COLD STORE FROST HEAVE - CAUSES AND SOLUTIONS

Ian Connor
Senior Structural Engineer and Principal, Kingston Morrison Limited, Christchurch

1. INTRODUCTION

Frost heave is upwards heaving or buckling of ground caused by freezing of groundwater. Frost heave can significantly reduce the value and operability of cold stores. Frost heave occurs when water in the soil freezes sufficiently to create suction to draw additional water into the soil matrix. The accumulation of this water, and its expansion on freezing can cause upward forces of such magnitude that they exceed the loadings from cold store floors above and create heaving. Frost heave requires susceptible soils, freezing temperatures, and water. Prevention of frost heave is much cheaper than trying to repair it, and involves removing one or more of these prerequisites.

2. DESCRIPTION OF FROST HEAVE

Frost heave is upwards heaving or buckling of ground caused by freezing of groundwater. The magnitude of the forces created can exceed structure and floor loadings from cold stores above causing serious damage. Frost heaving forces have been observed at 760 kPa and measured at 1,800 kPa [Andersland], far exceeding the floor loadings of approximately 50 kPa in a 9 m stud single-storey cold store typical in New Zealand. Water expands approximately 9% on freezing - insufficient in itself to cause such frost heave when water may only be 20% or so of the volume of soil. Frost heave occurs when additional water is drawn into the soil matrix as it freezes, accumulating as lenses of ice and creating expansion forces which exceed the loadings from cold store floors above and create heaving. In fine-grained silty soils, upwards heave of ground can be up to 100% [Yong] of the depth of frozen soil - with consequent damaging effects on any structures above.

The mechanism of frost heave is a complex process involving the interaction of soil, water, and freezing temperatures. As the temperature in soil under a cold store lowers below 0°C, water in the soil will begin to freeze. This water is comprised of free water in the pores between soil particles, and adsorbed water existing as a thin film of chemically bonded water around soil particles. The free water, being purer, freezes first. The freezing will begin as a "bud" or minute crystal of ice which will grow as the free water within a pore freezes around it. As freezing progresses, these frozen "buds" grow and begin to encroach on the adsorbed water around soil particles. This sets up an osmosis-like suction drawing free water from adjacent soil pores into the "bud" which grows to form a lens of ice. This suction force also draws water from the warmer layer of soil below, drying the surrounding soil.

The flow of water towards the growing ice "bud" occurs in a "fringe" of partially frozen soil immediately below the frozen soil. It assists to understand the process by thinking of the heat and mass flow [Yong, Forland, Yershov] that occurs. The flow of water towards the frozen soil from the wet unfrozen soil below is a process of heat flow towards the cold store above. "Warm" water migrates through the pores of the soil structure towards the frozen fringe where it freezes, releasing heat [Konrad]. The formation of ice occurs above the 0°C isotherm - in the frozen fringe where water and ice exist together [Piper]. There is a range of explanations for what causes the migration of water towards the frozen fringe:

i) The most commonly accepted explanation [Andersland] is that when water freezes at the lower edge of the frozen soil, it creates a pressure deficiency across the frozen fringe by forcing the soil particles apart.

ii) Another view [Wallace] is that the formation of ice dries the ground below the frozen fringe, and that water flow from wet soil below to the dry zone by capillary action. This mechanism fits well with frost heave occurring in soils with less than 100% moisture content [Wallace].

iii) With the freezing of part of the adsorbed water around soil particles, it also appears possible that some of this suction may be due to water flowing in to dilute the more concentrated adsorbed water in a similar fashion to what occurs in freeze-thaw breakdown of concrete [Connor]. As a result, depending on the permeability of the soil, water will flow up through the partially frozen zone towards the unfrozen adsorbed particle water in the frozen soil [Andersland, Konrad].

iv) In non-saturated soils, the differential vapour pressure between the cold frozen ground above frozen fringe, and "warm" soil, below will create a driving force for water vapour to migrate towards the ice front in similar manner to convection heat transfer into the cold store above.

If a "bud" of ice grows sufficiently it forces the soil particles apart and forms an ice lens, lying normal to the direction of heat flow [Yong]. The frozen fringe occurs at the bottom of the ice lens [Miller]. This ice segregation process continues to dry the free water out of the soil immediately below, but the lens will only grow as long as the suction forces exceed the adsorption forces of water to soil particles. The rate of water flow into the ice lens depends on the inter-relationship between the temperature and arriving water supply. If the temperature, soil and water conditions are suitable, these lenses in the soil can form as several layers spread throughout the soil matrix down to the frozen fringe. This cumulative process of attraction of water and formation of ice lenses is the process of frost heave. The maximum frost heave pressure is the pressure difference which stops the upward flow of water [Forland]. Steady state conditions will occur when an equilibrium is established between the incoming heat from the soil below and the heat flow into the cold store above.

3. WHAT CAUSES FROST HEAVE

Frost heave requires:

- susceptible soils - fine grained and permeable
- freezing temperatures, generally well below 0°C
- water

3.1 Susceptible Soils

Soil properties vary widely, with the proportion of adsorbed pore water to free pore water being the fundamental property of susceptibility of soils to frost heave action as described above. The assessment of this susceptibility can involve a variety of methods.

3.1.1 Soil Particle Size

From the process of frost heaving, the size of the soil pores is a measure of the susceptibility of a soil to frost heaving, and the proportion of free water in the voids to adsorbed water around the soil particles determines the magnitude of frost heave forces. As it is not possible to measure pore size, soil particle (grain) size is used a general classification for soils. Fine grained soils are potentially susceptible frost heave; coarse grained soils are less so.

On grain size basis, a frost susceptibility assessment is [Tscebotarioff]:

<u>Group A</u>: Non-frost susceptible soils
- clean gravels and sands which will not form "lumps" when dry
- less than 20% of soil particles smaller than 0.5 mm
- less than 3% of soil particles smaller than 0.02 mm

<u>Group B</u>: May be frost susceptible
- fine sands, silty sands, organic sands which will form weakly cemented "lumps" on drying which can be picked up by hand but which easily crumble
- 20 - 30% of soil particles smaller 0.02 mm

<u>Group C</u>: Frost susceptible soils
- cohesive soils and organic muds
- more than 30% of soil particles smaller than 0.5 mm
- more than 10% of soil particles smaller than 0.02 mm
- hard or very hard (stiff) soils when compacted at low water content

These soils are likely to frost heave unless high above the water table or the water content is low

3.1.2 Permeability and Capillarity

Permeability of soils is a major factor in the frost heave potential of a soil - water must be able to flow through the soil to allow for ice growth and frost heaving. Accepting the explanation of capillary flow described above as a significant contributor to frost heave, the relationship between permeability and capillarity provides a basis for assessing frost heave susceptibility of soils [Tscebotarioff].

Clean sands and gravels (coarse sands with particle sizes of 2.0 mm to 0.25 mm and larger) are not susceptible because of low capillary rise (assessed at 15 to 120 mm), and high permeability.

Silts (particle sizes 0.05 mm to 0.005 mm) are both permeable and have a high potential capillary rise (assessed at 610 mm to 6.1 m),. Fine sands (particle sizes 0.25 mm to 0.05 mm) are permeable with a lower capillary rise than silts (assessed at 120 to 610 mm), but can be susceptible, particularly when combined with silts as often occurs.

Clays (particle sizes 0.005 mm to 0.001 mm) have a high capillary rise (assessed at 6.1 m to 30.5 m), but low permeability. They are only frost susceptible when subjected to freezing temperatures over a long period as the low permeability inhibits the addition of water.

3.1.3 Segregation Potential

Generally grain size and permeability are used as measures of soil potential for frost heaving, but the potential for the water suction and ice segregation process of frost heaving can be defined by assessing a soils segregation potential [Konrad]. This is the ratio of the intake flux of water migration to the temperature gradient adjacent to the frozen fringe when the heat regime in the freezing soil has become stable. This measurement requires specific testing of soils.

3.1.4 Soil Frost Susceptibility

A general assessment of frost action susceptibility combining the above characteristics has been evolved using the Unified Soil Classification System (USCS - after A.Casagrande, 1948), modified by US Army Corps of Engineers [Andersland] - Table 1 below. This provides a general guide to which soils are particularly frost susceptible, but on all cold stores detailed site investigation is required to confirm soil properties. If temperature is low enough, and water is available, most fine grained soils have the potential to frost heave.

Table 1 US Army Corps of Engineers frost design soil classification system

Frost Susceptibility	Frost Group	Soil Type	% Soil particles finer than 0.02 mm (by weight)	Typical soil type un USCS[a]
Negligible to low	non-frost susceptible	gravels	0 - 1.5%	GW, GP
		sands	0 - 3%	SW, SP
Possibly	possibly frost susceptible	gravels	1.5 - 3%	GW, GP
		sands	3 - 10%	SW, SP
Low to medium	S1	gravels	3 - 6%	GW, GP, GW-GM, G GM
Very low to high	S2	sands	3 - 6%	SW, SP, SW-SM, SP-S
Very low to high	F1	gravels	6 - 10%	GM, GW-GM, GP-GM
Medium to high	F2	gravels	10-20%	GM, GM-GC, GW-G GP-GM
Very low to very high		sands	6 - 15%	SM, SW-SM, SP-SM
Medium to high	F3	gravels	> 20%	GM, GC
Low to high		sands, except very fine silty sands	> 15	SM, SC
Very low to very high		clays, plasticity index (I_p) > 12	-	CL, CH
Low to very high	F4	all silts	-	ML, MH
Very low to high		very fine silty sands	> 15	SM
Low to very high		clays, plasticity index (I_p) < 12	-	CL, CL-ML
Very low to very high		Varved clays and other fine-grained banded sediments	-	CL & ML; CL, ML & S CL, CH & ML; CL, C ML, & SM

a. G = gravel, S = sand, M = silt, C = clay, W = well graded, P = poorly graded, H = high plasticity, L = low plasticity

3.2 Freezing Temperatures

As indicated above, temperatures below freezing are required in the soil beneath a cold store to initiate frost heave. The actual heavi temperature can vary significantly depending on soil type and water proximity. For instance, at -20°C less than 2% of the water in silt w remain unfrozen [Yong], whilst at 0°C, only 7% of the water in silt will be frozen. To prevent freezing of the soil, the temperature needs to be ke above 0°C.

The heat flow under a cold store is generally from the soil to the cold store - the cold store is normally colder than the soil. The major heat inp is from the soil - warmed by ambient air above the ground, groundwater movement, and any heating under the cold store. The heat flow may relatively simply calculated once the soil properties - soil type, ambient temperatures, water presence/flow - are known [Andersland, Ruckli, Tomlin Oheim]

In addition to the storage temperature and ambient ground temperature, the rate and duration of application of heating and cooling from the sources has a major impact on the occurrence frost heave and how rapidly it develops. Fast freezing of subsoil freezes the water in the subsoi but must be maintained for some time before the process of frost heave can occur [Feng]. The heat and mass flow/balance required to build i lenses and create frost heave explains this [Forland, Piper, Tomlinson, Feng], and the time required for frost heave to develop can be calculated if the relevan information is available. This time lag before frost heave develops has been confirmed by observation [Xu, Cooling]

Insulation under the cold store floor will tend to slow the cooling of subsoil under the cold store, but will not stop it. The long-accepted desig concept for underfloor insulation is to design for a temperature no lower 0°C at the under-side of the underfloor insulation [Ruckli]. This desig process, which establishes a profile for the isotherms in the soil under a cold store, will determine whether heating is required. Seasona variations in the ambient soil temperature require consideration also - heating may only be required during winter months (it is assumed co stores operate constantly all year round).

3.3 Water

Water is the "fuel" for frost heave - for ice lenses to grow and create frost heave there must be a supply of water. Water can accumulate in soi that are severely frost heaved to 4 or 5 times the natural water content of the soil [Johnstone]. The increased water content in frozen soil can b calculated [Andersland] based on the volume change and known depth of freezing. It is important to note that this additional water content will tak time to drain away as frost heave re-settles on thawing. Frost susceptible soils are normally relatively slow draining, so rapid thawing with a hig moisture content can lead to soil slumping.

The source of water is commonly natural groundwater, but other sources to provide the groundwater for frost heave growth to occur include rain water run-off, burst water pipes or blocked drains.

4. PREVENTION OF FROST HEAVE

Prevention of frost heave is much cheaper than trying to repair it and the measures required are relatively simple. These involve removing one or more of the prerequisites for frost heave:

- susceptible soils - fine grained and permeable
- freezing temperatures, generally well below 0°C
- water

4.1 Treatment of Susceptible Soils

Susceptible soil conditions under freezer floors should be avoided. For slabs-on-grade, normally the most cost-effective method of cold store construction in New Zealand, this commonly involves removing any fine grained silts, clays and fine sands to the maximum anticipated depth of frost penetration. The excavated susceptible soil is then replaced with compacted no-fines granular backfill. The granular backfill should exclude any silt or fine sand fraction - particle sizes below 0.25 mm [Andersland, Yong, Johnstone]. A coarser gravel-only layer may be used being a more effective drainage layer to prevent water rising near the underside of the cold store. This is common overseas practice also [Leonoff]

Alternative measures may be appropriate when susceptible soil replacement is not practical. Treatment of the soils with modifying agents may be appropriate. Dispersants, aggregants, or waterproofing agents may be mixed with subsoil under a cold store to make the soil more permeable or less permeable [Yong]. Salt addition may be an option as this has also been recorded as having an effect on frost heave susceptibility [Feng, Lu]. Soil modification by chemical/additive treatment modification would require extensive laboratory sampling and testing - it is not a common practice for modification of frost susceptible soils in New Zealand.

Physical modification of soils is common for other soil uses and may be appropriate for frost susceptible soils. Dynamic consolidation, as used for improvement of bearing properties of soils, has been applied to alter the properties of silty clays/clays [Han]. The application referred to lowered the water table of the silty clay/clay, and reduced the permeability of the treated layer, creating an impermeable soil layer under foundations to prevent frost damage. As for chemical soil property modification, the aim is primarily to modify the permeability properties of the soil to make it less susceptible to frost heaving.

New Zealand experience for a typical -20°C to -35°C cold store is to remove approximately 600 mm of potentially frost susceptible subsoil, and replace with no-fines granular backfill. This design has evolved from the detailed analysis of the heat flows [Ruckli] in the subsoil under a large (50 x 60 m) single storey cold store [Kingston]

4.2 Insulation and Heating

Providing insulation and some form of heating below a freezer floor is normal to reduce heat flow from the soil into the freezer. Underfloor insulation is required to provide steady temperatures inside freezers, and for energy efficiency of refrigeration, and is normally designed for this purpose. The underfloor insulation barrier and any necessary underfloor heating should also be designed to maintain the temperature at the underside of the insulation above 0°C - ie. to prevent freezing of the subsoil.

Design procedures for ground freezing prevention have been refined and simplified over the years [Ruckli, Oheim, Webber], and are relatively straightforward. As noted above, they do require some assumptions of ground and groundwater properties, which are difficult to refine precisely. Frost heave may take many months or even years to commence as the ground is cooled to a sufficiently low temperature. It is important to note that a direct result of the additional water drawn into the soil matrix to cause frost heave may be to cause subsidence on thawing if the water content of the soil affects its bearing properties [Andersland, Yong Tschebotarioff], hence heating should be introduced before frost heave occurs. The installation of temperature probes through the floor of freezers is advisable to monitor the pattern of ground freezing so that additional heating can be introduced before frost heave occurs.

In all large cold stores and freezers - larger than about 10 x 10 m in New Zealand conditions - temperature probes should be installed with sensors at (common New Zealand practice) the underside of the insulation, about 600 mm down into the subsoil, and about 2.0 m down, to monitor temperature changes as the cold store is brought down to temperature. If temperatures stabilise at 0°, or continue to drop below 0° at 600 mm down, heating may be needed.

On the basis of soil temperature analysis and design of underfloor insulation, the large (50 x 60 m) single storey cold store referred to above was constructed with thermostatically controlled electric underfloor heating. Ground temperatures were monitored over a subsequent period which indicated approximately half the design heat was required to prevent ground freezing. The main difficulty in achieving greater design accuracy is the assumptions of ground temperature parameters - the nature of pore water and its latent heat, soil conductivity, specific heat of soil particles - are difficult to assess accurately for a large mass of soil. Ground temperature profiles and seasonal variations are obtainable from various agricultural institutions.

4.2.1 Heating

There are three main methods for providing underfloor heating:

- ambient heating
- applied heating
- waste heat recirculation from cold store refrigeration system

i) Ambient Heating

Ambient heating can be provided by creating an air gap under the floor with a suspended floor structure. This was traditional New Zealand and overseas [Cooling] practice for multi-storey cold stores from the early 1900s through to the 1970s. The expense of this would only be justifiable nowadays (in New Zealand) where foundation conditions preclude a slab-on-grade floor.

For a slab-on-grade, the installation of pipes through the ground under the floor to create air circulation will often be adequate to keep soil warm enough to prevent frost heave. Heat flow analysis using ground temperature profiles, ambient air temperatures and convective airflows can be used to design such piping arrangements. NZ experience is that convection flow in such pipes is often effective under -20° cold stores at up to 30 x 30 m in area, and has provided acceptable underfloor heating in cold stores up to 50 x 60 m in area.

ii) Applied Heating

Under larger coldstores, generally larger than 30 x 30 m in New Zealand experience, underfloor pipes are so long that convection flow is not sufficient to provide adequate heating. Air can be blown through the pipes or heating cables installed in the pipes. The level of heating required is generally low - of the order of 40 watts per square metre of floor when pipes are set about 300 mm below the underfloor insulation. Current New Zealand practice is to install convection pipes with draw-wires so heating cables may be installed at a later date if underfloor temperature monitoring is required.

Direct electric cable heating has been installed in situations where underground direct subsoil heating options are not appropriate. As this form of heating has higher capital cost and does not address the need to prevent water accumulating under cold stores, it has generally been used only where a sub-zero cold store has been installed over an existing concrete floor. Cables have sometimes been cast into a concrete slab below underfloor insulation - very similar to conventional underfloor house heating, but with low power heating - of the order of 60 watts/metre cables (eg Pyrotenax). Similar applications have involved sawcutting slots into an existing concrete floor and inserting cables to provide heating. Generally main and back-up circuits are cast/cut in as replacement of failed circuits is not practical later. Most New Zealand applications of such systems have often not really been warranted, being installed in small cold store applications where ambient heating of the ground would be sufficient to prevent frost heave.

iii) Waste Heat Recirculation from cold store refrigeration system

A more capital intensive, but operationally inexpensive heating system is to use waste heat recirculation from the cold store refrigeration system. This commonly involves a piped circuit connected to the freezer refrigeration condensers to recycle heat extracted from the freezers through a heat transferring liquid such as glycol in pipes under the freezer floor. This is common practice overseas [Oheim, Leonoff, Webber] and has been used in several large NZ cold stores. Typically small diameter 25 mm diameter polybutylene/alkathene pipes are cast into a concrete screed slab of the order of 125 mm thick. The pipes have been spaced at approximately 300 mm centres, with overlapped looped pairs of pipes bent to 600 dia diameter bends, connected to a larger 100 diameter header pipe at one end.

With such a constant heating system, operating whenever the cold store refrigeration system operates, heat inputs into the ground are significantly in excess of the heat required to prevent ground freezing. This generally will avoid the need for any susceptible soil replacement/modification, and also underfloor temperature probes. Ambient and applied subsoil heating in New Zealand practice is normally installed in conjunction with soil replacement with granular non frost susceptible subsoil.

4.3 Water

In all cases the floor of a cold store should be constructed above the groundwater table. For a slab-on-grade floor this should be achieved by backfilling so the underside of the underfloor insulation is higher than the anticipated groundwater table. A suspended slab (ie. where piled or slab-on-beam foundations are required) supporting a cold store floor should similarly be constructed so the underside of the underfloor insulation is higher than the anticipated groundwater table.

Removal of a water source may be possible. This may be able to be achieved by creating drainage around the freezer perimeter and/or installing underfloor pipes (which also serve as air circulation/ambient heating ducts) in no-fines foundation fill to drain water from under the cold store floor. Removal of a water source should also include the diversion of any drains or water pipes away from a cold store foundations.

Another means of removing water from the potential frost heave zone under a cold store is to create an impermeable layer so water cannot be drawn into the soil. This may most simply be achieved by laying a waterproof membrane (eg polythene film) below the assessed depth of ground freezing to prevent water being drawn up into freezing soil. This application may be appropriate where a poorly drained soil layer underlies non frost susceptible foundation soils for a cold store [Yu]. A variation on this protection method is to combine the impermeable membrane with geotextile which can enhance drainage of the subsoil [Henry]. As with many geotextiles, such applications will generally only be warranted where simpler, cheaper methods of removal of water sources are not practical.

Similar to chemical modification of soils, the groundwater under a cold store may be modified to lower its freezing point. The author has used the lower freezing temperature of salt water in designing for the prevention of frost heave in a -7°C refrigerated enclosure constructed in a concrete tank in tidal sands with minimal insulation.

5. REPAIR OF FROST HEAVE

Trying to repair frost heave after it has started is an uncertain art and potentially expensive. The costs involve include damage to the cold store structure resulting from frost heaving, loss of operation while repairs are effected, the costs of repairs, but potentially most of all the damage caused through thawing and slumping of frozen ground. As noted above, frost heaved soils have generally taken up additional water to create the heave - possibly 4 or 5 times their normal water content. In frost susceptible soils (ie not gravels or confined sands) slumping of the soil on settling is quite normal as internal shearing resistance in the soil is lost with the increase in water content. The relatively low permeability of frost susceptible soils requires slow drainage of water on thawing to allow drainage and preclude slumping. Detailed knowledge of soil properties may assist in designing a thawing regime for a frost heaved cold store, but ground thawing, if desirable, should be undertaken slowly and carefully.

The successful repair of frost heaved cold stores should include a similar approach to frost heave prevention - removal of the identified cause of the frost heave - susceptible soils, freezing temperatures, and/or water. It is not possible to provide precise guidelines for repair, but a brief description below of some successful New Zealand frost heave repair projects the author has been involved in provides some indication of the range of possible methods. The common ingredient of all these projects has been identifying the "trigger" for the frost heave - it generally occurs when the equilibrium of heat flows through subsoil is disrupted - and removing this cause or mitigating its effects.

5.1

Circa 1935 three-storey -18°C cold store with unreinforced brick external walls supporting a cork insulation envelope full height with internal reinforced concrete floors supported on reinforced concrete columns and bearing pad foundations. Frost heave of approximately 100 - 150 mm was noted in the slab-on-grade insulated ground floor. This slab was removed by the client for replacement, but no obvious cause of the frost heave was found. The floor was bedded on sandy gravels with a small silt fraction not considered exceptionally susceptible to frost heave, with no underfloor ventilation or heating. Concerns were held over the frost heaving potentially spreading to heave the foundation pads under upper floor support columns, so these columns were underpinned below the potential soil freezing level. This involved propping the upper floors off the frozen ground below the removed ground floor slab and casting 1.5 m deep mass concrete footings to underpin the foundation pads. To preclude any thawing and settlement of the frozen ground, the cold store was maintained at -10°C throughout construction, with special insulation, concrete mix design and concrete placing procedures to ensure full hydration and curing of the concrete placed at such low temperatures. Two years subsequently, a burst stormwater drain was located nearby and identified as having been the cause of the change in the cold store situation. It appears this triggered the frost heave by providing a water source in an area where the ambient groundwater table is approximately 8 m below floor level - well below the level expected to contribute to frost heave.

5.2

Circa 1940 three storey -18°C cold store with unreinforced brick external walls supporting a cork insulation envelope full height with internal reinforced concrete floors supported on reinforced concrete columns and bearing pad foundations. Frost heave was noted on the first floor slab with upwards deflection of approximately 40 mm and cracking over column lines. The columns were bedded on a silty sand, with the ground floor a retro-fitted concrete slab replacing an original timber floor. The ground floor slab was cast some years previously on timber formwork between concrete bearing walls which created ambient air ducts under the floor. The slab formwork had been left in place after the slab was cast because of access difficulties, severely obstructing the air space. After investigation of the soil temperature profile, ambient air was blown under the floor with constant monitoring of floor levels and ground temperature profiles. The floor settled back to level over three months, and monitoring was continued over six years with intermittent forced ventilation continued as required for ground heating. Inspection and monitoring of groundwater level records in the area indicated that the trigger for the frost heave was the lowering of a flowing water table under the cold store during a severe summer drought. It appears that the lowering of the water table reduced the ambient heat input which had maintained the ground freezing in a non-heaving equilibrium.

5.3

New three storey reinforced concrete structure - 18°C cold store on frost heaved ground. Following the demolition of a badly frost heaved circa 1910 multi-storey timber and pumice insulation cold store, the new cold store was constructed on the frost heaved ground. The ground floor was designed as a suspended reinforced concrete floor, supported on bored concrete piles penetrating the very soft, muddy thawed silty clay to bear on bedrock. The existing ground was used to support the ground floor for casting, with a synthetic geotextile filter layer preventing soil fines migration into a 600 mm deep no-fines gravel drainage layer. Drainage pipes with draw-wires for potential underfloor heating were laid in this layer immediately the ground floor slab on which the cold store insulation - 150 mm polystyrene - was laid. Temperature monitors were installed in the subsoil to a 2 m depth, but ambient heating proved adequate to prevent ground freezing.

5.4

Circa 1968 single storey -20°C polystyrene sandwich panel cold store. This store was constructed in standard New Zealand style of the era - external steel structure with external shade roof, sandwich panel wall and ceiling insulation, 150 mm polystyrene underfloor insulation with a 150 mm concrete wear slab. Foundations consist of a reinforced concrete ground slab on 400 mm no-fines gravel fill with pairs of 100 x 100 mm concrete block ventilation/drainage ducts at 600 mm centres . The floor frost heaved rapidly to +140 mm above the general floor level in a 6 x 6 m area of floor on unloading. On excavation of the floor and silty clay subsoil, ice lenses were found, and a very high water table noted - only 450 mm below the underside of the cold store floor insulation. The seasonally high water table was well known in the area of the cold store, and the floor construction appeared to be designed accordingly. Inspection of the cold store revealed several of the underfloor ducts had been covered at one end a few years earlier. It appears that this action, combined with a particularly high seasonal water table and the first unloading of the cold store floor for many years, had combined to trigger the frost heaving. The cold store was warmed to approximately 10°C to encourage slow thawing of the ground and settlement of the floor back to level followed. To prevent renewed frost heave the blocked ducts were cleared and forced ambient air ventilation provided for underfloor heating, before the floor was reinstated. Local well points are being installed to maintain a lowered water table under the cold store floor.

5.5 50 x 60 m single storey -20°C polystyrene sandwich panel cold store constructed in 1976 with external steel structure with external shade roof, sandwich panel wall and ceiling insulation, 150 mm polystyrene underfloor insulation with a 150 mm concrete wear slab. Subsoil consist of approximately 1.8 m of gravel/coarse sand fill, over wet silty clays. 150 mm dia. drainage/ventilation pies are installed in the fill at approximately 1.5 m centres, approximately 400 mm below the underside of the underfloor insulation, and have thermostatically controlled heating cables laid in them. Local frost heave was noted in an area of floor and on checking the heating cable circuits in the area were found to be not functioning. With the gravel/sand fill not being susceptible to loss of bearing strength on thawing, and the silty clay layer measured as being below the frozen fringe by temperature probes, the ground heating was reinstated and the floor settled back to level over a period of 6 six weeks.

As indicated in a the above examples, frost heaving can occur when any of the factors contributing to the heat flow under a cold store are altered. In many of the cold store frost heave repair projects undertaken by the author, monitoring of a frost heaved situation is all that has been done - the heaved cold store floor has not caused operational problems and repair costs are not warranted. In those cases monitoring of the frost heave effects, floor level and ground temperature has continued to allow detection of any changes which could alter the equilibrium of forces and cause damage to the cold store or stored product.

6. CONCLUSIONS

- Trying to repair frost heave after it has started is an uncertain art and potentially expensive. Frost heave prevention is the cheapest measure.
- Depending on the application, NZ experience is that frost heave prevention is primarily dependent on the size of the cold store: ambient heating from surrounding ground and air will often be enough to prevent frost heave occurring.
- Insulation should be provided, and depending on the size and temperature of the coldstore, heating considered.
- In all cases suitable soils should be selected under cold store floors - fine-grained silts, silty sands, and silty clays should be avoided.
- If there is any chance of water occurring under the cold store, drainage should be provided in some form.
- Typically in New Zealand, underfloor ventilation should always be provided for cold stores (ie 0° down to -20°) of larger than 10 x 10 m and for all freezers (ie below -20°).
- In New Zealand conditions, heating should not normally be required for cold stores or freezers under 30 x 30 m, but is quite common in cold stores of greater size. Provision should be made for heating in all large cold stores and freezers, and temperature probes should be installed to monitor ground freezing.
- If heating is required, electric cables will generally be cheaper to install than heat re-cycling systems, particularly if the cables can be left out until a heating requirement is proven. Operational costs will be cheaper with a heat recycling system.

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