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Frost Effects on Solar Farms in Canada and their Rehabilitation

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Abstract: Solar PV farms are a cheap source of renewable energy where the energy released by the sun is harnessed as electricity by the solar photo-voltaic panels and transmitted through the transmission systems. Generation of renewable energy through the solar photo-voltaic systems has gained popularity steadily with the ever-increasing number of such facilities being installed worldwide as the costs of solar photo-voltaic panels has kept downward trends. Generation of renewable energy by the use of solar PV panels is one of the cheap sources of renewable energy and such facilities are 100% recyclable on completion of their design/ contract period with negligible effects on the land, surroundings and the environment. These facilities are fully compliant sustainable resources. Renewable energy generation through the solar PV systems are quite popular in the province of Ontario in Canada which has become a popular location for setting up such renewable energy facilities. Strong growth in this sector is led by the strong initiatives of the Government of Ontario for sustainable development and its extremely attractive rates offered for generation of renewable energy through Ontario Hydro's popular Feed-In Tariff (FIT) Program. A large number of Solar PV Facilities are already generating carbon free energy in Ontario while many more are under various stages of development. Such facilities typically vary from 3MW to up to 10 MW for typical utility scale ground mounted systems though few facilities up to 260MW have also come up. Roof mounted systems generally vary from a few kilowatts to around a megawatt, depending on the size of the building roof area. The present official trend is to promote larger sized ground mounted solar PV generating facilities up to 200MW instead of smaller ones.

Typical utility scale ground mounted solar PV facilities usually comprise of solar PV panels mounted on series of racking tables supported on foundations mostly comprising of partially embedded steel pipes being the cheapest and most practical option. The governing loads for the foundations of these lightly loaded solar PV structures are usually frost loads especially in areas comprising silty/ clayey soils where large adfreeze stresses develop due to frost, resulting into uplift of foundation piles. Typical winter conditions in Ontario are harsh with extreme frost conditions in most areas which poses unique issues for design and construction of such farms. Being a relatively newer technology, the procedures, codes and standards for design and testing of lightly loaded solar PV structures are still being formulated. In the absence of any specific codes and standards regulating the design aspects of these lightly loaded solar PV structures with frost uplift being the governing load in almost every case for Ontario, Canada, frost heaving and its effects often create adverse conditions for these structures thereby affecting the production and continuous supply of renewable energy to the cities and towns in vicinity who purchase this energy. Due to larger depths of frost penetration in extreme winter conditions, understanding the action of frost and related development of ad-freeze on these lightly loaded pile foundations is extremely important. Many such Solar PV facilities have experienced frost uplift of foundation piles either during the construction phase or during its lifetime. Rehabilitation of such piles affected by frost is also a relatively newer issue with varied handling techniques being followed.

This paper investigates these unique issues related with the uplift of the foundation piles of the solar PV facilities and looks into the effects of uplift of the piles along with suggesting various options/ methodologies for rehabilitation of such piles affected by frost, which are presented in this paper. The authors have been involved in design reviews, pile selection/ design and pile load testing in the majority of the solar PV farms either operational or under construction in Ontario along with being heavily involved with the rehabilitation of solar PV farms affected by pile heaving issues [1, 2, 3].

Keywords: Renewable Energy, Solar PV, Racking Table Foundations, Panel Tables, Solar Panels, Foundation Piles, Rehabilitation, Frost effects

I. INTRODUCTION

It is now being widely understood that achieving sustainability is the best course going forward and is in the best interest of the humanity. Renewable energy is an important part of sustainable development and practices and carries a lot of interest worldwide. Wind and solar photo voltaic energy generation facilities are now a popular source of renewable energy in many parts of the world along with other renewable energy sources. Such facilities are gaining increasing popularity in the energy starved regions and countries around the world especially in many African, Asian and South American countries. The province of Ontario in Canada is one of the most sought-after locations for setting up renewable energy facilities because of its strong initiatives for sustainable policies and development. Ontario Hydro's popular Feed-In Tariff (FIT) Programme offers extremely attractive rates for renewable energy generated through such facilities. In addition to wind, numerous Solar PV renewable energy generation facilities are in various stages of development in Ontario, Canada. These solar PV renewable energy generation facilities are usually commissioned/ contracted for 20/25 years. Another major advantage of these facilities is that they are fully recycled at the close of the contract/ design life since almost every component of these facilities is recyclable.

Typical construction of the utility scale Solar PV facilities comprises of rows of solar PV panels mounted on racking tables connected in series and supported on foundations usually comprising of partially embedded steel pipes being a cheaper option. Rows of solar panels are connected through wires which take the DC generated through combiner boxes to inverter houses where inverters convert DC to AC. This AC is passed through step up transformers to raise the voltages suitable to be fed to the main utility lines to which the output is to be fed through a switching control and metering system. Suitable panel types with varying capacities from 77watts to 350watts are oriented in portrait or landscape orientations in various combinations of 2 to 4 panel heights in rows of racking supported on racking foundations. Fixed racking is common in Ontario with very few farms with sun trackers installed to move racking to face sun during the day.

The partially embedded foundation piles typically used for ground mounted systems may be fully driven into soil or installed in pre-drilled holes in hard soils and/or areas with boulders/cobbles and rock. Under reamed piles with concreted base are solutions for areas where sufficient resistance to uplift cannot be provided by straight piles but are slightly expensive as compared to straight pile options and are difficult to be installed in sandy soils without additional measures. Helical piles are also an option for cohesive and sandy soils however the helixes are likely to be damaged in soils containing cobbles/ boulders. Due to the large amount of piles, typically around 5000 piles for a 10MW solar PV farm, EPC contractors prefer steel piles, whether plain, screws or helical, since they can be installed fairly quickly since usual duration to complete a 10MW (usual size of farms being built in Ontario) is around 18 to 24 weeks including commissioning. In most cases, 2.75m to 4m embedment of 114mm to 125mm diameter steel pipes in dense granular and clayey soils usually produce the desired uplift resistance with or without 200mm diameter concrete jacketing usually carried out around the embedment depth. In case bedrock is available in near depth, the piles are anchored in bedrock through rock sockets which provide sufficient resistance against uplift. Most helical and screw piles with similar shaft sizes of around 114mm to 125mm diameters are commonly used in solar industry.

While the development of codes and standards for design and testing of these lightly loaded solar PV structures still need to be formulated, severe winters and extreme frost conditions in certain areas in Ontario poses unique issues with design and installation of these pile foundations. Frost uplift is usually the governing load in almost every case for these pile foundations in Ontario, Canada. Mechanics of adfreeze forces and their extent/magnitude is not very well understood by the developers, which usually creates issues with the design and testing of pile foundations for solar panels. In the absence of specific design codes/ regulations governing the design/ testing of such solar PV facilities, differences usually erupt between EPC contractors and designers/ owners/ buyers on design and testing of these foundation pile structures. Due to larger depths of frost penetration in extreme winter conditions and thereby resulting frost heaving and its effects may create adverse conditions for these structures thereby affecting the production and hence the continuous supply of renewable energy to the cities and towns which purchase this energy. This paper investigates these unique issues related with the uplift of the foundation piles of the solar PV facilities and looks into the effects of uplift of the piles along with suggesting various options/ methodologies for rehabilitation of such piles affected by frost.

II. THE PHENOMENON OF FROST HEAVING

Seasonal freezing of ground in cold weather is a common phenomenon in cold regions. As the ground freezes the surface of the ground may rise which is termed as "frost heaving." Upward displacement of the ground upon freezing is due to the freezing of water originally contained in the soil voids along with formation of clear-ice segregations in the soil. Ice segregations form as water is drawn to points of freezing continually from adjacent unfrozen ground due to lowering temperature gradients which permits the growth of such segregations.

As the freezing isotherm descends through the ground, water is changed from liquid to solid. The amount and location of frost heaving depends upon three factors mainly being the temperature of the air and the texture and moisture content of the ground. The most favorable condition for growth of ice segregations and for frost heaving is slow freezing of moist nonhomogeneous organic silt or silty clay. The freezing soils exert an upward force on the foundations due to the adfreeze stresses developing around the periphery of the foundations. When ground is forced upward during seasonal freezing, engineering structures are also forced upward if the forces acting upward are greater than the forces pushing the structure downward. With piles, the amount of the upward force depends upon:-

The amount of clear-ice segregations formed in the seasonally frozen ground,

The tangential ad-freezing strength, or bond, between the surface of the pile and the seasonally frozen ground, (3) The surface area of the pile in the seasonally frozen ground.

The main factor opposing the upward force is the grip of the ground on that part of the pile which lies below the seasonal frost. This grip is usually the "skin friction" of unfrozen ground. The tangential ad-freezing strength of frozen ground varies with the texture and moisture content of the sediment, temperature of the ground, and nature of the pile surface. It is strongest in ice-saturated fine sand and silt. The colder the ground, the greater the ad-freezing strength. Differential movement of piles is of paramount problem; since such action produces extensive damage to many engineering structures.

Effects of frost heaving can be devastating. Frost heaving has displaced wood piling upward as much as 14 inches in a single winter season on an Alaska railroad bridge near Fairbanks, Alaska. About 24 inches of frost heaving of piles has been recorded in a single year in Russia. About 8” of uplift has been recorded for a bridge piles at Norman Wells, Northwest Territory, Canada. The maximum recorded cumulative heaving of a pile in a Russian bridge is about 6½ feet. Piling of a bridge, 8 miles southeast of Big Delta, Alaska, has frost heaved by 11 feet. Frost heaving combined with wind uplift can overturn communication towers as shown in Figure 1 below.

Because of skin friction, and because unfrozen ground below the piles squeezes into the void left as the pile rises, the base of the pile does not return to its original position in summer [4].

Fig 1:- Tower foundation failing under effects of uplift and frost.

III.ESTABLISHING FROST HEAVING OF PILES AND ITS EFFECTS

A close visual inspection of the foundation piles is usually required to establish whether frost heave of the piles has occurred. Such inspections of solar PV facilities are usual when some of the circuits/ arrays in renewable generating solar PV facilities stop producing current or following an extreme event and at the end of every winter season. During such inspections, piles, combiner boxes and their wiring, solar panel racking and the joints where wires connect are closely inspected. Moving out of piles can be felt at the pile-grade interface, damage of combiner boxes at pile-box connections and wires at sockets getting into tension/ breaking, wire connections getting taut/ broken at the junction of racking/ panel connection, bending of racking beams along the longitudinal axis due to differential uplift of the piles.

In case some piles are visually observed to have heaved, a complete survey of the area is usually carried out to establish the extent of damage and the precise amount of heave which has occurred. Figure 2 below indicates a pile which has been affected by frost. It is quite rare that complete rows of piles experience uniform heave, though such heave will not create much of issues for the facility. Usually a number of piles in each row will experience pile heave while others will not be affected. The piles experiencing heave are usually observed to experience different values of uplift which are rarely uniform as can be seen in Figure 3. The generally acceptable limits of pile heaving are 36mm of differential heaving based on IEC 61646 (Thin-film terrestrial photovoltaic (PV)

Modules – “Design qualification and type approval”) since beyond these limits, excess torsional stresses are induced in the solar panels along with additional flexural stresses induced in the racking beams possibly causing structural damage in addition to the connecting wires and connections getting into failure/breakage due to induced tension.

IV. DESIGN VERIFICATION

Having established the extent of damage, the next phase usually is to verify the design/ establish reasons for heaving of piles which is carried out in following steps:-

A. Establishment of maximum frost depth for the area
B. Confirmation of factored design loads calculated based on wind, dead and ad-freeze loads
C. Confirmation of pile resistance
D. Review of pile load testing and pile installation procedures

Maximum frost depth at various locations in Ontario, Canada are specified by OPSD 3090-100 &101 which remain to be the most comprehensive data supported by extensive ground measurements over a prolonged period of time, and supported by numerical modelling and mathematical calculations with regards to maximum frost depths in Ontario. Having established the frost depth, frost load is to be calculated based on realistic ad-freeze stress values which need to be sensibly adopted against the appropriate soil type and the pile material as follows:

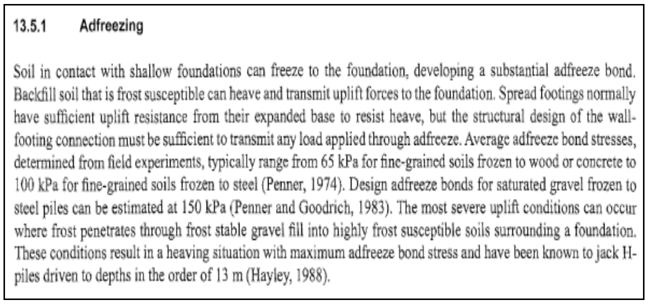
Figure 2. A pile moving out due to frost. The movement can be observed at the base of the pile.

Figure 3. Piles affected by frost showing deformation of the racking.

$F = \pi d l * \alpha$

Where F = Frost load, d = Outer diameter of pile, l = Frost depth and α = Ad-freeze stress (KPa) for the appropriate soil type, taken from Canadian Foundation Engineering Manual [5].

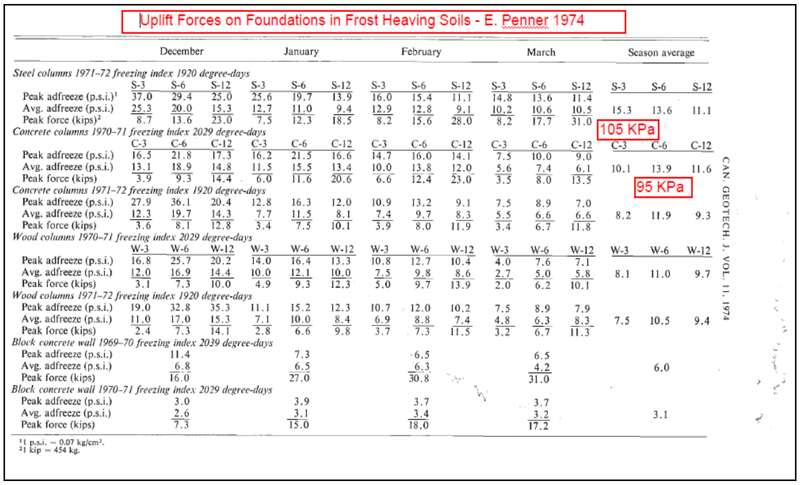
The estimate of ad-freeze stresses has to be sensibly made between the average values given in the CFEM as shown in Figure 1 below and the actual ad-freeze stress values observed in field testing by Penner, 1974 [6] as given in Figure 2 for clayey silts (70:30 ratio) and Penner and Goodrich, 1983 [7] as given in Figure 3 for frozen gravels adhering to piles, based on which the average values are given by CFEM. Whilst selecting appropriate values of ad-freeze stresses, it may be noted that the most favorable condition for growth of ice segregations and for frost heaving is slow freezing of moist nonhomogeneous organic silt or silty clay for which no values are given in CFEM.



13.5.1 Adfreezing

Soil in contact with shallow foundations can freeze to the foundation, developing a substantial adfreeze bond. Backfill soil that is frost susceptible can heave and transmit uplift forces to the foundation. Spread footings normally have sufficient uplift resistance from their expanded base to resist heave, but the structural design of the wall-footing connection must be sufficient to transmit any load applied through adfreeze. Average adfreeze bond stresses, determined from field experiments, typically range from 65 kPa for fine-grained soils frozen to wood or concrete to 100 kPa for fine-grained soils frozen to steel (Penner, 1974). Design adfreeze bonds for saturated gravel frozen to steel piles can be estimated at 150 kPa (Penner and Goodrich, 1983). The most severe uplift conditions can occur where frost penetrates through frost stable gravel fill into highly frost susceptible soils surrounding a foundation. These conditions result in a heaving situation with maximum adfreeze bond stress and have been known to jack H-piles driven to depths in the order of 13 m (Hayley, 1988).

Figure 4. Average ad-freeze stresses given by Canadian Foundation Engineering Manual.



Uplift Forces on Foundations in Frost Heaving Soils - E. Penner 1974

	December			January			February			March			Season average		
Steel columns 1971–72 freezing index 1920 degree-days															
	S-3	S-6	S-12	S-3	S-6	S-12	S-3	S-6	S-12	S-3	S-6	S-12	S-3	S-6	S-12
Peak adfreeze (p.s.i.)[1]	37.0	29.4	25.0	25.6	19.7	13.9	16.0	15.4	11.1	14.8	13.6	11.4			
Avg. adfreeze (p.s.i.)	25.3	20.0	15.3	12.7	11.0	9.4	12.9	12.8	9.1	10.2	10.6	10.5	15.3	13.6	11.1
Peak force (kips)[2]	8.7	13.6	23.0	7.5	12.3	18.5	8.2	15.6	28.0	8.2	17.7	31.0			
Concrete columns 1970–71 freezing index 2029 degree-days															
	C-3	C-6	C-12	C-3	C-6	C-12	C-3	C-6	C-12	C-3	C-6	C-12	C-3	C-6	C-12
Peak adfreeze (p.s.i.)	16.5	21.8	17.3	16.2	21.5	16.6	14.7	16.0	14.1	7.5	10.0	9.0			
Avg. adfreeze (p.s.i.)	13.1	18.9	14.8	11.5	15.5	13.4	10.0	13.8	12.0	5.6	7.4	6.1	10.1	13.9	11.6
Peak force (kips)	3.9	9.3	14.4	6.0	11.6	20.6	6.6	12.4	23.0	3.5	8.0	13.5			
Concrete columns 1971–72 freezing index 1920 degree-days															
Peak adfreeze (p.s.i.)	27.9	36.1	20.4	12.8	16.3	12.0	10.9	13.2	9.1	7.5	8.9	7.0			
Avg. adfreeze (p.s.i.)	12.3	19.7	14.3	7.7	11.5	8.1	7.4	9.7	8.3	5.5	6.6	6.6	8.2	11.9	9.3
Peak force (kips)	3.6	8.1	12.8	3.4	7.5	10.1	3.9	8.0	11.9	3.4	6.7	11.8			
Wood columns 1970–71 freezing index 2029 degree-days															
	W-3	W-6	W-12	W-3	W-6	W-12	W-3	W-6	W-12	W-3	W-6	W-12	W-3	W-6	W-12
Peak adfreeze (p.s.i.)	16.8	25.7	20.2	14.0	16.4	13.3	10.8	12.7	10.4	4.0	7.6	7.1			
Avg. adfreeze (p.s.i.)	12.0	16.9	14.4	10.0	12.1	10.0	7.5	9.8	8.6	2.7	5.0	5.8	8.1	11.0	9.7
Peak force (kips)	3.1	7.3	10.0	4.9	9.3	12.3	5.0	9.7	13.9	2.0	6.2	10.1			
Wood columns 1971–72 freezing index 1920 degree-days															
Peak adfreeze (p.s.i.)	19.0	32.8	35.3	11.1	15.2	12.3	10.7	12.0	10.2	7.5	8.9	7.9			
Avg. adfreeze (p.s.i.)	11.0	17.0	15.3	7.1	10.0	8.4	6.9	8.8	7.4	4.8	6.3	8.3	7.5	10.5	9.4
Peak force (kips)	2.4	7.3	14.1	2.8	6.6	9.8	3.7	7.3	11.5	3.2	6.7	11.3			
Block concrete wall 1969–70 freezing index 2039 degree-days															
Peak adfreeze (p.s.i.)		11.4			7.3			6.5			6.5				
Avg. adfreeze (p.s.i.)		6.8			6.5			6.3			4.2			6.0	
Peak force (kips)		16.0			27.0			30.8			31.0				
Block concrete wall 1970–71 freezing index 2029 degree-days															
Peak adfreeze (p.s.i.)		3.0			3.9			3.7			3.7				
Avg. adfreeze (p.s.i.)		2.6			3.1			3.4			3.2			3.1	
Peak force (kips)		7.3			15.0			18.0			17.2				

[1] 1 p.s.i. = 0.07 kg/cm².
[2] 1 kip = 454 kg.

105 KPa

95 KPa

CAN. GEOTECH. J. VOL. 11, 1974

Figure 5. Taken from Paper “Uplift Forces on foundations in frost heaving soils”, by Penner. E., Canadian Geotechnical Journal, Volume 11, No.3, 1974 based on which CFEM values of Average ad-freeze bond of 65kPa for concrete and 100kPa for steel have been suggested in fine grained soils.

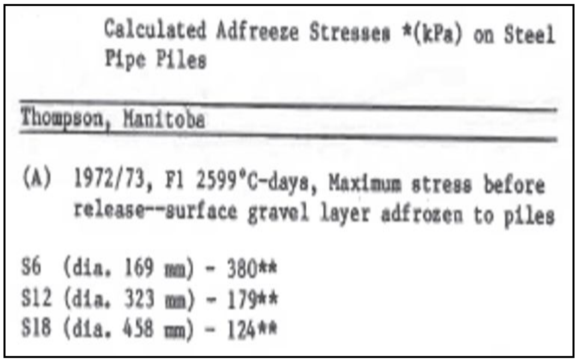
The pile resistance is calculated based on pile load tests and/or the geotechnical investigations report for the depth of the pile embedded below the frost depth. An average value of soil resistance obtained from the pile load tests may be used to calculate the resisting capacity of the piles for the embedment length below the frost depth however, the safe pile resistance must be derived considering the geotechnical factors suggested in Canadian Foundation Engineering Manual as follows [3]:- (Ref my paper on design of piles).

Safe Pile Resistance = $\pi d L * \frac{\beta}{GF}$

Where d = Outer diameter of pile, L = the embedment length of pile below the frost depth, β = Average soil resistance (KPa) obtained from pile load tests and GF is the appropriate geotechnical resistance factor taken from Canadian Foundation Engineering Manual.

A review of the on-site pile load testing results carried out based on ASTM D3689, D1143, D3966 [8, 9, 10] will indicate the soft spots in the area along with the performance of the piles during load testing while review of the pile installation procedures will indicate possible reasons for pile heaving like inadequate applied torques to helical/ screw piles, inadequate curing/ strength development of concrete jacketing, use of sand/ crush stone around screw or helical piles for anchoring, sloughing of the drilled holes/ high ground water levels etc.

A comparison of the pile resistance capacity with the factored design loads along with review of pile load testing and pile installation procedures will indicate the possible reasons for pile heaving at the site for which an appropriate remedy has to be carried out. It must be considered that filling up the predrilled hole with granular aggregate/ crush and thereafter installing the helical or screw pile will be guided by the ad-freeze values for frozen granular / aggregate around the pile which is much higher than the frozen silty/clayey soils around the pile.



Calculated Adfreeze Stresses *(kPa) on Steel Pipe Piles

Thompson, Manitoba

(A) 1972/73, FI 2599°C-days, Maximum stress before release--surface gravel layer adfrozen to piles

S6 (dia. 169 mm) - 380**
S12 (dia. 323 mm) - 179**
S18 (dia. 458 mm) - 124**

Figure 6. Taken from Paper "Ad-freezing Stresses on Steel Piles, Thompson, Manitoba" by Penner, E. & Goodrich, L.E., Proceeding of Fourth International Conference – Permafrost, Fairbanks, Alaska, July 17-22, 1983. Average design ad-freeze bond values for saturated gravel frozen to steel piles of 150kPa given by CFEM based on these test results.

V. SURVEY OF REHABILITATION METHODS AVAILABLE

There are two types of measures required for rehabilitation of piles which have heaved under the effect of frost which are:-
Short term measures include pushing the heaved piles back to their original position.
Long term measures include mitigation techniques to avoid any pile heaving issues in the long term.

A. Short Term Measures

In the short-term rehabilitation measures, the piles which have moved out beyond tolerances (36mm maximum as indicated in Section 3 above) due to frost heave have to be pushed back to their original position. Pushing back piles is a tedious issue since it requires panel tables fixed on top of the foundation piles to be removed which involves switching off of few circuits resulting into production losses. Some solar PV facilities constructed earlier and facing frost heaving issues with piles had to resort to this sort of rehabilitation since many piles at these sites moved out by 75mm to over 100mm (mostly differentially) thereby exerting additional stresses on the racking, distortion on the panels and tension on the connecting wires. To overcome this issue of pushing back the piles without having to remove the panels, few contractors in Ontario developed some kind of extension to be connected to the backhoe or hydraulic pile driver by the help of which the piles can be pushed back to their original position without having to remove the panels. This development saves loss of production at few of the sites facing pile heaving issues due to frost

B. Long Term Measures

Having completed the short-term measures, following long term measures are usually undertaken to mitigate the frost heave issue possibly for ever.

1) *Addition of dead load/ counter weight to the pile to overcome frost loads. :* Addition of dead load on the piles equivalent to the frost ad-freeze force creating uplift can prevent the effects of frost on the piles. This dead load can be added at or above the grade level of the partially embedded pile which will act as a counterweight against the frost load pushing the pile out of ground thereby maintaining an equilibrium. A usual form is concrete/ masonry blocks placed on welded arm plates with the piles. The solar arrays are not usually affected by this type of rehabilitation and the electricity may keep flowing through the system while the rehabilitation works are carried out.
2) *Strengthen existing piles by replacing with longer piles. :* Increasing length of piles embedment beyond the frost depth increases the resistance of the piles to pull out hence preventing them from any frost uplift effects. Existing piles are withdrawn and replaced on site with longer piles providing greater resistance as designed for the appropriate design loads based on sensibly selected ad-freeze stresses. Increased length of pile below the depth of frost will provide greater resistance. For this

type of rehabilitation works, groups of solar arrays have to be switched off during the period rehabilitation is carried out. Usually solar panels & racking has to be removed from the piles and may be temporarily held in place while new piles are installed. Switching off of groups of arrays in this type of rehabilitation can cause losses in terms of lost energy to the owner

3) *Installing additional piles adjacent to existing piles. :* Another way of strengthening the existing piles is to drive another longer pile adjacent to the existing pile and connect both the piles for added resistance. This procedure may not require any switching off of solar arrays hence the flow of energy may continue while the rehabilitation works can continue, however, this will require a connection design between the new and the existing pile so as both the piles can resist upward/ downward forces jointly
4) *Under reaming and concreting.:* Rehabilitation of existing piles through under reaming and adding concrete at the base to improve their uplift capacity is another way of strengthening the piles. In this process, soil around the existing piles is removed from one direction and a void is created around the base of the pile once the excavation reaches the bottom of the pile. A pre-designed quantity of concrete is then added at the base of the pile and the soil is thereafter backfilled and compacted in layers. The extended base is designed to provide sufficient resistance to uplift due to the weight of the concrete in addition to the weight of the soil cone above the concrete base. Necessary arrangements to hold the pile during this process will have to be arranged so as the energy keeps flowing through the system during the rehabilitation works are carried out otherwise switching off of groups of arrays can cause loss to the owner in terms of lost energy
5) *Restrict frost penetration around the piles by insulation.:* There are two methods of placing the insulation around the piles: - Placing insulation around the pile horizontally along the grade It is a common practice in the building industry to restrict frost penetration by extending the insulation horizontally, equal to the maximum frost depth in the area, around the buildings. Similar methodology is followed for restricting the frost penetration in the soil around the foundation piles. Using the methodology of insulation design around the buildings, a width of insulation equal to the maximum depth of frost penetration is designed for appropriate thickness according to the maximum freezing degree days from graphs given in certain books [5, 11]. This insulation is laid horizontally around each pile at an appropriate depth, usually 300mm below grade. The insulation is then covered by a layer of soil above to protect it. The insulation eliminates the frost penetration around the piles thereby reducing or eliminating the effects of frost. Though the solar arrays are not affected during the period this type of rehabilitation is carried out however, the placing of insulation in this manner is occasionally objected by environmental engineers since it reduces the effective area through which the percolation of storm water runoff is reduced thereby increasing the run off volumes for which a review of the storm water management may be required to be carried out. Placing insulation around the pile through the frost depth This method of frost mitigation requires the removal of soil around the piles up to the frost penetration depth levels and placing of insulation around the piles so as the freezing isotherms are contained by the insulation without any freezing of the soil to the pile surface thereby avoiding any ad-freeze forces to develop on the pile. Appropriate thickness of insulation according to the maximum freezing degree days from graphs given in certain books is selected [5, 11]. Necessary arrangements of holding the piles in place during the soil removal/ backfill/ compaction and placing of insulation will have to be made hence solar arrays may not have to be disconnected and energy may keep flowing whilst the rehabilitation works continue. After placing the insulation around the pile, the backfill is placed in layers and compacted accordingly.
6) *Adding frost sleeves to existing piles. :* Of sleeves around the piles through the frost zone helps the frozen soil move freely around the pile without exerting any uplift forces on the piles. Such methods are extensively followed in permafrost regions [9]. Sonotubes, PVC or LDPE/ HDPE sleeves usually wrapped in three concentric layers of polyethylene (10 mils usual thickness) with a dense/generous layer of lubricant like non-biodegradable petroleum jelly/ grease on the sleeve and between the layers is applied to the piles through the frost depth typically. The frozen soil around the sleeve thereby can freely move up & down in a frictionless manner with no contact with the pile hence preventing any ad-freeze forces to develop. Carrying out this type of rehabilitation on site is a bit of an issue but is possible. Existing piles will have to be held in place during the process the soil is removed from around the pile through the frost depth and frost sleeves are installed. It is possible to install the PVC/ HDPE/ LDPE sleeves in two halves around the piles and appropriately tapping them together or joining them by the help of adhesives. Layers of polyethylene appropriately lubricated are wrapped around the PVC/ HDPE/ LDPE sleeves, tapping the final edge of the polyethylene all along the length of the sleeve. The backfill is thereafter placed in layers and appropriately compacted to around 80 to 85% of SPMDD if it is open area and 95% if a road/ track exists along the solar arrays.

VI. SELECTION OF APPROPRIATE REHABILITATION METHOD FOR THE SITE

Having considered all the possible rehabilitation techniques, usually the best suited and economically viable technique for which local expertise is available, is adopted for which an appropriate design and application methodology are devised. For such cases, design loads usually comprise of wind uplift mainly minus the gravity loads, having eliminated ad-freeze forces on the piles. Compressive loads rarely govern the loads on these lightly loaded solar PV racking structures. Elaborate marking of the piles to be rehabilitated has to be carried out indicating the existing levels and levels after rehabilitation. Necessary safety precautions have to be undertaken to protect the racking and the solar PV panels during the process of rehabilitation.

VII. CONCLUSION

Severe winters and extreme frost conditions in Ontario, Canada pose unique issues with design and installation of pile foundations commonly used for solar PV racking structures. Frost uplift is usually the governing load, the mechanics of adfreeze forces and their extent/magnitude is not very well understood by the developers, which usually creates issues with the design and testing of pile foundations for solar panels. Due to larger depths of frost penetration in extreme winter conditions and thereby resulting frost heaving and its effects may create adverse conditions for these structures thereby affecting the production and hence the continuous supply of renewable energy to the cities and towns which purchase this energy. The development of codes and standards for design and testing of these relatively recently and lightly loaded solar PV structures still need to be formulated.

A thorough investigation into the reasons for uplift of piles followed by selection of an appropriate technique to rehabilitate frost affected piles can eliminate any such issues arising in the future. Many solar PV farms have faced uplift of piles due to frost and have been successively rehabilitated using various methodologies suggested in this paper. None of the solar PV facilities have any reported cases of frost heaving of any pile after the rehabilitation has been carried out.

Solar PV Farms are a great source of renewable energy to the towns and suburbs in which they are located. By following the best engineering practices, these Solar PV Farms can be erected with minimal effort in short durations. Over the years, most EPC contractors have become more experienced having faced issues at some of the solar PV farms along with most designers and quality of construction is improving with the understanding of the issues involved. Rapid construction and commissioning of these farms along with associated advantages of minimal maintenance, low running costs and higher returns has increased the interest of large investment houses and financial companies in this sector due to which a large number of such renewable energy facilities have come up while many more are in the development stage in various regions of Ontario in Canada.

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