Research on Foundation Design on Permafrost in Mongolia

Dashjamts Dalai, Ninjgarav Enebish
Mongolian University of Science and Technology, Ulaanbaatar, Mongolia
Batsaikhan Anand, Ariunjargal Anand
Soil Trade, LLC – Drilling and Geotechnical Investigation Ulaanbaatar, Mongolia

GEOQuébec 2015
Challenges from North to South
Des défis du Nord au Sud

ABSTRACT
Mongolia is a land-locked country in Central Asia, located between Russia and China. The country's high altitude results in cold, dry and harsh climatic conditions with permafrost being widespread through the territory. Permafrost is spread on 63.0 percent of the territory of Mongolia. Although the capital city Ulaanbaatar is sited on area with discontinuous permafrost, in next 10 years projects such as a university campus, a logistics center, “New Nalaikh” residential complex and the extension of railway and highway connecting Russia and China have been planned. Engineering-geological and geotechnical studies have been conducted for these construction projects. This paper emphasizes that the main conditions of permafrost existence are the climate and geocryological location. Regional classification of permafrost areas, in order to select optimal principle of foundation design have been suggested based on the many years of experience and lessons learned from construction works in Mongolian geotechnical and climatic condition.

RÉSUMÉ
La Mongolie est un pays enclavé en Asie Centrale, localisé entre la Russie et la Chine. La haute altitude du pays résulte en des conditions climatiques froides, sèches et rudes avec un pergélisol qui est en train de s’étendre sur tout le territoire. Le pergélisol occupe 63% du territoire de la Mongolie. Même si la ville capitale Ulaanbaatar est située sur une zone de pergélisol discontinu, 10 nouveaux projets, comportant un campus d’Université, un centre de logistique, le bloque résidentiel «New Nalaikh» et l’extension de la voie de chemin de fer et de l’autoroute connectant la Russie et la Chine, ont été planifiés. Les études d’ingénierie géologiques et géotechniques ont été conduites pour la construction de ces projets. Cet article met l’accent sur le fait que les conditions principales de l’existence du pergélisol sont le climat et l’emplacement géocryologique. La classification régionale des zones de pergélisol, dans le but de sélectionner le concept optimal pour les fondation, a été suggérée en se basant sur les nombreuses années d’expérience et sur les leçons tirées des travaux de construction dans les conditions climatiques et géotechniques de la Mongolie.

1 DISTRIBUTION, CLASSIFICATION AND CLIMATIC CONDITIONS OF PERMAFROST EXISTENCE IN MONGOLIA

Mongolia is a land-locked country in Central Asia, located between Russia and China. It has an area of 1,565,000 km^2 and population of 3 million (Figure 1).

Figure 1. Map of Mongolia

The formation of the permafrost deposits connected with the mutual relationship of climatic factors of warm and cold seasons of the year especially, peculiarities of warmth exchange between continuous frozen and thawed in summer time soil layers. The process of permafrost formation is developed under the constant influence of many factors such as seasonal changes, composition of the soil deposits, water cycle on ground surface, air temperature, precipitation, elevation level above sea and surface relief.

The frozen soil becomes permanent in condition when average annual ground temperature is below $0^{o}C$ and little heat form the sun penetrates into the ground. Following main factors are thought to influence the formation and development of permafrost in Mongolia:

- Climatic and geophysical conditions such as ground surface and air temperature, heat exchange between ground and air, solar radiation balance and seasonal changes in climate.
- Exchange of moisture between soil deposit and atmosphere, underground water position, its quantity and dynamic changes.
- Geologic and tectonic changes, formation and composition of hard rock layers and fluffy deposits.

- Geographical location, mountain formation, surface relief, absolute and comparative altitude and conditions of depressions and elevations.

Mongolia has extreme continental climate with average annual temperature fluctuating between -8^{o}C and +8^{o}C (Figure 2).

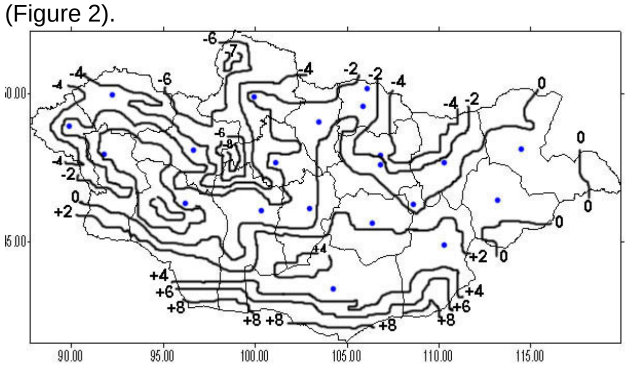


Figure 2. Average annual air temperature on Mongolian territory

The annual sum air temperature measures the warmth accumulation. The annual sum of daily temperature is estimated as minus 3700^{o}C in northwestern part, minus 2000-3000^{o}C in central part with high mountainous area; and minus 1500-2000^{o} in southern parts of the country. According to Tsytovich (1972) the permafrost in Mongolia is formed in much higher temperature than in Siberia, Russia. Main factors influencing the ground heat balance includes surface coverage (snow, vegetation and water coverage quantities), relief (surface altitude, and slope size and direction), swamps and hydro geological condition, composition and moisture of soil.

In Mongolia, discontinuously spread permafrost is formed at -2^{o}C, while in western Siberia, it formed at -3^{o}C. This difference can be explained with the extreme continental climate of Mongolia. Clear sky without clouds and comparatively thin snow coverage defines the winter season. On one hand, this thin snow coverage is insufficient to keep the warmth of the soil; on the other hand it blocks absorption of solar heat into the ground as sun rays bounce away. These bounced away sun rays under the influence of strong air flow then spend for the turbulent heat exchange of the atmospheric layers. Therefore, it is noted that permafrost in Mongolia existed for longer period of time.

In Mongolia, the snow coverage is very mild compared to Russia, Canada and Scandinavian countries. In winter and spring, relative air humidity drops up to 30-40 percent and the air becomes dry. The soil moisture content expands even in the process of ice and snow evaporation. Consequently, this dryness reduces the quantity of heat energy from the sun to be accumulated on the ground. Furthermore due to climatic conditions, the seasonal freezing of ground intensifies at the end of winter and beginning of spring. The result of soil measurement in Ulaanbaatar indicates the thickness of frozen soil increased by additional 50-60 cm.

Mongolia is located in the southern part of the world's permafrost deposit. 15 percent of the country's territory is equal to permafrost deposits that have been formed over the years. According to Professor N. Lonjid, a Mongolian permafrost researcher, the permafrost is distributed 63.0 percent of Mongolian territory.

The permafrost in Mongolian territory has been formed as a result of glaciation, and syn-genetic and epi-genetic permafrost rocks formed since the Pleistocene Age. Mongolian researchers N. Lonjid and G. Tumurbaatar (Lonjid 1969) have divided the frozen soil into five basic groups based on forms of distribution in the territory of Mongolia: 1. continuous permafrost; 2. discontinuous permafrost; 3. scattered permafrost; 4. sporadic permafrost, and 5. the seasonally frozen soil (Figure 3 and Table 1).

The average annual temperature of soil varies up to 0 ^{o}C-1 ^{o}C in sporadically permafrost spreading regions.

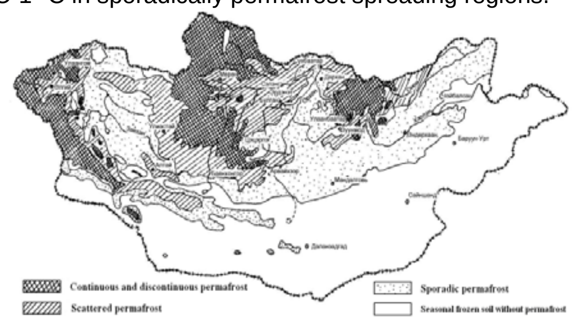


Figure 3. Permafrost distribution in Mongolian territory

Mongolian map of geocryological condition demonstrates the entire permafrost condition of Mongolia and can serve as a basis for the general design planning of regional development, industrial and civil construction facilities, and in selection of road locations in infrastructure development. In the future, it is necessary to conduct detailed study on permafrost in mutual connection with sustainable economic and social development of the region through a long-term program. The temperature cycle study of permafrost of Mongolia was conducted in 16 soums (administrative regions of Mongolia) in the north-west mountainous range of areas.

Table 1. Classification of permafrost in Mongolia

Type	Thickness, m		Temperature on 10m deep, °C	
	average	max	average	max
continuous permafrost	120-250	500	-3.0÷- 5.0	-8.0
discontinuous permafrost	50-120	250	-1.5÷ -3.0	-5.5
scattered permafrost	15-50	120	-0.8÷ -1.5	-3.5
sporadic permafrost	5-15	50	-0.5÷-0.8	-1.8
seasonally frozen soil	0-5	15	-0.3÷-0.5	-0.8

Note: average temperature summary expressed in intervals as it is includes different average temperatures for different areas

The measurement shows that the temperature of the permafrost soil fluctuates in a wide diapason between 0^{o}C and -3.7^{o}C. Therefore, it is necessary to prioritize consideration of the geocryological study findings in selecting the principles for construction. Here is the summary of results from above-mentioned permafrost study:

- Formation of permafrost in Mongolia is a result of the world glaciation. Today, there is almost no macro factors influencing on and its condition is comparatively stable because of the meso and micro factors influences on permafrost existence and its condition. There is a certain relationship between the average annual temperature and the ground temperature throughout the entire territories of Mongolia. However, no functional relationship was observed in the local areas (Table 1). This is connected with meso and macro factors influencing the permafrost condition which differ from area to area.
- The temperature of the permafrost is comparatively low due to dry climate and thin snow coverage. In such condition turbulent warm exchanges between ground surface and atmosphere and intensifies providing low temperature for permafrost.
- To design a foundation in areas with average annual temperature below -2 °C, it is possible to keep the permafrost in frozen condition (Figure 2).
- This conclusion was based on five key factors: the average air temperature, temperature stability of permafrost foundation soil, snow cover thickness influencing on quantity of the sun radiation and accumulated in the soil, wind speed and mild technogenic influence from ground surface due to remoteness of towns and settled areas.
-

2 CONSTRUCTION HISTORY ON PERMAFROST IN MONGOLIA

As mentioned before, permafrost is present for 63.0 percent of total Mongolian territory which includes 244 towns and settled areas out of 324. Centers of many towns are located on permafrost deposits. According to Dashjamts, Binderya and Altantsetseg (2013) from these 324 settled areas 140 have been located on continuous, discontinuous and scattered permafrost (Table 2).

Table 2. Settlement distribution and frozen soil type in Mongolia

Frozen soil type	Area, thousand hectares (%)	Permafrost layer thickness (m)	Number of settlements (%)
Seasonal frozen soil	579.0 (37)	1.5-5.5	80 (24.7)
Sporadic permafrost	460.1 (29.4)	6.5-10	104 (32.1)
Scattered permafrost	350.5 (22.4)	30-100	110 (33.9)
Continuous and discontinuous permafrost	175.3 (11.2)	100>	30 (9.3)
Total permafrost areas	985.9 (61.7)	-	244 (75)
Total area	1564.0	-	324

As of now, in areas of 28 districts of 7 provinces are faced with construction difficulties. Deformation of buildings in these areas was occurred as a result of construction conducted without a prior permafrost research.

As a result, substantial economic loss for reconstruction was experienced at that time. Therefore, it is necessary to conduct engineering-geologic and geocryologic studies within regions prior to construction. It is important to study the temperature regime of the frozen soil, physic-mechanic and thermo-physic characteristics and based on the findings, the optimal construction method for foundation design will be properly defined.

2.1 Continuous Permafrost in Khatgal City

Khatgal City is located in the northern part of Mongolia between Mountain range of Khovsgol and the upper zone of Khangai mountains range.

There is an extreme continental climate: it is cold in winter and cool in summer with average annual temperature of -3.8 ^{o}C. Khatgal City predominated by the coarse grains soil of gravel including sand. However, the sandy and clayey soils including gravel are widely spread in northern parts. Thickness of the permafrost is between 25m and 40m; but in some areas it may reach up to 100 m. The temperature of the frozen soil is -0.5 ^{o}C to -2.0 ^{o}C.

The development and construction in Khatgal started since 1930. The wool-washing factory, one of the country's first factories was established in Khatgal.

During 1957-1960, stone and brick buildings were started in Khatgal. During this period, new buildings for school, hospital and the wool-washing factory were completed. In this area, the continuous permafrost is contiguous in upper layer of seasonal freeze and thaw active layer. During the reconstruction, reinforced concreting was applied over the stone foundation of the building. However after a year of maintenance the school and hospital buildings were broken down and cracks appeared on the walls. Reinforced concreting had no results and settlement of these buildings continued so it became no longer functional.

As we consider, the first principle for constructing a building on the permafrost should have been followed which would suggest installation of ventilation hollows based on thermo-technical estimation and calculation of changes in permafrost temperature regime. The permafrost temperature around Khatgal City was relatively stable, ice concentration in soil is high and average annual temperature was above -3.8^{o}C.

2.2 Discontinuous Permafrost in Nalaikh Town

Nalaikh town is located in central part of the country in a tectonic depression at 36 km away from Ulaanbaatar, capital city of Mongolia. According to Jukov (1957) Russian scientist N.A. Tsytovich considered permafrost in this area is as a north part of world permafrost plateau and continuation of Siberian permafrost deposit. The soil composition consists of gravel, sand and clay. The first study on physical and mechanical properties of permafrost in Nalaikh town was conducted by N. A. Tsytovich in 1935 and later in 70s by N. Lonjid, G. Tumurbaatar, Ts. Tsagaan, Most recently A. Batsaikhan and T.Rentsendorj (2011 and 2012) have investigated the geotechnical characteristics. In the Nalaikh, depression average annual air temperature is -3.5°C and discontinuous permafrost exists. The thickness of the permafrost is 15-55 m and its temperature ranges between -0.7 and 1.0°C.

Figure 4. Administrative building (above) and entrance of vertical shaft of Nalaikh coal mining plant with ventilation hollow

The construction of buildings for a mining plant, one of the largest industrial buildings in Nalaikh, completed with ventilation hollows by specialists from Kuzbass Project Institute of Soviet Union based on a principle of keeping the permafrost conditions unchanged at initiative by Russian professor N. A. Tsytovich. The buildings were constructed on reinforced concrete foundation at depth of 4m. Around the entrance of mining vertical shaft there are double vertical walls constructed by N.G.Trupak's recommendation. This principle of keeping the permafrost condition was successfully implemented in the southern boundaries of the World permafrost.

2.3 Scattered Permafrost in Ulaanbaatar City

Ulaanbaatar city is located within Khentii mountainous zone which has scattered permafrost. The construction was conducted in the city between 1930 and 1960. Small islands of permafrost was found under the buildings of the Industrial complex, Thermo Power Station №1, Construction Material Producing Complex and National University of Mongolia are non-existent now due to gradual thawing of many years.

These buildings were built without ventilation hollows using the second principle for building on permafrost. Permafrost thawing resulted in foundation settlement, but it was comparatively low due to gravel contained in soil. The buildings of the National University of Mongolia, Children's Palace and administrative buildings in Ulaanbaatar constructed between 1950 and 1960. However after a year of exploitation, construction foundation was settled and cracks on the walls due to thawing of permafrost. The settlement was stopped due to comparatively thin layer of permafrost soil. The buildings were reconstructed in 60s and 70s and maintenance has been kept on regular basis ever since.

Construction reviews of permafrost in Khatgal, Nalaikh, Ulaanbaatar and other settled areas of the country, shows that most buildings have been damaged by permafrost thawing.

3. PRINCIPLES FOR OPTIMAL FOUNDATION DESIGN ON PERMAFROST IN MONGOLIA

There are two principles of foundation design in constructing buildings on permafrost. The Principle I is keeping the soil permanently frozen; the Principle II is thawing and compacting permafrost before the construction or take into account thawing process and construct directly on permafrost. According to Dashjamts (1999) Mongolian territory can be divided into two main zones depending on its geocryological and climatic conditions (Figure 5).

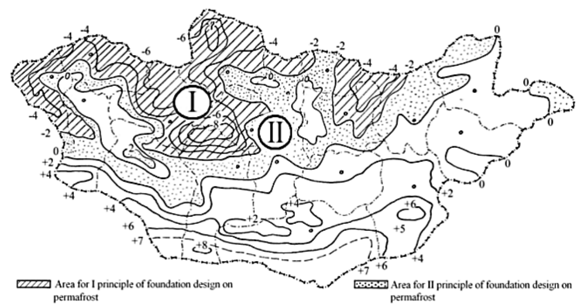


Figure 5. Zones for selecting optimal foundation design

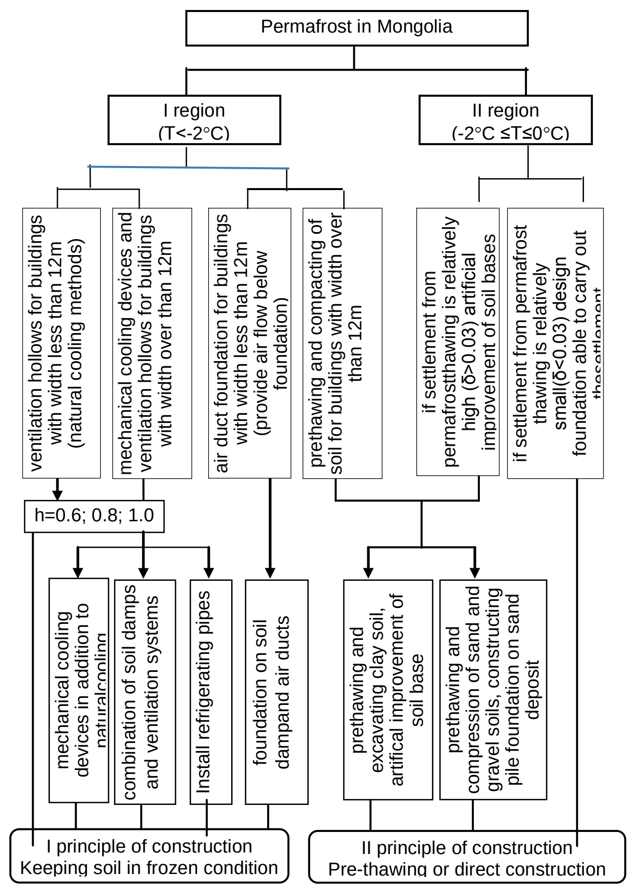
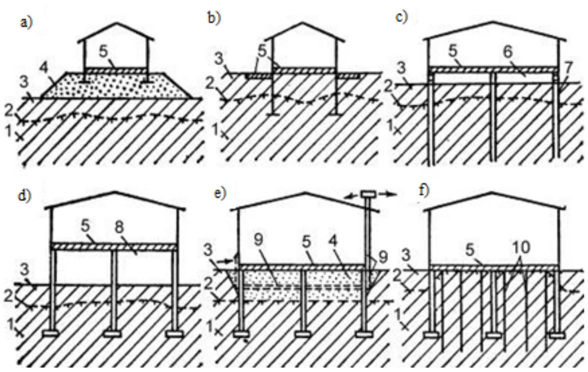


Figure 6. Scheme for optimal foundation design on permafrost in Mongolia

The discontinuous and scattered permafrost have been developed in the first area where climate is colder with average annual temperature dropping below -2^{o}C where soil can freeze permanently and continuously. In such conditions, the Principle I of foundation design on permafrost keeping permafrost in frozen condition is preferred. In the second area with average annual temperature ranging from 0^{o}C to -2^{o}C, the permafrost is relatively thin and sporadic. In such areas the Principle II should be followed which offers solutions to deal with possibility of permafrost thawing.

The Principle II of construction on permafrost should be used in areas with permafrost spread occasionally and offers two methods. The first method takes into account the possibility of thawing during exploitation and designs foundation which is able to carry out slight settlement (constructive method). The second method suggests thawing and compacting of the frozen soil prior to the construction. The first method should be used when soil settlement resulting from permafrost melting is expected to be within the permissible limit, whereas the second method can be used when rock and gravel deposit located under thin permafrost layer. If the thermal regime of permafrost is unstable then pre-thawing and compacting of the frozen soil suggested as a permanent solution (Figure 6).



1-Permafrost; 2-the upper limit of frozen soil; 3- the maximum depth in seasonal freezing cycle; 4-non frost heave backfill as a base; 5-thermal insulation; 6-ventilation hollows; 7-pile foundation; 8-natural insulation system; 9- mechanical coolant system; 10-ammonia filled cooling pipes.

Figure 7. Basic methods of keeping the permafrost in frozen state in Mongolia (Dashjamts 1999)

Figure 7 presents methods that can be used to keep the permafrost permanently in frozen condition according to the Principle I:

a) Constructing foundation on the compacted backfill or soil damp;
b) Covering foundation with thermal insulation material to prevent the heat transfer to soil;
c) Raising the building above the surface by shallow and pile foundation;
d) Constructing above the surface compartments without any heating to avoid the heat transfer from buildingof construction;
e) Constructing air duct foundation;
f) Installing additional cooling system under the structure.

Different methods of keeping the conditions of frozen soil had been used in construction of many buildings in Mongolia. In order to keep permafrost in frozen condition, it is necessary to assess the thermal regime of the building base and take measures to block the heat from building from penetrating into the base (Figure 8).

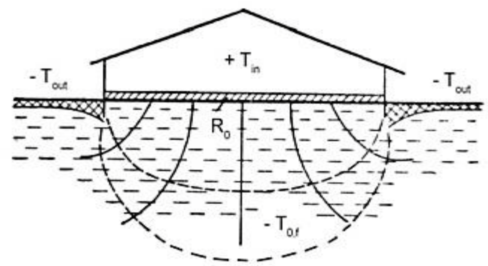
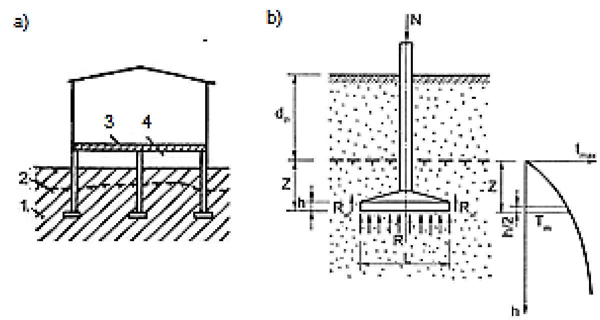


Figure 8. Heat transfer from building to permafrost

It is proven from the experience of many years of construction work in the country that the best way to keep permafrost in climatic and geo-cryological conditions of Mongolia is installing ventilation hollows under the building (Figure 9.a). In the area of the Principle I construction of buildings with width exceeding 12m installation of ventilation hollows is preferred (Figure 10.b). In summer time larger structures should have mechanical refrigerating devices to cool the pad. For smaller structures with width less than 12m, air duct foundation and soil dumps are required.



1-permafrost; 2-upper boundary of permafrost; 3-insulated floor; 4-ventillation hollow

Figure 9. Scheme of a) building with ventilation hollow and b) calculation for foundation on permafrost

Estimation of meso and micro factors of the area and dimension of the entire building with its thermo-technical indicators are perquisite to keeping permafrost in frozen condition by constructing ventilation hollows. The appropriate size of the ventilation hollow and the temperature inside should be estimated for each case individually.

Research results conducted on permafrost of Mongolia, thermal regime of building bases and soil temperature measurements indicated that the main factor affecting stability of foundation constructed on permafrost is climatic condition of the area. Therefore estimation of appropriate temperature in ventilation hollows is becoming main issue to be solved. This would help to solve the problems of foundation design on permafrost. The basic requirement for maintaining soil in frozen condition is keeping ventilation hollows constantly cool. Constant cooling of ventilation hollows stabilizes the temperature of frozen base of building. In other words, cooling devices help to reduce the temperature of the active soil layer that heated from the structure and keep the temperature of permafrost deposit under this layer constant. The difference between the temperature of upper boundary of the permafrost deposit (or bottom of the active soil layer) and temperature in ventilation hollow related to the difference between thermal conductivity coefficients of frozen and thawed soil.

The temperature of upper boundary of permafrost layer should be below or equal to the temperature inside the ventilation hollow with estimation made for summer time (Tsytovich 1972):

$$T_0^{`} \leq T_{c,a} \qquad [1]$$

Where $T_0^{`}$- The temperature of the upper boundary of permafrost layer; $T_{c,a}$- average annual temperature inside the ventilation hollow. The temperature of the upper boundary of permafrost deposit depends on the temperature in the ventilation hollow. Consequently, if the temperature in the ventilation hollow increases the permafrost layer starts thawing. The relationship between these two temperatures is following [1]:

$$T_0^{'} = T_{c,a} - \left(1 - \frac{\lambda_{th}}{\lambda_f}\right) T_{th,ca} \frac{\tau_{th}}{\tau_y} \qquad [2]$$

Where $T_{th,ca}$ - Average summer time temperature in ventilation hollow; τ_y- duration of the year in days, 365 days; τ_{th} -duration of the summer in the area. Mongolian Construction Standards Codes suggest following equation to estimate average annual temperature in ventilation hollow [3].

$$T_{c,a} = k_0 \cdot T_0 \qquad [3]$$

$T_0^{`}$ The temperature of the upper boundary of permafrost layer; k_0-coefficient related to the ratio of thermal conductivity coefficients of frozen and thawed soil (λ_f / λ_{th}) and duration of period of the year with temperature below 0^{o}C. Coefficient k_0 can be estimated by following equation:

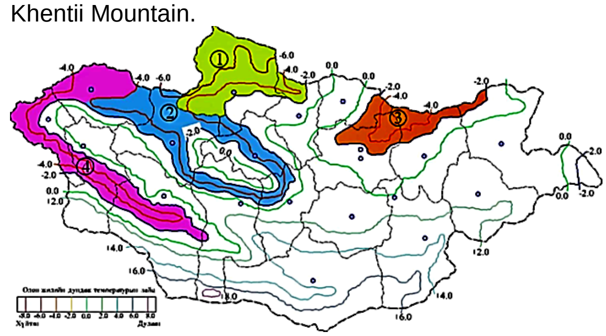
$$k_0 = 1/\left[1 - \frac{\tau_{th} - \frac{\tau_y}{\pi tg(\pi t_{th}/\tau_y)}}{\tau_y} \cdot \left(1 - \frac{\lambda_{th}}{\lambda_f}\right)\right] \qquad [4]$$

According to this methodology coefficient k_0 estimated in connection with regional soil characteristics and climatic condition of Mongolia.

For this research, 73 towns and settlements of Mongolia with average annual temperature below -2°C of are selected and classified into four basic regions as 1-Khovsgol, 2-Khangai, 3-Khentii and 4-Mongol Altai Mountains (Figure 10).

Determining the coefficient k_0 with respect to regional soil characteristics and climatic condition of Mongolia will improve probability of ensuring frozen soil stability under the building.

In this research coefficient k_0 is determined by indications of towns and settled areas where duration 185-220 days with minus temperature are considered. Herein: k_0 coefficient is identified by estimations of number of minus temperature days, for example, 190, 195, 205, 215 days in Khovsgol region; 200, 220 in Mongol Altai; 185, 190, 220 in Khangai Mountain; 185, 190 and 210 Khentii Mountain.



1- Khovsgol region
2- Khangai region
3- Khentii region
4- Mongol- Altai region

Figure 10. Regional classification for heating regime and coefficient of ventilation hollow in permafors of Mongolia

Table 3. Coefficient k_0 estimated in regional soil characteristics and climatic condition of Mongolia

λ_f / λ_{th}	Days in a year with temperatures below 0^{o}C							
	185	190	195	200	205	210	215	220
1.00	1	1	1	1	1	1	1	1
1.05	0.595	0.825	0.894	0.927	0.947	0.959	0.968	0.974
1.10	0.435	0.712	0.816	0.870	0.903	0.925	0.940	0.952
1.15	0.349	0.633	0.755	0.823	0.866	0.845	0.917	0.933
1.20	0.296	0.574	0.707	0.785	0.835	0.870	0.896	0.915

4. GEOTECHNICAL INVESTIGATION RESULTS AND FOUNDATION DESIGN: THE CASE OF URGAKH NARAN RESIDENTIAL COMPEX IN ULAANBAATAR CITY

Urgakh Naran residential complex is one of the projects developed as a solution to increasing population of Ulaanbaatar, the capital city of Mongolia (Figure 11).

.

Figure 11. Urgakh Naran residential complex

The name of the complex *"Urgakh Naran"* means *"Rising Sun"* as construction buildings are planned to be located in southwest from the city. Specifically, the site is located between Nalaikh District and Ulaanbaatar, in territory of 11th khoroo of Bayanzurkh district, in 3 km southeast from the Bayan-Zurkh regional station, and 200 m east from the existing road between Ulaanbaatar city and Nalaikh town.

Top soil overlies by the Upper and Modern Quaternary aged (dpQ_{III-IV}) dilivium-proluvium deposit predominating silty, clayey sand soil, in light yellowish to reddish yellow color and continued to end of drilling depth of 15m (Figure 12). Based on summarized data taken from investigation boreholes, the site comprise of 4 different soils through classification of engineering geological elements (EGEs)

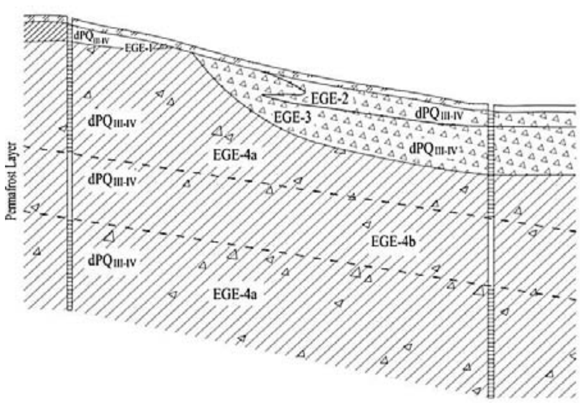


Figure 12. Site geological section

Figure 13 shows that the permafrost upper boundary starts from 7 m and reaches up to 10 m below ground surface (Dashjamts Binderya and Altantsetseg 2013). According to the permafrost distribution mapping of Mongolia, the site is situated within Khentii mountainous range of sporadic and scattered permafrost zone. The site can be defined to have an epigenetic origin with average thickness about 3 m and the thickness reaching up to 7-10 m.

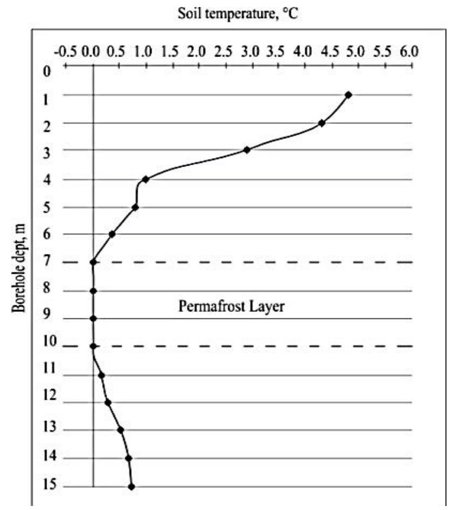


Figure 13. Site temperature measurement results

Upon determination of geocryological conditions the foundation of Urgakh Naran residential complex near Ulaanbaatar, capital city of Mongolia was designed following mentioned above construction methodology. The time required for complete melting of the permafrost located in 7 m depth from surface was estimated. On the other hand, possible solutions in case of keeping the permafrost in frozen state were considered carefully. Insulation of basement floor from soil with polystyrene foam and installment of air ducts in foundation were considered as possible solutions.

Figure 14 presents the case when basement floor was insulated with 200 mm thick polystyrene foam. The amount of settlement due to thawing was estimated for 0, 1, 2, 5, 10, and 50 years of building exploitation period when the internal temperature in basement floor T_{in} is not exceeding +2°C.

Then in the second case, which is presented in Figure 15, in addition to insulation, the foundation was designed to have air ducts in order to provide air circulation with cooling effect.

It was estimated that the structural stability can be maintained for 50 years keeping the permafrost in frozen condition, even if the internal temperature is much warmer around +10°C.

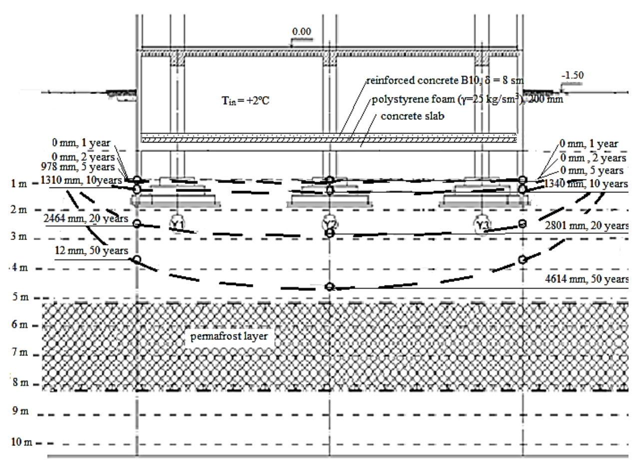


Figure 14. Foundation design and heat distribution scheme of thawing soil for period of 1, 5, 10, 20 and 50 years (version 1)

Therefore, the second case with insulation and installation of air ducts was considered as optimal for foundation design of Urgakh Naran residential complex.

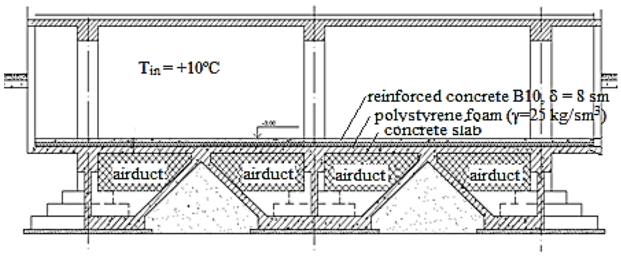


Figure 15. Foundation Design (version 2)

In this second foundation design, the module of air ventilation is defined as following.

$$M = A_v / A_b \qquad [5]$$

Where A_v is a sum of total area of air ducts, m^2 and A_b equals area of external perimeter of the structure, m^2. Additional aid ventilation is required if the ratio of air duct height h_k to width of structure is less than 0.02. In case of Urgakh Naran the basement area A_b equals 342 м^2. The area of each air duct 2.05 m^2, so for total 4 air ducts area -A_v found to be 8.2м^2. The module of air ventilation calculated as 0.023 which exceeds 0.02, therefore no additional air duct is needed and 4 is enough. In other words, the area which required to be ventilated found as $A_{v,sh} = M \cdot A_b = 0.023 \cdot 342 = 7.9$, which is less then total area of air ducts 8.2 m^2.

Findings from Urgakh Naran residential complex site: within these cases the last one is the most challenging for foundation design as permafrost layer is sandwiched between soil layers. Foundation design in such case was developed to keep the permafrost in frozen state by applying insulation material along with installation of air ducts. Main findings from these three sites can be concluded as following.

- Keeping the permafrost soil in frozen state is considered as an optimal option for foundation design.
- Permafrost layer varies thick and it liesbetween 7 m and 10 m depth below from building footing, with thickness of 3-5 m. The evidence of proper structural design has been proven on keeping the basement indoor temperature to +10 degree Celsius through the air duct system and insulating the basement floor.

CONCLUSIONS

Following conclusions have been drawn based on the mentioned above estimations:

1. It is necessary to conduct detailed geocryologic study in the regions of Mongolia where permafrost is spread and to establish functional relationship between the influencing factors of geocryologic conditions.
2. It is important to choose the optimal principle for construction work and foundation design according to the physical, mechanical and thermo-physical characteristics of permafrost in each region.
3. The detailed study on factors influencing permafrost thawing, resulting in settlement such as pressure of foundation to the frozen soil (base), soil composition, thermal regime of thawing and etc. is required for optimal foundation design.
4. Scheme for optimal foundation design on permafrost (Figure 6) have been developed according to geocryological condition of Mongolia and dimensions of the building.
5. The Principle I of construction on permafrost is keeping the permafrost condition using the ventilation hollows based on estimation of meso and micro factors of this area and dimension of the entire building and its thermo-technical indicators. The Principle I should be used in regions where annual average air temperature is below than -2^{o}C or in areas with continuous, discontinuous and scattered permafrost.
6. The Principle I of construction on permafrost should be used in areas with sporadic permafrost. The Principle I offers two methods of construction work on permafrost. If permafrost thawing beneath the foundation is slight structure could be constructed directly on permafrost. The second method is thawing of the frozen soil before constructing buildings.
7. In the areas (I region) of Mongolia where average annual temperature is below -2^{o}C for buildings with width over 12m, in addition to ventilation hollows, mechanical cooling devices could be used if required to keep the soil in frozen condition especially for summer season. For small structures with width less than 12m which is to be used only for summers season it is recommended to elevate foundation by soil damps.
8. In the regions with sporadic permafrost (II region), which thickness is comparatively thin, to thaw permafrost layer prior to constructing foundation is considered as a permanent solution. It is possible to design foundation directly on permafrost if settlement due to permafrost melting beneath the building expected to be slight.

REFERENCES

Batsaikhan, A. and Rentsendorj, T. 2011. *Geotechnical Investigation Report on the Proposed Urgakh Naran Districtin territory of Bayanzurkh district of Ulaanbaatar*. Ulaanbaatar, Mongolia.

Batsaikhan, A. and Rentsendorj, T. 2012. *Geotechnical Investigation Report on the Proposed Ulaanbaatar Terminal in Nalaikh Depression Region*. Ulaanbaatar, Mongolia.

Dashjamts, D. 1999. *Theoretical and practical bases for foundation design on permafrost of Mongolia*. *Science Paper of MUST* № 3/35.

Dashjamts, D., Binderya Z. and Altantsetseg J. 2013 *Geotechnical problems of Construction on Permafrost in Mongolia. “Sciences in Cold and Regions”*., 5 (5) 0667-0676: Ulaanbaatar, Mongolia. p. 667-676.

Jukov, M.F. *Construction Features of Seasonal Deep Freezing and Permafrost Soil of Mongolia*. Industrial Construction. 1957. №4. p. 52-54

Lonjid, N. 1969. *Mongolian Permafrost,* Ulaanbaatar, Mongolia.

Tsytovich, N.A. 1972. *Mechanics of Frozen Soils* Moscow, Russia.