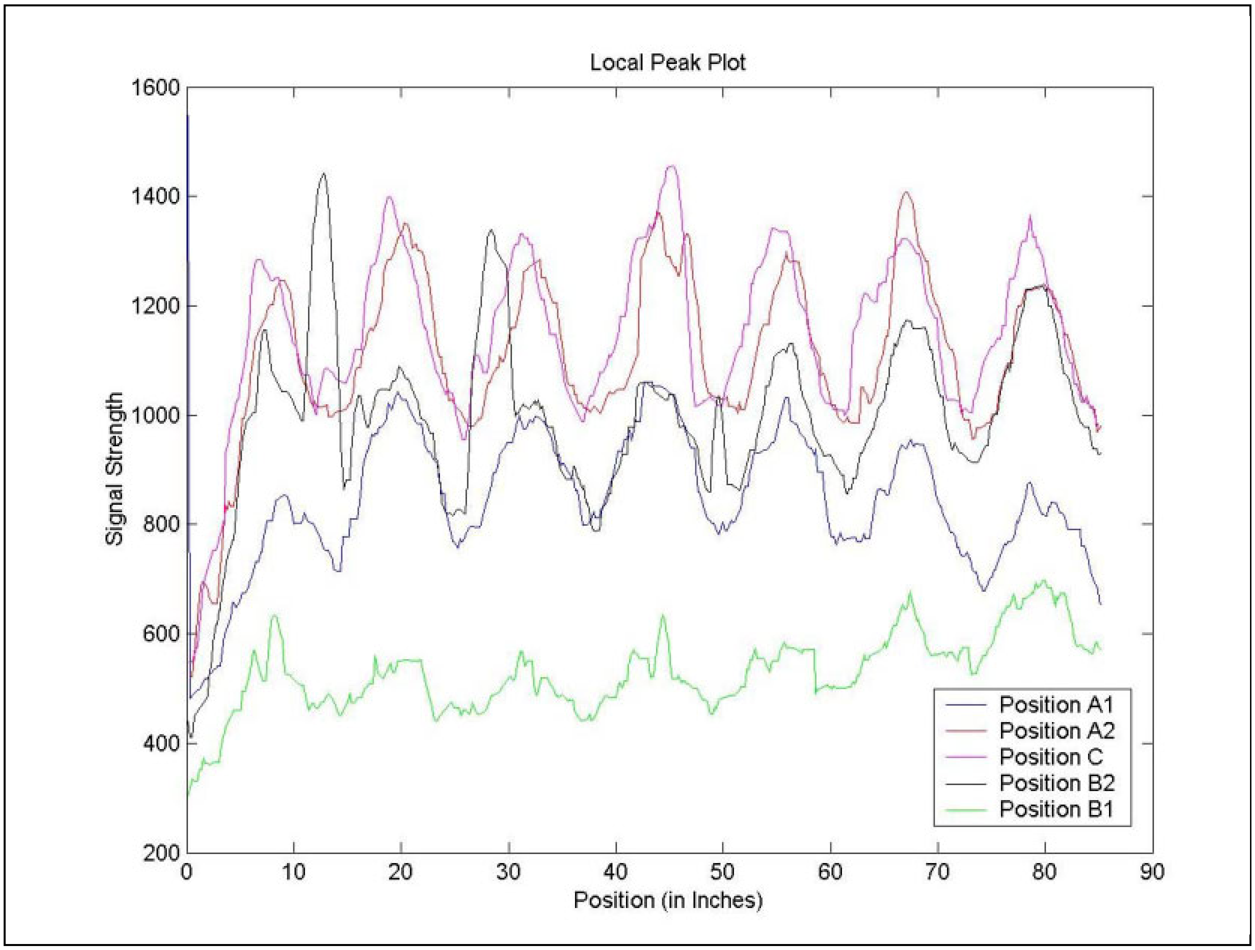


Figure C1. Strip chart of data from field trial on I-70, showing seven bars.

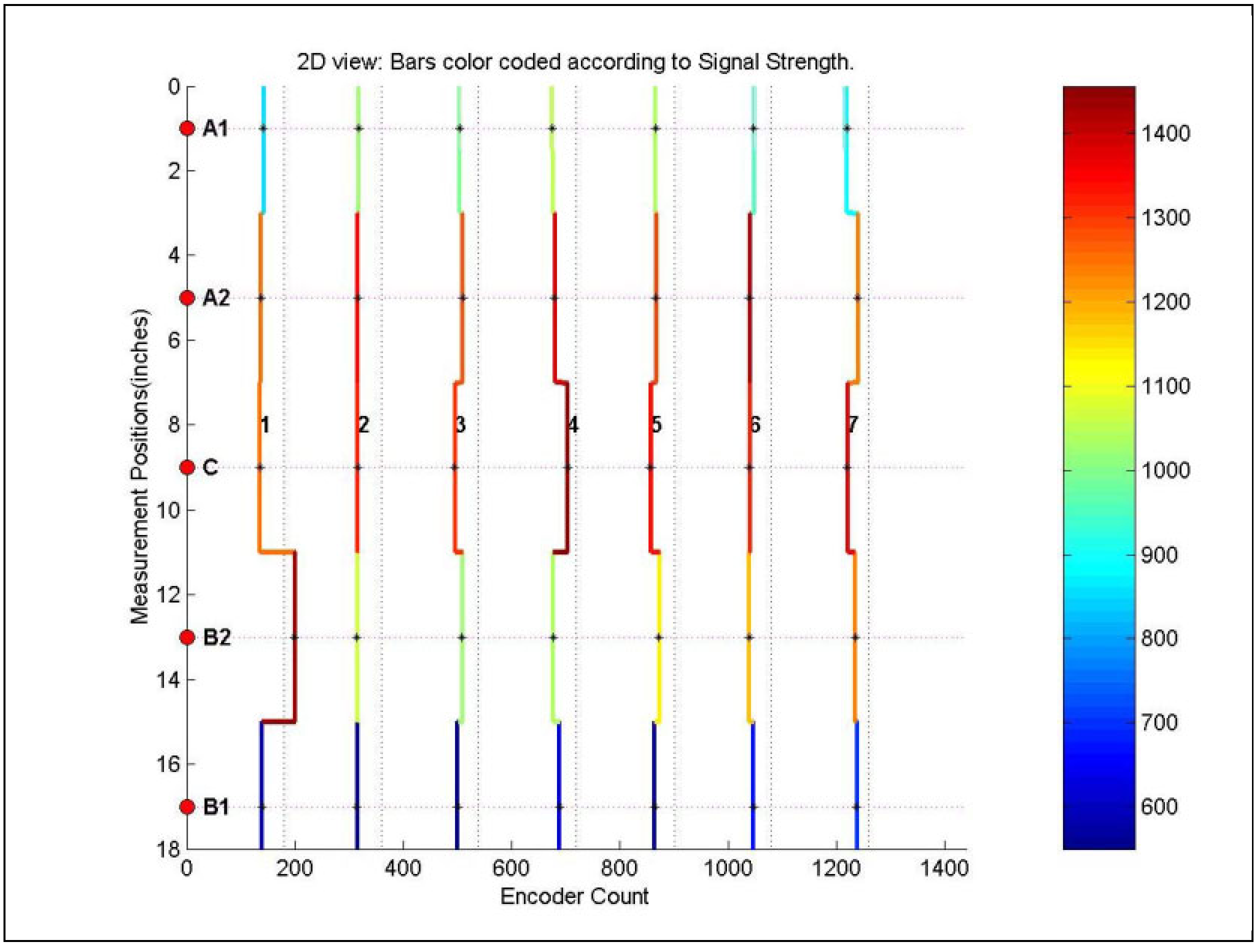


Figure C2. Top view of bars as calculated from data in Figure 1. Note that the signal strengths on lines B1 and B2 are weaker than corresponding A1 and A2, suggesting the bars are either pitched or shifted toward the A side.

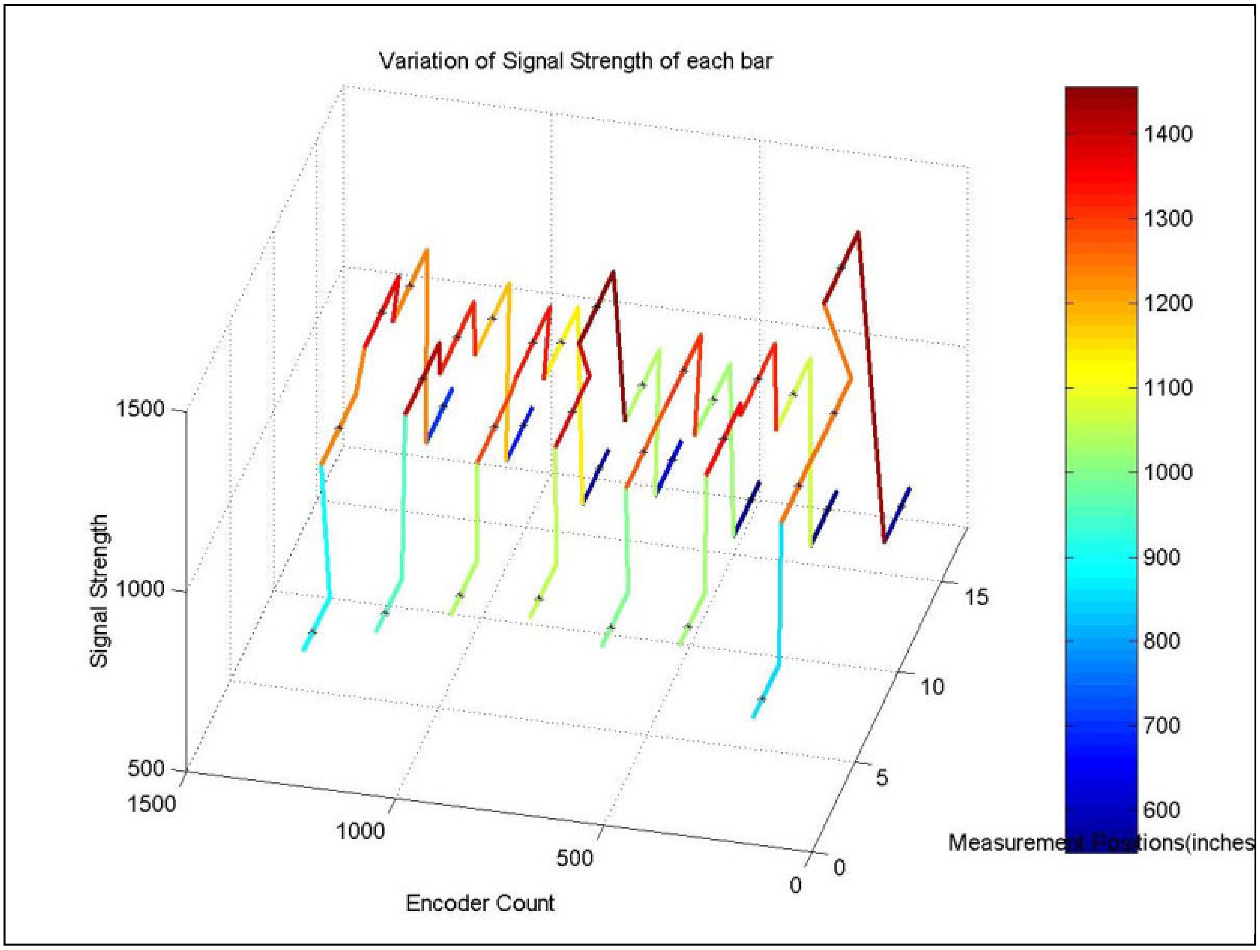


Figure C3. Same as Figure C2 but with signal strength shown on third axis.

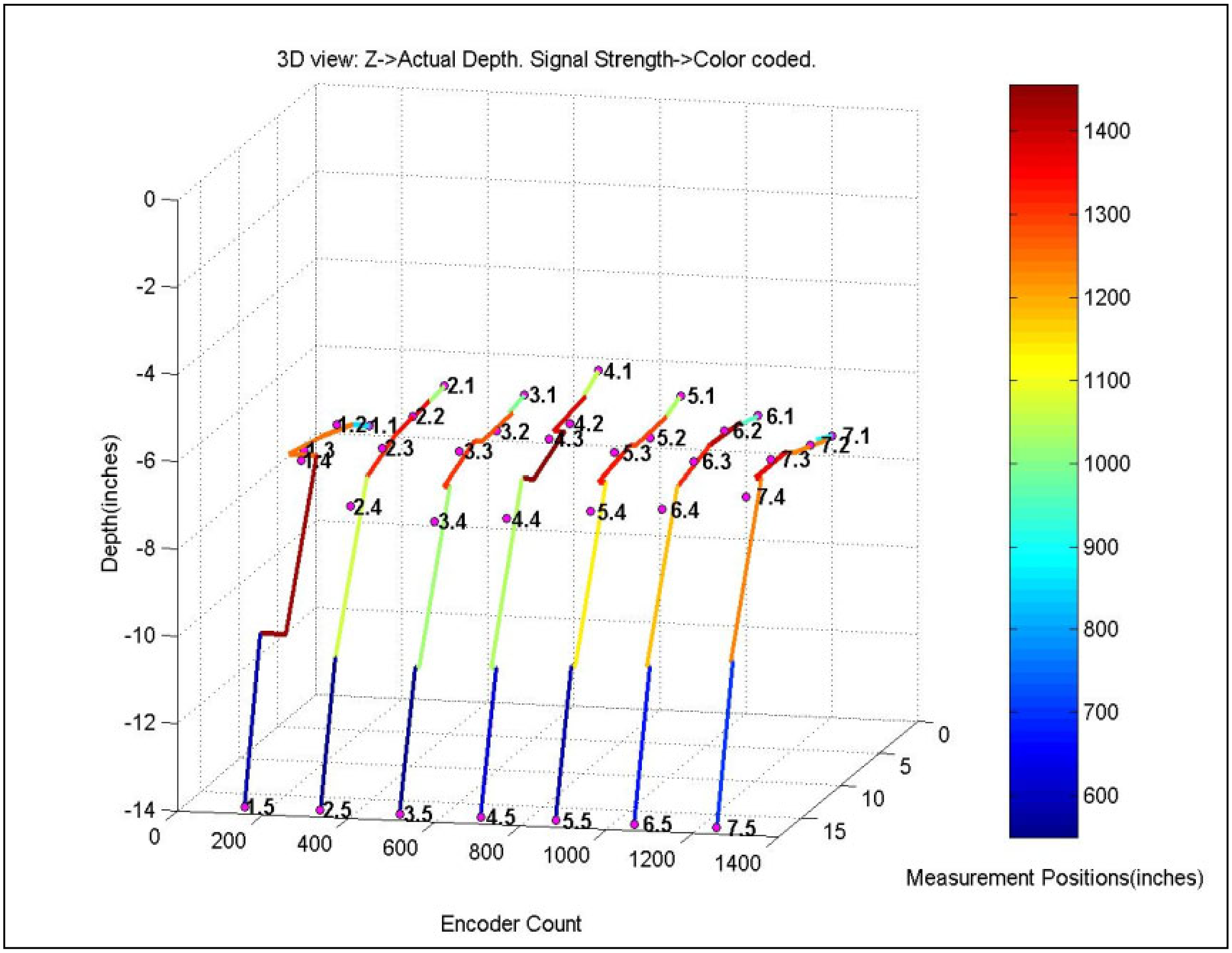


Figure C4. Calculated depths of bars from data in Figures C1-3 above. Note that as discussed in the main report, the 'B'end (nearest the viewer) signals are uniformly low, indicating the bars are pitched. The other option, that the bars are shifted in y, ought to have produced higher-than-expected signal strengths for the 'A1' positions.

K - TRAN

KANSAS TRANSPORTATION RESEARCH
AND
NEW - DEVELOPMENTS PROGRAM

A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:

KANSAS DEPARTMENT OF TRANSPORTATION

THE UNIVERSITY OF KANSAS

KANSAS STATE UNIVERSITY