

Geotechnical Instrumentations Lessons Learned from Contract MA-1A

Mo Salman" msalman@driggs.net – Superintendent for Contractor – John Driggs Corporation
01/19/2004

Attached please find our subcontractor' comments and recommendations concerning instrumentation. I would like to add:

- 1> SHA should share the responsibility with the contractor for any damage by using the instrumentations during the project time.
- 2> Some instruments were installed at the straps of the retaining walls and it make them very difficult to protect and install the straps and stone at the same time.
- 3> The submittals and approval procedures were lengthy and confusing to follow. we recommend outlined procedures and pre approve suppliers.
- 4> Some instruments are located on the slope of embankment that make them very difficult to protect or fix any future damages.
- 5> For future contract please out line procedures on how to protect the instruments, surveying coordination, and how to get to them (some instruments are required some efforts to get the readings). This way the contractor will allocate budget for.
- 6> In this contract we paid out of pocket cost for fixing damaged instruments by act of god or un usual weather.

Some of the above comments maybe repeated or visited by others recommendation.

Paul Martin
PCC MA1A Resident Engineer
01/19/2004

First, I think that special attention ought to be paid to the preconstruction soil sampling when considering an instrumentation program. I believe on this project that we ended up wasting money by having all of the VWPZ's placed when the clay layers were not continuous. The pre-construction sampling should be observed by a geotechnical engineer with random samples sent to the lab to compare his/her description with a lab analysis.

Inclinometers: I think that they have worked pretty good. It might be worth your while to consider adding MPBX magnets to all inclinometer installations. It can give you correlating settlement and horizontal displacement data at the same location. If you don't want that many MPBX's, you may at least want to consider having the MPBX's that you do want placed with inclinometers. They use the same casing and it was wasteful to have to drill and place 2 casings within a few feet of each other when 1 installation could have taken care of both. Another thing that I think would be useful would be to have an adjustable leg tripod connected to a collar that could go around near the top of the casing. This would help to maintain that the casing remains plumb. We have had some instances of the casings not remaining exactly plumb as they were extended. This is a recommendation that I make for settlement plates as well. Another thing that I would address is the 3 day limit for replacing inclinometers. I think that this is an unreasonably short time to get a drill crew in, place, and initialize an inclinometer.

MPBX: These were simple to read and I think that they were useful.

I noticed when looking through their literature that they also have ring magnets that you can place on the casings as the fill rises. Every 10 feet or so you just place a magnet over the casing and keep filling. This would enable you to monitor the fill as well as the original ground. I have noticed on some of the Rosalie Island MPBX's that we have 50' of soil or more before we get to our 1st magnet.

Strain gauges: My recommendation for the strain gauges is to have 3 or 4 placed at each location on the fabric. We would only accept the readings if we had at least 2 that collaborate with each other.

Settlement Profiler: This turned out to be a bulky machine that was not weatherproof. It was cumbersome to get into place and each test takes about 8 hrs. to run. It is not practical for monitoring a fill during construction. It may be a useful tool for a long term monitoring situation of a structure or an abutment if a set up area is built into the project and the tubes can be protected.

Settlement Plates: I think that these were useful and cheap. I don't see any real changes needed except the tripod collar mentioned above. A more specific spec for the surveying may be in order to ensure consistent readings. The way the PCC has been set up I don't have much control over the survey crew and getting surveys performed and having the surveyors address inconsistencies has had to be done by my negotiating instead of being able to instruct them to just do it.

DMP's: I suggest changing the spec to allow rebar for DMP's as we ended up using. It should bring down the cost of these items. Our contract quantity for DMP's was overrun because needing additional ones as the wall went up was not accounted for. They seem to be useful but could use the further control over the surveys as described above.

VWPZ's: It is a little hard to say if these were good or not. They confirmed to us that the soil was not a continuous clay layer. The manual reading of these instruments is very easy so it might be best to eliminate the automatic data loggers for them.

Geotextile Mounted Rod Extensometers: I haven't heard these discussed much at the Geotech meetings I have attended. I don't know enough about how you used their data to know if they were helpful.

Open standpipe piezometers: These didn't provide much guidance either but it is a relatively inexpensive instrument.

The limiting and threshold values chart was pretty confusing. It should probably be revisited before the next contract. Especially confusing were the values for the MPBX as they limited strain against fill height. Once you have had so much settlement, the only way to bring it back within tolerance is to add more fill. Referencing centerline settlement was difficult because some of the instruments were several hundred feet away from the centerline and along wall 1 we had 2 separate centerlines.

Another item to the spec that would be useful would be one for placing fill adjacent to the casings. It could stake out a radius around the instrument where fill would have to be hand placed using a sandy fill material and compacted with hand tools or small equipment.

Automatic Data logging: Sounds interesting but is high maintenance. I'm not sure that you get your bang for the buck with this system. We paid \$60,000 to have this system installed plus additional maintenance costs out of a \$120,000 maintenance lump sum item. I'm not convinced that it provided sufficient value.

Additional Drilling and Sampling: It would be good to have a contingency item set up in the project for additional drilling and sampling paid for by the linear foot. This could be used for extra depth drilling if some instruments need to go deeper than originally planned, for collecting undisturbed samples, or drilling in preparation for vane shear testing.

Instrumentation Website: I think that the website set up by Curt K. of URS has been helpful. However, it was not accounted for when estimating PCC's cost of managing the project. It needs to be considered. I also do not like the way that Curt has displayed the DMP information on the website. I think a different format for displaying the movement over time would be better.

As for the rate of fill placement, it comes down to motivation. JDCI is motivated to place as much fill as they can in as short a period of time as they can so they make more money per equipment hour. We were trying to limit the placement rate because we were worried about the geotechnical conditions. It isn't impossible to monitor the contractor to make sure he isn't trying to put in too much fill but it is a never ending battle. Perhaps one solution would be to make it a working days contract instead of a calendar day contract. That would ease some of the tension of the contractor feeling penalized by suspensions and waiting periods and would give us the flexibility to wait when we need to wait without feeling that we are hurting them.

The other problem situation that we faced, as you are well aware, was the letting of the MSE walls as a design bid item. You probably spent more time reviewing the plans from Foster than it would have taken to design it. Since it was a competitive bid, we also got the cheapest wall that was acceptable. It would be worth reviewing to see if a direct contract with a wall designer from WRA instead of through the contractor would be more cost effective.

That's all I have for now. I know it's a lot and you may have more questions about what I wrote. Please feel free to call me at 571-237-1433 if you want to discuss this.

Siva Kesavan
January 23, 2004

Following are my comments on the instrumentation program.

Inclinometers: Most useful instrument among all.

1. *In some areas the direction of lateral movement may not be easily estimated prior to loading. (We had large horizontal movement in both A-and B-directions in inclinometer 31003. It is good to have initialization in both A- B-direction on casings located in these critical areas.*
2. *Clip-on casing ensures minimal rotation of the casing during installation. Initialization with Spiral probe may not be required.*
3. *Frequency of readings may be reduced to once a week or once in two weeks in general during construction. Twice a week in critical areas only.*
4. *A good estimation should be made on required number of on-site technical personnel to read the instruments. In our opinion, one able bodied person may be able to read 8 inclinometers of 60 to 80 feet deep in an eight hour day*
5. *When inclinometer casing is extended, length of extensions may be restricted to 4 feet at a time. Longer than 4 feet extensions will hinder operator in obtaining readings.*

Settlement Plates: My favorite instrument. They are simple to use and provide valuable information.

1. *Settlement plates are the most damaged instruments by construction vehicles. Even though soft subsurface conditions and heavily loaded areas dictates the selection of the installation location, additional consideration should be given such that they are placed in a less obstructive areas to construction activities.*
2. *A detailed installation procedure may be specified on how to protect the settlement plates (such building a 2 feet high, 3 feet radius berm around the plate stem prior to placing fill)*

MPBX: Easy to read, most consistent.

1. *Readings and settlement were obtained is different elevations. However no magnet was provided at the settlement plate (plate bottom) elevations. It is prefer to have a magnet installed at the same elevation as bottom of nearby settlement plate. This would enable us to compare the settlements from settlement plate and MPBX.*
2. *Casings may be initialized with inclinometer probes so that it can be used as an inclinometer casing in the future. Also use same type of telescopic couplings as inclinometers (We tried to lower the inclinometer probes through the casings of MPBX 41002 and 41006 recently. Due to collapsed joints/coupling we were unable to lower the probe past a certain depth.)*

Vibrating Wire Piezometer: Provided valuable information about the type of soil layers rather than the hydro dynamic pressure.

1. *Based on the procedure specified and used for the installation of VWPZ, the piezometer will be embedded in a filter sand column of approximately 3.5 to 4.5 feet, with one foot of bentonite cap.*

2. *Based on the test borings drilled during the installation, the soft clay material, classified as A-1 material is not clean and continuous form but rather layered with pervious sand, gravel and silts. Except in two locations, the pure clay layer was less than 5 feet thick and majority of them were 3 feet in thickness or less.. The VWPZ with 3-4 feet long sand column, installed in the "dirty Clay" with sand layers, did not read increase in pore water pressure.*
3. *In thin layers of clay, push-in piezometers may be used (thanks to John Volk).*

Vane Shear Test Could not use the test successfully due to site conditions.

1. *As described in vane shear testing the clay material underlying the site is "dirty", consist of layers of sand and gravel. The sand and gravel within the clay layer lead to eronious results and in few instance, damaged gravel damaged the vane shear equipment in several occasions, the equipment was damaged*

Settlement Profiler

1. *No comments (*...*@!! # **)*

Geotextile Mounted Strain Gauges Valuable information for the designer.

1. *Two resistive type strain gauges were installed on the geotextile at each location (one on top and the other on the bottom of the geotextile) The total resistance from both gauges are read automatically at present. We feel strongly that instead of reading the total resistance, both gauges should be read individually. Individual readings would help identify malfunctioning locations easily.*

Geotextile Mounted Extensometer

1. *No comments (*...*@!! # **)*

John Volk
01/26/2004

1) Magnetic extensometers and inclinometers performed excellently. Would recommend more magnetic extensometers next contract. The fact that you do not need a survey crew to read and it only takes 15 min per locations with a "self benchmark", i.e., anchored below moving soils is excellent and allows more frequent readings in critical areas without mobilizing entire survey crew. Always use 3.34 inch O.D. inclin and mag extensometer casing to get maximum use before casing kinks and probe will not go through. At toe of slope - same casing can be used for mag extensometer and inclinometer.

- 2) Piezos are generally erratic - this project had no readings and that was a surprise but usually they are not a huge help. I would still recommend a few on MA-4.
- 3) Settlement platforms - poor readings are not uncommon, but usually not this bad. Inexpensive instr - keep for MA-4.
- 4) Liquid settlement device and rod extensometers for redundant strain readings on GT were not any help. None for MA-4.
- 5) Strain gages on GT good - I would recommend not placing on both sides of GT in all locations (some are OK to keep Barry happy). Would recommend strain gaging doing multiple layers in one section next time - did strain reach top layers??
- 6) Survey point on walls are fine.
- 7) Shear strength confirmation - vane shear, UU's on undisturbed samples, CPT's. Not imperative to do at all. Seams in sand messed up vanes and gave artificially high values. These tests took an inordinate amount of time to do and I think caused slight delays (see comment No. 11).
- 8) Interpretation of vane shear/UU's: I believe these should be confirmation only after settlement curves have turned. I believe WRA did not wait for settlement curves to turn on log scale on Wall 1, first stage and this caused some excess movement of Stage 2. Sand seams caused artificially high shear strength values and misled WRA.
- 9) Deformation Ratios: Use Ladd's (1991) interpretation - max hor movement at toe/ max vert movement at centerline, look at incremental values. Other ways to reduce data may be interesting but no database of experience. Again, we had high values in areas of project.
- 10) Factor of Safety: Use FS of 1.3 for short-term stability. FS of 1.2 was too low and caused a lot of excess movements.
- 11) Contractor or GEC install instrumentation?: Can be done both ways successfully. We did it with GEC in VA and I think it is 10 times easier than having Contractor do it. No fighting over submittals. Any changes are made quickly and more "nimble" or "agile". Alan Marr's firm was decent and it was still hard - a poor firm would have been a nightmare. Scheduling Tom Brown caused delay for shear confirmation testing. The big negative is that money comes out of GEC fee (8.5% of constr cost) if GEC installs. Also, FHWA pays for more of it when contractor puts in. If owner has right people installing and overseeing - much easier and nimble (do need penalties if Contractor destroys).
- 12) Database of Instr Data: Good and eliminated copying massive data reports. Negative - took a lot of effort and time to download data to see what was going on.

13) Stockpiles of Soils/Materials: They mess up instrumentation readings and could cause failure of embankment! Only should be placed on site if location and height approved by Engineer.

14) Compaction around instruments in fill and final paving: Paul Martin raised this and I agree - Need to use hand operated compaction equipment near instruments. After surcharges removed, overexcavate 2 to 3 ft below final grade and grout casing and proof-roll surface. Take out loose soils not compacted by proof-roll. Then construct pavement box.

Monica Paylor

01/27/2004

1. Data Acquisition and WEB based instrumentation results.

This was the most valuable part of the instrumentation program. The rapid accessibility of results in graphical form by all engineers with a vested interest in this project saved a significant amount of engineering time, data review and processing time, and communication costs in addition to rapid resolution of issues that arose during construction. There were several instances during the project where rapid access to data directly avoided delays in construction that would have occurred due to the normal prolonged conversion, transfer, reporting and review of data.

2. Lateral Movement (Inclinometers)

The inclinometers were the most critical instruments based on their importance in evaluating embankment performance. The readings indicated sections where movement was within tolerable limits all owing construction to continue on schedule. Also, sections where excessive movements occurred were clearly identified requiring movement of construction filling activities to other sections with additional monitoring. Along Retaining Wall 1, installing additional inclinometers led to avoiding a costly design modification, which would have required the use of lightweight fill. The placement of single inclinometers in wall sections led to difficulties in interpretation in a few areas. The inclinometers provided a good indication of where movement was occurring and the potential development of shear surfaces with depth; however, the installation of inclinometers in a single location for specific wall sections did not provide a clear picture of extent of lateral movement and the location of a potential shear surface developing over the entire wall mass (e.g., evaluation of lateral squeeze versus global stability). In the next phase, consideration should be given to placing two inclinometers in each wall section, one near the front and one near the back to assist in interpretation and provide better redundancy to check the readings.

The instruments performed very well with only one inclinometer location requiring replacement and that was due to excessive movement in that region. Unfortunately in some cases there was a slow response in obtaining inclinometer and survey readings and, in a few cases, the accuracy of survey data was questionable, both of which delayed critical decisions. On the next phase, consideration should be given to installing permanent inclinometers to avoid reading delays (as well as reduce interference with construction).

2. Settlement Monitoring (Settlement Plates, Vertical Survey Points, Vibrating Wire Extensometers, and Profilometer).

The other essential data for evaluating performance of the project was the settlement data, which was obtained from a variety of sources. The settlement plates and vertical survey points mounted on the face of the wall worked very well and were useful during evaluation of the magnitude and rate of consolidation as well as stability issues. Plots of vertical settlement versus lateral movement from inclinometers were used as an indicator of potential stability issues. There was some questionable survey data and more rigorous QA requirements for survey readings should be included in the next contract.

The probe extensometers worked very well. They provided an evaluation of vertical movement with depth and a check of survey measurements.

Vertical movement outside and beyond the toe of the wall was not available and would have been valuable in evaluating the potential of lateral squeeze during filling.

3. Pore Pressure (Vibrating Wire Piezometers)

The pore pressure measurements provided by the vibrating wire piezometers appear to be much lower than would be anticipated from consolidation settlement observations. The pore pressure transducers appear to be functioning based on observations of change with tidal variation; however, significant buildup of pore water pressure is not observed during loading. It is possible that the pore pressure is dissipating very rapidly due to sand seams in the soil and is not measured due to the frequency of the readings. More frequent readings have been advised during the next loading sequence to further evaluate this issue. It is also possible that there is some form of short circuiting occurring in the bore hole. For example, the bentonite may not have properly hydrated (e.g., the water used for mixing may have been contaminated) and the permeability is much higher than it should be.

On the next contract, a more rigorous QA program should be established during installation. Permeability requirements for the bentonite-cement mixture should be included in the specifications and samples should be taken at the site after mixing (i.e., with the on site water used for mixing). In addition, two or three standpipe piezometers should be installed in critical locations, each next to electrical piezometers to allow for field calibration. If the calibration is adequate during initial fill placement, the standpipe piezometers could be abandoned; however, if the results are significantly different, the contractor could be required to extend them through the fill and/or replace the electrical units at the contractor's expense.

5. Geosynthetic Strain (Strain Gages and Extensometers)

Strain gages mounted on the geotextiles also provided valuable information for monitoring stress conditions in the geosynthetic, confirming design assumptions and allowing for an evaluation of the critical state of the stress condition in sections where significant movements were occurring. The gage installation technique performed very well with only a few gage point failures. Gaging the top and bottom of the geotextile provided good redundancy such that when one gage failed or provided questionable readings the other gage could be used to confirm the results. Unfortunately a few gages in critical locations indicated substantially high strains before failure and artificially created some concern with performance. The aforementioned gage redundancy alleviated some concern and the installation of inclinometers in that section, as mentioned above, allowed for construction to proceed in that area as planned.

Rod Extensometers were also installed to provide redundancy with strain gages for evaluating strain/stress response. In the area where excessive strains were measured in the strain gages, abnormally low readings were obtained from the extensometers. There are several possible explanations for these results. The vertical movement at the toe of the wall, which is directly above and near the readout end of the extensometers, could have significantly bent and

pinched off this set of extensometers. On the next contract, a rigid platform should be placed above the extensometers to prevent abrupt loading directly on the readout end of the extensometers. Another possibility is related to unanticipated flooding of the extensometers at the beginning of the project. Sand may have washed into the extensometer tubes creating significant friction between the rod and tubing. On the next contract, the ends of tubing should be packed with grease and protected with a rubber sleeve to avoid this potential problem.

Strength Verification Testing

The vane shear testing to verify strength gain in the soft soils was not successful due to the presence of sand and gravel seams within the clay layer. Laboratory testing was successful; however, there were some delays in getting a drilling out to the project and obtaining test results. In the next contract, laboratory testing will be used; however, the testing should be requested prior to 90% consolidation to allow time for the drill crew to mobilize and laboratory testing to be performed.

Specifications

The specifications were extremely long and difficult to read through to determine which sections were applicable to each instrument. In the next contract, there should be general specifications for the instrumentation program and a section for each instrument.

These are some of our comments that will be incorporated into the report.

Murray Miller
GEC- URS
01/28/2004

Settlement Plates

- ❖ Were very valuable and useful in controlling rate at which fill could be placed.
- ❖ Number of plates could have been increased some, particularly to form a cross section of settlement along a given circle.
- ❖ Contractor fabricated plates well and installed them properly.
- ❖ Initially contractor was not careful in protecting them requiring hand digging and replacement of pipe extensions from a existing buried pipe joint. Instruct contractor's Foreman/Super early on.
- ❖ Age old computer program applied (GARBAGE IN – GARBAGE OUT)
- ❖ Quality of survey readings degraded with change in Survey crew and change in Chief of Surveys, may have been due to increase in other responsibilities.
- ❖ I don't believe replacement chief or survey crewman understood importance of what they were doing.

Inclinometers

- ❖ Installation went slowly but well and equipment worked well. Data was of high quality and very valuable.
- ❖ Data loggers worked well.
- ❖ Compressible couplings worked well.
- ❖ Numbers of inclinometers could have been a bit more frequent to create x-sections of movements along a given circle. For the future, pair lateral reading movements from inclinometers with a corresponding settlement plate.
- ❖ Initially contractor did not protect inclinometer casings well. A number had to be dug out and top sections replaced. Contractor became more careful with time. Get Foreman/Super onboard early-on.
- ❖ I believe it would have been useful to know when the casing was reaching max. curvature or max warping curvature (A direction combined with B direction) so that casing could have been replaced as a routine matter rather than wait until instrument got stuck . This information would have to come from manufacturer or Instrumentation Consultant.

Resistance Strain Gage

- ❖ These gages had to work in a difficult environment.
- ❖ I believe that the best available technique was used to install the gages but it is not good enough. Therefore, the method to use, to protect the project, is to install redundant gages while trying to find better ways to mount the gages to the fabric.
- ❖ Since the readout locations were out of the way of the construction activities shortly after construction began, the data gatherer would have been adequately protected at the terminal/readout locations. Hence the telemetry network was unnecessary. A simple change to the electrical circuitry to permit reading both gages in series or one gage and then the other would have been useful and contributed to correcting gage failure problems faster..
- ❖ It was important that these be installed because the magnitude of stress was proportional to the magnitude of strain. Excessive stress could have been disastrous.

Rod Extensometers

- ❖ These were supposed to be back up and verification for the strain-gages.
- ❖ The general concept of these instruments, in my opinion, is questionable. That is, it was a Contractor's design based upon specs prepared by the Instrumentation Consultant. In other words, it was design build. I hate design build. Just so no one misunderstands me, I will repeat. I hate design build. Although the Contractor's design was reviewed, the exact configuration and method of operation was not known, until presented in the field. They never worked to my satisfaction. Therefore, the telemetry was unnecessary and it would

have been better to mount more strain gages on the fabric (redundant gages) rather than use the rod extensometers.

Vibrating Wire Piezometers

- ❖ Although the piezometers would have been useful as an indication of the degree of consolidation that had occurred; i.e., data showing dissipation of excess pore pressure as the consolidation process proceeded, the gauges didn't work. I know that the method of installation was in accordance with the "shop drawing" submitted by "GeoComp" because URS reviewed the submission and I know that the shop drawing was in accordance with the sample installation method published in Slope Indicator's Manual. However, ever since this disappointment developed, I have tried to get to the bottom of the problem and just this week, after talking to many friends/acquaintances/experts, I came across an engineer who has licked the problem by use of total cement-bentonite grout rather than a sand pocket around the piezometer.
- ❖ I would want to learn more about this and see if other "experts" agree, but it looks good on paper. (Paper attached.)
- ❖ So if we, and our installation contractor had known more about this modified installation method, the piezometers may have worked.
- ❖ Once again the electrical leads terminating in the readout box would have been sufficient and the telemetry could then have been eliminated.

Magnetic Extensometer

- ❖ These were useful in pinpointing the seat of settlement, that is, what layer/layers were producing the settlement.
- ❖ They worked well, but fewer would have been sufficient.

Settle Monitor

- ❖ Until such time as this device is tested and developed as an accepted method by the profession, I would not use it. I believe we got hustled!

DMP's

Type 1 (at the bottom of the wall)

- ❖ These worked well and clearly indicated direction and magnitude of the settlement at the toe of the wall. They were read like settlement points/plates.

Type 2 (on the wall)

- ❖ These never produced the data that was expected; that is, the plumbness, tilt or buckling of the wire faced wall.
- ❖ I believe that the only way that these points could have been useful was if they were mounted directly to the wire mesh.

- ❖ For our purposes, a detailed visual inspection on a reasonable schedule would have been useful for checking buckling and readings from a plumb line hanging from the top of the wall would have sufficed for plumb/tilt.

The Website and Data Posting Procedure

- ❖ The WWB website was great and worked well particularly since so many people were involved in the project.

A - WR&A

B - Their Consultants

1 - Barry Christopher (traveling or in his office)

2 - Dov Leshchinsky (traveling or in his office)

3 - Victor Elias (traveling or in his office)

C - FHWA

D - MD SHA

E - The Contractor

F - PCC

The I Site

- ❖ I don't believe that the I-site with telemetry was useful. The data could have been obtained from the readout stations and put on the WWB website like other data was.

Dan Sajedi
MD SHA
02/04/04

Following are my comments for the lesson learned with the use of instrumentation for the MA-1A contract.

Discrepancy in the settlement plates reading due to the change in survey crew or the selection of the temp.bench marks.

Many damages to the instrumentations were observed.

Compaction controls were not maintained around the inclinometer and the settlement plates.

Strength confirmation using the VST was not a successful operation.

If the temp. Changes were adjusted in the settlement plate or the inclinometer readings.

How often the measuring devices for the inclinometer and others were calibrated.

The minimum interference to construction and access difficulties was not followed for the project which caused many damages to the in-place instruments.

Strain gages installed at top and the bottom of the high strength geotextile was not a cost effective measure.

The settlement profiler did not provided a measurable data.

The vibrating wire piezometer did not provided reasonable information. The lack of data may deal with the installation procedures or the type of the selected piezometer .

The information developed with the use of the extensometer was not fully useful tool in the settlement predictions for this project.

Few of the inclinometers was shear at relatively deep due to the deep seated failure. In event if larger horizontal movement is anticipated we may require another instrument to better with higher reliability to predict the settlement.

We may require more automatic data acquisition to minimize the physical labor to collect the data.