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Subsurface Exploration Non-Destructive Evaluation

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Facility Engineering and Asset Management Office
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Attn: Mr. Rob Callahan, Facility Project Manager

FINAL REPORT
Subsurface Investigation for
Structural Integrity Study of Aircraft Ramp at Hanger 4802
NASA Armstrong Flight Research Center
Edwards, California

In accordance with your Order for Services Number NDD16FF07P dated March 28, 2016, Advanced Geoscience presents this final report summarizing our field procedures and methods of data processing and evaluation for the subsurface investigation for the structural integrity study at the NASA Hanger 4802 north ramp. This report presents our interpretation of subsurface conditions based on this non-destructive investigation.

Advanced Geoscience appreciates this opportunity to be of service to the NASA Armstrong Flight Research Center.

Sincerely,
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SUBSURFACE INVESTIGATION REPORT
FOR
STRUCTURAL INTEGRITY STUDY OF
AIRCRAFT RAMP AT HANGER 4802
NASA ARMSTRONG FLIGHT RESEARCH CENTER
EDWARDS, CALIFORNIA

Final Report: June 9, 2016

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1.0 INTRODUCTION

This report presents the results of the subsurface investigation recently completed by Advanced Geoscience, Inc. This investigation was conducted in accordance with our proposal dated March 23, 2016 as part of a structural integrity study of the north aircraft ramp at Hanger 4802 shown in Figure 1. In this area, a fire water main ruptured three feet below the ground surface releasing more than 400,000 gallons of water. This resulted in the uplift and cracking of the reinforced concrete surface, and the wash out of an estimated 15 to 20 cubic yards of sub-grade soil material.

In accordance with our proposal we used the following non-destructive field procedures to investigate the shallow subsurface conditions beneath the reinforced 8 and 16-inch thick concrete areas and asphalt area shown in Figure 1.

1. High-density, ground-penetrating radar (GPR) profiling across the area shown in Figure 1 to investigate the extent of voids beneath the concrete and asphalt pavements.

2. Slab impulse response (SIR) measurements across a large portion of the concrete pavement to help support our interpretation of the radar reflection patterns indicating void and non-void areas.

3. Seismic shear-wave velocity profiling to investigate possible deeper void conditions and the loss of strength and pavement support in the underlying sub-grade soils caused by the wash out.

4. Color video camera inspection of the fire water main beneath the area to determine the location of the pipeline break.

The following section summarizes our field procedures and methods of data processing and evaluation. The concluding sections discuss our current interpretation of subsurface conditions and recommendations for additional investigation. This interpretation may be revised if additional subsurface data is made available from future core hole drilling.

2.0 FIELD PROCEDURES AND DATA EVALUATION

Advanced Geoscience mobilized a survey crew and equipment to the site and performed the field investigation on April 18 through 22, 2016.

A survey measurement grid was first set up across the north ramp area. The positioning of this measurement grid was parallel to the north edge of Hanger 4802 as shown on the site grid map in Plate 1. The grid points and distances were marked on the ground surface using white aerosol paint.

2.1 Ground-Penetrating Radar Profiling

High-density, ground-penetrating radar (GPR) profiling was first conducted across the measurement grid set up outside of Hanger 4802 to investigate the extent of voids beneath the concrete and asphalt pavements. The GPR profiles were recorded along north-south oriented survey lines spaced 2-feet apart (from grid lines 24 W to 212 E). This data coverage extended across most of the ramp area affected by the water main break. However, there were some gaps in data coverage on the east edge of the ramp near the walkway where the fire water main was excavated and also along the north edge where the metal storage bins covered the ground surface.

Additional GPR profiling was also conducted across a limited portion of the reinforced concrete floor leading into Hanger 4802. The GPR profiles were recorded along east-west orientated survey lines spaced 2-feet apart (from 0 N to 12 S). This data coverage extended south of the hanger door to cover a 10-foot wide portion of the hanger floor.

The GPR profiles were recorded using a Geophysical Survey Systems, Inc., System-2000 equipped with a 400-Mega Hertz GPR antenna. This system recorded radar waves transmitted into the ground in a continuous scanning mode as the antenna was moved slowly along the survey lines. Each radar scan was recorded with a 40-nanosecond record length with 16-bit analog to digital resolution. These parameters were set up to image conditions below the pavement in the upper 6 feet.

The digitally-recorded GPR data was later downloaded to a computer in our office for display and evaluation. The data profiles were entered into the RADAN GPR data processing software (developed by Geophysical Survey Systems, Inc.) to undergo computer processing and color-amplitude display to enhance reflections from the concrete-ground interface and void spaces.

Past experience with GPR investigations for subsurface voids demonstrates that anomalous, higher-amplitude reflections occur near the expected concrete-ground interface where a measureable air-space void exists below this interface. Deeper voids and porous conditions within the sub-grade soils often show more chaotic reflection patterns from the normal layered subsurface reflection patterns. The areas where we interpreted these anomalous reflection patterns indicating subsurface voids are delineated on the site grid map shown in Plate 1. Figure 2 displays selected GPR profiles across areas where we interpreted various void and non-void conditions. The correlation of these GPR profiles to future core hole measurements of void conditions would allow us to make a thickness evaluation of these void spaces beneath the ramp area.

The GPR profiles recorded across the limited area of the hanger floor could not be used to investigate whether void conditions existed. These profiles exhibited higher-amplitude reflection patterns near the bottom of the reinforced concrete floor from what appears to be a metal surface associated with a structural element below the floor slab. These strong, reverberating reflection patterns prevented an evaluation of subsurface conditions in this area.

2.2 Slab Impulse Response Measurements

Slab impulse response (SIR) measurements were conducted across most of the reinforced 8 and 16-inch thick concrete ramp area. These measurements were used to help support our interpretation of the radar reflection patterns indicating void areas immediately beneath the concrete pavement. The measurements were conducted along north-south oriented grid lines spaced 4 and 8 feet apart, starting at grid line 8 E and continuing to grid line 200 E. Along these grid lines the measurements were recorded at 5 and 10-foot intervals. The 5-foot intervals were used to obtain more data coverage across the area of the ramp where the GPR profiles detected obvious reflection patterns indicating voids.

An Olson Instruments, Inc. NDE 360 SIR data recording system was used with a load-cell instrumented hammer and single geophone velocity transducer mounted to the pavement at each measurement point. Following procedures specified in ASTM C1740 the instrumented hammer was used to induce sonic vibrations into the concrete slab that were measured by the geophone positioned 5 to 6-inches away. These time-series measurements from the hammer and geophone were downloaded to a computer and transformed into the frequency domain using the WinSIR software (developed by Olson Instruments) to calculate three mobility spectrums for each measurement point.

The average of the mobility spectrums for each measurement point were later evaluated in our office to identify areas where loss of pavement support or voids could exist beneath the pavement surface. Our evaluation of mobility spectrums from areas where the GPR profiles indicated void and non-void areas showed that the "mobility ratio" provided the best detection of possible void areas. The mobility ratio was calculated by dividing the peak mobility value between 0 and 100 Hertz by the average mobility between 100 and 800 Hertz. Figure 3 shows a contour mapping of this mobility ratio for the SIR measurement points positioned across the ramp area. In accordance with ASTM C1740, the areas showing a mobility ratio exceeding 2.5 indicate a likely loss of pavement support or possible void conditions. However, it is noted that higher mobility values in this frequency range could be caused by other factors such as internal defects within the concrete slab, changes in slab thickness, and nearness of joints. Therefore, the interpretation of these conditions based on SIR results alone is usually confirmed by other testing procedures such as GPR.

2.3 Seismic Shear-Wave Velocity Profiling

Seismic shear-wave velocity profiling was performed along five north-south orientated grid lines extending across the ramp area. These profiles were used to make an evaluation of deeper subsurface conditions across selected areas, to investigate the loss of pavement support strength (measured as shear-wave velocity) in the underlying sub-grade soils caused by the wash out. In addition, the velocity profiles were also used to help investigate the possibility of deeper voids or low density conditions and the possibility of controlling factors caused by the shallow bedrock.

The shear-wave velocity profiling was conducted along five 180-foot long survey lines designated as Lines 1 through 5 (shown in Plate 1). Lines 1, 2, 3, and 4 where positioned along grid lines 192 E, 128 E, 104 E, and 80 E and were expected to be in the wash out affected area. Line 5 was positioned along grid line 24 W and was expected to be outside the wash out area.

The shear-wave velocity profiling used the “active-source” multi-channel analysis of surface waves (MASW) method developed by the Kansas Geological Survey. The MASW data were recorded on Lines 1-5 using a 48-channel Seistronix EX-6 data acquisition system connected to a series of 4-Hertz geophones spaced 3-feet apart. This system was used to record Rayleigh-type surface waves from seismic vibrations created by a sledge hammer at numerous “source points” positioned on the survey line. The seismic vibrations from each source point were recorded into groups of 24 geophones also positioned along the survey line. The recordings were made in an end-on configuration, with the first source point positioned 27 feet south of the first active geophone position at grid line 0 N. After each recording, the source point and group of 24 geophones were shifted to the north by 3 feet. This shifting continued until the last source point at 81 N and last geophone position at 177 N were recorded.

The MASW data recorded along each survey line consisted of a total of thirty-seven 24-channel field records. The recording time length for each record was 1.0 seconds with a 0.5 millisecond sample rate.

The MASW data processing was performed in our office using the SurfSeis MASW data processing software (developed by the Kansas Geological Survey). The 24-channel, active-source MASW records were entered into SurfSeis to perform a specialized sequence of processing to prepare dispersion curves showing Rayleigh wave phase velocity versus frequency for each 24-channel field record. These curves were used to calculate 1-D models of shear-wave velocity layering for the center of each 24-channel geophone array. The resulting 1-D models generated along Lines 1-5 were then smoothed and gridded and color contoured to prepare the approximate 2D shear-wave velocity profiles shown in Figures 4 and 5. These velocity profiles are displayed at the same horizontal and vertical scale (1 inch= 10 feet) and show relative subsurface shear-wave velocity variations between grid lines 35 N and 139 N.

2.4 Video Camera Inspection of Fire Water Main

A color video camera inspection was conducted on the 20-inch diameter fire water main beneath the north ramp area. This video camera inspection was used to identify and inspect the location of the pipeline break. Prior to this inspection NASA completed an excavation and opening in the pipeline on the east edge of the ramp area for the camera to enter the pipeline. At this location the depth of the top of the pipeline was 2.4 feet.

Tunnel Vision Pipeline Cleaning and Video Inspection, Inc. (from Apple Valley, California) performed the video camera inspection on April 19. A cart-deployed, high-resolution color video camera system was used to record conditions inside the cast iron pipeline. This video recording started from the pipeline opening on the east edge of the ramp and continued to the west a total distance of 90.3 feet. At this point the video inspection was stopped due to a large break in the pipeline exposing the soil. A pattern of longitudinal cracks in the pipeline was also observed starting at 87.9 feet.

After this camera inspection was completed NASA was provided with an inspection report and a computer DVD containing the video file.

Based on this video inspection we determined the main break point was beneath grid line 124 E along the fire main as shown on Plate 1.

3.0 RESULTS OF SUBSURFACE INTERPRETATION

Evidence of void spaces was first detected beneath the concrete pavement of the Hanger 4802 north ramp during the field investigation as the ground-penetrating radar (GPR) profiles were recorded across the area surrounding the main break in the fire main. Patterns of anomalous, higher-amplitude reflections (displayed in Figure 2) were observed on the GPR profiles across this area where the reflection pattern from the concrete-ground interface was expected.

After the GPR profiles underwent computer processing and color-amplitude display in our office these anomalous reflection patterns were more visible across the ramp area. An evaluation was made of the GPR profiles recorded across the ramp to identify and map out anomalous reflection patterns indicating evidence of voids. The site grid map in Plate 1 presents this mapping and also shows areas where the strongest amplitude reflection patterns indicate thicker void spaces beneath the pavement. As expected, this mapping shows thicker void spaces beneath the 16-inch concrete pavement in the area surrounding the main break point.

The slab impulse response (SIR) measurements underwent computer processing and were compared to this mapping of GPR reflections. Plate 1 displays an overlay of the areas where the SIR mobility ratio was greater than 2.5 indicating possible loss of pavement support or voids. These areas were drawn based on the contour map of mobility ratio values in Figure 3. This mobility evaluation supports our interpretation of measureable void spaces beneath the fire main break area and other areas such as the north edge of the 8-inch concrete slab which is uplifted between grid lines 20 N and 50 N. In addition, the larger pattern of mobility ratios exceeding 1.5 on the contour map in Figure 3 also compares with the distribution of void-like GPR reflection patterns across the ramp area shown in Plate 1.

The seismic shear-wave velocity profiling along Lines 1 through 5 (located on Plate 1) provides some initial subsurface data on the conditions of sub-grade soils beneath the pavement. These profiles are displayed in Figures 4 and 5 and reveal lower shear-wave velocity areas that appear to be caused by the wash out. The velocity profiles for Lines 2, 3, and 4 show lower velocity areas extending to north of the fire main as indicated in Plate 1. These lower velocity areas appear to be consistent with the direction of soil wash out to the north which was observed on the surface at the concrete-asphalt separation along grid line 148 N after the fire main break.

The shear-wave velocity profile for Line 5 also shows a lower velocity area to the northwest which may or may not be caused by the wash out. This velocity profile in Figure 5 also displays subsurface geologic conditions from the lower part of the boring log obtained from nearby borehole B4 (on NASA drawings LDZ-2135). This log shows below the existing elevation of the concrete pavement a three-foot layer of granular, decomposed granite overlying a harder granite layer which had sampling refusal. This harder granite layer is interpreted as the upper surface of the weathered granite bedrock in this area. It is also noted that the other surrounding boreholes B2 and B5 in this area also reveal a 2 to 10-foot layer of unconsolidated, decomposed granite overlying harder weathered granite in this area. These subsurface geologic conditions and the variations in the 2,000 feet/sec shear-wave velocity surface on Lines 1-5 suggest there are topographic undulations in the shallow, impermeable bedrock surface that caused the more lateral movement of the water released from the fire main break.

It is also noted that Lines 2 and 3 positioned across the fire main break area show thicker lower velocity layers immediately north of the pipeline. These thicker lower velocity layers and the deeper GPR reflection patterns in this area indicate the possibility of deeper voids positioned north of the pipeline break point.

Based on these results we believe there is a thickness of voids beneath the north ramp pavement that can be measured in units of feet that extend outward from the pipeline's main break point to where they are too thin to measure. The shear-wave velocity profiles along Lines 2 and 3 also indicate there could be significant reduction in pavement support strength in the underlying sub-grade soils caused by the wash out. There could also be the possibility of deeper voids or low density conditions.

The limited GPR profiling recorded across the hanger floor could not be used to investigate whether void conditions exist in this area. As previously discussed, these profiles exhibited higher-amplitude reflection patterns near the bottom of the reinforced concrete floor from what appears to be a metal surface associated with a structural element below the floor slab. These stronger, reverberating reflection patterns prevented an evaluation of subsurface conditions in this area.

4.0 RECOMMENDATIONS

Further subsurface investigation by direct methods should be performed across the ramp area. We recommend that six to eight core holes be drilled in void and non-void areas shown in Plate 1 through both concrete and asphalt pavements. These core holes should be used to collect concrete cores and soil samples for laboratory testing. Accurate measurements of void spaces should be made together with visual observations using a borehole camera on the top layer of soil. Intact soil cores should also be recovered for laboratory testing of density.

These additional subsurface data should be correlated to the GPR and seismic shear-wave profiling results to help confirm these non-destructive test findings and also make a better evaluation of the distribution and thickness of voids and the sub-grade support conditions beneath the ramp area.

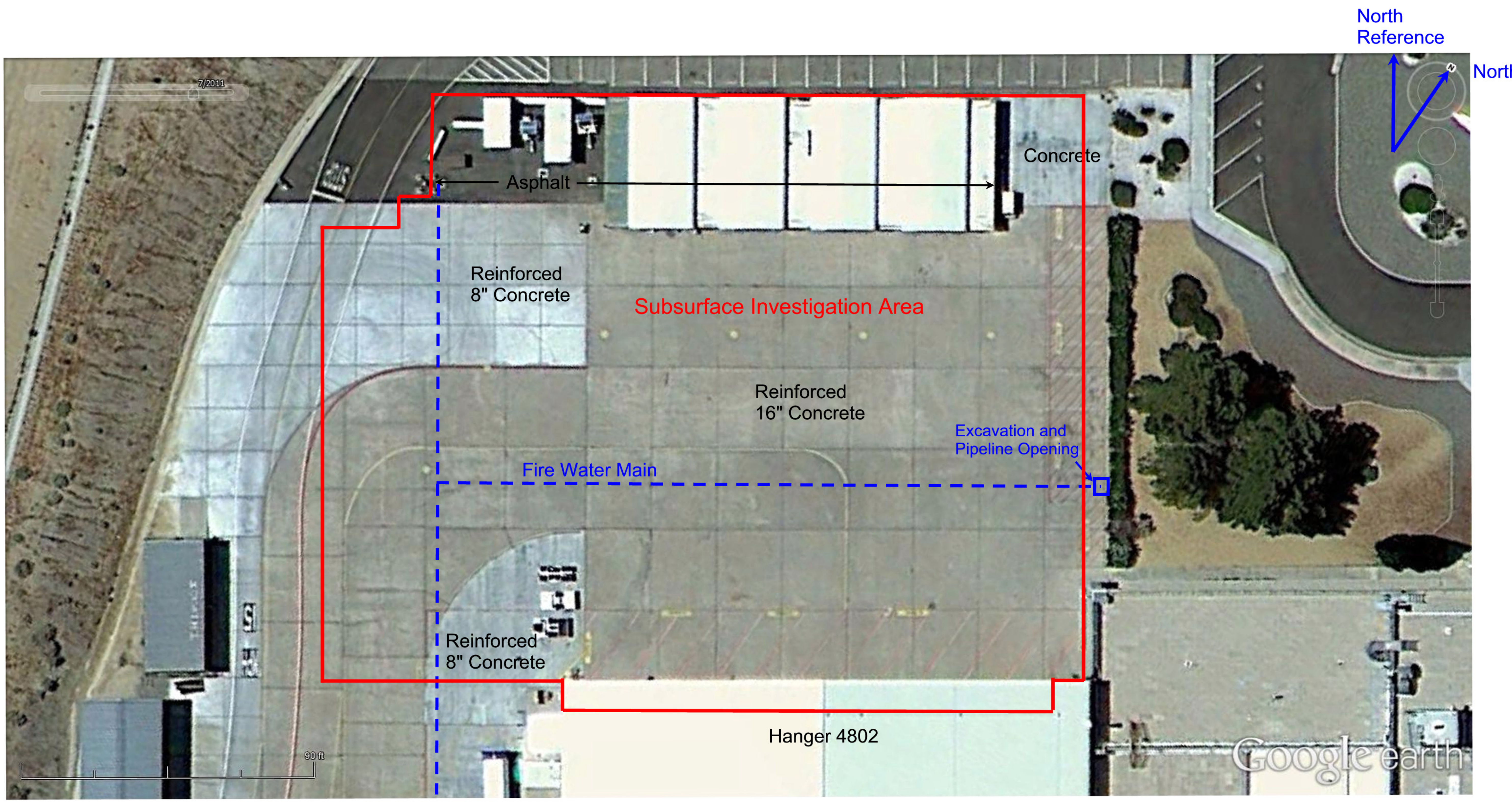
If ramp repairs are initiated without additional subsurface investigation it is recommended that the ramp's concrete tiles first be removed in the area shown on Plate 1 where the GPR profiling shows thicker void spaces surrounding the main break point. The subsurface inspection and subsequent removal of concrete tiles could then be continued in an outward direction from this area.

5.0 REFERENCES

Application of a Combined Non-Destructive Evaluation Approach to Detecting Subgrade Voids Below a Dam Spillway, D. A. Hollema, and L. D. Olson, Olson Engineering, Inc.

Plot Plan and Test Boring Pavement Details, NASA Armstrong Flight Research Center Drawings LDZ-2135, Sheets 1 and 5, 1952.

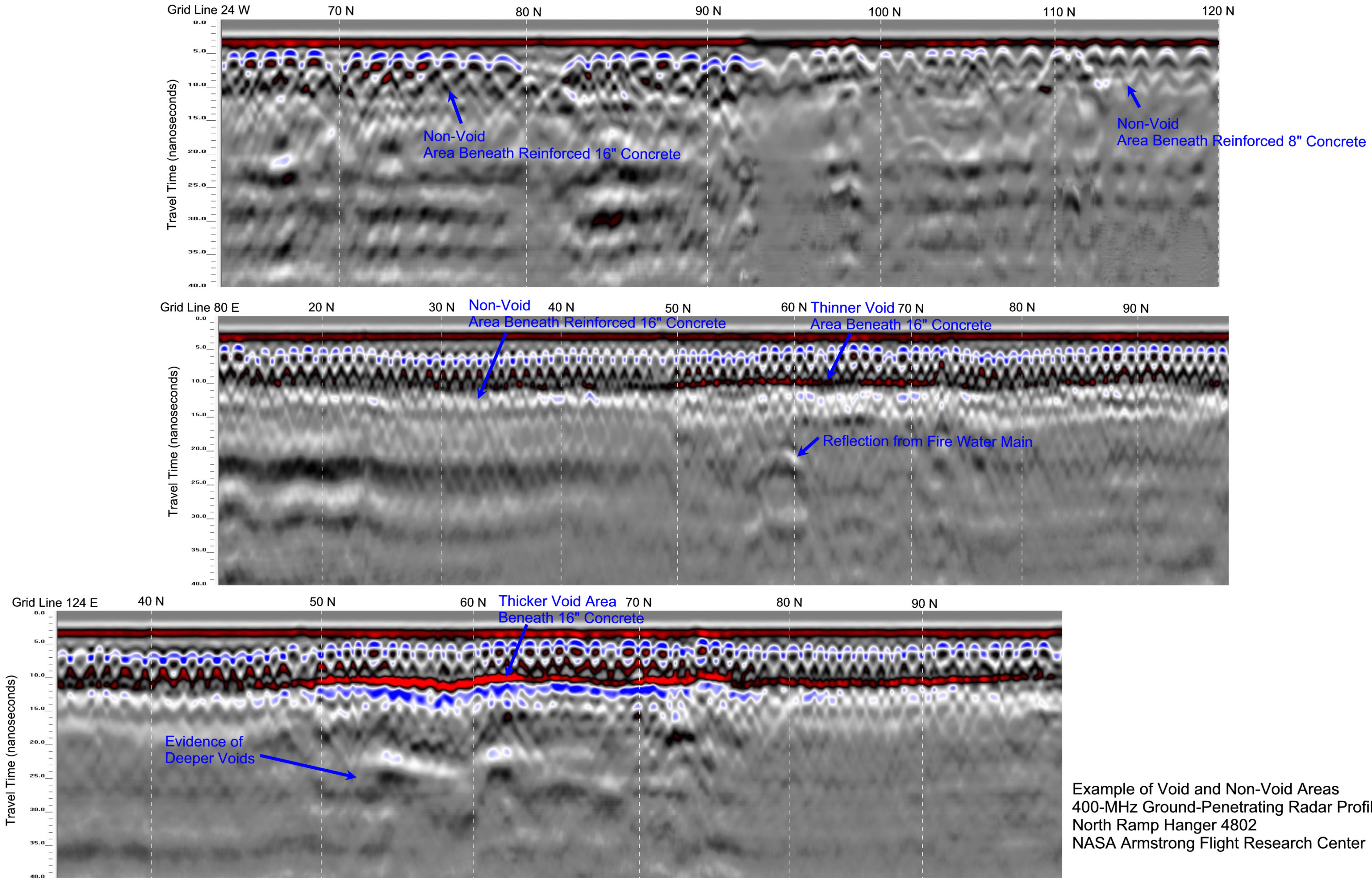
Standard Practice for Evaluating the Condition of Concrete Plates Using the Impulse Response Method, ASTM Method C1740-10, American Society for Testing and Materials, January, 2011.



Scale 1 inch= 30 Feet

Google Earth Site Map Showing
Subsurface Investigation Area
North Ramp Hanger 4802
NASA Armstrong Flight Research Center

Figure 1
Advanced Geoscience, Inc.



Example of Void and Non-Void Areas
400-MHz Ground-Penetrating Radar Profiles
North Ramp Hanger 4802
NASA Armstrong Flight Research Center

Figure 2
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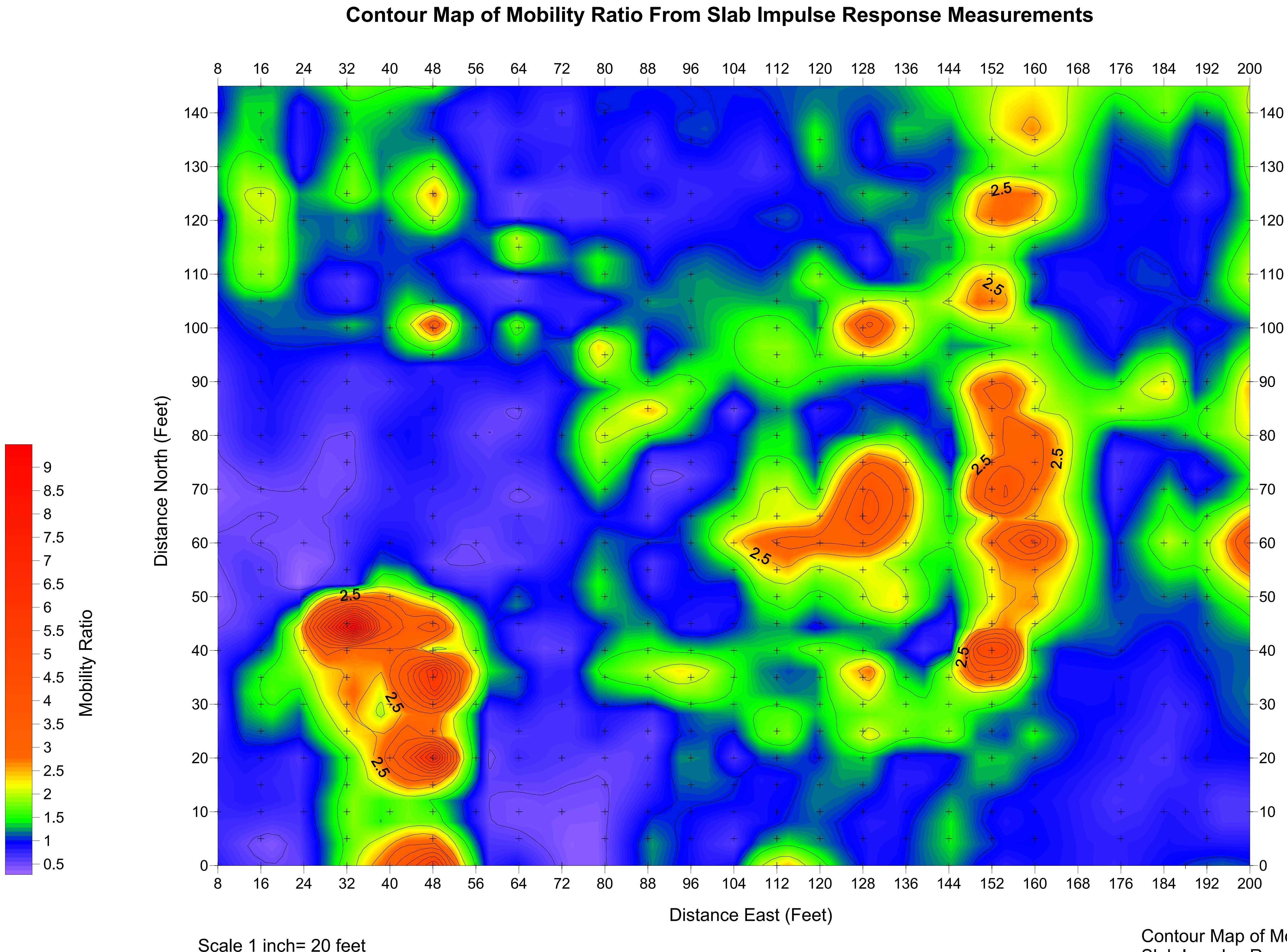
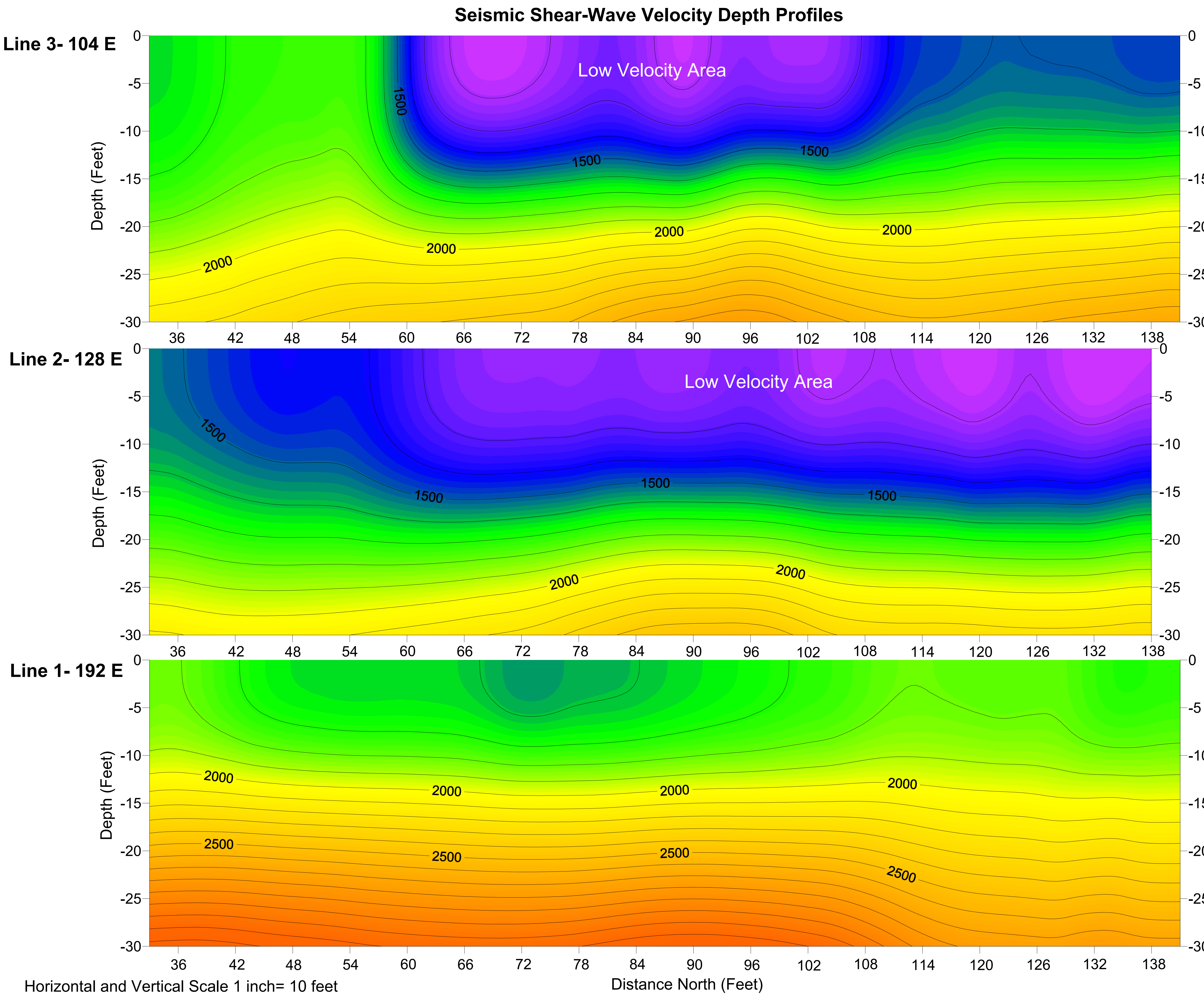


Contour Map of Mobility Ratio From
Slab Impulse Response Measurements Across North Ramp Area
Hanger 4802 NASA AFRC

Figure 3
Advanced Geoscience, Inc.



Seismic Shear-Wave Velocity Profiles
Lines 1-3 Across North Ramp Area
Hanger 4802 NASA AFRC

Figure 4
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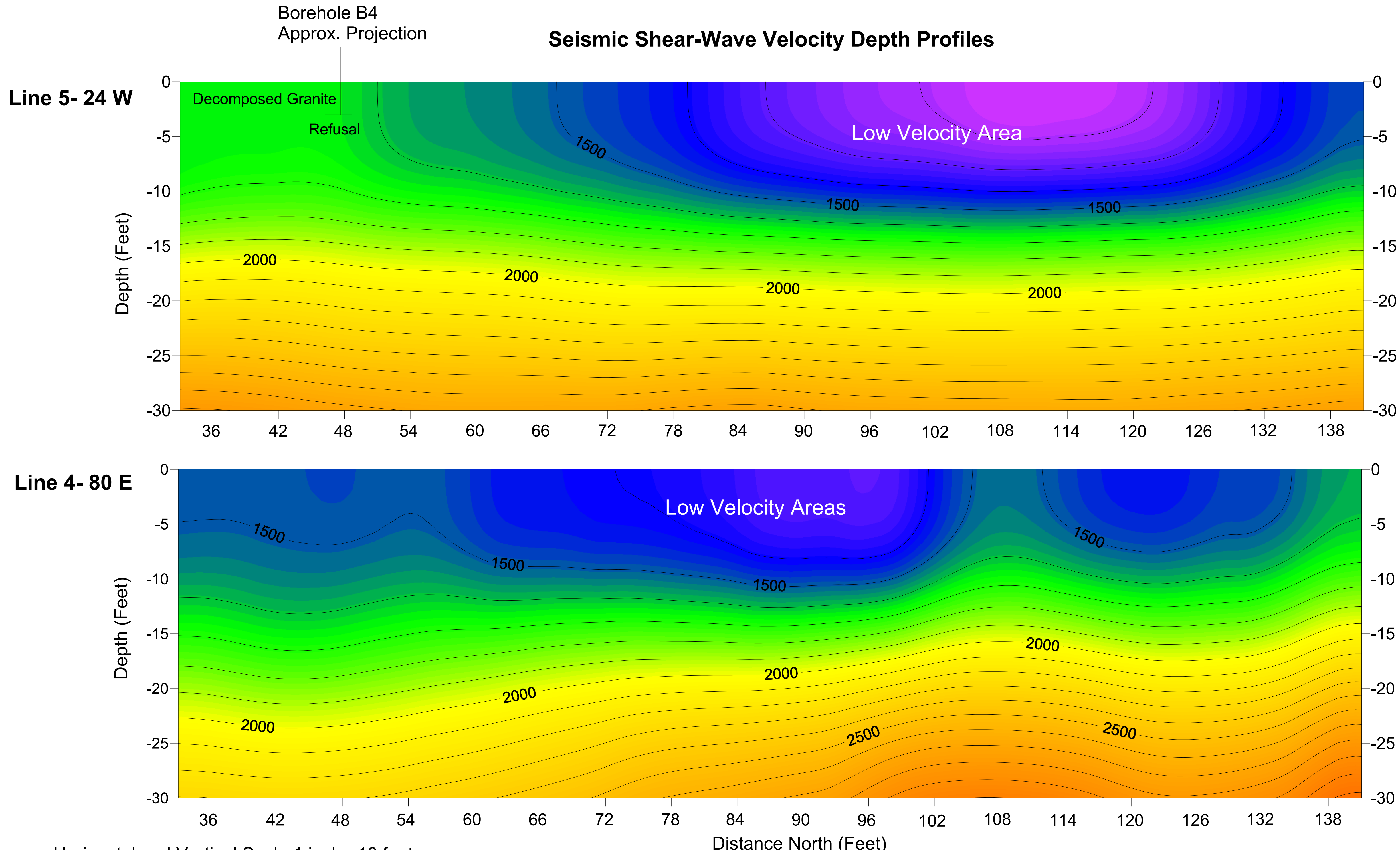
Seismic Shear-Wave Velocity Depth Profiles



Horizontal and Vertical Scale 1 inch= 10 feet

Seismic Shear-Wave Velocity Profiles
Lines 4-5 Across North Ramp Area
Hanger 4802 NASA AFRC

Figure 5
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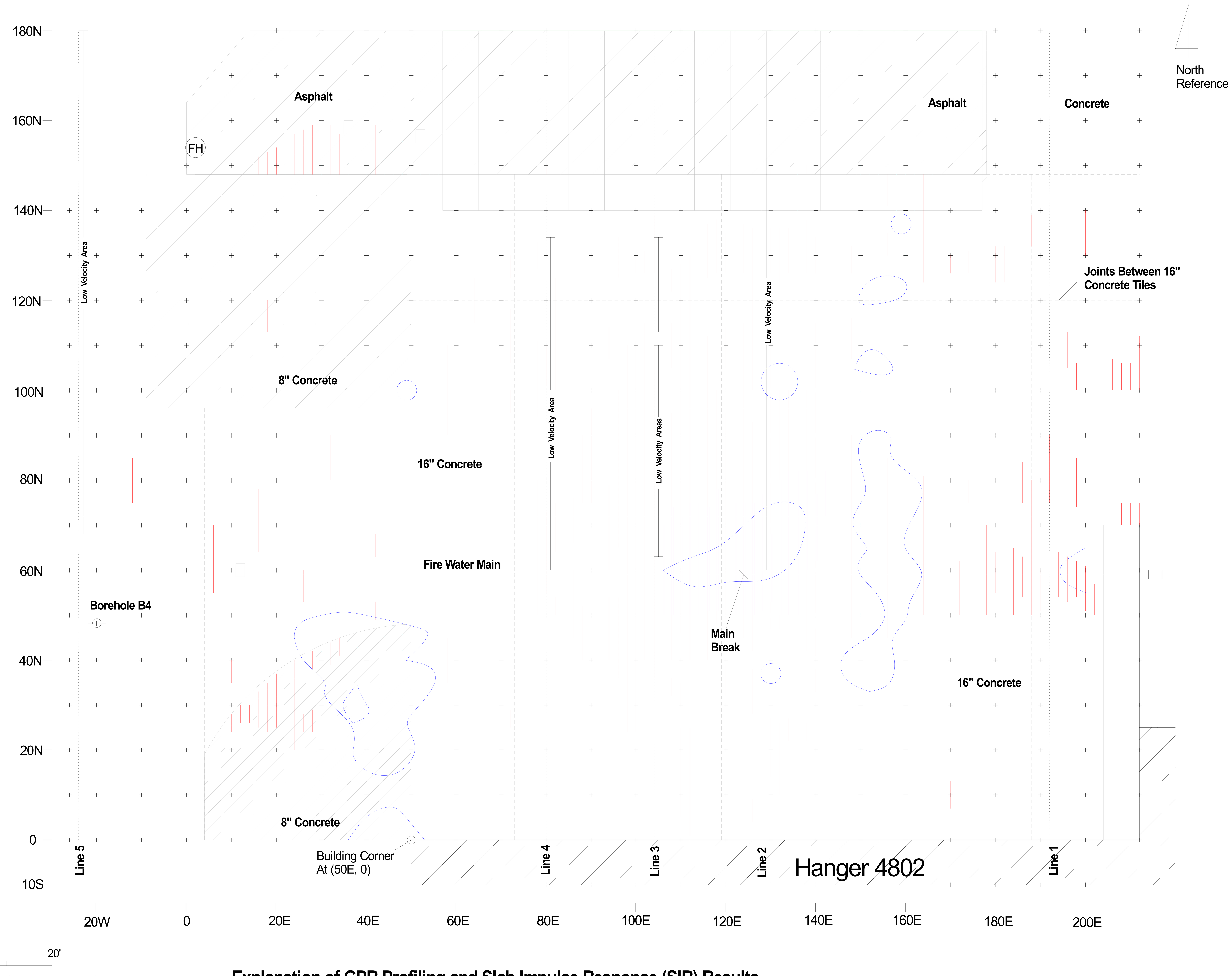

Explanation of GPR Profiling and Slab Impulse Response (SIR) Results

GPR Reflections Indicate Voids Beneath Pavement

GPR Reflections Indicate Thicker Voids Beneath Pavement

Areas Where SIR Mobility Ratio is Greater Than 2.5
Indicating Loss of Pavement Support or Voids Beneath Pavement

Site Grid Map Showing Results of Subsurface Investigation
North Ramp Area at Hanger 4802
NASA Armstrong Flight Research Center

Plate 1
Advanced Geoscience, Inc.