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Global Warming and Degradation of Permafrost Soils

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Nyamdorj Setev[1]*, Uranchimeg Davaasuren[2], Khishigee Ragnaa[3] and Duinkherjav Jagaanbuyant[3]

[1]*Geotechnical Research Center of the Mongolian University of Science and Technology*

[2]*Graduate Student Construction and Architecture Institute of the Mongolian University of Science and Technology*

[3]*Construction and Architecture Institute of the Mongolian University of Science and Technology*

***Corresponding Author:** Doctor of Technical Sciences (Sc.D), Professor. Geotechnical Research Center of the Mongolian University of Science and Technology, Ulaanbaatar, Mongolia.

Abstract

Permafrost is the subject of global research, it occupies about 25% of the entire land area of the globe, and also its degradation. Many works of international researchers reflect the results of work on permafrost soils common in North America, Canada, Europe, Asia, and naturally in the Arctic and Antarctica. As a result of the degradation of permafrost all over the world, including in Mongolia, permafrost of mainly discontinuous and island types is thawing, since here the thickness of frozen soils is from 2.0 ... 4.0 meters to several tens of meters, as a result of the last few decades, complete thawing is possible most island permafrost. From the point of view of permafrost engineering, thawing and degradation of permafrost leads to a decrease in the bearing capacity of the base soil, the latter leading to a loss of stability of buildings and engineering structures with possible catastrophic consequences.

Keywords: geocryology; thawing; methane release; active layer; mechanical properties of frozen soils

Introduction

Permafrost or cryolithozone is the top layer of the earth, characterized by a negative temperature of rocks, it includes permafrost rocks, underground ice and non-freezing saline waters. A significant part of modern permafrost was inherited from the last ice age, and at present it is melting at an increasing rate, that is, it is degrading and partially disappearing. According to forecasts, the thawing of permafrost as a result of global warming will lead to huge losses for the world economy.

From the point of view of permafrost engineering, thawing and degradation of permafrost leads to a decrease in the bearing capacity of the foundation soil, the latter leads to a loss of stability of buildings and structures with possible catastrophic consequences (Konishchev V.N. 2011. [1]; Shur Y, et al. 2009. [2]).

Other negative consequences of the thawing of the permafrost zone are the activation of outflows from the soil of methane gases and biomicrobes contained in frozen deposits, on the basis of this, the emission of greenhouse gases increases significantly, it must be recognized that no one knows what will happen from the released methane gases and microorganisms, but there are different scientific hypotheses (Bockheim J.G. et al. 1999. [3]; Burke E.J. et al. 2012. [4]; Frank-Fahle B.A. et al. 2014. [5]; Sullivan Taylor D. et al. 2021. [6]).

According to the Intergovernmental Panel on Climate Change, there are about 1,600 billion tons of carbon in the frozen reserves of organic matter in permafrost, the latter more than in all tropical forests and proven oil reserves. With the global melting of permafrost, global greenhouse gas emissions may double (Dutta K. et al. 2006. [7]; Semenov S.M. et al. 2012 [8]). It has been established that among the varieties of greenhouse gases, methane (CH_4) is more dangerous than carbon dioxide (CO_2), because methane retains heat in the atmosphere 23 times longer than CO_2. (Aleksandrov I. 2021. [9]).

Methods and Materials

Permafrost soils

Permafrost and its degradation is the subject of global research, it occupies about 25% of the entire land area of the globe and the total area of permafrost on Earth is 35 million km^2. The upper part of the earth's crust is the location of permafrost, the temperature of which does not rise above 0 °C for a long time (from 3 years to millennia). In the permafrost zone, groundwater is in the form of ice, its depth sometimes exceeds 1000 meters. (Wikipedia. https:ru.wikipedia.org).

Many works of international researchers reflect the results of work on permafrost soils common in North America (Harris S.A. 1983. [10]; Swanson David K. 2021 [11]; and others), Canada (Bonnaventure P.P. et al. 2013. [12]; Gagnon, Samuel. et al. 2021 [13]; and others) , Europe (Popescu Razvan, et al. 2021. [14]; Blucher Johanna, et al. 2021. [15] and others), Asia (Yuken Permafrost Network (YPN). 2010. [16]; Kong Xiangbing, et al. 2021 [17]; The mainland, where permafrost is absent, can only be Australia and Africa, while its presence is possible only in high mountain regions.

Degradation of permafrost

As a result of the degradation of permafrost around the world, including in Mongolia, permafrost of predominantly discontinuous and island types is thawing, since here the thickness of frozen soils is from 2.0 ... 4.0 meters to several tens of meters, as a result of the last few decades, complete thawing is possible most island permafrost (Jorenson M.T., et al. 2006. [18]; Bense V.F. et al. 2012. [19]; Dashjamts D. 2013. [20]; Pan C.G. et al. 2018 [21] and etc). The thickness of the active zone depends mainly on the height of the location of the region above sea level, the average annual temperature, the thickness and duration of the snow cover (Goodrich L.E. 1982. [22]; Fierz C. et al. 2009. [23]), density and vegetation height (Cornellissen J.H.C. et al. 2007. [24]; Epstein H.E. et al. 2013. [25]).

The results of numerous studies of engineering abomination studies and the construction experience of recent years on permafrost soils provide justification for the conclusion that classical design solutions, that is, principle I, are unsuitable for providing normalized values of permissible precipitation due to global warming. Because of this, there is a need to develop and apply new technical solutions, taking into account the possibility of controlling the temperature regime of permafrost base soils that can minimize the negative impact of global warming on constructed and designed buildings and structures. In the work of Igor. I. Sakharov, et al. 2019. [26] presents the results of a study of the current state of the construction of buildings and railways on permafrost soil and the causes of their deformations. Currently, to prevent thawing of perennial soils of the building foundation base, there is a method of freezing the soil using thermosiphon equipment, when the thawing soils have a certain degree of moisture (Igor Holubec. 2008.[27]; Efimov V.M., et al. 2017.[28]; Mangushev R.A., et al., 2023.[29]; Fei Wang. et al. 2023.[30]).

Some scientists have written that for the economies of countries with a significant area of permafrost, such as Russia and Canada, the effects of thawing of the crolitozone may be rather positive, since as a result the zone favorable for agriculture and human life will expand (The PLOS ONE staff (2020), [31]). However, from the point of view of a global scale, the positive aspects of this problem are not subject to discussion, it is obviously clear that the negative side is much larger than the positive ones.

Results of the Review Study

Euro-Asian permafrost soils

Much of today's Euro-Asian permafrost is inherited from the last ice age and is now slowly melting. During the ice age of Siberia and Alaska, where the current depth of permafrost is a relic of climatic conditions. During the ice age, where winters were about -11 °C (-20°F) colder than today (https: fb.ru/article/453355/vechnomerzlyie-gruntyi-rayonyi-rasprostraneniya-temperatura-osobennosti-razrabotki).

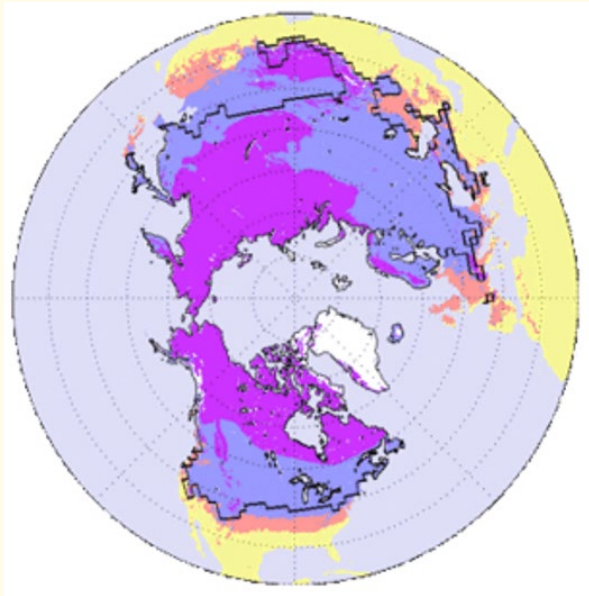

Figure 1: Distribution of perennial and seasonal frozen soils in the northern part of the globe. purple - areas of permafrost in the northern hemisphere, blue - areas of soil freezing for more than 15 days a year, orange - areas of soil freezing for less than 15 days a year, solid line - the southern border of the distribution of permafrost soils (Wikipedia. https: ru.wikipedia.org).

Figure 1 shows an overview map of the distribution of perennial and seasonal frozen soils in the northern part of the globe. From here it is clear that the territory of Mongolia is located in the Euro-Asian region and the southern border of the world permafrost zone passes through the capital of Mongolia, Ulaanbaatara (see Fig-1, where solid line).

For Mongolian researchers, the results of studies of Russian and Chinese scientists on permafrost soils are of great interest, because their territories are adjacent to the territory of Mongolia, and also the pattern of genetic origin, distribution patterns and geotechnical properties are similar in some sense.

Permafrost soils of Russia

Permafrost is common on 60...65% of the total territory of Russia, including in Eastern Siberia and Transbaikalia (Romanobskiy N.N. et al. 1993. [32]; Boike J. et al. 2013. [33] Japanese researchers (Institute of Observational Research for Global Change), in collaboration with colleagues from the Russian Academy of Sciences, measured permafrost temperature and atmospheric precipitation in three regions of Eastern Siberia. In 2004, the average temperature in the permafrost layer, located at a depth of three meters, was -2.8°C, in

2005 -1.8°C below zero, and in 2006 already -1.5°C.

According to the forecast of I.S. Shatilov and others [34];, global warming contributes to the degradation or disappearance of permafrost by 2050 in Russia by more than 3.6 million km^2, and by 2150 - by 5.6 million km^2, (Fig. 2).

Figure 2: Permafrost degradation in Russia in 2050-2150 [34].

The results of similar studies, especially in Southern Siberia and the Transbaikal region for the territory of Mongolia, have direct relationships that deserve appropriate conclusions.

Permafrost soils of China

According to a review article by Gevorkyan S.G. [35]: at the end of the 20th century, the area of distribution of permafrost soils in China (i.e., the area of "permafrost") was about 22.4% of the country's territory, i.e. approximately 2.15 million sq. km (Qiu Guoqing, Cheng Guodong. 1995. [36]; Ma Wie et al. 2012. [37]). China ranks third in the world (after Russia and Canada) in terms of permafrost area (Jin et al. 2000. [38]). Geographically, the area of distribution of permafrost in China can be divided into three sub-areas, respectively, including the high-latitude permafrost of Northeast China, the Alpine permafrost of Northwest China, and the permafrost of the high plateaus of the Tibetan Plateau. (Zhou Youwu et al. 2000.[39]; Zhao Lin et al. 2004. [40]) (Fig-3).

The literature widely reflects the results of studies of the features of geocryological properties and the regularity of the states of hydrogeological change, including for auto and railway construction on permafrost soils of Qinghai-Tibet, such as Zhang Guofei, et al. [41]; de Bruin, et al. 2021. [42]; Lmmerzeel Walter, et al. 2021. [43]. Lu Guowei, et al. 1993. [44] presents the results of a study of permafrost common in North-east China.

As tasks for future research on the mechanics of frozen soils in China, the authors name: further study of the physical characteristics and mechanical properties of frozen soils; modeling of mechanical behavior and thermodynamic properties of frozen soils; development of new and improved methods of field studies of the properties of frozen soils. According to them, with an increase in the temperature of the enclosing soil, the resistance of the side surface of the pile decreases; when frozen soils thaw, the resistance of the surface of a round pile is greater than that of square piles.

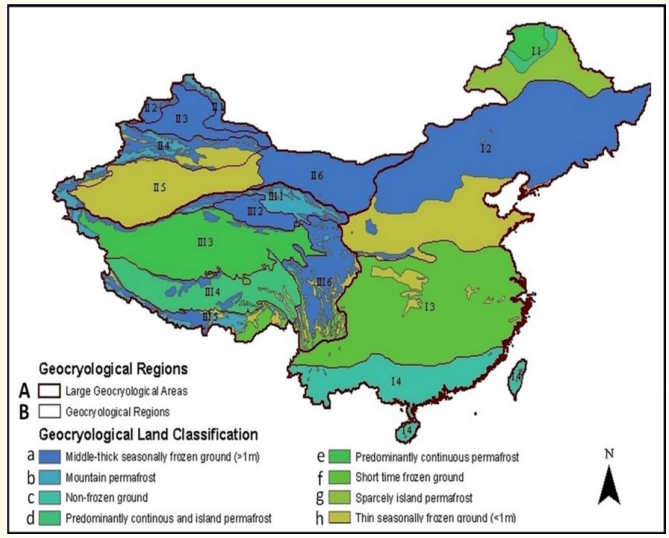

Figure 3: Geocryological map of the People's Republic of China (Zhou Youwu et al. 2000.[68]). http://staging.nsidc.org/data/docs/fgdc/ggd603_pf_maps_china/index.html).

Permafrost soils of Mongolia

The permafrost of the territory of Mongolia was formed during the late Pleistocene and early Holocene. At that time, the cryochron (permafrost aggradation) and thermochron (permafrost degradation) processes were repeatedly repeated. The age of modern permafrost 15...18 thousand years (Altai-Tunguska icing) (Popov A. 1965. [45]; Kaplin T.N. 2009. [46]) and the thickness is from 10.0 m to several tens of meters.

The results of studies of the regularity, origin and distribution, as well as the lower state of the Mongolian permafrost soils are presented in the works Longid et al., 1969. [47]; Tumurbaatar D. [48]; Gravis G.F. et al. 1974. [49]; Sharhuu N. 1998.[50]; 2001. [51]; Jambaljav, Ya. et al. 2008. [52]; Saruulzaja Adiya, et al. 2021. [53]; Qinxue Wang, et al. 2022. [54] and others.

Permafrost is common in almost half of the territory of Mongolia, mainly in the mountains of Altai, Khangai, Khubsugul, Khentii and adjacent low-mountain regions. Continuous and ice-rich permafrost occurs in the northern mountainous regions with a volumetric ice content above 30%, where degradation is moderate, while discontinuous island-type permafrost has a low ice content and is common in the central regions, where active degradation occurs.

Comparison by maps (Fig. 4) shows that the area of permafrost soils common on the territory of Mongolia is greatly reduced. The reduction occurred about 2 times (especially plastic-frozen soils) under the influence of global warming and technogenic impacts.

The first geotechnical studies on the direction of permafrost engineering of permafrost in the vicinity of Ulaanbaatar were carried out by the Russian researcher N.A. Tsytovich (Zhukov, 1957. [55]), subsequent studies were carried out and the results of which are presented in the works of Dashjamts D. 2007. [56]; Nyamdorj S. et al. 2019. [57] and others. Geologically, this region consists of metamorphic and sedimentary bedrocks with Lower Cretaceous deposits at a depth of 10 to 20 m. The deposits are overlain by Neogene Quaternary clay soils with gravel and sand inclusions.

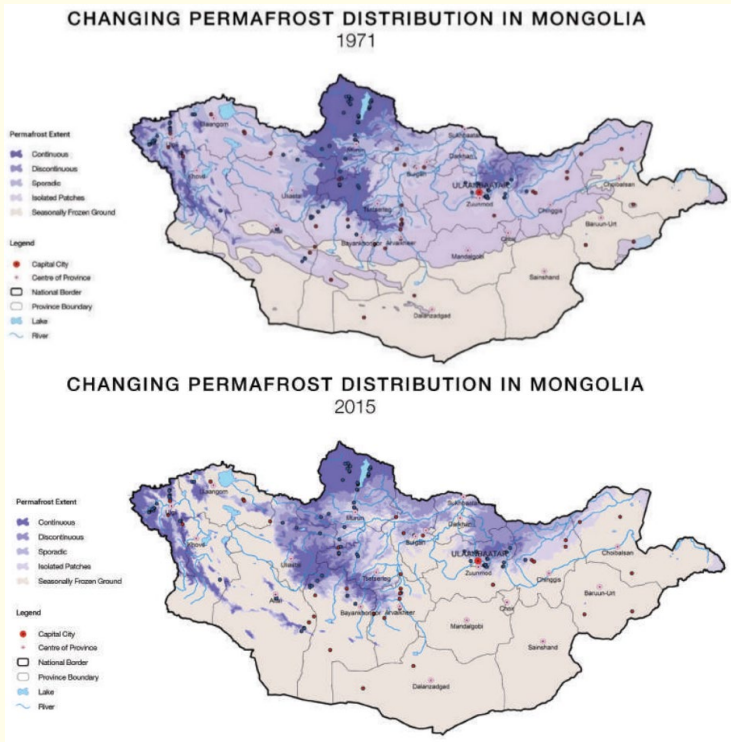

Figure 4: Maps of geocryology of the territory of Mongolia as of 1971 and 2015 (Department of Geokiology of the Academy of Science of Mongolia).

Issues for Discussion

The problems of global warming and degradation of permafrost soils are characteristic not only of certain regions but are also global. In this regard, we, researchers in the field of geotechnical engineering, are given tasks to discuss and solve specific issues of the following content:

1. Thawing and degradation of permafrost soils release a huge amount of methane gases, a number of man-made greenhouse carbon gases. The danger of methane gases lies in the fact that they retain heat in atmospheric environments more than 20 times more often than carbon gases,
2. During the thawing and degradation of permafrost soils, various microbes and microorganisms are released, familiar and unfamiliar in modern science to the corresponding profiles. What they will bring to humanity is still unknown to anyone, but there are only different scientific hypotheses, most of them are unfavorable and even scary.
3. Annual precipitation rates in the summer and winter seasons are increasing to unprecedented levels, which is leading to catastrophic consequences around the world. Information from leading scientific and information organizations working on these problems provides terrifying figures regarding human casualties and economic damage.
4. The need to develop a methodology for engineering calculations and principles for designing the base and foundations of buildings and structures designed on permafrost soils. In particular, to determine the deformation characteristics of frozen soils, it is necessary to use the hot stamp method, to take into account the influence of thawing of frozen soils to design the base and foundations, and also to develop a methodology for using artificial freezing and thermosiphon methods.

Conclusions

1. The results of the above cited scientific sources confirm that the problems of degradation of permafrost soils and their accompanying negative phenomena are characteristic not only of certain regions, including Mongolia, but are also very serious global problems and occurring at a noticeably increasing speed.
2. As a result of global warming and degradation of permafrost soils, traditional approaches to them are greatly changing, including the sublimation of seasonally and permafrost soils at certain depths in the surface zones of the earth, which is very typical for the climatic and geographical conditions of Mongolia.
3. Solving the problem of ensuring operational conditions of reliability and safety of buildings and structures previously built according to the first principle on permafrost soils. There are many such buildings and structures throughout Mongolia, a significant part of them are to some extent deformed, are in disrepair, and need in repair and restoration, and some are even subject to demolition;
4. It may be necessary to supplement and update the existing regulatory documents applicable in such conditions. In the current regulatory documents (BNbD 50-01-16) of Mongolia and literary sources, the problems of survey, calculation and design on frozen soils are reflected extremely poorly.

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