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MECHANICAL FOUNDATION SYSTEM FOR NEW AND RETROFIT CONSTRUCTION

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Abstract: Climate change is increasingly affecting the long term serviceability of structures, especially those structures in first nations northern communities located on permafrost and discontinuous permafrost soils. A mechanically joined foundation frame has shown to provide torsional stability and resist differential settlement thus ensuring the structural integrity of the buildings constructed upon it. Ongoing site observations and evaluations in excess of 30 years have proven that this mechanically joined three dimensional grid can be relied upon as a viable foundation system for a wide spectrum of uses, including retrofit. Applications of this Canadian foundation system can be found in Northern Canada, Alaska, Norway and Russia. The system is also being used in problem soil regions of California, Regina and recently in downtown Vancouver for several three storey housing facilities.

1 INTRODUCTION

Many Northern Nations in the world are experiencing the effects of global warming. Soil conditions are among the many signs indicating this warming trend. Where once year-round frozen ground was found, the underlying soils are now thawing and buildings are no longer positioned on frozen ground resulting in excessive differential movement and major damage to buildings.

This prefabricated foundation frame is being used for temporary buildings and buildings constructed on underlying contaminated soils which should not be disturbed.

2 COMMON FOUNDATION METHODS USED IN PERMAFROST LOCATIONS

Buildings in permafrost and discontinuous permafrost are generally elevated above the soil in order to prevent the heat from the building to melt the underlying frozen ground conditions. Different methods are used to elevate the buildings and preserve the existing soil temperatures. The most commonly used methods are

(1) Screw jacks
(2) Post and insulated pads
(3) Timber or steel piles.

2.1 Screw jacks

Screw jacks are the most economical method; however each support behaves differently due to the frost and thawing cycles. This uneven behaviour results in differential settlement of the building causing cracking or major structural damage. Adjustments can be made but unfortunately these are usually not made until excessive damage to the building has occurred. See Figure 1.

Figure 1: Typical Screw Jack Foundation System

2.2 Post and Insulated Pads

The soil is excavated to the permafrost layer. A sand layer and timber pads are placed in the hole and then a layer of insulation to preserve the permafrost. A timber post serves as a support for the framing members of the building above. Presently, due to the warming of the permafrost which causes the permafrost layer to recede, this method quickly becomes ineffective and has lost favour in application. See Figure 2.

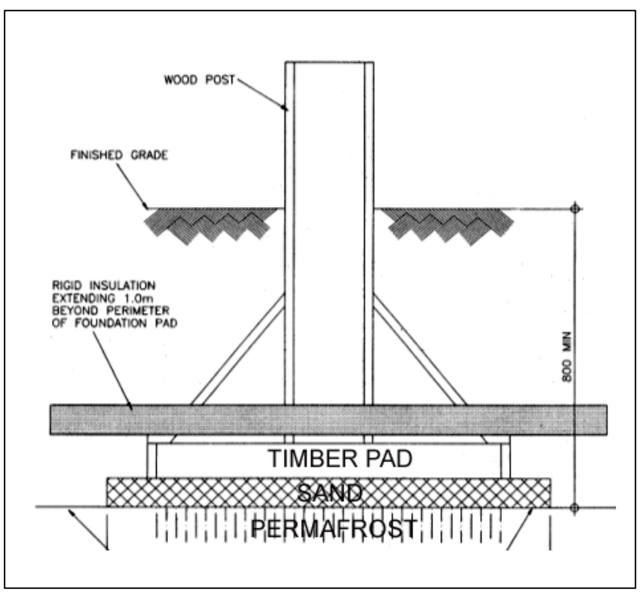

Figure 2: Post and Insulated Pad Foundation

2.3 Steel and Timber Piles

Either timber or steel piles are placed in drilled or augered holes and are backfilled with earth or a sand and water slurry and given time to freeze. This is called an add freeze pile. Although common in Northern regions the freeze thaw cycles and warming soils often interfere with the proper functioning of the piles and frequent adjustments have to be made to correct differential settlement between piles. See Figure 3.

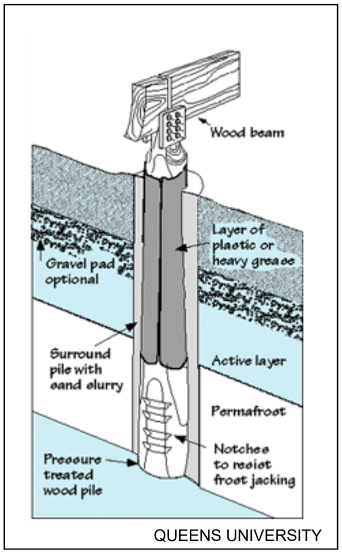

Figure 3: Steel or timber piles in permafrost

2.4 Thermosyphons

Thermosyphons are systems and devices which freeze the ground. Thermosyphons have been very effective in freezing the ground as well as keeping the ground frozen. Their use, so far, has been primarily for large buildings such as schools and large government buildings. They function on the basis of a heat exchange mechanism by extracting heat from the ground and discharging it into the atmosphere. The thermosiphon tubes are filled with a two phase liquid vapour and function as a convection heat transfer device. They are placed into drilled holes or are placed in a ground layer below the building. See Figure 4 and 5.

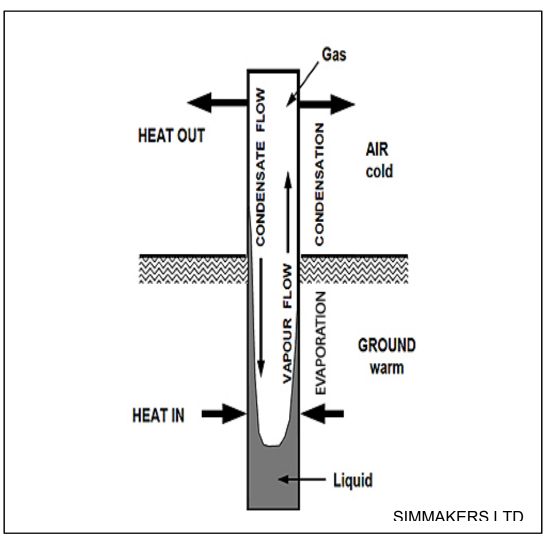

Figure 4: Thermosyphons

Figure 5: Thermosyphon Application

3. MULTIPOINT FOUNDATION FRAME

The foundation systems described in Section 2 above, except the Thermosyphon system, all have inherent issues with differential settlement. Buildings supported by independent points such as screw jacks, individual posts or piles understandably will have differential settlement issues especially with degradation of the permafrost. Some points under the building will have proper bearing supports were others will sink in the underlying soils causing major damage.

For the last 30 years a foundation frame has been developed which interconnects all support points into a large structurally sound frame. This frame acts like a raft and has torsional capacity to resist racking. The structural frame sits, by means of a large number of supporting points or pads on the native soil.

3.1 General Description

The foundation frame consists of an interconnected three dimensional tubular framework. Generally the depth of the frame is in the order of 36 inches or 900 mm. The bottom layer of the frame has a multitude of support points which rest on the ground. Not all support points need to be bearing on the soil. The frame is designed in such a way that it will function with less than 10% of the base plates bearing on the soil. The framework has the structural capacity to bridge over or cantilever away from areas of low bearing capacity. The building is bolted to the top of the frame and the entire assembly acts homogenously as one unit.

3.2 Structural Concept

The structure has a network of trusses which are interlaced and span in three directions. See Figure 6.

Figure 6: Intersecting trusses of the foundation frame.

By interconnecting the truss lines in three directions a rigid slab is created. If the ground sinks away in one corner of the building, the structure will span over this soft area and cantilever to keep the building intact. For instance, during spring thaws, localized flooding conditions may occur and cause soils to become saturated resulting in low to negligent soil bearing capacity. The rigid slab behaviour greatly enhances the frames capacity to resist differential settlement by sharing the loads of the building by means of a large number of interconnected support points.

3.3 Design Concept

We know that surface soil conditions are forever changing due to seasonal and climatic changes. To a large extent the design approach for this system ignores the soil conditions and focuses on providing structural strength to the building so that the entire unit has the capacity to bridge over problem soils or cantilever away from them. This approach is radically different from the prevailing design method which concentrates on the underlying soil conditions. It is acknowledged that an understanding of site conditions is helpful as it may influence site preparation or sizing of bearing plates. Where soft soils or wet conditions are prevalent, the bearing capacities of the soils are greatly reduced. These conditions benefit from timber pads which spread the loads over a larger surface area. See Figure 7 and 8.

Figure 7: Multiple support pads and frame to building connections.

Figure 8: Typical base support on larger timber pads.

3.3.1 Design Process

A computer model consisting of a geometric array is created and primary loads, including seismic loads are tabulated and placed at node points. See Figure 9. The entire assembly is supported by a multitude of support points. The support points are modeled as springs with a resistance factor based on the geotechnical information available.

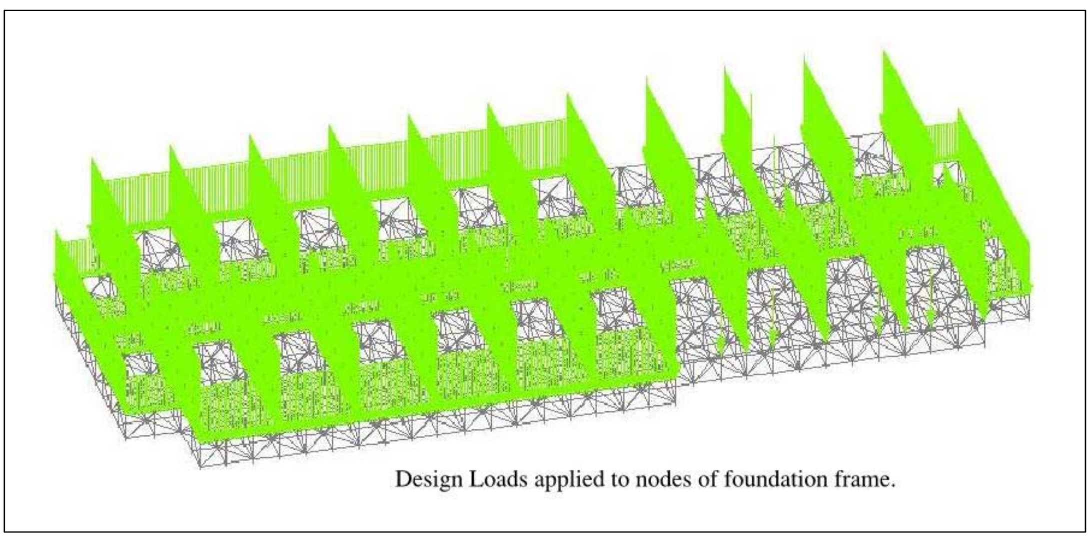

Figure 9: Foundation node points are loaded with design loads.

Numerous probabilities and scenarios of soil support and loading conditions are tested which provide detailed information on the anticipated reaction forces at each of the supporting points. The resulting information from this extensive analysis allows support plate dimensions to be determined based on the load bearing capacity of the soil.

3.3.2 Design Criteria of Base Supports

The design and development of this foundation system involved extensive computer modelling and a probability study on a variety of possible support conditions. Support conditions may range from full support to a condition where only half of the bearing points are doing all the work. Of course the ultimate bearing capacity of the soil influences the pattern of support. For instance if a particular support under load creates a condition of soil failure then immediately adjacent to this "failed" support an array of other supports will pick up the load creating a safe load bearing condition which in turn relieves the failed support converting it to a safe load situation. This progressively creates a condition of equilibrium and uniform bearing capacity. The support pads are 10" x 10" which is relatively small and in localized areas may overload the soils resulting in soil failure. This is in fact a desirable phenomenon as it results in further distribution of stresses throughout the three dimensional grid.

From the numerous loading patterns studied, a selection of structural components is made which satisfies the conditions of load and support for the lifetime of the building

4. CASE STUDIES
4.1 Case studies for Retrofit Construction

4.1.1. Inuvik Housing Log Buildings

Many buildings in the North are resting on timber piles. Over time these wood piles start to rot or start to sink into the warming soils. In order to prevent the buildings from totally deforming wood shims are added to the top of the beams to accommodate the sinking of the piles. The more shims are added the more the buildings become unstable. See Figure 10. It is virtually impossible to replace timber piles while the building is in place. It is however possible to place a tubular foundation frame under the existing building and systematically shift the weight of the building onto the foundation frame and then remove the timber piles. This is the exact process that was used at some 23 log buildings in Inuvik. The log buildings are now exclusively supported by the foundation frames and the weight of the building is distributed over an array of base plates on the existing terrain. See Figure 11.

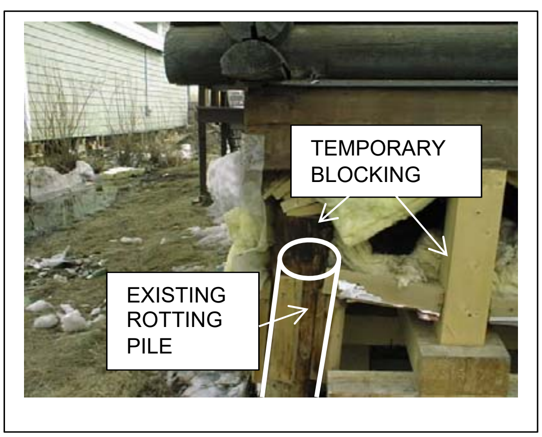

Figure 10: Before retrofit

Figure 11: After retrofit

4.1.2. Foundation re-built in Corte Madera, San Francisco Valley

A residence in the San Francisco Valley was built in a seasonally wet area. Traditional foundations are concrete slab on grade. Many homes in the area suffer from cracked foundation slabs and water infiltration due to the unstable soil conditions. An engineering study determined that a new reinforced concrete slab could possibly function as a new foundation for the building. The slab under consideration would need to be 12 to 18 inches (460 mm) thick. The weight alone of such a slab would contribute to excessive deflection and permanent settlement.

It was decided that the best solution would be to lift the existing home and place it on a modular tubular foundation. A Multipoint® Triodetic® foundation system was selected. Each supporting pad would be embedded and anchored to a thin concrete slab. The concrete slab in this case 5 inches (127 mm) thick, serves as a raft and improves the overall bearing capacity by uniform bearing distribution.

The existing residence was subsequently placed on the new foundation and skirted with timber panels to obscure the foundation frame. See Figure 12 and 13. Since the completion of this project the foundation has experienced two occasions of high tide washouts. No damage, deformation or settlement have been observed in this flood prone and muddy Bay site.

Figure 12: Tubular foundation frame and slab

Figure 13: Existing building on new foundation

4.2 Case studies for New Construction

4.2.1. Wha-Ti Community Centre in the North West Territories

Wha-Ti is a community on the edge of Lac LaMartre in the North West Territories. The site chosen by the community for their Community Centre was known for its difficult site conditions with a substructure of discontinuous permafrost. The shape of the building was also irregular making it a very good candidate for a modular foundation system which could be pre-fabricated to the specific architectural configuration of the building. See Figures 12 and 13.

Figure 14: Modular frame layout

Figure 15: Completed Wha-Ti Community Centre

4.2.2. Vancouver Three Storey Apartments

A critical shortage of affordable housing has created a need to develop and provide rapid deployment of housing units. The City of Vancouver has initiated a program where city owned sites are being developed to provide housing on a permanent or temporary basis. These buildings are all three storeys, constructed using prefabricated modular units. The entire assembly of units sits on a prefabricated modular foundation. See Figures 16, 17 and 18.

Some of the sites are located on underlying contaminated soils which cannot be disturbed making this application a perfect candidate for a foundation above ground. Other sloped sites require the foundation frame to be partially cut into the grade necessitating backfill against the foundation frame with a membrane and a weeping tile to evacuate ground water. See Figure 19. On some downtown Vancouver sites, the foundations and three storey apartments sit on existing pavement.

Figure 16: Modular foundation assembled

Figure 17: Modular housing units installed

Figure 18: Completed Building

Figure 19: Retaining Wall at Foundation

5. THE MODULAR SYSTEM DESCRIBED HEREIN

The system described in this paper is a Canadian system with a long history of building modular frameworks for domes and spaceframes. Applications of the system for foundations have been used for the last 30 years in permafrost regions. In problem soils areas as well as contaminated sites where soils cannot be disturbed the application is relatively new. The system is prefabricated to the exact parameters of the buildings and can be dismantled and moved to another site if required. See Figure 20 for a typical connection and 21 for a close up of the framework.

Figure 20: Typical Joint

Figure 21: Assembled frame work showing beam support line.

6. CONCLUSION

New applications of this foundation frame, such as the foundation frames for three storey apartment buildings, confirm its consistent structural performance under even the worst soil conditions. Field tests and field observations over the last thirty years have shown such a frame resists differential settlement and preserves the building envelope. Since minimum site preparation and geotechnical input is required, the space frame is a reliable and economic alternative to pile foundations.

At present three story buildings with a footprint in the order of 22,500 square feet (2,100m2) have been successfully constructed.

The foundation frame concept described herein represents a real breakthrough in eliminating differential settlement and presents a dependable alternative to housing authorities and builders constructing on permafrost, contaminated soils and unstable soils.

References

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