

ARTIFICIAL GROUND FREEZING: STATE OF THE PRACTICE

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ABSTRACT

This keynote paper is a tribute those devoted to the practice of ground freezing. I use the term “freeze guy”, but it is not gender specific. A discussion of some of the legends in AGF is included. I’m sure I’ve missed a few, but these individuals had a great impact on my career.

KEYWORDS

Artificial ground freezing, ‘freeze guys’

INTRODUCTION

To fully understand the state of the practice, I believe it is necessary to contemplate where we started to fully appreciate where we are today. The ground freezing engineer or practitioner entering the field today may not fully appreciate the advancements in the state of the practice over the last 40 years. Forty years is a reference point for when I first became involved in ground freezing. Very early in my career, a German engineer told me that I would learn something new on every ground freezing project I would work on. I would like to add that I would learn several new things. To discuss the state of the practice without describing what it used to be like would deprive the readers of the benefit of experiences that ultimately lead to our current state of technology and methods.

The state of the practice could easily be described in terms of equipment, instrumentation and monitoring, and engineering design and analysis. A lot of the improvements in these categories were brought about by research and development, experiences on projects, and basic human ingenuity. But before getting carried away and celebrating all the changes in forty years, we must also reflect on a few things that have remained constant. I hate to admit it, but on most projects, the freeze pipes still always seem to be about one meter apart, almost always a function of the time a contractor will permit for the freeze to develop. The one thing that has not changed throughout my career is the need for experienced and dedicated field personnel: the drillers, superintendents, and mechanics. As I tribute to those individuals that I have crossed paths with, they will be included in this paper.

In our original preparation, Alan Auld asked me to prepare a paper on the “state of the art” or, as some would say, “state of the practice.” I started to think about that. How exactly do we use those terms? The last symposium was 17 years ago. A lot has changed since then, but many things remain the same. Those terms jogged my memory to something that happened to me in 1980, when I graduated from Michigan State University and started my first job for a geotechnical firm, McClelland Engineers, in Houston, Texas.

Leo

Leo Nothstine was a professor in the Civil Engineering Department at MSU. I had him for several classes and became a teaching assistant in his surveying classes. I kept in touch with him once I left college and shared my experiences during my first year. When I returned from the Mideast, I received a letter from him. In that letter, he wrote, “...instrumentation, precision, equipment and state of the art will change. The importance of people and relationships will not.” *With that in mind, I think it is fair to say that the state of the art is a secondary component to people who implement the state of the art, and I shall address and perhaps honor them within the text of this paper.*

GROND FREEZING LEGENDS (FREEZE GUYS)

The term “freeze guy” popped out of my mouth one day while sitting in a meeting with about 30 engineers and consultants contemplating a massive ground freezing project in Northern Canada. The job would be unprecedented in size and require engineering, equipment, and material resources larger than seemed practical. Of course, the meeting started with the normal go around the table and introduce yourself—you know, name, company, and title. As I sat there contemplating the magnitude of this proposed project, it occurred to me that while everyone else in the meeting had impressive credentials and even more impressive titles, no one had ever been near a ground freezing project. Somehow, over the years, I accumulated a lot of initials after my name that were inversely proportional to the amount of hair on my head. When it was my turn to introduce myself, the title that popped out of my mouth was simply “freeze guy.”

So, who are these legends or “guys” implementing the state of the art? I think it’s fair to say that it is those of us who truly have a passion for ground freezing. If you are reading this paper, I consider you one of those. But if you have any doubt, consider a few “freeze guy” traits that follow. I apologize if some of these are archaic and may no longer apply.

You may be a “freeze guy” if you are convinced that the gradual lowering of the brine level in your reserve tank is contraction as the system cools and not the leak that you will spend the next week trying to find.

You may be a “freeze guy” if you are about to crawl into bed in some remote hotel and just want to go check the job or the freeze plant one more time for the day. You know if you go out and check it, everything will be fine. But if you don’t, something will be gravely wrong in the morning.

You may be a “freeze guy” if you chilled your champagne or beer on the coolant manifold or ran your liquid nitrogen exhaust gas into your cooler.



Figure 1. Celebration

You may be a “freeze guy” if you always pack an extra hydrometer in your luggage because you know the one on the job site is either missing or broken.

You may be a “freeze guy” if your spouse or significant other threatens to leave you because you spend too many weekends running PLAXIS models.

I would like to dedicate this keynote paper to the “freeze guys” who not only had an impact on the ground freezing industry but also on my career. They all introduced me to the state of the practice at given times in my career and different aspects of the technology. Alan Auld’s introduction to this symposium gives well-deserved credit to Professors Jessberger and Klein, whose research and publications had a major impact not only on my career, but on the ground freezing state of practice as we know it. There were certainly others, however, that contributed to the industry through dedicated field work and actually built the projects.

O.B. Andersland

Orlando B. Andersland “Andy” was a professor of Civil Engineering at Michigan State University. Andy was well known for his work in cold regions geotechnical engineering, and among his many publications, the first of three books, “Geotechnical Engineering for Cold Regions”, co-authored by his long-time friend, Branko Ladanyi, Professor of Civil Engineering at Ecol Polytechnique in Montreal, Canada. I returned to MSU in the fall of 1982 to start a graduate program with Andy.

It was in his Cold Regions class that I was first introduced to and fascinated by the concept of Artificial Ground Freezing. Andy is probably most recognized for Chapter 5 of his book, “Frozen Ground Engineering.” In this chapter, he discussed the mechanical properties of frozen ground, specifically creep deformation.



Figure 2. O.B. Andersland

I pursued an additional degree and entered a Ph. D program with Andy, devoted entirely to evaluating creep behavior. Our research at the time truly pushed the state of the art as we worked on computer programs to apply the Finite Element Method to time-dependent creep behavior. Andy saw the incredible potential of the FEM, and what we considered state-of-the-art in the 1980s seems archaic to practitioners today. We wrote our own code on numbered punch cards that we had to take to the computer science center to run the programs on large mainframes and pay unthinkable prices for CPU time.

While these programs truly were the state of the art in the 1980s, then, like now, were only as good as the material properties used in the input. In addition to long nights troubleshooting code, there were just as many nights in the frozen soil laboratory running unconfined creep tests. Data was recorded on a data sheet hanging on a clipboard attached to the loading frame. Andy was a pioneer in our profession. Most of

us still rely heavily on his textbook for reference. I've read chapters of that book many times, and each time, I seem to pick up something new. A little-known fact about that book: if you read closely, in the sections related to arctic engineering, Andy comments on the need to account for climate change in design. These notes go back to the mid-seventies. In those days, climate change evaluation was pure science, demonstrating Andy's brilliance and progressive thinking.

While remembering Andy, my thoughts always go back to our conversation regarding my final year of coursework as his Ph.D. student. I had selected a few geology classes and something related to airport and highway soils (undoubtedly the easiest course in the department). You can almost guess my mind when he came back with different selections. His choices were continuum mechanics, the theory of elasticity, and the theory of plasticity. I was in a state of shock. I just wanted to cruise through my last few semesters. We discussed his choices, and I wasn't winning the argument. I finally said, "Dr. Andersland, I'm not a theoretical person, and I have no intention of teaching at a university. Can you give me one good reason for taking these classes?" His response was, "You'll be a better person for it". I think the jury is still out on that one.

Francis Sayles

I don't think I've ever run into a "freeze guy" who has not referenced the paper(s) Sangar and Sayles once. Sangar and Sayles were researchers at the U.S. Army Corp of Engineers Cold Regions Research Engineering Laboratory in Hanover, New Hampshire. The classic paper, Ground Freezing for Construction, walks a practitioner through all aspects of AGF, focuses intensely on thermal and structural computations, and very simply addresses the safety factor. When this paper was written in 1968, it was truly the current State of the Art, and some may argue that it still is. Very few things have changed or improved the methods of closed-form solutions used in that paper. I can recall several times early (and even now) in my career when numeric thermal and structural models were compared and criticized when compared to Sayles' work. I recall hearing terms like "garbage in, garbage out," "pretty colored outputs that no one understands," "too precise, not practical," etc.

It was almost as if Sangar and Sayles loyalists were offended by anyone altering their approach. But why do I single out Frank Sayles and not Frederick Sangar? Because I met Frank and talked to him on several occasions. Frank was the first one who saw the potential of the numeric models in those days. Particularly when analyzing creep behavior and thermal models with multiple rows of freeze pipes and non-uniform pipe spacing. It should also be noted that in that classic paper, there are no methods to account for including temporary liners. However, there are those of us who will always have some doubt about the output of the models. And real "freeze guys" will always do a Sangar and Sayles calculation on the back of an envelope. Just to be sure.

Bernd Braun

Bernd Braun graduated from college with an engineering degree in 1968 and immediately started a 50-year career in the ground freezing industry. After working on ground freezing project all over the world in his first few years, his company sent him to the United States where helped start the Terrafreeze Corporation in Lorton, Virginia with his colleague John Shuster. Terrafreeze evolved to the Geofreeze corporation and Bernd then joined Moretrench's Freezwall division. John was actually the sponsor of my Ph.D., research and a member of my doctoral committee. I first met Bernd in 1985 when we worked together on projects all over the United States. Bernd was an "engineer's engineer" and we still remain friends. A true legend and certified "freeze guy".

Derek Maishman

Derek was the original "freeze guy" at Moretrench American Corporation. Derek was the face of Moretrench's Freezwall division. Derek started his ground freezing career in the United Kingdom and then moved on to the Canadian potash mines, where ground freezing was used extensively in sinking deep shafts.

Derek was instrumental in bringing artificial ground freezing technology to civil construction projects in the United States. Projects in New York City and Boston pushed the technology to new limits. Derek remained dedicated to ground freezing for his entire life. For the first 26 years of my career, we were competitors. In 2010, when I joined Moretrench, we started working together. Derek was then retired but always managed to come into the office about once a week and would check up on the projects and review the temperature data. When Derek passed away, it was noted at his funeral that he prided himself on the statement, “I never had a failure”.



Figure 3. Derek Maishman

Martin “Dutch” Vliegenthart

When I first met Dutch, he was the General Superintendent for the J.F. Shea Company on the Milwaukee Deep Tunnel Project. Dutch had extensive experience with ground freezing on the Canadian Potash shafts. At that time, after several failures with slurry diaphragm walls, ground freezing was selected as the way to sink over 25 shafts and structures. I had no practical experience then, and as part of my dissertation research, I monitored several shafts for deformation during excavation. I was basically at the mercy of Dutch, a tried and true, hard-core miner who never hesitated to throw his hard hat on the ground and let me know when he didn’t approve of how I was doing things. During twenty years on various projects, we became close friends.

As ground freezing engineers, we get very wrapped up in our laboratory tests, calculations, and numeric models and forget that someone must build the systems. I had the opportunity to be involved at the field level with the drilling, manifold installation, freeze plant operation, and instrumentation. The Milwaukee projects in the mid-1980s were some of the first projects where the state-of-the-art numeric model results were compared to field performance. While Dutch was strictly a field operations man, he was an engineer by training and truly appreciated the changes occurring in ground freezing since the early days of the Potash mines.

The Milwaukee shafts provided unique experiences of what can go wrong with freezing shafts. While constructing three drop shafts, another contractor was mining a large-diameter tunnel in the underlying bedrock. The tunnel boring machine mined into a zone of fractured, highly permeable rock and immediately flooded the Cross-Town Tunnel. They were able to continue the mining while pumping massive quantities of groundwater. This pumping not only led to a drawdown across the entire downtown area but created groundwater velocities that retarded and even prevented the formation of frozen earth structures in the alluvial deposits.

The effects of the velocities were readily observed with shafts that simply would not freeze. Unfrozen shafts were common, but so were the mitigation techniques. They were straightforward: 1) locate the unfrozen zone with temperature profiling, 2) drill and install a second row of grout pipes in the unfrozen zone, 3) pump a cementitious grout, and 4) convert the grout pipes to liquid nitrogen. After two weeks of freezing with liquid nitrogen, the shafts were ready to excavate.

While the above procedures seem straightforward and methodical, only a real “freeze guy” can relate to that sick feeling in your stomach when you show up to the job site in the morning and see your shaft is flooded. At the same time, only the “freeze guys” celebrate and relish in the successful completion of these shafts.

Dutch and I froze several more shafts until 2013, when he retired to his beloved boat, “The Flying Dutchman”.

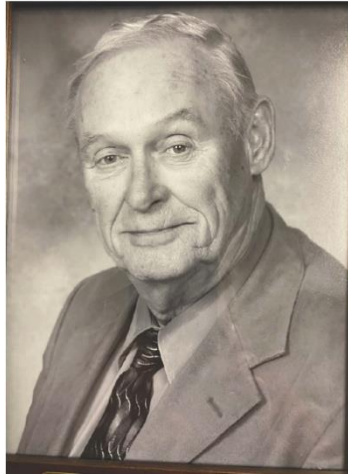


Figure 4. Martin “Dutch” Vliegenthart

Leo Rutten

Leo was one of those behind-the-scenes “freeze guys” that you rarely saw, hardly ever heard from, but would miss his absence. Leo was the freeze superintendent for Moretrench’s Freezewall Division, who started his freezing career on several deep shafts in the Congo. Leo was the master of setting up the systems and running the freeze plants. Leo’s intimate knowledge of each system he put together eliminated the need for much of the high-end instrumentation we rely on today. He could listen to a freeze plant and know it wasn’t running properly. He could look at a freeze pipe and know there was an airlock. Without the benefit of thermal computations or models, Leo could tell you when the shaft would be ready to dig.

Leo lived on the projects. I remember many nights in 2010 when we were freezing a shaft in Milwaukee. I would come to the job site around 9 p.m. with hot coffee. Leo was always in his little shop, wire brushing equipment, or simply walking the site. There seems to be a line of thinking that “Leos” can be replaced with “state-of-the-art” instrumentation or computer software. Good luck with that.



Figure 51. Leo Rutten

Philippe Rosseels

I had never heard of Phillippe in the ground freezing world until I met him on a project in Miami, Florida, in 2013. I learned that Phillippe had done a lot of ground freezing in Congo and worked with Leo in their younger days.

Philippe and I discussed the changes and state of the art. He had an interesting perspective. In his opinion, the most significant advancement in ground freezing was the screw compressor. Having to deal with the old reciprocating compressors in the 1980s, I heartily agree. But when discussing the other advances in the industry, he replied, “Joe, you don’t need any of that. Just give the ground enough time to freeze, and everything will work out fine”.

CONCLUSION

I hope that by reading the above stories, you the current state of the art will be clear. The state of the art will not change with time. The state of the art is where it always has been. It is the passion of the “freeze guys.”