Don't Mess with a Geophysicist's House: A Case Study of Ground Penetrating Radar for Concrete Moisture Mapping and Void Detection in the Saturated Soil beneath the Concrete Foundation

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Site Background

The subject residence is located in the northwest part of Houston, Texas. The house is 8 years old. The homeowner replaced the carpets in the living room with wood one year after they moved in.

The wood floor started showing discoloring within 3 months right after they were installed (Figure 1).

The plumbing inspection results indicated that inspection of pipes revealed no leak at the house. A flooring company visited the living room and took some moisture readings for reconnaissance purposes. Approximate locations of the readings and values are shown in Figure 1. An engineering company was contracted to evaluate the moisture problem in the living room. However, results from the plumbing and engineering studies neither pinpoint the source of the moisture specifically nor the conditions of the concrete slab and the soil beneath it. To address the problem, the homeowner hired his own geophysical company to perform ground penetrating radar surveys in the living room.

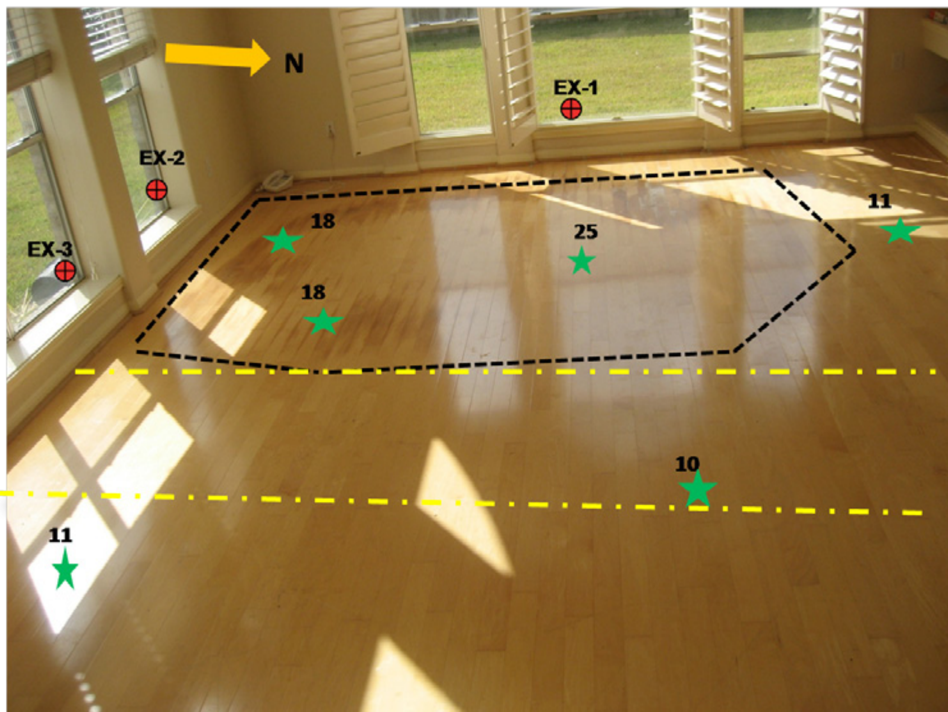

Figure 1. GPR study area showing the discolored portion of the wood floor with dashed black lines. Location of moisture readings are shown with green stars. Moisture readings 10 and 11 are background whereas 18 and 25 are high-moisture areas. Dashed-yellow lines show two post-tension cables embedded into the concrete at about 3 inch. Red circles are excavation points.

Clayey soil is present throughout the area where the subject residence is located. This type of soil expands when it gets wet, and shrinks as it dries.

Purpose of Ground Penetrating Radar (GPR) Surveys

The purpose of the GPR study was three-folded: 1) to determine whether there were water and/or sewer pipes crossing the living room; 2) to locate potential leaks and/or moisture distribution of the slab due to leaking; 3) to locate voids within the concrete foundation and/or soils underlying the concrete.

GPR Instrumentation and Survey Design

GSSI SIR-2000 GPR system was used during the surveys with antennas of 1500 and 400 MHz, whose ranges have depth penetration of up to 1 feet and 8 feet, respectively, depending on the conductivity of the concrete slab and the underlying soil. A schematic map of the living room is shown in Figure 2.

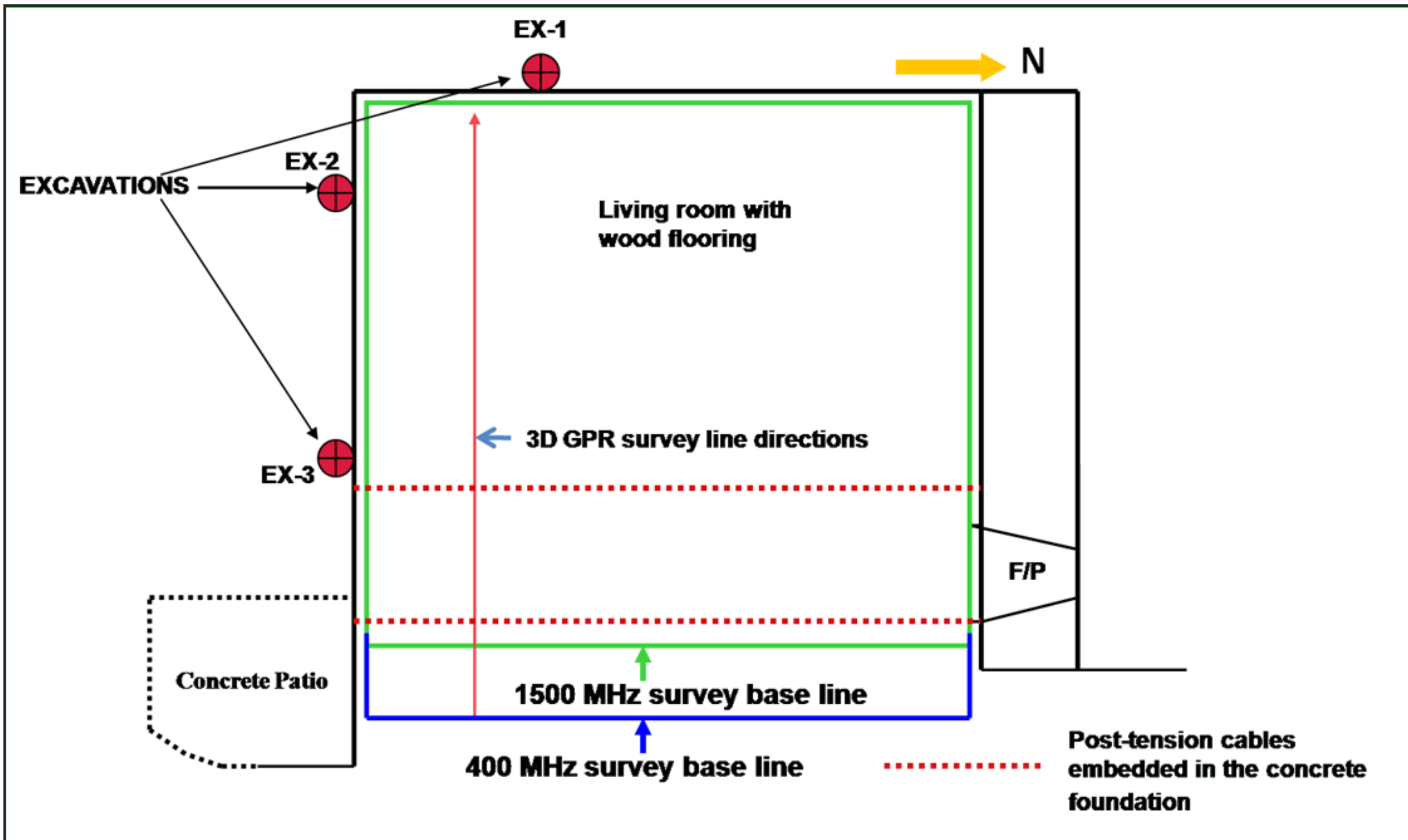

Figure 2. Schematic site map showing 3D GPR survey design.

The 1500 MHz antenna was used with a hand-held cart system to collect three-dimensional (3D) GPR data (Figure 3). 26 profiles of GPR data with six (6) inch spacing were collected.

The 400 MHz antenna was used with a cart system to collect 3D GPR data (Figure 4). 15 profiles of GPR data with one (1) foot spacing were collected. It should be noted that this survey's baseline (X =0, Y=0) starts 3 feet to the east of the 1500 MHz surveys

GPR is the general term applied to techniques that employ radio waves in the 1 to 1000 megahertz (MHz) frequency range, to map near-surface structures and

Figure 3. Picture showing the 1500 MHz GPR survey in the living room. The GPR data was collected at every 6 inch.

Figure 4. Picture showing the 400 MHz GPR survey in the living room. The GPR data was collected at every one foot.

man-made features. The GPR system consists of a transmitter and receiver antennas, and a colored display unit. Depth penetration of the radio waves is limited by the antenna chosen (larger antennas generate lower frequencies which offer greater penetration) and the conductivity of the soil.

The ability of a GPR system to work successfully depends upon two electrical properties of the subsurface, electrical conductivity and relative dielectric permittivity (i.e. dielectric constant). Dielectric constant is a dimensionless measure of the capacity of a material to store charge when an electric field is applied.

The value of the dielectric constant ranges between 1 (for air), and 81 (for water). The dielectric constant for concrete varies from about 5 when dry to 10 when saturated.

Thus, differences in dielectric constant of subsurface materials along distinct boundaries, such as moist and dry concrete and pipes embedded within the concrete slab, can cause highly significant reflections in the radar signal, which are recorded and displayed by the system.

In summary, GPR radar reflections occur when GPR waves encounter a change in velocity due to dielectric contrast. The bigger the change in concrete and/or soil properties the more signal is reflected.

Data Preparation and Processing

GPR surveys with 1500 and 400 MHz antennas were completed on August 7, 2008 and October 12, 2008, respectively. Two different baselines for the surveys were established due to different sizes of the antennas and their logistics. The direction of the profiles was from east to west. The length of the GPR profiles for the 1500 MHz survey was about 12 feet with 6 inch profile spacing. The length of the GPR profiles for the 400 MHz survey was about 15 feet with one foot profile spacing. Both surveys included the moisture free and moisture affected areas of the living room.

Upon completion of the survey, the data was transferred into a laptop computer and the x and y coordinates of each data point were determined. The data was then processed using GSSI's RADAN software.

The presentation of the 1500 and 400 MHz GPR data is in color to provide rapid visual recognition of the GPR anomalies. In the color mode the GPR data is displayed in a color-amplitude format, and a color is assigned to a specific positive or negative value of the recorded signal. In this study, red and yellow colors on the GPR profiles correspond to the highest amplitude positive pulse. Therefore, when it appears on the radar record, it means that there is a strong reflection where yellow and red colors are observed due to a high dielectric contrast. Dark blue could also represent a "strong" negative reflection and similar high dielectric contrast.

Dielectric constants of 6 and 20 were used for the concrete pad and the underlying soil, respectively, and these numbers were calibrated with known subsurface targets, i.e., the concrete thickness (6 inch) and soil depth (2 feet).

Discussion of 1500 and 400 MHz GPR Data

3D GPR results for the1500 MHz surveys are given in Figure 5, which shows a 3 inch depth-slice view of the entire study area. The map view displays two significant linear GPR anomalies shown with red and yellow colors. These anomalies trend in the north-south direction and are labeled as PTC-1 and PTC-2, whose sources are caused by ferrous materials within the concrete. In fact, a ¾ inch post-tension cable was observed on the concrete foundation outside the study area. PTC-1 anomaly appears to lose its high-amplitude strength in the middle of the study area. In other words, the integrity of the post-tension cable appears to be compromised. A very significant anomaly is also shown with light brown and yellow colors to the west of PTC-1 anomaly. This anomaly is outlined with a dashed-black line on the map (top) view of Figure 5. The geometry of this anomaly is quite correlative with the observed moisture- affected areas of the wood floor (see Figures 1 and 5). A void anomaly immediately beneath the concrete slab is also located in the 2-D section of Figure 5.

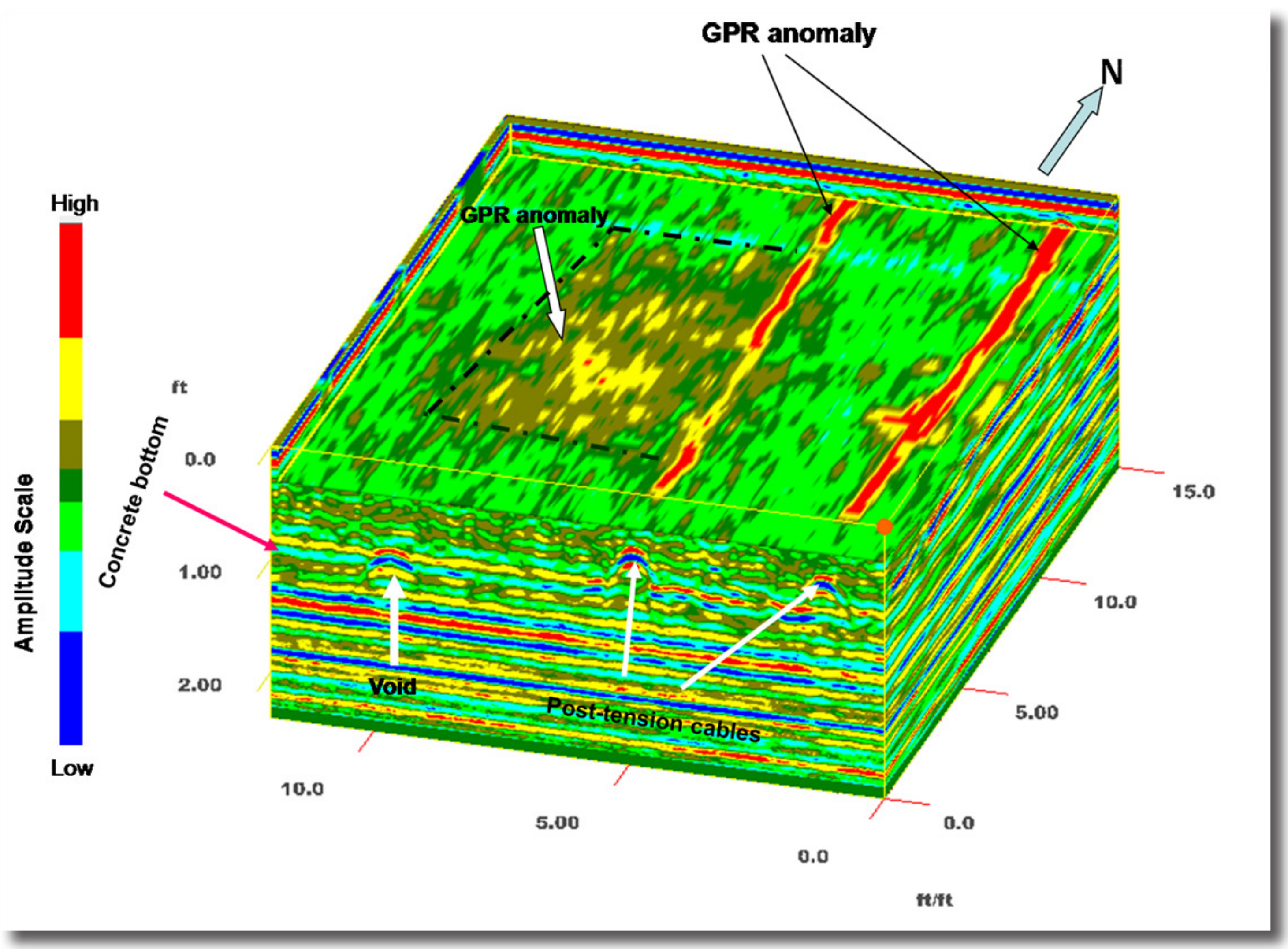

Figure 5. 3D GPR data for 1500 MHz survey showing a depth-slice view at 3 inch into the concrete foundation.

3D GPR results for the 400 MHz surveys are given in Figure 6, which shows a 2.5 foot depth-slice (top view) of the entire study area. The map view displays two linear moderate-to-high amplitude anomalies in the north-south directions. The majority of these anomalies are shown with the yellow color, which is caused by dielectric contrast (low dielectric vs. high dielectric values) within the soil underlying the concrete foundation. Source of these anomalies are not known: but they could be caused by voids filled with partly water and soil. However, there are high amplitude zones (red color) within the anomalies shown with the yellow color. The red areas are probably caused by voids filled with air. It should be noted that two linear anomalous features are approximately located beneath the post-tension cables embedded within the concrete. This correlation between the linear anomalies in the soil and the location of linear PTC anomalies within the concrete is either coincident or they are somehow related. A deeper 4-foot depth-slice does not indicate the presence of the two linear GPR anomalies or any other significant subsurface targets within the soil underlying the concrete foundation (Figure 7).

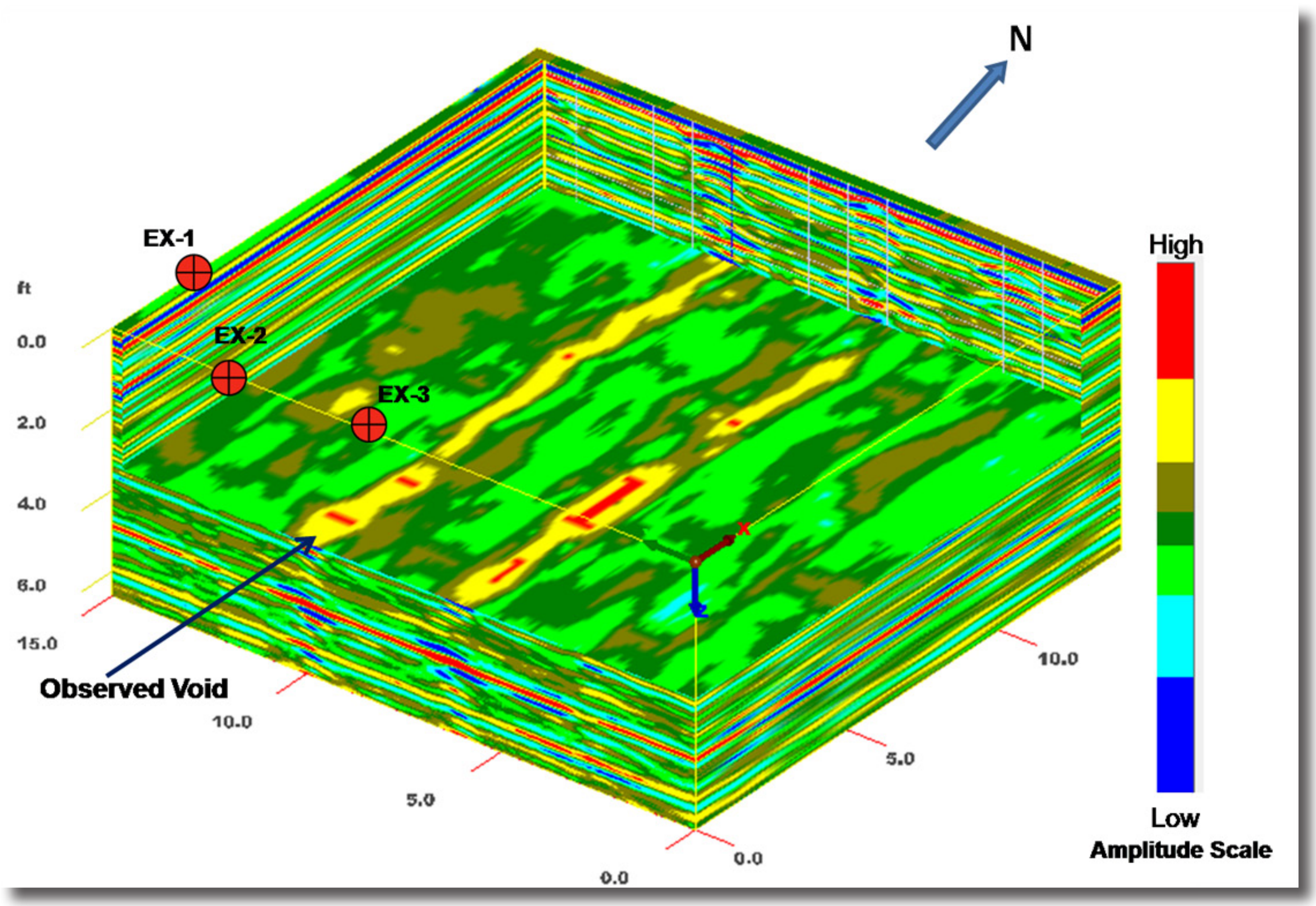

Figure 6. 3D GPR data for 400 MHz survey showing a depth-slice view at 2.5 feet. EX-1, 2 and 3 are excavation locations along the foundation.

Three locations (EX-1, EX-2 and EX-3) were excavated next to the foundation on October 8, 2008. These locations are along the foundation next to the southern and western walls of the living room (see Figures 1, 2 and 6). The EX-1 and EX-2 locations did not reveal any void or wet zone beneath the foundation; however, the EX-3 location revealed a void beneath the foundation (Figure 8). As soon as

2.5 feet depth is reached, the excavation hole was filled with ground water flowing from the soil underlying the foundation. The height of the water reached to 4 inch on October 8, 2008. A 3 feet long stick was pushed into the void with little resistance from the soil. This observation correlates well with the presence of the high-amplitude GPR void anomaly at EX-3 location. The hole was filled with dirt and covered, and the location was visited back on October 27, 2008. The water height in the hole reached one inch on this visit (Figure 9).

The fluctuations on the water height beneath the foundation could be explained by the local monthly participation (Houston: Bush Intercontinental Airport Participation Data, 2008) where the subject residence is located nearby (Figure 10). Based on this data, the area received 12.07 inch rain during the month of September (Hurricane Ike visited Houston on September 12, 2008). The water height on the excavation was measured about 4 inch on October 8, 2008. The area received 8.67 inch rain during the month of October. The water height on the excavation was about one inch on October 27, 2008.

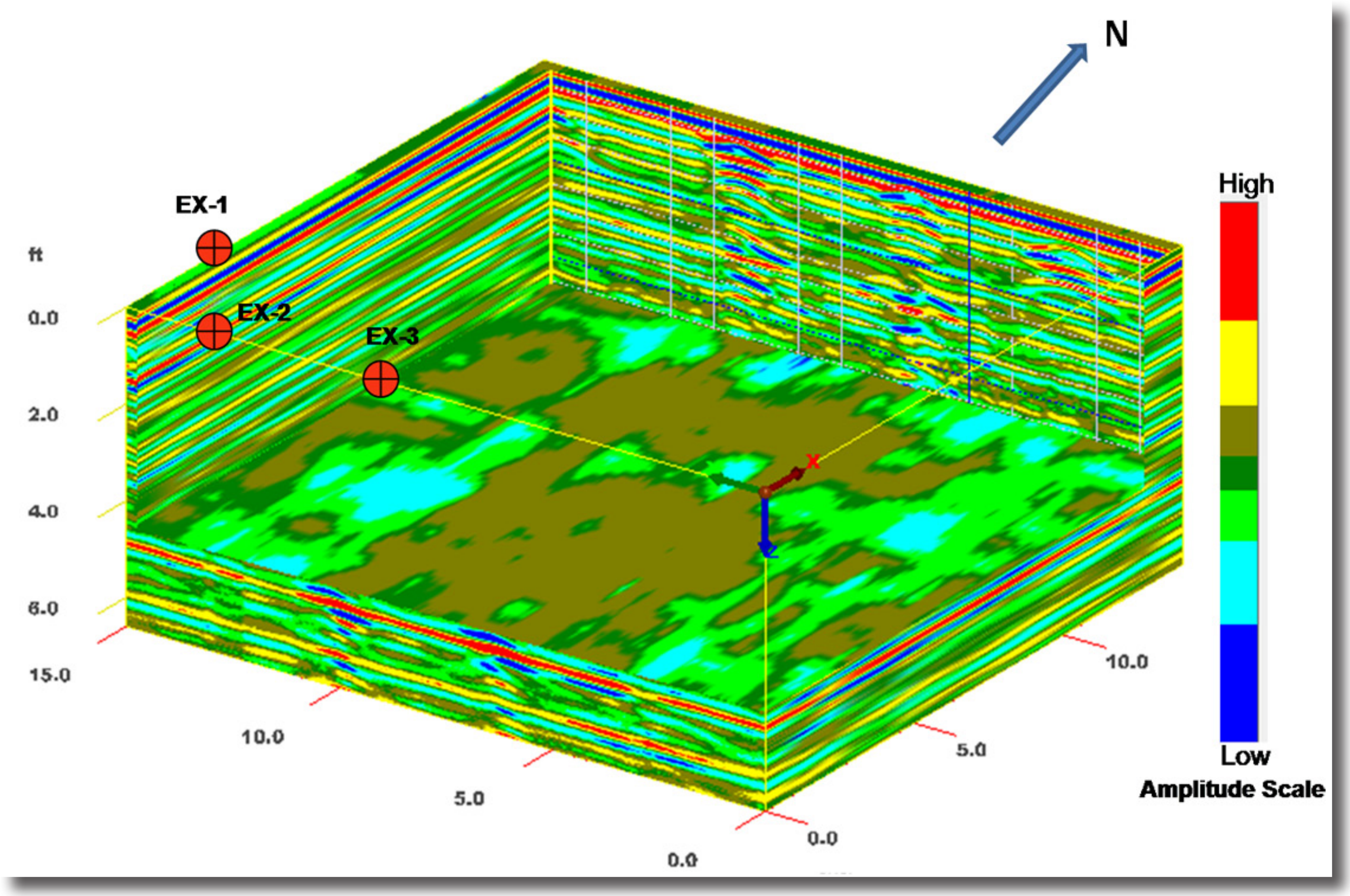

Figure 7. 3D GPR data for 400 MHz survey showing a depth-slice view at 4 feet.

Conclusions

1500 MHz GPR results revealed significant anomalies within the concrete:

- A void was detected at the bottom of the concrete foundation

• Two embedded post-tension cables were located at a depth of 3”;

• One of the post-tension cables did not have a strong amplitude anomaly compared to the other one. This may indicate that the integrity of the PTC is somewhat compromised;

• A low to moderate amplitude anomaly is observed to the west of the compromised PCT. The shape of this anomaly correlates well with the discolored, moisture-affected areas of the wood floor. This correlation suggests that the cause of the anomaly could be the moisture leaks through the concrete foundation from the disintegrated PTC (see Figure 5);

Figure 8. Picture showing the EX-3 excavation in the south wall of the foundation.

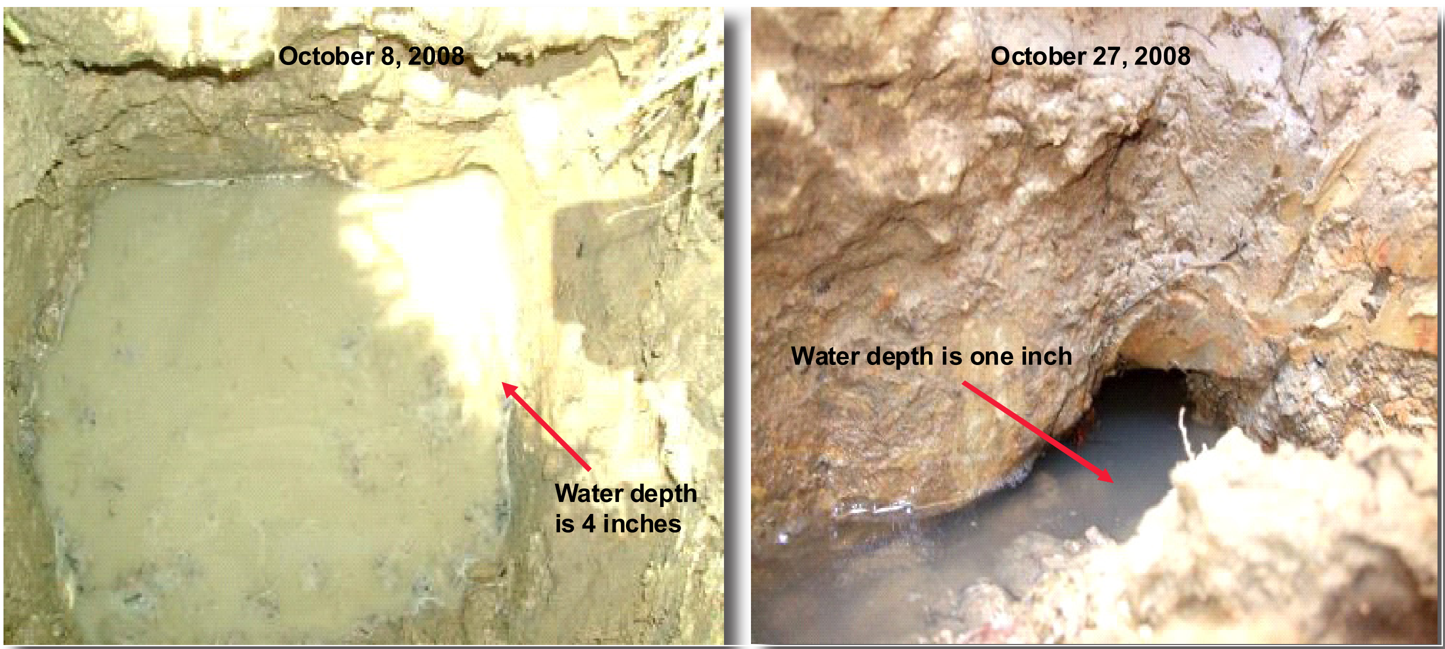

Figure 9. The void in the soil underlying the foundation at EX-3 location. Pictures are taken in October 8 and 27, 2008, respectively. Decrease in water height could be tied up to local monthly participation (see Figure 10). The top of the void is about 2 feet below the concrete pad. The material above the soil appears to be hardened clay or grade materials.

400 MHz results located significant anomalies within the soil underlying the concrete foundation:

• Two linear GPR anomalies were detected at a depth of 2.5 feet from the surface of the concrete foundation. These anomalies are mostly moderate in amplitude. However, they show areas of high amplitude as well. These anomalies trend in the north-south direction, and approximately located beneath the PTCs;

• The GPR data do not show any significant anomaly at a depth of 4 feet;

• Three locations (EX-1, EX-2 and EX-3) were excavated along the foundation outside the living room. EX-1 and EX2 locations did not reveal any wet soil or water, as expected because there were no GPR anomalies, beneath the concrete foundation; however, EX-3 excavation was chosen to be next to one of the linear GPR anomalies, and it did show a significant void beneath the foundation. The other linear anomaly was not tested because the location was covered with the concrete patio.

Visual inspection of the surface conditions next to the foundation in the vicinity of the void indicated ponding conditions, which may have resulted in (over the years), saturated soil conditions along the faulted foundation and forced the water under the slab through a created void.

A French Drainage system was installed along the foundation in order to decrease the saturated soil conditions, and the wood floor was replaced with the ceramic tile.

Houston: Bush Intercontinental Airport				
	Average Temp	**Departure**	**Precipitation**	**Departure**
January	**52.2**	**+0.4**	**4.62"**	**+0.94"**
February	**60.1**	**+4.7**	**4.00"**	**+1.02"**
March	**63.6**	**+1.3**	**2.41"**	**-0.95"**
April	**69.4**	**+0.9**	**1.46"**	**-2.14"**
May	**77.8**	**+2.0**	**4.57"**	**-0.58"**
June	**84.5**	**+3.2**	**2.06"**	**-3.29"**
July	**84.9**	**+1.3**	**1.09"**	**-2.09"**
August	**84.0**	**+0.7**	**7.45"**	**+3.62"**
September	**78.2**	**-0.7**	**12.07"**	**+7.74"**
October	**69.5**	**-0.9**	**8.67"**	**+4.17"**
November	**62.4**	**+1.5**	**2.92"**	**-1.27"**
December	**55.6**	**+1.9**	**1.68"**	**-2.01"**
ANNUAL	**71.5**	**+2.7**	**53.00"**	**+5.16"**

Figure 10. 2008 Annual Precipitation in northwest of Houston.

Acknowledgement

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