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THE FUTURE OF BUILDING FOUNDATIONS IN THE CANADIAN NORTH

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Abstract: The Canadian North is experiencing several building engineering problems which must be addressed now to avoid worsening problems in the future. The permafrost layer is retreating downward in the Canadian North. This is resulting in many unstable homes in the 14 villages of Quebec`s Nunavik. Current tripod adjustable footings, while the most popular, are not the way of the future. Several other methods such as concrete footings on bedrock, or on deep permafrost, exist. When bedrock is very deep, steel piles represent a good way to stabilize buildings. Some cases require add freeze piles when bedrock is too deep to reach economically. Lattice truss systems on tripod footings have also been used. This report explores the most prominent solutions of the future and reinforces which methods are believed to best perform going forward.

1 Introduction

The foundation is arguably the most important element for consideration in the construction of a new building. Excessive repair jobs and architectrual reports are showing that current desgin practices may not be adequate for the future in the Canadian North. Climate change is causing the retreat of the permafrost across the world, leaving previously stable buldings sitting on soft unstable ground. Structural building engineers must reasses the current designs of foundation and provide a solution that will ensure stable buildings now and into the future.

2 Heat Transfer to Permafrost

The active layer is a narrow top layer of soil that undergoes freeze thaw action seasonally. At a certain depth however under the surface, and going down to bedrock, the composition is completely frozen. In Canada, this active layer normally measures between 0.6-1.5m, meaning the permafrost starts at that depth and descends to bedrock. Permafrost is characterized as essentially frozen water with small amounts of soil particles. (Group, Thermosyphon Foundations for Buildings in Permafrost regions, 2015) It is not a frozen mass of earth. This poses a greater risk, because if permafrost is allowed to thaw, it has almost zero compressive capacity, since it is essentially water. Globally, scientists believe with global warming, the active layer will increase over time, meaning the permafrost will retreat downwards. (Post, 2017) For Canada, here lies the important design condition, since all 14 villages in the Quebec north, are located on permafrost. Nunavik is area located above the 55th north Parallel. When a building is built, it is heated a large part of the year. A major problem consists of the heat travelling from the building downwards and thawing the permafrost on which the building sits. Several different foundation types are currently being used, and each has their advantages and disadvantages, as will be studied. The challenge however to prevent heat transfer to the soil under the building however is among the greatest design considerations for ensuring an appropriate life cycle cost of the building, and preventing major overhauls over the life of the building. Since land is so readily available there is no incentive to build high buildings, rather buildings are generally limited to a ground floor and a second story. Some buildings have a basement; however this is rather rare in the north.

3 Problems with Foundations: Instability of Tripod Footings

The most commonly used method of supporting buildings in the Canadian north is via adjustable steel tripods, sitting on wooden plank bases. The main reason for this is that it is initially the least costly alternative, and due to the fact that all buildings in the north are low rise, the loads to be supported are relatively small. The tripods raise the building 2 feet above the ground, preventing the heat from the building to descend into the ground. The 2 feet also allows the wind to disperse the snow, allowing it to pass under the building and prevent accumulation. Major problems result when a minimum of 2 ft is not left under the building. Traditionally, the design consists of 12 tripods under a duplex home, which is the most common. It has been seen that should 2 feet not be left, snow accumulates triangularly up to the roof of the home the residents cannot enter without unreasonable shoveling. A disadvantage of this widely used system that is seen in almost every case is differential movement of the top soil and permafrost variations, resulting in cracks in the walls, opening of joints which allows snow and debris to enter into the envelope and causes major renovations to be needed a few years after the building is handed over to the residents. Over the past 3 years, 20 homes were completely renovated following a 27 year life span. The home was reduced down to its wood studs. Every home had nails being pulled apart, requiring realignment. Every tripod footing had to be readjusted. The tripods are adjustable and the attempt to balance the buildings each spring is conducted; however the shortage of trained technicians who do a competent job is a huge problem. Often the adjustments are done by people who do not know how to perform this task and the problem becomes worse. A different option is needed to provide a better solution for the northern community. The current strategy necessitates we send trained technicians to the communities ever year to lead the adjustments of the tripods, repair architectural damages and other damages that have resulted from the primary damages. For example, when the joint in the building envelope opens up because of excessive stress due to the building shifting, snow can enter and rot the wood. Mold forms and wears away the structure. Moisture gets on steel from the ventilation system and can cause rust. These are all secondary issues that arise and must be treated yearly resulting in a very high lifecycle cost and large follow up efforts, coordination of professionals and yearly work. (Duguay, 2017)

Figure. 1: Steel tripod footing.

Figure 2: Steel footing under steel beam.

4 Alternative: Concrete Footings on Bedrock

Other alternatives exist, such as digging down to the bedrock and sitting concrete footings on solid bedrock and having piers and foundation walls that come up to the surface. This design can be with or without a basement. Meaning, that a slab on grade can sit on backfilled soil, and a superstructure be built atop the foundation walls, or a structural slab can sit on the foundation walls, with an open basement below. This foundation type is an excellent option as the building will not shift. The problem arises when the bedrock is too deep not making it economically feasible to excavate to such a depth. This option should therefore be considered when the depth of bedrock is not very deep.

A second option that employs concrete footings, in cases where the bedrock is too deep, is to sit the concrete footings on permafrost. This method is employed when the permafrost is structurally sound, at a depth of just over 2m. Sand is placed under the footing with rigid insulation above and below the footing. This method is less used due to its reliance of the long term performance of permafrost which determines the building stability. Even during excavation, contractors must be careful to not permit the permafrost to thaw as the warmer air blows over the permafrost. Global warming also leads designers to believe despite the grounds current stable nature, the permafrost may retreat and cause instability for buildings over the next 30 years.

Figure 3: Building Basement in the North

5 Alternative: Bored Piles

Another very viable option is to use bored piles. This option results in no settlement, and can be used when the bedrock is very deep. It accompanies pile caps on which a steel structure is connected. This method is the one most commonly used in Europe, such as Norway. In Norway, deeper piling is being used, and buildings are sitting on the piles, leaving a space between the underside of the building and the ground. This allows the air to circulate underneath, and keep the ground frozen. This conserves the permafrost, even if the building stability is not dependant on it, because it is resting on piles. (Post, 2017) When the bedrock is very deep, it prevents having to excavate such a large area to attain solid rock. The bored piles generally descend and are anchored into the bedrock. The cost of the piles thus depends on the depth of the bedrock. This encourages the preparation of performing a geotechnical reports with sample boreholes. Again, this is a challenge since it is difficult to get qualified geologists to perform accurate tests. The samples indicate the depth of the initial soil layer, the permafrost depth and the depth at which the bedrock is found. The tests are critical in determining what type of foundation system to use. Should the bedrock be very deep making it uninteresting to bore piles to such a depth, the piles can be anchored into the permafrost in a special type of modified pile called add freeze piles. (Group, Thermosyphon Foundations for Buildings in Permafrost regions, 2015) This type of system consists of boring a hole slightly larger in diameter than the pile diameter to be placed. Once the hole is made, the pile is inserted in the center of the hole and the surrounding area is filled with water. The water freezes and adheres to the permafrost. The friction built between the pile and to the surrounding permafrost acts to hold the pile in place. This design however requires a minimum 2 feet space between the pile cap and the building, to ensure no thawing of the area around the pile. This would be a major problem as the pile is withstanding the compression and tension forces via the ice bond. This system is therefore not suitable where basements are required.

6 Alternative: Lattice System of Trusses

The final system that is a viable alternative in the northern community is a lattice system of trusses resulting in many supports that attempts to be able to absorb variable settlement. This system however is difficult to obtain due to limited suppliers capable of providing this concept, and the coinciding high cost. The design is custom and is performed by a manufacturer. It cannot easily be mass produced and with each manufacturer having their distinct details, the purchasing is difficult to manage. The system also has been found to be congested and the system is dependent on the gravel base underneath. Should the base not be well compacted or should there be a problem with the structural integrity of the gravel, the system will not perform well.

Figure 4: Lattice structure under northern home

The problem however is not so much the past, as the trend for the future. Within the past 5 years, the permafrost has retreated significantly in several northern villages, especially Salluit which is known to have very unstable ground. The method of tripod footings may have worked in the past; however it is becoming more and more clear that it will not work for the future, and another method to stabilize buildings will be required. (Duguay, 2017)

The conclusion to the question of foundation choice suggests that when the bedrock is close to the surface, excavating through the top soil and permafrost is ideal. This way the concrete footings will sit on the bedrock which will not vary in properties. Concrete foundation walls and piers extend from the concrete footings to the surrounding surface. The hole is backfilled and a structural slab is constructed with backfill underneath or rigid insulation that serves also as formwork. If the bedrock is deep, it becomes economically preferable to use an equally good method: that of bored piles, anchored to bedrock. Piles anchored to bedrock are preferred over those used in add freeze conditions. The use of piles over other methods of foundations is becoming the norm in areas such as Nunavut. Both these methods offer a more sustainable option with a lower life cycle cost due to the much lower maintenance required.

7 Alternative: Use of monitoring sensors.

It is a known fact that the geography and soil behavior is changing each year in the north. Some communities are suffering more than others, such as Salluit. Another possible solution, is to continue using tripod footings however to install monitoring sensors near each sector of footing to follow the temperature of the ground. Should the temperature rise, as it will due to global warming, and permafrost retreat, adjustments can be made through inserting shims and using the adjustors. This will allow for a more accurate portrait of the building movement at prevent damage, through faster detection. Many providers and manufacturers exist and the ground temperature sensors can and should be equipped with wireless information transmission. With large quantity purchases, the price would inevitably be lower, however even currently, unit sales are very affordable. This would provide continuous data being sent back to a main control center, possibly located in main cities with qualified staff able to analyse the data. Should a trend be determined requiring the addition of shims or other work, it can quickly be tented to. Another issue is that there currently is not significant data on the permafrost performance in the Canadian Great North. It would be important to also follow best practice for the compaction of gravel under the tripod footings. This requires that the contractor wait 1 full year after compacting the gravel before building on top, or placing any load. This allows the gravel to have its initial and most important settlement. This is considered best practice for major cities also, where it is recommended that owners for example, wait a full year before constructing their home extension, or driveway, after having compacted the soil. The continuous monitoring via ground temperature sensors could provide data for scientists to better understand the future behaviour of the land in the North.

8 Alternative: Use of Thermosyphon Foundations

With growing concern of climate change and the warming of the planet, researchers are seeking ways to ensure the ground under buildings in the north remains stable and safe. This brings the option of Thermosyphons. Originating in Alaska in the 1960`s, and coming to Canada in the 1970`s, their application is vast, however not common. The main way to ensure stable foundations is to keep the ground frozen. One such technique is via thermosyphons and thermopiles. Currently there is only one company producing such a system in Canada. The closed system is a passive one that works only in winter when the ambient air temperature is colder than the subsoil temperature. The system is a closed and pressurized one, ranging between 2100 – 4800 kPa. (Group, Thermosyphon Foundations for Buildings in Permafrost regions, 2015) Thermopiles incorporate the thermosyphon technology, in a vertical set up. The radiators, to disperse the heat, are in an air space between the ground and the building structure. In thermopiles, the condensate circulation occurs by gravity. The load of the structure rests on the head of the thermopile therefore they must be designed knowing the soil characteristics and the load of the structure. (Group, Thermosyphon Foundations for Buildings in Permafrost regions, 2015)

While other companies have tried gases such as nitrogen, the only company to successfully market their product, use carbon dioxide. During the winter, the colder ambient air causes the carbon dioxide to condense on the inside of the closed system. This is because cold air can hold less moisture, and therefore condenses. As the liquid carbon dioxide drips down the closed system, it turns back to gas and absorbs heat from the ground and rises back to the top of the closed pipe. This process continuously extracts the heat from the ground keeping it cold, thus frozen. The heat in the warm gas is dissipated via evaporator fins. Insulation is placed above the closed system to prevent heat from the warm ambient air and building from descending into the cold ground.

The planning and execution of a good geotechnical study is most important for the thermosyphon type of foundation, as compared to all other types of foundations. (Group, Thermosyphon Foundations for Buildings in Permafrost regions, 2015) The Canadian Standards Association identifies several factors of utmost importance to consider when deciding if the system is appropriate. The first being the depth and variation in the active soil layer. The second being the temperature of the ground and the content of the ground, either ice or water. Ground temperature instruments should be placed and the temperature monitored to have an accurate temperature profile. The third factor to consider is to identify if there is deep seasonal thawing, or potential presence of a soil composition of talik, which is a layer of soil that is permanently unfrozen, located between the active layer and the permafrost. Finally, it is important to know if there exists groundwater flowing within the active layer. All this is determined via the geotechnical report, confirming its utmost importance. Very commonly, project managers attempt to save money by limiting the number of boreholes in a geotechnical report, assuming that the ground composition is the same over a large area. This can be very misleading, and costly, as the reality can show varying soil structures over a small area. Often project managers will use what are called test pits. This strategy only excavates to the top of the permafrost and looks only at the active layer. This is highly discouraged and considered poor engineering practice. It does not give an accurate profile of the permafrost and the soil composition and properties. (Group, Thermosyphon Foundations for Buildings in Permafrost regions, 2015)

The use of thermosyphons allows buildings to be built on grade yet not worry about the heat being transferred from the building to the permafrost thus causing instability. It has been proven that insulation under the slab alone, is not enough to prevent the heat from transpiring and melting the permafrost. Insulation merely retards the passage of heat, it does not prevent it. Thermosyphons are not ideal for freezing the ground rather they can help maintain the ground frozen. They are not recommended in areas with large underground water currents. (Group, Thermosyphon Foundations for Buildings in Permafrost regions, 2015) While it is rare to find a site that would remain stable should the permafrost melt, this is possible. Such a case would arise if the bedrock is very close to the surface, or if the permafrost layer was gravel or frozen sand. Should the building be located on ground that is not susceptible to becoming unstable in the case of a thaw, thermosyphons would not be required. It is essential that the building be on stable permafrost, with fully functioning thermosyphons before construction begins. The challenge with this approach is that most often construction materials such as the thermosyphons, gravel, and insulation would arrive via sea shipment in the later summer. By the time everything is installed, it would be fall, at which point the ground would be partly thawed, contractors would have to wait until later in the winter to begin construction, or spring at which point the ground would have re-frozen. In order for this system to be feasible with construction delays, improved coordination would be required to have the equipment supplied on the ship in the first sea delivery of early spring in order to have the system installed by late spring and begin construction while the ground is still frozen. When using thermosyphons, construction is recommended to be above ground. Very often crawl spaces below homes end up becoming filled with water, causing flooding. This is highly discouraged, and all construction should be above ground.

While thermosyphons are available for use in the great north, their limited freeze capacity limits the time frame in which construction can occur. They require specialists to properly install them, which are limited in such environments, and should there be a mishap in the working condition, the integrity of the building could be jeopardized without much warming. For these reasons, despite possible uses in the future after technological advances, currently, thermosyphons do not represent the best option. While their usage is limited, they still do exist, and are seen in dams located on a permafrost foundation, where they prevent the foundation from thawing, and prevent water channels from forming under the foundation through the permafrost, resulting in seepage. They are also seen in road embankment construction. Thermosyphons are also seen in Alaska for the trans-Alaska pipeline project among others. (Post, 2017) Should a road or railway embankment be thawing, thermosyphons have successfully been used to prevent further thaw. The lifecycle of a thermosyphons is 20-30 years. (Group, Thermosyphon Foundations for Buildings in Permafrost regions, 2015)

9 Challenge of Permafrost Thaw and Water pooling during summer excavation

A serious problem that must be anticipated and controlled during excavation, for concrete footings for example, is that of water pooling during summer excavation due to permafrost thawing. Excavation is required for big footings and in commercial buildings such as school, pools and water facilities for example. The ground composition consists of a thin top soil layer, followed by a thick permafrost layer. This permafrost layer, as studied, consists of mostly water, with little soil particles. While the top layer of soil undergoes freeze thaw cycles, the layer of permafrost does not, hence its name permanent frost – permafrost. When excavation of a new building, often one with a basement, takes place, the excavation can descend several meters. Even if the excavation does not descend into the permafrost layer, the exposed soil at a depth of several meters allows the heat from the air to easily access the permafrost. These conditions lead to the melting of the permafrost, thus the transition from frozen state to liquid state. This means that the capacity of the bottom of the excavation drastically decreases and floods. Great effort must be made to prevent the permafrost from thawing, and should some thawing be inevitable, a sophisticated pump system must be in place to remove water to keep a dry excavation to allow the workers acceptable working conditions. Concrete cannot be poured in a puddle of water either, therefore if excavation down to bedrock, through permafrost, construction managers must anticipate the water that must be dealt with. Pumps must be in place to remove the water preventing further damage, and preventing the compromising of concrete quality which cannot be poured in water.

10 Conclusion

Based on the preceding information, comparing the pros and cons of each method, it can be concluded that it is best design practice to build concrete footings on bedrock or use anchored piles when bedrock is too deep to excavate economically. This strategy will ensure the stability of the building now and in the future. Care must be taken to prevent permafrost thaw, with adequate pumping planned for during excavation. The foundation of a building is arguably the most important element of the building construction, hence why its consideration must be of utmost importance.

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