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RAPID DEPLOYMENT OF CAMP FACILITIES UTILIZING POINT-SUPPORTED STRUCTURES

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Abstract: The work described in this paper summarizes the design and initial field testing of a point support foundation system for structures placed on snow. The foundation members consist of augers which can easily be driven into the snow by hand. A load frame and instrumentation package located at the Greenland Ice Sheet Program-Phase II (GISP II) are described, as well as the initial proof-of-concept testing prior to field deployment.

1. Introduction

Remote science camp deployment in arctic conditions is generally difficult and sometimes dangerous. Remote field camps are often located at high elevations and subject to strong winds and severe cold. These conditions are exacerbated by a lack of logistical support due to the remote geographical location of such facilities. A successful camp deployment can often be the difference between the success and failure of a scientific field season.

Processed snow foundations for camp facilities located in arctic regions present many engineering challenges. Among these are high costs for transportation, equipment and personnel intensive installation, differential settlement of building structures, and high environmental impact.

The keys to a successful camp deployment are speed and simplicity in establishment of camp housing and research structures (CURTIS and KOCI, 1991). Current camp erection techniques generally call for a solid foundation for buildings and structures. This is usually achieved by processing the snow by plowing and packing to allow it to sinter into a harder base. Large wooden beams or steel grillages are often set onto this processed snow base which then acts as the foundation for structures built on them (CURTIS and TOBIASSON, 1991). The deployment of building foundations, therefore, generally requires a major expenditure of heavy equipment, manpower, and time.

Aircraft to support camps in arctic regions often cost $6,000/hr. of flight time (CURTIS *et al.*, 1991). Flying in materials and equipment is often, then, one of the largest costs of a research project. The processed snow type of foundation is also prone to differential settlement, which requires leveling devices between the structure and the foundation. All of these factors greatly increase the cost of establishing camp facilities for research work.

Another concern, which is receiving a great deal of attention lately, is the environmental impact associated with establishing remote camp facilities. It can be very difficult to extract foundation beams which have been covered over with snow. Retrograding processed snow foundation materials is, then, very uncommon because of both the expense and difficulty involved in removing them. These materials are typically left in place when the camp is abandoned and become a permanent part of the base camp site.

An ideal foundation for buildings for remote science camps is one which is light weight, easily deployed with little manpower and time, requires no heavy equipment and is easily adjustable for differential settlement of foundation components. One system that can be used to achieve these goals is a point support foundation member which can simply be screwed into the snow. This type of installation procedure has the added benefit of relatively effortless retrograde once the camp's design life is reached.

2. Methods

The method chosen to achieve the goals just delineated on the project described herein involved the use of screw augers. Initially, off-the-shelf ice augers (which are used for drilling holes for ice fishing, etc.) were investigated for proof-of-concept testing. A variety of sizes in both the length and diameter chosen for investigation were available, but they were all rather bulky and heavy, making them inappropriate for field use at remote science camps.

Another problem with the commercially available ice auger is that it screws into the snow with a minimum of the mixing action which causes the sintering that is desirable in snow foundations. The proof-of-concept project described in this paper utilizes augers fabricated from aluminum plate and shafting. Aluminum was chosen for light weight, ease of forming and machinability.

For the initial test model an auger diameter of 20.3 cm (8 inches) was chosen. This diameter results in an area of approximately .031 m^2 (1/3 ft^2). A circular section was cut from 3.2 mm (1/8 inches) thick aluminum plate. Two flights were added to the flat plate which cause the auger to screw itself in as it is rotated against the snow (see Fig. 1). Additionally, these flights allow the auger to be unscrewed for retrograde. Both flights form a 45 degree angle to the flat plate and are 3.2 cm (1-1/4 inches) wide by 8.6 cm (3-3/8 inches) long. One of the flights was formed by cutting a slit in the plate and bending the resulting tab of metal down, while the second flight was welded to the other exposed, cut face of the plate. This plate assembly is then welded to an aluminum bushing 7.62 cm (3 inches) long with a bore of slightly over 2.54 cm (1 inch). The flight/plate/bushing assembly is then bolted to a 1.22 m (4 foot) piece of 2.54 cm (1 inch) diameter aluminum shaft. The shaft is designed to be easily coupled to extension shafts to make longer sections. A steel bit was added to the end of the aluminum shaft to aid in breaking up the snow ahead of the shaft during installation.

This design differs from a commercially available auger in that the flights are not continuous, but, instead, composed of “pie plates”. There are several advantages to the “pie plate” configuration when compared to the continuous flight arrangement, which is, essentially, a screw with a high pitch. The bolt-on “pie plate” arrangement leads to a much more compact package during transport. This arrangement also leads to a modular design which can be tailored to meet the specific needs of the site/structure it is supporting. More than one auger plate can be added to a shaft, as well as plates which vary in diameter and thickness.

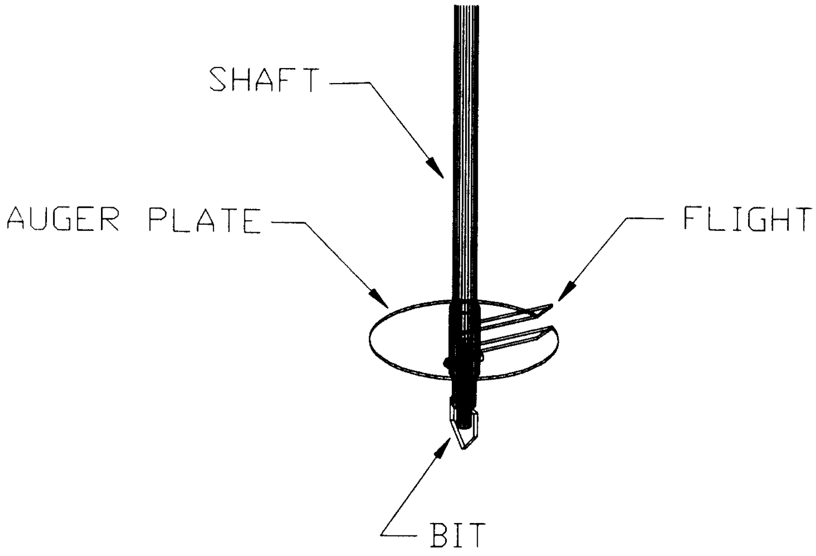

Fig. 1. Typical "pie plate" auger.

The "pie plate" design also causes a thorough mixing action in the snow as the augers are screwed in. This, in turn, causes the snow which is in contact with the auger to sinter into a much harder and stronger base. It is possible that higher load bearing capacity could be achieved by driving the auger beyond the intended depth and then unscrewing it upwards slightly. This would process the snow below the auger as well. A drawback of having the auger do so much processing is that it will cause a slight increase in installation time as the majority of the plate is not effective in driving the auger.

3. Initial Testing

Initial proof of concept tests were performed during the winter of 1991–92, in Fairbanks, Alaska. Unfortunately, this was not a year of high snowfall in the Fairbanks area. The low snowfall necessitated constructing an artificial "snow field" to simulate conditions one might encounter at sites in Antarctica or Greenland.

A mound of snow was generated by directing the discharge from a snowblower to a central point within an open field. A snow mound approximately 2.4 m (8 feet) high and 6 m (20 feet) in diameter was constructed. Density readings of the processed snow were taken after several days and were in the range of .45 to .5 g/cm^3. This is well above what one would encounter in actual field conditions, which are typically approximately .30 to .35 g/cm^3 in naturally deposited snow. It was recognized the procedure used to construct the mound resulted in a "processed" snow foundation with a density higher than naturally deposited snow. It was felt, however, that this would still give some indication of auger performance.

After allowing two weeks for the snow to harden, three augers were installed in the artificial snow mound. The three augers respectively consisted of a shaft connected to: a single plate, a two plate system, and a three plate system, with a 20.3 cm (8 inches) spacing between the plates on the multiple plate augers. The number of plates per auger was varied to assess the strength increase, if any, associated with multiple-plate augers. All were driven in such a way that the depth of the bottom plate was 0.92 m (3 feet) below the snow surface. They were installed with a T-bar handle which temporarily mounted to the end of the auger shafts. It took approximately 15 min to drive each of the augers to depth. Surface disturbance and mixing sufficient to cause sintering was observed for each of the augers during installation.

The augers were allowed to set up for one week prior to loading. An ultimate pullout strength test was then performed using a hand winch attached to a large steel tripod mounted above the augers to be tested. The free end of the hand winch was attached to the single plate auger. A 22241 N (5000 lbs) load cell was placed in series with the winch to monitor the pullout forces.

The single plate auger was loaded to 718000 N/m^2 (15000 lbs/ft^2) on the embedded plate surface with a corresponding 1.3 cm (1/2 inches) of vertical displacement. It proved to be impossible to extract the single plate auger at this load level. The 718000 N/m^2 (15000 lbs/ft^2) figure is much in excess of the 47800 to 192000 N/m^2 (1000 to 4000 lbs/ft^2) generally used in processed snow/grillage foundation design.

The three augers were excavated from the side to allow observation of the vertical profile of the snow adjacent to the plates. The single plate auger showed a noticeable amount of permanent deformation (the flat plate was beginning to dish into the shape of a cone) upon removal and inspection.

It was further observed that voids had formed between the plates of both the two and three plate auger systems. This was attributed to the fact that flights were "pumping" snow above the plates. With a single plate this will not occur, but with multiple plate auger systems, the plates located above the base plate will likely carry a reduced load. Because of this, multiple plate augers were not employed in subsequent concept testing.

Similar high load pullout testing was performed by Austin Kovacs during the summer of 1962 on the Greenland ice sheet at Camp Century (KOVACS, 1967). Hydraulic rams were used in that testing procedure. The investigators in that study were primarily interested in both a quick extraction and a sustained load test of circular plate ground anchors in snow. Circular steel plates with an area of .073 m^2 (.785 ft^2) showed an ability to resist short term loads of as much as 311400 N (70000 lbs), which is 4267000 N/m^2 (89100 lbs/ft^2). Sustained load tests showed low strain rates of .005 mm/day (.0002 inches/day) with an applied load of 316010 N/m^2 (6600 lbs/ft^2). KOVACS' anchors were placed in pre-excavated holes with snow manually compacted during the backfill operation. The auger-type anchors used in the GISP II study have the advantage of eliminating the excavation and subsequent backfill operations.

4. Field Testing

The next phase of "pie plate" auger testing was intended to provide information on the strain rates that could be expected to occur in single plate auger systems loaded in both tension and compression under actual field conditions. The GISP II, site run by the National Science Foundation (NSF) through the Polar Ice Coring Office (PICO) at the University of Alaska Fairbanks (UAF), was chosen because logistical support for camp operations was already in place.

As was to be expected, with the lower snow densities at the GISP II site (approximately .34 g/cm^3 in the top two meters of undisturbed snow (R. ALLEY; unpublished manuscript, 1989) the augers were much easier to drive by hand into the snow. A final depth of 2.13 m (7 feet) was reached in only 5 minper auger. Again, it was observed that the augers provided a thorough mixing action to the snow during installation.

The load frame and instrumentation package used in the GISP II field testing needed to meet a number of criteria. Among these were: light weight, easily deployed (field deployment by a single person), able to operate unattended for a one year period with minimal power consumption, provide little environmental impact, supply a constant force to the test augers throughout the testing period, capable of monitoring low strain rates/displacements, operate without a fixed elevation datum and resistant to high winds and the accumulation of snow. A cable stayed loading tripod and instrumentation package was designed and built to meet these requirements for the field tests.

The tripod legs were fabricated in three 1.83 m (72 inch) sections of 6061 alloy aluminum schedule 80 pipe. At each leg joint, three struts extend radially outward (see Fig. 2). These struts were employed to tension 2.38 mm (3/32 inches) diameter aircraft cable stays which were attached at the leg joints. The cable stays provide lateral stability to the legs of the tripod.

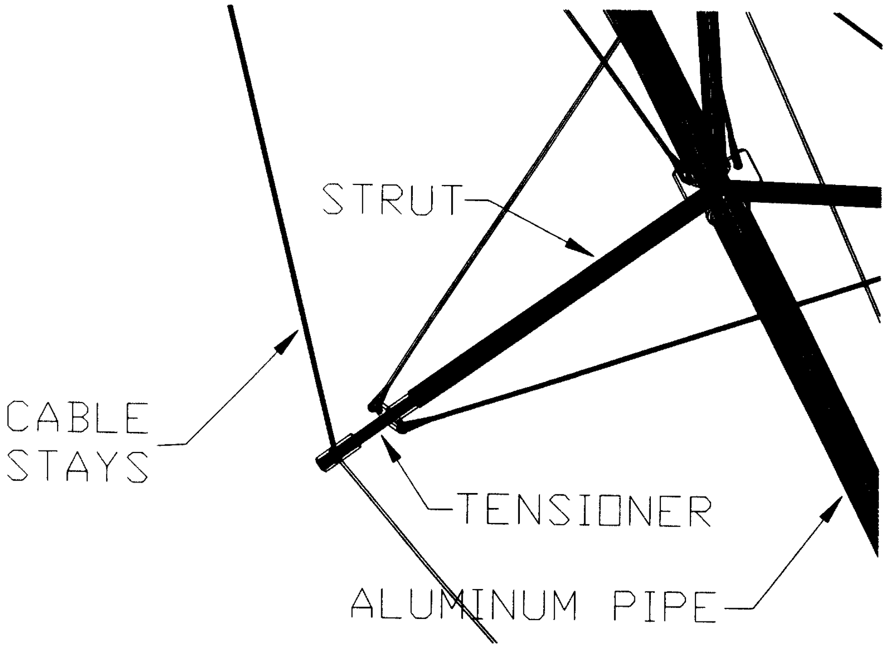

Fig. 2. Load frame cable-stayed joint.

The loading tripod (see Figs. 3 and 4) was approximately 5.49 m (18 feet) tall, weighed 334 N (75 lbs) and could be collapsed into a standard ski bag for transport. The tripod was designed for a capacity of 6672 N (1500 lbs) and to be erected in under than three hours by a single person.

The tripod load frame applies load to six augers simultaneously; three in tension and three in compression. The augers placed in compression are clamped to the legs of the

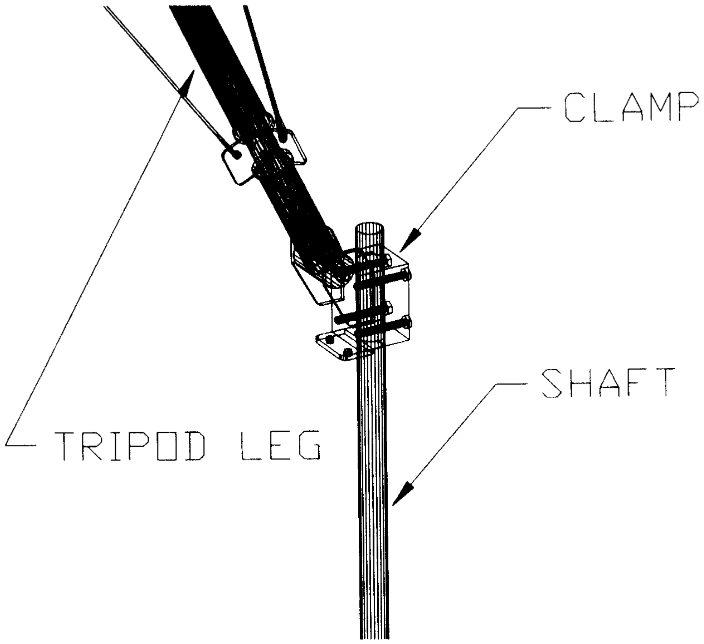

Fig. 3. Load frame - auger interface.

tripod (see Fig. 3). Clamping the tripod directly to the auger shaft facilitates levelling of the tripod. To supply a downward compressive force to three of the augers, three other augers placed inside of the base of the triangle formed by the tripod legs, are placed in tension (see Fig. 4). An equal but opposite reaction force is developed between the tension and compression augers. The tension/compression auger system allowed the test to be performed without the application of a large amount of dead load.

Load for the test is provided by an off-the-shelf hand cranked, boat/trailer winch which was modified for the test program. The handle of the winch was removed and replaced with a pulley sheave. A steel drop weight was attached to the pulley by a cable which was wrapped around the pulley. To ensure a constant radius (and hence, a constant force applied to the system), the sheave was designed such that the cable would not overlap itself. The winch is attached to the top of the loading tripod.

The field test auger design load was set at 47800 N/m^2 (1000 lbs/ft^2) as this figure is commonly used in processed snow foundation design (CURTIS and TOBIASSON, 1991). To achieve this design pressure, each of the 20.3 cm (8 inches) diameter single plate auger assemblies required approximately a 1481 N (333 lbs) load. This resulted in a total force in the system of 4448 N (1000 lbs) applied in the vertical direction to each set of three augers loaded in either tension or compression. A vertical displacement failure limit of 15.2 cm (6 inches) in the tension or compression auger sets was selected for the field test.

With these operating parameters, the load frame needed to supply 678 N-m (500 ft-lbs) of energy to the auger system. This energy was supplied through the winch assembly by a drop weight of 156 N (35 lbs) suspended 4.57 m (15 feet) above the snow surface. When installed in the field, the drop weight is released, thus energizing the system.

To isolate the compressive-force augers from the lateral components of the axial loads which develop at the base of the tripod legs, cables were attached between each of the

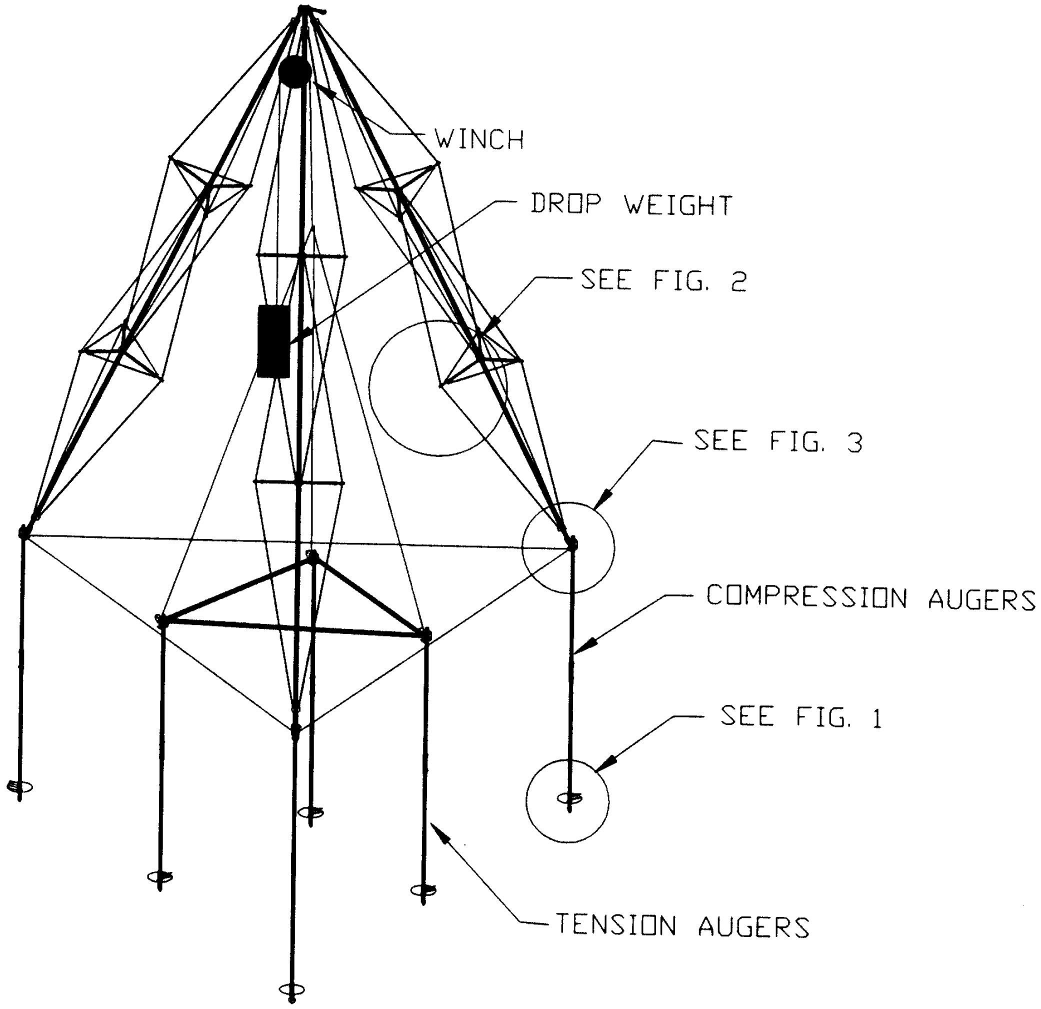

Fig. 4. Load frame and drilled auger configuration.

tripod legs. Compressive members attached to the tops of the tension augers isolated them from the tensile forces in the cables which would tend to cause them to deflect inward. Two statically determinate systems are created in which the forces in the individual augers can be calculated given the geometry of the tripod arrangement.

5. Instrumentation

Settlements and strain rates occurring in the individual augers are currently being measured and recorded on a Campbell Scientific 21X datalogger. Lithium batteries were chosen to power the unit because of their high energy density and unimpaired cold temperature performance. A drawback associated with the use of lithium cells is that they are considered a hazardous material; making transportation and disposal rather difficult and of prime importance in the selection of a power source.

As the Greenland ice sheet is continually moving, it is impossible to establish a fixed reference elevation and position on the surface of the snow for settlement measurements.

Rather, a datum must be established for use as a reference point. The reference point is not stationary but, if established in an area in which the snow can be considered to be unloaded, can be used to "zero out" the global movements of the ice sheet from local displacement measurements. This was accomplished for this study by installing an additional, unloaded auger adjacent to but outside the tripod area. As only local settlement is of concern in foundation design under such conditions, this would serve adequately as a stationary point from which to measure relative displacements.

Differential-pressure gage transducers mounted in a system of silicone oil filled tubing are used to measure the movement of the augers with respect to the datum auger. The differential pressure transducers are placed, with the datalogger, in an instrumentation box located at a point between the datum auger and the load tripod. A run of copper tubing extends from the datum auger to each of the individual augers associated with the load tripod, with a pressure transducer mounted in each tubing run.

Silicone oil was chosen as the working fluid as it is compatible with the transducers, has a fairly constant viscosity with temperature, and is quite inert; making it safe to use from both an environment and operator safety point-of-view. The silicone oil was forced into the tubing on either side of the gage, thus ensuring that all air was eliminated from the system as the lines were filled.

As the loaded auger system settles, information on the differential pressure is gathered on a regular basis by the 21X. Measured settlements and times can be used to calculate the strain rate in the foundation. Current funding and resources will allow the load frame and auger system to be monitored for a one year period.

The data processed by the 21X is sent to a storage module with a separate battery backup. Utilization of the storage module allows data to be downloaded without interruption of data gathering efforts as storage modules can be changed on a periodic basis.

6. Conclusions and Further Research

The screw-in auger-style point support foundation system has performed well during initial proof-of-concept testing. Load-bearing capacities appear to be quite high compared to conventional processed snow type foundations. The auger is easy to install with minimal equipment and personnel. Adapting this style of foundation to actual field use should result in both cost savings and improved performance.

Further development is necessary to refine design procedures for the auger style foundation system. Future work includes: 1) examination of the effects of multiple flights on auger performance and load capacity, 2) development of a system to alleviate snow voids between auger plates, 3) development of a mathematical model to predict both short- and long-term load capacities based on snow conditions such as density, temperature and depth of burial, and 4) determination of the lateral load capacities of the auger system.

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