

# CANADIAN CONSULTING ENGINEERING AWARDS 2013

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INNOVATIVE APPLICATION OF THERMOSIPHON TECHNOLOGY  
FOR FOUNDATIONS IN CONTINUOUS PERMAFROST



Nunavik Nickel – Canadian Royalties Mine



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*As the short arctic summer drifts into fall, a huge ice-breaking bulk carrier leaves Deception Bay with a load of nickel, copper, platinum and palladium ore bound for Finland. This first shipment to cross the Hudson Strait marks the debut of a new era for an \$800 million project many years in the making.*

## The Nunavik Nickel Mine

Nunavik Nickel's mine is located on the northernmost tip of Quebec, some 30 km from the village of Salluit and 80 km from Kangiqsujaq. Development of the site was started in 2007 by Canadian Royalties, a Val-d'Or, Quebec, junior mining company but was halted in 2008 due to the financial crisis that followed.

In January 2010, Jilin Jien Nickel Industries Co. – China's second largest Nickel producer – completed its acquisition of Canadian Royalties through its Canadian subsidiary Jien Canada Mining Ltd and construction was re-launched. The project was revised to upgrade the concentrator's production capacity from 3500 to 4500 tons per day.

Work was completed in late 2012, and production is now underway. It's expected to reach its 150,000-ton per year capacity in 2014 and to last for at least 13 years. Concentrate will be stored at Deception Bay and will be shipped from temporary floating docking facilities.

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*Nunavik Nickel  
mine complex,  
August 2012.*



The company plans to ship concentrate nine months a year under a deal to supply nickel to Russia's Norilsk Nickel in Finland and other European interests. It will be carried by a brand new Polar Class 4 vessel owned and operated by Montreal based Fednav Group, who already has the world's largest fleet of ice-class vessels and who operates year-round in ice-covered waters.

## An innovative approach to a complex problem

Canadian Royalties called upon GENIVAR because of its vast experience in arctic and sub-arctic construction projects, not only from the logistical point of view – the design and planning had to allow for the usual and particular constraints and challenges of High North construction: lack of access, extreme cold, high winds, drifting snow, manpower, etc. – but also for the team expertise and knowledge of permafrost conditions.

The original project included conceptual study and design for many elements: concentrator, grinding area, truck shop, power plant, water supply and distribution, waste water treatment facility, start-up camp facilities, site drainage, and civil engineering.

Construction of the mine's 5-generator, 3.3 MWH power plant and of the ore processing facilities capable of handling 4500 tons per day was particularly complex. Both had to be erected in continuous permafrost, and were big buildings destined to house very heavy and powerful equipment.

This represented the largest industrial facility in the world to adopt this technology.

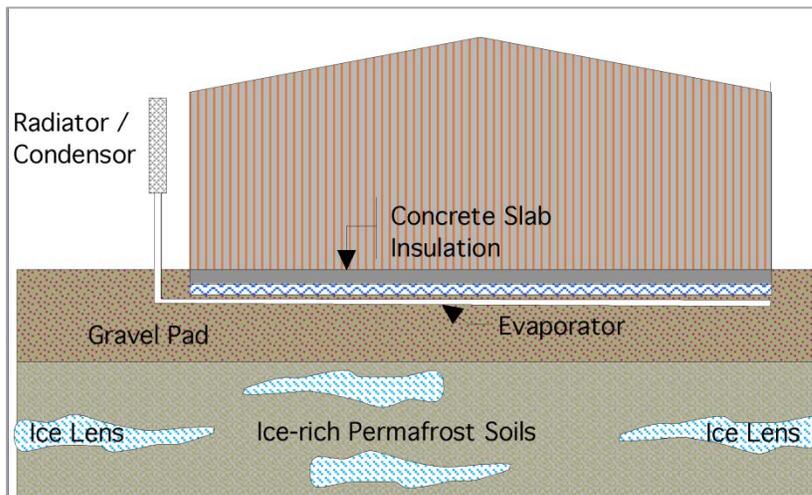
## Problematic soil conditions

A preliminary study had recommended construction on piles. However, further geotechnical surveys revealed that the rock on the selected site was of poor quality and presented problems in terms of its load-bearing capacity.

In essence, the soil was composed of a thin organic layer on the surface, and of a 1 m to 1.6 m active layer that would freeze in winter and thaw in summer and the actual stable permafrost, which was 200 m deep. Of that layer, about 6 m were composed of sand and silt with little traces of clay, and the rest was of low-quality, fractured rock.

This made it very difficult to build on piles as was previously recommended. While not impossible, this option would have meant fabricating a large number of piles in the South, transporting them on site, and driving them into the ground to support the buildings. Not only would that have had a significant impact on construction budgets, but it would have been extremely time-consuming and would have made it almost impossible to respect the planned time-line.

GENIVAR's team proposed to increase the soil load bearing capacity, by using instead a slab foundation system resting on engineered fill 1.6 m deep, with some 25 thermosiphons designed and built by Winnipeg firm Arctic Foundations Inc. to remove heat from foundation soils in order to control its freeze-thaw cycle, to increase the strength of the natural soil layer and eliminate frost heaving.



*Example of passive thermosiphon system*

Illustration source: Arctic Foundations, Winnipeg

Thermosiphons are passive heat transfer devices that transfer heat using the simple process of convection through vaporization and condensation. They act like mechanical refrigeration units, but require no power to work. They remove heat during the freezing season, actually freezing the fill so that it is completely frozen when temperatures rise and thawing begins.

Although in use since the construction of the Alaska pipeline when they were invented, thermosiphons are still relatively rare. To this day, only a few hundred buildings have been erected using them. The Canadian Royalties project was the first large scale industrial project to use them.

Sourcing fill locally eliminated the need to fabricate, move and install steel piles. It would also have another important benefit: the sizing of the aggregates used would allow for winter ice to expand in a controlled, predictable way – without causing the soil to heave and move – thus maintaining building stability and integrity.



*The early construction site*

## **An innovative thermal model**

The GENIVAR team developed a new mathematical model to analyze, compare and interpret the geotechnical survey and climate data, the heat exchange patterns of the various possible solutions and desired building performance. The development of this model required a thorough understanding not only of thermodynamics, but of the special characteristic of frozen soils.

For constructions located outside permafrost zones, the accepted strategy is to build on the ground table below the freeze line, therefore guaranteeing the stability of the structure year round. In permafrost zones, this is not applicable, the ground being frozen to significant depths (200 to 400 m). Also, one has to remember that building on ice calls on a totally different theory than building on non-frozen soil (even though code specifications are the same). Ice doesn't settle like soil, it compresses and creeps at a rate that varies with temperature. Spreading and balancing loads helps minimize that phenomenon – and should it occur – ensures that compression is even and that the building does not shift or sink unevenly.

The normal construction sequence is to spread the fill, to install the thermosiphon system and to lay the foundations through the summer and then wait for a complete seasonal cycle before proceeding with building construction, essentially on ice. However, GENIVAR model also showed that by hooking up the thermosiphons to compressors, and essentially turning them into an active refrigeration system, construction could begin immediately and that the ground would be completely frozen when the project got to the buildings' superstructures.

This finding represented a major breakthrough, since it would have meant starting mine production a year earlier. Unfortunately, the project was halted due to Canadian Royalties financial problems, in the midst of 2008's industry-wide downturn.

An added benefit of this hybrid passive-active system is that Global Warming will not cause any problem to the building. If temperatures rise too much, starting the compressors will keep the ground frozen and prevent any damage. This is a plus, considering that the mine is located in the area of the arctic currently experiencing the fastest temperature increases.

In order to monitor ground temperatures and track any changes, all thermosiphons have been equipped with a full range of probes and instruments. These also help by spotting any problem, leak or failure of the thermosiphons, which makes service and repairs easier and enhances the system's reliability.

## Solutions that impacted building design

GENIVAR'S model was also important in the design of both buildings. For the power plant, designers had to take into account the massive amount of heat it would generate.

Heat transfer to the fill was controlled by extra insulation, and by increasing the thickness of the fill and the density of the thermosiphons. The objective, as everywhere, was to maintain the natural ground level in a continuous frozen state.

Extra care was taken in the placement of the various pieces of equipment not only to spread the load on a wider surface, but also to balance the foundation's slab so that any movement of the building would be uniform and level.



*View of finished power plant*

For the ore concentrator plant, the challenge was on three levels. First, the equipment to be installed was extremely heavy. Second, it would generate a lot of shocks and vibrations and, third, the concentration process relies on large quantities of water to separate ore from the rocks.

The building had to be designed with extreme care. The foundation thickness was boosted considerably to resist the constant shocks and vibrations generated by the ball mills used to crush the incoming rocks.

GENIVAR also decided to use an active thermosiphon system in order to completely freeze the fill and to keep it frozen. This increased the ground's load-bearing capacity and, by keeping temperatures very cold, minimized ice creep.



*Concentrator and power plant buildings stand out*

Another problem to take into account is that the concentration process relies on water. So there is always a lot of water on the building's floor. But, since the ground below is kept continually frozen, that floor can also freeze any water spill. GENIVAR's thermal modeling showed how to strike a balance between heating the floor to allow water to be collected, adding insulation to prevent that extra heat from spreading to the ground and the density of thermosiphons required to keep it frozen.

## Preventing contamination and thaw induced by other liquids than water

In order to keep the Natural Ground frozen, GENIVAR also took some extra steps to prevent any spillage of glycol, diesel fuel or other liquids that, due to their low freezing temperature, could induce an irreversible thawing of the fill and the ground below.

The first step was to lay an impermeable membrane under the buildings' foundation in order to control any liquid that could seep through the floor. Second, all foundation joints and other openings were sealed and concrete cracking was monitored carefully and controlled in order to keep the building as tight as possible. Last, all plumbing systems were designed in such a way as to prevent and control any spill or leak.

## Environmental and economic benefits

GENIVAR'S approach meant that aggregates needed for the engineered fill would be extracted locally – a simpler, quicker and less energy intensive method than fabricating, moving and sinking steel piles.

In the original project, the added benefit of this technology would have been to cut almost 6 months of construction time, which would have meant substantial savings, but also would have allowed production to start a year earlier. Financial problems prevented this from happening, but the costs and energy savings remained.



*Equipment at work in the pit*

## Easier clean up and site remediation

The net result of GENIVAR's sealed building system is that there is no ground contamination, so that site remediation at mine closure will be a lot easier.

Buildings will be demolished, thermosiphons taken out and fill spread out. The active and continuous permafrost layer will return to their original levels and adapt to whatever conditions exist at the time.

## Opportunities for tomorrow

More and more, Canada's North is going to be the site of exploration in order to find the natural resources the World needs to keep growing. New mines are going to open; new airports, new roads and new ports are going to be built. The use of thermosiphons and GENIVAR's thermal regime model are going to give rise to opportunities, not only for Engineering firms from the Southern regions of the country but also for the people of Nunavik and Nunavut.