GEOLOGICAL AND GEOPHYSICAL SURVEY RESULTS AND REMEDIATION OPTIONS FOR SINKHOLES ON US 18 IN CERRO GORDO COUNTY, IOWA

Matthew Trainum: Soils Design Section, Office of Design, Iowa Department of Transportation

ABSTRACT

In May 2004, sinkholes formed along the Avenue of the Saints corridor (US 18) in Cerro Gordo County, Iowa. The general area of concern was approximately 120 meters wide by 450 meters long. A geotechnical field review, in June 2004, determined that a comprehensive investigation was needed to identify the cause of the problem and the potential threat to road integrity. The investigation included a Soil Survey Drilling Program, a Road Rater Review, a Ground Penetrating Radar (GPR) Survey, and a Resistivity Survey.

The Road Rater Review and the GPR Survey indicated that there was no identifiable voids present directly beneath or within two meters of the pavement. The Soil Survey identified a very irregular limestone bedrock surface below the pavement grade, overlain by sands and gravels, and bordered by shale to the west and east of where the sinkholes had formed. The geological interpretation is that this geologic profile represents an old drainage channel or glacial trough that has been undergoing karst formation and dissolution within joints and fractures, and that soil piping of the granular overburden material into cavities within the limestone bedrock has lead to the formation of the sinkholes.

The Soil Survey identified numerous voids, a total of 14, within the limestone just below the overburden/bedrock contact. The Resistivity Survey identified numerous anomalies that were interpreted as voids within the limestone and overburden. Although the Soil Survey did not confirm any voids within the overburden there was a relatively good correlation between the Soil Survey and Resistivity Survey.

Based on the geological and geophysical reviews the Iowa Department of Transportation (IDOT) has determined that a remediation/solution is needed to protect the integrity of the road and insure public safety. Two options were proposed for consideration: either a double reinforced overlay or a double reinforced inlay (both options include double reinforced paved shoulders).

Since the 2004 investigation, an additional sinkhole has formed in the vicinity of the area. A second investigation was initiated to determine if any voids have developed under the pavement since the 2004 surveys. This investigation included a Ground Penetrating Radar (GPR) Survey and a Multi-Channel Analysis of Surface Wave (MASW) Survey. Numerous anomalies were identified in both the GPR and MASW surveys; however most were interpreted as being related to road construction or natural features below the pavement grade. Three of the anomalies, identified as potentially being voids were slated for further Soil Survey investigation. The result of the most recent Soil Survey has identified one void directly under the pavement. At the time of this writing, the Iowa Department of Transportation is in the process of evaluating this concern and planning the next step in the process of remediation.
In late May of 2004 several sinkholes formed along the Avenue of the Saints (US 18) in Cerro Gordo County, Iowa. Two sinkholes formed on the shoulder of the Eastbound Lane (EBL) (one on the inside shoulder and one on the outside shoulder) at approximately Station 248+85 (Figures 1 to 3). One large sinkhole formed at the edge of the right of way on the south side at approximately Station 249+20 and right 20 meters from the edge of pavement (Figures 4 to 5). Several small sinkholes also formed within the south ditch and numerous sinkholes formed south of the large sinkhole in the adjacent plowed field. An example of the later is shown in Figure 6. Prior to a field review, the sinkholes on the shoulders were filled by granular material and flowable mortar.

The construction for US 18 was completed in 2000 and 2001, and this is first incident of sinkhole formation to occur within the project. Prior to this incident, IDOT was unaware of the potential for sinkhole formation. It was however conveyed to IDOT, at the time of this incident and not prior to construction, that sinkhole formation in the surrounding area was common and that the local practice was to fill and plow over the sinkholes.

A geotechnical field review was done in early June 2004. It was initially estimated that the primary area of concern was between Station 247+50 and Station 254+00 (Figure 7). This encompassed an area west and east of the large sinkhole at the edge of the south ditch and included the area of the sinkholes that formed on the EBL shoulders. The locations of identified/known sinkholes in the area, from the Iowa Department of Natural resources, are shown on Figure 8.

FIELD INVESTIGATIONS

The Soils Design Section of the Office of Design, IDOT initiated a geological and geophysical investigation to determine: 1) if any cavities were present under the pavement or within the road embankment; 2) the subsurface nature of the underlying bedrock; and 3) if there were any large voids in the subsurface that could be attributed to the sinkhole surface expression and could pose a potential threat to the roadway. The investigation consisted of: 1) a Soil Survey (series of borings); 2) a Road Rater Review; 3) a Ground Penetrating Radar (GPR) Survey; and 4) a Resistivity Survey.

During the investigation, a question was posed as to whether there was a possible influence from or correlation to field tile lines within the area (i.e. could field tiles be responsible for the development of the sinkholes?). From information compiled by the regional field office on the locations of field tile lines in the area, it was determined that there was no correlation between the field tiles and the sinkholes that developed.

Soil Survey

The Soil Survey crews completed 191 borings for a total drilling footage of 2,239 meters (7346 feet). Drilling began in mid June 2004 and was completed in late September 2004. Figure 9 shows the location of the majority of the borings. The borings were started at Station 241+50 (600 meters to the west of the area) and spaced every 50 meters. The
spacing of the borings was reduced to 10 meters through the area of concern, with additional borings (ahead and behind) every three meters if a void was encountered. Additional borings drilled to the west of the area of concern was to get subsurface information that was not obtained during the design of the project, due to access denials at the time, and to tie that information to the known subsurface profiles. The high concentration of borings within the area of concern was to obtain a relatively detailed subsurface profile of the bedrock below the road embankment, determine if there were any voids within the bedrock and overlying sediment, and for comparison to the geophysical surveys.

Road Rater Review
Soils Design Section and the Office of Materials of IDOT arranged for the testing of the road with the IDOT Road Rater in mid July 2004. The area tested was between Station 241+50 and Station 254+00 on both the Eastbound Lane (EBL) and the Westbound Lane (WBL). Testing was to be done at midslab and at joints. Coring was also proposed if any identified suspicious areas were detected.

Ground Penetrating Radar Survey
Terracon Consultants, Inc. of Des Moines, Iowa, an IDOT On-Call Geotechnical Contractor, arranged for a Ground Penetrating Radar (GPR) Survey in late July 2004, by 3D Geophysics of Mendota Heights, Minnesota. The area investigated was between Station 241+50 and Station 254+00, using a 250 MHz antenna. The Consultant was instructed to specifically concentrate on the most critical area, utilizing procedures that would provide the most detailed information. Both travel lanes in both the eastbound and westbound direction were to be surveyed. The purpose of the GPR Survey was to identify any locations that might represent voids under the pavement slab and mark these locations for any follow-up drilling by the Soil Survey crews.

Resistivity Survey
In July 2004, the Soils Design Section arranged for Power Surveying Co, Inc. of Fredrick Colorado to provide a Resistivity Survey of the area of concern. Three resistivity lines (Figure 10) were located between Station 247+85 and Station 250+50: one in the median (Line A); one in the north ditch (Line B); and one in the south ditch (Line C). The locations for the lines were predetermined by Soils Design and Power Surveying to cover the main portion of the area of concern. The purpose of the Resistivity Survey was to identify any locations where there might be voids both under the pavement slab and/or deeper (above and/or within the bedrock) that could be associated with sinkhole expressions at the surface. If any anomalies were identified, they would be evaluated with additional Soil Survey.

RESULTS

Soil Survey
The developed Composite Geologic Profile (Figure 11) indicates that between Station 248+50 and Station 252+50 there is an irregular surface for the limestone bedrock, a missing overlying shale unit, and the presence of sand and gravel in the area of concern.
Most of the limestone is medium hard with a quite a few locations where it is either broken/weathered or “poor quality” (as described by the Soil Survey crews) in the upper portion of the bedrock. In general the limestone bedrock is 5 to 10 meters below the existing grade. There are several pronounced depressions in the surface of the limestone bedrock, ranging up to 17+ meters below grade. The limestone approaches the natural ground surface at the Winnebago River, just east of the area.

During the initial Soil Survey 12 voids within the limestone unit were encountered in borings on the outside shoulders of the EBL and WBL and the inside shoulder of the EBL. The voids are generally 1 to 2 meters below the overburden/bedrock contact, ranging in height from 0.5 to 5.5 meters, and ranging in length from 2 to 15 meters. No widths were determined and no indications of complete cavity collapse were found. More important is that no voids were found within the overlying predominantly granular sediment. There was also no indication of overburden material in any of the voids encountered within the bedrock.

A shale unit overlies the limestone to the west and east of the area of concern. To the west, this shale reaches a thickness of 7 to 9 meters and is relatively constant toward the west. To the east, the shale reaches a thickness of about 4 meters and thins eastward toward the Winnebago River. In the area of concern (within the “gap” in the shale) the overlaying material above the limestone is predominately granular sediments (sands and/or sands and gravels, occasionally with significant amounts of clay, silt, and shale).

Road Rater Review
Although the Road Rater is not designed for detecting voids below the slab, it does measure subgrade support. The testing indicated that there appeared to be adequate support throughout the area of concern, and therefore no identifiable voids were detected immediately below the pavement. Therefore no cores were taken.

Ground Penetrating Radar Survey
The 250 MHz antenna was selected to provide the best penetration and resolution; however the quality of the GPR data was average with depth penetration moderate to poor according to the Consultants. The depth of resolution for the GPR was 1.2 – 1.8 meters. Though not a good as anticipated, the GPR Survey did extend the investigation below the pavement subgrade (depth of the Road Rater) and was used to determine if there were any voids immediately under the pavement or within the upper embankment. The results confirmed the Road Rater Review, that there were no identified voids that would cause a loss of subgrade or pavement support. In the opinion of 3D Geophysics, they did not find anomalies within the 1.2 – 1.8 meters effective depth range of the GPR that would indicate any voids under the existing pavement. Figures 12 and 13 are typical profiles from the GPR Survey.

Resistivity Survey
After completing Line A, using 3 arrays (Werner, Schlumberger, and Dipole/Dipole), Power Surveying determined that the Schlumberger array provided the best overall information for depth and resolution, and used that array for Line B and Line C (Figure 10). Power Surveying identified seven anomalies that were recommended for further investigation (i.e. drilling to obtain confirmation “ground truth”). Also, the resistivity
crew identified an additional sinkhole in the north ditch (WBL), at approximately Station 249+27. The anomalies ranged from a very high resistance anomaly on the Line A Dipole-Dipole Profile (Figure 14), to a high resistance anomaly on the Line A Schlumberger Profile (Figure 15), to moderately high resistance anomalies on the Line B Schlumberger Profile (Figure 16), to a low resistance anomaly on the Line C Schlumberger Profile (Figure 17). The interpretation of the anomalies, by Power Surveying, ranged from possible void, to sands and gravels spanning the soil/limestone interface and therefore possibly a void near the bedrock surface extending into the overlying soil, to lenses of coarse grain sediments due to the presence of soil piping, to a clay filled void.

The general interpretation presented, by Power Surveying, for the formation of surface sinkholes is the formation of soil pipes connected to a karst surface of the limestone bedrock. Although not stated in Power Surveying’s final report, it was conveyed to the Soils Design Section by the field geophysicist that, from experience, the karst activity in northern Iowa is or should be similar to that in the Rochester, Minnesota area for which soil piping is the primary cause for surface sinkhole formation. Power Surveying suggested that, in their opinion, the values for resistance of the geologic units present were not typical (not as expected). Therefore, Soils Design sent initial geologic profiles, based on the Soil Survey, to Power Surveying to aid in the final interpretation.

ASSESSMENT OF SURVEY METHODS

Soil Survey
The Composite Geologic Profile (Figure 11) provides a relatively detailed interpretation of the subsurface based on the boring log data. There is a very good correlation between surface expressions (i.e. sinkholes) and the irregular limestone surface, significant depressions within the bedrock surface, and the presence of voids within the limestone. The shale unit appears to prevent or suppress the formation of sinkholes by capping the limestone as a relatively impermeable barrier. The interpretation of this 300 meter gap within the shale, the irregular limestone bedrock surface, the deep depressions within the bedrock surface, the thick accumulation of granular material, and presence of voids within the limestone is that this may represent either a pre-Wisconsin Glacial (Iowan) drainage channel or glacial trough that subsequently filled with alluvial sediments and/or glacial outwash sediments of the Wisconsin Glacial (Iowan) Stage. The irregular surface of the limestone is interpreted as karst formation resulting from dissolution at joints and fractures. The voids, dissolution joints, and fractures probably serve as conduits for the soil piping of the overlying granular material during times of high water saturation of the overburden. Since no overburden sediments were found in any of the voids, it is speculated that material infiltrating into voids is carried away by groundwater.

The geologic profile, based on the subsurface data, suggested a revision to the initial area of concern (Station 247+50 and Station 254+00). The area of concern has been subsequently adjusted to be between Station 248+50 and Station 253+00. This revised area is bounded to the west and east by the presence of the overlying shale and would include the voids identified by the Soil Survey.
Road Rater Review
This testing provided a good foundation for determining the immediate threat to the pavement at the time of this fieldwork.

Ground Penetrating Radar Survey
This survey, though not as useful as expected, did provide reasonable results to determine that there was no identifiable threat beneath the pavement or within 1.2 – 1.8 meters of the pavement surface. Greater penetration would probably have required a larger unit and/or different frequency than what was used.

Resistivity Survey
The resistivity interpretation was improved by the incorporation of the Soil Survey information/geologic profile. Apparently the values for resistance of the geologic units present were atypical. A comparison of the initial interpretation and the final interpretation (enhanced from the ground truth) for the subsurface profile indicates that there is no clear-cut separation in resistivity values between bedrock types or between bedrock and overlying sediments (Figures 18 to 21). However, the Resistivity Survey results correlated fairly well with the Soil Survey, particularly when considering the area of apparent karst formation and pronounced depressions at the limestone bedrock surface, the general area of voids within the bedrock, and even the “poor quality” or broken and weathered limestone in the upper parts of some of the bedrock surface (Figures 22 to 24). The Resistivity Survey indicated a few reasonable locations for further investigation. The sinkholes that formed on the shoulder of the EBL (and that were filled early on) show up very well on the Schlumberger profiles for Line A (Station 248+75 to 80 – Figure 15) and Line C (Station 248+85 to 90 – Figure 17). There is a good correlation between the irregular surface, the pronounced depressions within the limestone surface, and the voids as shown on the Composite Geologic Profile (Figure 11) and the very large high resistance anomaly on Line C, the large high resistance anomaly on Line A, and the large low resistance anomaly on Line B (Figures 17, 15, and 16 respectively).

SOIL SURVEY FOLLOW-UP OF THE RESISTIVITY SURVEY
Six resistivity anomalies were chosen for a further investigation with a Soil Survey. The very high resistance anomaly (at a depth of 14 meters) on the Dipole/Dipole profile of Line A (Figure 25) was drilled and no void was found; however, the boring logs described the bedrock as “poor quality” limestone at a depth of 10 meters and this could contribute to an indication of a possible void at either a greater or even lesser depth. The high resistance anomaly (at a depth of 10 meters) on the Schlumberger profile of Line A (Figure 26) was drilled and although no void was found, again there is some correlation to broken and weathered and/or poor quality limestone encountered at a depth of 13 meters in the borings. The several small and shallow moderate resistance anomalies (at a depth of 5 +/- meters) on the Schlumberger profile of Line B (Figure 27) were drilled and although no voids were encountered within the overburden, one void within the bedrock was found at Station 249+10 at a depth of about 11 meters for which there is no obvious indication on the resistivity profile.
The very large, very high resistance anomaly (around 7 to 15 meters in depth), and between Station 248+75 and Station 249+80) on the Schlumberger profile of Line C (Figure 28) was drilled at a few locations and one void within the bedrock was found at Station 249+00 at a depth of 12 meters, essentially at the base of the anomalous feature. The total number of voids encountered within the bedrock therefore increased to 14 (Figure 11).

The low resistance anomaly (at a depth of 20 meters +/-) on the Schlumberger profile of Line A (Figure 15 and 26) and the low resistance anomaly (at a depth of 17 meters +/-) on the Schlumberger profile of Line C (Figure 17 and 28) were both considered too deep for further investigation, likely beyond any reasonable remediation/solution, and therefore were not chosen for further investigation/drilling. A significant depression drawn on the Schlumberger profile of Line C (Figures 17, 21, 24, and 28), at Station 249+60 is assumed to be a graphical error, incorrectly illustrating the geologic profile information from the Soil Survey.

SUMMARY – 2004 Investigation

The Road Rater Review and the GPR Survey indicated that there were no voids directly beneath the road or within the upper few meters of the road embankment. The relatively good correlation between the Resistivity and the Soil Survey suggests that there appears to be no large voids present below the pavement, within the embankment, or within the overlying sediment above the karst limestone surface. However, the Soil Survey indicated and the Resistivity Survey suggested that there are numerous voids within the bedrock that could be attributed to the sinkhole surface expressions. The existence of sinkholes at the ground surface and within the shoulders of the roadway, suggests that soil piping or a similar mechanism is active though maybe not continuously, and that the overlying sediments and embankment material are at risk of infiltrating into the voids and being carried away by groundwater. Even though there appears to be no immediate threat to the integrity of the roadway, the possibility for sinkhole development will continue to pose a potential threat to the integrity of the roadway structure, and therefore remediation will ultimately be required to minimize the potential threat and insure public safety.

PROPOSED REMEDIATION

In early discussions the Office of Design of the Iowa Department of Transportation considered a few radical to simple approaches to prevent the loss of embankment and/or pavement should sinkholes form within the area of concern. Possible solutions ranged from: 1) the total excavation to and sealing off of the limestone between Station 248+00 and Station 253+00 and the rebuilding to the present road grade; 2) solidifying or strengthening the embankment with injected grouts; and 3) double reinforced pavement through the revised area of concern.

The Office of Design reviewed and presented estimates for two options thought to be the most cost effective, most reasonable, and least disruptive solutions. These proposed solutions are either a double reinforced overlay or a double reinforced inlay. Both solutions include double reinforced outside and inside paved shoulders on both lanes. Figure 29 shows the two concepts.
The double reinforced overlay would extend from Station 246+50 to Station 253+00 (illustrated on the WBL in Figure 29) with an estimated cost of $1,987,000 while the double re-enforced inlay would extend from Station 248+00 to Station 253+00 (illustrated on the EBL in Figure 29) with an estimated cost of $1,685,000. Both options are considered to provide an acceptable level of safety, while minimizing cost and effects on traffic flow. Since there is no practical means to alter the geological mechanism in the area of concern, these two options for remediation were proposed for consideration and to be accomplished as soon as realistic. It is also the Iowa Department of Transportation’s intention to continue monitoring this portion of roadway and to perform continued geological and geophysical investigations until such time that a remediation project can be scheduled.

2005

BACKGROUND

After the 2004 geological/geophysical investigations and the proposing of the two options to remediate the potential hazard to the road and public, the Iowa Department of Transportation began a continuing monitoring project of this portion of US 18 in Cerro Gordo County, Iowa. Because of the potential for continuing problems, any void near the area of concern on US 18 warrants action and poses the question as to whether any new voids have formed within the embankment.

In late May/early June of 2005 the Soils Design Section was informed that a new sinkhole had developed outside the right of way in a plowed field adjacent to the roadway.

FIELD INVESTIGATIONS

The Soils Design Section initiated an investigation to determine if any voids had developed under the pavement since the surveys of the previous year, and where further investigation might be needed. Blackhawk, a Division of Zapata Engineering from Golden, Colorado was contracted to provide the geophysical survey. This investigation included a Ground Penetrating Radar (GPR) Survey and a Multi-Channel Analysis of Surface Wave (MASW) Survey, within the revised area of concern (Station 248+50 and 253+00).

The GPR and MASW surveys were performed down the center of the right and left lanes of both east and west bound lanes, covering an area approximately 120 meters by 300 meters (Figure 30). (The reader should note there is an equation within the area and therefore the length is 50 meters short). Blackhawk used both a 200 and 400 MHz antenna for the initial Ground Penetrating Radar Survey and, after processing, determined that the 400 MHz data was more appropriate to meet the objectives of this survey. The MASW data quality was only fair because, as Blackhawk reported, the resolution is dependent on the shear wave velocity characteristics of, and resulting wavelengths through, the material investigated. Blackhawk noted that in their judgment, the thick pavement trapped most of the seismic energy with only a narrow frequency range...
propagating through to the receiver. Therefore the confidence in the survey results was not as high as anticipated.

RESULTS

Blackhawk identified 23 anomalies in the GPR and MASW surveys. Of the 23 anomalies (Figures 31 - 35), nine (3, 4, 7, 8, 10, 12, 13, 15, and 23) were recommended for further Soil Survey, and of these nine anomalies, six (3, 7, 10, 12, 13, and 15) were given a “Priority 1” designation and three (4, 8, and 23) were given a “Priority 2” designation. The Priority 1 anomalies are those that are possibly related to voids within the first two meters and the Priority 2 anomalies are those that are possibly related to voids deeper within the subsurface. The remaining 14 anomalies were interpreted to be horizontal layers, generally attributed to the construction of the embankment that ground truth could clarify.

ASSESSMENT OF 2005 SURVEY METHODS

The anomalies were compared with the results from the GPR Survey, the Resistivity Survey, and the Soil Survey conducted the previous year. It was determined that most of the anomalies could be related to the construction of the embankment while some appear to be natural features below grade.

Of the Priority 1 anomalies, all were identified on the GPR Survey and none had any correlation to any feature on the MASW Survey. Blackhawk described anomaly 3 (Figure 31), at a depth of about 0.5 meters, as characteristics of a potential void but could also be caused by a construction change rather than an air pocket, and anomaly 7 (Figure 32), at a depth of 0.3 meters, as a possible void showing very distinct characteristics of an open air-filled void. A review of the previous surveys indicated that these anomalies appeared to be the sinkholes that formed on the shoulders in 2004 and were subsequently filled with granular material and flowable mortar.

The remaining Priority 1 anomalies 10, 12, 13 and 15 (Figure 33 and 34) were described as potential voids, as a change in construction or material, or water enriched areas. A review of the Soil Survey information indicated that these anomalous features are probably either construction or material related, as Blackhawk suggested as one possible explanation, or based on their location, may be existing features in the undisturbed natural ground under the road embankment.

Of the Priority 2 anomalies, two anomalies (4 and 8) were identified in the GPR Survey with some correlation in the MASW Survey, and one anomaly (23) was identified in the MASW Survey.

Both anomalies 4 and 8 (Figure 31 and 32) are horizontally dipping features. As possible explanations, Blackhawk suggests these could be the result of settlement of the fill, or a collapse at depth due to a void at a depth greater than the GPR investigation. There is a small correlation to a void found during the 2004 Soil Survey at a depth of about 11 meters and roughly 3 meters within the limestone bedrock (Figure 11), at Station 251+60 EBL.

A more detailed ground truth plotting of the 2004 Soil Survey which would involve the correlation of the minor soil units that were previously grouped together for ease of
plotting could probably better explain anomalies such as 4 and 8. This additional plotting could also be used to explain the anomalies that appear to be either horizontal features associated with construction and/or existing natural features below grade and embankment. This plotting is currently in progress.

Priority 2 anomaly 23 (Figure 35), at Station 249+50 is described as a small low velocity zone at a depth of 5 meters, and although data confidence is low, Blackhawk stated that, in their opinion, the loss of cohesive strength due to collapse from an underlying void should appear as a low shear wave velocity zone. A review of the previous geological and geophysical data suggests that this anomaly has some correlation to the Soil Survey, in that it is above a significant and deep feature in the bedrock, encompasses the portion of the pavement across from the very large sinkhole that formed at the edge of the right of way, and is just east of the sinkholes that formed on both the outside and inside shoulders (Figure 11). There is also some correlation between a zone of high resistance at a depth of approximately 10 meters on Resistivity Survey (line C) and a void in the bedrock at a depth of approximately 12 meters, encountered during the Soil Survey follow-up (Figure 28).

**SOIL SURVEY FOLLOW-UP of GPR and MASW SURVEY**

Three anomalies (3, 7, and 23) identified as potentially being voids were chosen for a further investigation with Soil Survey. Anomalies 3 and 7 (between Station 248+70 and Station 248+74, EBL - outside lane and between Station 248+80 and Station 248+84, EBL - inside lane respectively) were chosen because they are the most shallow of those identified by Blackhawk, are possibly related the sinkholes that formed on the shoulders in 2004, and therefore were considered more likely to have a re-occurrence that would be considered a potential threat to public safety.

Anomaly 23 (between Station 249+20 and Station 249+60, EBL - inside lane) was chosen because of the correlation to the 2004 Soil Survey and Resistivity Survey. Also, despite this MASW anomaly being shallower than both the subsurface feature from the Soil Survey and the anomaly in the Resistivity Survey, it was deemed to be worthy of further drilling investigation because of its possible association to the sinkholes that formed in the shoulders of and adjacent to the roadway.

The Soil Survey did not encounter any voids at the locations for anomalies 3 and 23 but did identify a void space, directly under the pavement, in the vicinity of anomaly 7 (Figure 32). This void space is at and a little west of the limits for anomaly 7 (between Station 248+77 and Station 248+82) and ranges between 0.03 meters and 0.1 meters in height.

**SUMMARY 2005 Investigation**

The 2005 GPR and MASW surveys have provided additional information to combine with the 2004 surveys for evaluating the problem site on US 18 in Cerro Gordo County, Iowa. The GPR Survey identified a couple of locations within two meters below grade that were worth monitoring or further investigation. One void was discovered at one anomalous location; however it was much shallower than the indication on the survey (0.03 - 0.1 meters compared to 0.3 meters). The MASW was not as successful as desired,
however the information provided does offer some potential correlation, and the survey identified one anomalous feature, though no void was encountered at that location.

REMEDICATION REVISITED

At the time of this writing, the Iowa Department of Transportation is evaluating the current void encountered under the pavement, in the vicinity of anomaly 7 from the 2005 GPR Survey, and is in the process of making plans for an immediate solution. The two initial proposed options for a remediation project are still the preferred choice for a long term solution; either a double reinforced overlay or a double reinforced inlay, including double reinforced paved shoulders (Figure 29). Until such time that the remediation project can be funded, planned, and implemented the Iowa Department of Transportation’s intention is to continue monitoring this portion of roadway and to perform geological and geophysical investigations as needed.

CONCLUSION

Although the Soil Survey as quite extensive and no voids were found within the overburden (nor was there any indication of overburden material in those voids that were encountered within the bedrock), it is not unreasonable to assume that voids could easily have been missed. It would appear obvious that the sinkholes that formed along the shoulders and in the vicinity of the roadway resulted from some mechanism/process, such as soil piping (connecting voids within the karst limestone bedrock to the overlying predominately granular sediment and the roadway embankment material). Sinkhole development is considered to probably continue to pose a potential threat to the integrity of the roadway structure, and therefore remediation is ultimately recommended to insure road integrity and the public safety.

Contracted Geophysical Investigators
Terracon Consultants, Inc
600 SW 7th Street, Suite M
Des Moines, Iowa 50309

3D Geophysics
721 3rd Avenue
Mendota Heights, MN 55118

Power Surveying Company, Inc
7800 Miller Drive, Unit C
Frederick, CO 80504

Blackhawk A Division of Zapata Engineering, P.A.
301 Commercial Road, Suite B
Golden, CO 80401
Sinkhole on Eastbound Lane - inside shoulder

Sinkhole on Eastbound Lane - outside shoulder
Figure 3
Sinkhole on Eastbound Lane - outside shoulder

Figure 4
Sinkhole at edge of right of way and south ditch
Sinkhole at edge of right of way and south ditch

Sinkhole in adjacent farm field
US 18 in Cerro Gordo County, Iowa

Known Sinkholes locations from Iowa DNR
Location of the majority of borings from the 2004 Soil Survey
Schematic of the 2004 Resistivity Survey

Figure 10
Composite Geologic Profile from 2004 Soil Survey
Typical GPR survey line from 2004  

Figure 12

Typical GPR survey line from 2004  

Figure 13
Figure 14

Resistivity profile with geologic profile from the Soil Survey
Resistivity profile with geologic profile from the Soil Survey
Resistivity profile with geologic profile from the Soil Survey
Resistivity profile with geologic profile from the Soil Survey
Comparison of the initial subsurface interpretation of the resistivity with the final interpretation using Soil Survey data

Figure 18
Comparison of the initial subsurface interpretation of the resistivity with the final interpretation using Soil Survey data
Comparison of the initial subsurface interpretation of the resistivity with the final interpretation using Soil Survey data  

Figure 20
Comparison of the initial subsurface interpretation of the resistivity with the final interpretation using Soil Survey data
Comparison of geologic and resistivity profiles
Comparison of geologic and resistivity profiles
Comparison of geologic and resistivity profiles

Figure 24
Soil Survey of resistivity anomalies
Soil Survey of resistivity anomalies

Figure 26
Soil Survey of resistivity anomalies
Soil Survey of resistivity anomalies

Figure 28
### Remediation Options

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**Figure 29**

Remediation Option 1: Double Reinforced Overlay Over Current Active Area, With Transition Both Directions, Same For Both Lanes.

Remediation Option 2: Double Reinforced Inlay Full Length, Thicker Over Current Active Area, Same For Both Lanes.

Note: Both Options Include Inside and Outside Faced (Reinforced) Shoulders, Both Lanes.
Anomalies on 2005 GPR survey
Anomalies on 2005 GPR survey

Figure 33
Anomalies on 2005 GPR survey
Anomaly on MASW survey