Artificial Ground Freezing for Underground Construction
by Mr. Christian Sanyas

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A technical lecture was delivered by Christian SANYAS and chaired by Ir. Chandrasegaran (Co-opted member of GETD) at Tan Sri Prof. Chin Fung Kee Auditorium, Wisma IEM on 14th May 2014. Christian SANYAS is the expert adviser at Soletanche Bachy Group. The talk was attended by 32 participants

Christian SANYAS started the lecture with sharing background history of Artificial Ground Freezing (AGF) with first known project in 1862 in Wales and its widespread usage in mining industry before mass adaptation in the construction industry. He explained AGF's 2 key properties namely increased shear strength and "zero" permeability that enables safe excavation in nearly all types of soil with excellent water cut off provided by AGF

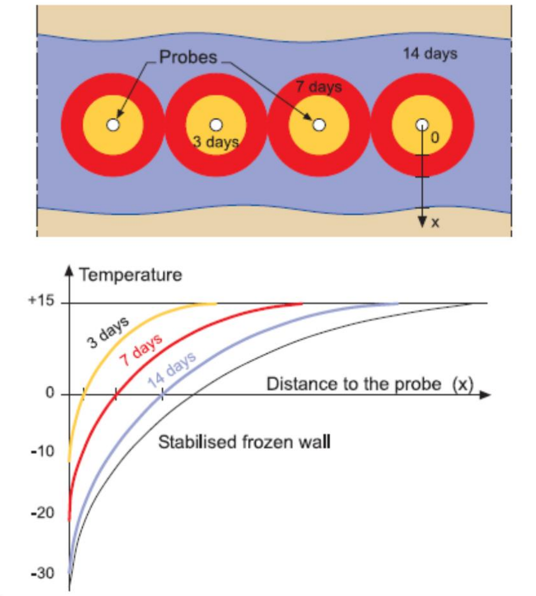


Figure 1: Progressive ground freezing with time

The freezing of a soil results from the transfer of calories from the soil to a low temperature fluid circulating in a freeze probe driven into the ground.

The water around the probe turns into ice, forming a sheath of frozen ground around the probe, thickening with time, thus creating impervious and solid barrier. The process off freezing is explained in Figure 2 and 3.

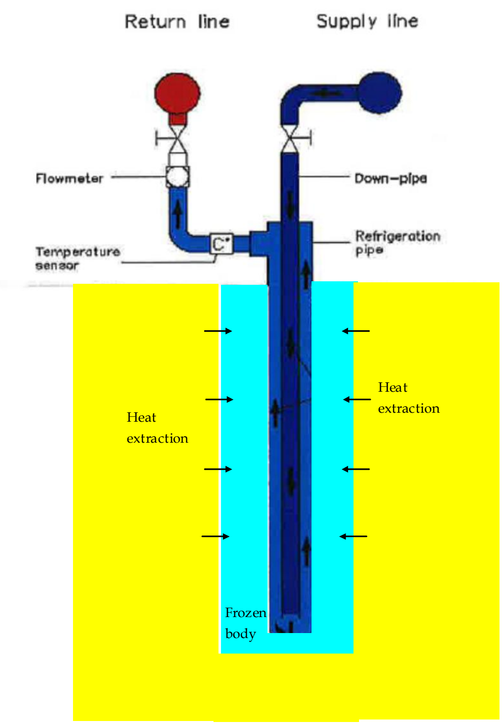


Figure 2: The "Freeze Probe"

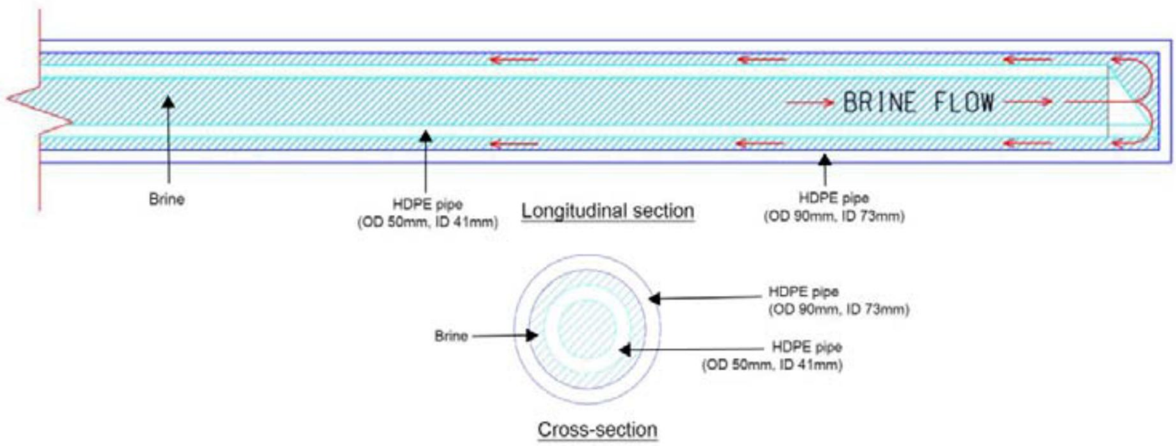


Figure 3: Details of Freeze probe

The ground freezing could be done with mechanical refrigeration by "closed circuit" (Figure 4) or Cryogenic refrigeration by "Open circuit" (Figure 5). The open circuit with liquid nitrogen as the freezing agent is quicker and forms 1.5m wall in quick time but slightly more expensive and slightly noisy. More care is needed to store liquid nitrogen in open space. Brine requires 5 to 6 days for ice wall formation, but is lot more easier to handle. Both methods require same time for "thawing".

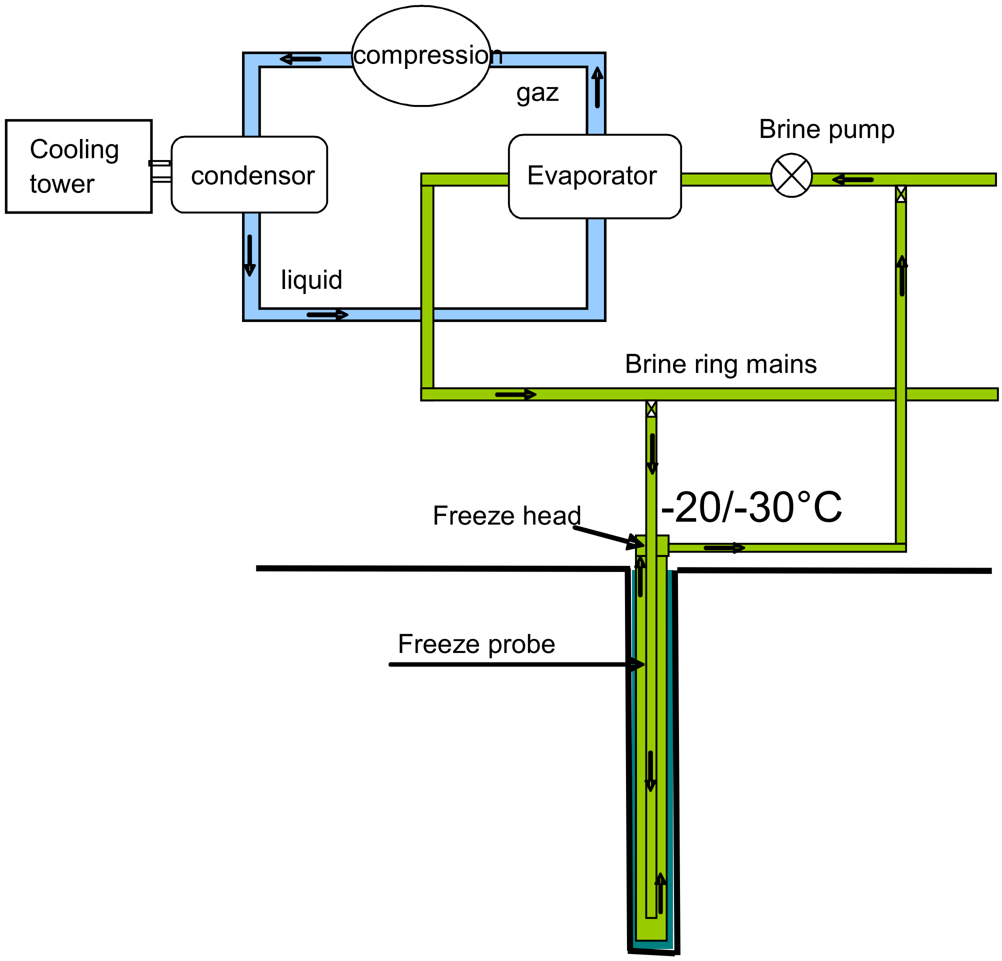


Figure 4. Mechanical refrigeration – Closed circuit

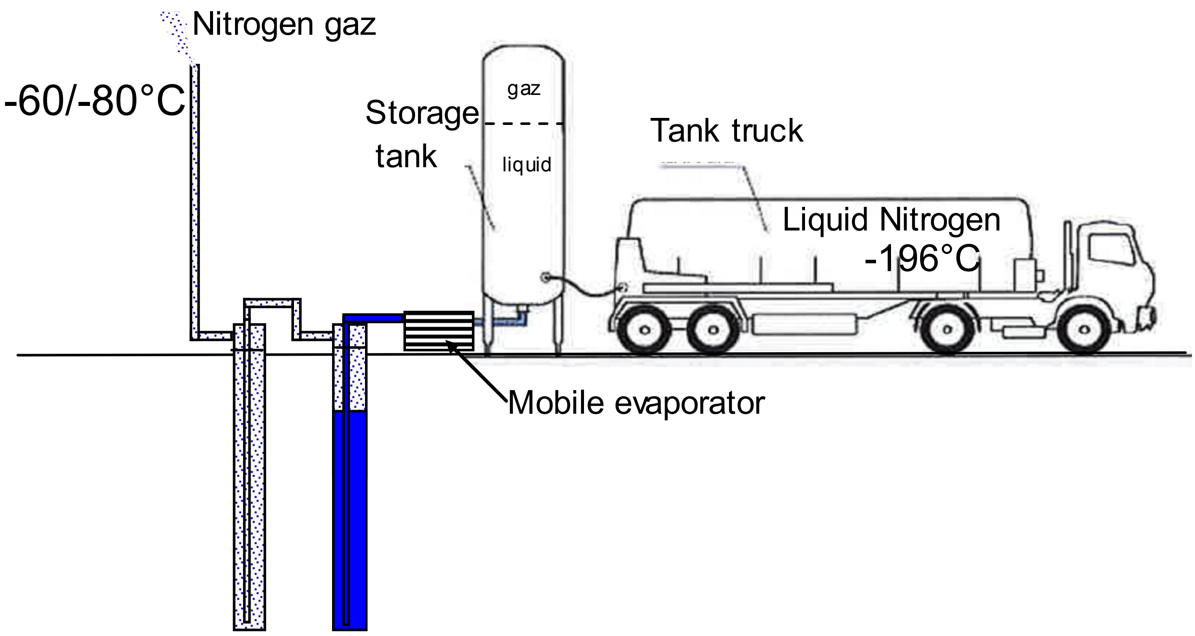


Figure 5: Cryogenic refrigeration – Open circuit

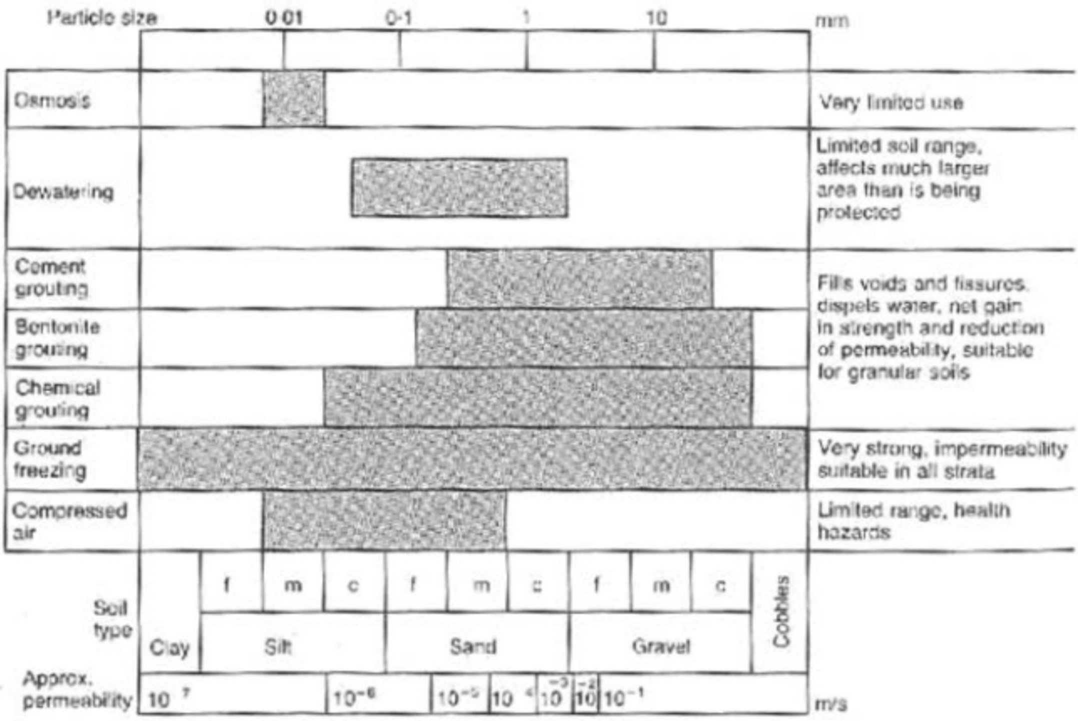


Figure 6: Applicability according to soil types

Technology of freezing

Stages of growth of ICE-WALL (Fig 7 and 8)

1. Isolated cylinders around freeze tubes
2. Closure of ring
3. Design thickness attained
4. Complete freezing of core

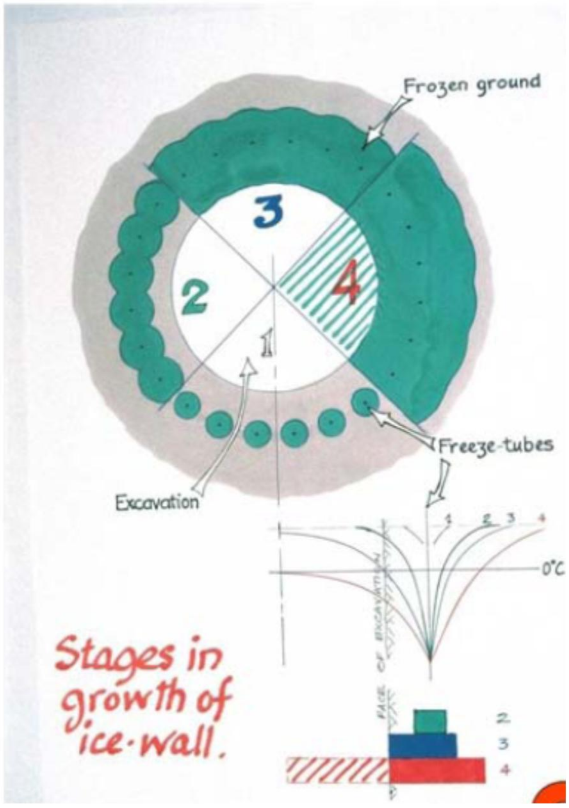


Figure 7: Stages of freezing

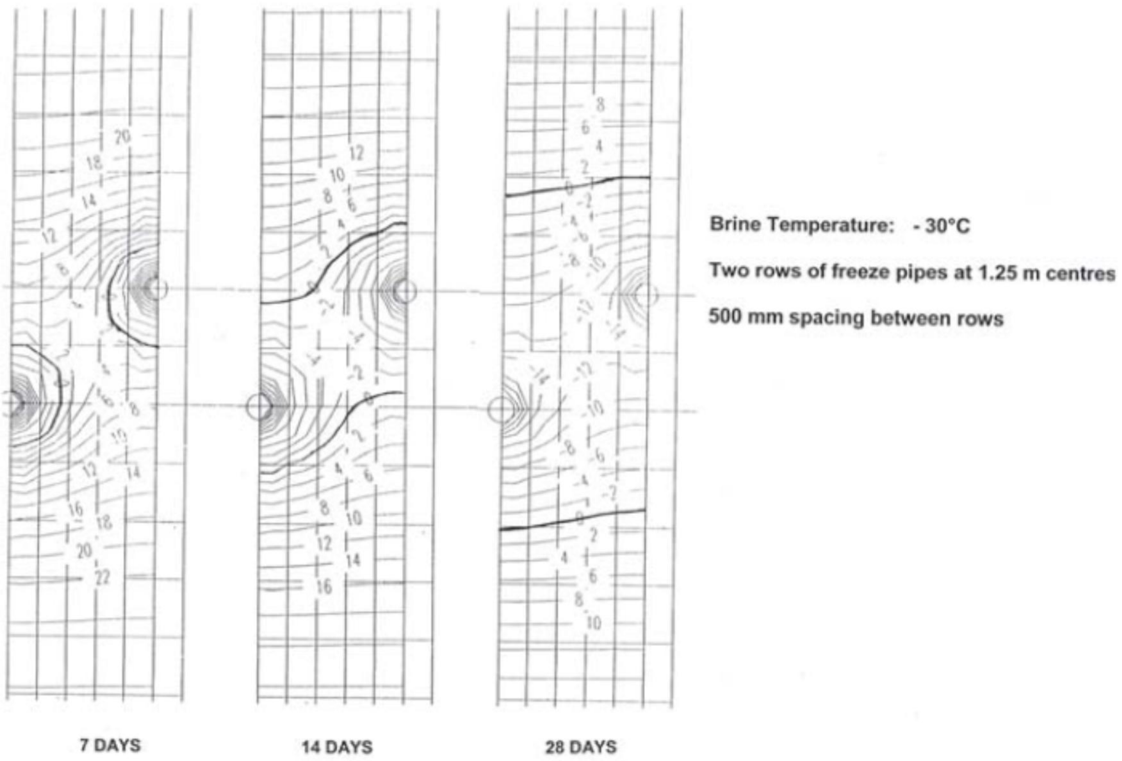
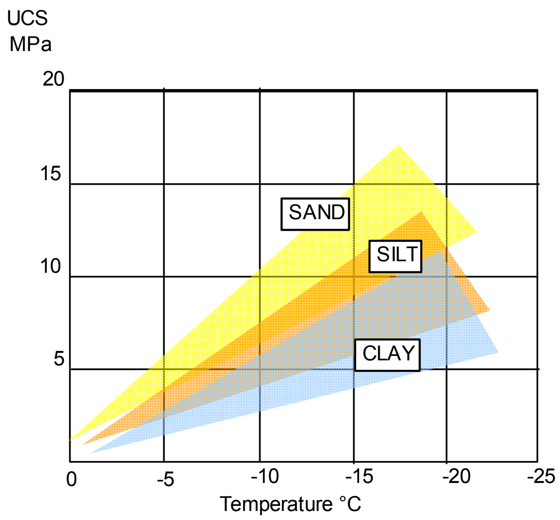


Figure 8: Growth of freezing with time

Key aspects of behaviour

Strength / Stiffness (Fig 9 and Fig 10)



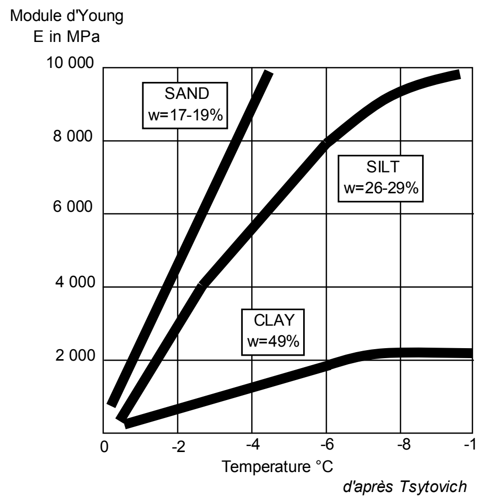


Figure 9: Strength and Stiffness VS Soil types

- Increases with decreasing temperature
- Increases with coarser soils
- Decreases with decreasing water content
- Decreases with salt content
- Decreases with loading time (creep)

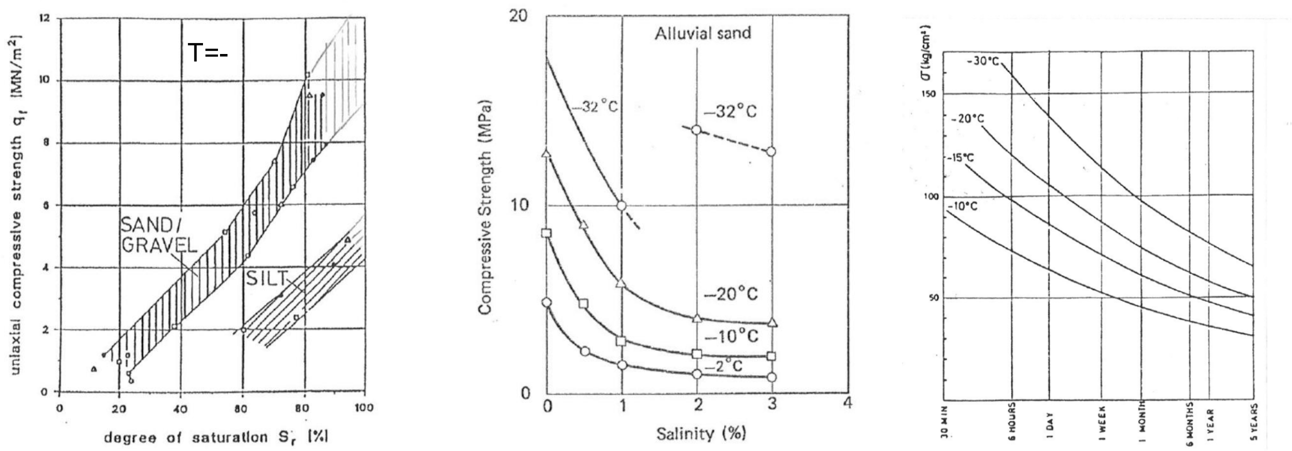


Figure 10: Strength VS different properties of soil being treated

Frost heave – Thaw settlement

TWO CAUSES

- Volume expansion on phase change (~ +10%)
- Suction induced at freezing face attracts water – ice segregation

REDUCING FACTORS

- Soil permeability: negligible in sand & gravel
- Applied pressure drastically reduces expansion
- Rate of freezing: fast freezing rate tends to reduce deformation

Mitigating measures against heave

- Establishment of a compressive barrier between the "structure" to protect and the frozen body
- "curtain" of hot water to prevent freezing front expansion

Following thawing, re-compaction (by grouting) may be applied.

Laboratory tests are needed to check the following properties

- soil type and mineral analysis
- sieve analysis
- water content, porosity, degree of saturation
- plastic limits
- ground water analysis
- organic content
- conductivity unfrozen and frozen
- UCS test before freezing and after thawing
- UCS tests at -5°C, -10°C and -15°C
- uniaxial creep test at -10°C
- triaxial tests at -10°C and on thawed samples
- frost heave test

Design – Observational technique

The AGF includes thermal design and structural design. Monitoring is needed to verify the hypothesis.

- development of ground temperature in probe hole equipped with sensors
- temperatures at structures interfaces
- ground water pressure variation
- freezing operating parameters: flow and temperatures in-out of freezing fluid, running parameters for a freezing plant
- Deformation of structures and the ground.

Christian SANYAS showed examples from 9 projects. The project references are attached in the material handed over to IEM

Generally speaking, the use of ground freezing is to form temporary supports for projects with high water pressures, restricted space and access.

Conclusion and Key Points

The freezing capacity of a single pipe is limited by

- a closer spacing is better to cope with possible soil heterogeneity

- water circulation shall be limited (pre-grouting): 1-2m/day for brine, 20-50m/day for liquid nitrogen
- heat sources shall be insulated
- typical exchange capacity, per meter of pipe:

Type	Brine	Nitrogen
Freezing	150 W/m	750 W/m
Maintenance	75 W/m	400 W/m

Soil water content is the main parameter with more than 50% of the required freezing energy corresponds to the latent heat of water.

During the Q&A session, the following discussion as raised.

a. Environmental aspects of freezing design was enquired and this is in general related to transport, storage and noise during working in the urban environment. He clarified that criteria can be met safely

b. On usage of nitrogen and brine, Christian explained it would depend on the project requirements and how rapid the freezing needs to be achieved.

About the energy consumption Christian explained there are two aspects to the cost, energy or capacity required for initial freezing followed by maintenance .

The talk ended with a presentation of certificate of appreciation by GETD committee member, Ir. Kenny Yee to the speaker (Figure 11).

Figure 11: Certificate presentation to Christian SANYAS