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Geotechnical Appreciation of Soil and Rocks of Schirmacher Hills, East Antarctica

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Abstract

Indian permanent station, Maitri was constructed during Seventh (1987-88) and Eighth (1988-89) Indian Antarctica Expeditions. A concerted effort towards geotechnical appreciation of the area was made during present Expedition by evaluating the physical and strength properties of soil and rocks around the station. These geotechnical parameters achieve significance in so far as the foundation, water management and waste disposal systems are concerned.

Introduction

The Indian permanent station 'Maitri' (70°S, 11°45'E), situated on the Schirmacher Hills of East Antarctica, is our farthest outpost and gives us a sense of pride as it is fully constructed out ot indigenous resources. The station has been functioning smoothly since its commissioning in the austral summer of 1988-89 and has withstood the test of the time During the IX expedition the author undertook studies to check the durability and structural stability of the station. A systematic geotechnical appreciation was carried out by testing soil and rocks and analysing norms for rheological deformation. Hitherto very scanty data was available about soil and rocks of Schirmacher Hills (Joshi *et al.*, 1988, Mukherjee et al., 1988). The various physical tests on soil and rocks samples, and their strength parameters alongwith the engineering and geological properties, bring out the salient characteristics about stability of the structure.

Experimental Programme

Representative samples of soil and rocks from Green House and Priyadarshini Lake area around Maitri, Schirmacher as also the rock samples from Gruber massif area, were collected. Data on some sub-surface profiles and morphometry of the terrain were analysed to arrive at applied geomorphological norms.

The rocks and soil of Central Dronning Maud Land Area come under "Coastal Oasis Greater" Antarctic zone. Normally, Antarctic climate is cold and arid with poor moisture content. The moisture content of soil has played an important role in weathering, especially chemical and frost-heaving actions etc , which is vital to the terrain and building, pavement, foundation design etc. At Schirmacher, the soil is of glacial origin. Generally, grey soil of sandy gravel composition, lacking in organic material is found. As is observed, the soils are principally glacially derived and vary from fine silts, sands and sometimes clay to coarse grained soil comprising gravel and stones. Much of the soil is of recent origin. Periglacial features ranging from gelifluction/solifluction lobes to a variety of patterned ground (stone stripes, polygons,) are common with presence of permafrost phenomenon. All patterned grounds appear on glacial till or fluvioglacial deposits which are at least 1000 years old (Bonner *et al.,* 1985; Walton, 1987).

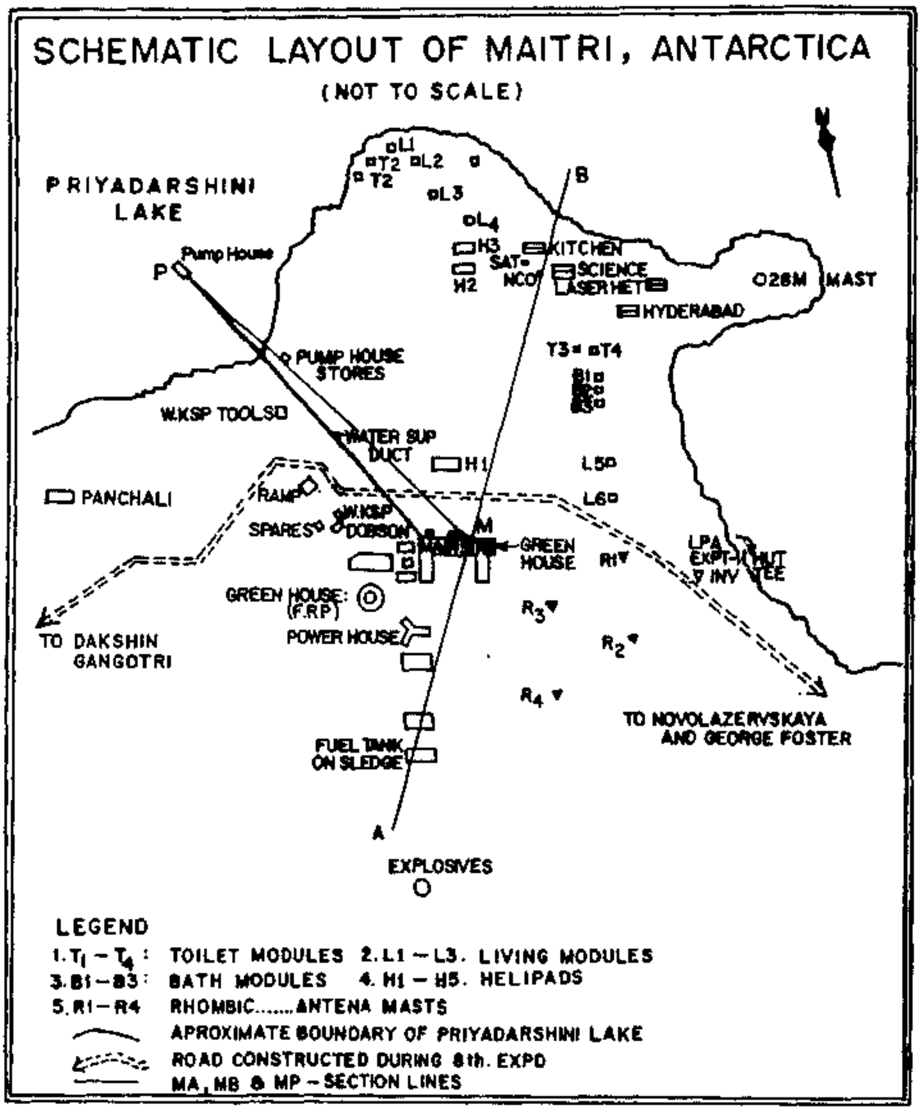

Fig.1. Schematic layout of Maitri, Antarctica.

The various physical tests, index and strength properties of soil and rocks have been carried out according to IS and prevailing code of practice specifications.

Terrain Evaluation

Schirmacher hills expose various types of metamorphic rocks like streaky gneiss, augen gneiss, garnet biotite gneiss, banded gneiss, migmatitic coarse grained gneiss, lit-par-lit gneiss etc. (Sengupta 1986, Singh 1986). A schematic layout of Maitri station is given in Fig. 1, which covers all the constructional activities till IX Expedition. The general lie of the terrain is boulderous with varying sizes of boulders. The area is sloping in a general S-N direction i.e. the glacier front is of higher relief than the Maitri station and the lacustrine area. The Schirmacher Hills have many lakes of different dimensions. The two bigger lakes are located at Maitri (Priyadarshini) and the other near Russian Station (Novolazrevskaya). Both lakes have been tapped for drinking water by Indian and Russian stations respectively. The VIII Expedition Winter team had tried to construct a track joining Indian and Russian Stations, a distance of approximately 5 kms, by dozing down the boulders The track is only partly complete upto a distance of 2 kms from Indian side the rest of the track could not be completed due to technical problems. An appreciation of boulderous terrain can be had by Fig.2 which depicts boulders, bigger than 1 m dia. around Maitri station. Many rock shattering phenomena, due to frost action have been noted. Typical sorted polygons/circles (Fig.3) and non-uniform stripes have been observed especially near the lakes where moisture is present. Stone flow (Kurums) have been noticed at places. The Schirmacher Hill and adjoining Humboldt mountains are the typical examples of periglacial and glacial features having many interesting geomorphological forms (Pathak, 1990a, Ravindra *et al.,* 1991).

A fair amount of slope appreciation around Maitri Station can be had from three sections as shown in Fig.4.

Typical slopes have been considered along the sections MA, MB and MP for the purpose of taking slope and its morphometrical analysis for further planning of structures and its vital life support systems. Herein, 'M' denotes Maitri Station. 'A'is the Glacier end, 'B' is summer kitchen end and 'P' is the Pump house for the water supply system (Refer Fig.1). Based on the configuration of the ground and from the analytical study of slope, it is noticed that the slope on cross section MP is more than other two, which is around 12% in just a distance of 155 m with a drop of about 17.5 m. In section MA, a drop of about 34.5 m is noted for a horizontal distance of 750 m from Glacier to Maitri Station main accommodation, which gives an average slope of 6%. Likewise, on MB, the ground slopes from Maitri Station to Summer Kitchen Hut varying from 122.5 m to 105 m i.e. a drop of 17.5 m, is observed in a horizontal distance of 350 m, giving an average slope of 5%.

Subsurface profiles

For studying the soil and rock characteristics/physical properties, some boreholes (BH) have been drilled around Maitri Station and their samples studied (Refer Fig.5B). In all, about seven holes have been drilled and their Litho-logs drawn (Fig.5A). In the area around Maitri, it is observed that fine to coarse grained sandy soil, silty-sandy soil and sand and gravel mixture of cohesionless aggregates of angular, sub-rounded, flat fragments of more or less unaltered rocks or minerals are found. The rock varieties encountered in the various profiles have been identified as garnet-biotite gneiss and banded gneiss with migmatised

Fig.2. Boulderous terrain around Maitri Station.

Fig.3. Sorted polygon.

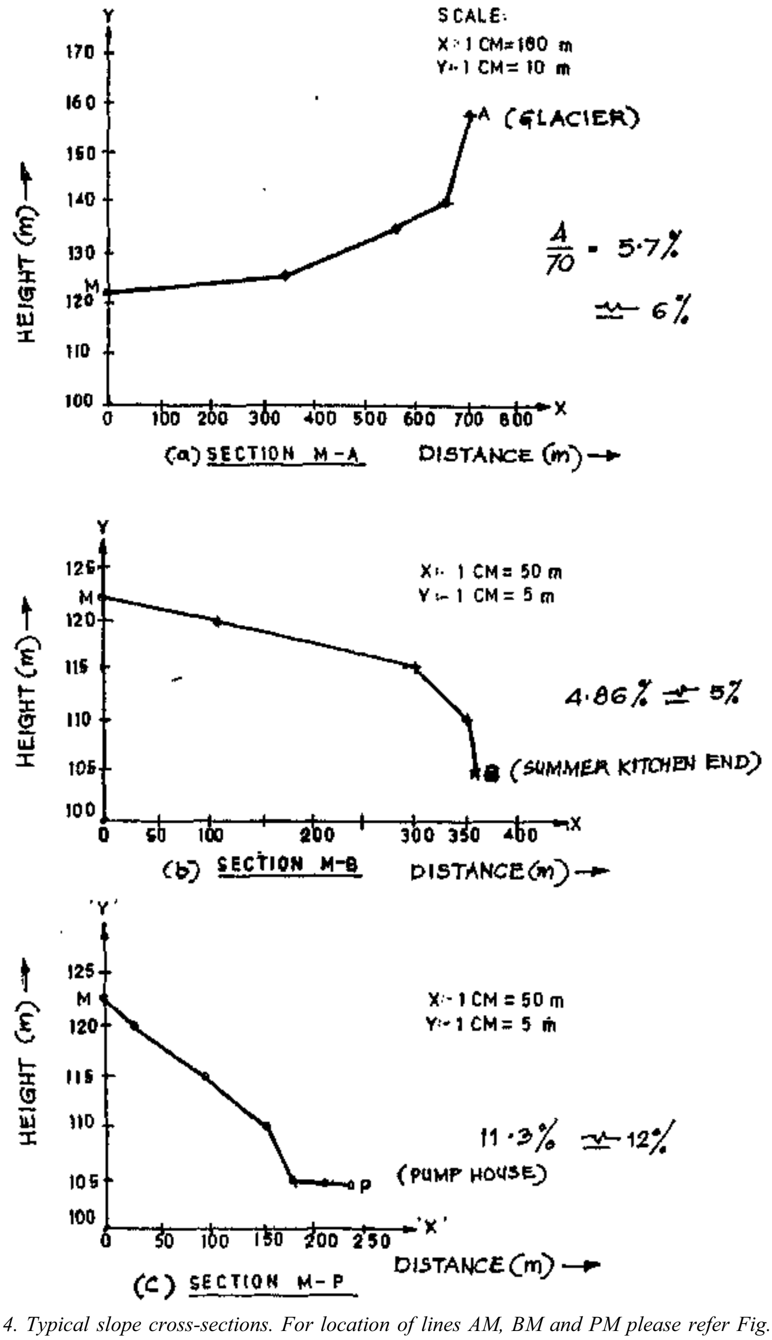

Fig. 4. Typical slope cross-sections. For location of lines AM, BM and PM please refer Fig.1.

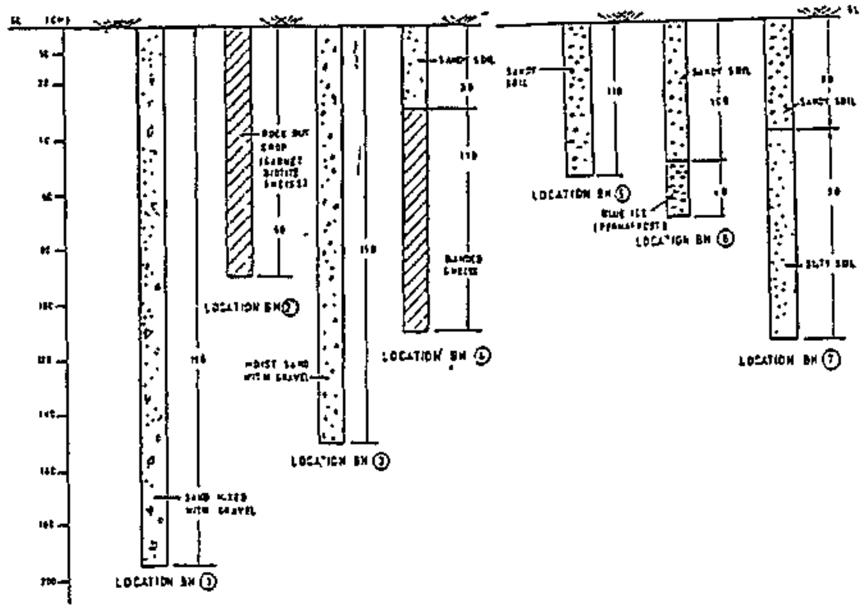

Fig. 5A. Sub-surface profiles.

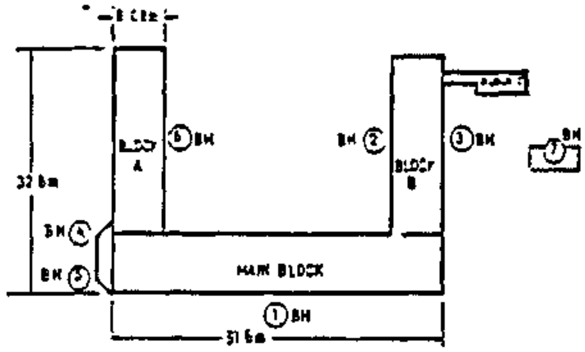

Fig. 5B. Location of boreholes around Maitri Station.

li-par-lit gneiss. The foliated augen gneiss is also occasionally observed. In BH 6, near A-Block i.e. old generation shed, permafrost has been struck beneath one metre of the foundation. The permafrost is overlain by one metre sandy soil crust. Some of the engineering properties of soil and rock have been listed out from first hand preliminary site/field studies below.

Physical Index Properties of Soil

The physical preliminary engineering properties of the soil obtained from the BH around Maitri have been studied as per the IS: 1498-1970. The salient details are given as under:-

(a) Colour: Dull grey.

(b) Fine to coarse grained soil texture having gritty-sandy silt composition. At some places the sandy-gravel soil is obtained.

(c) A moist part of the soil once pressed, sqeezes between the fingers. Its surface again becomes dull. The moist part does not leave any viable sticky paste on palm once shaken and removed. This definitely shows that soil has no clay content and is rich in silt content. Gulhati (1978) gives further account of some geotechnical properties of soils like effective shear stress, compressibility and permeability.

(d) Some organic soil with mosses etc. is found near the lake areas.

(e) Visual inspection by magnifying glass indicated presence of shining particles of quartz and micacious materials.

(f) Soil is less cohesive.

(g) Some of the seepage observation indicates high perviousness of soil in natural condition.

Engineering Index Properties of the Rocks and Their Identification

Some of the salient physical tests, carried out as per IS: 7746-1975, BS: 3618, BS: 812 (1977) on rocks after McClean (1985) and Stag *et al,* (1969) etc. are described below:-

(a) The rock outcrop samples found around Maitri and from boreholes were identified as garnet-biotite gneiss, banded gneiss, foliated coarse grained gneiss, augen gneiss, lit-par-lit gneiss etc. The gneissic rocks have been found rich in quartz, mica and feldspar.

(b) While drilling the boreholes/foundation, lumps of consolidated sand and gravel rich soils were encountered. This shows the presence and transgression of moisture through the porous media of soil.

(c) Dry density of augen gneiss and banded gneiss is around 2.83 g/cc.

(d) Water absorption of gneiss is 0.48% and effective porosity around 1.09%.

(e) The uniaxial compressive strength of gneissic rock is 66 M pa.

Computation of Results

The soil of the Maitri area has been tested vide IS: 1498-1970 IS: 2720 (Part-II) 1973. The test results of soil at Green House and samples near Priyadarshani lake areas are tabulated at Tables 1 and 2. The rock tests were done as per IS: 2720 (Pt III) 1964 and International Society of Rock Mechanics (ISRM), ISRMs 1972 and 1978. The results of the rock samples of Maitri (Schirmacher Hills) and Gruber Massif (Wohlthat Mountains) are given at Tables 3 and 4, respectively. The various geological findings from the rock samples obtained from Maitri (Refer Table 3) are enumerated below:

Table 1: Geotechnical Soil Testing
(Sample from Maitri Green House Location)

Gradation test		
Silt	:	8%
Sand	:	64%
Gravel	:	28%
IS Classification (IS 1498)	:	SP - SM (Sandy - Gravel/ Sandy - Salt
Shear Test		
(Remoulded at dry density YD = 107 gm/cc with sample finer than 4.75 mm)		
Cohesion (C)	:	0.0 kg/sq.cm.
Angle of ( ) internal friction	:	26.5°
Atterberg's limit	:	Non-plastic
Colour visual	:	Grey

Table 2 : Geotechnical Testing of Soil
(Sample from the area near Priyadarshini Lake)

Gradation test		
Silt	:	29.15%
Fine sand	:	42.00%
Coarse sand	:	22.04%
Sandy clay	:	5.87%
As per (IS 1498-1970) - Classification	:	SP-SM SP-SC
Physical characteristics		
Apparent density	:	1660 kg/m^3
Moisture content	:	24.66%
Specific gravity	:	2.079%
Pore space	:	41.81%
Volume expansion	:	nil
Visual colour	:	grey to dull grey

Note - The soil capacity to hold water was poor, though it was found to be very wet while digging up.

Table 3 : Geotechnical Testing of Rock Sample
(Sample from Maitri)

Sample no.	Rock type	Density gm/cc	% Absorption	Unconfined compressive strength (kg/sq. cm)
1	Quartzite/feldspathic granite gneiss	2 52	0 58	537 7 (53 7 MPA)
2	Biotite gneiss	2 53	0 23	—
3	Granite gneiss	2 68	0 06	—

Table 4 : Geotechnical Testing
(Rock sample from Wohlthat ranges)

Ser no.	Sample	Dry density g/cc	Grain density g/cc	Water absorption, %	Effective porosity, %
1	Gneiss	2.63	2.32	0.48	1.098
2	Augen gneiss	2.84	2.88	0.74	2.077
3	Basic granulite	2.66	2.56	0.63	1.580

Strength Parameter

		Brazilian strength (MPa)
1	Gneiss	— 7.80
2	Basic granulite	— 8.71

(a) *Sample I: Granite Gneiss*

The representative sample is a coarse-grained metamorphic rock, consisting of quartz, alkali feldspar and biotite as predominant minerals. Apatite and magnetite are found as accessory minerals. The presence of tourmaline is indicated in pegmatites veins Quart7 is also found in the form of veins, intruded along the weak joint plane. The rock is not subjected to high weathering and is compact. Hence, it is suitable for foundation as well as other building material.

(b) *Sample II Biotite Gneiss*

Texturally the rock is coarse-grained. It is compact and impervious in nature. It consists of quartz, feldspar and biotite as predominant minerals. Magnetite and apatite occur as accessory minerals. Tourmaline is present in a less abundant quantity. The rock is aligned with alternate mafic and felsic minerals giving rise to gneissic texture. It is less weathered and compact. Hence, suitable for foundation and building material.

(c) *Sample III Granite Gneiss*

Quartz, alkali feldspar and biotite are the predominant minerals, while apatite and magnetite are the accessories. It is fine grained and the boundaries are corroded. It is moderately weathered. The gneissic texture is very much conspicous. The rock is free from major joints. However, as the rock is affected by the weathering process, it is not as durable as the other two rocks mentioned above.

Geotechnical Appreciation of Results

The tests carried out of the representative rock and soil samples are very encouraging and they conform to the accepted norms of engineering practice and are within the allowable limits. The various aspects of the result obtained are discussed in the succeeding paragraphs.

(a) The rock and soil samples have adequate strength and are suitable for building and foundation work, without pile foundation.

(b) The soil is sandy and porous which is likely to entail seepage on slopy ground conditions. 'c' and parameters of soil have suitably led to computation of strength parameters (Gulhati 1978).

(c) While taking subsurface profiles, author (Pathak 1993) has come across permafrost beds at about 1 m deep at 'A' block (Gensets accommodation) of the main complex of Maitri. Due to the gradual slope in topography (Fig.2) and advancing heat front, the level of permafrost may appear to be sloping towards North of the station. It should be noted that if the ground contains excess ice then the heat of building on the surface will gradually melt the permafrost and in few years, a differential settlement may take place or the building may buckle or sink (Pathak 1988, Sugden 1982). In such cases many types of foundations are suggested (Fukan 1985, Eranti *et al.,* 1986; Andersland *et al.,* 1978; Tsytovich, 1975) e.g. to place warm buildings on pads of gravel, which are sufficiently thick, to insulate the underlying permafrost from the heat. A more permanent solution is to build structures on stilts or piles which are frozen into the permafrost. The air circulates beneath the buildings and insulates the ground from the heat of the building.

(d) Support services are even difficult to provide and are extremely costly in permafrost. Water pipes and sewers cannot be laid underground without special protection and insulation. One solution for such a problem has been to build pipes in utilidors above the ground and to insulate them all. A central heating pipe is often used as a source of heat. The water supply from Priyadarshini Lake to the main station Maitri, is one such example of utilidor. The problem of surface utilidors is more cumbersome and expensive due to extremely low air temperature and maintenance. In Russia, there is a new practice to insulate the pipes and bury them. If ice-rich soil can be avoided and there is no subsidence, then this is advantageous as the pipes are subjected to less severe temperatures than at the surface.

(e) Waste disposal is a problem in permafrost because waste does not decompose in extremely cold climate. Also, environmental management systems have to be planned properly to suit the periglacial/glacial or sub-zero conditions.

(f) Frost-Heaving. Due to freeze-thaw cycle in the frozen ground, a lifting up effect is observed at the surface of the ground, which even can lift piles out of the ground. The frost-heaving phenomenon is quite rampant in the periglacial region which also gives rise to various geomorphological features like, sorted circles, polygons etc. (Washburn 1979). The requisite conditions for frost-heave are generally:

frost-susceptible soil, presence of moisture or water and subfreezing temperature (Chamberlain 1986). As per US Army Corps of Engrs (1956) frost design and soil classification system (Pathak *et al.,* 1990b) the presence of silt with gravel around 3 to 10% has about moderate to high chances of frost-susceptibility. In the present soil sample, the silt content is 8% which fall well within this range and therefore, the soil is frost-susceptible. The areas more vulnerable to this phenomenon are the river banks, bridges, piers etc. Modern building practice should ensure that the pile is embedded sufficiently deeply in the frozen ground to resist upfreezing within the active layer. The frost-heaving should also be taken into account for designing airfields, helipads and pavements apart from the foundation of the buildings.

(g) It should be checked that around stilt foundation no snow-thawings or water spillage should take place, as this will entail to ice lens formation due to freezing of water which will uproot the foundation by frost heaving action as volume of ice increases by 9% once it freezes.

Discussions

The results of rock and soil representative samples are encouraging and generally fall within the accepted range of results. Some accepted bearing capacity of ice/snow cover is discussed below for the purpose of static/moving loads for various constructional properties. The structure to be founded on snow field should be thermally and mechanically stable which is not the case with the unstable nature of the snow (Eranti *et al.,* 1986; Mellor 1969; Mellor & Reed 1967). Separate or strip footings and friction piles are typical foundation structures used on snowfields. Bearing pressure values for moderate relative settlement rates are usually less than 50 KPa (7 lb/in^2), and footing may be tied together to avoid shear. For piles, the allowable long term skin friction values may be of the order of 10 KPa (1.5 lb/in^2). In the foundation and tunnel design, one must take into consideration the movements of snow layers in both the vertical and horizontal directions. The movements are absolute as well as relative (with respect to the snow surface), as the snow undergoes visco-elastic deformation under over burden pressure. In all this, snow density and temperature are the most important parameters in the foundation design. The large buildings are to be planned on lifting-mechanism/jack-up platforms to cater the structure in case of uneven foundation settlements. The thermal stability of the snow is maintained by undertaking the airspace between the protective steel arch and the heated facilities. Due to all the above reasons and constraints the effective life span of any undersnow structure is limited. Due to Theological deformation being quite prominant, the bearing capacity of the ice cover is considered to have reached its ultimate value when a circumferential crack forms at the top of the radially cracked ice-cover. According to the various observations in,the field, the nominal short term flexural strength for good quality of fresh water ice is of the order of 1.5 to 20 MPa (200 to 350 lb/in^2). The nominal sheer strength for rapid loading conditions may be about 0.5 MPa (70 lb/in^2) or more.

For seasonal frost and permafrost or frozen ground, for foundation design purpose the ground thermal regime and knowledge of active layer and its fluctuation is more important and should be kept in mind. The foundation depth should be taken below the active layer for stability purposes (Pathak 1988).

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