Research Report
KTC-08-31/SPR307-05-1F

KENTUCKY TRANSPORTATION CENTER

INVESTIGATION OF THE EXTENDED USE OF GROUND PENETRATING RADAR (GPR) FOR MEASURING IN-SITU MATERIAL QUALITY CHARACTERISTICS

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College of Engineering

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1. Report No. KTC-08-31/SPR307-05-1F	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Investigation of the Extended Use of Ground Penetrating Radar (GPR) for Measuring in-situ material quality characteristics		**5. Report Date** **September 2008** **6. Performing Organization Code** KTC-08-31/SPR307-05-1F **8. Performing Organization Report No.** **Interim**
7. Authors **Brad Rister, Clark Graves, Jamie Creech**		**10. Work Unit No. (TRIAS)**
9. Performing Organization Name and Address **University of Kentucky** **College of Engineering** **Kentucky Transportation Center** **176 Oliver Raymond Building** **Lexington, KY 40506-0281**		**11. Contract or Grant No.** **Final**
12. Sponsoring Agency Name and Address **Kentucky Transportation Cabinet** **200 Mero Street** **Frankfort, KY 40622**		**13. Type of Report and Period Covered** **14.Sponsoring Agency Code**
15. Supplementary Notes **Prepared in cooperation with the Federal Highway Administration, US Department of Transportation**		

16. Abstract

This project tests the application of Ground Penetrating Radar (GPR) as a non-destructive tool for highway infrastructure assessment. Multiple antennas with different frequency ranges were used on a variety of highway infrastructure projects. This report highlights the pros and cons of using GPR on highway projects and what results may be anticipated for each application.

17. Key Words **Ground Penetrating Radar, GPR**		**18. Distribution Statement** **Unlimited, with approval of the Kentucky Transportation Cabinet**	
19. Security Classification (of this report) **None**	**20. Security Classification (of this page)** **None**	**21. No. of Pages 21**	**22. Price**

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

Final Report

Investigation of the Extended Use of Ground Penetrating Radar (GPR) for measuring in-situ material quality characteristics

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June 2008

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ACKNOWLEDGEMENTS

The authors would like to thank the following committee members and reviewers for their assistance and recommendations for the successful completion of this research study: Transportation Cabinet personnel: Steve Criswell.

EXECUTIVE SUMMARY

This project was set up to test the application of using Ground Penetrating Radar (GPR) as a non-destructive tool for highway infrastructure assessment. In efforts to perform this task multiple antennas with different frequency ranges were used on a variety of different highway infrastructure projects. This report will highlight the pros and cons of using GPR on highway projects and what the anticipated results may be for each application. The following list identifies what tests were performed and their summarized results. Additional information about each project is contained in the discussion section of this report.

Project A: Use newly manufactured 2.2 GHz air-launched antenna to determine thin asphalt surface mix overlay thicknesses (less than 1.5 inches) nondestructively. In addition try using 2.2 GHz. GPR data to determine density and air voids in asphalt pavements.
Results: Limited usability: New governmental restrictions regarding ultra wideband technology stipulate that air-launched GPR must not interfere with restricted bands of the radio spectrum[2] (namely cellular signals and earth-to-satellite communication). Therefore, the power behind the GPR signal must be reduced in those restricted spectrums, and thus GPR data collected in those spectrums are subject to low quality data due to outside interferences.

Project B: Use 900 Mhz. antenna to determine clay layer beneath settling concrete pavement in lieu of destructive drilling.
Results: Works exceptionally well in determining total pavement layer thickness, degree of saturation of sub-grade material, and sub-grade/sub-base soil classification

Project C: Use 200 Mhz. ground coupled antenna to determine size and extent of sink-hole
Results: Works exceptionally well in determining the size and extent of active sink-hole

Project D: Use 900 Mhz. antenna to determine size and location of voids beneath concrete pavement in the Cumberland Gap Tunnel.
Results Works exceptionally well in determining the locations of voids beneath concrete pavements greater than ½ inches in depth. Can only determine the presence of voids, and not the depth of the voids

It is expected that GPR will be a part of infrastructure assessment prior to reconstructive design in Kentucky. With GPR's ability to determine total pavement layer thickness, sub-base thickness, sub-grade depth, identification of voids and/or sinkholes, and sub-grade saturation conditions, decisions on reconstructive efforts can be made easier. In addition, GPR has multiple benefits for infrastructure assessment in that it can be deployed with minimum traffic control, data collection/processing can be done with relative ease, and it is a non-destructive testing device.

I. INTRODUCTION:

This project was set up to test the application of using Ground Penetrating Radar (GPR) as a non-destructive tool for highway infrastructure assessment. In efforts to perform this task multiple antennas with different frequency ranges were used on a variety of different highway infrastructure projects. This report will highlight the pros and cons of using GPR on highway projects and what the anticipated results may be for each application. The following list identifies what tests were performed.

A.) Use newly manufactured 2.2 GHz air-launched antenna to determine thin asphalt surface mix overlay thicknesses nondestructively. In addition try using 2.2 GHz. GPR data to determine density and air voids

B.) Use 900 Mhz. antenna to determine clay layer beneath settling concrete pavement in lieu of destructive drilling

C.) Use 200 Mhz. ground coupled antenna to determine size and extent of sink-hole.

D.) Use 900 Mhz. antenna to determine size and location of voids beneath concrete pavement in the Cumberland Gap Tunnel.

A discussion of the findings from each application above will follow in the discussion section of this report, but before we talk about the individual projects we would like to talk about what is Ground Penetrating Radar. GPR is a device that uses a transmission antenna to send out high frequency electromagnetic waves and closely spaced receiver antennas to measure the strength and speed of the reflected waves. Common uses of GPR are utility detection, concrete inspection, pavement thickness determination, bridge deck condition assessment, concrete cover determination, rail-bed condition assessment, geological soil strata, and archeology.

There are two different configurations of antennas: ground coupled and air coupled. Ground coupled antennas are in direct contact with the ground and are more suitable for slow speed investigations over short distances. Air coupled antennas are suspend just above the ground and are more applicable to higher speed applications over longer distances. The transmitting antenna emits a series of electromagnetic waves which are affected by differences in soil conductivity, dielectric permittivity, and magnetic permeability. The receiving antenna measures the time it takes for the reflected waves to return.

With this information, it is possible to determine the approximate depth of an object by adjusting for the electromagnetic propagation properties of the material. For example, the depth of a buried culvert can be determined if the speed at which the wave travels through the soil is known. The depth may be roughly estimated using assumed wave properties based on experience with similar soils. More precise results may be obtained if the transmission speed is refined through sampling and laboratory testing of the soil.

The frequency of the antenna is an important component of the effectiveness of GPR. Typically, lower frequency waves will penetrate deeper into a medium, but with much less resolution. Conversely, higher frequency waves will provide greater signal resolution but will not penetrate as deep. The chart below illustrates some common antenna frequencies and their typical applications;

Table 1: Antenna frequencies:

Antenna Frequency	Depth of Penetration	Typical Applications
2.2 GHz.	0.5 ft.	Concrete evaluation
1.6 GHz.	1.5 ft.	Concrete evaluation
900 MHz.	3.0 ft.	Pavement thickness, voids
400 MHz.	13.0 ft.	Utility, voids
270 MHz.	20.0 ft.	Utility, geotechnical
200 MHz.	23.0 ft.	Geotechnical
100 MHz.	65.0 ft.	Geotechnical, mining
16-80 MHz.	0.0-165.0 ft.	Geotechnical

II. DISCUSSION:

A.) Use newly manufactured 2.2 GHz air-launched antenna to determine thin asphalt surface mix overlay thicknesses nondestructively. In addition try using 2.2 GHz. GPR data to determine density and air voids.

In the past, the Kentucky Transportation Center field tested the 1.0 GHz. Air launched antenna to try and determine asphalt pavement layer thicknesses. Results from this study KTC-02-29/FR101-00-1F reveled that the 1.0 GHz. Antenna could determine pavement layer thicknesses greater than two inches fairly accurate when multiple calibration cores were taken. The results below show the summarized results from that study

- Asphalt greater than two inches:
  +/-10.32% or +/-0.20 inches

- Asphalt bases of eight to nine inches:
  +/-2.73% or +/-0.24 inches

- Concrete nine to twelve inches:
  +/-14.24 or +/-1.66 inches

However, this previous study revivals that the 1.0 GHz. Antenna was not well suited for determining asphalt pavement layer thicknesses less than two inches. It was concluded that a higher frequency antenna (2.2 GHz.) would be needed to determine asphalt pavement layer thicknesses of 1.5 inches or less.

In efforts to verify the 2.2 GHz. Air launched antenna's ability to determine the thickness of thin asphalt overlay projects, KTC selected five overlay projects in Kentucky during the 2005-2006 construction years(Table 1).

Table 1: Test sites

County	Route	Milepoints	Design thickness (inches)
1. Kenton	KY 16	3.646-9.541	1.25
2. Marshall	US 641	5.117-7.85	1.5
3. Hopkins	US 41	4.105-10.417	1.0
4. Bell	US 119	0.24-5.074	1.5
5. Barren	KY 90	0-3.933	1.5

After several field tests were conducted with the 2.2 GHz. antenna, on the projects listed above, it became apparent that outside radio frequency noise was interfering with collecting desirable radar data. Figure 1 below identifies a 600 foot long section of radar data from project number one above. As seen in figure 1, only in short segments can multiple pavement layers be determined beneath the surface reflection. As noted, most of the data is washed-out with noise (namely outside radio frequency noise)--thus allowing for difficult interpretation of the data. It is suspected that a majority of this outside interference came from communications such as: mobile-satellite, fixed mobile, and other wireless communications (Appendix A).

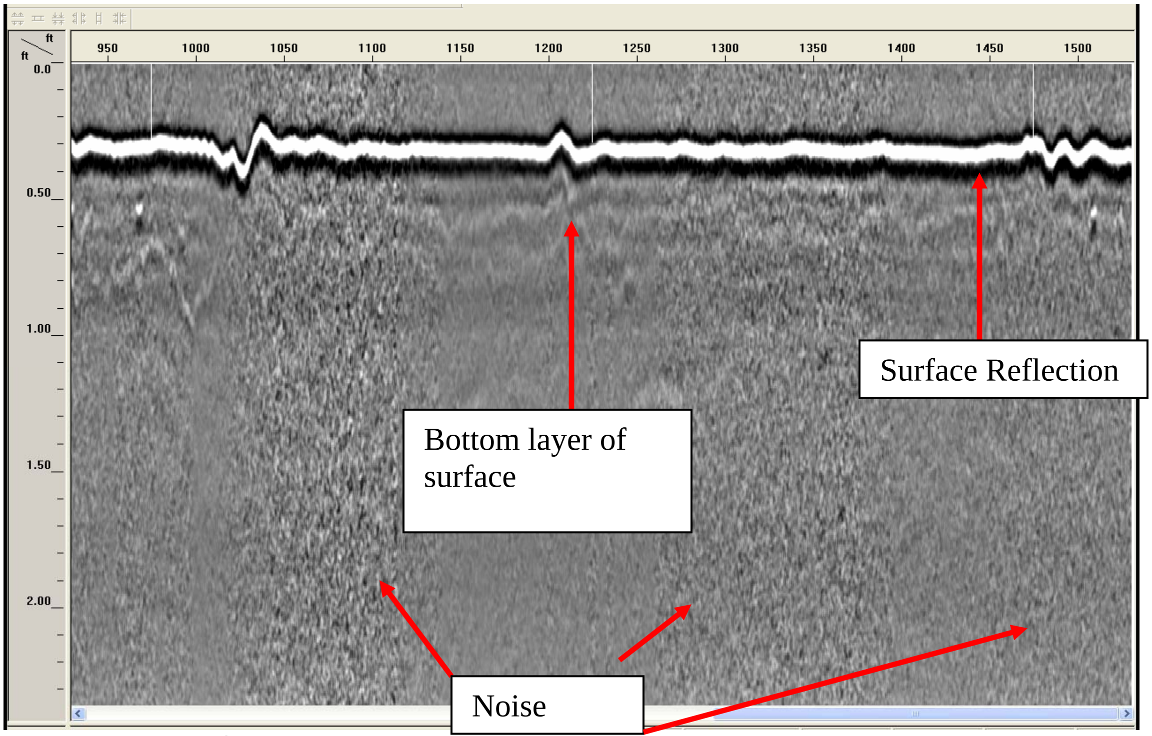


Figure 1: Display of noise captured in 2.2 GHz. data

Provided that a majority of the collected data was too noisy to be adequately processed for thin layer asphalt thickness, it also proved to be too noisy for segregation and density analysis.

In efforts to justify the noise limitations of the 2.2 GHz. Antenna, a literature search was conducted to gain a better understanding of the FCC rules that govern air-wave transmissions. The new governmental restrictions regarding ultra wideband technology in the range of 960 MHz.

to 2.2 GHz., indicate that air-launched GPR must not interfere with restricted bands of the radio spectrum (Appendix A). Therefore, the power behind the GPR signal must be reduced in those restricted spectrums, thus attributing to the noise seen in the collected data in Figure 1 above. Therefore, it appears that for the present, that the 2.2 GHz. Antenna might not be able to produce the desired results for determining thin pavement overlay thicknesses for quality control and quality assurance measures in Kentucky. However, the previous KTC report KTC-02-29/FR101-00-1F indicates that the 1 GHz. antenna can produce thickness values in thicker pavements within reasonable tolerances, but the new restrictions also limit the effectiveness of that antenna as well.

B.) Use 900 Mhz. antenna to determine sub-grade conditions beneath settling concrete pavement in lieu of destructive drilling.

A complete survey of the pavement and subgrade conditions was performed on I-265 in Jefferson County between mile-points 15.17 to 18.34, in both the eastbound and westbound directions. The investigation was prompted by several areas along the 3.17 mile section experiencing differential settlement of one to two inches between the right and the left driving lane. In efforts to determine why the right driving lane had been settling and to test the existing integrity of the pavement structure, several different destructive and non-destructive tests were performed. The field survey involved testing the 3.17 mile segment with Ground Penetrating Radar (GPR), and taking core samples of the pavement structure. The following information will highlight some of the beneficial uses of GPR.

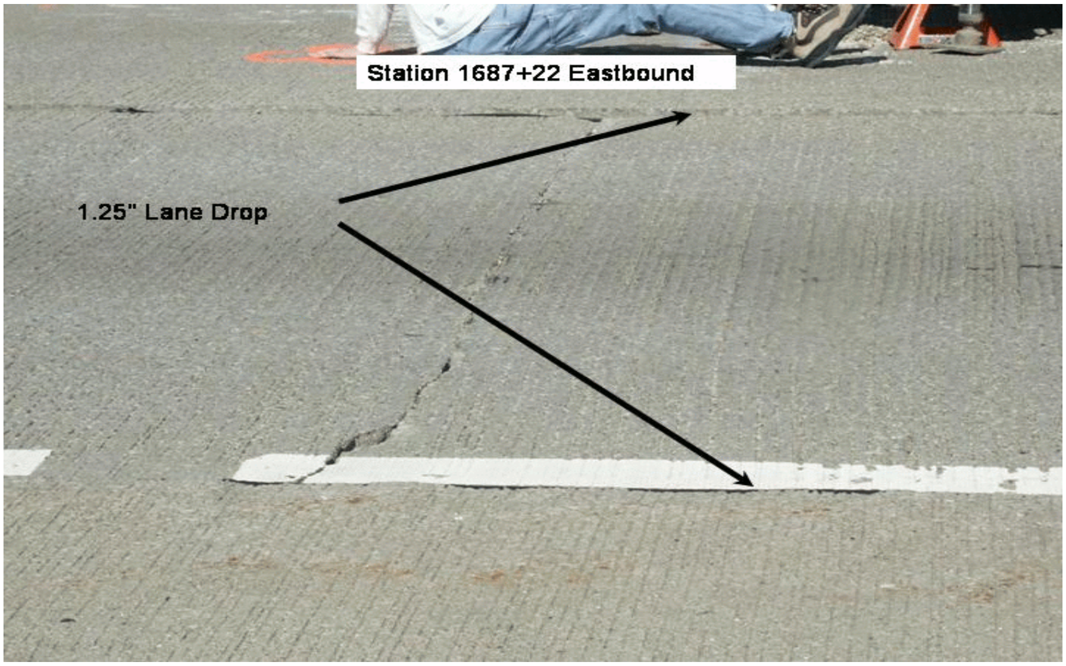


Figure 2: Lane settlement between driving lane and shoulder

In efforts to determine the condition of the sub-grade (GPR) was initially used along the I-265 corridor to determine the presence of voids beneath the pavement and to detect areas that maybe saturated with water. The GPR survey consisted of using a 900 MHz. ground-coupled antenna and taking one reading every six inches. The traffic impact was minimal and was performed under a rolling lane closure that proceeded at 20 m.p.h.

After reviewing the radar output, it was determined that using GPR to determine voids beneath the pavement proved to be inconclusive. However, the GPR was able to determine areas that were retaining water between the bottom of PCCP and the top of the DGA layer. In addition a layer of clay/weathered shale was located between the rock sub-grade and the DGA layer.

Figures 3, 4, and 5 indicate GPR's interpretation of water beneath the PCCP or in the DGA layer. However, GPR does not have a way to quantify the amount of water being displayed. Therefore, engineering judgment was used to quantify the amount of water that the GPR data graphically displays. Figure 3 has been determined to be an area that represents severe water (where the DGA layer appears red in color), Figure 4 has been determined to be an area that represents moderate water (where the DGA layer appears more green in color), and figure 5 represents an area that is determined to have little or no water beneath the PCCP (where the DGA layer appears more yellow in color).

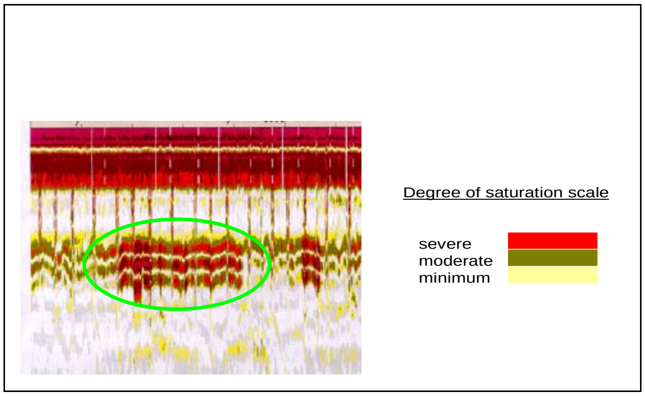


Figure 3: GPR data displaying severe water beneath pavement

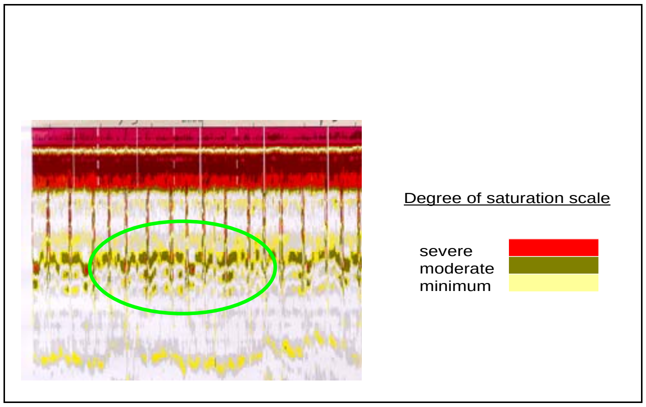


Figure 4: GPR data showing moderate water beneath pavement

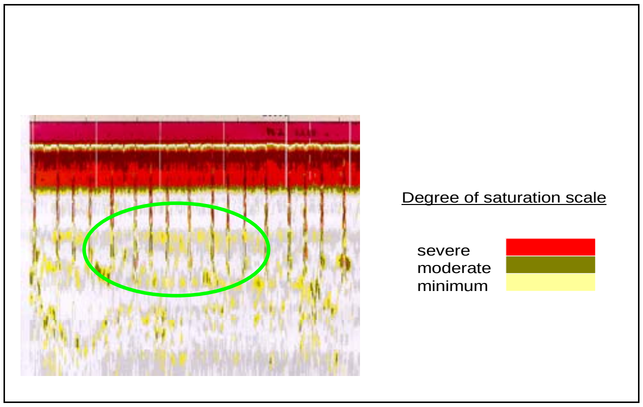


Figure 5: GPR data showing minimum water beneath pavement

Once a visual threshold was established for the amount of water present in the DGA layer, a rating was given to every 200 feet in both the right and left lanes of both the east and west bound directions. Ten points were given to the sections with severe water, five points were given to the sections with moderate water, and zero points were given to the sections with little or no water. In order to determine how each 200-foot section varied along the route all water ratings were graphed. Figures 6 and 7 show the right and left lanes of the eastbound direction, and figures 8 and 9 show the right and left lanes of the westbound direction, respectfully. This type of information allowed design engineers the opportunity to make provisions for drainage for the reconstruction process.

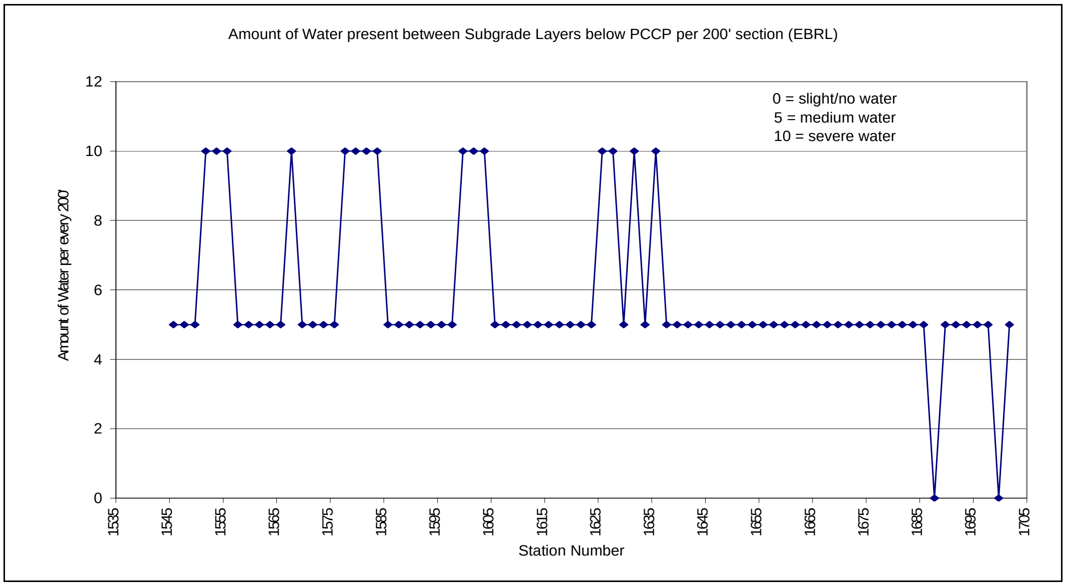


Figure 6: Degree of water beneath pavement 200 ft. section Eastbound Right Lane

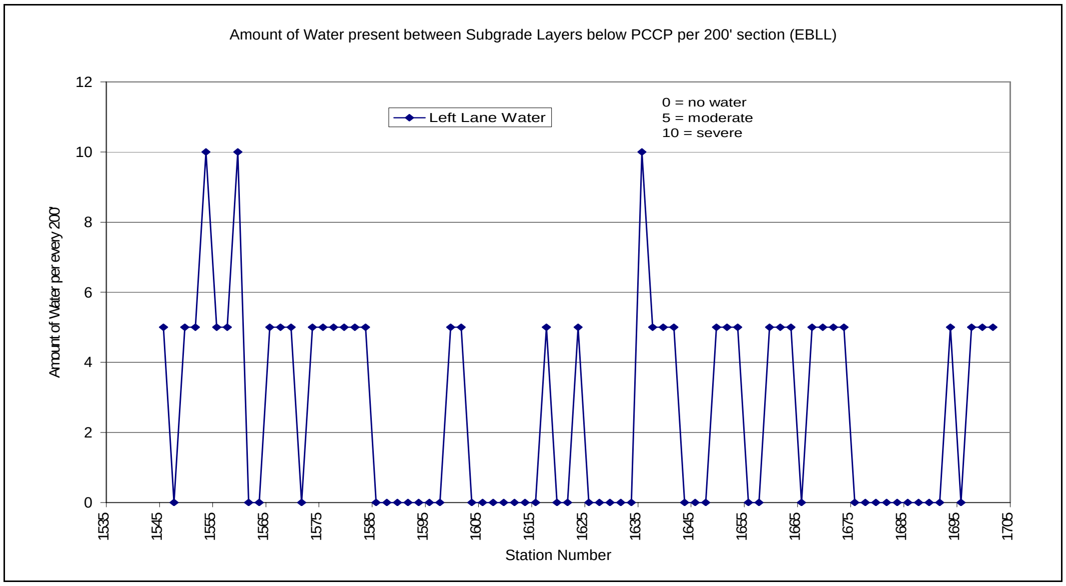


Figure 7: Degree of water beneath pavement 200 ft. section Eastbound Left Lane

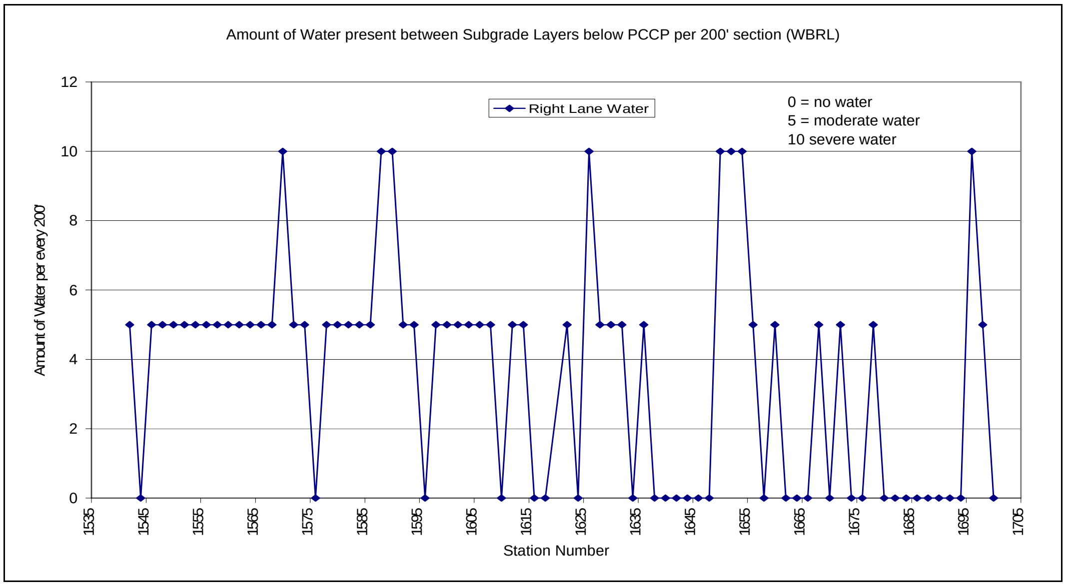


Figure 8: Degree of water beneath pavement 200 ft. section Westbound Right Lane

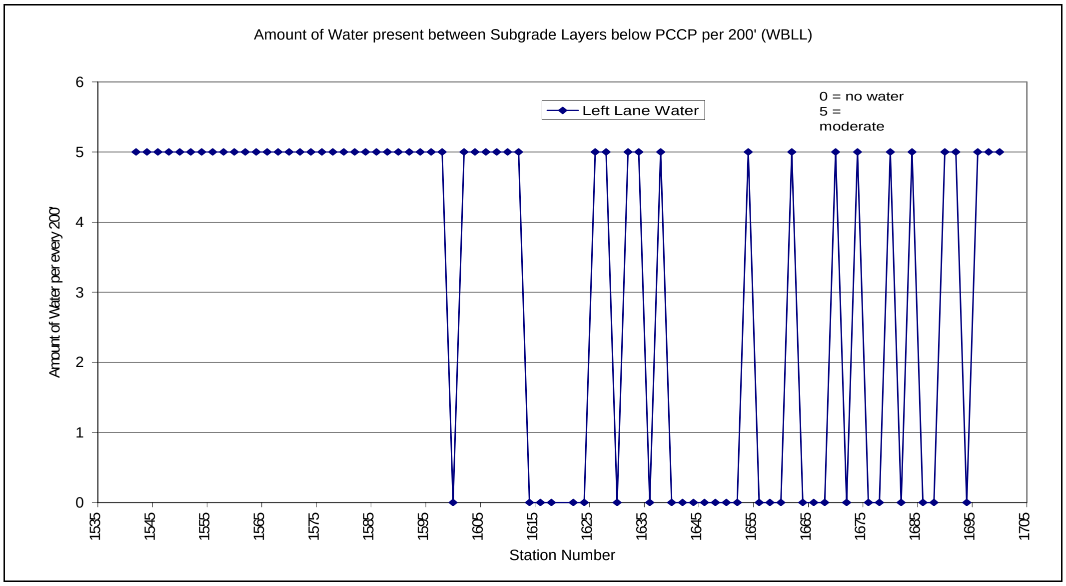
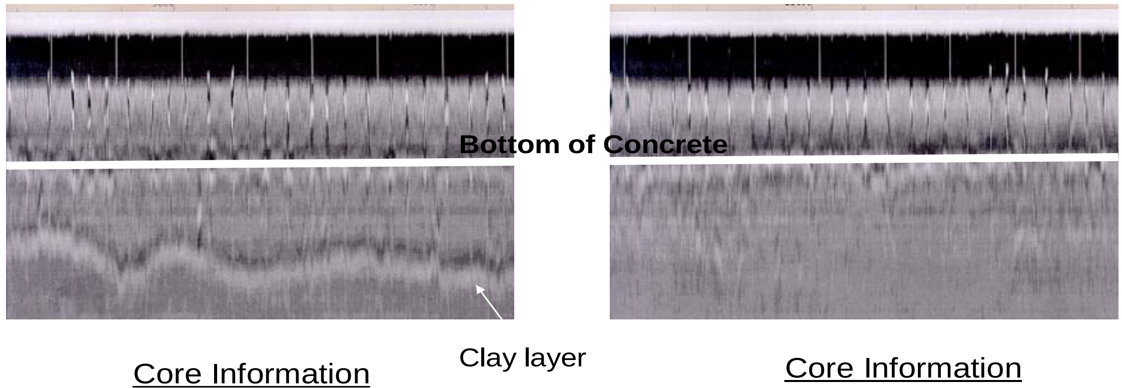


Figure 9: Degree of water beneath pavement 200 ft. section Westbound Left Lane

GPR was also able to detect an additional layer of material located between the rock subgrade and the DGA layer. Core analysis indicates that this is a clayey type material and/or weathered shale. Figure 10 shows radar data from the roadbed with both the additional clay layer and with rock roadbed. The entire project was scanned with GPR, the limits of areas with clayey material beneath the dense graded aggregate (DGA) could be defined. However, in efforts to support the sub-grade material conditions produced by GPR, geotechnical drilling was conducted in both the east and west bound lanes every 1000 feet. Figure 12 and 13 identifies the results from the geotechnical drilling at every 1000 ft in the west and eastbound directions, respectfully. As can be seen in figure 12-13, the GPR data had a 100 percent correlation in locating the clay layer beneath the DGA to the findings of the geotechnical drilling.



<u>Core Information</u>

Approx. 2” between lane faulting
Clay layer beneath 6 inches of DGA

<u>Core Information</u>

No between lane faulting
No clay layer present btw.
DGA and rockroad bed

Figure 10: GPR data showing extra clay layer

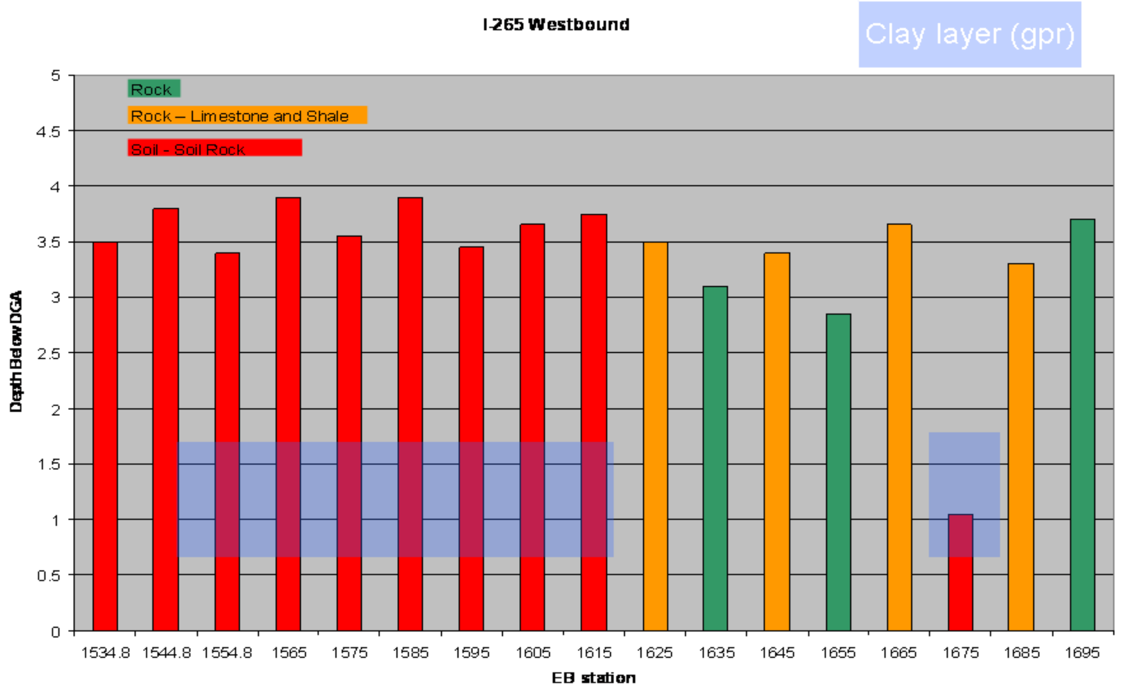


Figure 111: Comparison between Geotechnical Drilling and GPR, Westbound

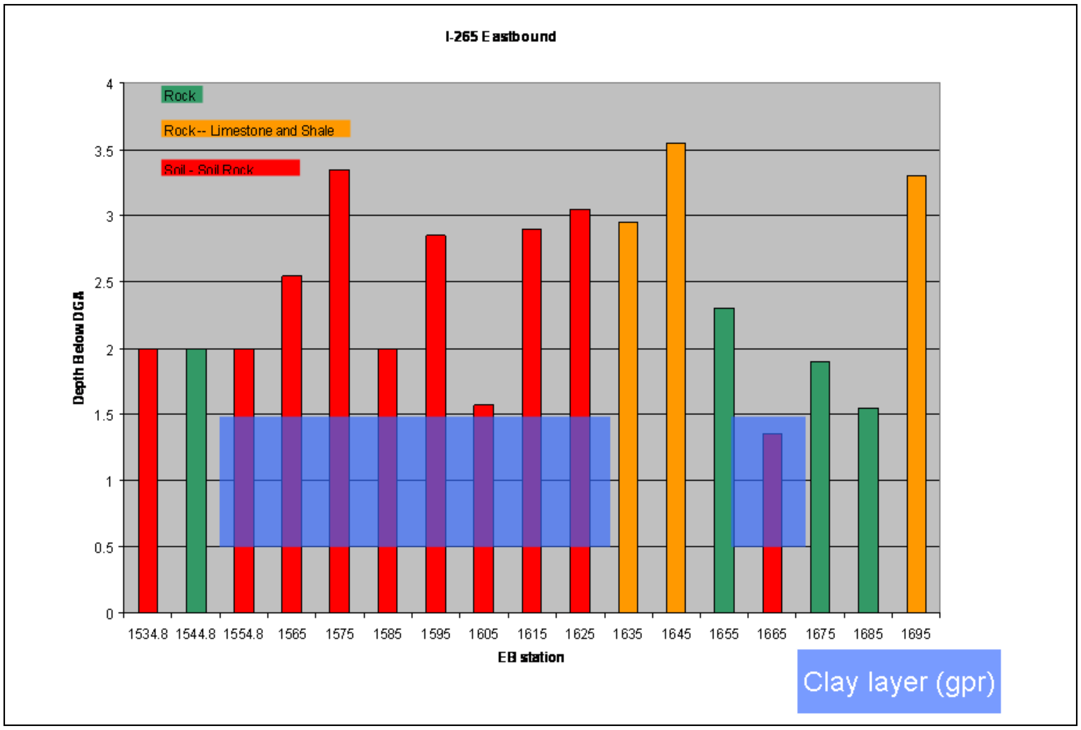


Figure 12: Comparison between Geotechnical Drilling and GPR, Eastbound

In efforts to repair the settled pavement prior to the GPR analysis of the sub-grade conditions, seven design alternates were proposed for rehabilitation. However, after all of the GPR data was consolidated and presented to the Cabinet professionals, it was determined that only one design proposal made sense. It was determined that the clayey type material found beneath the DGA layer was compressive in nature, and do to heavier traffic loads in the right lane, that this had lead to the cause of the differential settlement between right and left lanes. Therefore, this material needed to be removed and replaced, instead of being buried deeper by an additional overlay. Ultimately the Cabinet's design committee determined that the GPR data gave the appropriate information for selecting the best design alternate, thus allowing for a long term cost savings by addressing the poor sub-grade conditions in the design phase. As a follow-up, to confirm the correlation between the radar data and the sub-grade conditions, a site visit was conducted during the reconstruction phase. As can be seen in figure 13, the clay layer identified from the radar data aligns with the sub-grade field conditions.

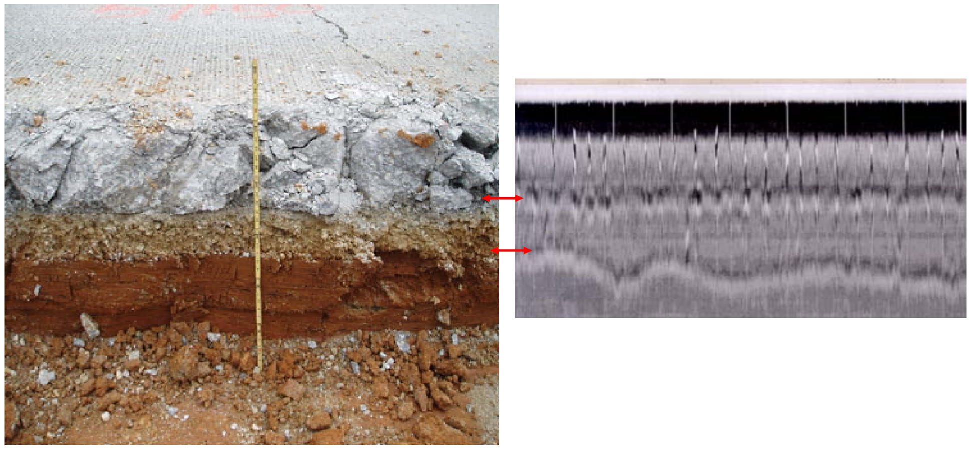


Figure 13: GPR data compared to excavation photos

C.) Use 200 Mhz. ground coupled antenna to determine size and extent of sink-hole.

In late 2005, the Kentucky Transportation Cabinet requested a field evaluation of an existing sink-hole along US 23 in Summerset, KY, to determine its depth, circumference, and relationship to the adjacent roadway. Since the sink-hole had opened up in the recent past with a close proximity to the roadway (Figure 14), it proved vitally important to understand where and how far underneath the roadway that the existing sinkhole resided.

Figure 14: Sink-hole, US 27

In efforts to determine the size and extent of the sink-hole, a 200 MHz. antenna was used to survey the sink-hole after it was filled with stone material (Figure 15). The process of surveying the sink-hole with the radar antenna consisted of making multiple passes over the sink-hole roadway area, approximately two feet-on-center. Figure 16 displays one line of GPR data output. As can been seen in figure 16, both the vertical and horizontal measurements of the sink-hole can be obtained for the GPR data. After all radar data was processed, the vertical and horizontal measurements were taken from all scanned lines and placed into Surfer, a three-D modeling program (Figure 17). As can be seen in figure 17, an understanding of the location and proximity of the sink-hole in relation to the roadway can be concluded. This information allowed for Cabinet officials to mitigate strategies for correcting the elevation of the roadway surface. As a follow-up, GPR technology has continued to be used to scan the roadway surface in hopes of predicting any additional failure that might occur at this sinkhole area.

Figure 15: 200 MHz. GPR inspection

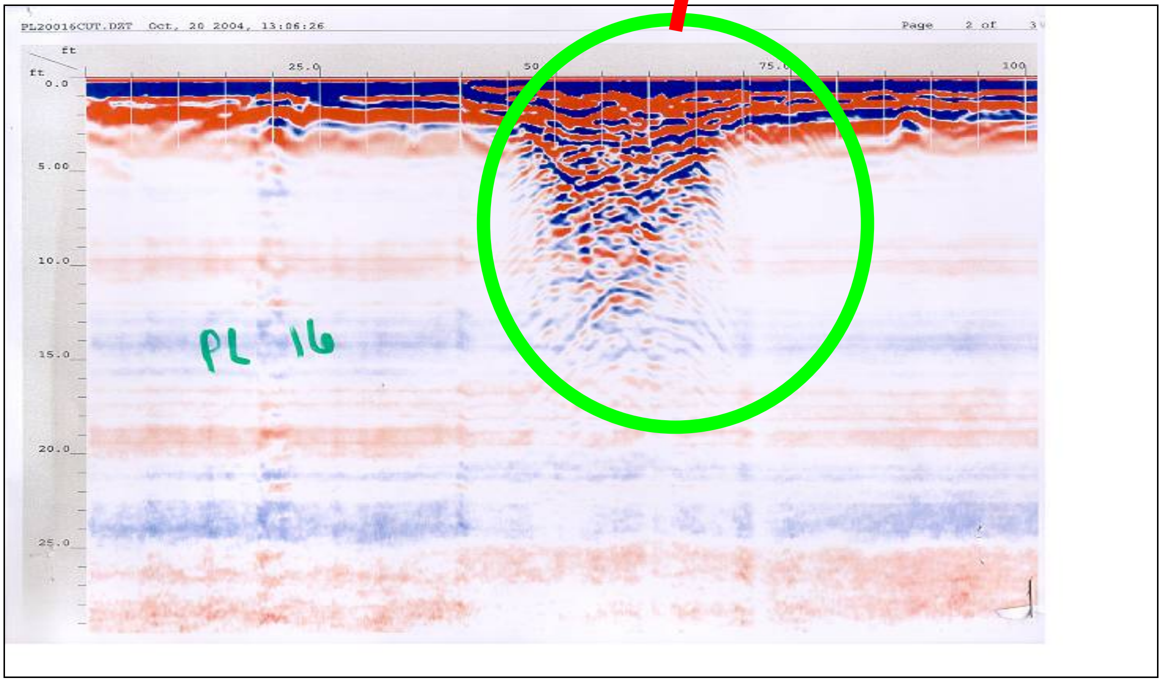


Figure 16: 200 MHz. radar data

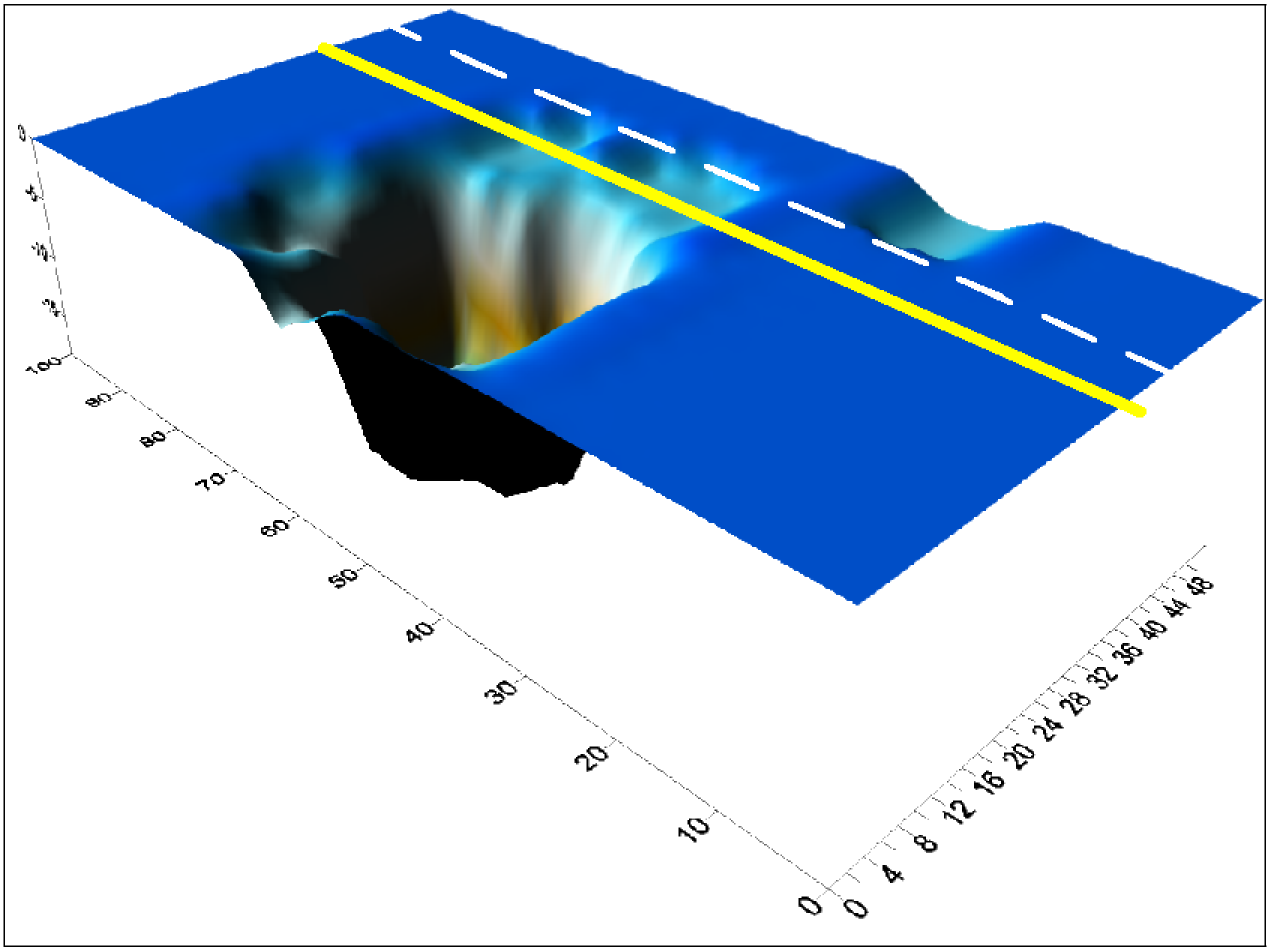


Figure 17: Sink-hole relief map

D.) Use 900 Mhz. antenna to determine void size beneath concrete pavement at the Cumberland Gap Tunnel

The Cumberland Gap Tunnel, which is a 4600 foot long twin bore tunnel that carries approximately 23,000 vehicles a day between Kentucky and Tennessee on US 25, has been experiencing settlement issues in its concrete pavement since late 2003. In the summer of 2005 some of the settled pavement areas measured approximately 3.5 to 4 inches down from its original elevation. Provided that the settlement issues were of great concern and not fully understood, a ground penetrating radar survey was conducted on the pavement surface to determine if any anomalies could be identified beneath the pavement.

The survey consisted of using a 900 MHz. ground coupled antenna pulled behind a pick-up truck (Figure 18) in both the right, left, and center lines of each lane. The collection rate was 12 scans per foot, with an anticipated scan depth of 3-5 feet. The most noticeable anomaly was discovered in the settled areas (Figure 19). This anomaly is/was indicative of a void space beneath the pavement surface. At this particular location the void depth was approximately four inches. Through trial and error and with field calibration cores, the 900 MHz. antenna appeared to verify voids greater than ½ inch in depth. However, GPR was unable to determine the depth of the voids. It was determined that once the GPR signal went into the free space of a voided area that the signal was not retrievable. Therefore, the GPR data below the void area is not decernable.

Figure 18: 900 MHz. antenna behind pick-up truck

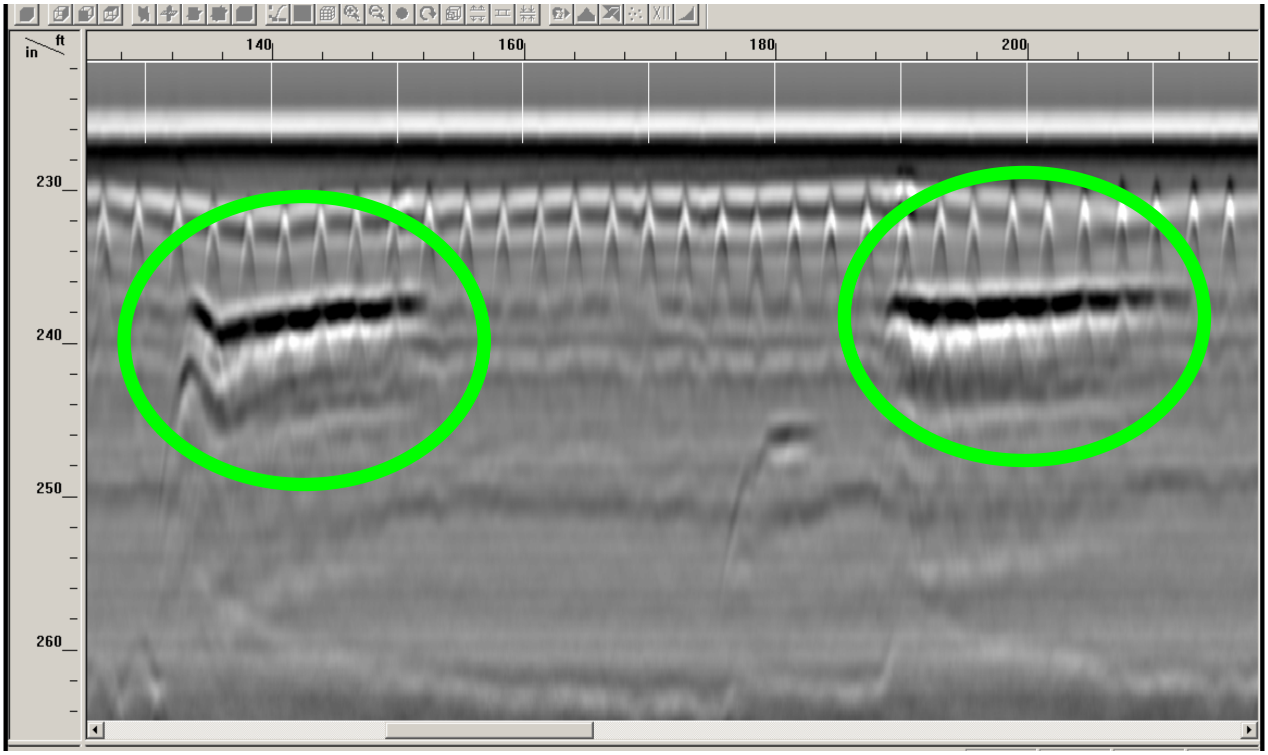


Figure 19: GPR data showing voids beneath concrete pavement

In efforts to understand the difference between radar data with and without voids, figure 20 below gives an idea of a normal cross section of the radar data and how it correlates to the pavement design. By comparing figures 19 and 20, the dark black areas in the radar data beneath the concrete layer are referred to as negative amplitudes in the radar data and can be classified as void spaces. Again, the void depths in figure 19 are cannot be determined with radar data alone. Only after drilling into the void areas was the depth of the voids able to be measured.

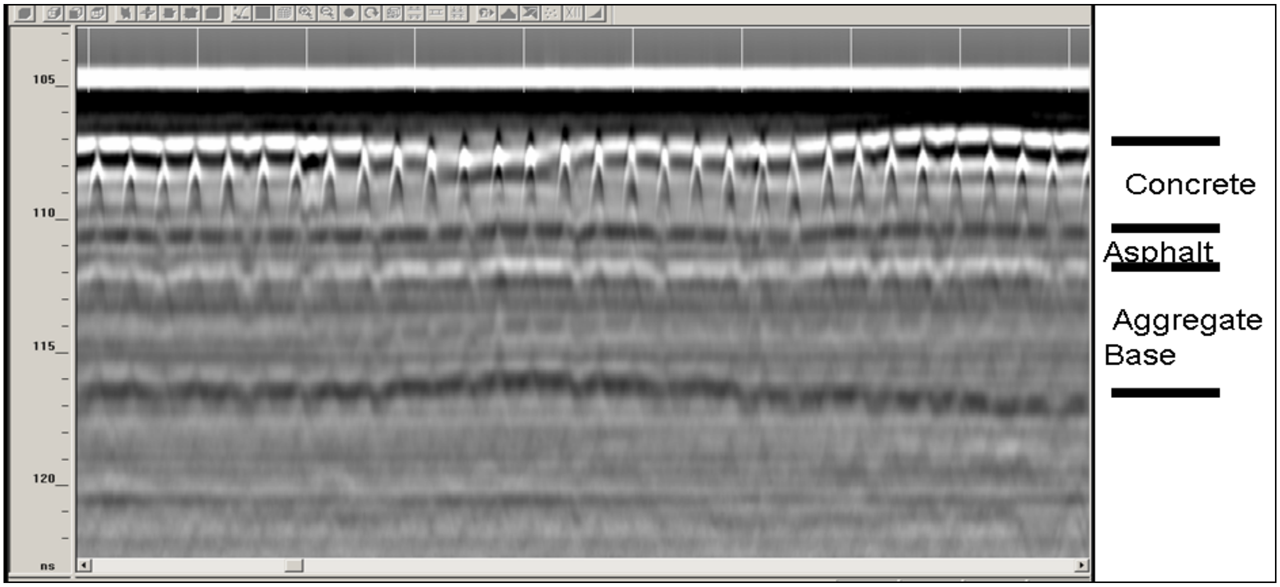
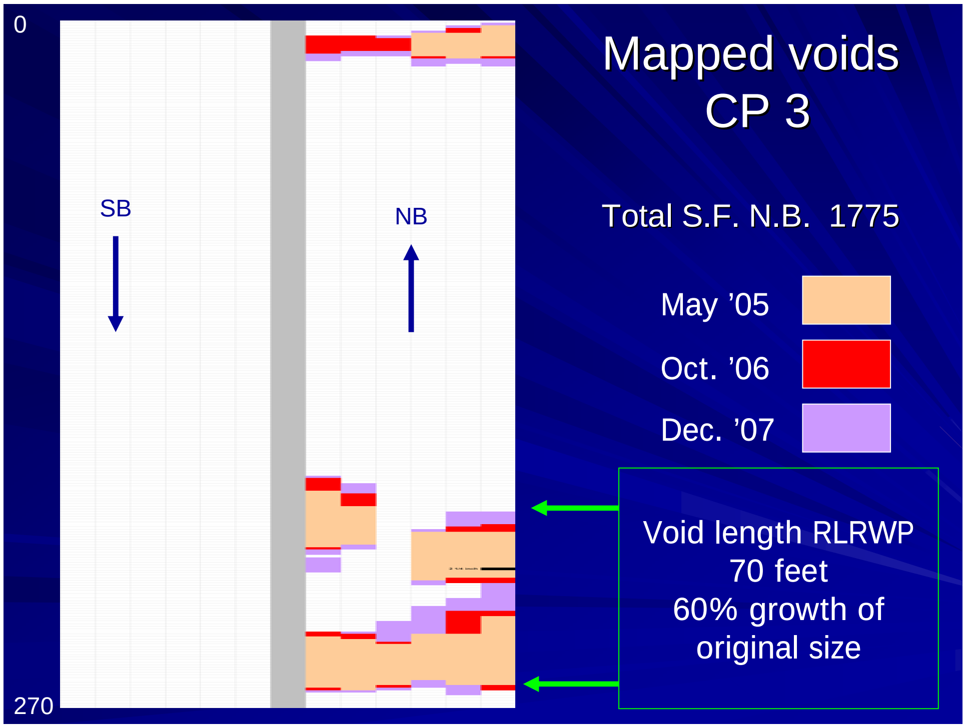


Figure 20: GPR data displaying pavement layers

Once all areas with void spaces beneath the concrete pavement were identified throughout both tunnels, maps were draw in 2-D (Figures 21-23). These maps indicate the approximate location of the voids in relation to the right and left driving lanes. In addition, multiple radar scans were taken over a three year period to map the growth of the void spaces. In all three areas the GPR equipment was able to identify the growth of the voids. This information has been used by engineers at both the State and Federal level to initiate a remedial fix. More information about the fix for the void spaces maybe found in KTC report 05-35-KH50-1F.



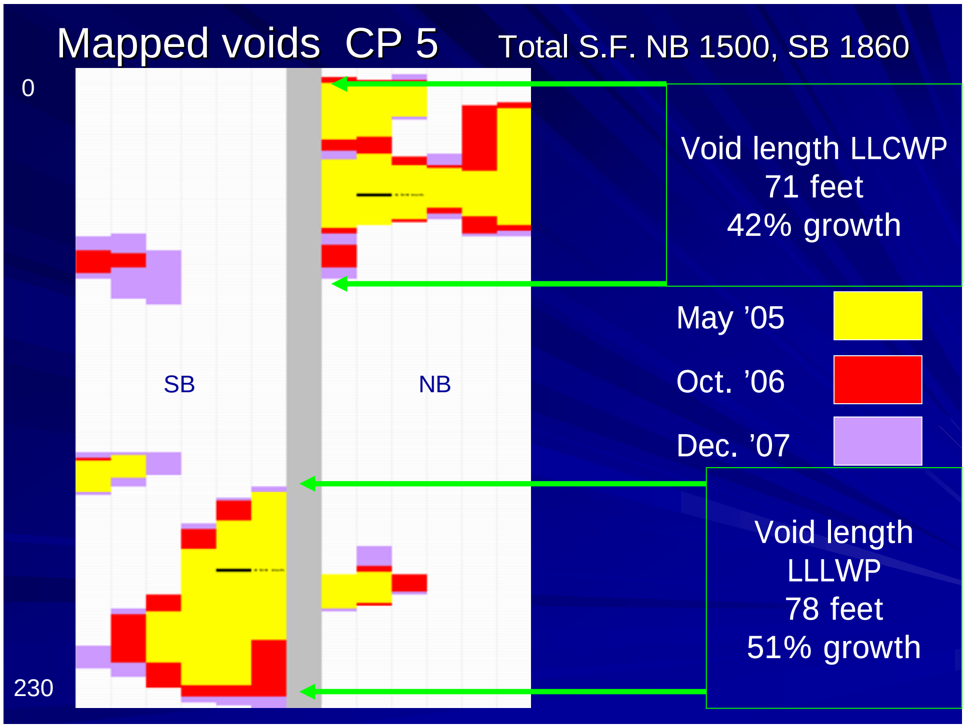
Mapped voids
CP 3

Total S.F. N.B. 1775

May '05 🟧
Oct. '06 🟥
Dec. '07 🟪

Void length RLRWP
70 feet
60% growth of
original size

Figure 21: Void area number 1



Mapped voids CP 5

Total S.F. NB 1500, SB 1860

Void length LLCWP
71 feet
42% growth

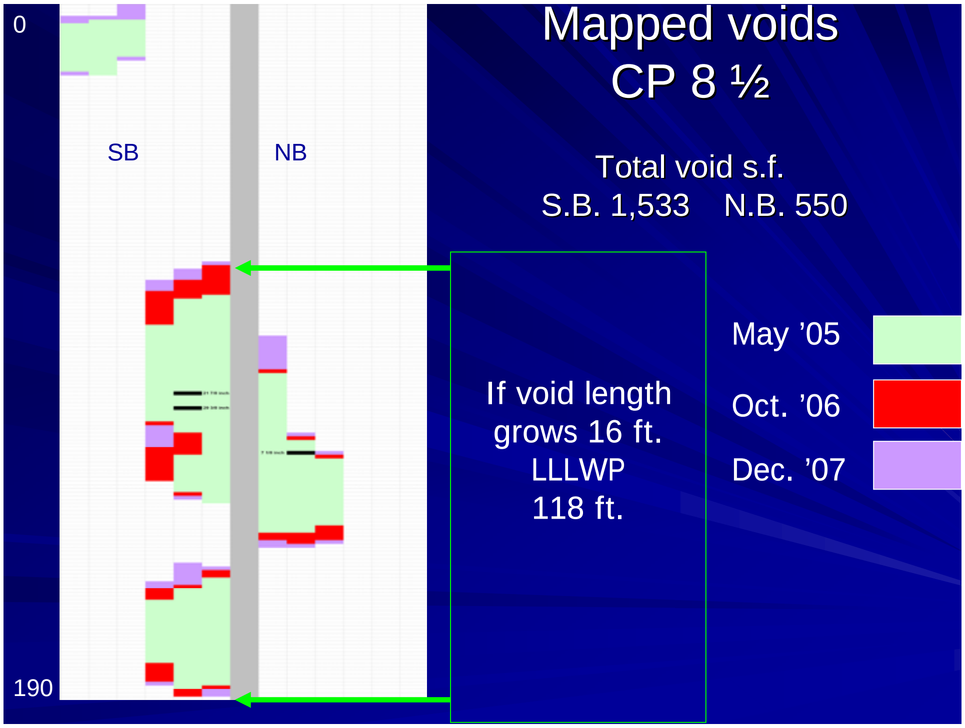
May ’05 🟨

Oct. ’06 🟥

Dec. ’07 🟪

Void length
LLLWP
78 feet
51% growth

Figure 22: Void area number 2



Mapped voids
CP 8 ½

Total void s.f.
S.B. 1,533 N.B. 550

If void length
grows 16 ft.
LLLWP
118 ft.

May ’05 🟩

Oct. ’06 🟥

Dec. ’07 🟪

Figure 23: Void area number 3

II. CONCLUSIONS:

Ground Penetrating Radar (GPR) has been used in a variety of infrastructure assessments. Although one of the original intents of the study was to determine the thickness of thin layer asphalts (less the 1.5 inches) along with determining air voids and segregation, it appears that the governmental restrictions placed on high frequency air launched antennas have limited their usability. Only in areas that do not have a considerable amount of cellular and earth-to-satellite communication can the air launched antenna provide reliable information.

However, the use of the ground coupled antenna systems can be used with great success in many different applications. Ground coupled GPR, can be used in lieu of destructive drilling to determine subgrade conditions. This operation has multiple benefits, such as, greater data density for total project assessment, can be used in a moving environment to reduce traffic delays, and results can be easily processed and graphically displayed to assist in project design. GPR technology can also contribute to determining the size and depth of sink-holes that are actively moving, and the locations of voids beneath concrete pavement structures.

In the future, GPR should be a part of infrastructure assessment prior to reconstructive design. GPR's ability to determine total pavement layer thickness, sub-base thickness, and sub-grade saturation will aid reconstructive decisions. In addition, GPR has multiple benefits for infrastructure assessment in that it can be deployed with minimum traffic control, data collection and processing can be done with relative ease, and it is a non-destructive testing device.

APPENDIX A

Geotimes
JUNE 2002

Web Extra **Thursday, June 6**

New rules endanger GPR

On April 18, an Amtrak auto train was passing through Crescent City, Fla., on its way to Washington when it derailed, killing four people and injuring more than 160 others. Many investigators believe that waterlogged soil caused the tracks to move around and derail the train. A group of geoscientists, led by Ernest T. Selig and Colorado School of Mines geophysicist Gary Olhoeft, think they may have a found a way to prevent future accidents -- using ground penetrating radar (GPR) to measure the amount of water beneath the rails. But a ruling to restrict the use of GPR by the Federal Communications Commission (FCC) may stop them dead in their tracks when it goes into effect this month.

The use of GPR to create an automated, water-measuring system for the federal railroad administration is only one of this technology's many applications. In his 30 years of GPR experience, including 20 years at the U.S. Geological Survey, Olhoeft has used GPR for everything from studying agricultural pollution to finding lost utilities to preventing damage from excavation to mapping archaeological sites prior to digging. At a congressional hearing on June 5, industry representatives and members of Congress highlighted GPR's contributions in an effort to curb the coming FCC regulations on ultra-wideband (UWB) technology, including GPR -- regulations based on concerns about potential interference with military and transportation systems.

"This technology has too many promising applications to stifle it based on unfounded, and unproven, concerns," said House Energy and Commerce Committee Chairman Billy Tauzin (R-La.). GPR uses a large range of frequency in the radio spectrum to look downward into the earth, water, ice or man-made materials to see the unseen. The FCC regulates the non-government use of the radio spectrum, and the National Telecommunications and Information Administration (NTIA) handles the frequency spectrum for federal agencies.

Until 1998, the wide use of GPR went largely unnoticed and unregulated. After three companies applied to use new UWB devices, the FCC and NTIA decided it was time to draft rules for their use. Now, after four years of discussion, the FCC has issued frequency and application restrictions, and calls for GPR manufacturers and users to obtain certification for their systems and to submit advanced notification of use. According to the FCC rules, GPR systems can operate at frequencies below 960 MHz and between 3.1 and 10.6 GHz, but its use in those ranges is "restricted to law enforcement, fire and rescue organizations, to scientific research institutions, to commercial mining companies, and to construction companies," banning use by independent geoscientists. All use is banned between 960 MHz and 3.1 GHz.

"I think they're being too conservative, because they're going to end up putting a lot of people out of business and unfortunately they're going to eliminate a bunch of applications like evaluating pavements, bridge decks, concrete runways. Those all are using radars right in that frequency range [960 MHz to 3.1 GHz]," Olhoeft says.

These rules result from intense pressure from the Departments of Defense and Transportation to protect spectrum-based infrastructures that provide national security and public safety. These government agencies fear that unrestricted use of certain bands of the radio spectrum will interfere with their use of the spectrum. "Even thinly spread UWB energy interferes with very low power signals from distant sources, such as GPS [global positioning system] satellites, which are over 12,000 miles away. In such a case, prudence is dictated because no one knows for sure," testified Steven Price of the Department of Defense.

GPS runs right around 1 GHz and, Olhoeft says, the Department of Defense is trying to protect both the current GPS system and the future system the agency has proposed building. "One of the biggest errors in geophysics is not knowing where you are at, so we use the GPS too. And we've shown them that it doesn't interfere." Indeed, at the Congressional hearing, when questioned by Rep. Tauzin, Julius Knapp of the FCC stated that in GPR's 30 years of use, there have been no reported cases of interference from GPR.

Dennis Johnson of Geophysical Survey Systems Inc. (GSSI) testified on behalf of GPR manufacturers and users. Having sold about 2,500 systems since the company started in 1970, GSSI is the largest U.S. manufacturer of GPR. Johnson said the GPR industry is worth $200 million in the United States alone. "If the rules are not changed, the outcome and consequences for the GPR industry are extremely serious. Many companies will go out of business, and the public's access to a very useful technology will be severely limited, if not eliminated," Johnson said.

A source at the FCC says that the agency plans to interpret the rules as broadly as possible, granting a waiver to those who request one. In fact, he says that the FCC has already met with several groups to get a jump-start on granting them permission and certification for GPR usage. He does concede, however, that the process is subject to the NTIA's corroboration. No one really knows what will happen when the rules change this month.

In its rules, the FCC admits to its conservatism and says it will review the rulings in six to 12 months, after extensive testing of GPR and other devices affected by the ruling. Members of Congress at the hearing pressed both the FCC and the NTIA to construct a strict timetable to promote a speedy resolution.

Lisa M. Pinsker

The above story will appear in the July print edition of Geotimes.

Links:

FCC press release with links to the ruling
NTIA
Radar Solutions International
GSSI
Site about GPR and regulations

Geotimes Home | AGI Home | Information Services | Geoscience Education |
Public Policy | Programs | Publications | Careers

U.S. Spectrum Allocations
300 - 3000 MHz
A Vertical Bar Chart With Frequency Bands Shown Approximately To Scale[1]

John R. Williams
OPP/FCC
November 2002

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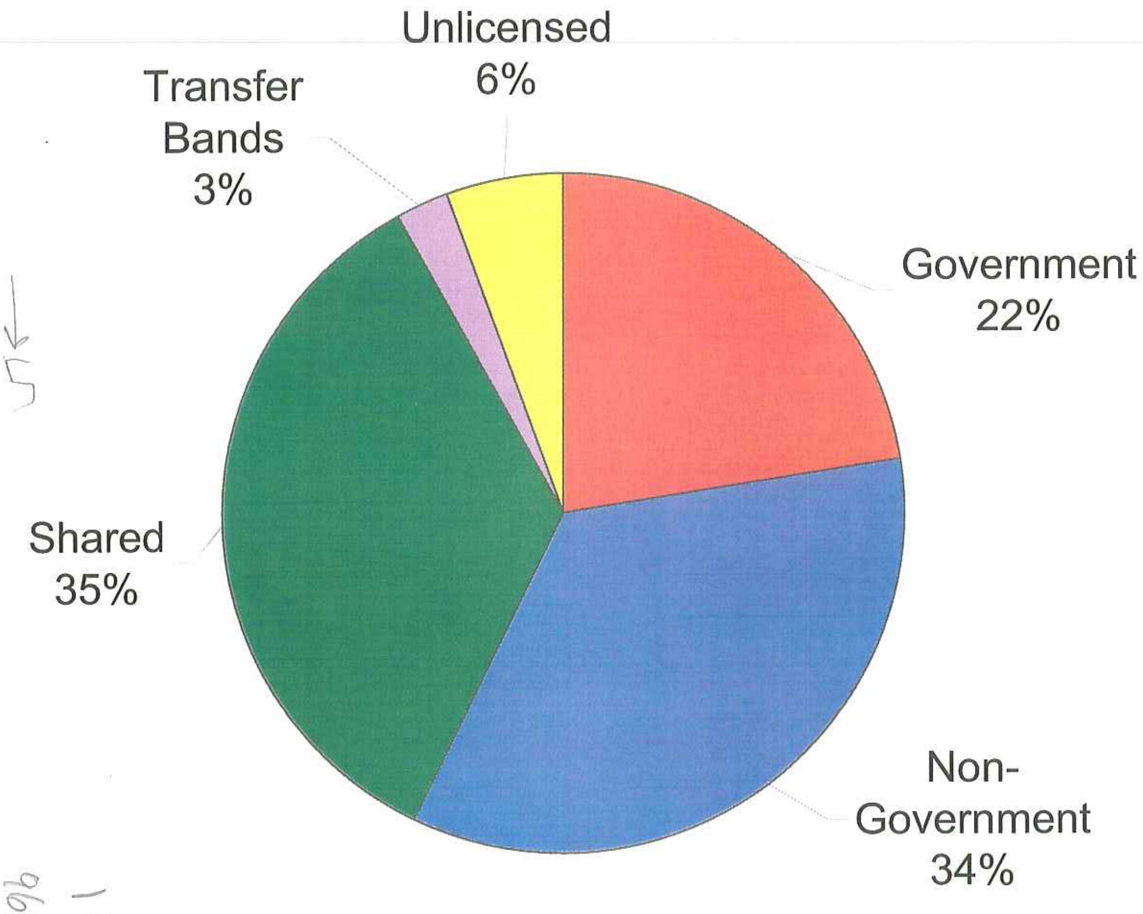
[1] Small bands have been enlarged slightly for legibility. This chart is optimized for printing on legal size paper with a color printer. Services and footnotes in the expanded chart were transferred directly from the FCC's online Allocation Table (Revised as of September 25, 2001) and are believed to be complete and accurate, but have not been cross-checked. Some errors are therefore possible. The official FCC Table of Frequency Allocations is the one published in the Federal Register. The text of footnotes has not been included in this chart but is available on the FCC's

300-3000 MHz

Division of Spectrum Between Government and Non-Government

	G	NG	G/NG	T	UL
MHz	621.6	964.97	965.4	70	156
%	22.38	34.74	34.75	2.52	5.62
Total	2778				



T
UL

960
1 Ghz

🟦	NON-GOVERNMENT
🟩	SHARED
🟪	TRANSFER BAND
🟨	UNLICENSED

ALL CAPS - PRIMARY ALLOCATION
FIRST LETTER CAPS - Secondary Allocation
RED - GOVERNMENT
BLUE - NON-GOVERNMENT
GREEN - GOVERNMENT AND NON-GOVERNMENT
ITALICS - FCC Service Name and (R(le Part No).
BLACK - FOOTNOTES AND OTHER INFORMATION

LISTED IN FCC LLOCATION ABLE IN THE RANGE 322 - 3100 MHz		
322-328.6	🟥	FIXED, MOBILE, G27, S5.149.
328.6-335.4	🟩	AERONAUTICAL RADIONAVIGATION, S5.258.
335.4-399.9	🟥	FIXED,MOBILE, G27, G100.
399.9-400.05	🟩	MOBILE-SATELLITE (Earth-to-space), RADIONAVIGATION-SATELLITE, S5.260, US319, US322.
400.05-400.15	🟩	STANDARD FREQUENCY AND TIME SIGNAL-SATELLITE (400.1 MHz), S5.261
400.15-401	🟩	METEOROLOGICAL AIDS (radiosonde), METEOROLOGICAL-SATELLITE (space-to-Earth), MOBILE-SATELLITE (space-to-Earth), SPACE RESEARCH (space-to-Earth), Space operation (space-to-Earth), S5.263, 647B,
401-402	🟩	METEOROLOGICAL AIDS (radiosonde), SPACE OPERATION (space-to-Earth), Earth exploration-satellite (Earth-to-space), Meteorological-satellite (Earth-to-space), US70.
402-403	🟩	METEOROLOGICAL AIDS (radiosonde), Earth exploration-satellite (Earth-to-space), Meteorological-satellite (Earth-to-space), US70, US345. *Personal Radio (95)*.
403-406	🟩	METEOROLOGICAL AIDS (radiosonde), US70, US345, G6.
406-406.1	🟩	MOBILE-SATELLITE (Earth-to-space), S5.266, S5.267.
406.1-410	🟩	FIXED,MOBILE, RADIO ASTRONOMY, US74, US13, US117, G5, G6.
410-420	🟥	FIXED, MOBILE, US13, G5.
420-450	🟥	RADIOLOCATION,, Amateur, S5.286, US7, US87, US217, S5.282, US228, US230, G8, G2, NG135. *Private Land Mobile (90), Amateur (97)*.
450-454	🟦	LAND MOBILE, S5.286, US87, NG112, NG124. *Auxiliary Broadcasting (74),Private Land Mobile (90)*.
454-455	🟦	FIXED, LAND MOBILE, NG12, NG112, NG148. *Public Mobile (22), Maritime (80)*.
455-456	🟦	LAND MOBILE. *Auxiliary Broadcasting (74)*.
456-460	🟦	FIXED, LAND MOBILE, S5.288, 669, NG112, NG124, NG148. *Public Mobile (22), Maritime (80), Private Land Mobile (90)*.
460-462.5375	🟦	FIXED, LAND MOBILE, S5.288, S5.289, 669, US201,US209, US216, NG124. *Private Land Mobile (90)*.
62.5375-462.7375	🟦	LAND MOBILE, S5.288, S5.289, 669, US201,US209, US216. *Personal Radio (95)*.
62.7375-467.5375	🟦	FIXED, LAND MOBILE, S5.288, S5.289, 669, US201,US209, US216, NG124. *Private Land Mobile (90)*.
67.5375-467.7375	🟦	LAND MOBILE, S5.288, S5.289, 669, US201,US209, US216. *Personal Radio (95)*.
467.7375-470	🟦	FIXED, LAND MOBILE, S5.288, S5.289, 669, US201,US209, US216, NG124. *Private Land Mobile (90)*.
470-512	🟦	FIXED, BROADCASTING, LAND MOBILE, NG66, NG114, NG127, NG128, NG149. *Public Mobile (22), Broadcast Radio (TV) (73), Auxiliary Broadcasting (74), Private Land Mobile (90)*. CORE TV BAND
512-608	🟦	BROADCASTING, NG128, NG149.*Broadcast Radio (TV)(73), Auxiliary Broadcasting (74)*. CORE TV BAND
608-614	🟩	LAND MOBILE, RADIO ASTRONOMY, US74, US246, US350. Personal (95)
614-698	🟦	BROADCASTING, NG128, NG149. *Broadcast Radio (TV) (73), Auxiliary Broadcast. (74)*. CORE TV BAND
698-746	🟦	FIXED, MOBILE, BROADCASTING, NG128, NG149.*Wireless Communications (27), Broadcast Radio (TV) (73), Auxiliary Broadcast (74), Private Land Mobile (90)*. FLEXIBLE
746-747	🟦	FIXED, MOBILE, BROADCASTING, NG128, NG159.*Wireless Communications (27), Broadcast Radio (TV) (73), Auxiliary Broadcast (74), Private Land Mobile (90)*. GUARD BAND MANAGER
747-762	🟦	FIXED, MOBILE, BROADCASTING, NG128, NG159.*Wireless Communications (27), Broadcast Radio (TV) (73), Auxiliary Broadcast (74), Private Land Mobile (90)*. FLEXIBLE
762-764	🟦	FIXED, MOBILE, BROADCASTING, NG128, NG159.*Wireless Communications (27), Broadcast Radio (TV) (73), Auxiliary Broadcast (74), Private Land Mobile (90)*. GUARD BAND MANAGER
764-776	🟦	FIXED, MOBILE, NG128, NG158, NG159. *Auxiliary Broadcasting (74), Private Land Mobile (90)*. PUBLIC SAFETY
776-777	🟦	FIXED, MOBILE, BROADCASTING, NG128, NG159.*Wireless Communications (27), Broadcast Radio (TV) (73), Auxiliary Broadcast (74), Private Land Mobile (90)*. GUARD BAND MANAGER
777-792	🟦	FIXED, MOBILE, BROADCASTING, NG128, NG159. *Wireless Communications (27), Broadcast Radio (TV) (73), Auxiliary Broadcast (74), Private Land Mobile (90)*. FLEXIBLE
792-794	🟦	FIXED, MOBILE, BROADCASTING. *Wireless Communications (27), Broadcast Radio (TV) (73), Auxiliary Broadcast (74), Private Land Mobile (90)*. GUARD BAND MANAGER
794-806	🟦	FIXED, MOBILE, NG128, NG158, NG159. *Auxiliary Broadcasting (74), Private Land Mobile (90)*. PUBLIC SAFETY
806-809.75	🟦	FIXED, LAND MOBILE, NG30, NG31, NG43, NG63. *Public Mobile (22), Private Land Mobile (90)*. SMR
809.75-816	🟦	FIXED, LAND MOBILE, NG30, NG31, NG43, NG63. *Public Mobile (22), Private Land Mobile (90)*. PLMRS AND SMR (INTERLEAVED)
816-821	🟦	FIXED, LAND MOBILE, NG30, NG31, NG43, NG63. *Public Mobile (22), Private Land Mobile (90)*. SMR
821-824	🟦	LAND MOBILE, NG30, NG43, NG63. *Private Land Mobile (90)*. PUBLIC SAFETY
824-849	🟦	FIXED, LAND MOBILE. NG30, NG43, NG63, NG151, *Public Mobile (22)*. CELLULAR
849-851	🟦	AERONAUTICAL MOBILE, NG30, NG63. *Public Mobile (22)*.
851-854.75	🟦	FIXED, LAND MOBILE, NG30, NG31, NG63. *Public Mobile (22), Private Land Mobile (90)* .SMR
854.75-861	🟦	FIXED, LAND MOBILE, NG30, NG31, NG63. *Public Mobile (22), Private Land Mobile (90)*. PLMRS AND SMR (INTERLEAVED)
861-866	🟦	FIXED, LAND MOBILE, NG30, NG31, NG63. *Public Mobile (22), Private Land Mobile (90)*. SMR
866-869	🟦	LAND MOBILE, NG30, NG63. *Private Land Mobile (90)*.
869-894	🟦	FIXED, LAND MOBILE, US116, US268, NG30, NG63, NG151. *Public Mobile (22)*.
894-896	🟦	AERONAUTICAL MOBILE, US116, US268. *Public Mobile (22)*.
896-901	🟦	FIXED, LAND MOBILE, US116, US268, G2. *Private Land Mobile (90)*.
901-902	🟦	FIXED, MOBILE, US116, US268, G2. *Personal Communications (24).*
902-928	🟨	RADIOLOCATION, G59, S5.150, US215, US218, US267, US275, G11. *ISM Equipment (18), Private Land Mobile (90), Amateur (97).*
928-929	🟦	FIXED, US116, US215, US268, NG120, G2. *Public Mobile (22), Private Land Mobile (90), Fixed Microwave (101)*
929-930	🟦	FIXED, LAND MOBILE, US116, US215, US268, G2. *Private Land Mobile (90).*
930-931	🟦	FIXED, LAND MOBILE, US116, US215, US268, G2. *Personal Communications (24)*.
931-932	🟦	FIXED, LAND MOBILE, US116, US215, US268, G2. *Public Mobile (22).*
932-935	🟩	FIXED, US215, US268, G2, NG120. *Public Mobile (22), Fixed Microwave (101).*
935-940	🟦	FIXED, LAND MOBILE, US116, US215, US268, G2. *Private Land Mobile (90)*
940-941	🟦	FIXED, MOBILE, US116 US268 G2. *Personal Communications (24).*
941-944	🟩	FIXED, US268, US301, US302, G2, NG120. *Public Mobile (22), Fixed Microwave (101).*
944-960	🟦	FIXED, NG120. *Public Mobile (22), International Fixed (23), Auxiliary Broadcast. (74), Fixed Microwave (101).*
960-1215	🟩	AERONAUTICAL RADIONAVIGATION, S5.328, US224. *Aviation (87).*
1215-1240	🟥	RADIOLOCATION, RADIONAVIGATION-SATELLITE (space-to-Earth), S5.333, G56, GPS BAND
1240-1300	🟥	RADIOLOCATION, Amateur, S5.333. *Amateur (97)*
1300-1350	🟩	AERONAUTICAL RADIONAVIGATION, Radiolocation, G2, S5.149
1350-1390	🟥	FIXED, MOBILE, RADIOLOCATION, G2, S5.149, S5.334, S5.339, US311, G27, G114
1390-1395	🟪	RADIOLOCATION, Fixed, Mobile, G2, S5.149, S5.339, US311, US351,G27, G114. *Note: 1390-1395 MHz became on-Federal Government exclusive spectrum in January 1999.*
1395-1400	🟩	LAND MOBILE, US350,S5.149, US5.339, US311, US351. *Personal (95)*
1400-1427	🟩	EARTH EXPLORATION-SATELLITE (passive), RADIO ASTRONOMY, SPACE RESEARCH (passive), S5.341, US74, US246
1427-1429	🟪	SPACE OPERATION (Earth-to-space), FIXED, MOBILE except aeronautical mobile, Fixed (telemetry), Land mobile (telemetry and telecommand), S5.341. Satellite Communications (25), Private Land Mobile (90), Note: 1427-
1429-1432	🟦	LAND MOBILE, Fixed (telemetry), Land mobile (telemetry and telecommand), US350, S5.341, US352. *Private Land Mobile (90), Personal (95).*
1432-1435	🟪	FIXED, MOBILE, Fixed (telemetry), Land mobile (telemetry and telecommand), S5.341, G30. *Private Land Mobile (90), Note: 1432-1435 MHz became mixed-use spectrum In January*
1435-1525	🟩	MOBILE (aeronautical telemetry), S5.341, US78. Aviation (87)
1525-1530	🟩	MOBILE-SATELLITE (space-to-Earth), Mobile (aeronautical telemetry), S5.341, S5.351, US78. *Satellite Communications (25), Aviation (87).*
1530-1535	🟩	MOBILE-SATELLITE (space-to-Earth), MARITIME MOBILE-SATELLITE (space-to-Earth), Mobile (aeronautical telemetry), S5.341, S5.351, US78, US315.
1535-1544	🟩	MOBILE-SATELLITE (space-to-Earth), MARITIME MOBILE-SATELLITE (space-to-Earth), S5.341, S5.351, US315. *Satellite Communications (25), Maritime (80)*
1544-1545	🟩	MOBILE-SATELLITE (space-to-Earth), S5.341, S5.356. *Satellite Communications (25), Maritime (80)*
1545-1549.5	🟩	AERONAUTICAL MOBILE-SATELLITE (R) (space-to-Earth), Mobile-satellite (space-to-Earth), S5.341, S5.351, US308, US309. *Aviation (87).*
1549.5-1558.5	🟩	AERONAUTICAL MOBILE-SATELLITE (R) (space-to-Earth), MOBILE-SATELLITE (space-to-Earth), S5.341, S5.351, US308, US309. *Aviation (87)*
1558.5-1559	🟥	AERONAUTICAL MOBILE-SATELLITE (R) (space-to-Earth), S5.341, S5.351, US308, US309. *Aviation (87).*
1559-1610	🟩	AERONAUTICAL RADIONAVIGATION, RADIONAVIGATION-SATELLITE (space-to-Earth), S5.341, US208, US260. *Aviation (87), Note: The NTIA Manual (footnote G126) states that differential GPS stations may be authorized*
1610-1610.6	🟩	MOBILE-SATELLITE (Earth-to-space), AERONAUTICAL RADIONAVIGATION, RADIODETERMINATION-SATELLITE (Earth-to-space), US319, US260. *Satellite Communications (25], Aviation (87).*
1610.6-1613.8	🟩	MOBILE-SATELLITE (Earth-to-space), RADIO ASTRONOMY, AERONAUTICAL RADIONAVIGATION, RADIODETERMINATION-SATELLITE (Earth-to-space), US319, US260, S5.341, S5.364, S5.366, S5.367, S5.368, S5.372,
1613.8-1626.5	🟩	MOBILE-SATELLITE (Earth-to-space), AERONAUTICAL RADIONAVIGATION, RADIODETERMINATION-SATELLITE (Earth-to-space), Mobile-satellite (space-to-Earth), US319, US260,
1626.5-1645.5	🟩	MOBILE-SATELLITE (Earth-to-space), MARITIME MOBILE-SATELLITE (Earth-to-space), S5.341, S5.351, US315. *Satellite Communications (25),*
1645.5-1646.5	🟩	MOBILE-SATELLITE (Earth-to-space), S5.341, S5.375.
1646.5-1651	🟩	AERONAUTICAL MOBILE-SATELLITE (R) (Earth-to-space), Mobile-satellite (Earth-to-space), S5.341, S5.351, US308, US309. *Aviation (87)*
1651-1660	🟩	MOBILE-SATELLITE (Earth-to-space), AERONAUTICAL MOBILE-SATELLITE (R) (Earth-to-space), S5.341, S5.351, US308, US309.
1660-1660.5	🟩	AERONAUTICAL MOBILE-SATELLITE (R) (Earth-to-space), RADIO ASTRONOMY, S5.149, S5.341, S5.351, US308, US309.
1660.5-1668.4	🟩	RADIO ASTRONOMY, SPACE RESEARCH (passive), S5.341, US246.
1668.4-1670	🟩	METEOROLOGICAL AIDS (radiosonde), RADIO ASTRONOMY, US74, S5.149, S5.341, US99.
1670-1675	🟪	METEOROLOGICAL AIDS (radiosonde), METEOROLOGICAL-SATELLITE (space-to-Earth), S5.341, US211. *Note: 1670-1675 MHz became mixed-use spectrum in January 1999.*
1675-1700	🟩	METEOROLOGICAL AIDS (radiosonde)
1700-1710	🟩	FIXED, METEOROLOGICAL-SATELLITE (space-to-Earth), Fixed, G118, S5.289, S5.341.
1710-1755	🟪	FIXED, MOBILE, S5.341, US256. Note: Proceeds from the auction of the 1710-1755 MHz mixed-use band are to be deposited not later than September 30, 2002.
1755-1850	🟥	FIXED, MOBILE, G42.
1850-1910	🟦	FIXED, MOBILE. *Personal Communications (24). Fixed Microwave (101).*
1910-1930	🟨	FIXED, MOBILE. *RF Devices (15)*
1930-1990	🟦	FIXED, MOBILE. *Personal Communications (24). Fixed Microwave (101).*
1990-2025	🟦	MOBILE-SATELLITE (Earth-to-space), NG156. *Satellite Communications (25)*
2025-2110	🟩	SPACE OPERATION (Earth-to-space) (space-to-space), EARTH EXPLORATION-SATELLITE (Earth-to-space) (space-to-space), SPACE RESEARCH (Earth-to-space) (space-to-space), FIXED, MOBILE, S5.391, S5.392,
2110-2150	🟦	FIXED, MOBILE, US252, NG23. *Public Mobile (22), Fixed Microwave (101), Note: 2110-2150 MHz must be auctioned by*
2150-2160	🟦	FIXED, NG23. Domestic Public Fixed (21), Fixed Microwave (101).
2160-2165	🟦	FIXED, MOBILE, NG153, NG23. *Domestic Public Fixed (21), Public Mobile (22), Fixed Microwave (101).*
2165-2200	🟦	MOBILE-SATELLITE (space-to-Earth), NG23, NG168. Satellite Communications (25).
2200-2290	🟥	SPACE OPERATION (space-to-Earth) (space-to-space), EARTH EXPLORATION-SATELLITE (space-to-Earth) (space-to-space), FIXED (line-of-sight only), MOBILE (line-of-sight only including aeronautical tele-metry, but
2290-2300	🟩	FIXED, MOBILE except aeronautical mobile, SPACE RESEARCH (deep space) (space-to-Earth).
2300-2305	🟪	Amateur, G123. *Amateur (97), Note: 2300-2305 MHz became non-Federal Government exclusive spectrum in August 1995.*
2305-2310	🟦	FIXED, MOBILE except aeronautical mobile, RADIOLOCATION, Amateur, US338, G123. Wireless Communications (27), Amateur (97).
2310-2320	🟦	FIXED, MOBILE, RADIOLOCATION, BROADCASTING-SATELLITE, Fixed, Mobile, Radiolocation, US339, US328, US327, S5.396, G120, US338. *Wireless Communications (27).*
2320-2345	🟦	BROADCASTING-SATELLITE, Fixed, Mobile, Radiolocation, US327, US276, US328, S5.396
2345-2360	🟦	FIXED, MOBILE, RADIOLOCATION, BROADCASTING-SATELLITE, Fixed, Mobile, Radiolocation, US339, US328, US327, S5.396, G120, US338. *Wireless Communications (27).*
2360-2385	🟩	MOBILE, RADIOLOCATION, Fixed, G2, G120, US276.
2385-2390	🟪	MOBILE, RADIOLOCATION, Fixed, MOBILE, US276 US276, G2, G120. *Note: 2385-2390 MHz will become non-Federal Government exclusive spectrum in January 2005.*
2390-2400	🟨	AMATEUR, G122. *RF Devices (15), Amateur (97)*

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