Long-Term Instrumentation Program to Monitor Various Geo-Technologies Used on the I-15 Reconstruction Project, Salt Lake City, Utah

By

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Abstract

The Utah Department of Transportation (UDOT), in conjunction with Wasatch Constructors, recently reconstructed a 27 km (16.8 mile) portion of Interstate I-15 in Salt Lake City, Utah. As part of this $1.5 billion design-build project, several types of innovative foundation and embankment treatments were used in order to expedite construction on soft, clayey foundation soils. Currently, the UDOT Research Division is monitoring and evaluating the construction and long-term performance of four different geo-technologies utilized during the reconstruction project: lime cement columns, two-stage MSE walls on soft soil sites, geofoam, and large earth embankments on soft soil sites. This is known as the I-15 Foundation and Embankment Performance project. A total of twelve arrays have been installed along the I-15 corridor to gather performance information. The instrumentation for each array was installed to meet specific objectives relating to each geo-technology type. The information learned from this project is being used to validate the geotechnical design used for the I-15 reconstruction project and to improve the state-of-practice in designing earthen structures and other geo-technologies associated with construction on soft, clay foundations. This study was initiated in the summer of 1998 and is expected to continue for a 10-year post-construction period. The funding for the instrument installation and monitoring was obtained in conjunction with the I-15 National Test Bed Program. This paper provides a valuable case history of the implementation of a long-term instrumentation-monitoring program.

Keywords: instrumentation, performance monitoring, long-term behavior

INTRODUCTION

The Utah Department of Transportation (UDOT), in conjunction with Wasatch Constructors, recently reconstructed a 27 km (16.8 mile) portion of Interstate I-15 in Salt Lake City, Utah, beginning in north Salt Lake City (approximately 600 North Street) and extending to Draper City (approximately 10600 South Street). As part of this $1.5 billion design-build project, several types of innovative foundation and embankment treatments were used to expedite construction on soft, clayey foundation soils. For example, foundation treatment and embankment construction consisted of prefabricated vertical drains (PVD), surcharging, geotextile reinforced slopes, lime cement columns (LCC), lightweight fill (e.g., geofoam and volcanic scoria), and mechanically stabilized earth (MSE) walls.

Currently, the UDOT Research Division is monitoring and evaluating the construction and long-term performance of four different geo-technologies utilized during the reconstruction project: lime cement columns, two-stage MSE walls, geofoam, and large earth embankments on soft soil sites. This is known as the I-15 Foundation and Embankment Performance project. A total of twelve arrays have been installed along the I-15 corridor to gather performance information.

The I-15 Foundation and Embankment Performance project began in 1998 in conjunction with the I-15 National Test Bed Program. The I-15 National Test Bed Program was set up to address the unique opportunity created by the reconstruction of a major interstate facility to answer questions regarding the innovative processes, techniques, designs and materials relating to the new construction, as well as the design capacity and durability of the existing facilities being replaced (*1*). The I-15 Foundation and Embankment Performance project was not specifically part of the TEA-21 Fiscal Year 99 funding of the I-15 National Test Bed, but was part of additional research being performed in conjunction with the I-15 Reconstruction Project being funded with Utah Department of Transportation annual research dollars. What began as a $598,000 project has since expanded into a more than $1,000,000 project, with the costs being spread out over a 10-year period. However, around 80% of those costs were utilized within the first 5-years of the project. Actual instrumentation costs (equipment and labor) are estimated to be on the order of about $300,000. The remainder of the budget would then be for reading the arrays, evaluation of the data, and costs associated with reporting results and lessons learned.

The project originally began as an in-house study being performed by personnel from within the UDOT Research Division. As the scope of work expanded, additional groups were brought in to perform various aspects of the research relating to their areas of expertise. Project management duties, including reading and interpretation of most of the arrays, have since become shared between the UDOT Research Division and the Civil and Environmental Department from the University of Utah. In addition the Geofoam Research Center at Syracuse University assisted with the installation of instrumentation of the Geofoam arrays as well as interpretation and reporting of the associated data (*2*). The Civil and Environmental Department from Utah State University also instrumented an MSE wall and has continued with the monitoring and interpretation of that data (*3*).

This paper serves as a brief summary of the I-15 Foundation and Embankment Performance project and focuses on the various instrumentation arrays that have been installed. Special attention has been given to each of the four different geo-technologies and the desired objectives for each, along with a brief description of the specific instrumentation applications utilized to achieve those objectives. Finally, some of the lessons learned during the implementation of this project are included.

SUBSURFACE CONDITIONS

The following section, describing the subsurface conditions found in the I-15 reconstruction project, explains the geotechnical challenges faced during the I-15 Reconstruction Project and why the long-term monitoring project has been established. It should be noted that many of the adjacent valleys, particularly the Utah Valley to the south of the Salt Lake Valley, exhibit similar subsurface conditions as the Salt Lake Valley because Lake Bonneville, an ancient lake covering much of northern Utah, stretched through the adjacent valleys as well.

Geologic Setting

The surficial and shallow geology of the Salt Lake Valley is dominated by Holocene sediments deposited after the regression of Lake Bonneville in shallow lakes, flood plain and river and stream channels that occupy much of the valley. In general, the northern I-15 alignment crosses Holocene lacustrine, marsh and alluvial sediments deposited after the last major regression of Lake Bonneville. These recent deposits include clay, silt, sand, peat, and minor gravel. The southern section of the I-15 Reconstruction Project is underlain by Holocene stream alluvium deposited within the Jordan River and its flood plain. The stream alluvium consists of sand, silt, and minor clay and gravel. The deposits of stream alluvium, which reach maximum thickness of about 5 to 10 meters (16.4 to 32.8 ft), are underlain by clay, silt, and minor fine sand and gravel deposited by Lake Bonneville.

The total thickness of Lake Bonneville deposits near the northern section of the I-15 Reconstruction Project is not clearly defined, but is usually greater than 10 meters (32.8 ft). Much of the Salt Lake valley was occupied by Lake Bonneville during the late Pleistocene time (between about 30,000 years ago and 10,000 years ago). The lake regressed about 10,000 years ago and has since remained close to the present level of the Great Salt Lake.

Underlying the Lake Bonneville deposits is a considerable thickness of alluvial and lacustrine sediments that were deposited between 30,000 and 800,000 years ago. Estimates of the total thickness of Pleistocene and Holocene deposits underlying the Salt Lake Valley have been produced and range from approximately 600 meters (1,969 ft) to as much as 1,200 meters (3,937 ft) (*4*).

Engineering Characteristics of Subsurface Soils

Underlying the embankment fill along the I-15 corridor is about 5 meters (16.4 ft) of recent alluvium, which in turn is underlain by about 20 meters (65.6 ft) of soft, compressible lake deposits from prehistoric Lake Bonneville. Near the downtown area, these lacustrine soils are clay (CL, CH), clayey silt (MH) and silt (ML) with inter-bedded, thin, fine, sand layers (SM, SP-SM).

From a geotechnical perspective, the Lake Bonneville Sediments in the northern part of the I-15 reconstruction project are more problematic because of the presence of soft, compressible clay layers. For example, the clay in a representative CPT sounding from this area (Figure 1) begins slightly beneath the ground surface and extends to a depth of about 15 meters (49.2 ft). Below this depth are interbedded layers of gravel, sand, silt and clay that were deposited by Pleistocene streams and lakes predating Lake Bonneville.

Issues Regarding Lake Bonneville Sediments

The compressibility and shear strength of the Lake Bonneville deposits were important considerations during the design and reconstruction of I-15. Regarding settlement performance, the major concerns were:

- The large amount of primary settlement
- The relatively long duration of primary settlement
- The rate and amount of secondary settlement

Because of strict project time constraints and scheduling issues, prefabricated vertical drains were used in the clay layers to accelerate the rate of primary consolidation. The embankments were also surcharged to minimize the amount of secondary consolidation and reduce its rate with time. The surcharge amounts were typically 30 to 40 percent of the embankment height in areas with soft clayey deposits.

TYPES OF DATA AND MONITORING ARRAYS

There was a large amount of geotechnical data gathered from the I-15 Reconstruction Project. This data can be broken into three different categories: the baseline geotechnical data which was gathered prior to reconstruction, the Wasatch Constructors construction data, and the UDOT Research construction and post-construction data. This paper focuses primarily on the latter.

Baseline Geotechnical Data

The baseline geotechnical data was utilized primarily by the contractor during the design process of the I-15 reconstruction project. The primary sources of data that were incorporated into the design included borehole logs with SPT and undisturbed (i.e., Shelby tube) samples, CPT soundings, and laboratory consolidation and shear strength tests. These data were collected by various geotechnical firms prior to the bidding and award of the I-15 Reconstruction contract. The corresponding geotechnical reports and subsequent data were supplied to UDOT and the potential design-build teams on compact disk.

Construction Monitoring Arrays Installed by Wasatch Constructors

During reconstruction, the design-build contractor (Wasatch Constructors) collected field instrumentation data to monitor the performance of the embankments and foundation treatments (*5*). Much of the contractor's monitoring program focused on the large embankments in the northern part of the project, including the 2400 South area (i.e., the I-80, I-15, and SR-201 Interchange, also called the 'Spaghetti Bowl') and the downtown area between 2100 South and North Temple Streets (See Figure 2). These portions of the project had the most concern for construction settlement related problems, including the magnitude and rate of primary settlement. Primary settlements in this section typically exceeded 1 meter (3.3 ft) for a 12-meter (39.4 ft) tall embankment including surcharge.

For design purposes, the design-build contractor grouped the geotechnical data in the northern part of the I-15 alignment into four geographical areas: 600 South, 1300 South, 2400 South, and 3300 South. The design-build team installed and monitored settlement plates, magnetic extensometers, vertical inclinometers, open and closed-end piezometers and optical surveying of fill heights and settlement monuments. The reconstruction project team used the construction monitoring data to validate key design assumptions and to assess embankment stability and the time rate of settlement at various locations. The Asaoka procedure was used in conjunction with the construction monitoring data to determine the end of primary settlement, and thus when to release the surcharges. Also, during the second phase of the project the construction monitoring data were used to modify the foundation treatment layout and embankment design, as required.

Unfortunately, there was no contract deliverable requiring the contractor to supply UDOT with the construction monitoring data. This data provided valuable information about the engineering behavior of the subsurface soils during construction. Thus, one of the objectives of the UDOT Research Project was to gather and compile these data into an ArcView^{TM} GIS database for subsequent evaluation and public use. This has been done and the electronic files are now available for much of the data (*6*). Field and laboratory data that have been reduced and interpreted include borehole and CPT logs and laboratory oedometer tests. Construction monitoring data that have been interpreted and used in correlation analyses include settlement plate, magnetic extensometers and fill height versus elapsed time surveys.

Construction and Long-Term Monitoring Arrays Installed by UDOT Research

The design-build contractor did not install any instrumentation to monitor the post-construction performance of the embankments and foundation treatments. All of the construction-installed arrays were destroyed by the construction activities. Since there were several innovative geotechnical technologies utilized during the reconstruction project, UDOT determined that there needed to be some instrumentation to monitor the long-term (i.e., 10 year) behavior of those technologies. The general design consideration used was to limit secondary settlements to less than 7.62 cm (3.0 inches) over a 10-year post-construction period. Thus, the I-15 Foundation and Embankment Performance project began. In order to capture that post-construction behavior and verify the design, UDOT Research installed additional arrays that are described in this paper. Many of the arrays were actually installed during construction and thus were also able to capture construction related behavior as well. The arrays have been grouped according to geo-technology type and are summarized in Table 1. The location of each of these arrays is also shown in Figure 2.

OBJECTIVES OF LONG-TERM MONITORING STUDY

The overall purpose of I-15 Foundation and Embankment Performance study has been to evaluate the construction and long-term (i.e., 10 year) performance of different foundation treatment and embankment systems used on the I-15 Reconstruction Project. Four different geo-technologies were identified for evaluation in this study and include the following: lime cement columns, two-stage MSE walls, geofoam, and large earthen embankments built on soft soil sites.

The data gathered from this study is being used to validate the geotechnical design used for the I-15 reconstruction project and to improve the state-of-practice in designing earthen structures on soft, clay foundations. This will be valuable for future projects within Utah and elsewhere that may be constructed on similar soft soil lake deposits. These overall project objectives will be done by:

- Gathering field performance data during construction and post-construction periods
- Comparing the performance data against the design performance goals and/or design criteria
- Assessing the adequacy of the design methods in meeting the performance goals/criteria
- Making recommendations regarding the application and/or modification of these I-15 geotechnical design methods for potential use on other projects founded on similar soft soils

INSTALLATION AND INSTRUMENTATION CONSIDERATIONS

There are many considerations that must be taken into account when beginning an instrumentation project. An instrumentation project, just like any other type of general project, must have a balance established between the project scope, schedule, and budget. The following questions are examples of the types of issues surrounding the project scope that should be addressed during the planning process of the project:

- What do we need to learn about this foundation treatment/embankment?
- What instrumentation types are available to provide us with this information?
- Will that instrumentation provide both the desired level of accuracy and precision?
- Is there a site where this instrumentation can be accommodated and effectively used?
- Will the instrumentation layout meet the overall project objectives?

Of course the scope issues must be balanced with the budget issues. The following questions are examples of the types of issues surrounding the project budget that should be addressed during the planning process of the project:

- How much funding is available?
- What type of instrumentation can we afford and how much of it?
- Where will the funding best be spent to achieve project objectives?
- How much of the funding will need to be budgeted to maintain and read the instrumentation?
- Will certain types and amounts of instrumentation save the project money? (i.e., by providing information to save time, refine designs, etc.)

Additional considerations to be taken into account include:

- How will the instrumentation be protected from construction related activities once installed?
- Will the instrumentation be accessible once construction is complete?
- What precautions are needed to ensure that the reader remains safe from traffic during reading procedures?
- How will the instrumentation be protected and maintained for long-term reading?

Finally there are staffing considerations that have to be taken into account. These include:

- Who is going to collect the data?
- Who is going to maintain the data?

- Who is going to interpret and report the data?

PRACTICAL APPLICATION AND LESSONS LEARNED

One of the constraints placed upon the I-15 Foundation and Embankment Performance instrumentation study, is that none of the research activities could impact the cost or the critical path schedule of the reconstruction project. With that in mind, all of the installation activities had to therefore be correlated with the contractor. Additionally, this meant that the installation had to work around the contractor's schedule. In general, most of the coordination was done directly with field supervisors.

The first step in laying out an instrumentation array was to identify the desired objectives (i.e., by answering the questions listed previously). The next step involved looking through the construction plan set along the corridor to identify a suitable location to place instrumentation (meaning a site with the appropriate embankment geometry, that would remain accessible and safe during construction and beyond). The contractor was then notified of the potential to install an instrumentation array. Coordination involved primarily staying apprised of the contractor's construction schedule and keeping the contractor informed of what instrumentation was going in and where it was going. Installation often took place during construction activities, where the contractor allowed a brief window of time for installation to take place. In many cases the personnel involved with installation of instrumentation spent a great deal of time simply waiting for a window of time when they could get in and get the work done. The contractor was often changing the construction schedule around, so it also became critical to simply check the site and also check with the contractor regularly, keeping apprised of any schedule changes.

Much of the instrumentation involved connecting various pieces together (i.e. PVC pipe being extended up through a fill), where once one piece was installed, the contractor would continue construction activities until an elevation was reached allowing for the subsequent piece to be connected to the first. It was imperative to inform, remind, and in many cases continue to re-remind, the contractor that the instrumentation was there. The contractor was generally cordial enough to be careful with the instrumentation, when he remembered that it was there. In addition, to help remind the contractor, all instrumentation that was left exposed was clearly marked, either with bright paint or flagging. Unfortunately, accidents still happen, and so it became imperative to keep track of the instrumentation and the construction activities by checking on them regularly. In so doing, when instrumentation was damaged it could generally be repaired. It was simply a matter of being prepared to find solutions to unexpected problems. Common problems included PVC pipe being broken and having to be replaced as well as cables being cut and having to be spliced back together.

When an array was being installed, a general rule of thumb was to keep instrumentation, even different types of instruments, in groups where possible. This not only made it more efficient for the readers to gather readings, but also made it easier for the contractor to remember where the instrumentation was located and thus avoid damaging it. Additionally, because the various types of instruments capture different behavioral aspects, a group of instruments is able to provide a better understanding of the global behavior of the wall or foundation. For example, if the settlement beneath the wall is being captured, it is also nice to then measure the pressure acting at that point, causing the settlement to occur.

In some instances several arrays had similar instrumentation array layouts. This provided for some redundancy in gathering measurements. It is impractical to consider that instrumentation could be placed in every single wall or foundation. Therefore, it was important that the sites selected were representative of similar locations throughout the project. Thus the effort was to provide enough instrumentation to adequately represent each geo-technology, yet still provide some redundancy in the data. The redundancy also allowed for the potential loss of instrumentation, whether that may be caused by construction activities or by some other means.

Another important issue was getting the instrumentation prepared for long-term reading. This included providing safe secure boxes or covers for the instrumentation. These were included to keep the instrumentation safe from primarily weather and vandals. In most cases the final locations of the instrumentation were meant to look as inconspicuous as possible, so as not to draw attention to them.

Several pieces of instrumentation have already been abandoned. Several of the horizontal inclinometers that were used to monitor foundation movements beneath MSE walls during construction were buried beneath the slope work during final construction activities. It was determined that the magnitude of secondary settlement would be small enough to monitor from the face of the wall, and there was not any reason to suspect that the horizontal inclinometers would have been able to measure any measurable differential secondary settlement occurring. Rather than have to try and make them accessible beneath several feet of fill, they were abandoned. Additionally, some thermistor wires were damaged during installation, and could not be repaired. These too were abandoned. Unfortunately when the thermistor wires were damaged, construction over most of the project was complete and there was not really any practical way to replace that instrumentation.

This project has had the good fortune of being able to maintain consistency amongst the main players. For a project that has the potential to extend beyond a 10-year time frame, there is a high possibility that there will be personnel turnover amongst the main players. For the most part, the data has been gathered with personnel from both UDOT Research and the Civil and Environmental Department at the University of Utah. Field books have been kept by those installing and reading the instruments. Every entry includes the date, time and any additional pertinent information (i.e., fill height and changes in loading conditions of the embankment, for example the surcharge being removed). UDOT Research has continued to be the primary keeper of the data. A spreadsheet has been set up for each instrument and each is stored according to the array in which it belongs. Backup digital copies of these spreadsheets are periodically made. Data maintenance is simply a matter of inputting the new data after a reading has been taken. Instrumentation readings that are gathered digitally (i.e., by connecting some sort of readout box that stores the readings) have a hard copy of the raw data printed and stored in binders within the UDOT Research Division. Additionally, a photocopy of each of the field books is also stored in the same data binders. One field book has already become lost, and the backup photocopy has already proven invaluable. Interpretation and reporting of the data is also being shared between UDOT and the University of Utah.

OVERVIEW OF INSTRUMENTATION ARRAYS

For the I-15 Foundation and Embankment Performance project specific emphasis was placed upon behavior relating to edge effects, transition zones, abutments, foundation behavior, wall behavior, and roadway surface behavior. Instrumentation was selected and installed to capture behavior relating to applicable areas for each of the different geo-technologies.

Lime Cement Columns

Lime cement columns are a deep soil mixing technique used to treat and stiffen soft foundation soils. An auger is inserted to depth in the ground and lime and cement are injected into the ground as the auger is removed. The result is a column of lime, cement, and native soil, which is stiffer than the surrounding soils. Numerous columns can be placed at the design spacing to stiffen the foundation materials. It was originally intended that lime cement columns would be placed in many locales within the I-15 reconstruction project, but due to project time constraints only one location actually had lime cement columns installed. (*7*) Thus, this location was the only lime cement column site (LCC Array) selected for instrumentation and monitoring. A large MSE wall was placed on the treated foundation.

Instrumentation used within the lime cement column array include: horizontal inclinometers placed within the base of the MSE wall (i.e., directly above the lime cement column treated foundation); a magnet-reed extensometer placed within the foundation soils; pressure cells and settlement cells placed directly on a column and in between columns at the surface of the treated foundation (i.e., directly below the MSE wall); and settlement points placed in the ground surface both parallel to and extending away from the MSE wall. In addition to the UDOT instrumentation at this array, the contractor installed a vertical inclinometer at the face of the wall. Figure 3 shows the layout view of the instrumentation placed at the LCC Array.

The objectives of the instrumentation installed at the lime cement column array are:

- Measure the total and differential construction settlement in column panel areas and column transition zones during embankment loading using horizontal inclinometers

- Measure the lateral movements of the foundation system during construction using a vertical inclinometer
- Determine the settlement versus depth in the soil profile using a magnet extensometer
- Measure the differences in load transfer and settlement behavior in the treated and non-treated areas using vibrating wire pressure cells and settlement cells
- Measure the construction and post-construction settlement (i.e., creep) of the embankment/wall system and the adjacent property near the face of the wall using survey points
- Provide measurements and soil properties for numerical modeling of LCC treated soil

MSE Walls

Mechanically stabilized earth (MSE) walls were used extensively throughout the I-15 reconstruction project. Two different types of welded wire MSE walls were used: one-stage walls, where the reinforcement is connected directly to the face panel, and two-stage walls, where the reinforcement is connected to welded wire faces and the exterior face panels are later attached after settlement occurs. Two different MSE wall arrays were established, both in two-stage walls. Utah State University was involved in most of the work done to instrument and monitor the 35th South Array. A portion of this array and the entire other array (2nd South Array) were installed and monitored by UDOT Research.

The instrumentation installed and monitored by Utah State University includes, horizontal extensometers, horizontal inclinometers, strain gauges, total pressure cells, vertical extensometers, and vertical inclinometers (*3*). The instrumentation installed and monitored by UDOT Research include: a horizontal inclinometer in the base of the 2nd South MSE wall; and settlement points placed in the ground surface both parallel to and extending away from the walls.

The objectives of the instrumentation installed at the MSE wall arrays are:

- Measure the settlement profile that develops underneath the MSE wall during primary and secondary settlement using data from the horizontal inclinometers
- Measure the settlement pattern that develops in front of the MSE wall during primary and secondary settlement using data from the survey points
- Compare the gathered data with results obtained from conventional settlement analyses to determine the adequacy or inadequacy of such methods in predicting settlement

Note that the above objectives only pertain to those being measured and evaluated by UDOT. They do not include the research objectives of the instrumentation being done by Utah State University.

Geofoam

Expanded Polystyrene (EPS), or geofoam, was placed in several locales along the I-15 corridor, generally as an alternative to earthen fill. It was primarily used as a lightweight fill material at locations where settlements had to be virtually eliminated due to utilities or other sensitive infrastructure. The extensive use of geofoam on the I-15 Reconstruction Project has generated widespread interest in EPS as a lightweight fill. An extensive program of instrumentation and field observation of geofoam embankments was initiated at two sites: the 33rd South Array (8) and the 1st South Array (9). Smaller arrays have also been installed at the SS-05 Array and the SS-07 Array. The geofoam research is being carried out jointly between UDOT Research, Syracuse University and the University of Utah.

The instrumentation installed within the geofoam arrays include: horizontal inclinometers both within the foundation directly beneath the geofoam wall and at the surface level of the geofoam wall; magnet-reed extensometers with magnets placed at various levels between the geofoam blocks; total pressure cells placed both horizontally and vertically within the foundation and abutment area of the wall and at various levels between the geofoam blocks; settlement points placed both in the roadway surface above the geofoam and along the face of the geofoam wall; and thermistors placed at various levels within the pavement profile above the geofoam. An example of instrumentation placement for the 33rd South Array can be seen in Figure 4.

The objectives of the instrumentation installed at the geofoam arrays are:

- Monitor the construction and long-term settlements and compare the settlement performance of geofoam and earthen embankments using horizontal inclinometers, magnet extensometers, and settlement points
- Measure the vertical stress distribution in a pavement section underlain by geofoam using pressure cells
- Measure the vertical and horizontal stress distribution in an abutment area using pressure cells
- Measure the temperature profile within the pavement structure and on the surface to establish relative tendencies to produce differential icing in winter and elevated temperatures in summer using thermistors

Large Earth Embankments

Large Earth Embankments were used in conjunction with pre-fabricated vertical drains (i.e., wick drains) and surcharging throughout the I-15 Reconstruction Project. The I-15 Contractor monitored these embankments during construction for stability related problems as well as determining the end of primary consolidation and therefore when to release the surcharges. UDOT Research installed four arrays (4th South Array, 9th West Array, I-15 Mainline Array, and I-15 Merger Array) to monitor the rate and magnitude of secondary settlement. In addition, construction was concurrently taking place at the University Avenue Interchange in Provo (located approximately 35 miles to the south of the I-15 Reconstruction Project). Since the subsurface profiles were very similar to those along the northern end of the I-15 Reconstruction Project, an array was installed at this location (Provo Array) to monitor the construction and post-construction related settlements. These locations were selected as suitable locations based on the height of the embankment and accessibility to install and read instrumentation.

The instrumentation installed within the large earth embankment arrays include: a horizontal inclinometer extending from toe to toe beneath an embankment; magnet-reed extensometers placed through the embankment and into the subsurface soils; pressure cells placed beneath an embankment; settlement manometers placed within the base of an embankment; and settlement points placed both along the toe of the embankment and adjacent to the pavement at the surface of the embankment.

The objectives of the instrumentation installed at the large earth embankment arrays are:

- Measure the magnitude and rate of the primary settlement with the horizontal inclinometers and settlement points
- Measure the associated pressure causing settlement to occur with the pressure cells
- Measure the long-term settlement (i.e., secondary settlement) along the new I-15 alignment to determine the adequacy of the surcharge design in minimizing long-term settlement
- Use the results to determine the adequacy of the surcharge design as implemented by Wasatch Constructors

READING SCHEDULE

Most of the arrays were installed during the summers of 1998, 1999 and 2000. To date approximately 4 to 6 years of data have been gathered at the arrays. The intent of the program is to gain 10 years of post-construction settlement behavior at most of the arrays. Thus, the project is intended to end by 2008 to 2010, at the discretion of UDOT and the University of Utah. However, the reading of any individual array or instrument within an array can be terminated early. Possible reasons for early termination of readings may include: damage to the array by construction activities, instrumentation destroyed or damaged by other circumstances, or additional readings will not add any benefit to understanding the long-term behavior (i.e., secondary settlement, or creep, has greatly diminished, or stopped, for all practical purposes).

The following lists the recommended reading schedule that was originally established:

- Weekly reading of the arrays during active fill placement or construction or after any change in loading conditions has occurred
- Weekly reading during the first three months thereafter
- Monthly reading during the subsequent 9 months
- Quarterly reading during the second and third years
- Semi-annual reading during the subsequent years

However, this schedule has not been strictly followed due to various construction activities, project personnel changes, technician work schedules, inclement weather and traffic and safety concerns. UDOT has periodically modified the reading schedule according to these considerations.

CONCLUSIONS

The I-15 Foundation and Embankment Performance study has been successfully implemented, and readings continue to be gathered to monitor the long-term behavior of four different geo-technologies used on the I-15 reconstruction: lime cement columns, two-stage MSE walls, geofoam, and large earthen embankments on soft soil sites. Twelve different instrumentation arrays were installed to capture specific objectives relating to each of the different geo-technologies, ensuring that accessibility and safety to the instrumentation be maintained through the duration of the monitoring project. To date, many of the project objectives have been accomplished and subsequent papers and reports are being prepared to identify the specific project results. The long-term monitoring of these arrays is intended to extend for at least a 10-year post-construction period.

In general, the lessons learned about instrumentation installation include:

- Keep track of instrumentation during construction
- Keep instrumentation in groups where possible
- Provide redundancies
- Have backup plans
- Provide protection for instrumentation
- Be prepared to find solutions to unexpected problems

This research is being performed because it provides a great benefit to the Utah Department of Transportation in following the long-term behavior of the recently reconstructed section of I-15 in the Salt Lake Valley. Each of the four geo-technologies has had specific objectives set, and the instrumentation has been installed accordingly to meet those. In general the benefits include:

- Assess the adequacy of the design methods used
- Make recommendations regarding the application and/or modification of these design methods for use on future projects

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LIST OF TABLES AND FIGURES

Table - 1 UDOT Long-Term Monitoring Arrays for I-15 Reconstruction Project.

Geo-Technology	Array # (As shown on figure 2)	Name	Types of Instrumentation						
			Horizontal Inclinometers	Magnet-Reed Extensometers	Pressure Cells	Settlement Cells	Settlement Manometers	Settlement Points	Thermistors
Lime Cement Columns	1	LCC Array	X	X	X	X		X	
MSE Walls	2	2nd South Array	X						
	3	35th South Array	X					X	
Geofoam	4	1st South Array	X	X	X			X	X
	5	SS-07 Array			X				
	6	SS-05 Array	X	X				X	
	7	33rd South Array		X	X			X	
Large Earthen Embankments	8	4th South Array		X				X	
	9	9th West Array		X				X	
	10	I-15 Mainline Array		X				X	
	11	I-15 Merger Array		X				X	
	12	Provo Array	X		X		X	X	

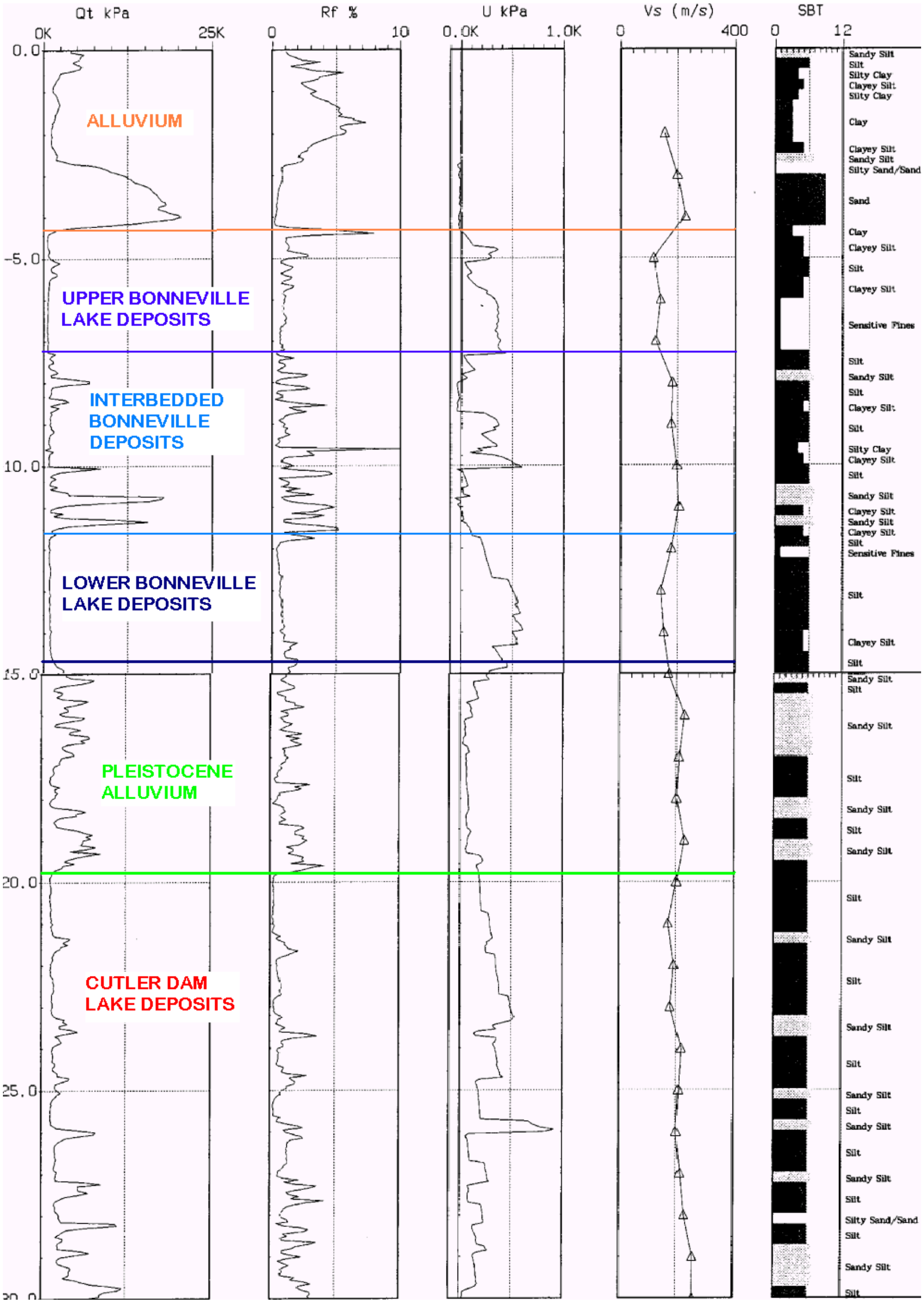

Figure 1 - Typical CPT Profile and Subsurface Layering for Northern Section of I-15 Reconstruction Project.

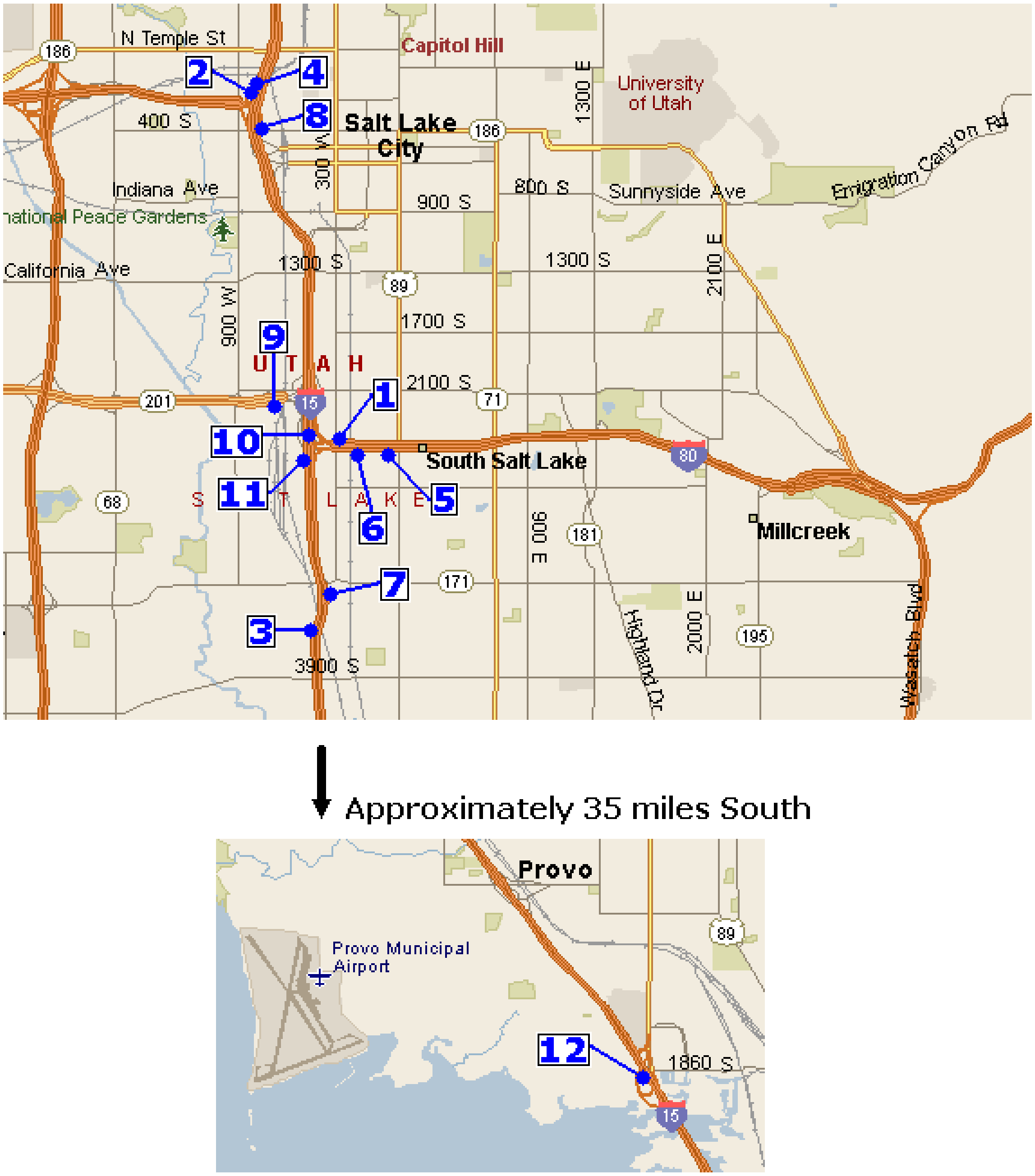

Figure 2 - Map of I-15 Long-Term Monitoring Array Locations.

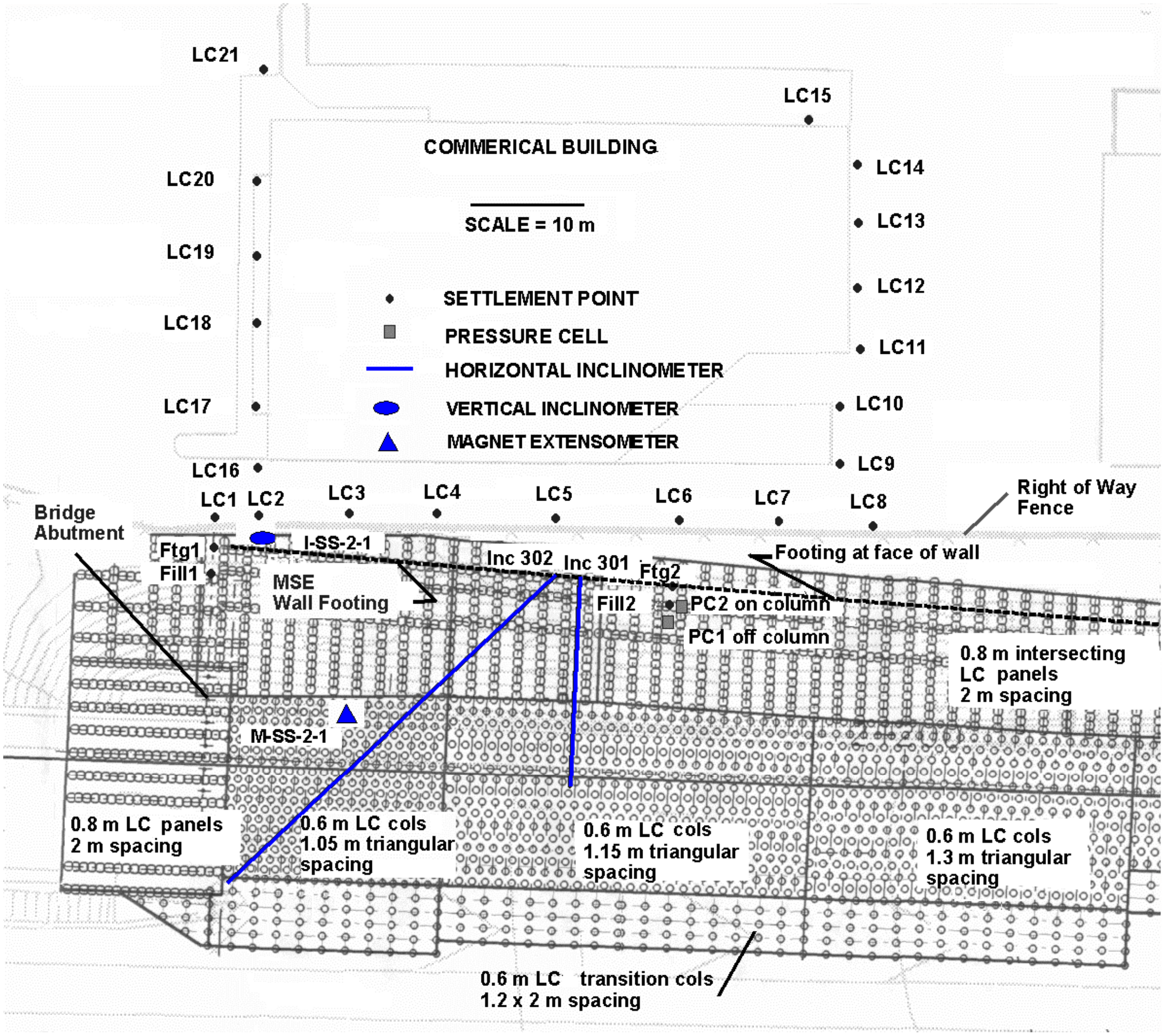

Figure 3 - Instrumentation Layout (Plan View) for the Lime Cement Column Array.

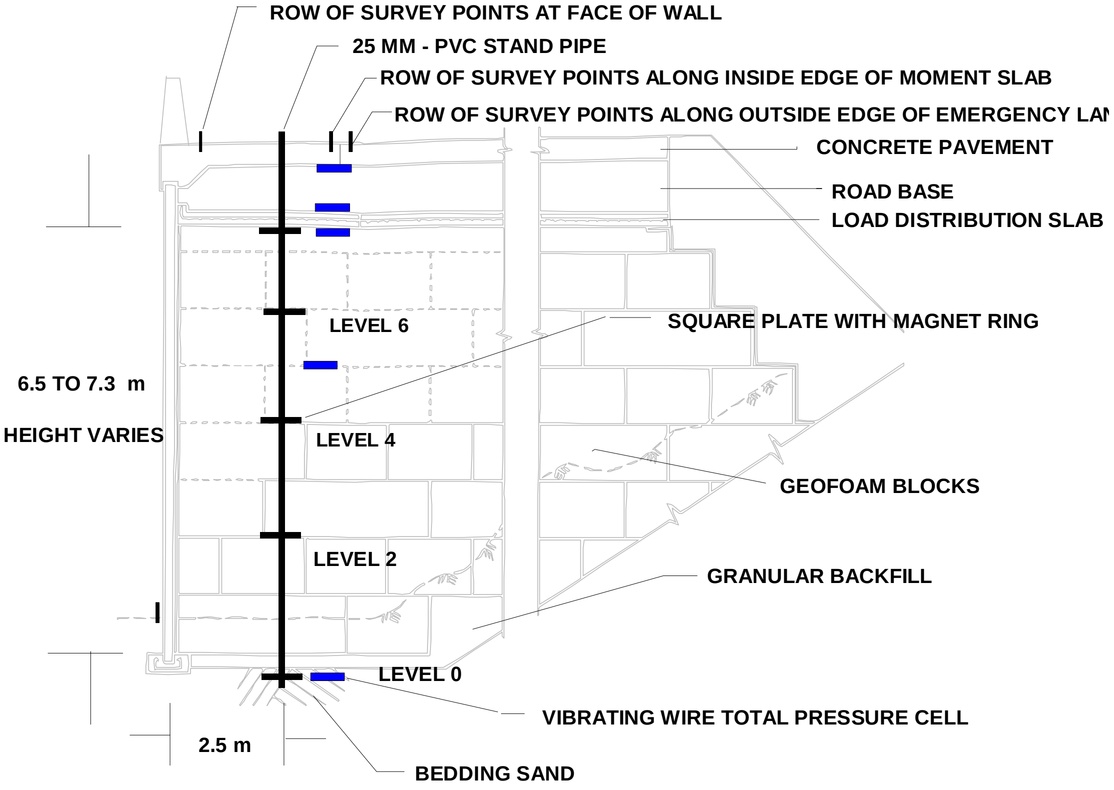

Figure 4 - Typical Instrumentation Layout (Profile View) for the 33rd South Geofoam Array.