Geotechnical Instrumentation NEWS

Geotechnical Instrumentation News

John Dunnicliff

Introduction

This is the thirty-seventh episode of GIN.

Strut Load Measurements with Vibrating Wire Strain Gages

There have been three previous articles in GIN on this subject, in 2000 and 2001. Here's an additional contribution, by Hashash and Marulanda, which references the previous three. The current article teaches us about the importance of taking account of variations in the strut-wall-soil stiffness if the accuracy of earth load determinations is to be maximized.

Another Update on Grout et al

In the previous episode of GIN I gave an update on four items relating to sealing instruments in boreholes, and indicated how you can get hold of two publications. The first is on backfilling borehole with grout, the second on installation of piezometers in boreholes by grouting the entire borehole, i.e. no sand and no bentonite seal.

The third item, lab testing of cement-bentonite grouts to determine strength, permeability, compressibility and volume stability, is underway. We hope to have results in the next episode of GIN.

The fourth item, lab testing of bentonite chips and pellets, to determine which are most suitable when they are used for sealing piezometers in boreholes, is included in an article by Tyson Kaempffer in the following pages.

International Symposium on Field Measurements in Geomechanics, 15-18 September 2003 in Oslo, Norway (FMGM-2003)

If you weren't there, you missed an exciting few days. Our Norwegian hosts excelled themselves with their organizational skills and their hospitality. The combination of technical and social interaction truly hit the spot.

105 papers were accepted for the proceedings, written by just over 300 authors and co-authors from 27 different countries. The topics of the papers covered a wide spectrum within three main themes:

- Case studies with a story to tell, or a lesson learned about the role of field measurements
- State-of-the-art and trends in measurement technology
- Planning, administration and quality assurance of monitoring programs

A novel and successful format was adopted for the technical sessions. 24 papers were selected for presentation, in five sessions. After each of the five sessions there was a "Meet the Authors and Their Papers"(MAP) session. Each of the 105 papers was summarized by the authors on a single page, and these

Norwegian Geotechnical Institute's Vibrating Wire Strain pages were enlarged to a uniform format by the Organizers to become posters, which were then displayed in logical groups around the same room in which the technical session were held. At each MAP session about one fifth of the papers were displayed, and authors were asked to stand in front of their posters and interact with whoever came along. This created an excellent and relaxed atmosphere for technical discussion, and is well worth considering for other geotechnical symposia.

Among the many events that stick in my memory, three had maximum impact (or perhaps I should say had the strongest glue!). In chronological order:

First, a presentation by Elmo DiBiagio of Norwegian Geotechnical Institute, Chairman of the Organizing Committee extraordinaire. During the opening session he entertained us with a presentation titled "A Tale of Two Instruments". He gave specifications for a good vibrating wire strain gage, and then explained that he had twelve in front of him, arranged so that we could hear the vibrations. A keyboard was attached to the gages (see the photo), and a colleague played Auld Lang Syne to great applause. Next, Elmo gave a much less comprehensive specification for a different kind of vibrating wire instrument, and then invited a violin and piano duo to play three short classical pieces, to yet more and sustained applause. His conclusions:

- **We can specify as much as we want, but it's the performance that matters.**
- **We need to define what we want an instrument to do, and then to use it only for the purpose for which it was designed.**
- **The violin is a much better instrument for playing music than the vibrating wire strain gage.**

Second, the invited lecture by Ralph Peck, titled "The Power of Observation". Here it is, immediately following this 'column', transcribed just for you.

Third, the presentation by Tony Simmonds, International Projects Manager for Geokon, during the symposium banquet on the last evening. Tony was asked to speak on behalf of the sponsors of the symposium, many of whom were also exhibitors. Among his points, having polled the other sponsors:

- **The sponsors welcome the fact that FMGM provides a symposium where academia is not the leading partner. Instead, it provides a level playing field where research institutes can exchange information, and a place where manufacturers and users have the opportunity to try to establish some common rules and standards that may ultimately be of benefit to us all.**
- **All the sponsors agreed that they were pleased to be present and would attend the next symposium in four years. Some sponsors expressed a wish to involve more clients, while others indicated a need to introduce some younger blood into the fold.**
- **But the main observation, shared by most sponsors, was that they felt there could be more communication within the present FMGM community, between project owners, users, research institutes and manufacturers: there still seems some distance between all these parties. Ideally there shouldn't be an "us and them" attitude, instead we should try to adopt an 'everyone needs everybody else' philosophy.** ***[He then demonstrated this last point by asking to stand - in turn and with applause - the symposium organizers, the spouses and significant others, the designers, the consultants, the instrument installers, the universities, the research organizations, the manufacturers, and everybody else].***
- **The sponsors believe that the FMGM community is strong and with everyone's help will continue to grow and be successful, concluding with an old saying, "we will not labor in vain unless we plan to fail."**

Ralph Peck (at right) in the Terzaghi Library at Norwegian Geotechnical Institute during FMGM-2003. His son-in-law, Allen Young, is on his right.
Photo by Björn Möller.

The next FMGM will be in USA in 2007. Watch this space, and follow the FMGM website, *www.fmgm.no.*

Closure

Please send contributions to this column, or an article for GIN, to me as an e-mail attachment in MSWord, to *johndunnicliff@attglobal.net, or by fax or mail: Little Leat, Whisselwell, Bovey Tracey, Devon TQ13 9LA, England. Tel. and fax +44-1626-832919.*

Huli Pau! (Hawaii). "To curl over", as with breaking wave. Thanks to Bobbi Daugherty for this.

RST Ad - 4 colour

full page

pick up from page 45
of September 2003 issue of GN

The Power of Observation

Ralph B. Peck

The following is a transcript of an invited lecture given on September 16, 2003 during the opening session of the Symposium on Field Measurements in Geomechanics in Oslo, Norway.

The full title of this talk is really "The Power of Observation, Before, During, and After" with the word "construction" understood. "Observation" has slightly different meanings in the three time periods.

Terzaghi provided me with one of the best examples in the first category, although it was not strictly before construction. In the early days of World War II, when the United States was not yet a participant but was devoting much effort to becoming the "arsenal of democracy", there was a mandate to double its steel-production capacity. Nearly every steel plant was designing and constructing a new facility. One of these was being designed by the Republic Steel Corporation in the south end of Chicago. Although the Chicago Subway work was closing down I was still employed on the project, but several of my associates had already left and some were working on the design of the new steel plant. They held evening meetings that I attended in connection with the foundations, and at one of these meetings I was asked if I would go to Cleveland where the company was building another plant on the Cuyahoga River and had run into some difficulties with the pile foundations for their ore-storage facility.

As you probably know, much of the iron ore used in the United States comes from the north side of Lake Superior and is shipped in large ore boats to the steel plants in Illinois, Indiana, and Ohio. The transport is very economical, but because the Great Lakes freeze over in winter, enough ore must be accumulated in the summertime to last through the winter. So every steel plant has an ore yard adjacent to a dock parallel to the waterfront that usually consists of a pair of high retaining walls between which enough ore can be accumulated to provide for the winter. These are large structures, heavily loaded, that tend to slide toward the ship channel. They are almost always supported on piles.

So, I arrived in Cleveland, found the piles being driven, and also found that the Raymond Concrete Pile Company was making borings and obtaining samples like those we had been obtaining in Chicago. I watched the pile-driving, felt the samples and, as we were accustomed to do in Chicago, estimated their unconfined compressive strengths, which I judged to be about 0.6 ton/sq. ft. It was not difficult to conclude why the piles were not adequate; the piles consisted of steel pipes, each with an enlarged base established at about mid-thickness of the clay layer. Obviously, the piles needed to extend to the hard material under the clay, where they would not need the enlarged pedestals. That recommendation seemed obvious, but it appeared to me that there was a strong likelihood that, under the weight of the ore, the dock wall and retaining structure would slide into the river. So when I returned to the office, I made a back-of–the-envelope calculation, using my estimate of the undrained strength of the clay, and came out with a factor of safety of about 0.6. When I reported this to the chief engineer and explained the calculation, he nodded his head gravely and asked, "What do you propose we do about it?" I could reply only, "I don't know — call Terzaghi," and then went home.

They did call Terzaghi. He came the next week, went through the same routine I did, felt the clay samples, told the client to use the long piles, and said he was concerned that the ore pile might fail. Only then did they tell him they had consulted me, and that I had said the same thing. But then Terzaghi went on the say, "However, there may be some hope. When I first looked out across the valley where the steel mills are, I noticed that the valley is surrounded by bluffs of sand. The sand must have been deposited as the delta of the river and must have covered the whole area. The bluffs must be underlain by the same clay that exists under the steel plants. I looked around the base of the sand bluffs and didn't see any signs of instability. The bluffs, about 100 feet high in sand weighing, say, 120 lb/ cu ft, are roughly equivalent to 60 or 70 feet of iron ore at 160 lb/cu ft." His suggestion was to set up an observational program to measure movements, loads, and pore pressures, and to proceed with the planned loading with care. This was done; it was found that in the initial years the last loads began to cause movements, but over the succeeding years consolidation improved the clay appreciably

Terzaghi and I had looked at the same valley, the same evidence. How he interpreted the evidence made the difference. Indeed, I sometimes think Terzaghi, in his first visit to a site, took pleasure in trying to deduce what problems and solutions might be found, even before the first boring was made.

The power of observation during construction is nowadays widely appreciated. To you in the instrumentation community this hardly needs comment. In only one regard do I have some concerns.

Instrumentation to control the effects of construction, especially of open excavations and tunneling, can be quite elaborate, and the quantity of data can be daunting. This has led to widespread use of the "traffic-light" analogy — to establishing in advance the limits of movements or other quantities that are satisfactory (green), of possible concern (yellow or amber), or excessive (red), requiring a halt in construction until remedies are applied. With the large masses of data that can now be obtained, displayed electronically, and observed in an office possibly remote from the action in the field, there is a danger of missing some vital clues to adverse behavior. We should not wait to analyze occurrences until a reading is in the "amber" zone. The first, perhaps most significant, observations that should be carefully analyzed, are often in the "green" zone. The small movements that may be noted, for example, should be carefully correlated with construction activity, so that the consequences and causes of larger movements can be judged in timely fashion if they occur.

Finally, there are observations to be made after construction is over. These are particularly significant in evaluating the long-term behavior of earth dams and in monitoring landslides. Here, although instrumentation plays a significant role, the appearance of apparently unmotivated change are often the first sign of distress. Observations of over-all phenomena become more relevant than "spot" occurrences. Measurements of flow or appearances of new springs, for instance may be more revealing than piezometric data from discrete, but maybe not the most indicative, instruments.

Perhaps something can be learned from Arthur Morgan's hydraulic-fill dams of the Miami Conservancy District, built after the devastating flood in Dayton, Ohio, in 1913. Each dam has a grassed downstream slope, each slope is mowed by the dam's caretaker, and each caretaker lives in a house on the downstream side of the dam. Deviations from normal behavior, correlated with disturbing factors such as unusual precipitation and the like, become increasingly valuable in the hierarchy of field observations.

Temperature Correction and Strut Loads Interpretation in Central Artery Excavations

Youssef M.A. Hashash
Camilo Marulanda

Introduction

Vibrating wire strain gages can be an excellent tool to monitor the behavior of struts during construction. However, analysis of data obtained from the gages is difficult due to a) errors in the collected data set, and b) temperature changes during the measurement period. Great care has to be exercised during the data collection process to minimize the number of erroneous measurements. The calculated load in a strut consists of two components: a) load transferred from the retained soil through the supporting wall, referred to as earth load, and b) load induced by temperature change in the strut referred to as thermal load. Quantifying each of these load components is important for understanding the earth pressures acting on the support system and for estimating additional thermal loads that a strut experiences due to temperature change.

Thermal Load Calculation Procedure

Several articles in GIN have focused on interpretation of strain gage data (Boone and Bidhendi 2001; Boone and Crawford 2000a; Druss 2000). Readings from strain gages on struts, typically taken several times each day, give the change in strain reading due to incremental temperature changes. As the temperature increases, the partially restrained ends prevent the strut from moving and the load read by the gage increases. As the temperature decreases, the strut is free to contract and the soil is allowed to rebound. These movements and changes in load are generally small and the system is assumed to be linear elastic (O'Rourke and Cording 1974). Boone and Crawford (2000b) identify this linear-elastic behavior in the field by plotting incremental changes in load (ΔP_i) versus incremental changes in temperature (ΔT_i). A best-fit plot results in a straight line through the origin with slope *m*. The *m* coefficient is representative of the stiffness of the strut-wall-soil system and is referred to as the thermal load coefficient. All the previous studies use a constant value of *m* independent of the excavation configuration.

Thermal load Coefficient Dependence on Construction Stage

The variation of *m* coefficient with excavation stage is investigated using a simplified numerical model of the excavation (Hashash et al. 2003). The results show that the *m* coefficient is not constant and generally decreases with increasing excavation depth and addition of cross-lot bracing. The construction-stage dependent temperature correction procedure is applied to the struts of section PS-09 in Contract C11A1 of the Central Artery/Tunnel (CA/T) Project in Boston, Massachusetts. The incremental change in load (ΔP_i) is plotted versus the incremental change in temperature (ΔT_i). The *m* coefficients are determined for time periods between significant steps in the construction sequence (i.e. installation of subsequent struts) with a maximum time limit of 30 days. Figure 1 shows the computed construction-dependent *m* values for all struts. In general, m decreases with increasing excavation depth and is dependent on the construction stage.

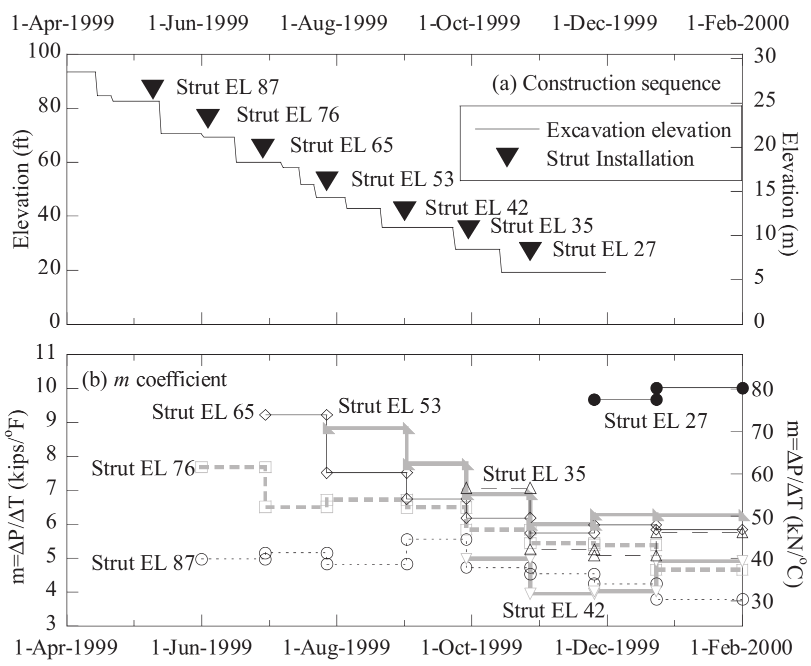

Figure 1. Construction-stage-dependent m coefficient calculations, all instrumented struts, Section PS-09.

Earth and Thermal Load Interpretation from CA/T Strut Measurements

Earth and thermal loads for the CA/T struts are computed using both a single *m* coefficient throughout the excavation sequence and the construction-sequence-dependent *m* coefficient. The earth loads based on variable *m* coefficients are generally less than the single *m* earth loads at the beginning of the construction sequence and greater than the single *m* earth loads for the end of the construction sequence. This difference is due to the decrease in *m* with increasing excavation depth. The difference in computed earth load is as large as 30%.

Details of the study can be found in a recently published article by Hashash et al. (2003).

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Update on Bentonite Chips and Pellets for Sealing Piezometers in Boreholes

A. Tyson Kaempffer

Abstract

Bentonite chips and pellets are widely used products for sealing piezometers in boreholes. Inherent with these products are their potential to become lodged above the intended depth – this is known as bridging. A testing apparatus was created to simulate borehole conditions for investigating the settling velocity and the point of adhesion of bentonite chips and pellets. It was discovered that ¼-inch uncoated pellets have the greatest potential to bridge at shallow depths, and are not recommended. Large pellets and especially coated pellets performed the best and are recommended for deeper installations. Chips would perform well in shallow installations provided they are sieved to remove any dust and broken pieces. Rate of placement is important, as the uncoated material has a tendency to clump, increasing its potential for bridging. Clumping is the act of chips or pellets adhering to one another. Coatings placed on pellets greatly aid in reducing this clumping effect. All tested products were found to seal the borehole adequately, however certain products were superior, creating stiff impervious seals with reserves of unsaturated bentonite. These seals were still plastic enough to seal around duplex pneumatic tubing, eliminating any vertical hydraulic short circuits between the tubing and the borehole wall.

Introduction

Mikkelsen (2002) and Mikkelsen and Green (2003) discuss the installation of diaphragm piezometers in drilled boreholes using the fully-grouted method. This method involves filling the entire borehole with a carefully selected bentonite-cement grout, i.e. no sand around the piezometer and no bentonite chips or pellets.

While the fully-grouted method has good merit and is likely to be accepted by many engineers as the best method of installing diaphragm piezometers, the market may not be ready to accept this practice universally. In light of this, a review of the performance of bentonite chips and pellets has been made.

Bentonite Chips and Pellets

Bentonite is a naturally occurring clay mineral, consisting mainly of sodium montmorillonite. Montmorillonite, a member of the smectite clay mineral group, contains interlamellar surfaces and cations that can be readily hydrated and dehydrated (Papp, 1996). This gives bentonite the ability to readily absorb water and swell up to 10 to 15 times its dry volume. The majority of sodium bentonite originates in Wyoming, however sizable deposits of calcium bentonite occur elsewhere in the world. Bentonite chips are irregularly shaped chunks of raw-mined sodium montmorillonite, which has been mechanically separated into different sizes. Bentonite

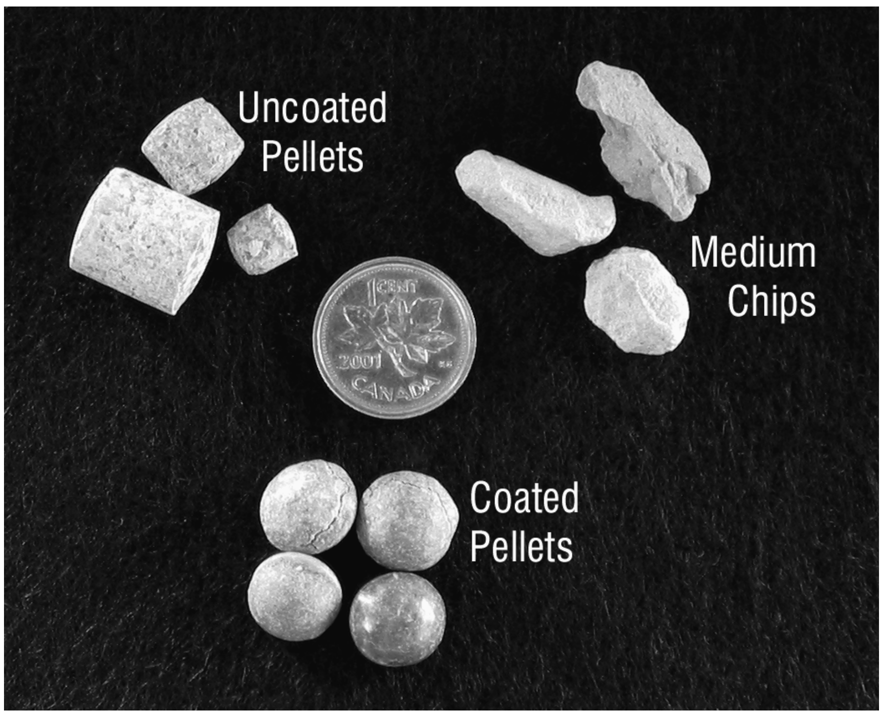

Figure 1. Various forms of bentonite products used in this testing program (penny included for scale).

pellets are formed by high-pressure compression of bentonite powder into small-diameter cylinders or tablets. Bentonite chips and pellets are shown in Figure 1.

Tested Products

The following products were tested.

Bentonite Chips:

Brand	Coated or Un-Coated	Size
Baroid Hole Plug	Un-Coated	3/8”
Cetco Pure Gold Chips	Un-Coated	3/8”
Wyo-Ben Enviroplug	Un-Coated	3/8”
PDSCo Bentonite Plug*	Un-Coated	3/8”

Bentonite Pellets:

Brand	Coated or Un-Coated	Size
Baroid Bentonite Pellets	Un-Coated	1/4”
Cetco	Coated	1/4”, 3/8”
Cetco Volclay	Un-Coated	1/4”, 3/8”, 1/2”
PDSCo Pel-Plug TR30*	Coated	1/4”, 1/2”
PDSCo Pel-Plug*	Un-Coated	1/4”, 3/8”, 1/2”
Wyo-Ben Enviroplug	Un-Coated	3/8”
Wyo-Ben Enviroplug	Coated	3/8”

* Note that these products do not originate from Wyoming.

Bridging

Bridging is defined as the lodging of chips or pellets above their intended depth. This process begins when the bentonite has hydrated sufficiently enough to stick to the sides of the borehole or to the piezometer pipe, tube or cable, or to each other before reaching their intended depth. In order to test various bentonite products for bridging potential, a transparent pipe with removable sections and valves was constructed as shown in Figure 2.

Bentonite products were tested both with and without the presence of duplex pneumatic tubing. Duplex pneumatic tubing consists of two individual plastic tubes set in a polyethylene jacket. This tubing was chosen for its large size, which presents a significant potential for interference with the falling bentonite pieces. During the course of the testing program, none of the products completely bridged the test pipe, however several showed the onset of bridging. Had the test pipe been longer than 3 metres, bridging may have occurred. Samples which showed the most severe bridging were ¼” uncoated pellets. Without the pneumatic tubing, an average of 5-10 pellets per run would adhere to the smooth walls of the PVC pipe. Once the pneumatic tubing was introduced into the system, the uncoated ¼” pellets began to wedge between the side of the pipe and the tubing (Figure 3). In one case, a significant amount of material began to bridge at the base of the tubing (Figure 4). The pellets were sticky enough that they remained stuck to the pneumatic tubing even upon the removal of the tubing from the testing apparatus. Despite this onset of bridging, the bulk of the product still made it to the bottom of the apparatus and sealed the system.

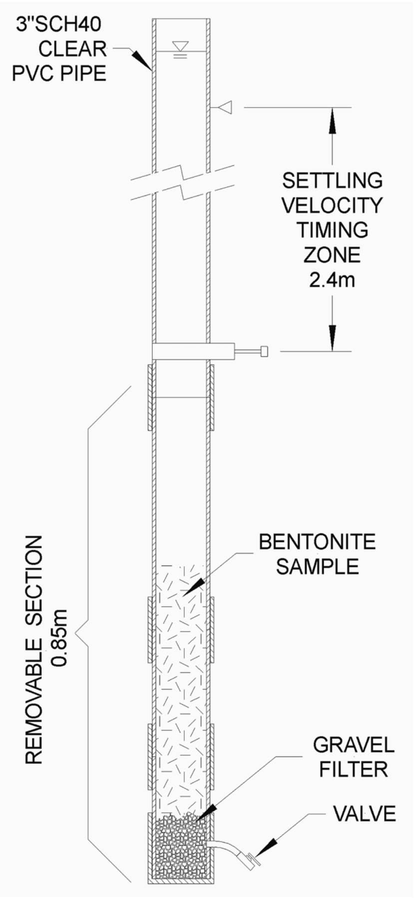

Figure 2. Bentonite test apparatus

¼-inch uncoated pellets performed the worst because they became sticky almost instantaneously upon contact with water. They are less dense than chips, which allows infiltration of the water into the pellet at a higher rate, thus allowing them to swell faster (resulting in their increased stickiness). The cylindrical shape of the pellet also lends itself to bridging as it has a larger contact surface than a chip with which it can stick to the borehole wall or to other pellets. Some of these stuck pellets would hydrate to the point where the weight of the pellet overcame its adhesion, resulting in a timed release from the side of the tube. The size of an uncoated pellet has a major role in its ability to stick and remain stuck.

In contrast, the coated pellets performed very well, with none of them sticking to the sides of the pipe. All reached the bottom of the test apparatus

Figure 3. Onset of bridging with ¼" uncoated pellets.

and sealed it.

None of the bentonite chip samples stuck to the walls of the pipe to a significant degree and none showed the "wedge" effect (Figure 4) in the presence of the pneumatic tubing. Chips and coated pellets are therefore less likely to bridge than ¼" uncoated pellets.

To define at what point the bentonite products becomes sufficiently sticky to adhere to the sides of the borehole, a series of tests were performed in 400mL beakers (Figure 5).

A hole was drilled through each sample, and these were suspended in a beaker of water. A polyurethane coating was applied with a small brush around the edge of the hole. This was done to prevent water from hydrating the sample through the drilled hole in an effort to represent true swelling. The samples were gently and repeatedly pulled into contact with the smooth wall of the beaker until they adhered.

In order to determine the settling velocity of bentonite chips and pellets, 20 pieces of each product where timed as they fell through the "settling velocity timing zone" as shown in Figure 2. The velocities were averaged, and combined with the results of the adhesion test to produce Figure 6.

As highlighted in the plot, the ¼" uncoated pellets become sticky the fastest and one sample in particular had a low settling velocity which further increased its probability of bridging. Chips performed somewhat better, and larger uncoated and coated pellets per-

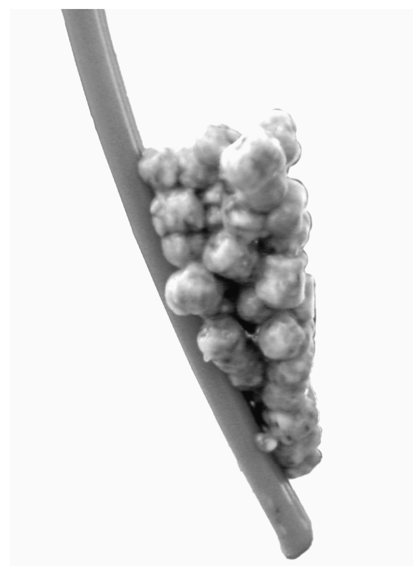

Figure 4. Onset of bridging at the base of the pneumatic tubing.

formed the best having relatively higher settling velocities and longer times to adhesion (note log time scale on plot).

It is proposed that the depth at which bentonite products can successfully be placed may be determined by combining the results presented in Figure 6. Therefore, multiplying the time to adhesion by the settling velocity yields the depth at adhesion. This is the depth at which the sample is sticky enough to adhere to the borehole wall (Figure 7).

By this method, uncoated ¼" pellets have the greatest chance of bridging within the first 10 metres of a borehole. Bentonite chips could bridge at depths of 20 to 30 metres and the larger sized uncoated and all coated pellets present a much lesser risk of bridging. Therefore, provided there is enough annular space to physically fit the larger sized pellets, these products perform well.

Additional Thoughts on Adhesion and Bridging

The results presented in Figures 6 and 7 may be conservative, because the time to adhesion was determined under static conditions. In reality, the bentonite will be falling through a water column and its momentum would reduce its tendency to adhere to the borehole wall and/or the pneumatic tubing. Therefore the depth at which bridging would occur could be somewhat deeper than indicated.

Rate of placement is an important factor when placing granular bentonite.

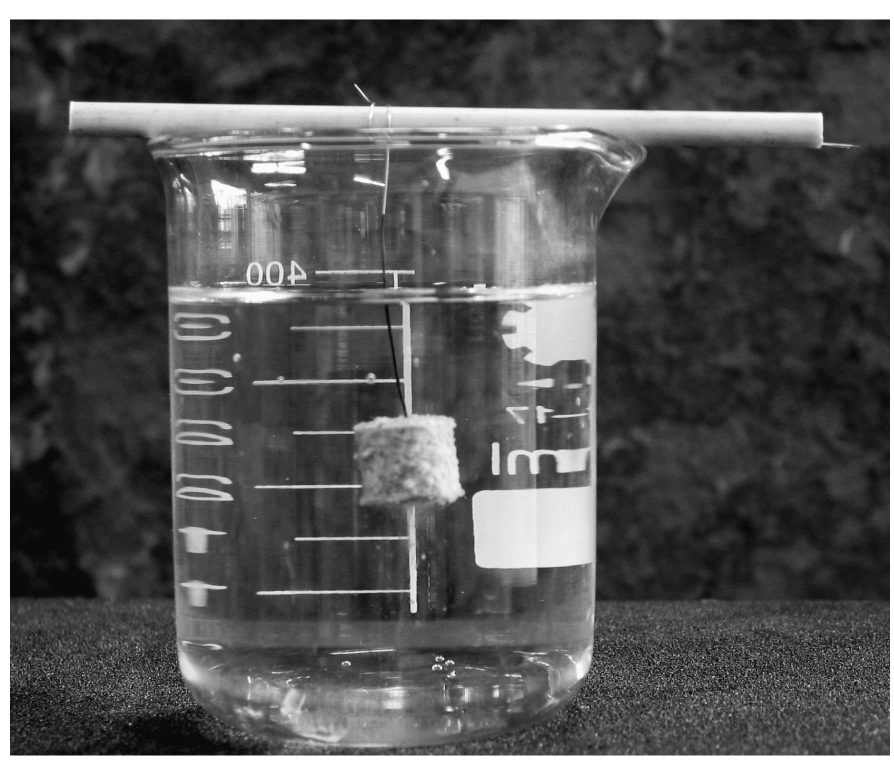

Figure 5. 400mL beaker used to determine the time to stickiness of bentonite. Stickiness was measured by recording the time at which the sample was able to stick to the side of the beaker.

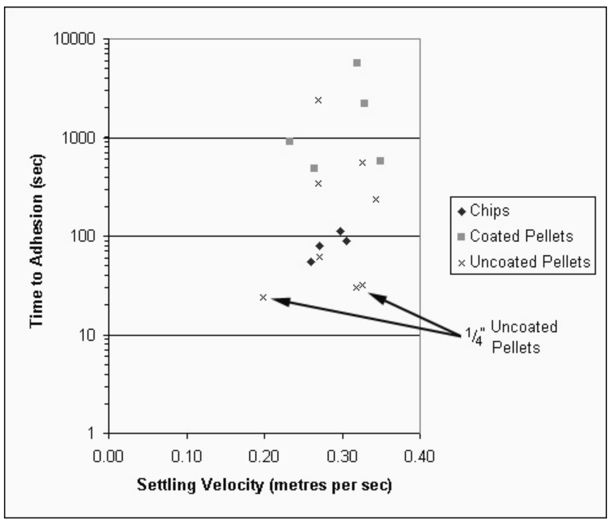

Figure 6. Settling velocity vs. time to adhesion

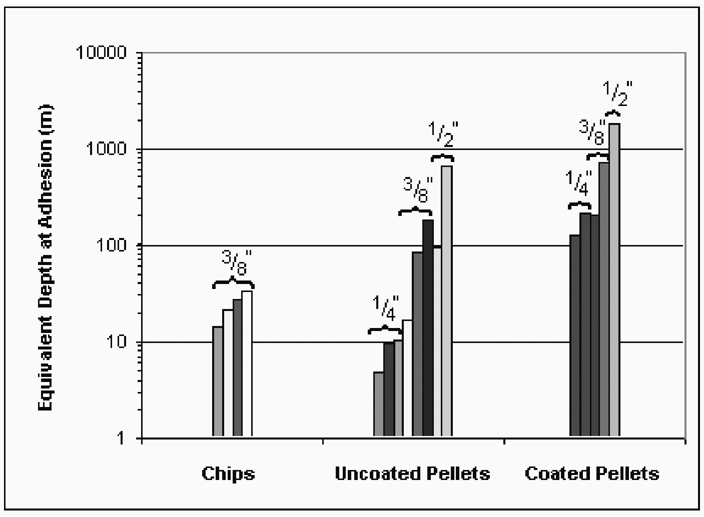

Figure 7. Depth at adhesion

Even in the short 2.4 metre length of the "settling velocity timing zone" in the test apparatus, clumping of the material was observed in one brand of chip and the uncoated pellets. None of the coated samples showed this behavior. Anytime this occurs, the chance of the material bridging is greatly increased. In a real borehole situation, this effect could be much worse due to the larger depth.

Clumping tended to occur at a greater frequency for those samples that became sticky rapidly upon contact with water, and those that had slower settling velocities. Hydrodynamics play an important role. As the product is added to the water, the first pieces of bentonite are subjected to friction effects due to the viscosity of the water. They create a parting wake behind them that allows the following bentonite particles to accelerate and come in contact with them. If at that point, the particle has hydrated enough that it has become sticky, the particles will clump together. The increased mass and surface area of the clumped particle increases the friction and the size of the wake and encourages other particles to adhere to it. Therefore, if the product is poured in at a slower rate, this effect could be reduced.

The fine dust that is unavoidably mixed in with the chips and pellets can make conditions increasingly sticky, which can lead to bridging. Significant dust was observed even in the small (1.5L) sample sizes used in these tests (chips and uncoated pellets were the worst). In several cases there was enough mulch to make the water opaque. Often the dust is not the result of the manufacturing process, it is an inevitable occurrence due to transport of the product. The dust increases the viscosity of the water, slowing the rate of fall of the product and any smaller (broken up) particles in the sample tend to stick more readily to the sides of the pipe. Sieving the bentonite before placing it in the borehole is always a good practice.

Not only is it important to sieve the bentonite, but also care must be exercised in the type of sand used to create the filter zone around the standpipe piezometer tip. Fines in well-graded sand may remain suspended for substantial periods, reducing the settling velocity of the bentonite product. It is therefore recommended that engineered sand (e.g. Ottawa sand) be used to reduce the amount of suspended particles.

Seal Integrity

All the tested products effectively sealed the test apparatus in a period of less than two hours. A differential head of approximately 0.85 metres was used to obtain this seal time (see Figure 2, removable section). It was discovered that the ¼" uncoated pellets sealed the fastest, however this is really inconsequential, because these products have the greatest propensity to bridge. Nearly all of the samples formed plastic, impervious seals with large reserves of unsaturated bentonite. The exceptions to this were products that did not originate from Wyoming. The seal formed by these products was highly saturated and relatively weak.

An additional test was performed to evaluate the sealing performance of bentonite products within the space between two duplex tubes. Concern has been expressed regarding the adequacy of bentonite seals in the interstices between pipes, tubes or cables or at the interface between these and the wall of the borehole. If the bentonite product is not fluid enough, it will not adequately seal at these interstices and interfaces, creating a hydraulic short circuit.

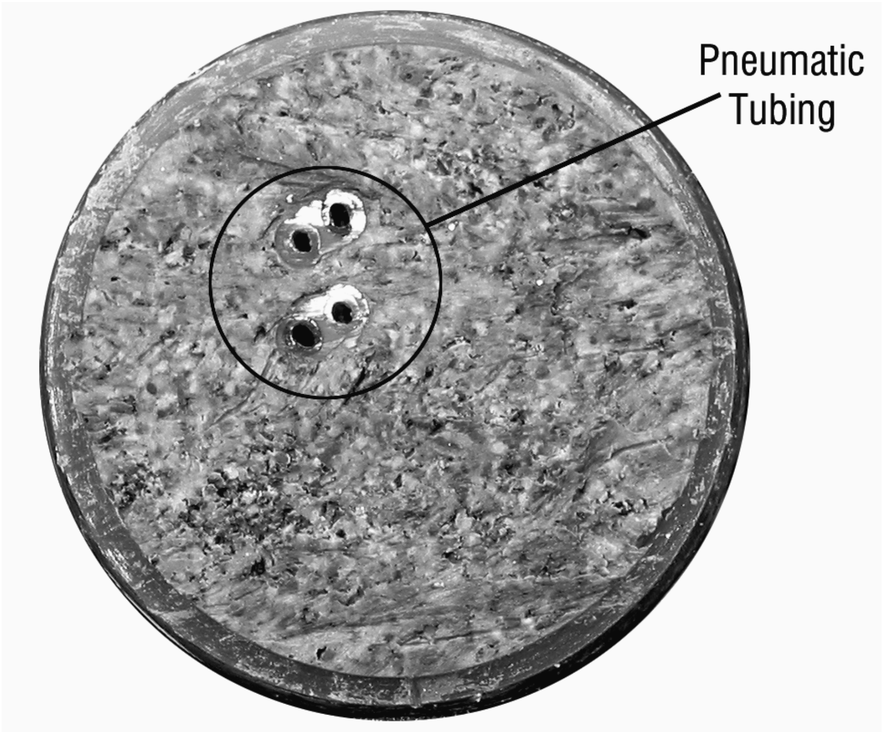

Figure 8. Cross section illustrating the seal around two sets of duplex pneumatic tubing

Figure 8 reveals how the bentonite was fluid enough to seal in between the two sets of tubing and create an effective seal (Cetco ¼" pellets shown in figure). Even in a section where the tubing was lying directly along the inner wall of the PVC pipe, the bentonite adequately sealed the section.

Limitations of Testing Program

Inherent with this testing program are a number of limitations that must be identified.

The testing apparatus only approximates field conditions. In reality, an actual borehole will be significantly deeper, and have permeable, irregular walls, which will encourage bridging. Total volume of each sample was kept to a constant 1.5 litres. More bentonite product is typically added to a borehole (for a 3-inch diameter borehole, a 3-foot depth of bentonite seal corresponds to just over 4 litres of volume), significantly increasing the amount of dust and broken particles which promote bridging.

The results of the bridging tests where influenced by the positioning of the pneumatic tubing in the test apparatus. The position of the tubing could not be kept constant from sample to sample. Several runs of a single brand of bentonite product yielded one run that bridged significantly, while the others did not. In some cases the test was repeated three times and the material would not bridge the way it did during the first run.

- The time to adhesion tests were taken with the samples in a static position and therefore the results are quite conservative. Falling bentonite pieces have momentum, which works against their chance of adhering to the borehole wall, even if they are sticky enough to do so.

The water used in for the testing was ordinary tap water from Vancouver, B.C. (average pH = 6.8). Different pH levels of groundwater can have a significant affect on the swelling properties of bentonite and all manufacturers of bentonite products recommend that their product be tested overnight in sample water before using it in the field. This gives the user a better idea of how much the material is going to swell, and therefore how much product will be needed to seal the borehole. Further investigation into the effect of pH on the swelling of bentonite could be beneficial for determining the ability and time it takes each product to seal adequately.

Conclusions

Various brands of bentonite chips and pellets were tested to investigate their behavior. Primary focus was placed on the settling velocity and amount of time it takes the material to become sticky enough to adhere. It is clear that bridging can be a problem. Large pellets and especially coated pellets performed by far the best, having the best immunity from bridging due to their weight and longer time to adhesion. ¼ -inch uncoated pellets cannot be recommended for free-drop in a borehole. These products would perform better if placed in a screen pack and placed at their intended location.

Any method for minimizing dust and broken chips/pellets should be used. Even with the small sample sizes (1.5L), significant dust was noted in the system for several products. Excessive dust in the water increases its viscosity slowing the rate of fall and increasing the chance of bridging. Given the price differential, chips may be preferred to uncoated large pellets, provided the dust is removed.

Hydrodynamics control the rate of settling of the bentonite. Irregular shaped bentonite chips have a slightly slower settling velocity than uniformly shaped pellets. The settling velocity of the coated pellets is the fastest due to their smooth sides and they tend to not clump together, giving them a greater chance to reach the proper destination without bridging. Chips should perform well in shallow installations provided they are placed at a slow enough rate to avoid clumping of the material. Large coated pellets are generally excellent and preferred for deep holes and automatic placement.

Time to seal was not an issue with the water being used (pH ~6.8), as most of the products were able to seal the system in under two hours, which is more than adequate for most field installations. It was noted however, that products originating from Wyoming had better sealing characteristics than those from elsewhere. These products created a stiff impervious seal with significant unsaturated bentonite. This allows the bentonite to conform to the sides of the borehole and be able to expand and contract in response to changing ground conditions.

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Canamara (Wyo-Ben) *www.canamara-united.com*

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