Lectures 15 and 16

NPTEL Course

GROUND IMPROVEMENT

Heating and freezing methods
Blasting methods

Prof. G L Sivakumar Babu
Department of Civil Engineering
Indian Institute of Science
Bangalore 560012
Email: gls@civil.iisc.ernet.in

Changes in soil state due to water content variation are effected by hydraulic modification methods. Changes in soil structure apart from water content variations are brought about using modifications based on temperature and use of appropriate modifiers.

Methods based on temperature control are classified as:

1. Heat treatment method.
2. Ground freezing method.

Heating methods

Temperature control methods depend on

- Thermal conductivity of the soil
- Heat capacity of the soil
- Heat of fusion
- Heat of vaporization

Thermal conductivity of the soil

It is defined as the amount of heat passing through a unit cross-sectional area of soil under a unit temperature gradient.

$$K_T = \frac{q}{A(T_2 - T_1)/L}$$

q = heat flow, watts, W, A = area of cross section, m^2

T = temperature, K, L = length of the soil element, m

At 0°C K_T for water = 0.58 W/ m.K, for ice = 2.2 W/ m.K

For denser frozen sand K_T = 4 W/ m.K and less in unfrozen state,

For soils, thermal conductivity increases with water content and dry density.

Heat capacity of a soil

It is expressed as the amount of heat required to raise the temperature by 1°C or 1°K. it is expressed in terms of unit volume (volumetric heat capacity) or per unit mass (specific heat capacity)

$$Q = CM\,\Delta T$$

Heat capacity of water C_w = 4.2 kJ/kg °C= 4.2 mJ/m^3 °C.

ice C_i = 2.2 kJ/kg °C = 2.2 mJ/m^3 °C.

Heat capacity of ice is less than that of water.

Latent heat of fusion (L_F)

It is the change in thermal energy when water freeze or ice melts. It is 334 MJ/m^3 of water.

To melt a mass M of ice, heat quality (Q)

$$Q = L_F M$$

For a 1 m^3 of soil with water content w

$$L_{Fs} = \rho_d \, w \, L_F$$

$$= 334 \, \rho_d \, w \quad KJ/m^3$$

Heat of vaporization of water

It is the energy required to boil water from liquid state to gaseous state. At atmosphere,

Heat of vaporization of water = L_V = 2.26 MJ/kg

= 2260 MJ/m^3.

To remove all the free water at 100°C in one m^3 of soil with water content (w), the energy required is

$$L_{Vs} = 2260\ \rho_d\ W.$$

The above definitions are useful to calculate theoretical estimates, but losses need to be accounted for in design

Heat treatment of soils

Heat treatment of a clay soil to about 400°C results in pronounced changes in engineering properties.

Heating is energy intensive and to stabilize one m^3 of soil 50 to 100 liters of fuel oil are required.

It is not recommended now a days except in places where it is already available as inherent energy in waste products and in landfills.

However use of geothermal piles as heating systems is prevalent in places like UK.

Methods of heating soil in-situ

- Ground surface heating
- Heating through boreholes
- Use of thermally stabilized building blocks
- Thermal piles

Geothermal piles are an innovative system of building foundations for use in combination with ground-source energy technology. Conventional ground-loops are installed in building piles, through which water or another fluid is pumped. The fluid and ground-transfer heat energy is then passed through a heat exchanger in the building to provide cooling or, more commonly, heating in the winter. The geothermal system is essentially the same as closed-loop borehole systems; however, since they are installed in the building foundations, the technology serves a dual purpose.

CODE FOR SUSTAINABLE HOMES

The Code for Sustainable Homes (CFSH), UK is an environmental assessment method for rating, and certifying, the performance of new homes in terms of sustainable design. The code includes factors such as water, waste and materials, for use of geothermal technology, energy and CO_2 emissions. Building regulations state that all new homes must be zero carbon by 2016. Energy transferred from the ground to the building using geothermal piles is considered renewable under the code and represents one way of increasing the carbon savings of a new house.

Ground Freezing

- Ground freezing is a process of making water-bearing strata temporarily impermeable and to increase their compressive and shear strength by transforming joint water into ice.
- Freezing is normally used to provide structural underpinning; temporary supports for an excavation or to prevent ground water flow into an excavated area.
- Successful freezing of permeable water-bearing ground affects simultaneously a seal against water and substantial strengthening of incoherent ground.
- No extraneous materials need to be injected and apart from the contingency of frost heave, the ground normally reverts to its normal state.

•It is applicable to a wide range of soils but it takes considerable time to establish a substantial ice wall and the freeze must be maintained by continued refrigeration as long as required.

May be used in any soil or rock formation regardless of structure, grain size or permeability. However, it is best suited for soft ground rather than rock conditions.

Freezing may be used for any size, shape or depth of excavation and the same cooling plant can be used from job to job.

As the impervious frozen earth barrier is constructed prior to excavation, it generally eliminates the need for compressed air, dewatering, or the concern for ground collapse during dewatering or excavation.

Principles of Freezing

- The effectiveness of freezing depends on the presence of water to create ice, cementing the particles and increasing the strength of the ground to the equivalent of soft or medium rock.
- If the ground is saturated or nearly so it will be rendered impermeable.
- If the moisture does not fill the pores, it may be necessary to add water.
- The strength achieved depends on freeze temperature, moisture content and the nature of the soil.
- Freezing can be particularly effective in stabilizing silts, which are too fine for injection of any ordinary grouts.

•On freezing, water expands in volume by about 9% which does not itself impose any serious stresses and strains on the soil unless the water is confined within a restricted volume. With water content up to about 30% the direct soil expansion may be about 3%. Frost heave which may occur in fine silts and clays, is a slightly different phenomenon.

•In rock and clay ice lenses may build up and enlarge fine fissures so causing increase in permeability after thaw.

•If there is a flow of water through the ground to be frozen the freezing time will be **increased** by reason of the continuing supply of heat energy and, if the flow is large and the water temperature high, freezing may be completely inhibited.

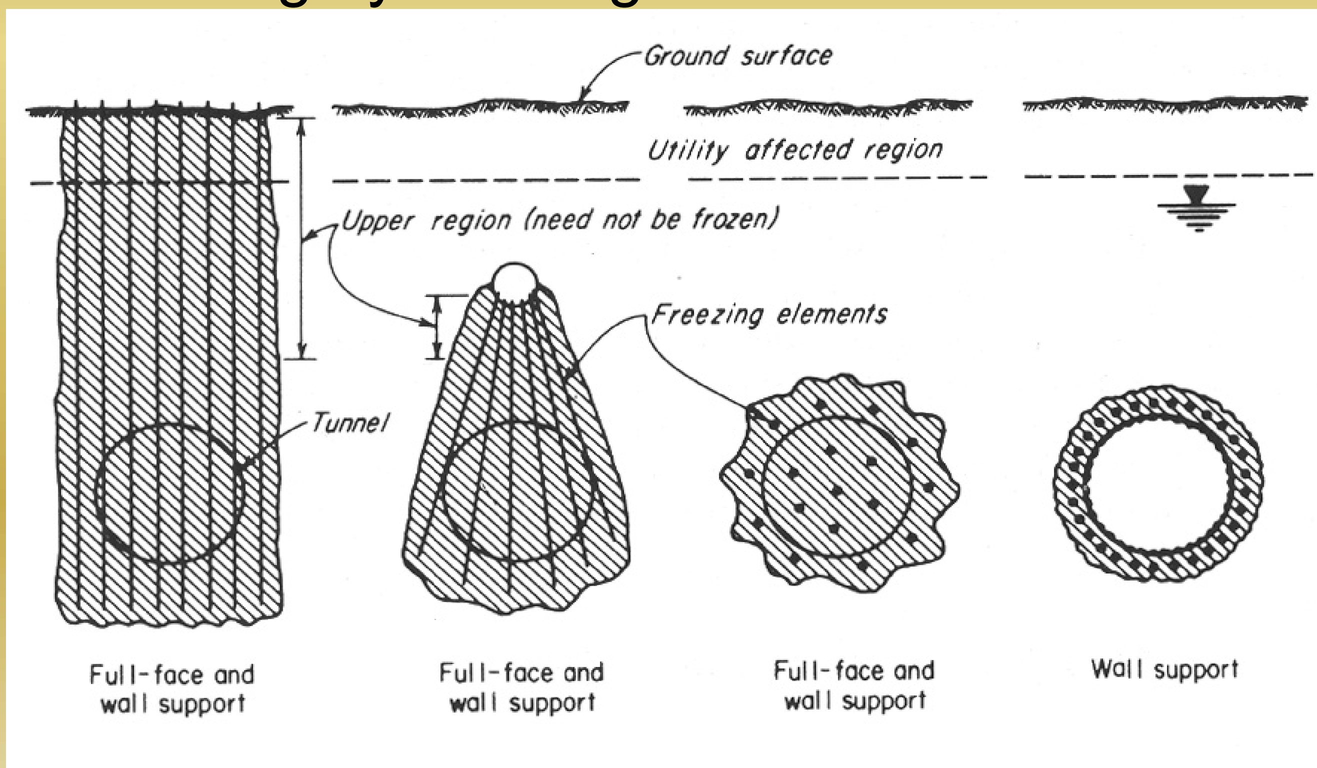
- As in all ground treatment techniques, adequate site investigation is necessary to allow the best system to be chosen and to design the appropriate array of freezing tubes and select plant of adequate power.
- After the initial freezing has been completed and the frozen barrier is in place, the required refrigeration capacity is significantly reduced to maintain the frozen barrier
- Because freezing can be imposed uniformly on a wide range of soil types in a single operation, it may offer greater security in mixed ground than treatment by injection of various grouts.

Applications:

- Temporary underpinning of adjacent structure and support during permanent underpinning
- Shaft sinking through water-bearing ground
- Shaft construction totally within non-cohesive saturated ground
- Tunnelling through a full face of granular soil
- Tunnelling through mixed ground
- Soil stabilisation

Once the freezing process has begun, monitoring is required to ensure formation of the barrier wall and also to verify when freezing is complete. During the drilling process, temperature-monitoring pipes are installed to measure the ground temperature.

Below are the techniques for temporary support of a tunnel heading by freezing:



Freezing process

Freezing may be:

- Indirect, by circulation of a secondary coolant through tubes driven into the ground
- Direct, by circulation of the primary refrigerant fluid through the ground tubes
- Direct, by injection of a coolant into the ground, such as liquid nitrogen.

Indirect cooling

•Primary refrigeration plant is used to abstract heat from a secondary coolant circulating through pipes driven into the ground. The primary refrigerant most commonly used will typically be some alternative to Freon, which due to it's ozone-depleting characteristics had to be phased out until 1996. Other primary refrigerants are ammonia, NH_4 (–33.3°C) and carbon dioxide, CO_2 – now not commonly used. The secondary coolant, circulated through the network of tubes in the ground is usually a solution of Calcium Chloride. With a concentration of 30% such as brine has a freezing point well below that of the primary coolant.

- The primary refrigeration process is basically the Carnot cycle of compression and expansion reversed. The time required to freeze the ground will obviously depend on the capacity of the freezing plant in relation to the volume of ground to be frozen and on the spacing and size of freezing tubes and water content in the grounds.

Direct cooling

- In these systems the primary refrigerant is circulated through the system of tubes in the ground, extracting directly the latent heat, therefore having a higher efficiency than the indirect process.

- Direct freezing time is similar to that for the indirect process. The choice will depend on plant availability, estimates of cost and perhaps personal preference.

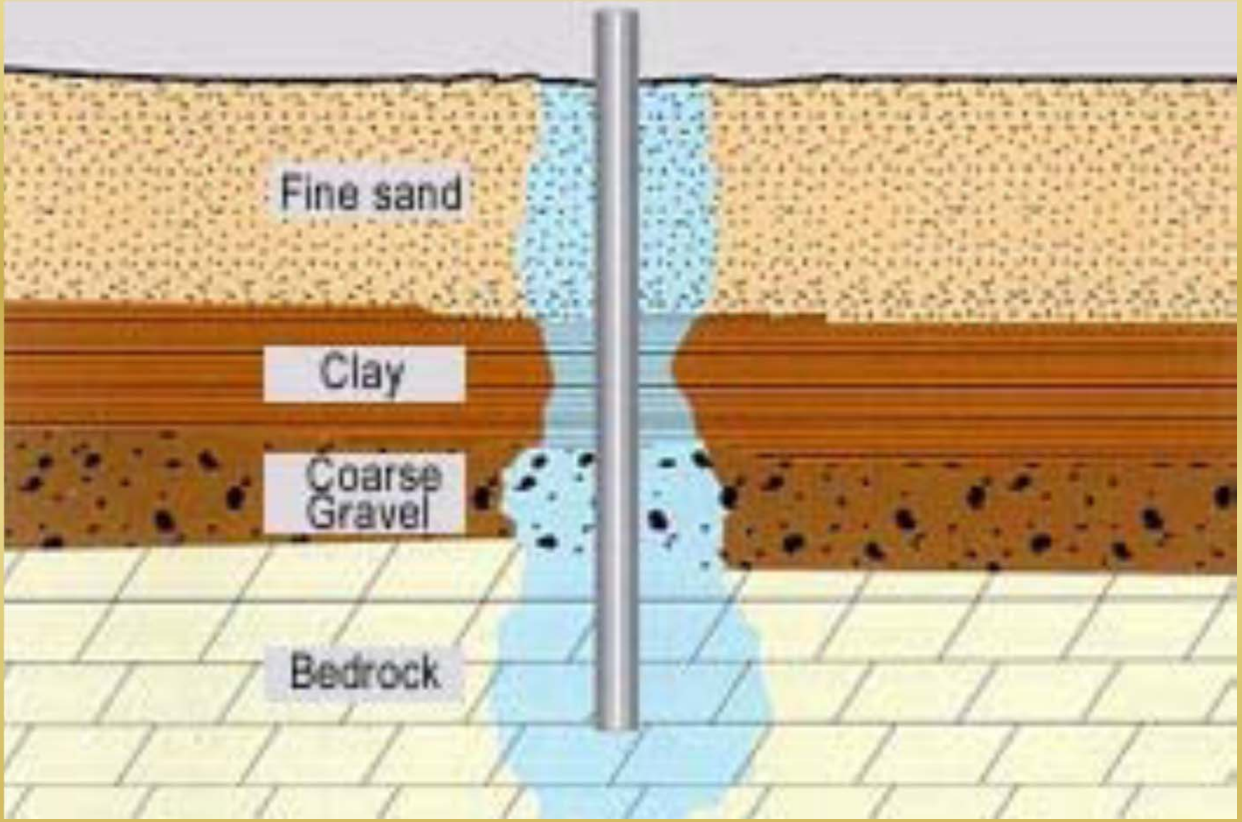
Liquid Nitrogen (LN_2)

•With this method a large portable refrigeration plant is not necessary, and the temp is much lower and therefore quicker in application. The nitrogen under moderate pressure is brought to site in insulated containers as a liquid which boils at –196°C at normal pressure and thereby effects the required cooling. It can be stored on site.

•There is a particular advantage for emergency use, i.e quick freezing without elaborate fixed plant and equipment. This may be doubly advantageous on sites remote from power supplies. In such conditions the nitrogen can be discharged directly through tubes driven into the ground, and allowed to escape to atmosphere. Precautions for adequate ventilation must be observed.

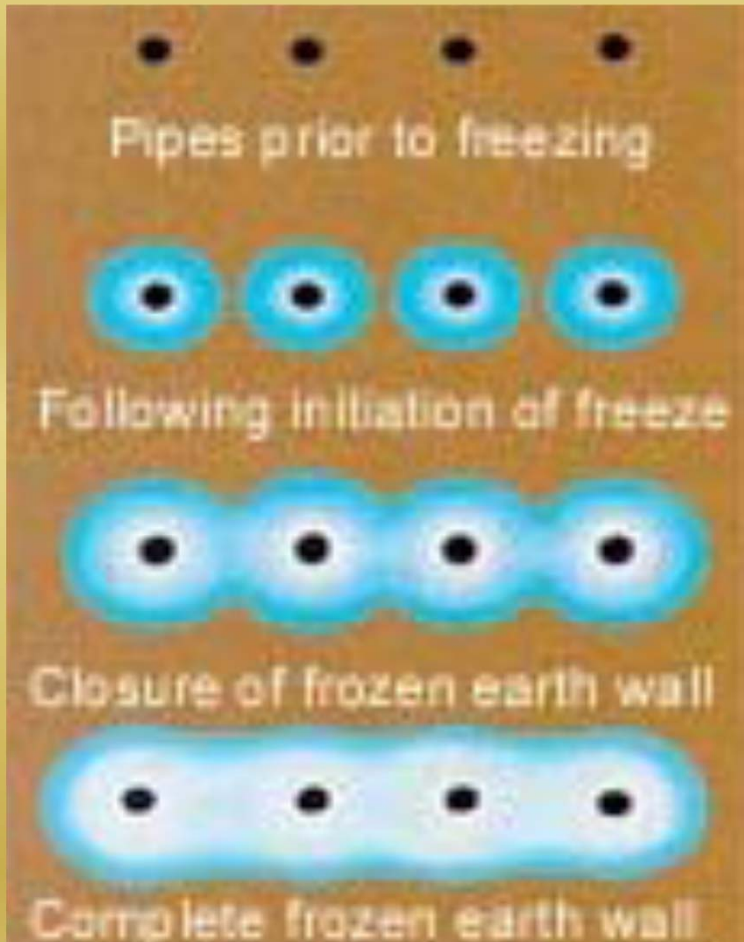

- When there is time for preparation, an array of freezing tubes is installed for the nitrogen circulation, including return pipes exhausting to atmosphere.
- The speed of ground freezing is much quicker than with other methods, days rather than weeks, but liquid nitrogen is costly.
- The method is particularly appropriate for a short period of freezing up to about 3 weeks. It may be used in conjunction with the other processes with the same array of freezing tubes and network of insulated distribution pipes, in which liquid nitrogen is first used to establish the freeze quickly and is followed by ordinary refrigeration to maintain the condition while work is executed. This can be of particular help when a natural flow of ground water makes initial freezing difficult.

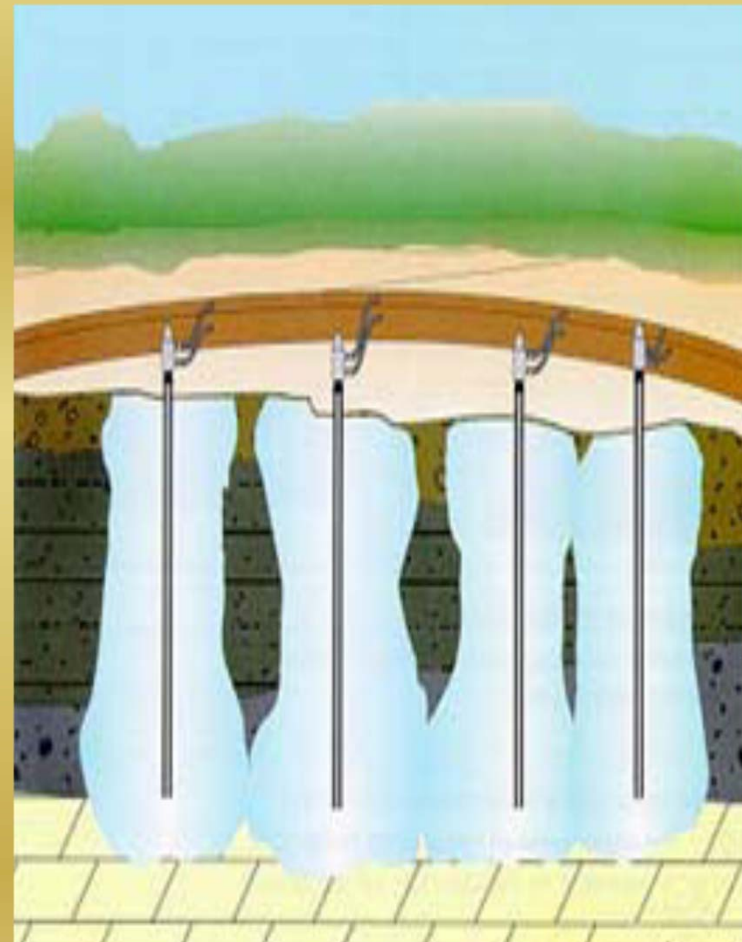
- The design of a frozen earth barrier is governed by the thermal properties of the underlying soils and related response to the freezing system.



Formation of frozen earth barrier develops at different rates depending on the thermal and hydraulic properties of each stratum. Typically, rock and coarse-grained soils freeze faster than clays and silts.

- When soft clay is cooled to the freezing point, some portion of its pore water begins to freeze and clay begins to stiffen. If the temperature is further reduced, more of the pore water freezes and the strength of the clay markedly increases.
- When designing frozen earth structures in clay it may be necessary to provide for substantially lower temperatures to achieve the required strengths.
- A temperature of +20 °F may be adequate in sands, whereas temperatures as low as –20 °F may be required in soft clay.
- the frozen earth first forms in the shape of a vertical cylinders surrounding the freeze pipes.
- As cylinders gradually enlarge they intersect, forming a continuous wall.


Pipes prior to freezing
Following initiation of freeze
Closure of frozen earth wall
Complete frozen earth wall

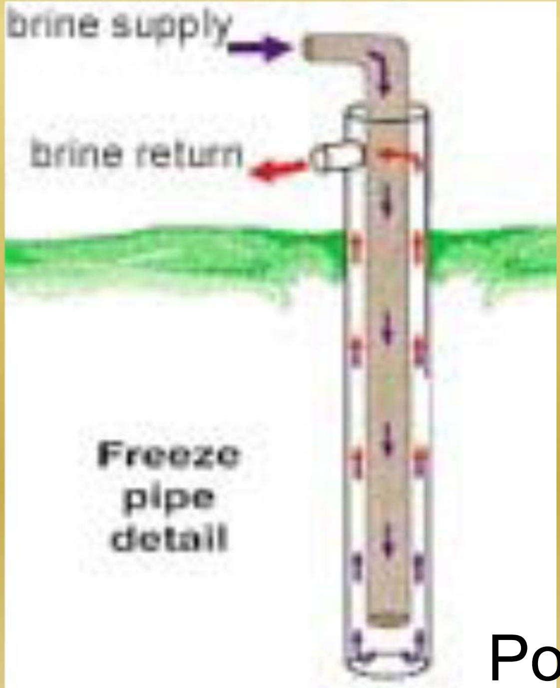


- If the heat extraction is continued at a high rate, the thickness of the frozen wall will expand with time.
- Once the wall has achieved its design thickness, the freeze plant is operated at a reduced rate to remove the heat flowing toward the wall, to maintain the condition.

Freezing Equipment and Methods

•The most common freezing method is by circulating brine (a strong saline solution – as of calcium chloride).

•Chilled brine is pumped down a drop tube to the bottom of the freeze pipe and flows up the pipe, drawing heat from the soil.



Portable twin 60-ton brine refrigeration unit

- The liquid nitrogen (LN2) process has been applied successfully to ground freezing.
- The cost per unit of heat extracted is much higher than with circulated brine. Nevertheless for small, short term projects, particularly in emergencies, the method can occasionally be competitive.
- Because of the extremely low temperature, freezing

with LN2 is rapid, and high strengths of frozen clay can be achieved.

This technology finds application in the following construction projects:

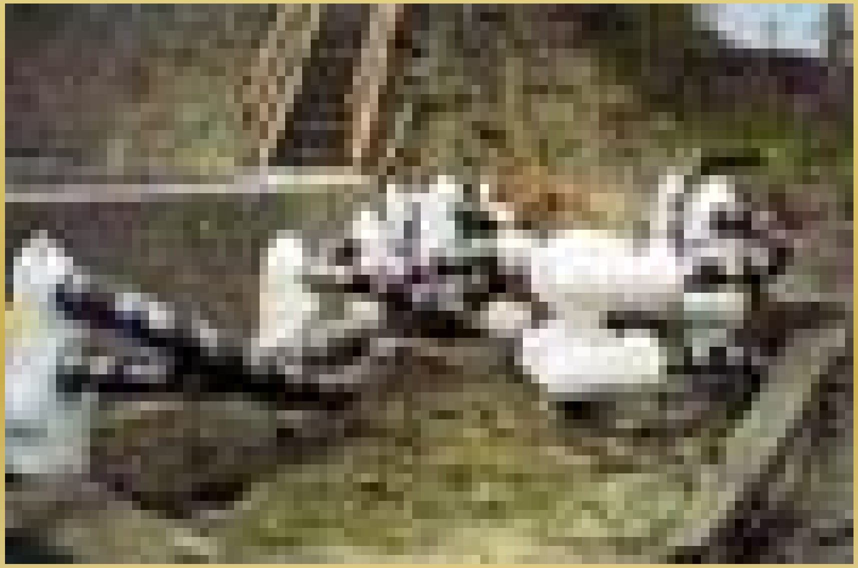
- Underpinning
- Tunnel roof freezing
- Freezing of cross-cuts in tunnel tubes
- Clearing out of tunnel fall-ins
- Forcing of framework constructions into railway embankments
- Foundation skirting
- Removal of intact soil samples
- Rehabilitation measures

Ground Freezing

1. Assembling freeze pipes.

2. Installation of freeze pipes.

3. Application of freeze with electronically controlled refrigeration plant.

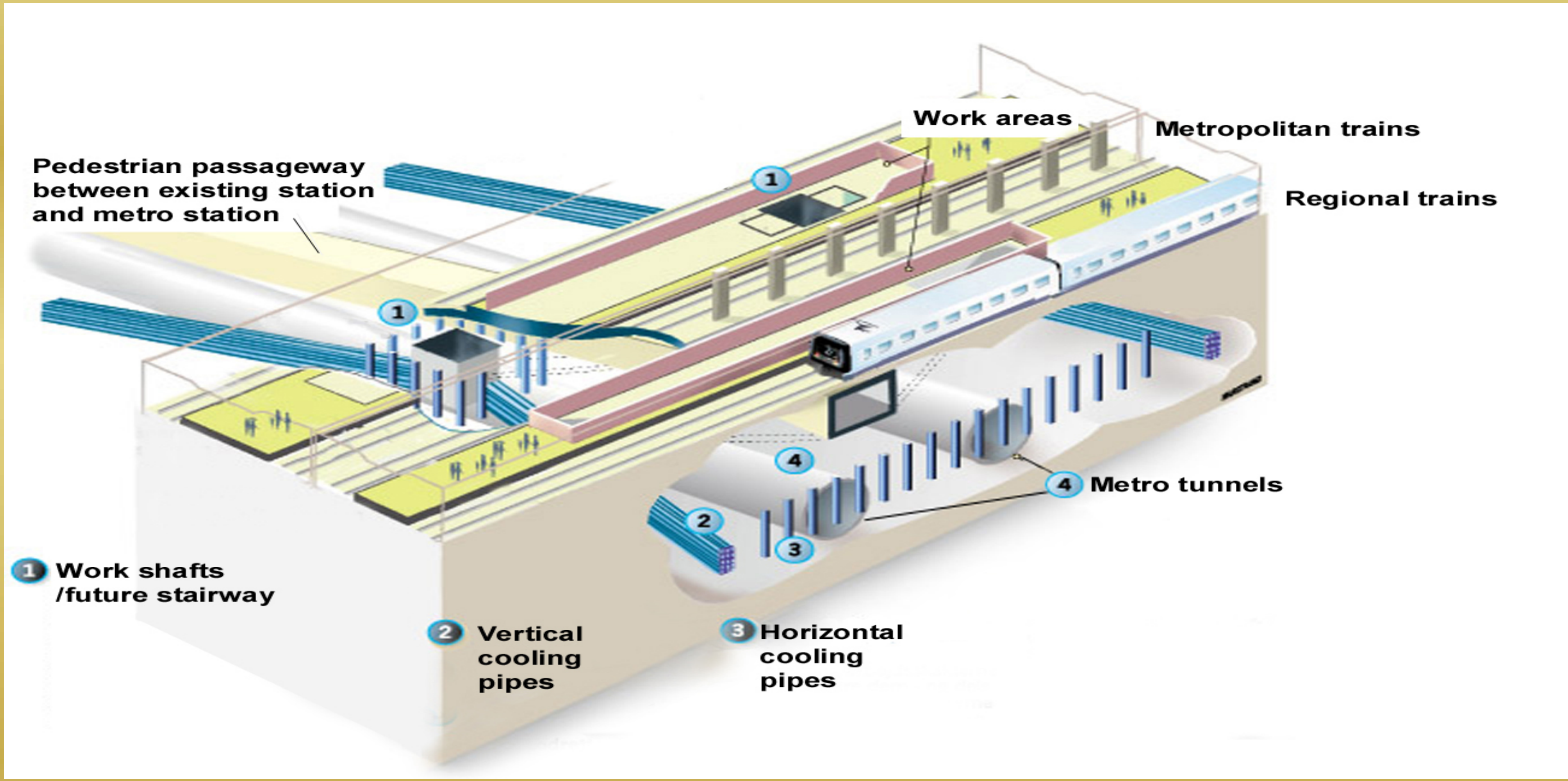


4. Frost development on freeze pipe headers.

5. Excavation following completion of freeze wall.

6. Construction of concrete liner. Once completed, refrigeration can be shut down.

- The following figure shows an application in the Copenhagen Metro project where a pedestrian passage from a new metro station to an existing railway station was constructed underground. Since the existing rail traffic had to continue, the ground had to be frozen to avoid the risk of collapse due to excavation of the transfer tunnel. Two 100 kW chillers located on the surface cooled the soil around the pipes to -24°C.


Work areas
Metropolitan trains
Regional trains
Pedestrian passageway between existing station and metro station
1
1
4
2
3
4 Metro tunnels
1 Work shafts /future stairway
2 Vertical cooling pipes
3 Horizontal cooling pipes

BLAST-DENSIFICATION

➢Blast-densification is a ground improvement technique for densifying loose, relatively clean, cohesionless soils.

➢It increases the density of loose granular deposits, above or below the water table.

➢The explosive wave temporarily liquefy the soil, causing the soil particles to rearrange to a higher relative density as excess pore pressure dissipate.

➢It has been used to treat soils to depths of up to 40m.

➢As depth increases, the size of the charge necessary to destroy the soil structure and liquefy the soil increases.

Excess pore pressure and settlement due to explosion are related to the ratio

$$N_h = \frac{W^{1/3}}{R}$$

where

N_h= Hopkin's number

W= weight of explosives, equivalent kilograms of TNT

R= radial distance from point of explosion, m.

If N_h is less and in the range of 0.09 to 0.15, liquefaction does not occur and the equation can be used to estimate safe distance from explosion.

Example

N_h = 0.12 and W= 10kg

Radial distance from point of explosion,

$$R = \frac{W^{1/3}}{N_h}$$

R = 17.95m

Experience with sandy soils in Netherlands suggested the following relationships obtained from statistical analysis of field results:

$$\frac{\Delta u}{\sigma'} = 1.65+0.65\ln N_h$$

$$\frac{\Delta h}{h} = 2.73+0.9\ln N_h$$

where N_h is calculated using units of kilograms for W and meters for R. Barendsen and Kok (1983) state that for optimum densification a ratio of $\frac{\Delta u}{\sigma'}$ more than 0.8 is required.

CASE STUDIES

Highway 504 Bridge over Coldwater Creek

- The proposed location of Bridge 12 over Coldwater Creek along State Route 504 was underlain by 40m of debris flow.
- The debris flow was composed of very loose silty sand and gravel with boulders and cobbles.
- Under seismic event, the soils would be susceptible to liquefaction, which could result in the proposed bridge being seriously damaged or destroyed.

- The Washington State Department of Transportation looked for several ground improvement technique and found that blast-densification was the most economical technique.
- Becker penetration tests showed a large increase in liquefaction resistance for the soils at this site.

Westover Airpark North , Chicopee, MA (1992)

- Blast densification was used to densify foundation soils for a large, one story manufacturing facility.
- Building was underline by alluvial deposits.
- The alluvium consisted of saturated very loose fine to medium grained sands with traces of silt and gravel.
- A seismic evaluation indicated the site would liquefy unless the alluvium was densified.
- Blast-densification was selected over dynamic compaction and vibro-compaction as the best alternative.

- A blast-densification test program was conducted at the site to verify the increase in soil density, determine the optimum blasting parameters, correlate density improvements with surface settlement, and to obtain ground vibration data.
- Electronic cone penetration in-situ test done before and after blasting showed that the soil strength was sufficiently increased to resist the design earthquake at the site.

Concluding remarks

- Use of thermal methods and blasting methods in ground improvement needs considerable expertise in the analysis, design and implementation of the technique in the field.